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Record Number: 198

File Name (TITLE): Detection of Fireball Light at Distances

Document Number (ID): WT-646

DATE: 8/1958

Previous Location (FROM): CIC

AUTHOR: M. H. Oleson, USAF

Addditional Information:

OrMIbox: 13

CyMIbox: 8

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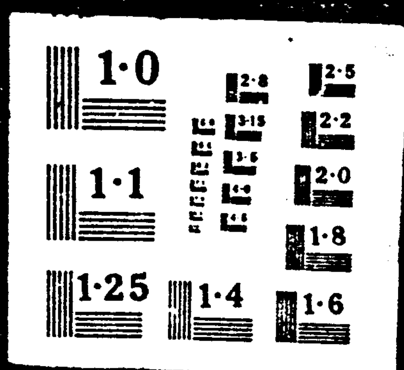

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No. 38 of 55 copies, Series A

Operation IVY

PACIFIC PROVING GROUNDS

November 1952

Project 7.6

DETECTION OF FIREBALL LIGHT AT DISTANCES

Issuance Date: August 29, 1958

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WT-646

OPERATION IVY—PROJECT 7.6

Report to the Scientific Director

DETECTION OF FIREBALL LIGHT AT DISTANCES

M. H. Oleson

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

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ABSTRACT

Attempts were made to detect at long distances the light emitted from the Ivy detonations. Two locations, Johnston Island (3,100 km) and Kwajalein Island (620 km), were chosen. At Kwajalein, in addition to a ground installation, equipment was also mounted in a plane flying above the cloud cover. Measurements were made with red- and blue-sensitive photocells.

Out of a possible total of six records only one positive detection was made and this was from the equipment in the plane on the occasion of King shot. The remaining cases are accounted for as follows: Three cases were timing notification uncertainties which make it impossible to state that the equipment was operating at detonation time; one case where it is known that the equipment was started after the detonation; and one case where the equipment was operating at the right time but there is no record of the light signal.

It is concluded that light from a nuclear detonation can be detected to a distance of about 600 km under favorable conditions. Any further work should emphasize a basic study of the phenomena involved in the transmission of light beyond the horizon.

[redacted]

PREFACE

The work under AFOAT-1 Project Authorization B/117 for optical measurements during Operation Snapper was extended by amendment to include measurements in the Pacific during Operation Ivy as Project 7.6. Since the Ivy experiments can be considered a continuation of 7.1b Snapper, 7.2 Buster and Annex 1.12 Greenhouse, much information previously given is not repeated in this report. Enough material is included to make this report reasonably self-sufficient but for those desiring further detail, reports of the above projects should be consulted. (See References.)

The field work was performed under the supervision of Capt Carroll L. Hasseltine, USAF. The equipment was designed and constructed and the records analyzed under the supervision of Mr. E. A. Colson of Edgerton, Germeshausen and Grier. This summary report is based on reports received from both Capt Hasseltine and Mr. Colson.

CONTENTS

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DETECTION OF FIREBALL LIGHT AT DISTANCES

OBJECTIVES

This project was performed in order to obtain further information on the feasibility of detecting the light emitted at the time of a nuclear detonation at distances of 1,600 km or more. It was hoped to use this phenomena to further the usefulness of the Long Range Detection System. More specific objectives can be summarized as follows: (1) Gain additional information on the mechanism of light transmission along the curvature of the earth; (2) determine energy released by measurement of curves of light intensity versus time; (3) determine attenuation factors at a ground station and an aircraft station, both the same distance from the bomb detonation point; and (4) obtain operational experience under field conditions for possible future use.

BACKGROUND

Visual sightings of the light from an atomic explosion at distances of several hundred miles were reported during Sandstone (Operation Fitzwilliam), Spring 1948, and Ranger, early 1951. AFOAT-1 has supported measurements to determine the characteristics of the emitted light at various distances during Greenhouse (Reference 1)(early summer 1951); Buster (Reference 2) (fall 1951); and Snapper (Reference 3) (early summer 1952).

A detection of Greenhouse Easy at the Pacific Proving Ground was made from a plane 12,500 feet above the surface of the ocean at a distance of 1,000 km from the detonation point. The calculated yield by measurement of time to minimum light gave good agreement with that obtained in the vicinity of the detonation. Attempts to measure the light from the earth's surface at Saipan (1,850 km) on the occasion of Shot Dog, and Wake (980 km) on the occasion of Shots Dog and Easy, were unsuccessful. No attempts were made to perform long range light detection experiments during Shot George because the detonation took place in daylight, when detection was impossible with the equipment then in use. Since it was understood that Shot Item would also be detonated after sunup, the personnel and equipment were returned to the United States before detonation time.

Experiments during Buster at the Nevada Proving Ground utilized both a slit camera at Las Vegas, approximately 110 km from the detonation point, and photoelectric equipment insensitive to constant or slowly varying light, at Flagstaff, Arizona (430 km) and Albuquerque, New Mexico (885 km). Equipment difficulties at Las Vegas resulted in only one successful detection (Shot Easy). At Flagstaff, at least one channel furnished a positive record for all shots attempted (Baker, Charlie, Dog, Easy). No detections were made at Albuquerque, due mostly to stormy weather at the chosen mountain site. Wherever a detection could be made, there was generally good agreement between the time to

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minimum as compared with the corresponding close-in bhangmeter measurements at the Nevada Proving Ground.

For Snapper, stations at the following locations were manned initially: Ephrata, Washington (1,160 km); Mountain Home, Idaho (692 km); Flagstaff, Airzona (447 km); Pyote, Texas (1,420 km), and Del Rio, Texas (1,640 km). For the last two shots (No.7 and No.8) Pyote and Del Rio were abandoned because it became apparent that no detections would be made at the two spots. The equipment at the two eastern locations was added to the Mountain Home station, and a new location added at Baker, Oregon (845 km) intermediate between the two northern locations. The time constants of the circuitry were set to admit only the frequencies ~ 100 cycles to 30 kc in order to discriminate against natural light scintillation; this bandpass does not accurately reproduce the light minimum and, hence, in these experiments, good estimates of yield were not possible. Equipment sensitive to both blue (~ 4,000 Å) and red (~ 8,000 Å) was used. Experiments with a polarizer for maximum discrimination from background were also performed. Detections at Flagstaff and Mountain Home were generally successful. Baker was successful one time out of two tries. No detections were made at Del Rio, Pyote, and Ephrata. The red cells showed approximately two orders of magnitude less absorption than the blue cells, although the signal-to-noise ratio was approximately the same for both color sensitivities.

Because we do not know the precise mechanism of transmission, the light source is treated as a directly viewed point source. The relationship then follows the familiar:

$$W_D = \frac{W_T}{4\pi D^2} e^{-kD} \quad (1)$$

Where: W_D = irradiance per spectrum band at distance D from the point source

W_T = total emitted radiant flux of the source in the band

k = absorption constant per unit distance

This relationship holds reasonably well for distances up to a few kilometers. However, when the source is below the horizon, and not directly viewed, it is obvious that it is not proper to expect the relationship to hold. We have treated the data of past operations as though the relationship did apply.

As distance increases, with receptions made beyond line-of-sight and below the horizon, k decreases, which seems to indicate that the path for transmission of the light is at higher altitudes where absorption would be less.

Two empirical formulas for the relationship between time to minimum, t, and energy yield in kilotons-equivalent, E, from reference 1 are:

$$E = 1.88 \times 10^{-3} (t + 7)^2 \quad (2)$$

$$E = 0.1 t^2 \quad (3)$$

OPERATIONS

Criteria for selection of a site for an experiment in long-range light detection includes the following: (1) lack of clouds; (2) little movement in the foreground; (3) clear atmosphere; (4) low wind velocities; and (5) freedom from man-made light flashes such as airplane beacons, reflections from moving objects and automobile lights.

Since experimental atomic detonations usually take place in the morning, the observing

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sites should be located to the east, the south, or the north of the light source, so the light collectors do not view the eastern sky as background.

In the Pacific, possible ground locations are limited to islands on which experiments can be supported. Needed weather data for some of the Pacific islands are meager. After consideration, the islands selected were Johnston Island (3,100 km) and Kwajalein (620 km). Arrangements were also made for shock mounting light detection equipment in a C-47 Air Force plane and flying it above Kwajalein on a course that would properly orient the equipment to receive the emitted light at detonation time.

The stations were operated by Air Force officer and enlisted personnel who had participated in Project 7.1b Snapper, with additions, to provide a total of six men for the three stations. Before being sent into the field, all people participating became familiar with the operation of the equipment at an AFOAT-1 field office.

Radios were used to monitor the AFSAL timing signals of the Task Force alert and timing system. Accurate timing signals were necessary because the recording period was short, varying between about 14 seconds and 20 seconds, depending on the freshness of the camera-operating battery. A supplementary radio communications link was set up between Program 7 Headquarters on Kwajalein and the station on Johnston Island.

Two recording channels were used at the Johnston and the Kwajalein ground stations, one a lens pickup and the other a reflector pickup. The aircraft station used a lens pickup. All pickups used a red-sensitive (RCA 925) photocell except the lens pickup at Johnston which was blue-sensitive (RCA 929). Iron posts to hold the pickups were cemented in the earth at both ground stations. The aircraft pickup pointed out an open window and was shock mounted to reduce vibration as much as possible.

As reported by Capt Carroll L. Hasseltine: "AFSAL time signals giving the time until detonations were received from the forward area during the entire operation. The scheduled detonation times were compared with the times given by the AFSAL signals. [Camera starting times] were obtained from stop watches checked against WWVH time signals in Hawaii which was contacted periodically. Cameras at Johnston and the ground camera at Kwajalein were started in operation for the Mike shot with the AFSAL five-second-until-detonation signal which occurred at approximately 1914: 59 Zulu on 31 October 1952. The camera installed with the 'bhangmeter' equipment in the aircraft was started by using a stop watch for timing at 1914: 55 Z. Photographs of the horizon in the target direction were taken as soon as practical after the shot. All 16-mm film was forwarded to Headquarters, Program 7 after the shot. The aircraft carrying the 'bhangmeter' equipment was at approximately 9 degrees 15 minutes North, 167 degrees 04 minutes East at 16,000 feet flying a 201 degree magnetic course when the camera was started. For the King shot the camera at Kwajalein was started with the AFSAL five-second-until-detonation time signal which was 2300: 04 Z on 15 November 1952. The aerial camera was started approximately 55 seconds after hearing a 'bombs away' broadcast on the radio. The airplane was located over the field at 12,000 feet. The Johnston cameras were started sometime between their scheduled five-second starting time, 2329: 55 Z, and the AFSAL five-second signal which occurred at 2330: 04 Z 15 November 1952. Target horizons were photographed as soon as possible after the shots and the film forwarded to Mr. Colson of Edgerton, Germeshausen and Grier."

INSTRUMENTATION

The system used for long range light detection is described in the final report of 7.1b Snapper (Reference 3). Briefly, a single channel consists of the following main components: (1) a light collector: this was either a tube with a condensing lens and photocell or

[redacted]

a searchlight reflector, with the lighting element replaced with a photocell; (2) cathode follower; (3) preamplifier, Hewelett-Packard Type 450a (not used in the airplane); (4) cathode ray tube with associated amplifiers; two circuits were used, one set at a gain of about 15 times the other in order to provide a wide latitude scale for recording the varying-amplitude light pulses; (5) strip film camera for photographing both 'scope faces; and (6) associate equipment such as power supplies, communications radios, standard light pulse generator for camera speed calibration frequency meter.

Figure 1, taken from Reference 3, is a block diagram of a typical remote station. As during the Snapper tests, the time constants of the Ivy equipment were set to give maximum discrimination against background; so times to minimum, and hence yield calculations, from the Ivy data, are not applicable.

RESULTS AND DISCUSSION

Mike time of detonation, as reported by reception of the electromagnetic signal by the National Bureau of Standards (NBS) under Project 7.1, was 31 October at 1914:59.204Z. As stated above under OPERATIONS, the Johnston Island and Kwajalein Island camera runs were started by the AFSAL five-seconds-until-detonation signal at 1914:59 Z. Starting by stop-watch only 0.2 second before the actual detonation, it cannot be stated whether or not the equipment was operating at detonation time; in any case, there is no indication of a signal at either station. The camera run on the airplane was started at 1914:55 Z, so it is likely that the equipment was in operation at detonation time, but no bomb trace can be located on the film.

As indicated above for King shot on 15 November 1952 at Kwajalein Island, the film run was started at about 2330:04 Z, according to the AFSAL five-second-alert signal; however, the shot actually went off at 2329:59.789Z as determined by the reception of the electromagnetic signal. It is apparent that the equipment was started too late. At Johnston Island the run was commenced sometime between the scheduled minus-five-second starting time and the actual five-seconds-until-detonation signal which occurred about four seconds after the half hour. It cannot be stated whether or not the equipment was started before detonation time; there is no signal discernible on the record. The bhangmeter equipment in the C-47 plane was over Kwajalein at 12,000-foot altitude, and was started by allowing for time-of-fall, about 55 seconds, after hearing the bombs-away broadcast signal. During this experiment, a signal from the bomb was recorded; it is reproduced in Figure 2.

The absorption can be calculated from the signal amplitude on the trace shown in Figure 2. The signal on 16-mm film was 0.016 film-inch on the low gain trace and off scale on the high gain trace; the sensitivity ratio between the two is 18.5.

Equivalent signal $0.016 \times 18.5 = 0.296$ film-inch

Equivalent voltage $= 0.415$ volts

Photocell current $= 0.083\ \mu a$

$$\text{Measured irradiance} = \frac{\text{current} \times \text{cell sensitivity}}{\text{area cell} \times \text{collector gain}}$$

$$= 0.083\ \mu a \times \frac{\mu \text{watt}}{0.042\ \mu a} \times \frac{1}{3.28\ \text{cm}^2} \times \frac{1}{50}$$

$$= 0.083 \times 4.07\ \mu\ \text{watts/cm}^2$$

$$= 337 \mu\ \text{watts/m}^2$$

[redacted]

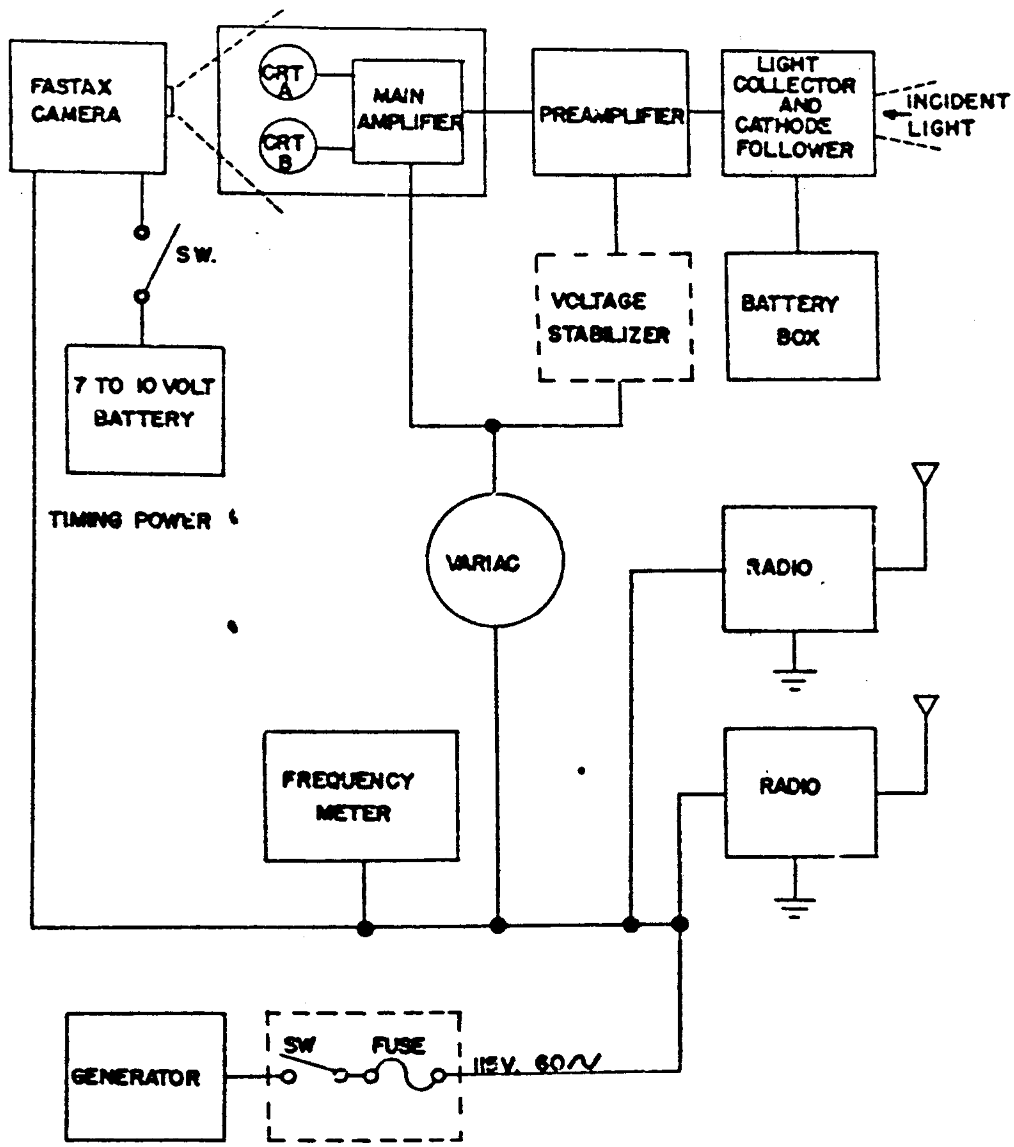

Figure 1 Remote station block diagram.

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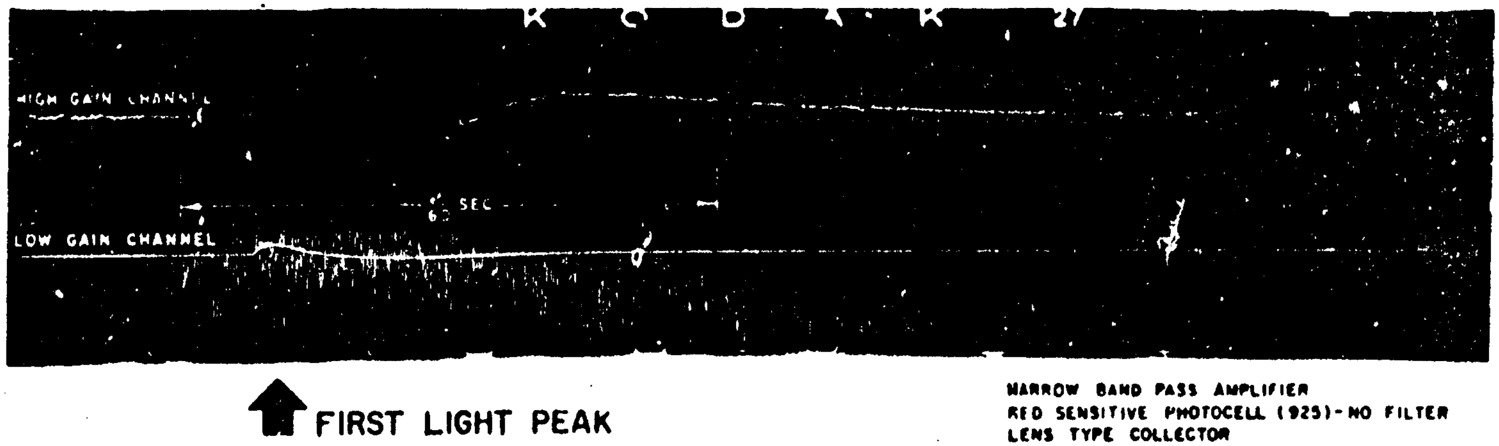

Figure 2 King shot, 15 November 1952; time, 2330 Z. Light time record from aircraft at 12,000 feet over Kwajalein; bearing, 298.5 degrees.

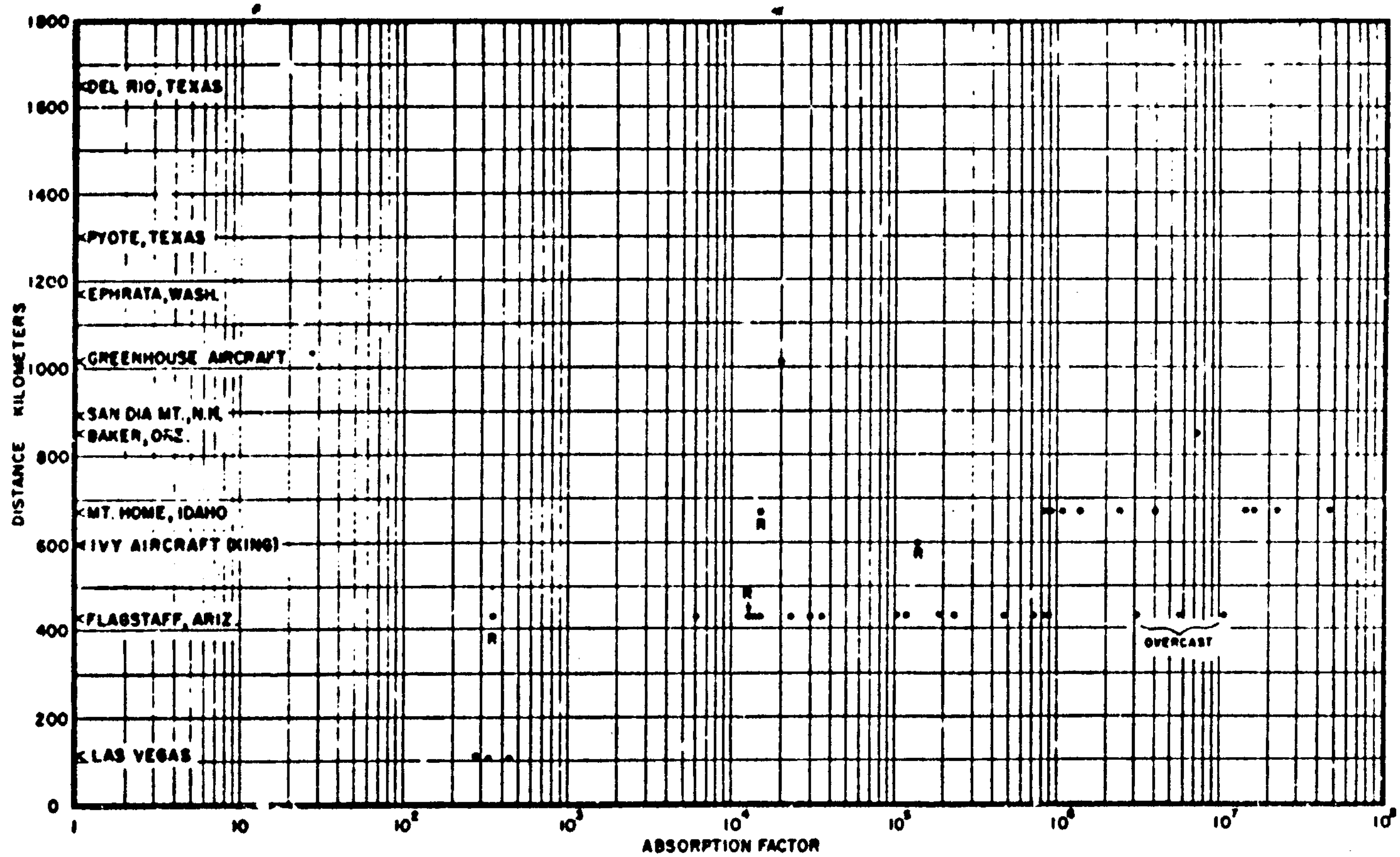

Figure 3 Absorption versus distance. Greenhouse, Buster, Tumbler-Snapper, and Ivy. Blue-sensitive photocell (generally Type 929, except Greenhouse used Type 5819). Where noted, R, red-sensitive (Type 925) was used. Absorption factor determined from measured irradiance at observing station and: $W_D = (W_T/4\pi D^2\ e^{-kD})$. Value plotted is effective e^{kD}.

Source: First peak of bomb light watts radiated in region in which photocell is sensitive

$$A_0 = 0.5 \times 10^{14}$$

Distance 600 kilometers

Irradiance at receiving station by inverse square attenuation

$$A_0 \frac{1}{4\pi D^2} = \frac{0.5 \times 10^{14} \text{ watts}}{4(6 \times 10^5)^2 \text{ m}^2} = 50 \text{ watts/m}^2$$

Assume that various absorption phenomena cause the difference between the measured irradiance and that calculated by inverse square attenuations; then the absorption is the ratio between these two values:

$$\text{Absorption} = \frac{\text{irradiance by inverse square}}{\text{measured irradiance}}$$

$$= \frac{50 \text{ watts/m}^2}{337 \times 10^{-6} \text{ watts/m}^2}$$

$$= 1.4 \times 10^5$$

For the one successful record the following may be added to data as presented in Table 3.1 of Reference 3: Shot King; Radiant flux emitted (approximate flux emitted in visible band); 2,000 Å wide centered for red cell at 8,000 Å: 0.5×10^{14} watts. Observing station and distance aircraft, 600 km, altitude 12,000 feet (3.7 km). Detector photocell sensitivity and polarization data; red (no polarizer used). Signal amplitude; output voltage at cathode follower of photohead, measured to top of first peak 0.415 volts. Irradiance; by inverse distance calculated by Equation 1, 50 watts/m^2. Ratio of irradiance by inverse square to that measured (absorption factor); 1.4×10^5. Signal-to-noise ratio; ~13.

Figure 3 is a reproduction of Figure 3.1, Reference 3, with the additional point added. About all that can be stated is that it is in general agreement with previous data.

The light flash was not visible to observers at any of the stations for either shot, although Mike was heard at Kwajalein as three distinct rumbles about 35 to 40 minutes after the shot.

During the analysis of the records, all were examined independently by two people accustomed to evaluating bhangmeter film recordings.

Line-of-sight to the horizon from 12,000 feet is about 220 km. It is apparent that the light is dispersed around the earth's surface for reception at 600 km.

A word should be said regarding the feasibility of an airborne station for long distances. During the Tumbler-Snapper series, an experiment was performed to determine the noise level in a C-47 plane flying around sunrise in the vicinity of Flagstaff, Arizona. The noise level recorded was between 18 and 42 millivolts using a system similar to that of the Ivy tests. This is but one or two orders of magnitude less than the peak shown in Figure 2. Present data indicate that a signal would be at noise level at a distance of approximately 800 to 1,000 km in the early morning.

Since the Kwajalein station did not produce data on either shot, it is not possible to make a comparison between the light flux received at the ground and at a point in the air above.

CONCLUSIONS AND RECOMMENDATIONS

Considering the results to date, it can be stated that with the type of equipment used,

[redacted]

under favorable conditions the detection of bomb light can be made to about 600 km distance.

At the present stage of development, it does not appear that the detection of light from a nuclear bomb burst is a feasible tool for long range detection.

It is believed that any further work should be devoted to a study of the basic phenomena; for example, the travel of the emitted light following the curvature of the earth and the lower noise level in the red region of the spectrum.

[redacted]

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