UNCLASSIFIED

AD NUMBER
ADA995500
CLASSIFICATION CHANGES
TO: **UNCLASSIFIED**
FROM: **CONFIDENTIAL**
LIMITATION CHANGES
TO: **Approved for public release; distribution is unlimited.**
FROM: **Distribution authorized to DoD only; Test and Evaluation; NOV 1952. Other requests shall be referred to Armed Forces Special Weapons Projects, Washington, DC 20301. Restricted Data.**
AUTHORITY
8 aug 1974 per document marking; 24 oct 1985 per document marking

THIS PAGE IS UNCLASSIFIED

UNCLASSIFIED

AD NUMBER
ADA995500
CLASSIFICATION CHANGES
TO: **CONFIDENTIAL**
FROM: **SECRET**
AUTHORITY
31 JAN 1970 dodd 5200.10 gp-3

THIS PAGE IS UNCLASSIFIED

PHOTOGRAPH THIS SHEET

AD-A995 500

DTIC ACCESSION NUMBER

LEVEL

INVENTORY 1

WT-644

DOCUMENT IDENTIFICATION

NOV 1952

This document has been approved for public release and sale; its distribution is unlimited.

DISTRIBUTION STATEMENT

ACCESSION FOR		
NTIS	GRA&I	☒
DTIC	TAB	☐
UNANNOUNCED		☐
JUSTIFICATION		
BY		
DISTRIBUTION /		
AVAILABILITY CODES		
DIST	AVAIL AND/OR SPECIAL	
A-1		

QUALITY INSPECTED 2

DTIC SELECTED SEP 0 9 1987 E

DATE ACCESSIONED

DISTRIBUTION STAMP

UNANNOUNCED

DATE RETURNED

87 9 1 227

DATE RECEIVED IN DTIC

REGISTERED OR CERTIFIED NO.

PHOTOGRAPH THIS SHEET AND RETURN TO DTIC-FDAC

DTIC FORM 70A MAR 86

DOCUMENT PROCESSING SHEET

PREVIOUS EDITION MAY BE USED UNTIL STOCK IS EXHAUSTED.

AD-A995 500

[redacted]

019081

WT-644

This document consists of 35 pages

No. 25 of 50 copies, Series A

Operation IVY

PACIFIC PROVING GROUNDS

November 1952

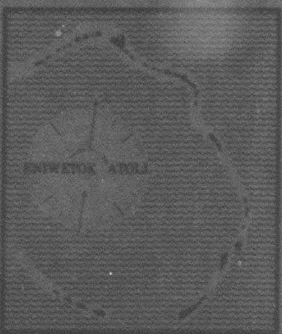
Project 7.1

ELECTROMAGNETIC EFFECTS FROM NUCLEAR EXPLOSIONS

[redacted]

Issuance Date: January 31, 1958

[redacted]



JOINT TASK FORCE 132

Inquiries relative to this report may be made to

Chief, Armed Forces Special Weapons Project
Washington, D. C.

When no longer required, this document may be destroyed in accordance with applicable security regulations. When destroyed, notification should be made to

AEC Technical Information Service Extension
P. O. Box 401
Oak Ridge, Tenn.

DO NOT RETURN THIS DOCUMENT

2

COUNTED

[redacted]

WT-644

OPERATION IVY--PROJECT 7.1

Report to the Scientific Director

ELECTROMAGNETIC EFFECTS FROM NUCLEAR EXPLOSIONS

M. H. Oleson
Headquarters, U.S. Air Force
Office of Atomic Energy, DCS/Operations
AFOAT-1
Washington, D.C.

[redacted]

[redacted]

3-4

[redacted]

FC/ 01581089

ABSTRACT

Electromagnetic pulses emitted by the Ivy detonations were received at distances from 1,920 km to 11,670 km. By means of standard direction-finding techniques, a location for Shot Mike was obtained about 440 km, and for Shot King, about 170 km, from the detonation points.

Electromagnetic energy from Shot King was mostly in the very low frequency band (peak about 13 kc), but evidences were recorded at frequencies up to 17.95 Mc, which was the maximum usable frequency for the transmission path from the detonation point to receiving site at the time of the explosion.

Energy calculations indicate that a King-sized bomb (565 kt) produces considerably more electromagnetic energy than energy values quoted in the literature for a typical lightning flash.

PREFACE

The experimental and theoretical studies summarized in this report are based on work reported by A. Glenn Jean, Jr., Central Radio Propagation Laboratory of the National Bureau of Standards; Major Clayton Jensen, Air Weather Service of the Military Air Transport Service; and Lawrence Mansur, Air Force Cambridge Research Center of the Air Research and Development Command.

The above groups exhibited an imaginative and persistent interest in the problem of trying to determine at distances some characteristics of electromagnetic pulses emitted by nuclear detonations.

Mrs. Margaret Beach was helpful in the preparation of charts, graphs, and plates and in typing the drafts and final copies of the report.

CONTENTS

[redacted]

TABLES

[redacted]

[redacted]

ELECTROMAGNETIC EFFECTS FROM NUCLEAR EXPLOSIONS

1. OBJECTIVES

The objective of the 7.1 Ivy program was to learn as much as possible about the phenomena of the generation and transmission to distances of the electromagnetic pulse emitted at the time of detonation of a nuclear device. More specific objectives were to: (1) determine the feasibility of using direction-finding techniques to "fix" the source of a nuclear explosion; (2) determine pulse character at different locations; (3) attempt to correlate pulse characteristics with bomb characteristics; (4) determine means of discriminating between electromagnetic pulses generated by lightning and by nuclear detonations; and (5) learn probable maximum detection distances.

2. BACKGROUND

During Crossroads (1946) and Sandstone (1948), attempts were made to detect changes in (1) emitted radiations by radio transmissions through the atomic cloud, (2) radar reflective qualities of the atomic cloud, (3) the ionosphere and (4) atmospheric electrical disturbances due to the explosion. The results were inconclusive. During Ranger (Nevada, January-February, 1951) large excursions were noted on a Brush recorder attached to a long wire and crystal diode. Hastily-planned measurements, using oscilloscopes, during Greenhouse (Eniwetok, early Summer, 1951) demonstrated pulses with sharp rise times coincident with the detonation of the nuclear devices. In the Fall of 1951 (Nevada, Buster-Jangle) electromagnetic effects which could be fairly well correlated with the atomic explosions were reported by stations at varying distances from the detonation points. Encouraging results were obtained, at distances up to 4,700 km, from radio goniometry experiments first attempted during Snapper (early Summer, 1952). Also, during Snapper bomb pulses were recorded at several distant stations, although not for all shots. At a close-in station, a rough estimate of field strength was made, and detonation times were determined to ±0.002 second, for correlation with data recorded at distant stations. This is presented in somewhat more detail in Reference 1.

[redacted]

3. OPERATIONS [redacted]

AFOAT-1 made arrangements with the Central Radio Propagation Laboratory (CRPL) of the National Bureau of Standards (NBS), the Air Weather Service (AWS) of the Military Air Transport Service, and the Air Force Cambridge Research Center (AFCRC) of the Air Research and Development Command to perform experiments at selected locations during Operation Ivy. Figure 1 indicates the locations of the stations manned by the above agencies, together with distances from Eniwetok, Pacific Proving Ground.

The NBS stations, with the exception of Matsushima, were all field locations of the CRPL ionospheric recording stations. Each station was manned by one person from NBS, Washington, with the assistance of members of the station complement, as needed. At Matsushima, the operations were carried out as a cooperative endeavor between NBS and AWS. The locations at Belmar, N. J. and Robins, Ga. were part of the AWS Atlantic sferics net and measurements were made by the normal sferics station complement. All of the AWS stations in the Pacific were installed for the Ivy experiments only, with a complement of one Air Force officer and two airmen assigned to each of the stations.

The Pacific stations used either WWVH (Maui, T. H.) or JJY (Tachikawa, about 30 km west of Tokyo, Japan) as a time base. Checks made by NBS at Guam showed that the agreement in time between the two timing stations was within ± 0.001 second.

At the AWS sites, runs were begun five minutes prior to zero time and continued for five minutes after zero time. Time checks with WWV, WWVH or JJY, and oscilloscope checks for azimuth calibrations were made at the beginning and end of each run. At the AFCRC station at Scituate, Mass., magnetic tape runs were started one hour before zero time and continued for 20 minutes after zero time. The NBS stations started their recording equipment a few seconds before detonation time and continued for about 60 seconds.

The 7.1 NBS stations needed accurate alert notifications because of the short recording periods (approximately 60 seconds). Joint Task Force 132 had made arrangements for a radio alert and timing system (AFSAL) for sending coded information on shot times. The AFSAL broadcasts were from the USS ESTES, close to Eniwetok, and a relay station was set up in Hawaii. In general, AFSAL reception was satisfactory, even at distances as far as the East Coast of the United States. Keying of the signals was sometimes poor. However, in most cases, the meaning was intelligible since the code letter groups were repeated several times. Some of the station operators misunderstood the code arrangements and, consequently, some recordings were missed. Without a radio alert system, however, data-gathering under the 7.1 Ivy program would have been more difficult.

4. INSTRUMENTATION

<u>4.1 Air Weather Service</u>. The AWS sferics direction-finding equipment is used as an adjunct for weather forecasting. By means of a net consisting of three or more separated stations, and with an accurate common timing system, "fixes" of individual lightning flashes can be

[redacted]

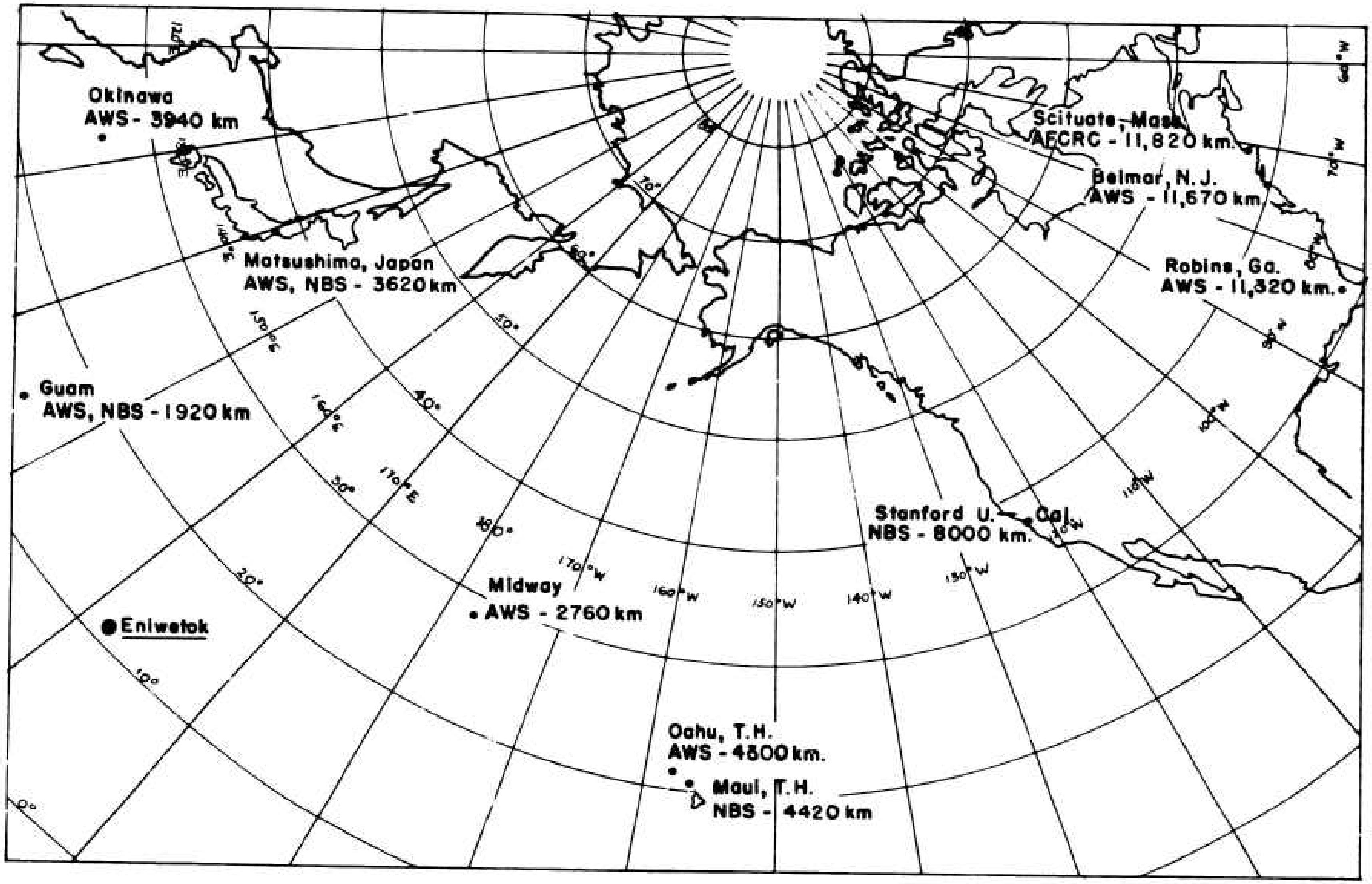


Figure 1 Location of 7.1 Ivy stations, with distances from Eniwetok, Pacific Proving Ground. Groups performing measurements at each location are indicated by initials: NBS, National Bureau of Standards; AWS, Air Weather Service; AFCRC, Air Force Cambridge Research Center.

[redacted]

obtained. The apparatus at each station was narrow band (approximately 1 kc) tuned to 10 kc. Two loop antennas were accurately oriented north-south and east-west; each loop feeding into amplifiers with identical electrical characteristics. The output of one amplifier went to the horizontal plates of an oscilloscope and the output of the other to the vertical plates; thus presenting, on the oscilloscope face, a line or flash giving direction and relative magnitude of the received lightning discharge. Time was indicated by means of film marks made by neon lights synchronized with a central time station such as WWV at the beginning and end of a run. The received flashes appearing on the oscilloscope screen, together with the timing marks, were photographed with a strip film camera operating at 2 in/sec. The AWS equipment at Guam and Belmar was modified to include sensing units to remove the 180 degree ambiguity. Further details on this standard equipment may be obtained from technical manuals (References 2 and 3).

4.2 Air Force Cambridge Research Center. At Scituate, Mass., about 30 miles southeast of Boston, Mass., three information channels were recorded on magnetic tape, together with WWV timing marks. A block diagram of the equipment hook-up is shown in Figure 2. Characteristics of the three channels follow:

Narrow band: Frequency, 22 kc; Antenna, ANGRD/1A loop (400 turns of wire on three foot square frame) oriented east-west; Amplifier, 22 kc with 4 kc band width; Gain, with battery-operated preamplifier and amplifier, 2140.

Broad band: Frequency, 100 cps to 150 kc; Antenna, long wire; amplifier, battery-operated; gain, 100.

Broad band: Frequency, 100 cps to 25 kc (filter inserted to reduce interference from higher frequency broadcasting stations); Antenna, long wire; amplifier, battery-operated; gain, 100.

Standard communications receivers were used to monitor WWV and AFSAL signals from Hawaii.

4.3 National Bureau of Standards. At Maui, T. H., a typical distant station, the following equipment channels were used:

Narrow-band high frequency: Antenna, Signal Corps Type A rhombic, oriented with main lobe at an azimuth of 264 degrees; two Hammarlund SP-600 receivers were connected in parallel; a standard signal generator was connected in series with the loop on the grounded side for calibration through 600 ohms to simulate the 600-ohm rhombic antenna.

Narrow-band low frequency: Antenna, triangular, 70 feet on a side; Navy RBA low frequency receiver; a standard signal generator was connected in series with the loop on the grounded side for calibration.

Timing: A timer, built in the NBS laboratory, consisted of a secondary frequency standard, frequency dividers and neon lights for marking recording film at regular intervals.

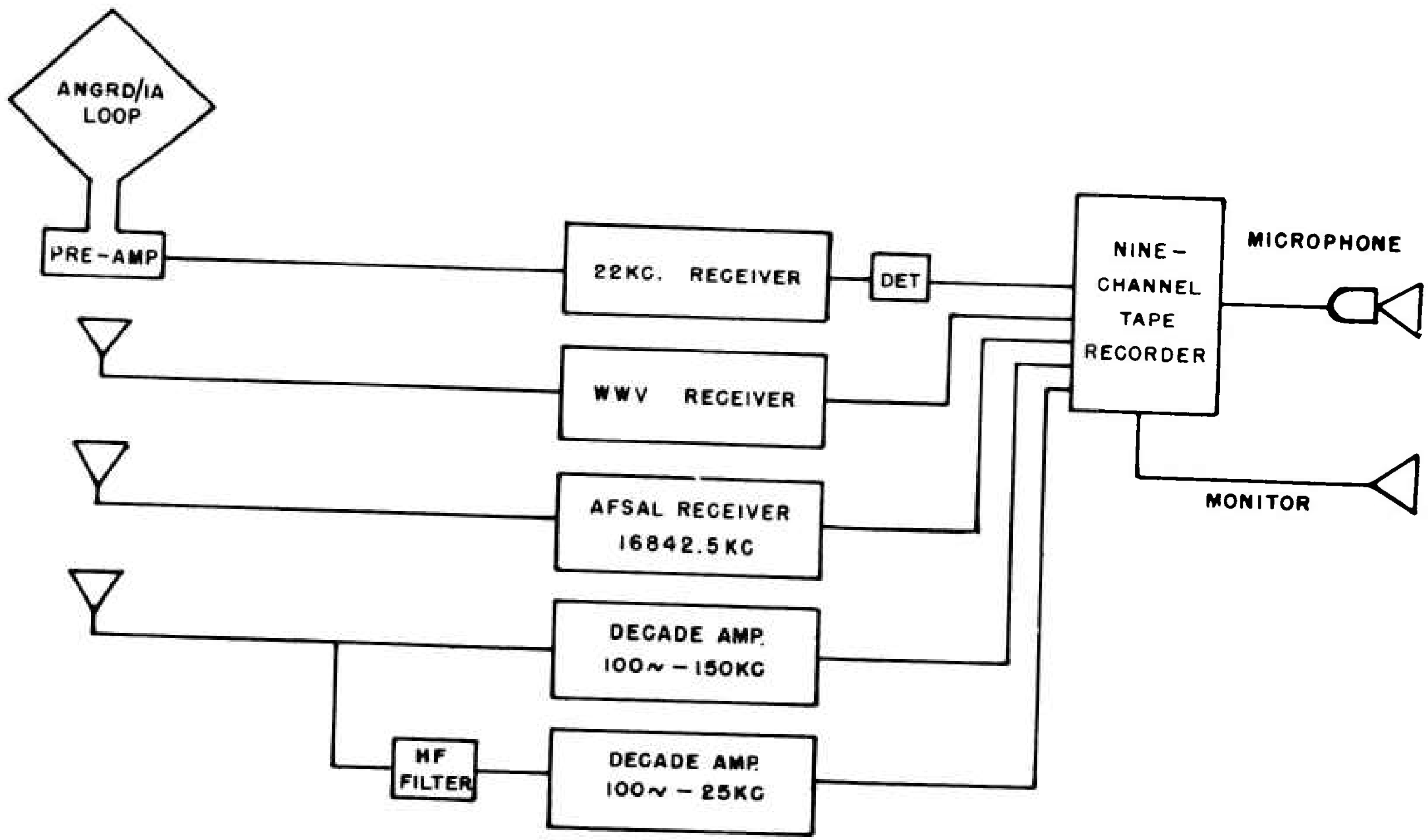


Figure 2 Block diagram of Air Force Cambridge Research Center's equipment.

Broad band: Antenna, short vertical wire, connected to a Tektronix 513-D preamplifier and oscilloscope which was set to trigger at a predetermined signal level. A low pass filter, consisting of three resistance-capacitance "L" sections with a 100 kc upper cut-off frequency, was used between the preamplifier and the oscilloscope to eliminate local broadcasting station interference.

Two narrow-band high frequency channels, one narrow-band low frequency channel, and timing, were each displayed on respective beams of a four-beam oscilloscope, and photographed with a strip film camera at

TABLE 1 SUMMARY OF AWS RESULTS *

Station	Shot Mike 31 October 1952 Zero time 1914:59.204Z		Shot King 15 November 1952 Zero time 2329:59.789Z	
Calculated Azimuth to PPG and Distance in km	Azimuth and difference from true azimuth (to nearest degree)	Time and difference from zero time (to nearest 0.01 second)	Azimuth and difference from true azimuth (to nearest degree)	Time and difference from zero time (to nearest 0.01 second)
Guam 95° 14' 1,920	95° ±0°	:59.21 +0.01	93° - 2°	:59.76 -0.03
Midway 232° 31' 2,760	235° +2°	:59.20 ±0.00	236° +3°	:59.78 -0.01
Matsushima 139° 25' 3,620	148° +9°	:59.15 -0.05	140° +1°	:59.75 -0.04
Okinawa 108° 1' 3,940	114° +6°	:59.20 ±0.00	110° +2°	:59.78 -0.01
Oahu 261° 46' 4,300	No record		258° - 3°	:59.77 -0.02
Robins 293° 6' 11,320	299° +6°	:59.23 +0.03	282° - 9°	:59.83 +0.04
Belmar 301° 22' 11,670	311° +10°	:59.25 +0.05	No record	

* Times are corrected by reference to standard time stations (but no corrections for times of propagation). Azimuths are corrected by reference to azimuth alignment checks prior to each run.

a speed of 17 in/sec. With this arrangement, time of detonation could be read to about ±0.002 second. A second strip film camera with a film speed of 10 in/sec recorded the broad band pulses.

The receiving apparatus at Matsushima, Japan; Guam, M. I. and Stanford University, Palo Alto, California was similar to that used at Maui. Figure 3 is a block diagram of the Stanford hook-up. Figure 4 shows the frequency response curves referred to field strength for the equipment shown in Figure 3.

5. RESULTS AND DISCUSSION

5.1 Air Weather Service. Reference 4 is the basis for the AWS results presented herewith. Table 1 is a summary of times of reception and azimuths of the bomb flashes. Zero times, as determined by NBS, with

[redacted]

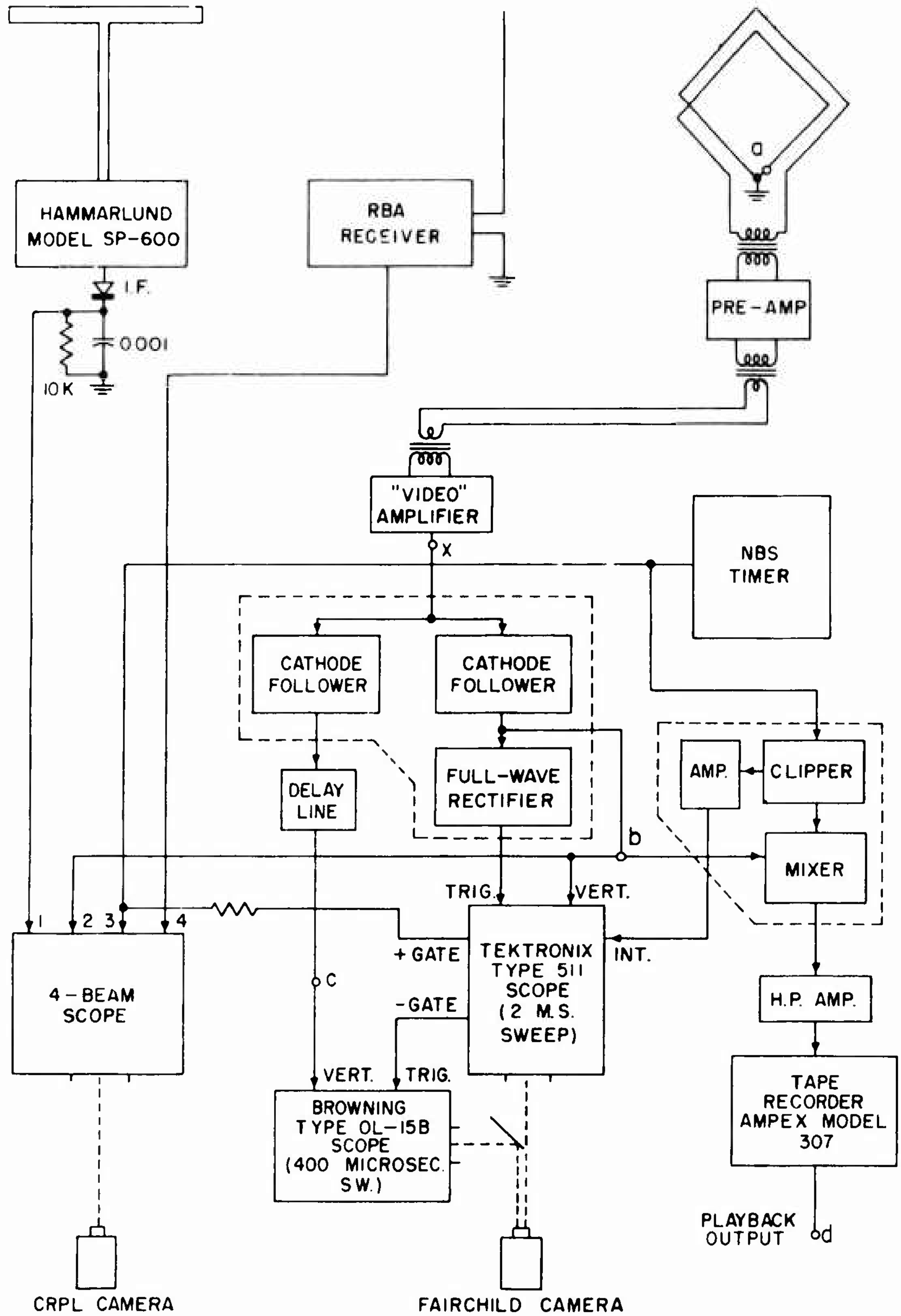


Figure 3 Block diagram of recording arrangement used at Stanford University.

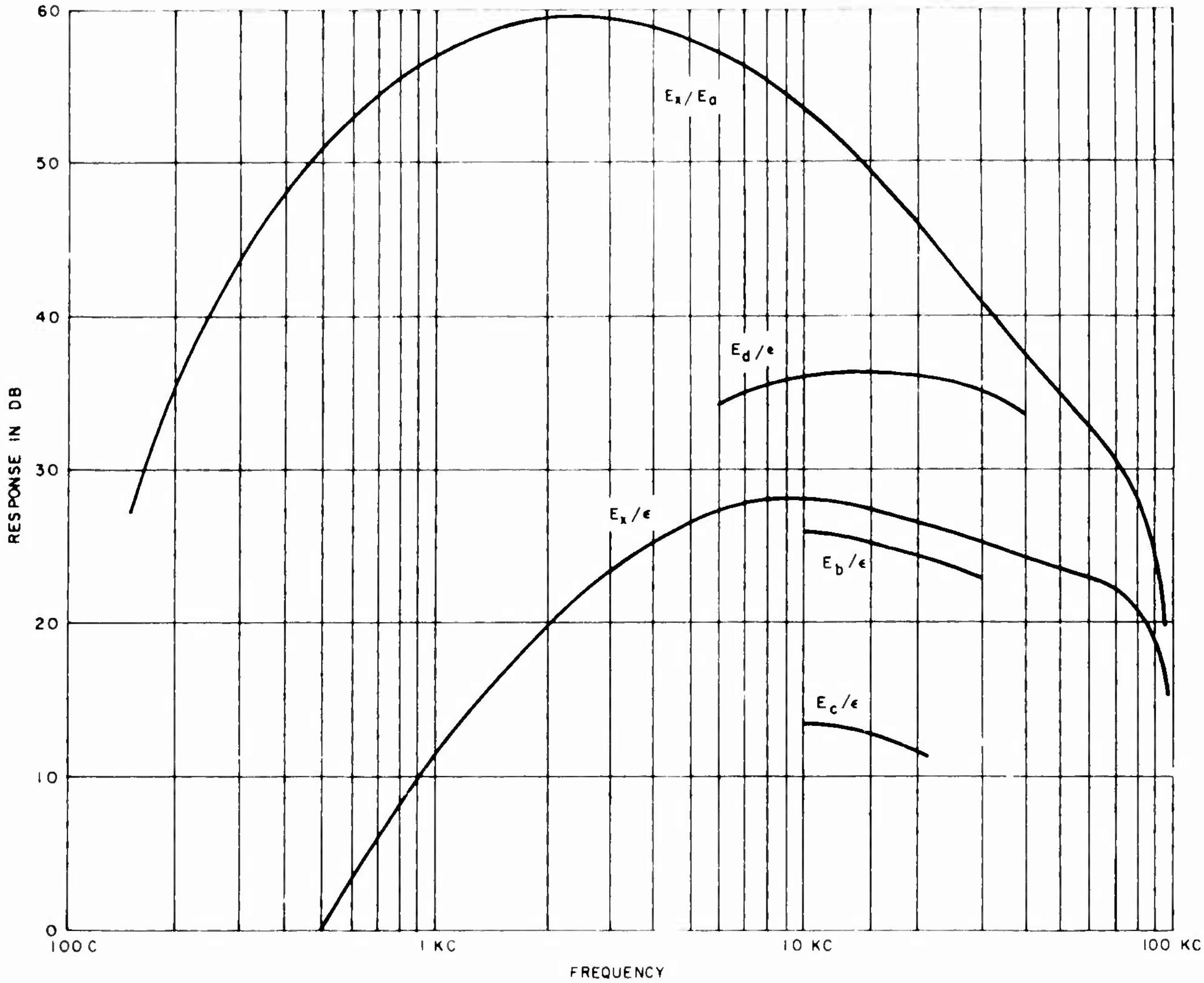
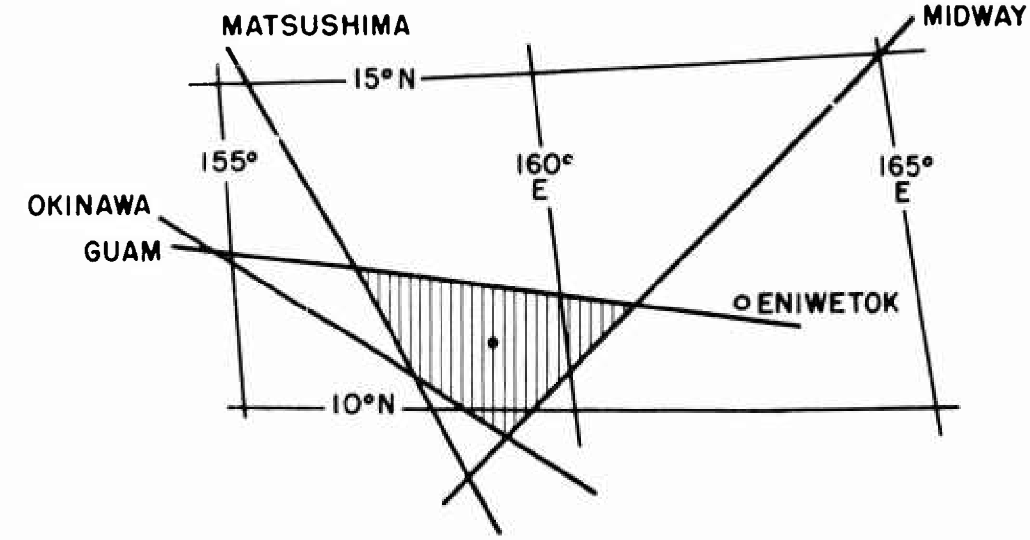


Figure 4 Relative response curves referred to field strength for various parts of the Stanford University equipment. (The letters a, b, c, d, and x refer to the points indicated in Figure 3.)

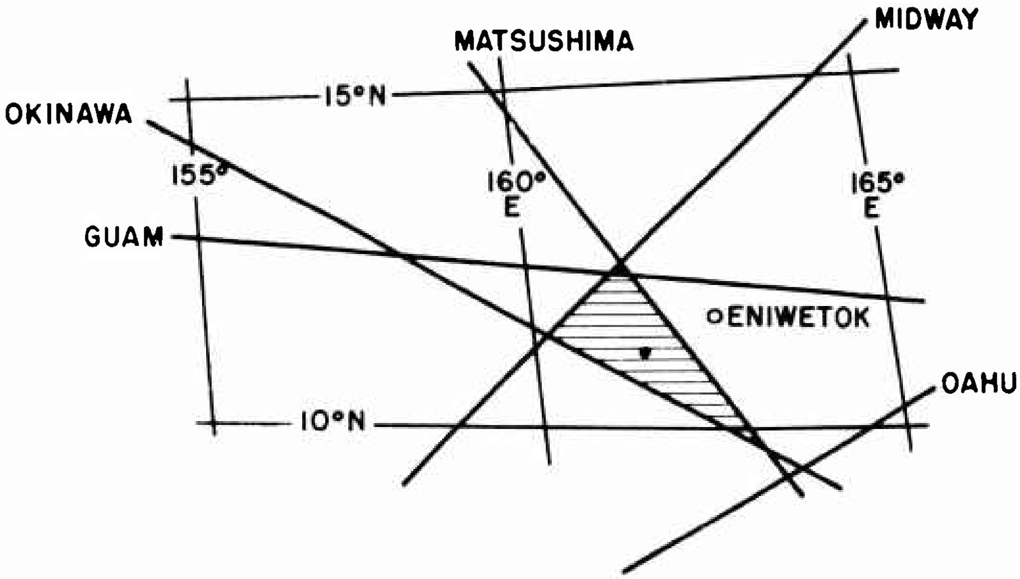
AWS deviations, and calculated azimuths, are also given in Table 1. Figure 5 shows the most probable sources for the two shots as determined by projecting the azimuths from each station. Figures 6 through 11 are two-times enlargements of sections of the 35-mm film records of each operating station which shows the suspected bomb flashes. The dots or dashes along the top of each record are 0.1 second marks; along the bottom are one-second marks and the photo of a counter numbering the seconds from the start of the run, when there was synchronization with a standard time station.

Due to uncertainties in the electromechanical timing system, the normal operational time tolerance is ±0.05 second. Bearing operational tolerance is ±3 degrees, although recent investigations by AWS and the Evans Signal Laboratories have shown that bearing errors up to ±10 degrees can occur each 90 degrees, beginning with 45 degrees. With these criteria in mind and by referring to Table 1, it will be noted

[redacted]



(A) SHOT MIKE, FIX AREA



(B) SHOT KING, FIX AREA

Figure 5 Locations determined by AWS goniometers. The most probable origin points, selected by inspection, are about 440 km from the detonation for Shot Mike and 170 km for Shot King (shown by a dot in the center of the fix areas).

[redacted]

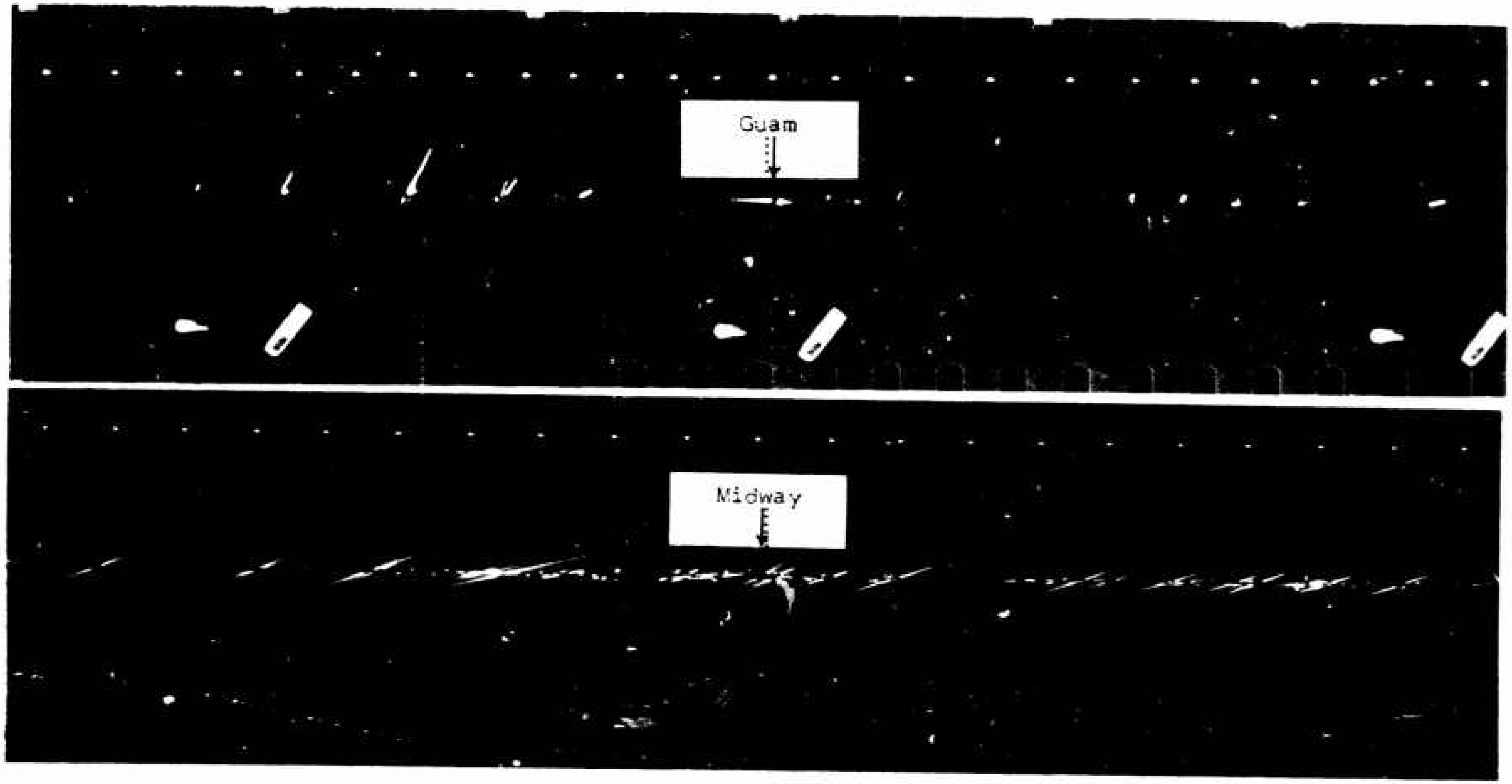


Figure 6 Air Weather Service records taken at Guam and Midway at the time of Shot Mike. The dotted line indicates zero time, corrected to WWVH or JJY. The arrow points to the suspected bomb signal. The directional flash for Guam presented 180 degrees off azimuth above appears in the right direction through the AWS sferics optical viewer.

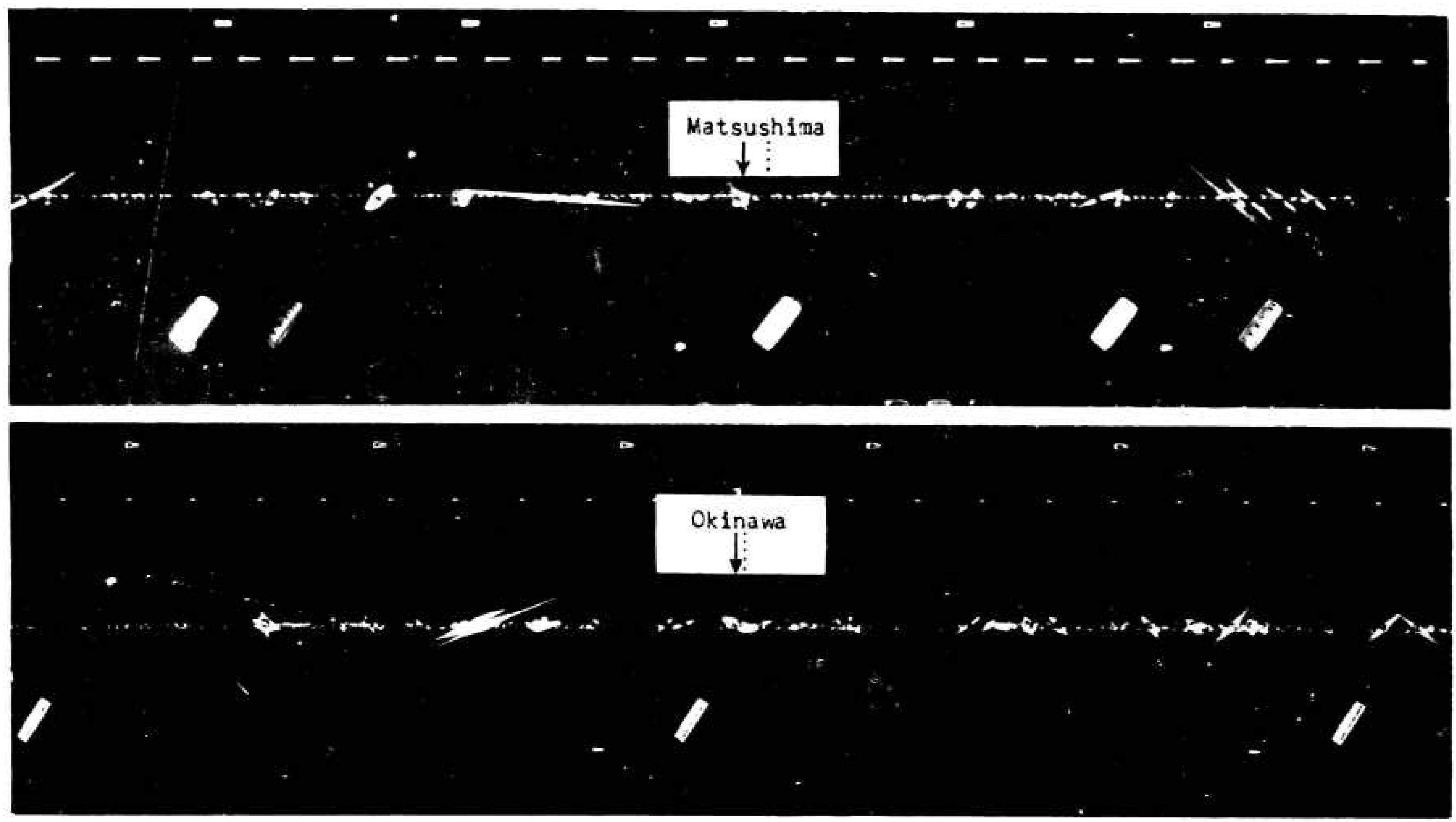


Figure 7 Air Weather Service records taken at Matsushima and Okinawa at the time of Shot Mike. The dotted line indicates zero time, corrected to WWVH or JJY. The arrow points to the suspected bomb signal.

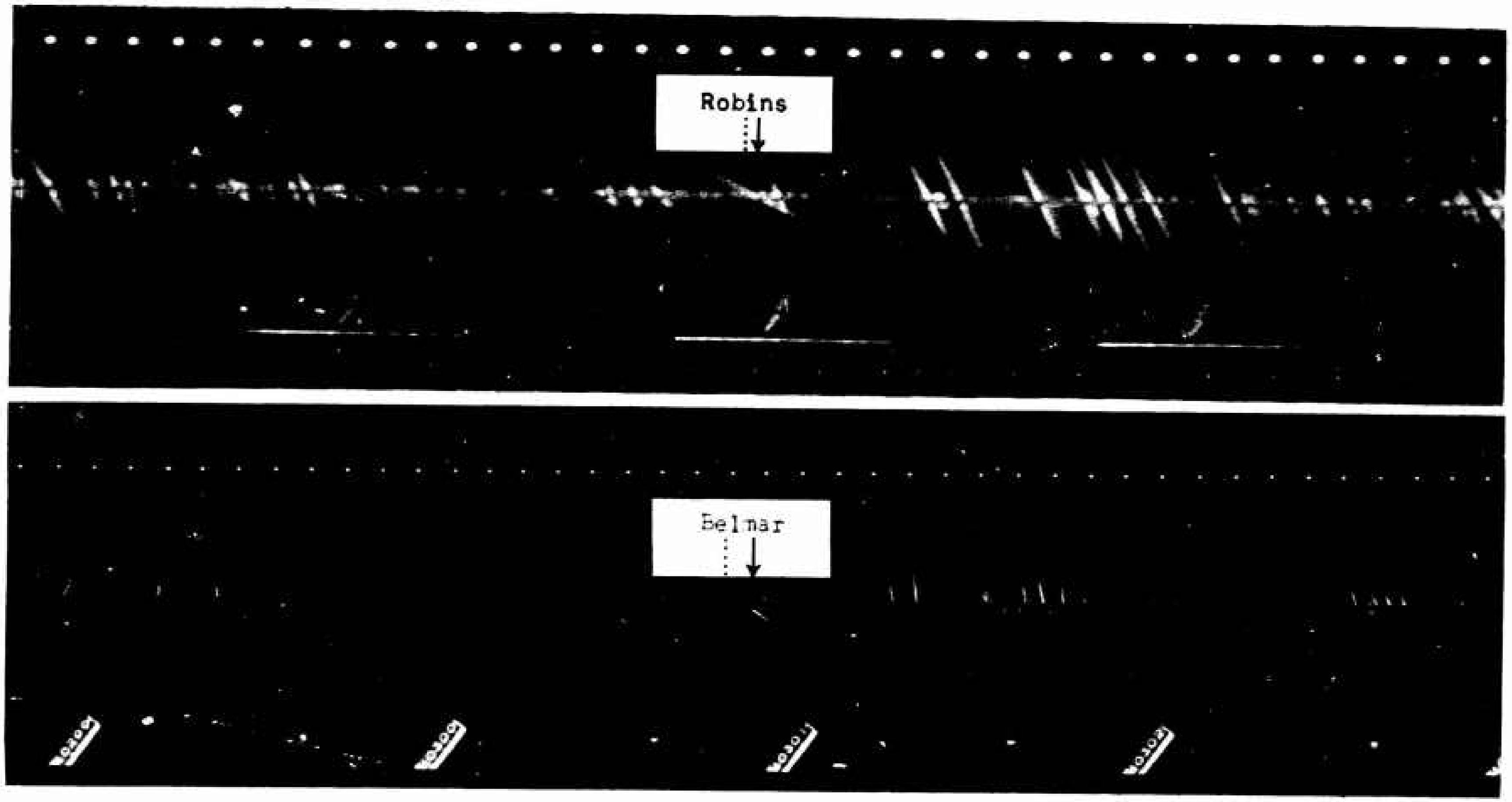


Figure 8 Air Weather Service records taken at Robins and Belmar at the time of Shot Mike. The dotted line indicates zero time, corrected to WWV. The arrow points to the suspected bomb signal. The directional flash for Belmar presented 180 degrees off azimuth above appears in the right direction through the AWS sferics optical viewer.

[redacted]

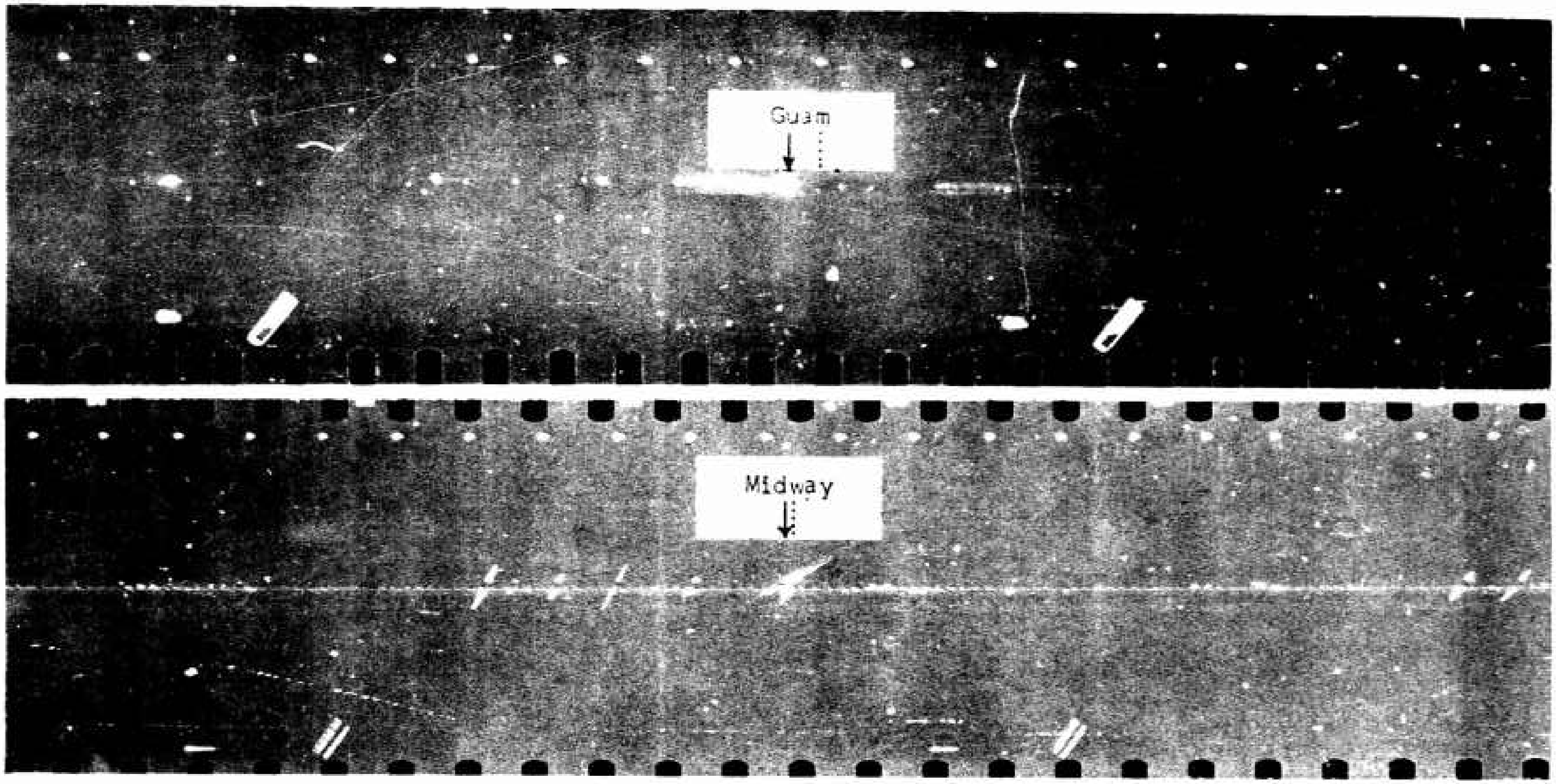


Figure 9 Air Weather Service records taken at Guam and Midway at the time of Shot King. The dotted line indicates zero time, corrected to WWVH or JJY. The arrow points to the suspected bomb signal. The directional flash for Guam presented 180 degrees off azimuth above appears in the right direction through the AWS sferics optical viewer.

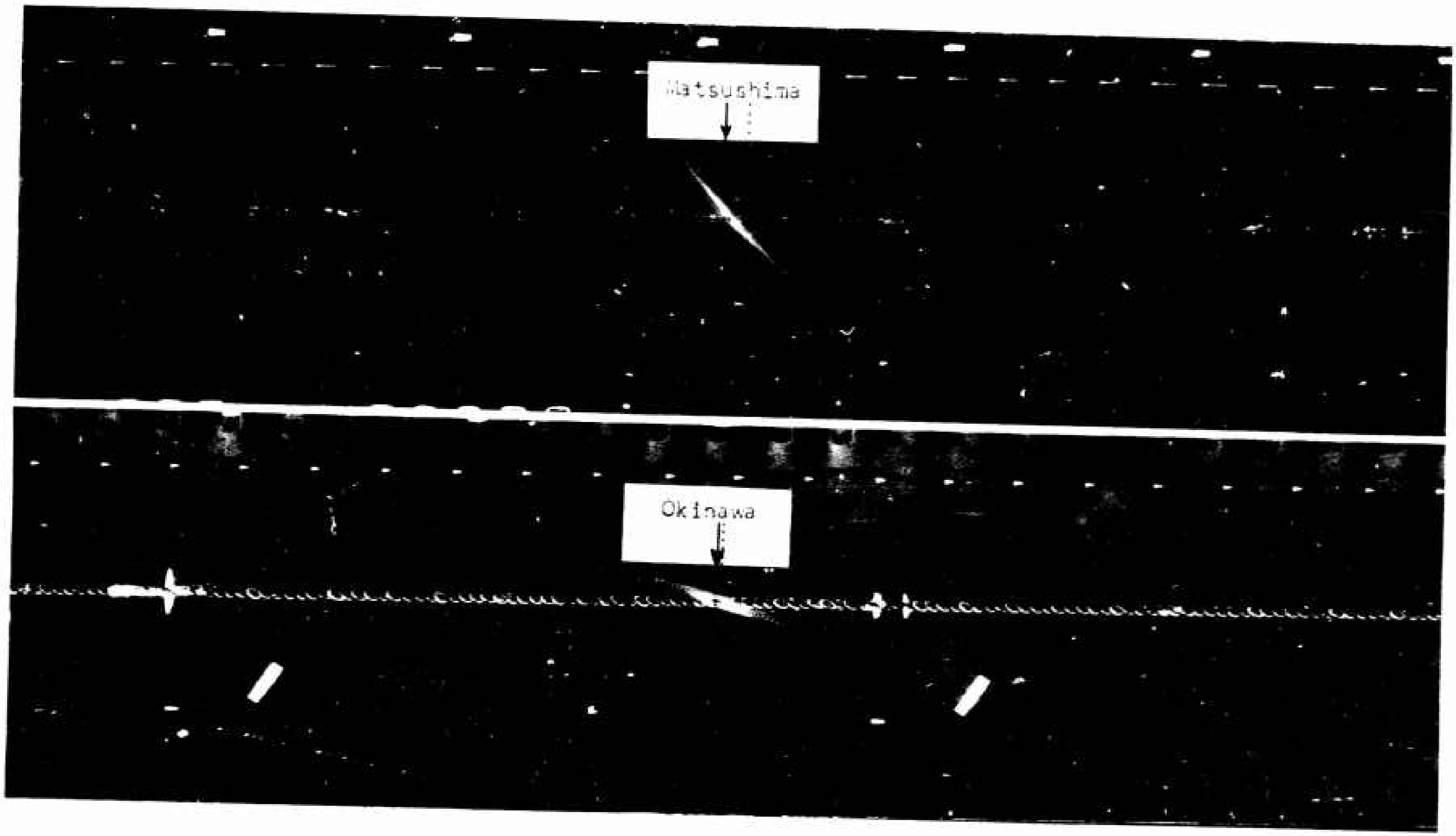


Figure 10 Air Weather Service records taken at Matsushima and Okinawa at the time of Shot King. The dotted line indicates zero time, corrected to WWVH or JJY. The arrow points to the suspected bomb signal.

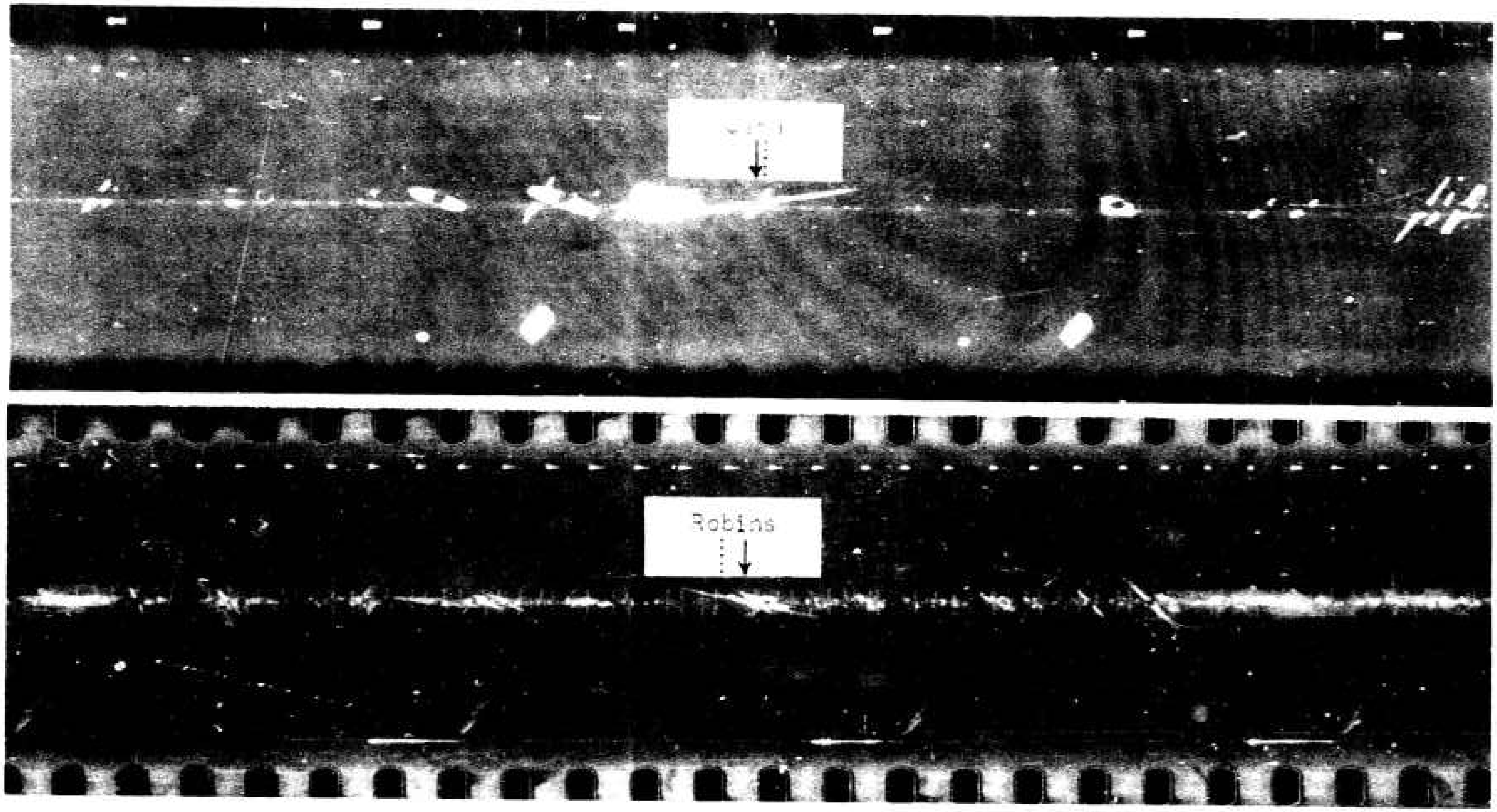


Figure 11 Air Weather Service records taken at Oahu and Robins at the time of Shot King. The dotted line indicates zero time, corrected to WWV or WWVH. The arrow points to the suspected bomb signal.

[redacted]

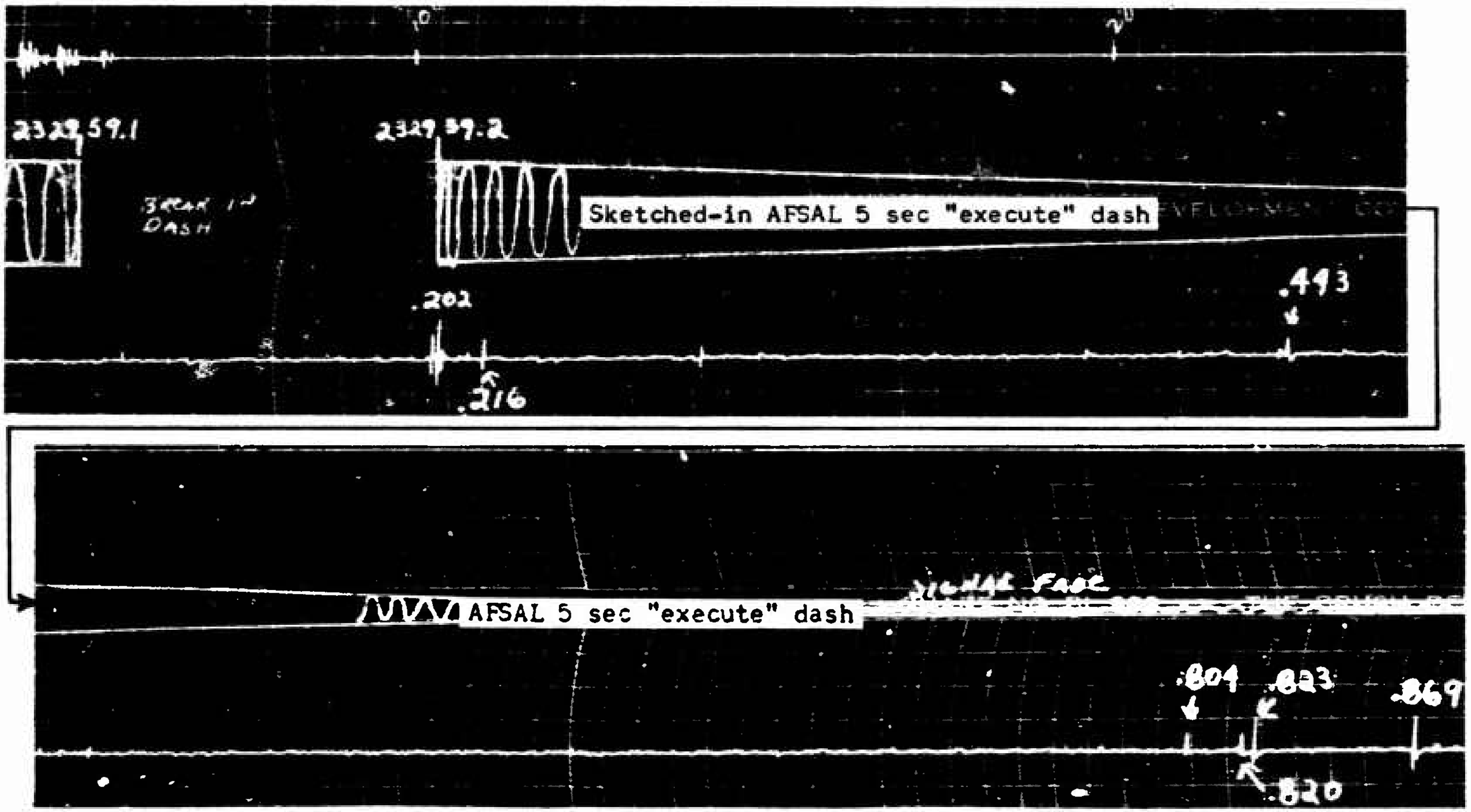


Figure 12 Air Force Cambridge Research Center record taken at Scituate, Mass. at the time of Shot King. This is a Brush recording of the 22 kc channel of the original magnetic tape recording, with the "execute" dash from another playback sketched in. The presumed signal, marked .823 above is 2329:59.823Z which agrees within 3 milliseconds with NBS Hawaii zero time, when allowance is made for propagation to Scituate.

[redacted]

that all stations operating at a given time received a flash within operational time tolerances, and all departures from calculated azimuths are reasonable, although not always consistent.

In general, the quality of the records from Shot King was better than that for Shot Mike. It is not known whether or not this has anything to do with the type of device exploded. It is more likely due to equipment or transmission vagaries.

5.2 Air Force Cambridge Research Center. Unfortunately, due to a misunderstanding of the timing code arrangements, the monitoring equipment at Scituate, Mass. was turned on too late to record electromagnetic disturbances caused by the Mike detonation.

Magnetic tape recordings were made of the WWV time signals, AFSAL from Hawaii on 16,842.5 kc, the broad band channel, and the narrow band at 22 kc. For purposes of analysis, a section of the magnetic tape including the detonation time was played back through a Brush recorder. The magnetic tape speed was slowed down and the Brush recorder speeded

TABLE 2 TIMES OF RECEPTION OF IVY ELECTROMAGNETIC SIGNALS AT THE NATIONAL BUREAU OF STANDARDS STATIONS

Station	Shot Mike 31 Oct 52 1914:59Z		Shot King 15 Nov 52 2329:59Z	
	Received	Corrected	Received	Corrected
Matsushima	a		:59.792	:59.783
Guam	:59.200	:59.203	:59.770	:59.785
Maui	:59.218	:59.205	:59.802	:59.789
Stanford University	a		:59.800	:59.787

[a] No recordings were made because of misinterpretation of AFSAL signal.

up, thus providing a means of determining times to ±0.002 second. No significant signals were recorded with the broad band equipment within two seconds of zero time. The narrow band channel at 22 kc showed pulses close to zero time (Figure 12), one of which may be the bomb pulse. A recording of AFSAL from Hawaii (sketched in from another record on the reproduction of the tape in Figure 12) showed that the "execute" signal continued through the time of detonation. It ended about 4.8 seconds after the explosion. Fading of this signal occurred at detonation time, but this is not considered significant since there were breaks and fades before and after.

5.3 National Bureau of Standards. The NBS report of the Ivy experiments gives a more complete analysis of results than the summary to be presented here (see Reference 5).

Table 2 presents times of detonations, as received at the various NBS locations, and times corrected by allowing for bomb pulse and time pulse propagation.

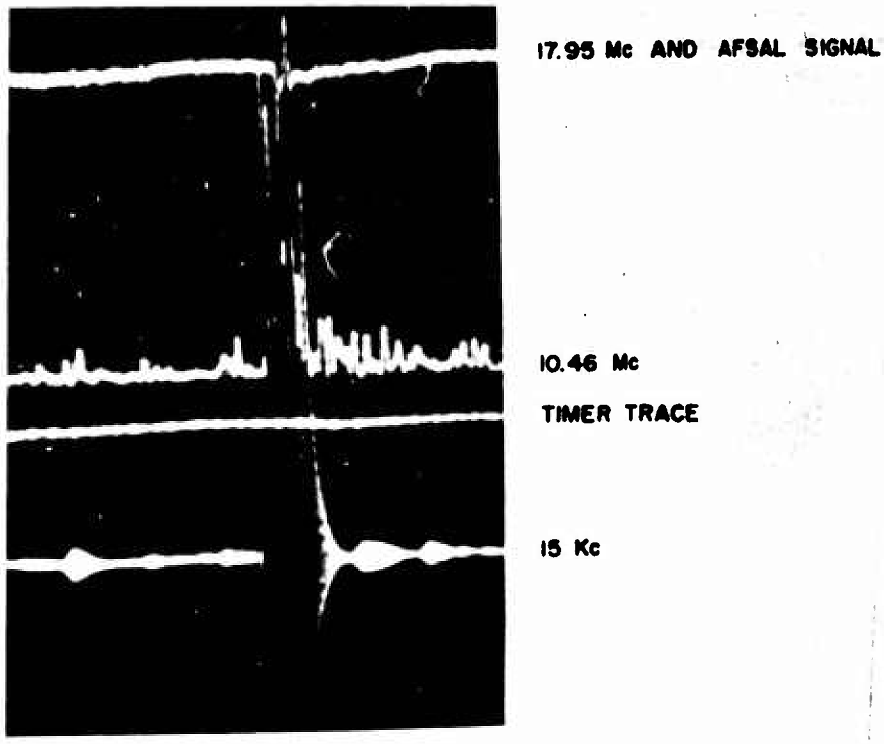


Figure 13 Shot Mike - National Bureau of Standards narrow band recording at Maui.

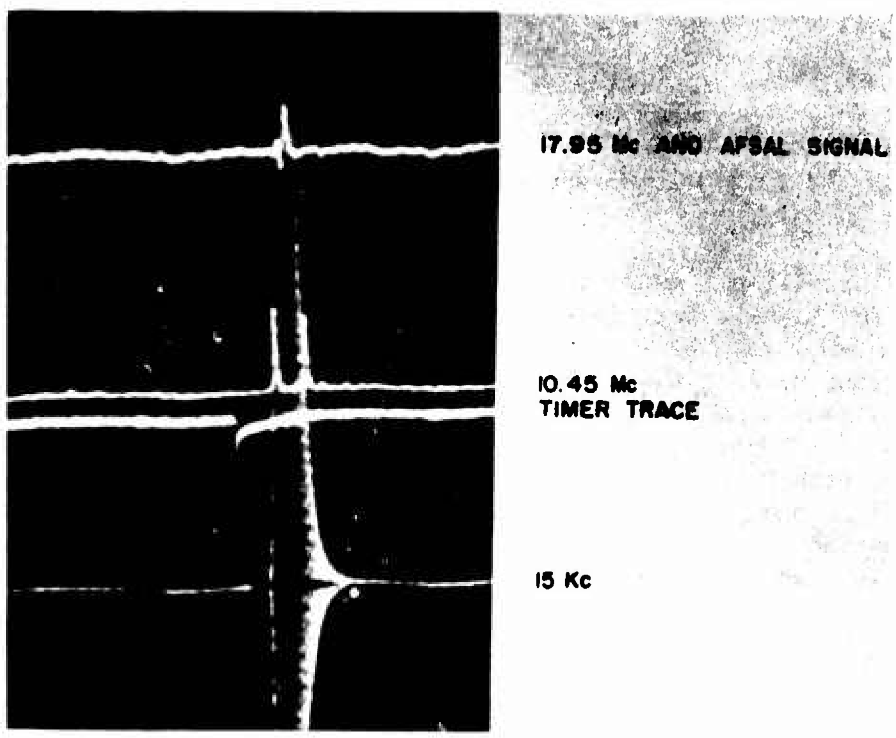


Figure 14 Shot King - National Bureau of Standards narrow band recording at Maui.

[redacted]

Matsushima: No recordings were made of Shot Mike because of a misinterpretation of the AFSAL signal.

A strong pulse was received at 4 Mc for Shot King. There was no signal on the broad band receiver (approximately 500 cps to 1 Mc) because of interference. No signal was received on the 20 Mc channel. It was later learned that 20 Mc exceeded the MUF (maximum usable frequency) for that time and path; hence, the bomb pulse could not have been received on that channel.

Guam: The Mike signal greatly overloaded all channels: 16 kc, AFSAL frequency at 4,215 kc and JJY on 4 Mc. Lightning pulses from visible flashes recorded on the 16 kc channel gave an approximation of the bomb pulse field strength as 1 v/m, or more.

For Shot King, gains were reduced. At 16 kc, with an RBA receiver, a signal corresponding to about 0.1 v/m was received. Strong pulses were also received on 17.95 Mc and 10.02 Mc, with equivalent signal values of about 70 and 1000 μv respectively.

Maui: Narrow band records for Shot Mike are shown in Figure 13. The broad band receiver (approximately 8 to 100 kc) was completely saturated by the Mike detonation pulse.

The low frequency (15 kc) narrow band records are not significant for interpretation as to shape because the reciprocal of the band width (approximately 500 cps or 0.002 second) is much greater than the duration of the pulse received (about 500 μsec, see below). This fact indicates that the output response of the receiver is essentially independent of pulse shape.

The high frequency narrow band records, in contrast to those at low frequencies, showed some differences. At 17.95 Mc there were apparently two pulses separated by about 1 msec (polarity of two pulses is not significant since it is dependent on the phase of the AFSAL signal on 17.95 Mc). The first portion of the 17.95 Mc signal arrived later than the 10.46 Mc signal. It is believed that these time differences and arrival times may be due to different path geometries for the different frequencies (see Reference 5).

Narrow band records for Shot King are shown in Figure 14.

A good broad band wave form was recorded from Shot King, Figure 15, which has the appearance of a damped wave train of gradually decreasing frequency. This smooth wave form is composed of sky wave pulses arriving by a number of different modes of propagation over the 4400 km path. (A mode of propagation here refers to a propagation path wherein the pulse is reflected between the surface of the earth (sea water in this case) and the ionosphere once or several times.) It is impossible to tell the arrival time of each sky wave because the individual pulses merge so smoothly. However, assuming an ionospheric height of 90 km for this distance, the first four sky waves would arrive over a period of about 400 μsec. Since the wave form is about 500 μsec long, and since the ground wave (a path not reflected from the ionosphere) would suffer higher attenuation, it is likely that the wave form is the resultant of pulses from the first four or five sky waves.

The King broad band pulse gave a field strength, center-to-peak, of about 1 v/m, which greatly exceeded any atmospherics recorded during the

[redacted]

two-minute period, as shown in Figure 16.

<u>Stanford University</u>: Due to a misunderstanding of the AFSAL signal, no records were made of Shot Mike.

On Shot King all narrow band low frequency equipment was saturated. A probable shape of the broad band record (1 to 90 kc) has been constructed (Figure 17) by reference to the four-beam oscilloscope record which showed higher unsaturated levels.

<u>Analysis of NBS Results</u>: Figure 18 shows the frequency distribution of the broad band wave forms from Maui and Stanford University, giving percentage of maximum amplitude between 0 and 50 kc. It will be

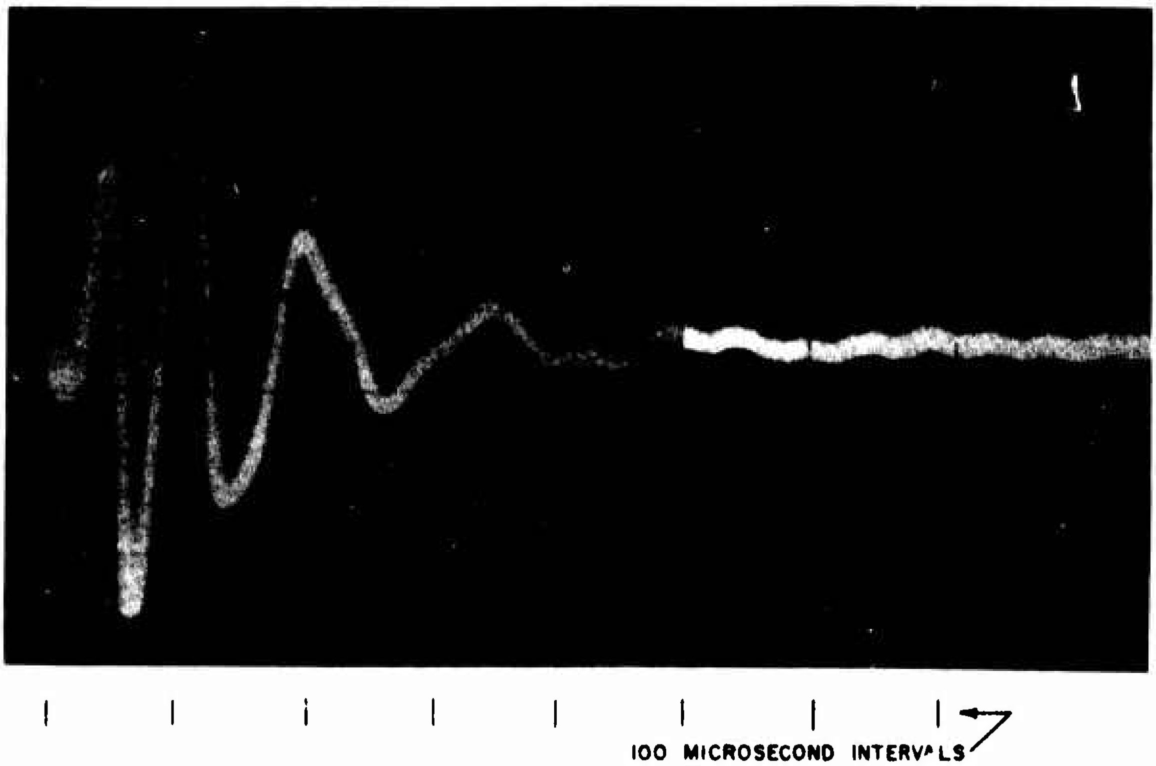


Figure 15 Shot King - National Bureau of Standards broad band recording at Maui.

noted that the maximum value at about 13 kc is the same for both stations, indicating that higher frequencies generated had been mostly attenuated in the first 4,400 km.

As indicated in Reference 5, the broad band wave form at Maui, Figure 15, may be used to estimate the energy in the pulse from about 8 to 100 kc. The recorded wave form was a faithful reproduction of the received wave form since the band width was wide enough to include most of the propagated energy.

The value of the total energy from the pulse passing through an area of one square meter is obtained by integrating Poynting's vector over the duration of the pulse. Assuming the impedance of the propaga-

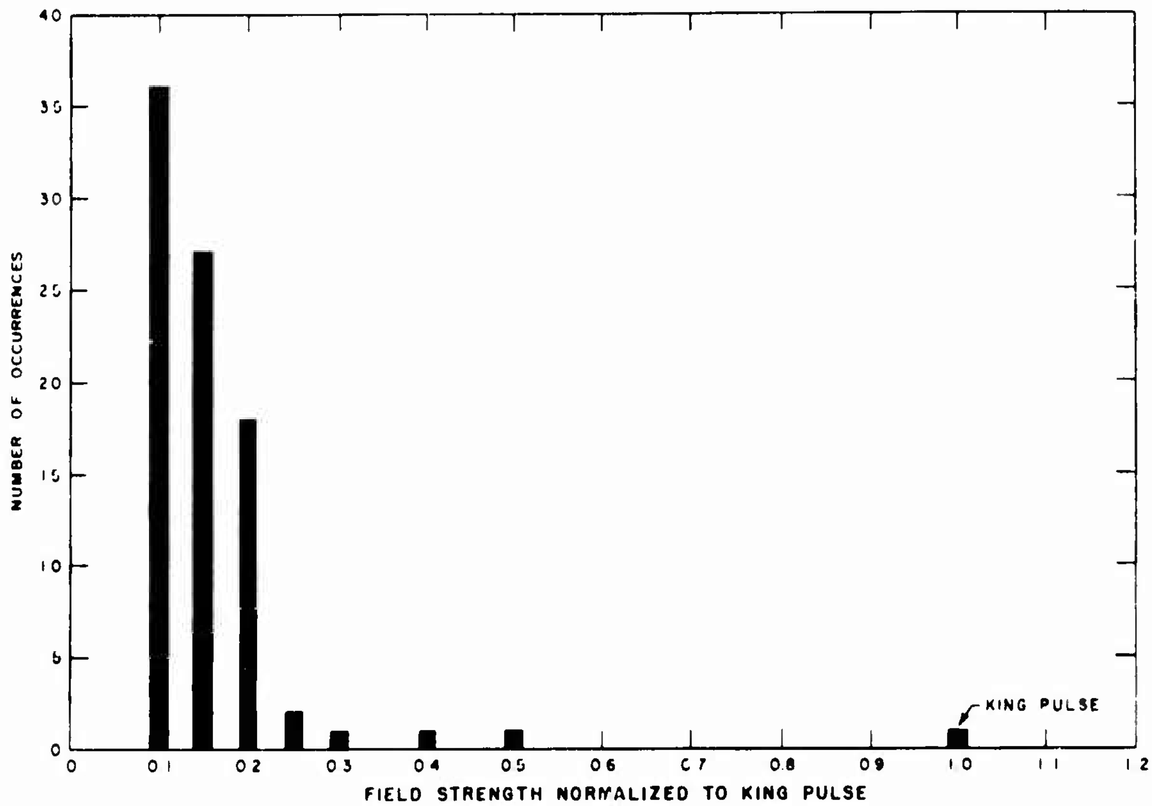


Figure 16 Peak amplitude distribution of atmospherics received during a two-minute interval at Maui, T. H. (Amplitudes are relative to the King pulse.)

tion space between the earth and the ionosphere is equal to the impedance of free space (377 ohms) the energy density can be represented by Equation 1.

$$\frac{1}{377}\int_{t=0}^{t=\infty} E^2\,dt \quad \text{in joules/meter}^2 \qquad (1)$$

Where: E = Instantaneous electric field strength, (volts per meter).
t = Time, (seconds).

Values of E were compiled by scaling field strengths from the film record and correcting for antenna length. The effective antenna length was determined by comparing the observed oscilloscope deflections with the received field strengths from NPM, Oahu. By this means, it was determined that one centimeter deflection corresponded to a vertically polarized field of 503 mv/m. Values of E^2 were then summed to give the integral. The resulting total flow of energy per square meter was 0.148×10^{-6} joules/m^2 at Maui.

A rough approximation of the total energy in the pulse at the 4,400 km radius may be obtained by assuming that the energy was uniformly

[redacted]

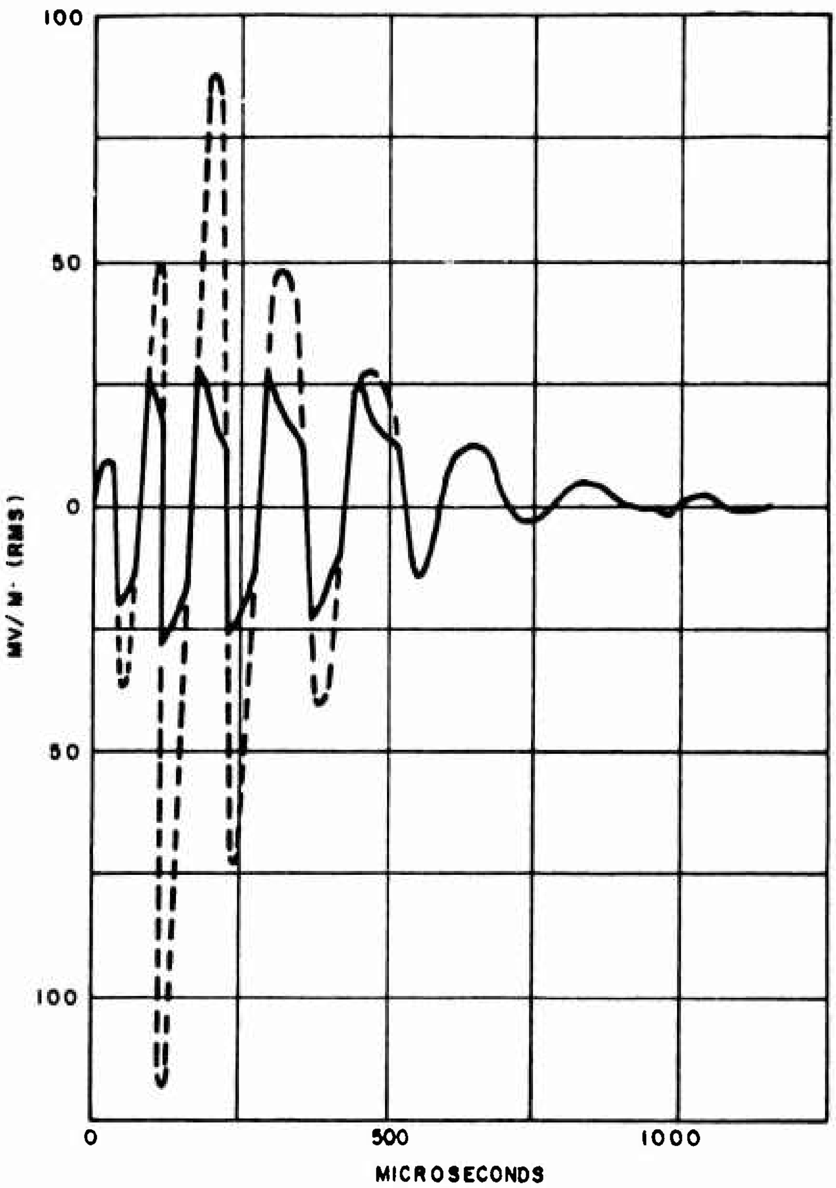


Figure 17 Shot King - National Bureau of Standards broad band wave form recorded at Stanford University. Dotted sections show probable shape.

distributed in the area bounded by the ionosphere and the earth. The area is given approximately by Equation 2.

$$A = 2\pi RH \sin 39.8^\circ \qquad (2)$$

Where: R = Radius of the earth, 6,370 km
H = Ionospheric height, 90 km
39.8° = Angle at the center of the earth subtending the 4,400 km great circle distance from the source to the area.

[redacted]

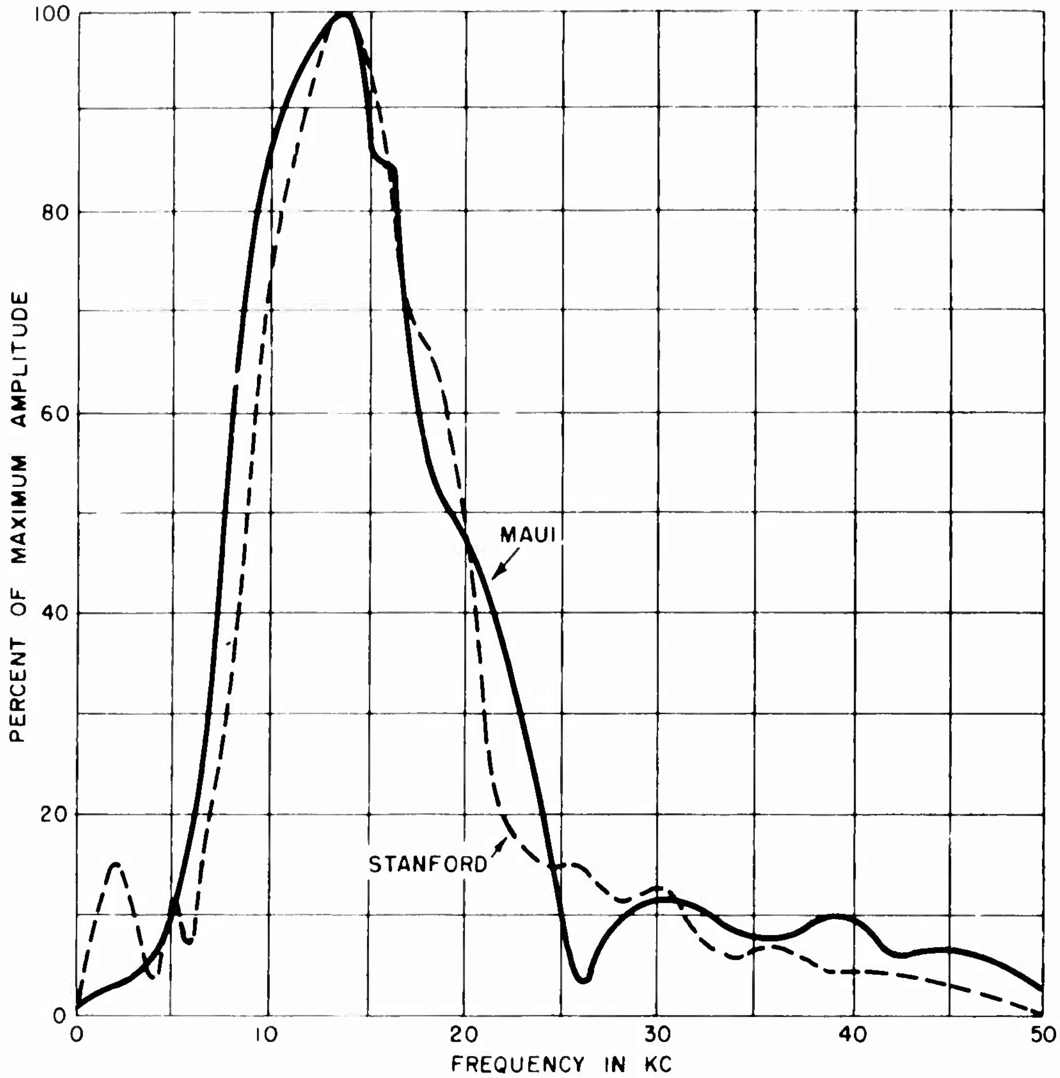


Figure 18 Frequency functions of the King pulse recorded at the National Bureau of Standards stations at Maui and Stanford University.

Substituting, for Maui.

$$A = (2\pi)(6.37 \times 10^6)(9 \times 10^4)(0.640)$$
$$= 2.31 \times 10^{12} m^2$$

The total energy then which passed through the area between the earth and ionosphere at 4,400 km from the detonation was

$$2.31 \times 10^{12} \times 0.148 \times 10^{-6} = 0.34 \times 10^6 \text{ joules}$$

In a similar manner the total energy flow per square meter at Stanford University was determined as 0.167×10^{-8} joules/m^2 and the area between the earth and the ionosphere at the 8,000 km radius from the source was calculated to be $3.42 \times 10^{12} m^2$ to give a total energy in the pulse at the 8,000 km distance of 0.57 x 10^4 joules or a ratio of 60 for the total energy at Maui over the total energy at Stanford University. This corresponds to a total attenuation of 17.6 db. Since geometric spreading between Maui and Stanford University is in the ratio of the total areas between the earth and ionosphere at the respective distances or a factor of 0.67, there is a reduction in the energy ratio to 40 or 16 db. Hence, only 1.6 db can be accounted for as a result of the spreading of the wave. The 16 db due to other losses is 4.4 db/1,000 km for the 3,600 km path between Maui and Stanford University.

From Reference 6 it is noted that a typical lightning flash contains 0.2 x 10^6 joules at the source. This is about the same energy as that remaining in the King pulse after being propagated 4,400 km, as calculated above. If a reliable attenuation factor could be applied, one could estimate the total electromagnetic energy in the detonation at the source. However, attenuation varies with frequency, and we do not know the frequency spectrum at the source. It is apparent, nevertheless, by applying the 4.4 db/1,000 km attenuation developed above, that a shot the size of King does produce electromagnetic energy considerably larger than a typical lightning flash.

Fireball Peripheral Discharges: After Operation Ivy was concluded, high-speed film (3,000 frames/sec) of fireball growth taken close-in by Edgerton, Germeshausen and Grier was reviewed (photographic record No. 16,101). This record showed discharges that had the appearance of lightning. The first discharge appeared about 2 msec after the first indication of a fireball, at a distance of about 0.65 km from the fireball, and extended about 0.3 km above the earth. At about 4 msec after the first fireball indication, the flash terminated on a cloud above the area. It is accepted that the main electromagnetic discharge from a lightning flash occurs at the instant of termination at the earth or cloud. Assuming that the bomb electromagnetic pulse is generated upon emission of the prompt gammas very shortly before a fireball is evident, any effect of this discharge should be apparent about 4 msec after the main electromagnetic pulse. No evidence of other pulses can be found on the NBS records. Later apparent flashes at $\sim$3.7 and $\sim$4.0 msec also are not indicated on the NBS film.

6. CONCLUSIONS AND RECOMMENDATIONS

It is concluded that: (1) nuclear detonations in the high kiloton or in the megaton range produce electromagnetic signals which are receivable thousands of kilometers from the source; (2) the electromagnetic energy from a nuclear detonation is predominately in the very low frequency band; (3) when the pulse can be identified, approximate source location can be obtained by using standard direction-finding techniques; (4) the "lightning" flashes photographed on the periphery of the fireball contain much less electromagnetic energy than the "main pulse;" (5) detonations generating energy similar to King or in the megaton range, produce an electromagnetic pulse considerably larger than a typical lightning flash; and (6) the very low frequency portion of the signal attenuates at about 4 db/1,000 km.

It is recommended that electromagnetic experiments be continued during future nuclear tests. In addition to measurements at distances, a station should also be set up close to the detonation area in order to obtain data before propagation variables become pronounced. Close-in data may also help in observing a relationship between electromagnetic pulse characteristics and bomb detonation characteristics. Naturally-occurring electromagnetic discharges should be studied and compared with nuclear electromagnetic pulses in order to more fully detail similarities or differences. The experimental work should also include an examination of azimuthal variations under different propagation and site conditions.

[redacted]

REFERENCES

1. Cleson, M.H.; Electromagnetic Effects from Atomic Explosions; Project 7.1a, Operation Snapper, WT-537, January 1953; AEC Technical Information Service, Oak Ridge, Tennessee; SECRET, RESTRICTED DATA.

2. TM 11-2693, Static Direction Finder AN/GRD-1A; 28 September 1945; War Department; UNCLASSIFIED.

3. TM 11-2338, Camera PH-557/TFH, Developer PH-559/TFQ, Viewer PH-558/TFP; 2 September 1957; War Department; UNCLASSIFIED.

4. RDF Detection and Location of Detonations at Great Distances; Project 7.1, Operation Ivy, 21 May 1953; Air Weather Service, Military Air Transport Service, USAF, Washington 25, D. C.; SECRET.

5. Jean, A.G., Jr, Watts, J.M., and Andersen, R.A.; Measurement of Electromagnetic Effects during Operation Ivy; Final Report on Operation Ivy, NBS Report No. 3C109, March 11, 1955; National Bureau of Standards, Boulder, Colorado; SECRET, RESTRICTED DATA.

6. Laby, and others; Waveform Energy and Reflection by Ionosphere of Atmospherics; Proceedings of the Royal Society of London, A Vol., Page 174, 1940; UNCLASSIFIED.

DISTRIBUTION

ATOMIC ENERGY COMMISSION ACTIVITIES

1 U. S. Atomic Energy Commission, Classified Technical Library, 1901 Constitution Ave., Washington 25, D.C. ATTN: Mrs. J. M. O'Leary (For Brig. Gen. Alfred Starbird, DMA)

2 U. S. Atomic Energy Commission, Classified Technical Library, 1901 Constitution Ave., Washington 25, D.C. ATTN: Mrs. J. M. O'Leary (For Dr. Spofford G. English, Res. Div.)

3 U. S. Atomic Energy Commission, Classified Technical Library, 1901 Constitution Ave., Washington 25, D.C. ATTN: Mrs. J. M. O'Leary (For Dr. C. H. Reichardt, Intell. Div.)

4- 8 Los Alamos Scientific Laboratory, Report Library, PO Box 1663, Los Alamos, N. Mex. ATTN: Helen Redman

NAVY ACTIVITIES

9 Chief of Naval Research, Department of the Navy, Washington 25, D.C. ATTN: Code 418

AIR FORCE ACTIVITIES

10 Commander, Air Weather Service, Andrews AFB, Washington 25, D.C.

11 Commander, Air Force Cambridge Research Center, L. G. Hanscom Field, Bedford, Mass.

12 Commander, Air Force Special Weapons Center, Kirtland AFB, New Mexico. ATTN: Tech. Info.

13-22 Asst. for Atomic Energy Headquarters, USAF, Washington 25, D.C. ATTN: AFOAT-1

OTHER DEPARTMENT OF DEFENSE ACTIVITIES

23-24 Chief, Armed Forces Special Weapons Project, Washington 25, D.C. ATTN: Documents Library Branch

25 Commander, Field Command, Armed Forces Special Weapons Project, PO Box 5100, Albuquerque, N. Mex.

ADDITIONAL DISTRIBUTION

26 Director, National Bureau of Standards, Washington 25, D.C. ATTN: Dr. S. N. Alexander

27 Director, National Bureau of Standards, Washington 25, D.C. ATTN: Dr. A. F. McNish

28 Director, National Bureau of Standards, Washington 25, D.C. ATTN: Dr. Ralph J. Slutz (CRPC-Boulder, Colo.)

29 University of Texas, Defense Research Laboratory, PO Box 8029, Austin 12, Texas. ATTN: Dr. O. J. Baltzer

30 Weapon Data Section, Technical Information Service Extension, Oak Ridge, Tenn.

31-50 Technical Information Service Extension, Oak Ridge, Tenn. (Surplus)

[redacted]

[redacted]