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UPSHOT-KNOTHOLE

NEVADA PROVING GROUNDS

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March - June 1953

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Project 8.10

PHYSICAL CHARACTERISTICS OF THERMAL RADIATION FROM AN ATOMIC BOMB DETONATION

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OPERATION UPSHOT-KNOTHOLE

Project 8.10

PHYSICAL CHARACTERISTICS OF THERMAL RADIATION FROM AN ATOMIC BOMB DETONATION

REPORT TO THE TEST DIRECTOR

by

Andrew Guthrie
R. W. Hillendahl

February 1954

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ABSTRACT

Measurements of some physical characteristics of thermal radiation are described in connection with five nuclear detonations at UPSHOT-KNOTHOLE. Data were obtained at ground stations and at distances from the point of detonation of 2350 and 5210 ft for Shot 3, 6785 and 8605 ft for Shot 4, and 6530, 16,960, and 26,810 ft for Shot 11. For Shot 9 ground measurements were made at stations covering a range of distances from about 2700 to 9800 ft. On Shot 10 the ground stations used covered a range from about 2200 to 14,000 ft. In addition to the ground measurements, some measurements were made from a B-50 aircraft on Shots 4 and 9.

The instruments (disk calorimeters and foil radiometers) used were similar to those used in previous field operations, although of a new design. This design led to simplified mounting systems both for the ground stations and the aircraft installation. A number of disk calorimeters were supplied to Projects 5.1, 8.1, 3.9, and 5.2.

In addition to measurements of the total thermal energy received as a function of distance, measurements were made of the thermal pulse shape, the spectral distribution, the energy reflected from the ground and the energy scattered by the atmosphere. Total energy measurements as a function of direction were made under smoke layers in connection with Project 8.4 on Shot 10. For this purpose, disk calorimeters with 180° fields-of-view were employed.

The results from this operation are consistent with those obtained at BUSTER and TUMBLER-SNAPPER. In general all of the equipment performed satisfactorily. In the case of Shot 3, the actual yield was considerably lower than that originally predicted. Consequently, the sensitivities chosen for the thermal instruments were such as to give meager results. The thermal yields obtained for Shots 4, 9, 10, and 11 are 4.0, 10.1, 5.2, and 20.3 KT, respectively. These values are based on transmission coefficients of 95, 92, 91, and 95 per cent for Shots 4, 9, 10, and 11, respectively. The spectral distributions obtained with the Corning Glass Filters agree quite well with those obtained at TUMBLER-SNAPPER.

The measurements made under the smoke layers on Shot 10 indicate a high degree of attenuation produced by both black and white smokes under

the particular conditions which prevailed at the time of the test (over 95 per cent in each case). These measurements might appear to show the white smoke to be more effective than the black smoke in attenuating the thermal radiation. However, it would not be justified to arrive at such a conclusion on the basis of the limited measurement made, and because of uncertainties in the concentration and distribution of the smoke layers.

The data obtained in this operation appear to fit, within experimental error, scaling relationships derived on the basis of previous operations. For example, the time to second peak, t_p in seconds, fits the relationship $W = 850\ t_p^2$, where W is the total yield of the weapon in KT of TNT equivalent. The times to second peak are as follows: 0.118 sec for Shot 4, 0.179 sec for Shot 9, 0.138 sec for Shot 10 and 0.257 sec for Shot 11.

The thermal measurements made from the B-50 aircraft again indicate the importance of ground-reflected energy.

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.

ACKNOWLEDGMENTS

The successful completion of Project 8.10 was due to the cooperation and unstinted efforts of many individuals at the USNRDL.

All members of the Thermal Radiation Branch, USNRDL, contributed in one way or another to this project. Valuable discussions were held with A. Broido concerning scaling laws. R. L. Hopton made substantial contributions to the project, particularly in connection with various instrumentation requirements. The success in meeting a rather rigid schedule can be contributed in no small part to the efforts of J. R. Nichols, AFC, USN, who served as Project Construction Inspector. A. L. Greig and F. I. Laughridge assisted in various technical aspects of the project both in the Laboratory and in the field.

In addition to the above personnel, the assistance of various individuals assigned from the Engineering Division, USNRDL, for the field phases of the project, is gratefully acknowledged.

It is a pleasure to acknowledge the assistance and encouragement of P. C. Tompkins, Scientific Director, USNRDL. The assistance rendered by personnel of the Directorate of Weapons Effects Tests, Field Command, AFSWP, contributed substantially to the success of the project.

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CHAPTER 1

INTRODUCTION

1.1 GENERAL

The thermal radiation produced during a nuclear detonation provides one of th› principal methods for the dissipation of the energy released. Consequently, it constitutes one of the prime sources of damage produced by such a detonation.

The degree of damage sustained by materials of military interest will be determined by the various pertinent physical characteristics of the thermal radiation. Project 8.10, Operation UPSHOT-KNOTHOLE, was designed to provide further information regarding certain of these characteristics. In addition, a number of measurements were made in support of other projects.

1.2 OBJECTIVES

Specific objectives were:

1. To measure the total thermal flux and the time-irradiance relationship as functions of distance for several detonations and at such elevations above ground as to minimize the effect of local obscuration caused by dust and smoke.
2. To measure the thermal flux and time-irradiance relationship as functions of direction and under an artificially produced smoke layer.
3. To measure the thermal radiation received at various ground stations as a function of the field-of-view of the measuring device.
4. To obtain a rough indication of the spectral composition of the thermal radiation received at several ground stations, including one located under an artificially produced smoke layer.
5. To obtain further information regarding the thermal energy reflected by ground areas adjacent to several ground stations.
6. To measure pertinent physical characteristics of the thermal radiation as received by aircraft located very nearly over the point of detonation at time of detonation and to determine indirectly the

contribution of reflected energy. Interest is in such characteristics as the total thermal flux, the time-irradiance relationship, the spectral composition and in the effect of field-of-view of the measuring device on total thermal flux.

7. To obtain additional data for purposes of checking proposed scaling laws for thermal radiation and for extrapolation to larger weapons.

8. To provide total thermal radiation energy data obtained under comparable circumstances for correlation with data obtained by the Naval Research Laboratory employing different techniques.

CHAPTER 2

EXPERIMENT DESIGN

2.1 BACKGROUND AND THEORY

Some measurements of the pertinent physical characteristics of thermal radiation were obtained at nearly all previous nuclear weapons tests. However, in several of these operations the weapons were mounted on towers. The obscuring dust produced by detonations near the ground complicated the results obtained and thus prevented the accumulation of suitable data for accurate extrapolation and generalization with regard to the thermal output of nuclear weapons. Even by eliminating the effect of the shock wave in producing obscuration of the thermal radiation, care must be taken in the interpretation of thermal data obtained relatively close to ground zero. Measurements made at GREENHOUSE(1) and BUSTER(2) indicated the presence of obscuring material at times and distances such that it appeared questionable that the obscuration was produced by the blast wave. Such obscuration apparently resulted through the incident thermal radiation by the production of smoke and by "popcorning" of the sand. These observations pointed to the necessity for carrying out measurements at a sufficient height above the ground level to minimize these effects resulting from the incident thermal radiation. In addition, it was indicated that the measurements should be carried out with the weapons detonated at a sufficient height above ground so as to minimize obscuration produced by the shock wave.

Measurements were made at TUMBLER-SNAPPER(3) under conditions satisfying the above requirements in large part. Project 8.10 was designed in part to provide a check on the numbers obtained at TUMBLER-SNAPPER, and in particular to obtain information regarding the physical characteristics of the thermal radiation for weapons of yields for which no previous measurements were available. In addition, UPSHOT-KNOTHOLE provided the first opportunity for determining the effect of an artificially produced smoke layer on the thermal radiation characteristics. In this connection, Project 8.10 was designed to provide more absolute measurements to serve as reference points for measurements being made by other projects.

Measurements made on aircraft in flight at TUMBLER-SNAPPER and IVY indicated that a substantial part of the thermal energy incident on the aircraft was due to reflection from the earth's surface. The importance of this reflected energy as pertaining to the operation of aircraft indicated the desirability of obtaining further information on this subject.

2.2 MAKE-UP AND LOCATION OF STATIONS

During UPSHOT-KNOTHOLE, measurements of certain physical characteristics of the thermal radiation were made with two types of instruments, disk calorimeters and disk or foil radiometers. Both of these types of instruments were used during TUMBLER-SNAPPER and proved satisfactory. The location of the instruments was made on the basis of the considerations of Section 2.1. As a result, where the thermal flux was expected to be high enough to cause considerable "popcorning" of sand and the production of smoke, the instruments were located approximately 50 ft above the ground level. In some cases where existing 55 ft towers were available from TUMBLER-SNAPPER, these locations were used again, although this was not essential in order to avoid obscuration effects in all cases. In general, at the positions where low thermal flux was anticipated, the instruments were located approximately 10 ft above ground level. Ground stations were instrumented for Shots 3, 4, 9, 10, and 11. Shots 3, 4, and 11 were fired in Yucca Flat in Area 7 with target locations 7-5a, 7-3, and 7-303 respectively. For Shots 3 and 4, two stations were instrumented along the TUMBLER-SNAPPER thermal line, using existing 55 ft towers and instrument shelters. These towers were located at distances of 3000 ft and 6000 ft respectively from the ground zero position for target 7-3. As for TUMBLER-SNAPPER, recording of the calorimeter and radiometer signals was carried out by means of Heiland Oscillographic Recorders. The make-up and location of the stations for Shots 3, 4, and 11 are summarized in Tables 2.1 and 2.2 and a plot plan of the station layout for these shots is shown in Fig. 2.1. Shots 9 and 10 were fired in the Frenchman Flat area with a ground zero 2000 ft due east of the TUMBLER-SNAPPER ground zero. For Shot 9 a total of seven instrument stations was used. Five of these stations were located along the old TUMBLER thermal line, and two were located along the new smoke line bearing East 20° North from ground zero. The make-up and location of the stations for Shot 9 are shown in Table 2.3. Except for instrument station F-216, an instrument shelter was provided for each tower installation, being located within 60 ft of the tower. The instruments on tower F-216 were recorded in the shelter adjacent to station F-202. A plot plan of the station layout is shown in Fig. 2.2. For Shot 10, stations F-202, F-208, F-210, F-295, and F-424 were used again. Two new stations were added, F810F located along the TUMBLER thermal line 14,000 ft from ground zero and F-422A along a line from ground zero bearing East 30° South of the thermal line. The make-up and location of the stations for this shot are summarized in Table 2.4. New calorimeter and radiometer designs (Mark 6F) were adopted for use in Project 8.10. All ground stations made use of these Mark 6F instruments.

TABLE 2.1 Station Locations, Shots 3 (31 March) and 4 (6 April)

Tower Station	Distance from GZ (ft)		Recorder Station	Recorder Number		Instruments	
	Shot 3	Shot 4		Shot 3	Shot 4	Cal.	Rad.
7-204	2,350	3,000	7-221	435 437	437 865	5 5	1 1
7-208	5,210	6,000	7-234	436 865	436 435	5 5	1 1

TABLE 2.2 Station Locations, Shot 11 (4 June)

Tower Station	Distance from GZ (ft)	Recorder Station	Recorder Number	Instruments	
				Cal.	Rad.
7-208	6,190	7-221	107 108	5 5	1 1
1-356	17,010	1-8.10A	435 436	5 5	1 1
812-1	26,790	1-8.10B	437 865	5 5	1 1

In addition to the ground stations, two Strategic Air Command (SAC) B-50 aircraft were instrumented. These aircraft, numbers 362 and 371, were assigned by the 93rd Bomb Wing, Castle AFB and were instrumented with the MK-6F field calorimeters and radiometers. In addition, a third B-50 aircraft provided by Wright Air Development Center (WADC) was instrumented with the same types of instruments but was operated in connection with Project 5.2. All three aircraft were operated in formation and at the times of detonation were located very nearly above the points of detonation. Consequently, the measurements made can be extrapolated with some degree of confidence.

All of the above stations except those under the smoke layer were intended to supply information specifically for Project 8.10. Calibrated calorimeters were also supplied to other projects. Project 5.1 was supplied with five calorimeters, two of which were mounted on each of two drone aircraft. These were of the design used on TUMBLER-SNAPPER (Mark 5F). Project 8.1 used ten Project 8.10 calorimeters (Mark 5F) for making measurements on aircraft located on the ground on Shots 9

TABLE 2.3 Station Locations, Shot 9 (8 May)

Tower Station	Distance from GZ (ft)	Recorder Station	Recorder Number	Instruments	
				Calorimeters	Radiometers
F-216	1,000	F-220	437	2	2
F-202	2,500	F-220	437	6	2
F-208	4,000	F8.10A	436	10	2
F-210	5,000	F8.10B	438	4	3
F-295	9,500	F8.10C	435	10	2
F-424	2,500	F8.10D	108	12	-
F-429	4,500	F8.10E	107	12	-

TABLE 2.4 Station Locations, Shot 10 (25 May)

Tower Station	Distance from GZ (ft)	Recorder Station	Recorder Number	Instruments	
				Calorimeters	Radiometers
F-202	2,500	F-220	437	6	2
F-208	4,000	F8.10A	436	10	2
F-210	5,000	F8.10B	438	4	3
F-295	9,500	F8.10C	435	10	2
F8.10F	14,000	F8.10G	107	11	1
F-424	2,500	F8.10D	865	12	-
F-422A	2,165	F8.10H	108	12	-

and 10. Project 3.9 made use of six Project 8.10 calorimeters (Mark 6F). Finally, Project 5.2 was supplied with one standard aircraft mount containing four calorimeters (Mark 6F) and two radiometers (Mark 6F).

2.3 DISK CALORIMETERS

The disk calorimeters used in Project 8.10 were basically the same type of instrument as used during GREENHOUSE, BUSTER, and TUMBLER-SNAPPER. However, the design was changed so as to simplify the mounting arrangements and to make the instrument more suitable for installation on aircraft. The design is such as to permit mounting each calorimeter in standard 2 in. IPS pipe fittings. In addition, the field-of-view can be readily changed by the use of the appropriate internal parts. This type of design was used so that a 180° field-of-view can be readily obtained. This requirement was set by Project 8.4 in connection with smoke measurements. A cross-sectional view of the 90° field-of-view disk calorimeter is shown in Fig. 2.3, while the 180° field-of-view

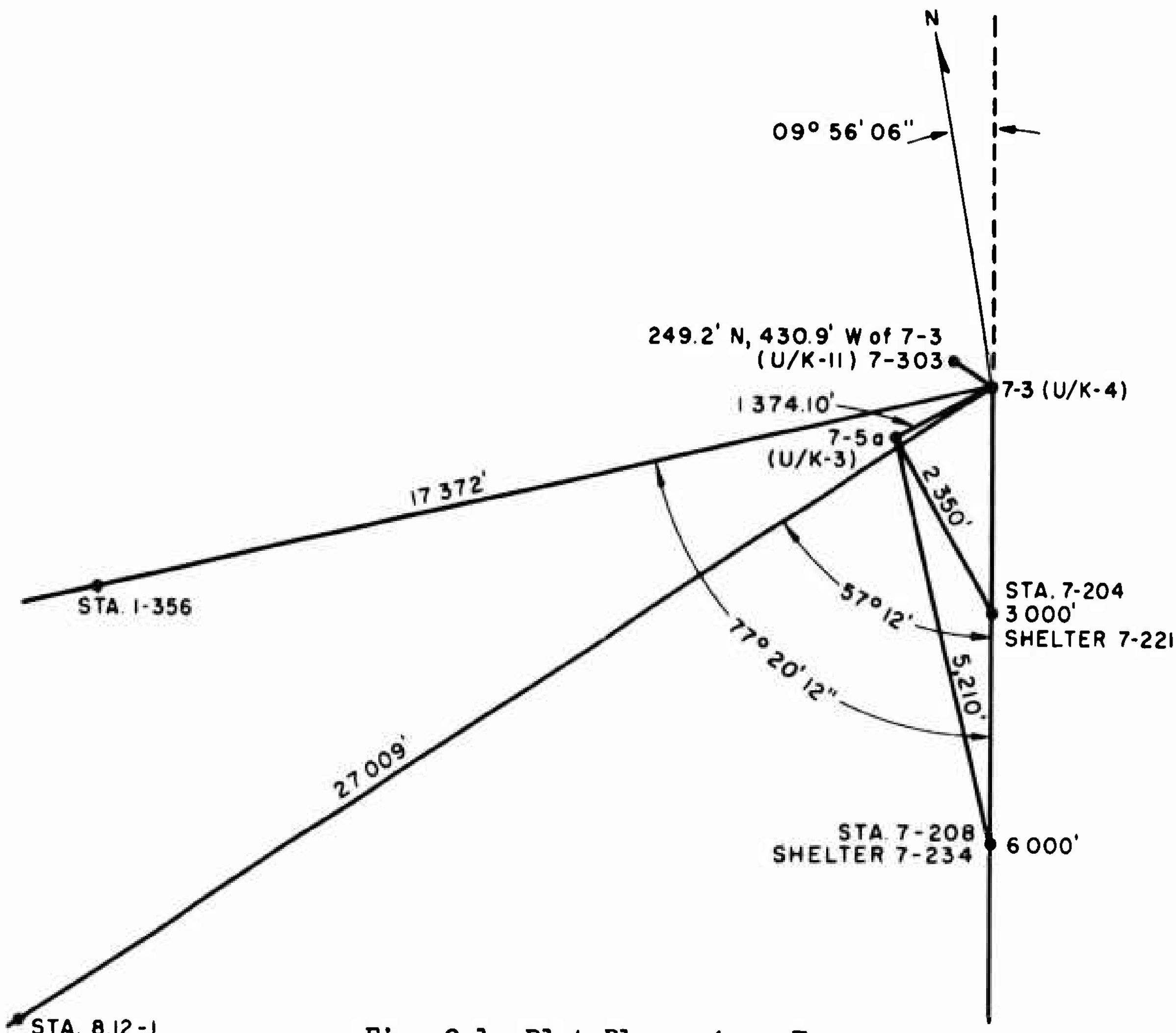


Fig. 2.1 Plot Plan - Area 7

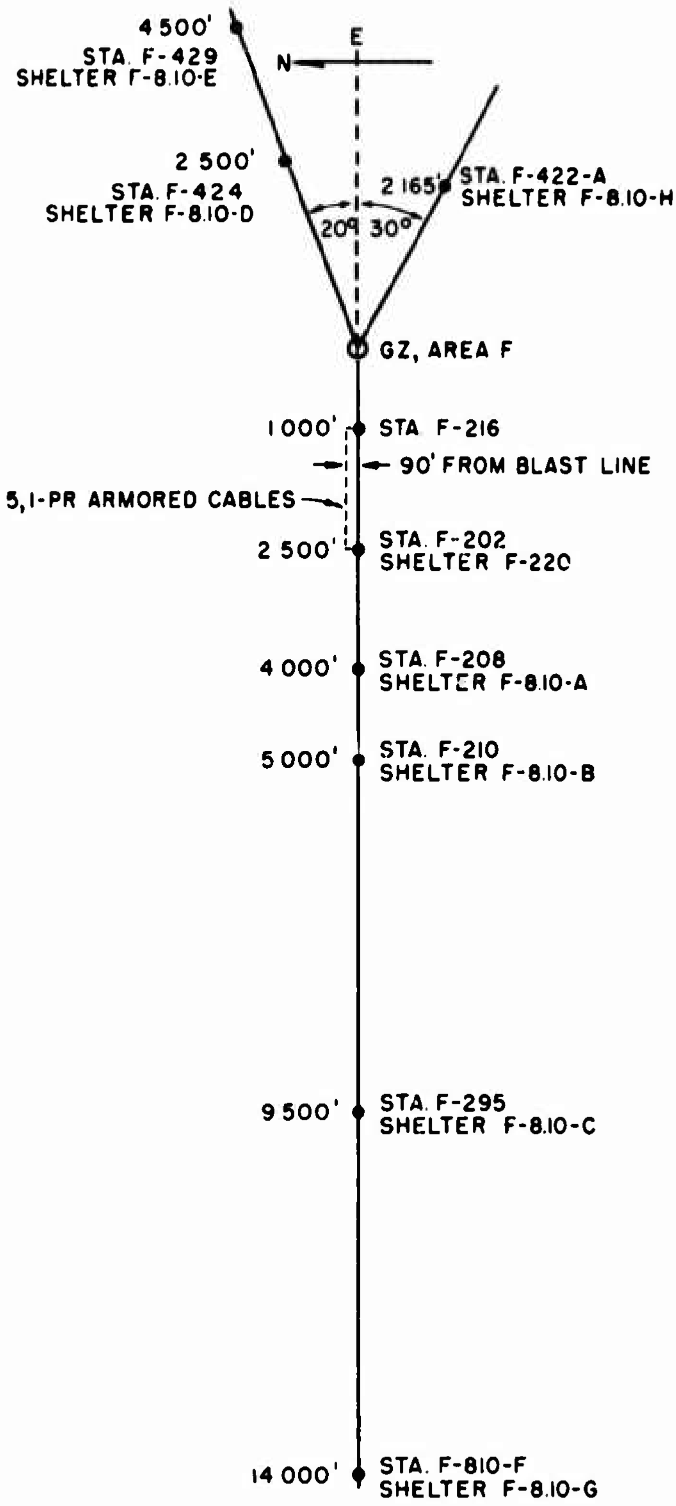


Fig. 2.2 Plot Plan - Area F

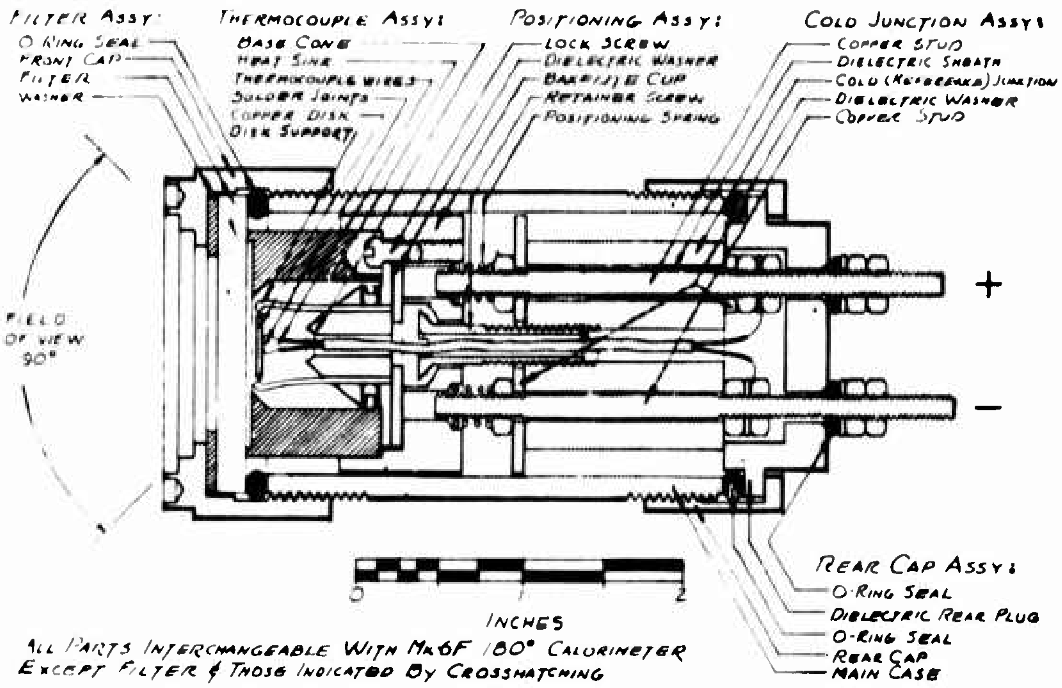


Fig. 2.3. MK-6F Field Calorimeter (90° Field-of-view)

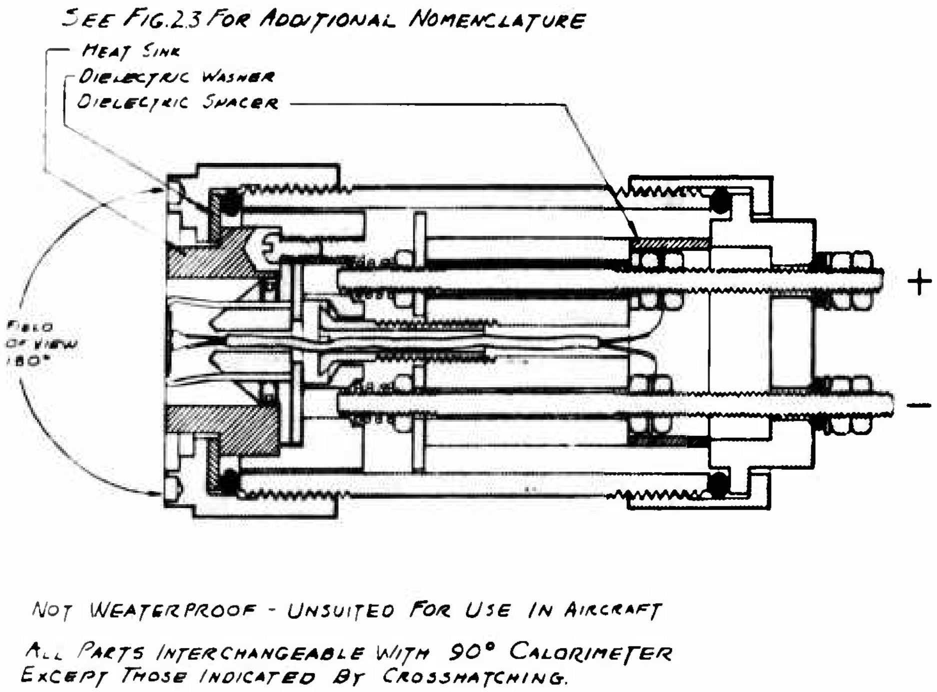


Fig. 2.4. MK-6F Field Calorimeter (180° Field-of-view)

instrument is shown in Fig. 2.4. This redesigned calorimeter met the time constant requirement for irradiance measurements (less than 20 msec) as set by the Armed Forces Special Weapons Project (AFSWP). The thicknesses of all disk receivers used, together with an indication of the energy for which these thicknesses were selected, are shown in Table 2.5a. In this table, col 3 gives the temperature in degrees centigrade above the ambient temperature, which the receiver will attain when exposed to the energy listed in col 2. Col 4 gives the voltage generated at the thermocouple and col 5 gives the voltage which the galvanometer records to produce the deflection in col 6. The difference in the two voltages listed is due to the necessity of including a series resistance into the thermocouple circuits in order to properly damp the galvanometer. Table 2.5b lists some criteria used in selecting calorimeter disks for use in making measurements in the field. The code colors listed in col 2 are used again in the portion of this report dealing with results. In general, the numbers listed in cols 3, 4, and 5 are those recommended in order that the greatest accuracy can be achieved. In practice, these criteria are not always met. The limitation on minimum energy for a given calorimeter disk is set by the galvanometer sensitivity while that on maximum energy is set by nonlinearity in response or physical destruction of the disk. The limitation on minimum energy for obtaining a time-irradiance curve arises from inaccuracies in the differentiation methods which must be used.

The 180° field-of-view instruments were used to measure total energy and the time-irradiance relationship with the receiving disk exposed to the atmosphere. All of the 90° field-of-view instruments, when used for measuring total thermal energy, were provided with quartz filters in front of the receiving disks, which transmitted in the region between approximately 2200 Å and 4.5 μ. For the spectral measurements, the same types of filters as used in TUMBLER-SNAPPER were used again, namely, Corning Glass Filters, Numbers 0-52, 3-69, 2-58, and 7-56. Transmission curves for these filters are included in the Project 8.3 report for TUMBLER-SNAPPER, WT-543(3). The disk calorimeters were used to obtain both total energy values for the thermal radiation and curves of irradiance vs time from differentiation of the total energy curve. A discussion of the procedure for obtaining the time-irradiance curve from the total energy curve is contained in the report, WT-543.

At a number of ground stations some of the 90° disk calorimeters were modified in an attempt to distinguish between direct fireball radiation, radiation scattered by the air, and radiation reflected from the ground. In a number of cases a shovel-like arrangement was attached to the calorimeter so that the button did not see the ground and therefore did not receive energy reflected from the ground. These shovels were made of galvanized iron, being about 8 in. in length and 4 in. wide. To eliminate the direct fireball radiation, obscuring disks were mounted in front of a number of calorimeters, the size of disk being determined by expected fireball radius, position of the ground station, and estimated errors in point of detonation and alignment of instrument. To obtain further information on the air scatter contribution as a function of angle of field-of-view, a number of the calorimeters were equipped with segments of pipe attached to the front ends. The field-of-view

TABLE 2.5a Galvanometer Deflections for Various Energies and Disk Thicknesses

Thickness (in.)	Energy (cal/sq cm)	Temperature (°C)	Thermocouple Signal (mv)	Recorded Signal (mv)	Deflection (cm)
0.125	40	150	6.8	3.2	4.3
0.0625	20	150	6.8	3.2	4.3
0.0312	10	150	6.8	3.2	4.3
0.025	5	95	4.2	2.0	2.7
0.020	3	70	3.2	1.5	2.0

TABLE 2.5b Calorimeter Selection Criteria

Thickness (in.)	Code	Thermal Energy (cal/sq cm)		Min. Energy for Time-Irradiance (cal/sq cm)
		Min.	Max.	
0.125	Red	10	> 20	20
0.062	Black	5	20	10
0.031	White	2.5	10	5
0.025	Gray	2	5	2.5
0.020	Brass	1.5	3	2.0

desired was then adjusted by choice of pipe length and pipe diameter. An alternative approach to that noted above, for getting some idea of the amount of ground-reflected energy, was to measure energy reflected from the ground to instruments looking directly down at the ground from a height of 35 ft. These were standard 90° field-of-view instruments.

With regard to the aircraft measurements, the spectral and total energy measurements were made in the same manner as at the ground stations using 90° field-of-view instruments. However, a number of instruments were modified so as to have a nominal field-of-view different than 90°. The actual types of arrangements used were set by geometrical considerations arising from the aircraft structure. It was necessary to modify the calorimeters internally so as to move the receiving disk farther from the front. An aperture in the front then defined the field-of-view. Because of this geometry it has to be stressed that these are purely nominal fields-of-view which represent the angles subtended by the apertures at the center of the button.

2.4 DISK OR FOIL RADIOMETER

This type of instrument was used successfully during the TUMBLER-SNAPPER operation. For Project 8.10, the radiometer was slightly modified for ease in mass production and so that the same mounting system could be used for both calorimeters and radiometers.

The arrangement used is shown in Fig. 2.5 in which the recorded signal is an indication of the temperature difference which exists between the center and the edge of the silver foil while under irradiation.

Some discussion of the calibration procedure used for this instrument is given in the report, WT-543.

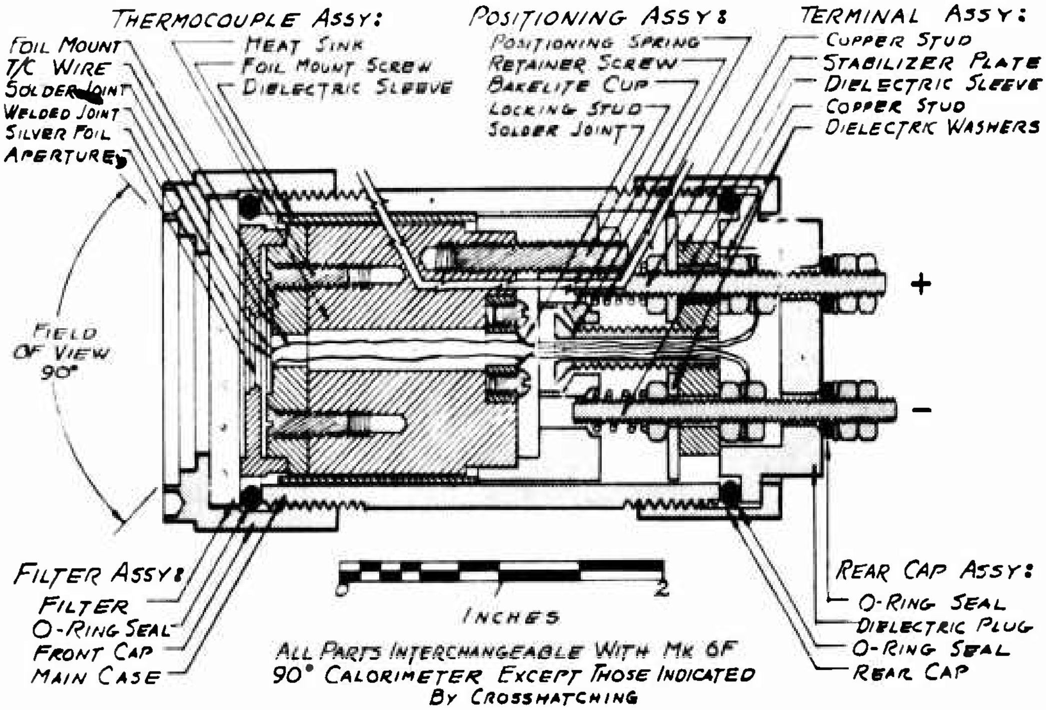


Fig. 2.5 MK-6F Field Radiometer (90° Field-of-view)

2.5 CIRCUITS

The same types of electrical recording circuits as for Project 8.3, TUMBLER-SNAPPER were used for Project 8.10. Considerable care was taken to use shielded circuits, properly grounded. The ground connections were made at each station to three copper rods in the ground, each embedded in a rock-salt solution.

Basically the recording of data for the Project 8.10 aircraft was performed in the same manner as for the ground stations. The Heiland recorders used were started manually through contact with the drop aircraft. These particular recorders were loaned to Project 8.10 by WADC.

Each smoke shutter arrangement was connected through a 5 mil molybdenum wire by Romex cable, protected from direct thermal radiation, to a junction box, an automobile starter relay, and a 24-volt aircraft battery power source in the instrument shelter. Current through the smoke shutter circuits was initiated by the starter relay which was activated by the minus 5 sec Edgerton, Germeshausen and Grier timing signal. The shutters were released by melting of the fine molybdenum wire. Every precaution was taken to isolate the smoke shutter circuits from the Heiland recorder circuits.

In general, the length of cable used to connect the instruments to the recorders was less than 150 ft. The one exception to this was for station F-216 on Shot 9 which was connected to the Heiland recorder adjacent to station F-202 and involved approximately 1700 ft of cable.

2.6 MOUNTING

As in the case of Project 8.3, TUMBLER-SNAPPER, 2 in. O.D. Tubelox pipe and clamps were used for supporting instrument mounts on the towers. Considerable time was saved by making use of standard mounting units assembled prior to being brought into the field. Four standard mount arrangements were used for holding one, two, four, or six instruments. Views of typical mount arrangements are shown in Figs. 2.6 and 2.7. Figure 2.6 also shows the standard albedo arrangement as used at the 35 ft level in the T-7 area for Shots 3 and 4 and at stations F-202 and F-208 on Shots 9 and 10 in the Frenchman Flat area. Figures 2.8 and 2.9 show views of the instrument arrangements along the smoke lines for Shots 9 and 10.

The Mark 6F design of calorimeter led to the adoption of a standardized mounting arrangement for the B-50 aircraft installations. This consisted of an instrument holder unit which could hold six calorimeters or radiometers and two GSAP cameras. The entire unit was mounted on a standard USAF camera mount, thus allowing adequate adjustability. Aircraft 362 was provided with two instrument holders, while aircraft 371 was provided with one such holder. Each holder in these aircraft contained five calorimeters, one radiometer, and two GSAP cameras provided with wide-angle lenses. In the case of aircraft 340, operated for Project 5.2, one instrument holder unit was used with two calorimeters, two radiometers, and two GSAP cameras. Details of the experimental arrangements as well as the results for this particular aircraft can be found in the Project 5.2 report, WT-749. Project 8.10 supplied the calibrated calorimeters and their holders for the three B-50 aircraft involved, while Project 5.2 supplied the GSAP cameras and operated the equipment. A top view of a double instrument holder unit is shown in Fig. 2.10, with the top cover removed from one unit.

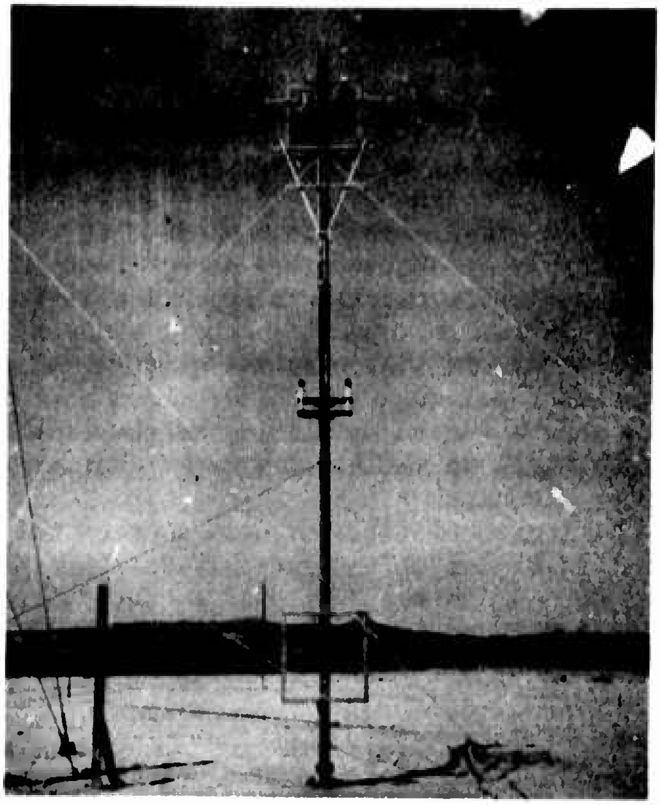


Fig. 2.6 Typical 50 ft Tower Installation

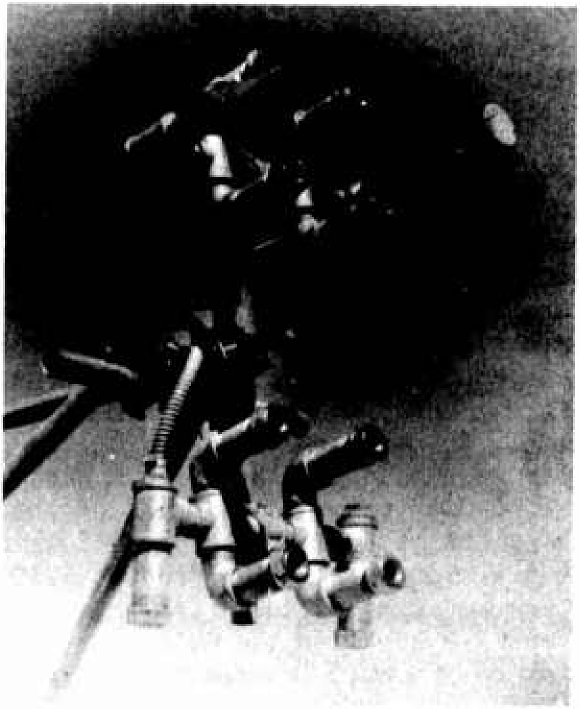


Fig. 2.7 Typical 10 ft Tower Installation

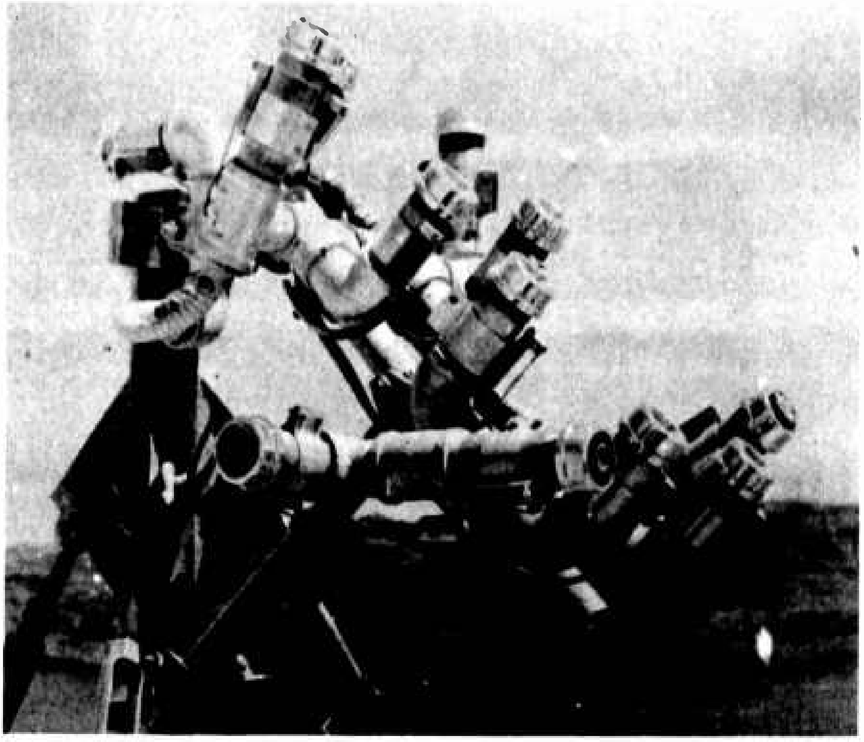


Fig. 2.8 Station F-424 Instrumentation

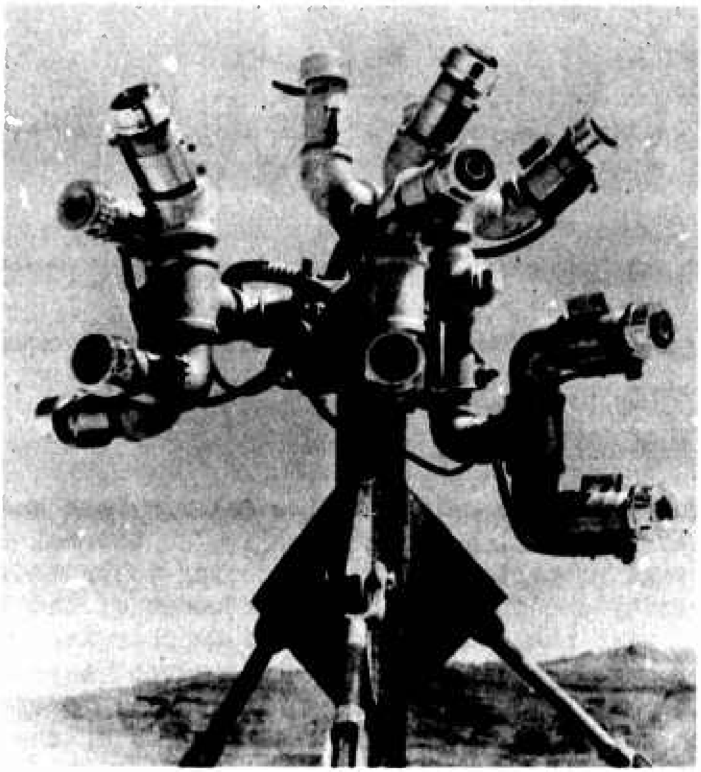


Fig. 2.9 Stations F-429 and F-422A Instrumentation

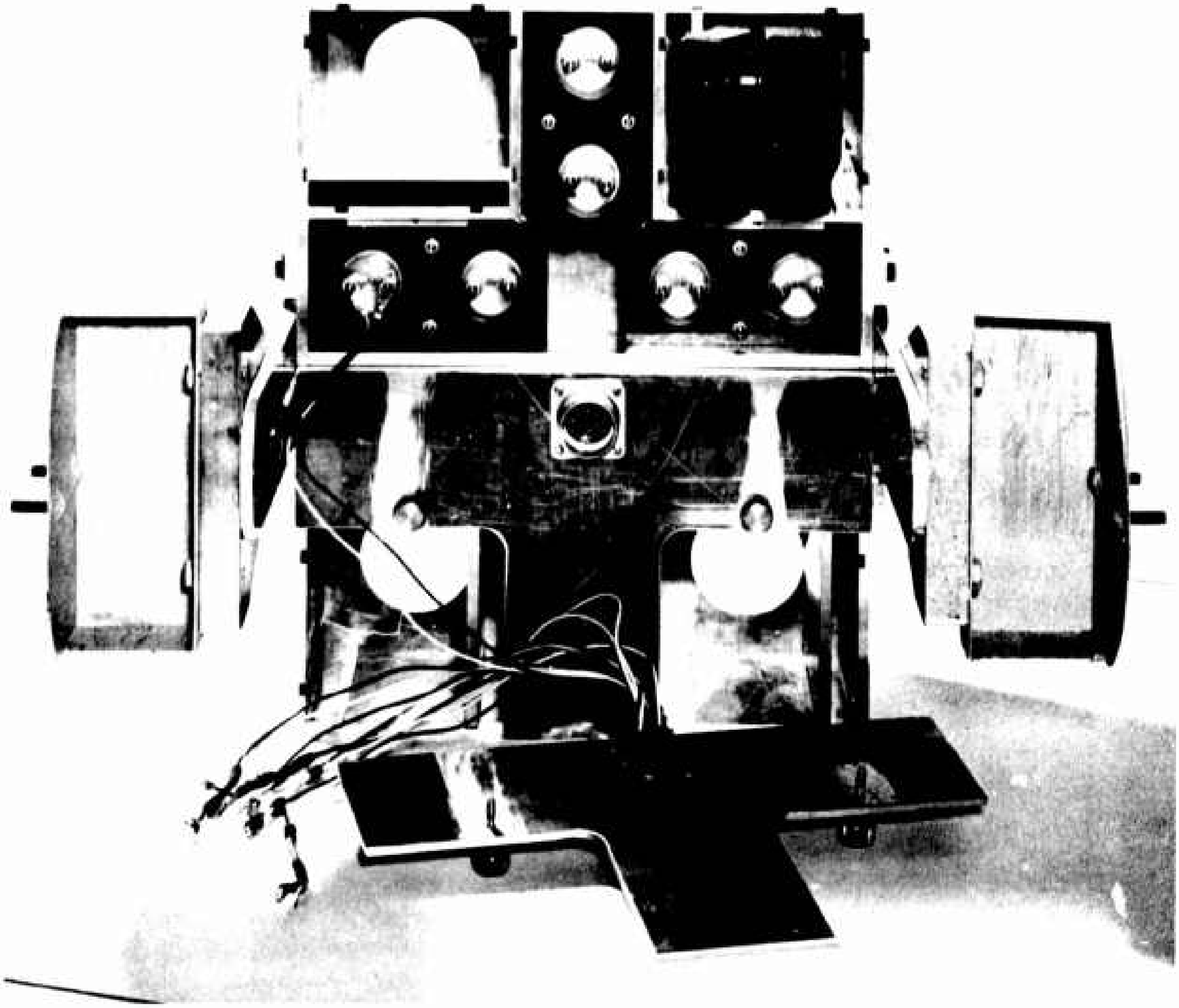


Fig. 2.10. View of Aircraft Instrument Holder

2.7 CALIBRATION OF INSTRUMENTS

The procedures used to calibrate the calorimeters and radiometers were of two types - thermal and electrical. The thermal calibrations concern the thermal properties of the measuring instrument itself and were usually made by a comparison of the response of the instrument being calibrated with the known response of another instrument or laboratory standard. This required the measurement of thermoelectric output. Such thermal calibrations were, in general, performed in the laboratory, both before and after the field phases of the operation. The experimental details of the thermal calibration were quite similar to those described in WT-543. The treatment of the calibration data differed only in the method of correction for change of thermoelectric power with energy range. The newer procedure replaces the averaging of "high" and "low" energy calibrations with a simple equation which takes into account the change of both thermoelectric power and specific heat with receiver disk temperature. This method gives greater accuracy for energy values differing from those used in the calibration procedure.

Since the thermal pulse generates an electrical signal which is recorded by a galvanometer not part of the detection devices, an electric calibration is necessary in addition to the thermal calibration. The electrical calibration took into account the characteristics of the electrical circuit used to record the thermoelectric signal generated by the particular detection device. Consequently, this type of calibration was performed in the field using the circuits that were used during the test itself. Details regarding the calibration procedures used in connection with the calorimeters and radiometers are to be found in reports on previous field operations and are not repeated here.

CHAPTER 3

RESULTS

3.1 GENERAL

After each detonation, the shot area was re-entered at the earliest moment following clearance by the Radiological Safety Group. The post-shot electrical calibrations were made and the Heiland recorder papers were recovered. The performance of equipment, except on Shot 3, was generally quite satisfactory for the entire operation. On Shot 3, Heiland recorders Nos. 436 and 437 failed to operate properly. However, the yield for this particular weapon was considerably less than anticipated so that the sensitivities of the instruments used were too low to record many of the measurements. On Shot 4 the timing circuit failed to operate properly on Heiland No. 436. A new timer was installed for subsequent shots. The smoke shutter mechanisms and associated circuits used in connection with Shot 9 and 10 performed in an entirely satisfactory manner. In several cases a small amount of electrical pick-up was recorded, but this was not sufficient to negate any of the results obtained.

A number of the instruments were damaged in connection with Shot 9 due to the absence of a protective smoke layer. In most cases the solder connection between the calorimeter disk and the thermocouple wires appeared to melt (see Figs. 2.3 and 2.4) and then to resolidify shortly afterwards. Most of these instruments did not appear to be physically damaged, but since too much reliance could not be placed on the original calibration factors, only a few of these instruments were used on the subsequent shots. No damage was sustained by the mounting arrangements, towers, or cables on Shots 3, 4, 9, and 11. In the case of Shot 10, some damage was sustained by tower F-202 so that the results obtained at this station should be examined critically.

The original Heiland traces for Shots 4, 9, 10, and 11 were read by Telecomputing Corp., Burbank, Calif., under contract with USNRDL. An examination of the Shot 3 records indicated that little would be gained by going through a complete machine operation. Due to the late receipt of the original B-50 aircraft records, these were read visually. In addition to reading Heiland records, Telecomputing Corp. inserted the appropriate calibration factors and arrived at integral and differential curves for the disk calorimeters and differential curves for the foil radiometers.

3.2 DISK CALORIMETERS

The total energy received by each calorimeter disk is given in Tables 3.1 through 3.5 for the ground stations. In these tables col 1 ives the calorimeter use code, col 2 the field-of-view of the calorimeters, col 3 the angle between the calorimeter axis and the horizontal plane for clear line stations or instrument position numbers as given in Fig. 3.1 for smoke stations, col 4 the nominal height above ground level, col 5 the calorimeter disk number, col 6 the filter designation, col 7 the data designation number for each instrument, and col 8 the energy received by the disk. The values reported in col 9 are obtained by making corrections to the values in col 8 for the transmission of the filters in the flat portions of their transmission curves. This correction amounts to about 8 per cent for quartz, 8 per cent for 0-52, 10 per cent for 3-69, 12 per cent for 2-58 and 12 per cent for 7-56. Referring to col 1 of the tables, a designation has been given to the instruments on the basis of the type of measurement for which they were used. These types of measurements are as follows: TE - total energy, GR - ground reflectance, SP - spectral distribution, AL - ground albedo, AS - air scatter contribution and FV - field-of-view other than the standard 90°.

Figure 3.2 shows plots of the incident thermal energy measured at the various stations vs the distance from actual GZ positions. The incident thermal energy values refer to the actual energies received at the stations and have been taken from col 9 of Tables 3.2 through 3.5. The extrapolated portions of the curves have been calculated from the inverse square plots (see Fig. 4.1).

The calorimeter results for aircraft 362 and 371 are summarized in Tables 3.6 and 3.7. The titles of the various columns have been previously defined in connection with the ground station measurements. In the case of Shot 4 the GZ position was 4350 ft above sea level and the altitude of the aircraft above sea level was 30,000 ft. Corresponding numbers on Shot 9 were 3132 ft and 21,735 ft, respectively. The special instrument geometries used at some of the ground stations and on the aircraft are shown in Fig. 3.3. This information is provided so that a somewhat more detailed analysis of the results shown in Tables 3.1 through 3.7 can be carried out.

3.3 FOIL RADIOMETERS

These instruments were not used along the smoke lines. Those mounted in the clear areas all had their axes aligned to pass through the expected point of detonation and they were intended to supply information regarding the time-irradiance relationships for the thermal radiation. All of these instruments had 90° fields-of-view and quartz filters.

In the cases of the ground stations, an irradiance-time curve was plotted for each radiometer and integrated to obtain the total energy. These total energy values were obtained by integration of the curves from 0 to 3 sec for Shots 4, 9, 10, and 11. This time interval was chosen on the basis of weapon size since the irradiance in each case has decreased at this time to a small fraction of the peak irradiance. Carrying the integration to longer times increases the uncertainties in the reduction of data, but adds little information of importance.

The radiometer results for the ground stations are listed in Tables 3.8 and 3.9. Column 6 gives the total energies incident at the station as determined with the radiometers and for the 3 sec time interval. Column 7 gives the total energy measured with the calorimeters at corresponding stations for comparison purposes. These energies are for the same time interval as in the case of the radiometers. All energy values have been corrected for filter losses as described in para 3.2. The times to second maximum, as recorded by the radiometers in aircraft 362 and 371, are listed in Table 3.10.

3.4 DISTANT STATION MEASUREMENTS

A limited number of measurements were made at manned, portable stations in connection with Shots 9, 10, and 11. In all cases calorimeters, radiometers and photocells were used with Heiland recorders, the equipment being mounted on a 1/2 ton pick-up truck. For Shots 9, 10, and 11 the station locations were at the Ranger C.P., the location used by Project 8.2 and station CP-400, respectively.

The calorimeter results for the distant stations are summarized in Table 3.11. This table includes the calculated slant ranges for the shots on which measurements were made. With the exception of the instrument designated as Brass 14, as is noted in the table, all instruments listed had 90° fields-of-view. Quartz filters were used in all cases.

Table 3.12 summarizes the radiometer and photocell measurements at the distant stations. All radiometers were standard MK-6F instruments. However, the radiometer designated as 10-4 (Data Serial No. 9-93) on Shot 9 was used with a pair of field binoculars held in front of the instrument to concentrate the radiation from the weapon. The photocells were mounted in sections of pipe and the irradiance levels were reduced by using pieces of tissue paper.

TABLE 3.1 Calorimeter Results, Shot 3

Use Code	Angle of Field of View (Deg)	Angle from Horizontal (Deg)	Elevation (ft)	Calorimeter No.	Filter	Data Serial No.	Total Energy under Filter (cal/sq cm)	Total Energy Incident (cal/sq cm)
			Station 7-204, Slant Range 2350 ft					
TE	90	1.2	50	White 1	Quartz	9-1	Instrumental difficulties	
GR	90	1.2	50	Brass 1	Quartz	9-2	"	"
SP	90	1.2	50	Brass 3	7-56	9-4	"	"
SP	90	1.2	50	White 3	0-52	9-5	"	"
AL	90	-90	35	Brass 7	Quartz	9-6	"	"
AS	90	1.2	50	White 2	Quartz	9-7	<0.02	<0.02
TE	180	1.2	50	White 6	None	9-8	0.34	0.34
SP	90	1.2	50	Grey 3	2-58	9-10	0.19	0.22
SP	90	1.2	50	White 4	3-69	9-11	0.25	0.27
AL	90	-90	35	Brass 5	Quartz	9-12	<0.03	<0.03
			Station 7-208, Slant Range 5210 ft					
TE	90	0.5	10	Grey 4	Quartz	9-13	Very small deflection	
AS	90	0.5	10	Grey 10	Quartz	9-14	" "	"
TE	180	0.5	10	Grey 11	None	9-15	" "	"
GR	90	0.5	10	Brass 9	Quartz	9-16	" "	"
SP	90	0.5	50	Brass 4	7-56	9-19	Instrumental difficulties	
SP	90	0.5	50	Brass 2	2-58	9-20	"	"
SP	90	0.5	50	Grey 2	3-69	9-21	"	"
SP	90	0.5	50	Grey 1	0-52	9-22	"	"
AL	90	-90	35	Brass 10	Quartz	9-23	"	"
AL	90	-90	35	Brass 12	Quartz	9-24	"	"

TABLE 3.2 Calorimeter Results, Shot 4

Use Code	Angle of Field of View (Deg)	Angle of Horizontal (Deg)	Elevation (ft)	Calorimeter No.	Filter	Data Serial No.	Total Energy under Filter (cal/sq cm)	Total Energy Incident (cal/sq cm)
			Station 7-204, Slant Range 6785 ft, Air Zero Angle 62.5°					
TE	90	+64	50	White 1	Quartz	9-25	6.7	7.3
AS	90	+64	50	Black 1	Quartz	9-26	0.38	0.41
SP	90	+64	50	Black 3	7-56	9-28	1.4	1.5
SP	90	+64	50	White 3	0-52	9-29	5.7	6.2
AL	90	-90	35	Black 7	Quartz	9-30	1.2	1.3
TE	90	+64	50	White 2	Quartz	9-31	6.2	6.7
TE	180	+64	50	White 6	None	9-32	6.2	6.2
SP	90	+64	50	Gray 3	2-58	9-34	3.1	3.5
SP	90	+64	50	White 4	3-69	9-35	4.1	4.6
AL	90	-90	35	Black 5	Quartz	9-36	1.2	1.4
			Station 7-208, Slant Range 8605 ft, Air Zero Angle 44.3°					
TE	90	+46	10	Gray 4	Quartz	9-37	3.9	4.2
SP	90	+46	50	Black 2	2-58	9-38	1.9	2.2
TE	180	+46	10	Gray 11	None	9-39	4.0	4.0
AS	90	+46	10	Black 9	Quartz	9-40	0.26	0.28
AL	90	-90	35	Black 12	Quartz	9-42	0.57	0.62
SP	90	+46	50	Black 4	7-56	9-43	0.78	0.89
TE	90	+46	10	Gray 10	Quartz	9-44	3.8	4.1
SP	90	+46	50	Gray 2	3-69	9-45	2.5	2.8
SP	90	+46	50	Gray 1	0-52	9-46	3.5	3.8
AL	90	-90	35	Black 10	Quartz	9-47	0.56	0.61

TABLE 3.3 Calorimeter Results, Shot 9

Use Code	Angle of Field of View (Deg)	Angle from Horizontal (Deg)	Elevation (ft)	Calorimeter No.	Filter	Data Serial No.	Total Energy under Filter (cal/sq cm)	Total Energy Incident (cal/sq cm)
			Station F-216, Slant Range 2700 ft, Air Zero Angle 61.5°					
TE	90	+67.5	50	Red 1	Quartz	10-1	91 *	99 -
TE	90	+67.5	50	Red 2	Quartz	10-2	86	94 -
			Station F-202, Slant Range 3535 ft, Air Zero Angle 42.2°					
AL	90	-90	35	Black 1	Quartz	10-5	9.7	10.5
AL	90	-90	35	Black 2	Quartz	10-6	9.7	10.5
TE	90	+44	50	Red 3	Quartz	10-7	53.6	58.3 -
TE	90	+44	50	Red 5	Quartz	10-8	57.8	62.8 -
GR	90	+44	50	White 25	Quartz	10-11	12.7	13.7
AS	90	+44	50	Gray 26	Quartz	10-12	Melt **	
			Station F-208, Slant Range 4715 ft, Air Zero Angle 30.3°					
TE	90	+31	50	Red 6	Quartz	10-13	33.2	36.1 -
TE	90	+31	50	Red 7	Quartz	10-14	33.6 ***	36.5 ***
GR	90	+31	50	White 23	Quartz	10-17	1.9	2.1
AS	90	+31	50	Brass 16	Quartz	10-18	Melt **	
SP	90	+31	50	Red 13	0-52	10-19	33.3	36.2
SP	90	+31	50	Red 14	3-69	10-20	23.7	26.3
SP	90	+31	50	Red 15	2-58	10-21	17.3	19.7
SP	90	+31	50	White 20	7-56	10-22	7.0	8.0
AL	90	-90	35	White 24	Quartz	10-23	5.0	5.4
AL	180	-90	35	White 22	Quartz	10-24	6.0	6.5

* Includes correction for difference in expected and actual air zero.
** Instrument probably melted due to difference in expected and actual air zero.
*** This value questionable due to erratic behavior of instrument.

TABLE 3.3 Calorimeter Results, Shot 9 (continued)

Use Code	Angle of Field of View (Deg)	Angle from Horizontal (Deg)	Elevation (ft)	Calorimeter No.	Filter	Data Serial No.	Total Energy under Filter (cal/sq cm)	Total Energy Incident (cal/sq cm)
			Station F-210, Slant Range 5585 ft, Air Zero Angle 25.2°					
TE	90	+25.8	50	Red 8	Quartz	10-25	25.1	27.3
TE	90	+25.8	50	Red 10	Quartz	10-26	23.9	26.0
TE	180	+25.8	50	Red 11	None	10-30	27.1	27.1
TE	180	+25.8	50	Red 12	None	10-31	24.6	24.6
			Station F-295, Slant Range 9820 ft, Air Zero Angle 14.3°					
TE	90	+14.2	10	White 1	Quartz	10-32	7.5	8.2
TE	90	+14.2	10	White 2	Quartz	10-33	7.0	7.6
GR	90	+14.2	10	White 7	Quartz	10-36	7.1 *	7.7 *
AS	90	+14.2	10	Brass 4	Quartz	10-37	0.80	0.87
AL	90	-90	10	Brass 5	Quartz	10-38	0.50	0.54
SP	90	+14.2	10	White 4	3-69	10-39	4.8	5.3
AL	90	-90	10	Brass 9	Quartz	10-40	0.50	0.54
SP	90	+14.2	10	Brass 3	7-56	10-41	1.6	1.8
SP	90	+14.2	10	White 3	0-52	10-42	7.3	7.9
SP	90	+14.2	10	Gray 24	2-58	10-43	3.6	4.1

* Instrument arrangement was such as to give total energy rather than ground reflection.

TABLE 3.3 Calorimeter Results, Shot 9 (Continued)

Use Code	Angle of Field of View (Deg)	Position from Fig. 3.1	Elevation (ft)	Calorimeter No.	Filter	Data Serial No.	Total Energy under Filter (cal/sq cm)	Total Energy Incident (cal/sq cm)
			Station F-424, Slant Range 3780 ft, Air Zero Angle 39.8°					
TE	180	9	10	White 14	None	10-44	No smoke	
TE	90	20	10	White 13	Quartz	10-45	layer.	
SP	90	20	10	White 9	3-69	10-46	Solder	
SP	90	20	10	White 8	0-52	10-47	connections	
TE	180	4	10	White 15	None	10-48	in instru-	
TE	180	5	10	White 16	None	10-49	ments	
TE	180	13	10	White 17	None	10-50	melted.	
TE	90	20	10	White 21	Quartz	10-51		
SP	90	20	10	White 5	7-56	10-52		
SP	90	20	10	White 12	2-58	10-53		
TE	180	1	10	White 18	None	10-54		
TE	180	2	10	White 19	None	10-55		
			Station F-429, Slant Range 5430 ft, Air Zero Angle 26.5°					
TE	90	5	10	Brass 1	Quartz	10-56	No smoke	
TE	180	5	10	Brass 10	None	10-57	layer.	
TE	180	4	10	Brass 18	None	10-58	Solder	
TE	180	2	10	Brass 19	None	10-59	connections	
TE	90	1	10	Brass 2	Quartz	10-60	in instru-	
TE	180	1	10	Brass 13	None	10-61	ments	
TE	180	9	10	Brass 20	None	10-62	melted.	
TE	90	13	10	Brass 12	Quartz	10-63		
TE	180	18	10	Brass 21	None	10-64		
TE	180	13	10	Brass 22	None	10-65		
TE	180	12	10	Brass 23	None	10-66		
TE	180	10	10	Brass 31	None	10-67		

TABLE 3.4 Calorimeter Results, Shot 10

Use Code	Angle of Field of View (Deg)	Angle from Horizontal (Deg)	Elevation (ft)	Calorimeter No.	Filter	Data Serial No.	Total Energy under Filter (cal/sq cm)	Total Energy Incident (cal/sq cm)
			Station F-202, Slant Range 2465 ft, Air Zero Angle 11.1°					
TE	90	+11.3	50	Red 3	Quartz	10-68	45.3	49.3
TE	90	+11.3	50	Red 3	Quartz	10-69	49.3	53.6
GR	90	+11.3	50	White 25	Quartz	10-72	13.8	15.0
AS	90	+11.3	50	Gray 1	Quartz	10-73	Melt *	
AL	90	-90	35	Black 1	Quartz	10-74	3.9	4.2
AL	90	-90	35	Black 3	Quartz	10-75	3.7	4.0
			Station F-208, Slant Range 3945 ft, Air Zero Angle 6.9°					
TE	90	+7.1	50	Red 6	Quartz	10-76	22.5	24.5
TE	90	+7.1	50	Red 7	Quartz	10-77	23.5	25.5
GR	90	+7.1	50	White 23	Quartz	10-80	3.8	4.1
AS	90	+7.1	50	Brass 1	Quartz	10-81	Melt *	
SP	90	+7.1	50	Red 13	0-52	10-82	24.2	26.3
SP	90	+7.1	50	Red 14	3-69	10-83	17.8	19.8
SP	90	+7.1	50	Red 15	2-58	10-84	12.7	14.4
SP	90	+7.1	50	White 20	7-56	10-85	4.3	4.9
AL	90	-90	35	White 24	Quartz	10-86	1.9	2.0
AL	180	-90	35	White 5	None	10-87	2.6	2.6
			Station F-210, Slant Range 4940 ft, Air Zero Angle 5.5°					
TE	90	+5.7	50	Red 8	Quartz	10-88	16.0	17.4
TE	90	+5.7	50	Red 10	Quartz	10-89	15.8	17.2
TE	180	+5.7	50	Red 4	None	10-93	17.4	17.4
TE	180	+5.7	50	Red 9	None	10-94	17.2	17.2

* Instrument probably melted due to difference in estimated and actual air zero.

TABLE 3.4 Calorimeter Results, Shot 10 (Continued)

Use Code	Angle of Field of View (Deg)	Position from Fig. 3.1	Elevation (ft)	Calorimeter No.	Filter	Data Serial No.	Total Energy under Filter (cal/sq cm)	Total Energy Incident (cal/sq cm)
			Station F-424, Slant Range 2810 ft, Air Zero Angle 10.5°					
TE	180	9	10	White 14	None	10-119	0.34	0.34
TE	90	20	10	White 12	Quartz	10-120	1.1	1.2
SP	90	20	10	Gray 5	3-69	10-121	1.0	1.1
SP	90	20	10	White 13	0-52	10-122	-	-
TE	180	4	10	Gray 31	None	10-123	1.2	1.2
TE	180	5	10	Gray 32	None	10-124	0.09	0.09
TE	180	13	10	Gray 4	None	10-125	0.32	0.32
TE	90	20	10	White 10	Quartz	10-126	1.2	1.3
SP	90	20	10	Gray 36	7-56	10-127	0.56	0.64
SP	90	20	10	Gray 37	2-58	10-128	0.68	0.77
TE	180	1	10	Gray 34	None	10-129	0.18	0.18
TE	180	2	10	Gray 35	None	10-130	Cable shorted.	
			Station F-422A, Slant Range 2235 ft, Air Zero Angle 13.3°					
TE	90	5	10	White 11	Quartz	10-131	0.22	0.24
TE	180	5	10	Gray 2	None	10-132	0.59	0.59
TE	180	2	10	Gray 3	None	10-133	0.80	0.80
TE	180	4	10	White 8	None	10-134	0.84	0.84
TE	90	1	10	White 9	Quartz	10-135	0.33	0.36
TE	180	1	10	Gray 6	None	10-136	0.80	0.80
TE	180	9	10	Gray 7	None	10-137	0.42	0.42
TE	90	13	10	Gray 8	Quartz	10-138	0.28	0.31
TE	180	18	10	Gray 9	None	10-139	0.31	0.31
TE	180	13	10	Gray 10	None	10-140	0.34	0.34
TE	180	12	10	Gray 12	None	10-141	0.32	0.32
TE	180	10	10	White 17	None	10-142	0.95	0.95

TABLE 3.4 Calorimeter Results, Shot 10 (Continued)

Use Code	Angle of Field of View (Deg)	Angle from Horizontal (Deg)	Elevation (ft)	Calorimeter No.	Filter	Data Serial No.	Total Energy under Filter (cal/sq cm)	Total Energy Incident (cal/sq cm)
			Station F-295, Slant Range 9430 ft, Air Zero Angle 3.1°					
TE	90	+3.0	10	White 1	Quartz	10-95	4.2	4.6
TE	90	+3.0	10	White 2	Quartz	10-96	3.8	4.1
GR	90	+3.0	10	White 7	Quartz	10-99	0.36	0.39
AS	90	+3.0	10	Brass 4	Quartz	10-100	0.10	0.11
FV	20	+3.0	10	Brass 5	Quartz	10-101	3.4	3.7
SP	90	+3.0	10	White 4	3-69	10-102	2.7	3.0
FV	20	+3.0	10	Brass 9	Quartz	10-103	3.4	3.7
SP	90	+3.0	10	Brass 3	7-56	10-104	0.75	0.85
SP	90	+3.0	10	White 3	0-52	10-105	3.5	3.8
SP	90	+3.0	10	Gray 24	2-58	10-106	1.9	2.2
			Station F6.10F, Slant Range 13925 ft, Air Zero Angle 2.2°					
TE	90	+2.1	10	Brass 7	Quartz	10-107	1.6	1.7
SP	90	+2.1	10	Brass 12	0-52	10-108	1.5	1.7
SP	90	+2.1	10	Brass 14	3-69	10-109	1.2	1.4
SP	90	+2.1	10	Brass 15	2-58	10-110	0.83	0.94
SP	90	+2.1	10	Brass 17	7-56	10-111	0.35	0.40
AS	90	+2.1	10	Gray 29	Quartz	10-112	1.3	2.0
TE	90	+2.1	10	Gray 33	Quartz	10-113	1.5	1.6
TE	90	+2.1	10	Gray 38	Quartz	10-114	1.7	1.8
FV	20	+2.1	10	Brass 28	Quartz	10-115	1.6	1.7
TE	180	+2.1	10	Gray 23	None	10-116	2.0	2.0
FV	20	+2.1	10	Brass 29	Quartz	10-117	0.50	0.54

TABLE 3.5 Calorimeter Results, Shot 11

Use Code	Angle of Field of View (Deg)	Angle from Horizontal (Deg)	Elevation (ft)	Calorimeter No.	Filter	Data Serial No.	Total Energy under Filter (cal/sq cm)	Total Energy Incident (cal/sq cm)
			Station 7-208, Slant Range 6530 ft, Air Zero Angle 11.3°					
TE	90	12	50	Red 1	Quartz	9-49	35.2	38.2 -
TE	90	12	50	Red 2	Quartz	9-50	34.2	37.2 -
TE	90	12	50	Red 5	Quartz	9-51	36.2	39.4 -
SP	90	12	50	Red 13	0-52	9-53	35.6	38.7
SP	90	12	50	Black 2	7-56	9-54	7.1	8.1
TE	90	12	50	Red 8	Quartz	9-55	37.3	40.5 -
TE	90	12	50	Red 7	Quartz	9-56	35.9	39.0 -
TE	90	12	50	Red 12	Quartz	9-57	Poor Record	
SP	90	12	50	Red 14	3-69	9-59	26.7	29.7
SP	90	12	50	Red 15	2-58	9-60	19.2	21.7
			Station 1-356, Slant Range 16960 ft, Air Zero Angle 4.5°					
TE	90	4.5	10	Gray 36	Quartz	9-61	4.5	4.9 -
TE	90	4.5	10	Gray 37	Quartz	9-62	Poor Record	
TE	90	4.5	10	Gray 38	Quartz	9-63	4.5	4.9 -
TE	90	4.5	10	Gray 1	Quartz	9-64	4.6	5.0 -
FV	20	4.5	10	Gray 39	Quartz	9-66	3.9	4.2
FV	20	4.5	10	Gray 8	Quartz	9-67	4.1	4.5
TE	90	4.5	10	Gray 24	Quartz	9-68	Poor Record	
TE	90	4.5	10	Gray 29	Quartz	9-69	4.8	5.2 -
TE	90	4.5	10	Gray 7	Quartz	9-70	Poor Record	
TE	90	4.5	10	Gray 33	Quartz	9-72	4.5	4.9 -

TABLE 3.5 Calorimeter Results, Shot 11 (Continued)

Use Code	Angle of Field of View (Deg)	Angle from Horizontal (Deg)	Elevation (ft)	Calorimeter No.	Filter	Data Serial No.	Total Energy under Filter (cal/sq cm)	Total Energy Incident (cal/sq cm)
			Station 8.12-1, Slant Range 26810 ft, Air Zero Angle 2.8°					
TE	90	2.6	10	Brass 4	Quartz	9-73	1.6	1.8
TE	90	2.6	10	Brass 5	Quartz	9-74	1.6	1.8
TE	90	2.6	10	Brass 2	Quartz	9-75	1.8	2.0
TE	90	2.6	10	4J-4	Quartz	9-76	1.6	1.7
FV	20	2.6	10	Brass 7	Quartz	9-78	1.5	1.6
TE	90	2.6	10	Brass 24	Quartz	9-79	1.6	1.8
TE	90	2.6	10	Brass 25	Quartz	9-80	1.7	1.9
TE	90	2.6	10	Brass 1	Quartz	9-81	1.8	1.9
TE	90	2.6	10	Gray 4	Quartz	9-82	1.8	2.0
FV	7	2.6	10	Brass 26	Quartz	9-84	1.0	1.1

TABLE 3.6 Aircraft Calorimeter Results, Shot 4

Use Code	Angle of Field of View (Deg)	Calorimeter No.	Filter	Data Serial No.	Total Energy under Filter (cal/sq cm)	Total Energy Incident (cal/sq cm)
Shot 4, Aircraft 362, Slant Range - 19,673 ft. Burst height above GZ - 6020 ft						
TE	90°	G7	Quartz	8-1	0.93	1.0
TE	90°	G8	Quartz	8-2	0.86	0.94
FV	45°	G34	Quartz	8-4	0.69	0.75
FV	30°	G32	Quartz	8-5	0.67	0.73
FV	15°	G9	Quartz	8-6	0.18	0.20
SP	90°	G39	0-52	8-7	0.77	0.84
SP	90°	G38	3-69	8-8	0.57	0.63
SP	90°	G37	2-58	8-10	0.40	0.45
SP	90°	G36	7-56	8-11	0.25	0.28
FV	7.5°	G29	Quartz	8-12	<0.1	<0.1

TABLE 3.7 Aircraft Calorimeter Results, Shot 9

Use Code	Angle of Field of View (Deg)	Calorimeter No.	Filter	Data Serial No.	Total Energy under Filter (cal/sq cm)	Total Energy Incident (cal/sq cm)
	Aircraft 362, Slant Range - 16,232 ft.	Burst height above GZ - 2423 ft				
TE	90	G7	Quartz	8-17	3.5	3.8
TE	90	G8	Quartz	8-18	3.4	3.7
FV	45	G34	Quartz	8-20	2.8	3.0
FV	30	G32	Quartz	8-21	2.3	2.5
FV	15	G9	Quartz	8-22	0.76	0.83
SP	90	G39	0-52	8-23	3.4	3.7
SP	90	G38	3-69	8-24	2.4	2.7
SP	90	G37	2-58	8-26	2.0	2.2
SP	90	G36	7-56	8-27	1.0	1.2
FV	7.5	G29	Quartz	8-28	0.27	0.29
	Aircraft 371, Slant Range - 16,232 ft.	Burst height above GZ - 2423 ft				
TE	90	G5	Quartz	8-29	3.6	3.9
TE	90	G6	Quartz	8-30	3.5	3.8
FV	45	G35	Quartz	8-32	2.8	3.0
FV	30	G33	Quartz	8-33	2.5	2.7
FV	15	G31	Quartz	8-34	0.84	0.91

TABLE 3.8 Foil Radiometer Results, Shots 3, 4, and 9

Station	Slant Range (ft)	Radio-meter No.	Data Serial No.	Time to 2nd Max (milli-secs)	Ave. Energy to 3.0 sec Radiometers (cal/sq cm)	Ave. Energy to 3.0 sec Calorimeters (cal/sq cm)
				Shot 3		
7-204	2350	50-1	9-3	Rec.Fail.		
7-204	2350	50-2	9-9	15	Deflection too low to give usable data.	
7-208	5210	10-3	9-17	Rec.Fail.		
7-208	5210	10-6	9-18	No Defl.		
				Shot 4		
7-204	6785	50-1	9-27	116	6.3	6.3
7-204	6785	50-2	9-33	112		
7-208	8605	10-3	9-41	127	4.0	3.8
7-208	8605	10-6	9-48	No time lines		
				Shot 9		
F216	2700	250-3	10-3	179	83.9	82.2
F216	2700	250-4	10-4	179		
F202	3535	250-6	10-9	182	52.8	52.1
F202	3535	250-7	10-10	Poor Record		
F208	4715	250-9	10-15	Small Defl.	Poor Records	31.1
F208	4715	250-10	10-16	173	for Station	
F210	5585	50-2	10-27	176	22.6	22.9
F210	5585	50-4	10-28	Spec. Exp.		
F210	5585	50-6	10-29	173		
F295	9820	10-3	10-34	183	7.5	6.8
F295	9820	10-6	10-35	184		

TABLE 3.9 Foil Radiometer Results, Shots 10 and 11

Station	Slant Range (ft)	Radiometer No.	Data Serial No.	Time to 2nd Max (millisecs)	Ave. Energy to 3.0 sec Radiometers (cal/sq cm)	Ave. Energy to 3.0 sec Calorimeters (cal/sq cm)
			Shot 10			
F202	2465	250-6	10-70	Off scale	Poor records	45.8
F202	2465	250-7	10-71	130	for station	
F208	3945	250-9	10-78	131	25.7	22.3
F208	3945	250-10	10-79	135		
F210	4940	50-2	10-90	130	15.0	15.4
F210	4940	50-4	10-91	Spec.Exp.		
F210	4940	50-6	10-92	134		
F295	9430	10-3	10-97	154	4.1	3.9
F295	9430	10-6	10-98	146		
F8.10F	13925	10-1	10-118	141	Small Defl.	1.6
			Shot 11			
7-208	6530	250-3	9-52	250	30.0	32.1
7-208	6530	250-4	9-58	252		
1-356	16960	10-3	9-65	264	4.8	4.1
1-356	16960	10-6	9-71	264		
812-1	26810	10-1	9-77	263	1.8	1.5
812-1	26810	10-2	9-83	251		

TABLE 3.10 - Aircraft Radiometer Results, Shots 4 and 9

Shot No.	Aircraft No.	Radiometer No.	Data Serial No.	Time to Second Max. (millisec)
4	362	10-2	8-3	125
4	362	10-5	8-9	120
9	362	10-2	8-19	175
9	362	10-5	8-25	175
9	371	10-1	8-31	180

TABLE 3.11 Calorimeter Results, Distant Stations, Shots 9, 10, and 11

Data Serial No.	Calorimeter No.	Total Energy Under Filter (cal/sq cm)	Total Energy Incident (cal/sq cm)
Shot 9, Ranger C.P. Station, Slant Range 36,675 ft.			
9-94	Brass 24	0.34	0.37
Shot 10, Project 8.2 Station, Slant Range 34,695 ft.			
10-145	Brass 32	0.27	0.29
Shot 11, C. P. 400 Station, Slant Range 56,925 ft.			
9-86	Brass 14**	0.29	0.31
9-89	Brass 28	0.28	0.31
9-90	4 JP*	0.29	0.32

* 4 Junction Prototype Designed for Operation IVY

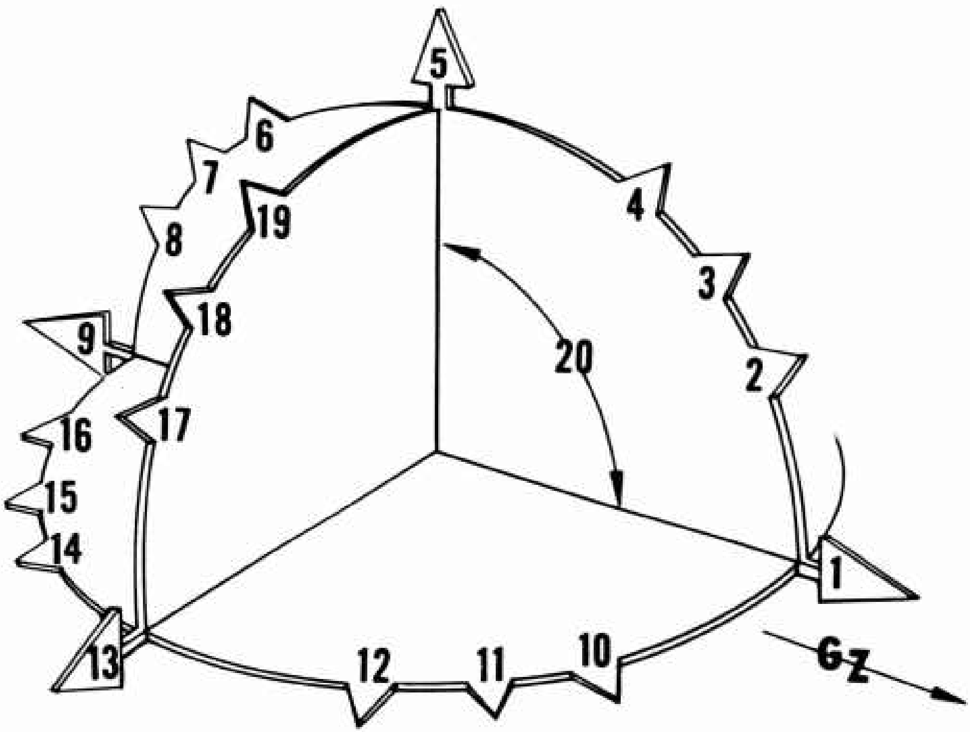
** 20° Field-of-view Instrument

TABLE 3.12 Radiometers and Photocells, Distant Stations, Shots 9, 10, and 11

Data Serial No.	Instrument No.	Time to Second Max. (millisec.)
	Shot 9	
9-91	Photocell	0.165
9-92	Photocell	0.170
9-93	Radiometer 10-4	0.150
	Shot 10	
10-143	Photocell	0.135*
10-144	Radiometer 10-4	0.145
10-146	Photocell	0.135
	Shot 11	
9-85	Photocell	Off-scale
9-87	Radiometer 10-5	0.250
9-88	Photocell	Off-scale

NOTE: All photocells used were Weston, Model 856 YG Photronic Cells.

* This is an estimate since the trace was off-scale near the peak.



Instrument Position Number	Elevation Above Horizontal	Deflection From GZ Line
1	00°	00°
2	30°	00°
3	45°	00°
4	60°	00°
5	90°	00°
6	60°	180°
7	45°	180°
8	30°	180°
9	00°	180°
10	00°	R 30°
11	00°	R 45°
12	00°	R 60°
13	00°	R 90°
14	00°	R120°
15	00°	R135°
16	00°	R150°
17	30°	R 90°
18	45°	R 90°
19	60°	R 90°
20	AZ	00°

GZ - Ground Zero AZ - Air Zero

Fig. 3.1 Geometrical Arrangement, Smoke Stations

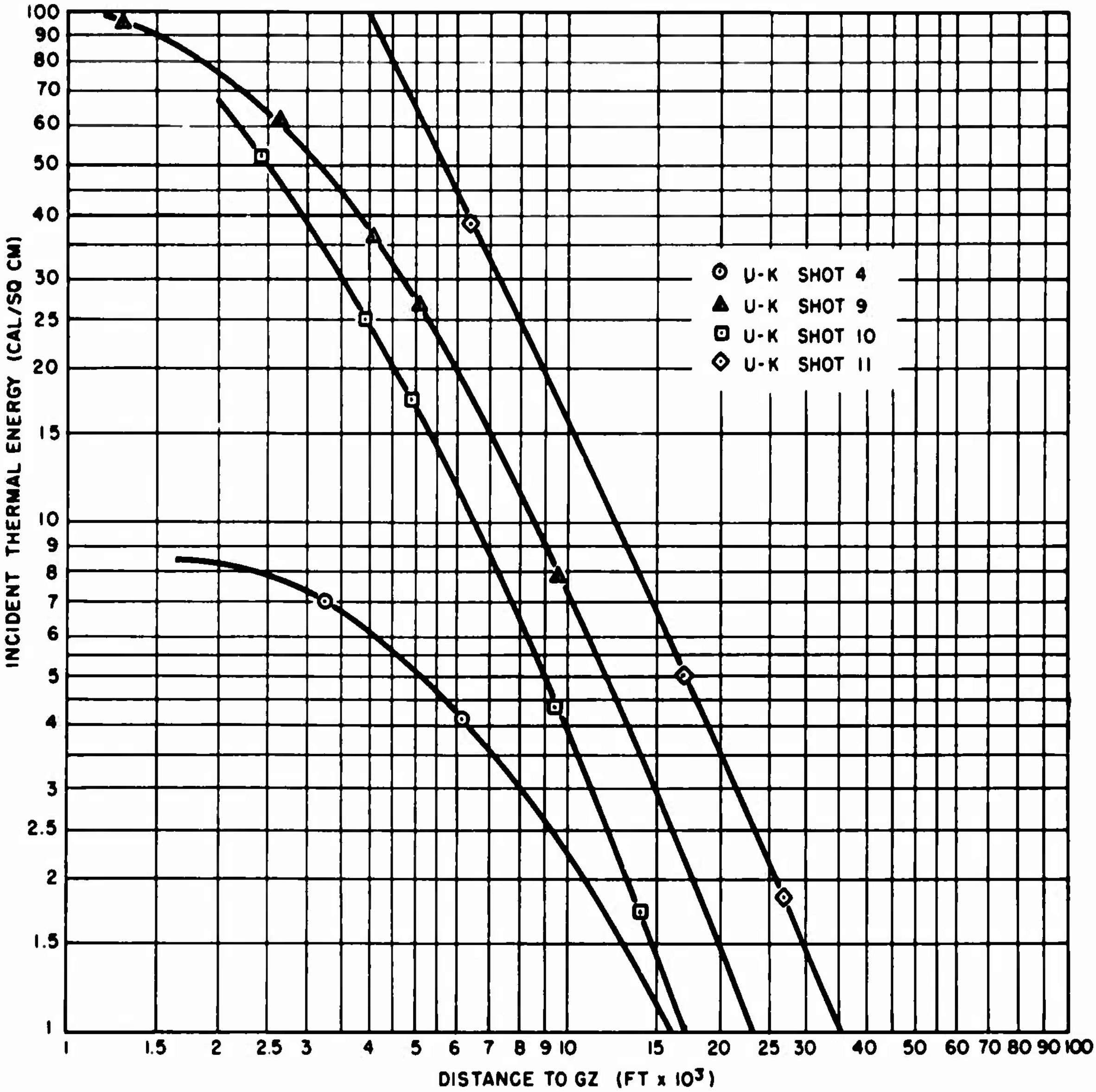


Fig. 3.2. Incident Thermal Energy vs Distance from GZ, Shots 4, 9, 10, and 11.

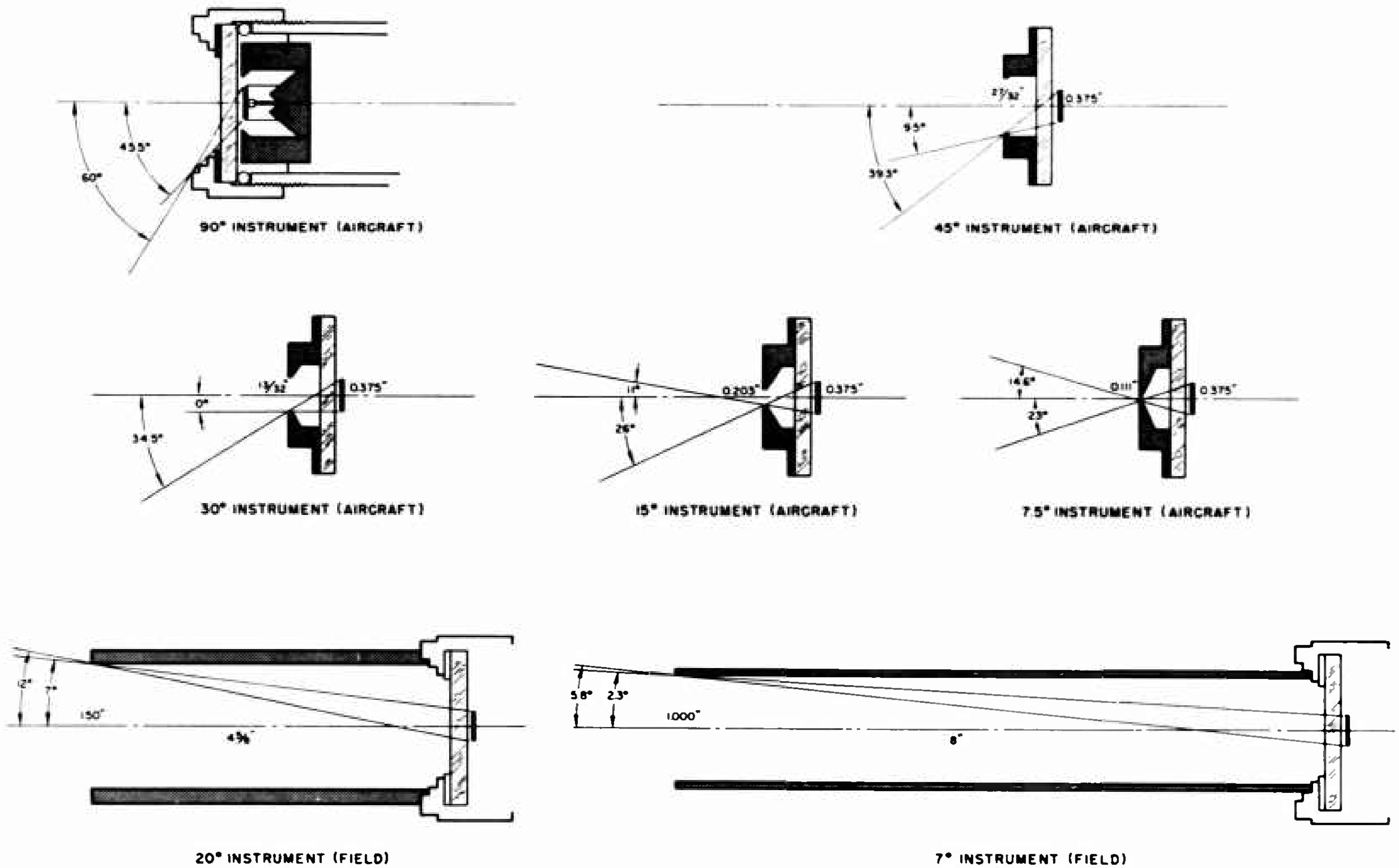


Fig. 3.3. Special Geometries Used With Field Instruments

CHAPTER 4

DISCUSSION OF RESULTS

4.1 GENERAL

Generally speaking, the data obtained during UPSHOT-KNOTHOLE were about as expected on the basis of observations made during previous operations. However, many of the difficulties encountered in previous measurements were minimized by making use of the experience gained in these past operations. Little difficulty was experienced with obscuring effects through more appropriate placement of the measuring instruments. Certain modifications in experimental design were made in connection with the albedo, field-of-view, air scatter, and smoke attenuation measurements. Due to the many factors entering into an analysis of such types of measurements, extreme care must be exercised in drawing conclusions from the tabulated data.

It should be kept in mind that all instrument alignments were made on the basis of certain predicted detonation positions which, except for Shot 3, differed to some extent from the actual positions. Calculations based on the data of Chapter 3 have used the following points of detonation: Shot 4 - 80 ft North and 560 ft East of the predicted GZ at a height above actual GZ of 6200 ft, Shot 9 - 837 ft South and 15 ft West of the predicted GZ at a height above actual GZ of 2423 ft, Shot 10 - 139 ft South and 86 ft West of the predicted GZ at a height above actual GZ of 524 ft and Shot 11 - 232 ft North and 172 ft West of the predicted GZ at a height above actual GZ of 1334 ft. For the ground stations, the slant ranges and air zero angles corresponding to these shot positions are listed in Tables 3.1 through 3.5. Station locations are such that the differences in actual and predicted shot positions introduce negligible cosine corrections in the instrument readings except for station F-216 on Shot 9. In this latter case the appropriate correction has been made. Slant ranges for the aircraft are given in Tables 3.6 and 3.7.

4.2 CALORIMETERS

For the ground stations, the total thermal energy values obtained with the calorimeters on Shots 4, 9, 10, and 11 are shown in station-to-station comparisons in Fig. 4.1. The energy values shown in this figure were taken from col 9 of Tables 3.2 through 3.5 and corrected for atmospheric attenuation.. It should be pointed out that incident energy values greater than 1 cal per sq cm have been rounded off to the nearest one-tenth of a calorie. In view of the fact that the yield for Shot 3 was much lower than predicted, the calorimeter receiver sensitivities chosen were not appropriate. Consequently, as noted from Table 3.1, sufficient information was not available from this shot to be included in Fig. 4.1.

The straight lines shown in Fig. 4.1 have been drawn on the basis of an inverse square relationship for thermal energy vs distance. Errors in the atmospheric transmission coefficients can have a considerable effect on the fit of the experimental points to these straight lines. This effect, of course, becomes more pronounced the greater the distance between the point of detonation and the point of measurement. The transmission coefficients used (per cent transmission per statute mile) are as follows: 95 per cent for Shot 4, 92 per cent for Shot 9, 91 per cent for Shot 10, and 95 per cent for Shot 11. The transmission data for Shots 4, 9, and 10 were furnished by the Director, Program 8. Since such data were not available for Shot 11, the value used was chosen fairly arbitrarily. However, some check on the reasonableness of the choice is provided by the fit of corrected thermal energy vs distance to an inverse square relationship (Fig. 4.1).

Results obtained with the 180° field-of-view calorimeters must be examined carefully. As pointed out in Chapter 2 of this report, this type of calorimeter was designed to provide data on the manner in which the thermal energy received at a point under a smoke layer is dependent on direction. The relative values obtained could then be correlated with actual energy values obtained by means of standard 90° field-of-view calorimeters. The difficulties with the 180° instrument, when used to give energy values, stem from the fact that the receiver disk is not protected by a filter. The atmospheric conditions can have considerable effect on the rate of heat loss of these instruments. Even using protective shutters released by the minus 5 sec timing signal, the disks may be coated with dust prior to shot time. In any case, results obtained after arrival of the shock wave are highly suspect, due to both dust and air movement.

For station 422A under the white smoke, the energy received at the station as measured with the 90° field-of-view calorimeter appears to be about 0.4 cal/sq cm. Several of the 180° instruments indicate values considerably higher than this, possibly showing a scattering contribution. The incident thermal energy expected at this station in the absence of a smoke layer is about 60 cal/sq cm. Consequently, as measured by a 90° field-of-view instrument the thermal energy is attenuated due to the white smoke layer by about 99 per cent. In the case of station 424, under the black smoke, the incident thermal energy as measured with the 90° instrument is about 1.2 cal/sq cm. In this case, the incident thermal energy in the absence of a smoke layer would be about 46 cal/sq cm. Consequently, again as measured with a 90° instrument, the incident thermal energy is reduced by about 97 per cent, due to the presence of the black smoke. As will be noted from Table 3.4 the spectral distribution, in the case of the black smoke, appears to be shifted toward longer wavelengths. These data have been transmitted to the Project Of-

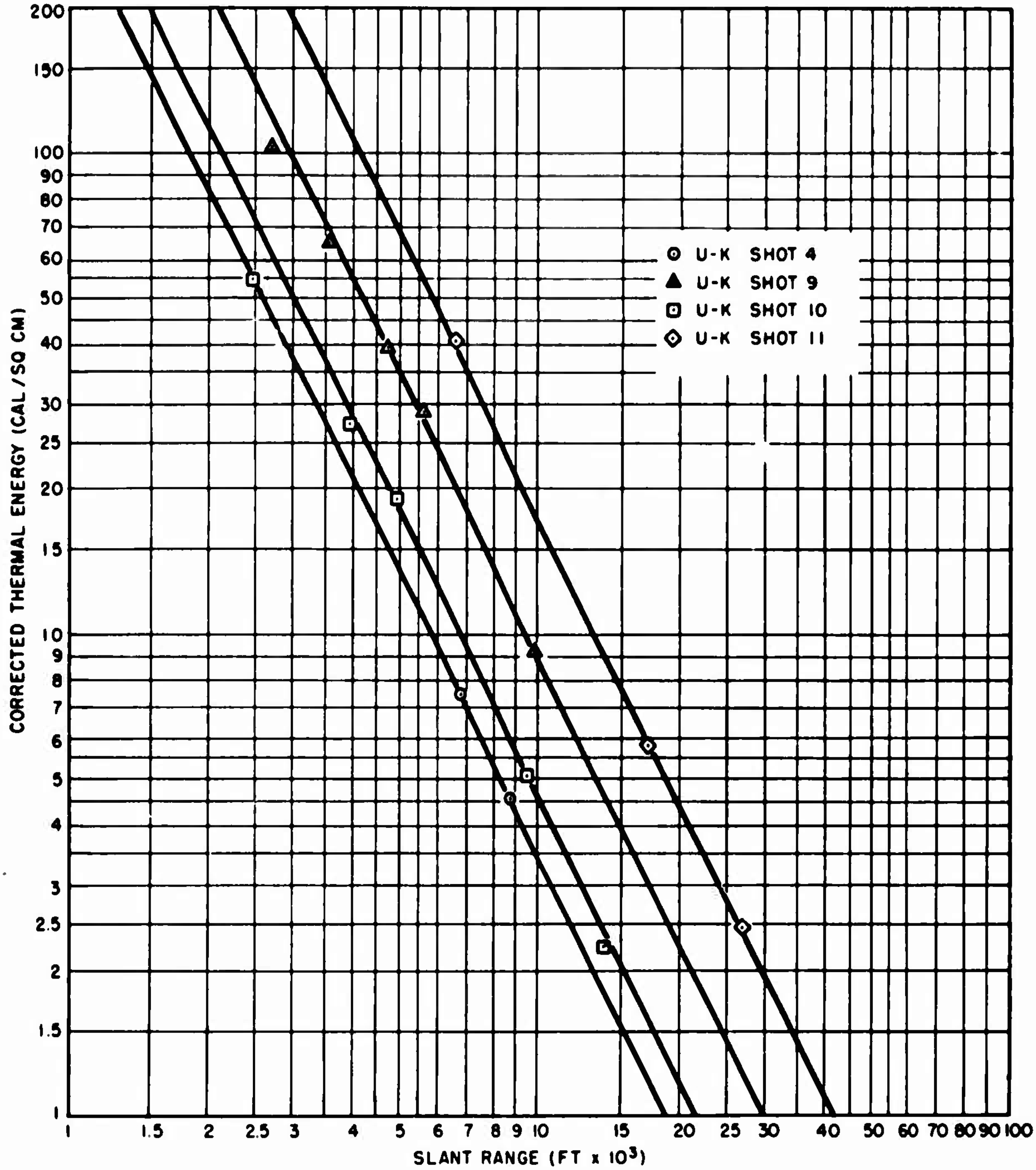


Fig. 4.1 Corrected Thermal Energy vs Slant Range, Shots 4, 9, 10, and 11

ficer, Project 8.4, and thus no detailed analysis has been carried out for this report.

An average irradiance vs time curve for each shot was obtained by averaging the results from the same calorimeters which were used in the corrected energy vs distance plots. In each case, the data from four or more calorimeters were used in obtaining the average curve. Although no individual calorimeter curves are shown, the variation in the shape of the curves obtained from the various calorimeters, as well as the reading errors, are much the same as shown in the WT-543 report. The composite best curve for each shot is shown in Fig. 4.2. These curves have been normalized to give the ratio (expressed in per cent) of the irradiance at any time to the total incident energy measured. The irradiance values shown have been corrected for losses due to the quartz filters.

The curve of Fig. 4.2 clearly indicates that the time to reach peak irradiance increases with increasing yield while the ratio of peak irradiance to total incident energy decreases. Although not shown completely in the figure, the higher yield weapons show much longer thermal tails. The irradiance vs time curves for station F-202 were not used in arriving at the composite curve for Shot 10. The low altitude of detonation may have given rise to obscuring effects at this station or the shock wave, by producing movement of the tower, may have changed the alignment of the instruments. This is indicated both by the abnormally high ratio of peak irradiance to total incident energy at this station (about 330 per cent) as well as by the fact that the corrected total thermal energy falls off the inverse square curve, as can be seen from Fig. 4.1.

Curves of per cent of total incident energy received at the ground stations as a function of time are shown in Figs. 4.3 and 4.4. As in the case of the irradiance vs time curves these are the composite best curves. In each case, at least four calorimeter measurements were used in arriving at each of these curves. In examining these figures it will be noted that the per cent of total energy received at any given time decreases as the total yield of the weapon increases.

In Fig. 4.5 the log of the corrected total energy per KT is plotted against the log of the slant distance. The line drawn through the points has a slope of minus two. In general the fit is quite good. In Fig. 4.6 a plot of the log of the thermal yield vs the log of the total yield is shown for Shots 4, 9, 10, and 11 of UPSHOT-KNOTHOLE and Shots 1, 2, 3, and 4 of TUMBLER-SNAPPER. For reference purposes, the total yields and thermal yields for the shots on which thermal measurements were made at BUSTER, TUMBLER-SNAPPER, and UPSHOT-KNOTHOLE are listed in Table 4.1. The best straight line through the points in Fig. 4.6 has a slope of 0.95. A fit of this line to the points for the shots of UPSHOT-KNOTHOLE appears to be reasonably good, with all points fitting the line within experimental error. It must be kept in mind that the values for the total yields may be changed at some later date, which may alter the slope of the line to some extent. Figure 4.7 is a plot of the log of the thermal efficiency vs the log of the total yield. A straight line of slope -0.05 has been fitted to the experimental points.

With regard to the aircraft measurements, an examination of Tables 3.6 and 3.7 shows quite good agreement between the values obtained with the various 90° total energy calorimeters on each of the

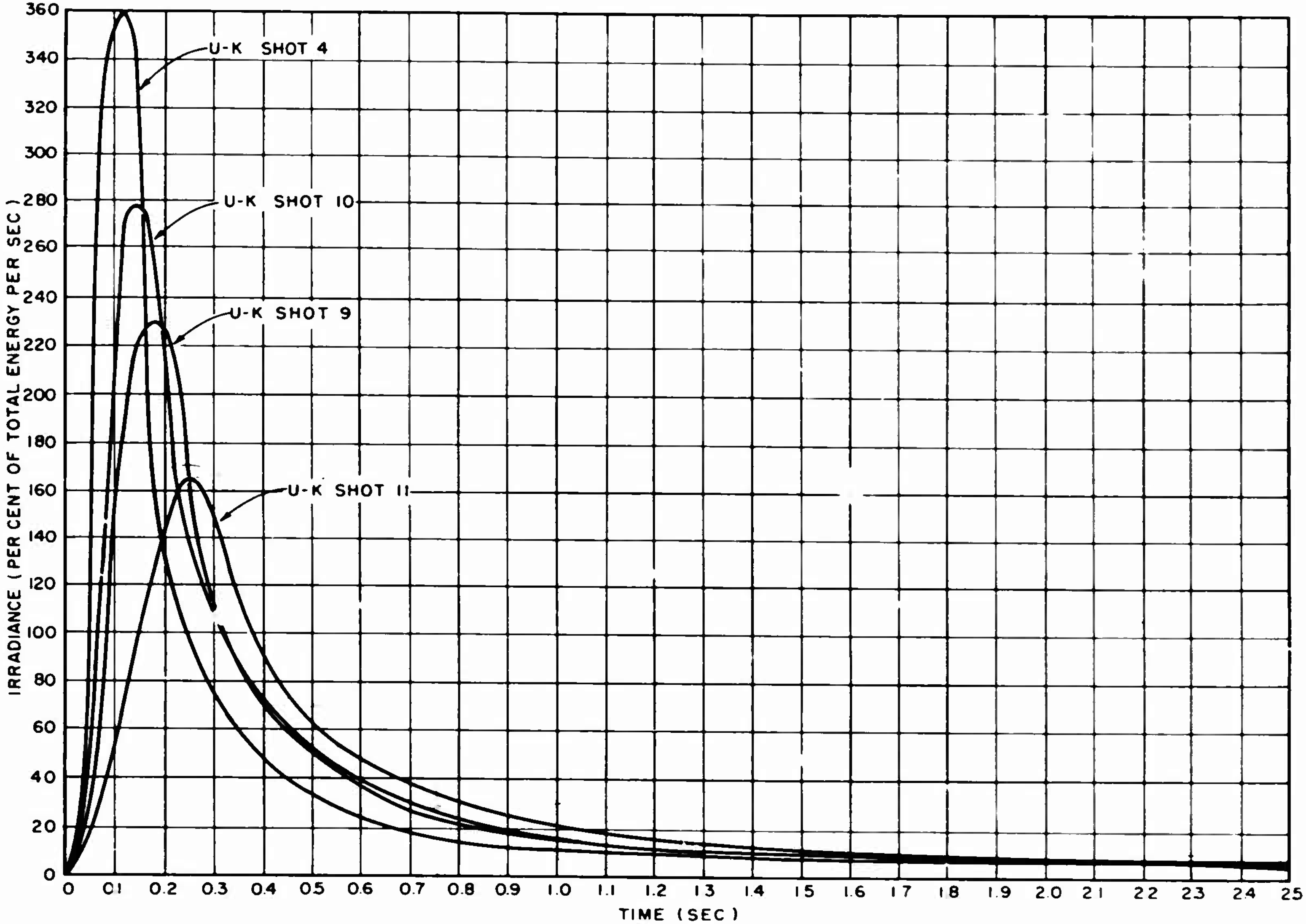


Fig. 4.2 Normalized Irradiance vs Time Curves, Shots 4, 9, 10, and 11

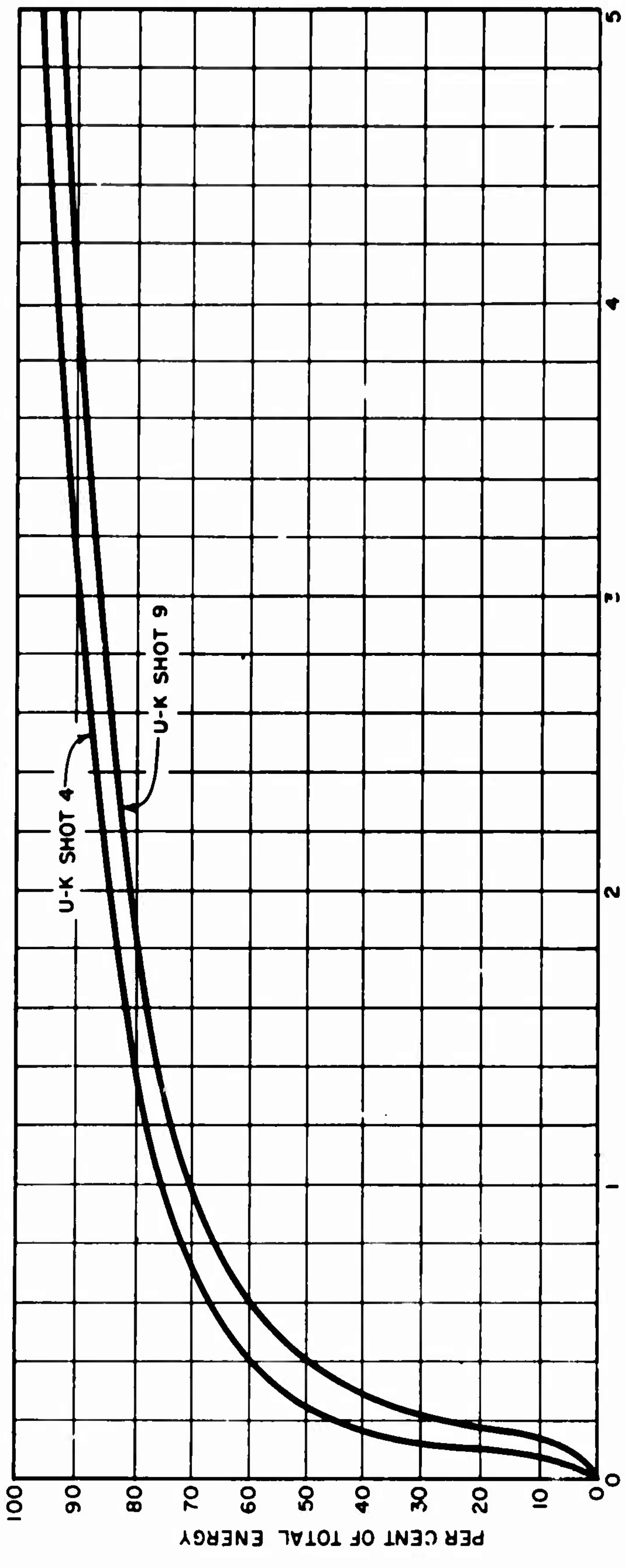


Fig. 4.3 Per Cent of Total Energy vs Time, Shots 4 and 9

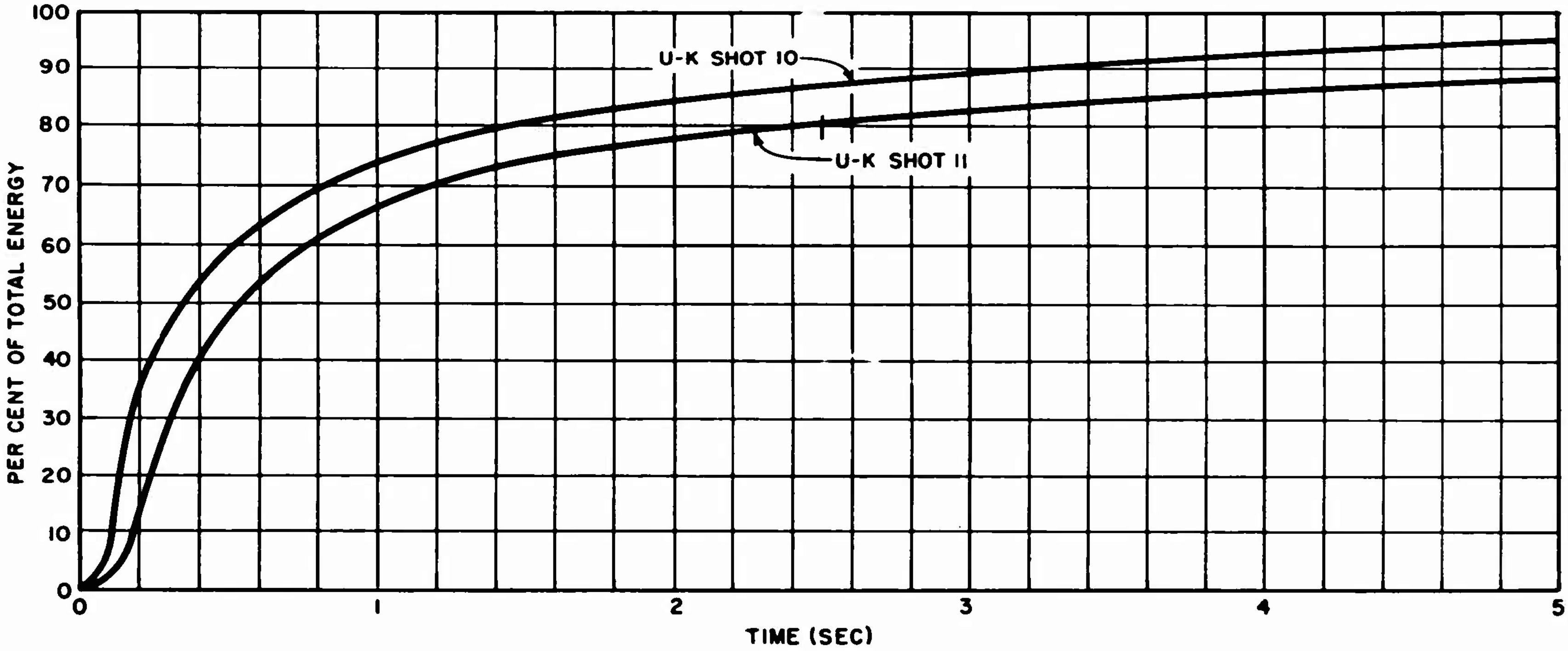


Fig. 4.4 Per Cent of Total Energy vs Time, Shots 10 and 11

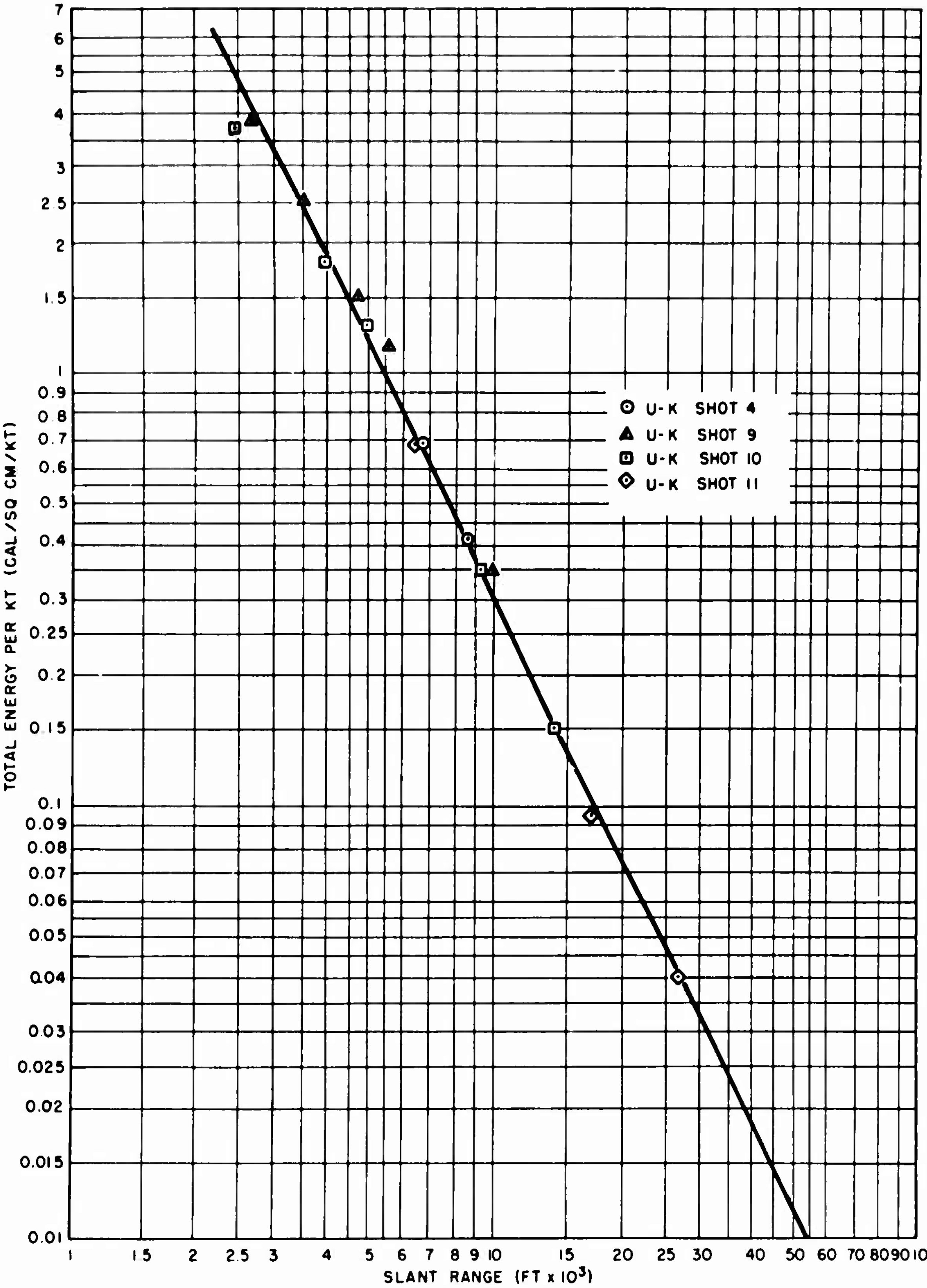


Fig. 4.5 Energy per KT vs Slant Range, Shots 4, 9, 10, and 11

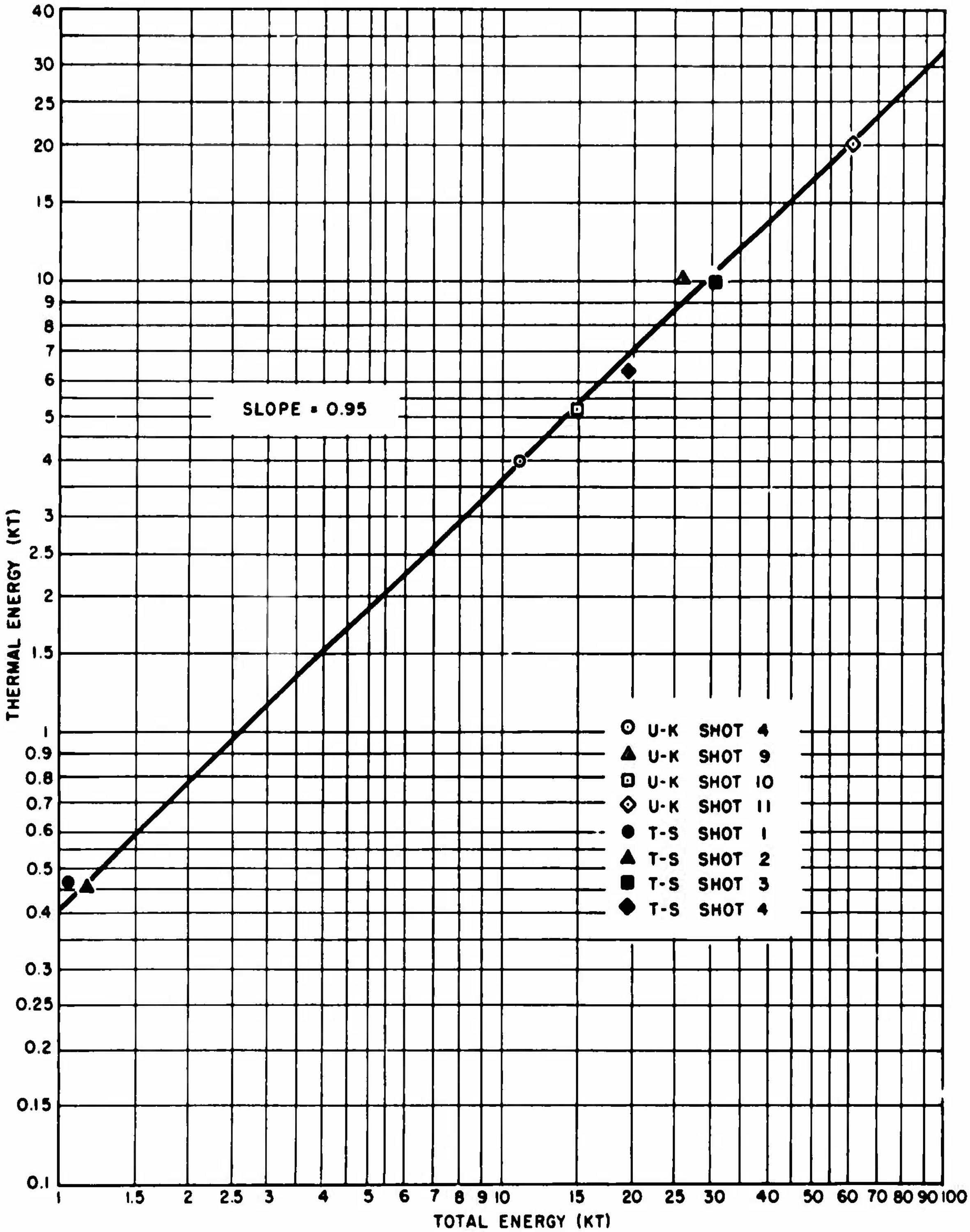


Fig. 4.6 Thermal Yield vs Total Yield, Operations UPSHOT-KNOTHOLE and TUMBLER-SNAPPER

two shots. Since the instruments used here are the standard MK-6F calorimeters with 90° fields-of-view and quartz filters, it is possible to make a comparison of the energies measured at the aircraft with what might be expected on the basis of the ground station measurements. This has been done by making use of Fig. 4.1. An extrapolation of the curves of this figure makes it possible to obtain the thermal energy, corrected for atmospheric attentuation, at ground stations with the same slant range as for the aircraft. Doing this, values of 0.88 cal/sq cm and 3.2 cal/sq cm were obtained for Shots 4 and 9, respectively. The incident thermal energies on the aircraft will then be given by these values corrected for atmospheric attenuation along the paths

TABLE 4.1 Total Yields for Operations UPSHOT-KNOTHOLE, BUSTER, and TUMBLER-SNAPPER

Operation	Shot	Total Yield (KT)	Thermal Yield (KT)
UPSHOT-KNOTHOLE[(a)]	4	11.	4.0
" "	9	26.	10.1
" "	10	14.9	5.2
" "	11	60.8	20.3
BUSTER[(b)]	B	3.48	1.4
"	C	14.0	5.9
"	D	20.98	8.0
"	E	31.4	11.2
TUMBLER-SNAPPER[(c)]	1	1.05	0.46
" "	2	1.15	0.45
" "	3	30.0	10.2
" "	4	19.6	6.5

(a) UPSHOT-KNOTHOLE data are radiochemical yields and were obtained from letter dated 24 September 1953 from LCDR R. G. Preston, Director, Program 8.

(b) Final radiochemical yields obtained from letter dated 14 August 1952 from Lt Col G.E. Page, Chief, Reports Branch, AFSWP.

(c) Values obtained from letter dated 5 August 1952 from Lt Col G. E. Page, Chief, Reports Branch, AFSWP.

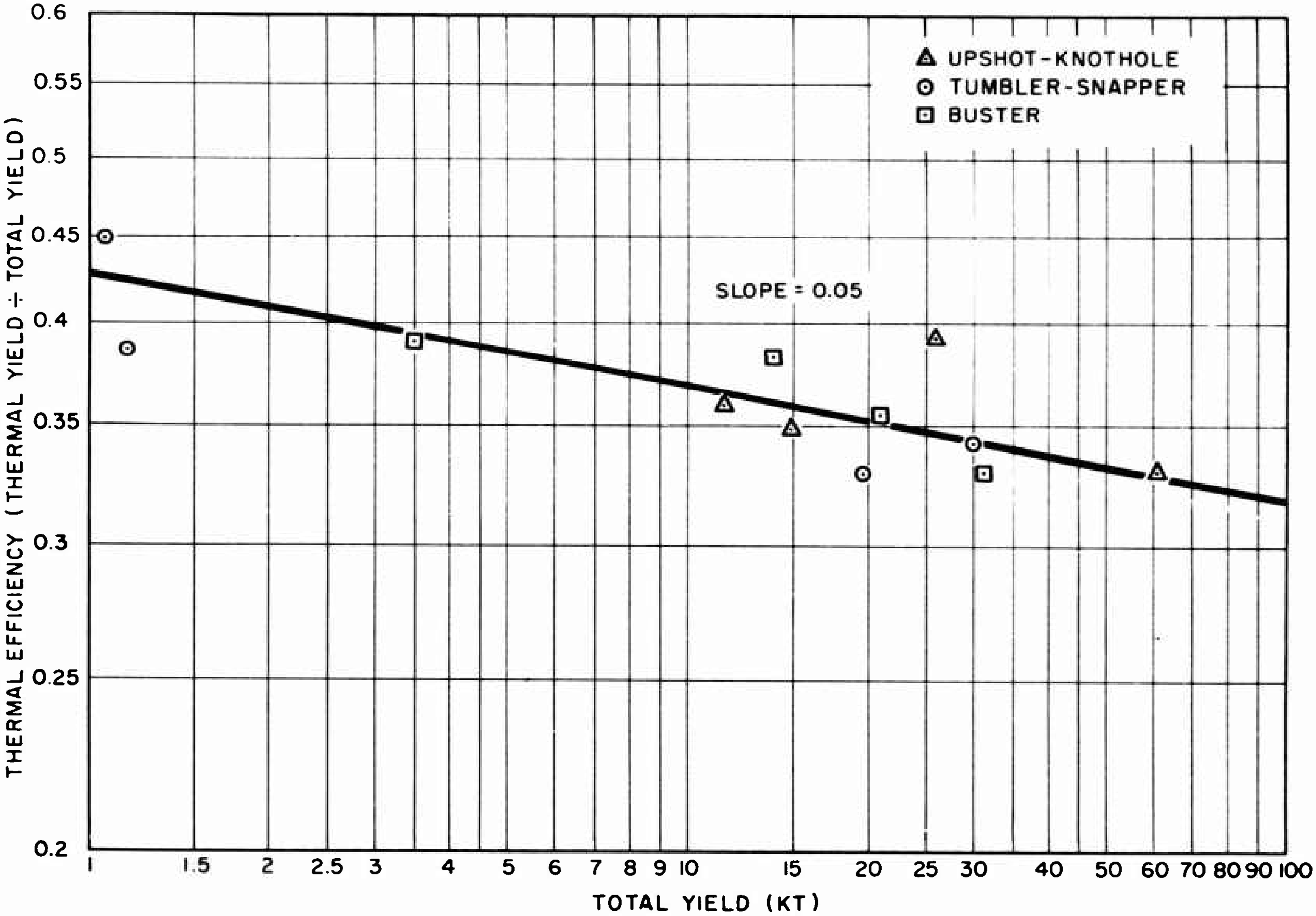


Fig. 4.7 Thermal Efficiency vs Total Yield, Operations UPSHOT-KNOTHOLE, TUMBLER-SNAPPER, and BUSTER

between the points of detonation and the aircraft. On Shot 4 an atmospheric transmission of 95 per cent per statute mile near ground level has been used. It is assumed that the transmission will be inversely proportional to the atmospheric density. Data regarding the atmospheric pressures and air temperatures have been provided by the Director, Program 8.

Atmospheric pressures at ground zero and at the height of the detonation for Shot 4 were 861 mb and 686 mb, respectively. Corresponding air temperatures in °C were 15.5 and -0.6. Using these data and the corresponding air densities, a value of 89 per cent total transmission was obtained. Consequently, the incident thermal energy expected on the aircraft for this shot will be 0.88 times 0.89 which gives 0.78 cal/sq cm. The actual measured thermal energy incident on the aircraft is about 0.97 cal/sq cm. Consequently, about 0.19 cal/sq cm are contributed by ground reflection, which corresponds to about 24 per cent of the directly received energy.

In the case of Shot 9, the same procedure has been followed. Here, the atmospheric transmission near ground level was taken as 92 per cent per statute mile. The atmospheric pressures at ground zero and at the height of the detonation were 900 mb and 825 mb, respectively. Corresponding air temperatures in °C were 16.7 and 8.0. These data then give an atmospheric transmission between the point of detonation and the aircraft of 83 per cent, thus giving a predicted incident thermal energy on the aircraft of about 83 times 3.2 cal/sq cm or 2.6 cal/sq cm. The average value measured is 3.8 cal/sq cm. The ground reflectance contribution in this case is then about 1.2 cal/sq cm or about 45 per cent of the directly received energy. It is clear that the different geometrics relating ground surface, point of detonation, and aircraft position on Shots 4 and 9 introduce a considerable difference in the percentage of energy received by the aircraft from ground reflection for these two shots. This is to be expected even on rather elementary considerations.

4.3 RADIOMETERS

Referring to Tables 3.8 and 3.9, the energies to 3.0 sec as given by the radiometers and calorimeters in cols 6 and 7, respectively, represent average values for the ground stations. In general two radiometers were used at each station. In certain cases of poor records or instrument difficulties, the results quoted are based on only one measurement. However, in general there is quite good agreement between the energy values quoted for the radiometers and for the calorimeters. The times to second maximum listed in these tables are somewhat high due to the intrinsic time lag of the instruments. Also, the time measured will increase as the sensitivity of the instrument is increased. On Shots 9 and 10 a special experiment to determine sensitivity drift is listed in the tables. This experiment was for checking instrument performance and not for making actual measurements. Thus, no results are quoted in these tables for these particular instruments. The times to second maximum determined by the radiometers on the aircraft are listed in Table 3.10. It is clear that these times are very much the same as those determined at the ground stations.

Comparison of the thermal pulse shapes of the weapons, as measured with the Mark 6F field calorimeters and radiometers at ground stations, is given in Figs. 4.8 through 4.11 for Shots 4, 9, 10, and 11, respectively. All curves have been normalized so that the peak irradiance is 100 per cent. It can be seen that the shapes of the curves for all instruments are very similar. However, as was the case in TUMBLER-SNAPPER, the radiometer curves lag somewhat behind the calorimeter curves. This time lag is predicted by the theory of operation of the instruments. A detailed account of these instruments is planned for later publication. The time constants of the Mark 6F field calorimeters are essentially the same as those given for the calorimeters used in TUMBLER-SNAPPER, as reported in the WT-543 report. An accurate determination of the time constant for the Mark 6F field radiometers has not been made.

With regard to the distant station measurements, an examination of Table 3.12 indicates that the times to second maximum agree reasonably well with those obtained at the close-in stations. Radiometer 10-4 on Shot 9 appears to be an exception. This may be due to the special arrangement used (see Section 3.4).

4.4 SPECTRAL ENERGY DISTRIBUTION

Table 4.2 gives the energy received under each filter as a percentage of the total energy received at the station in the spectral range transmitted by quartz. Also shown in this table are the percentages expected from a black body at 6000°K. Table 4.2 appears to indicate that, on the aircraft, for both Shots 4 and 9 more of the thermal energy appears at the longer wavelengths (Corning filters 2-58 and 7-56) than is the case for the ground stations. However, it must be kept in mind that these represent rather crude spectral measurements. Figures 4.12 through 4.15 show the irradiance vs time curves for the calorimeters under the various filters at the ground stations for Shots 4, 9, 10, and 11, respectively. The shift of energy to longer wavelengths with time is apparent from these curves. Table 4.2 and Figs. 4.12 through 4.15 are based on measurements made in clear areas.

4.5 FIELD-OF-VIEW, AIR SCATTER, GROUND REFLECTANCE, AND ALBEDO MEASUREMENTS

The general aim of these measurements was to provide further data regarding the various sources of thermal radiation seen by a 90° field-of-view instrument, viz., direct radiation from the fireball, air-scattered radiation and ground-reflected radiation. It is not believed that any definitive conclusions can be reached regarding this subject without treating data from previous operations along with these data. Such a treatment will be carried out and the results presented in a separate publication. However, the direct measurements made at this operation have been taken from Tables 3.2 through 3.5 and are presented in Table 4.3. The last column of this table represents the thermal energies measured by the instruments after correction for filter losses, where appropriate. Included in the table are the average incident thermal energies at the various stations, as measured by the standard

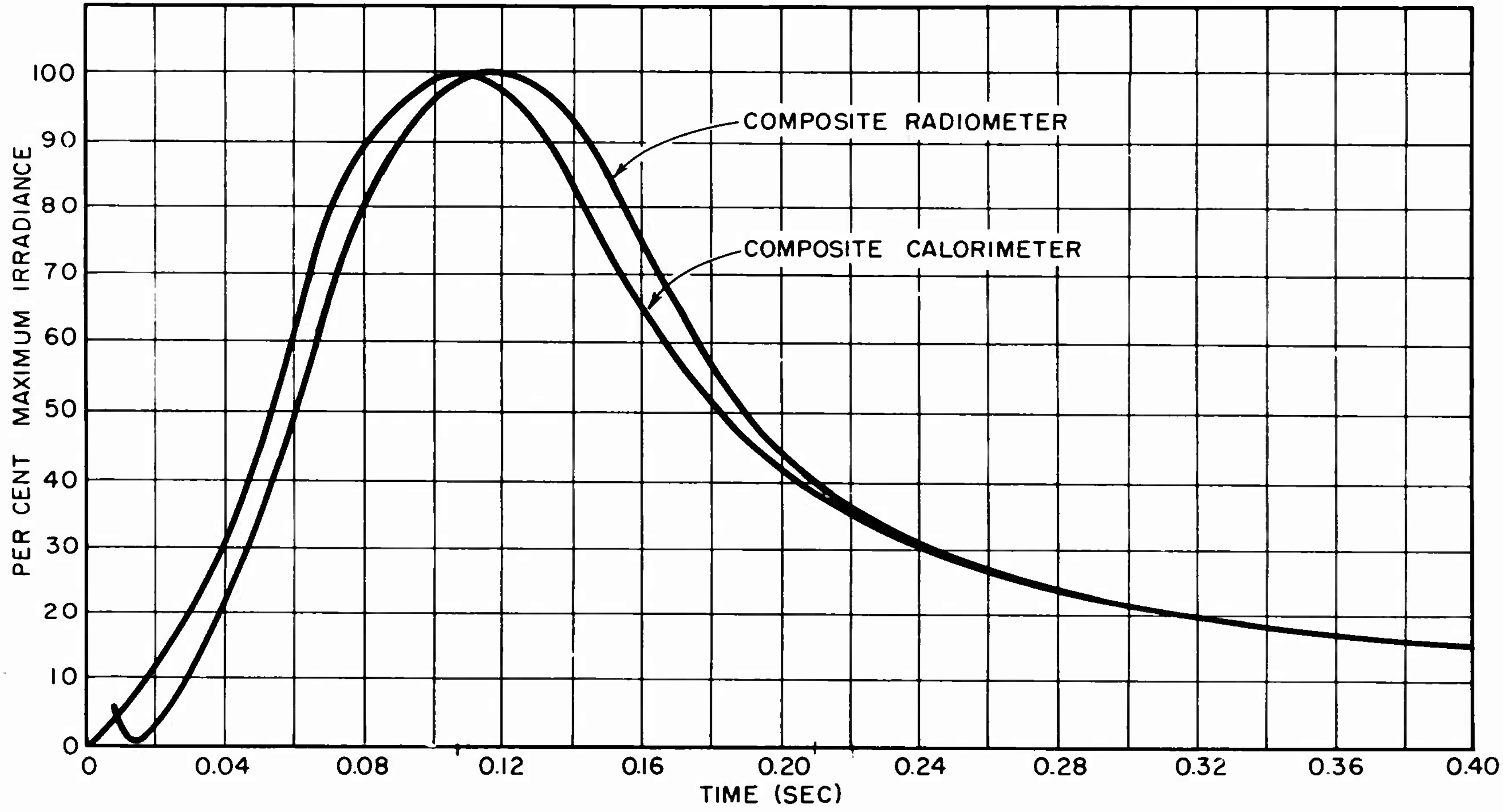


Fig. 4.8 Irradiance vs Time Curves for Calorimeters and Radiometers, Shot 4

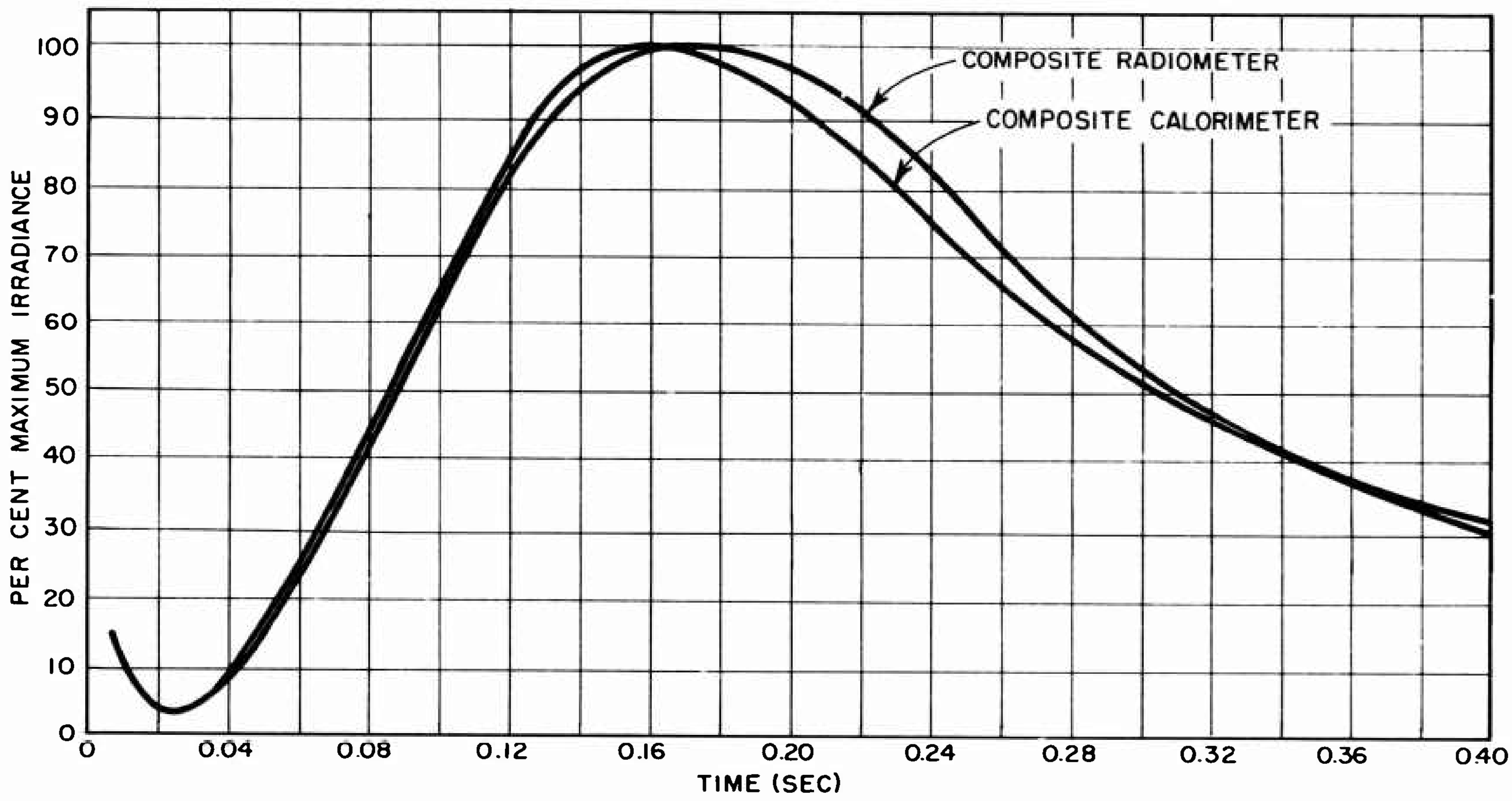


Fig. 4.9 Irradiance vs Time Curves for Calorimeters and Radiometers, Shot 9

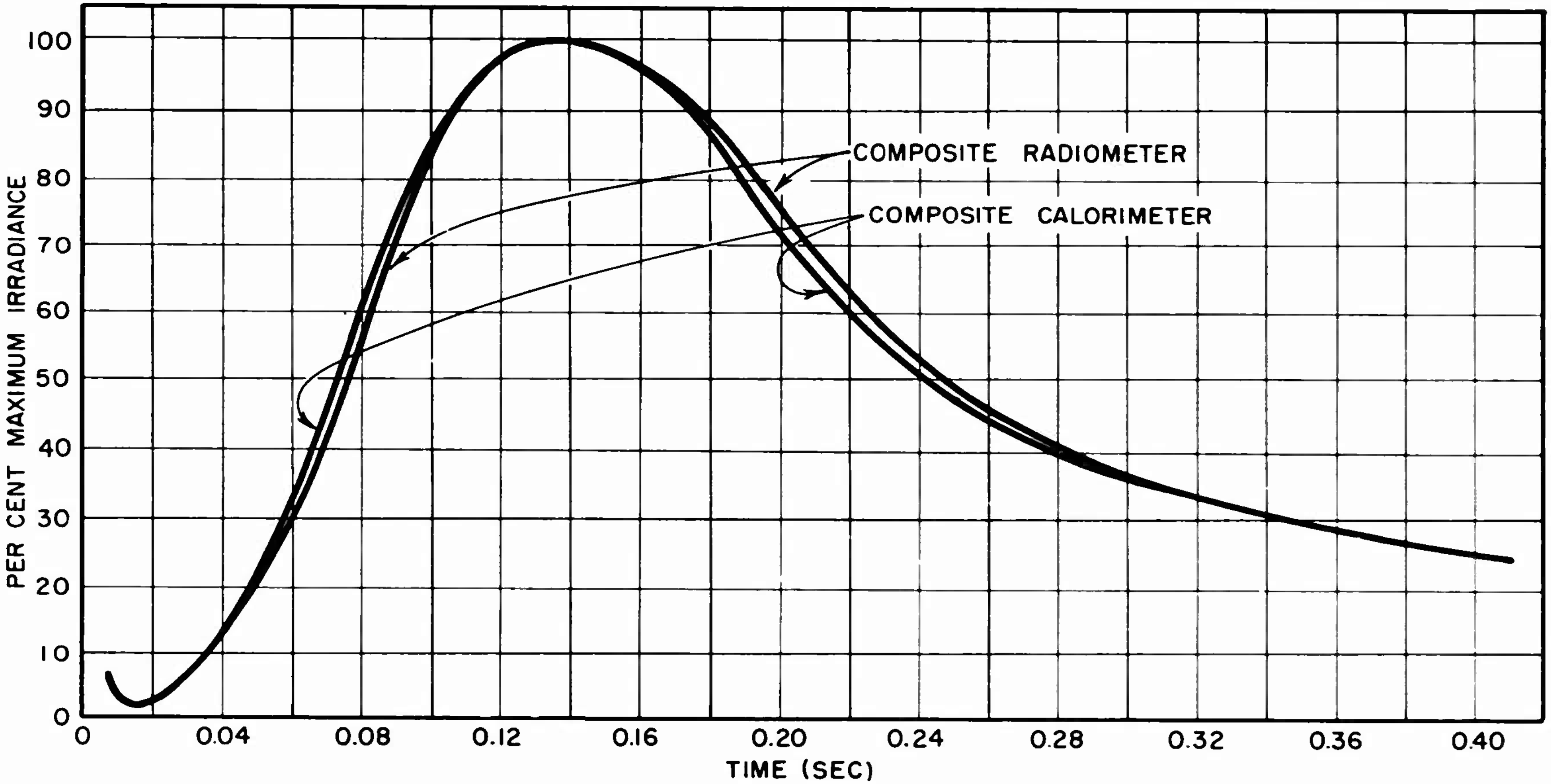


Fig. 4.10 Irradiance vs Time Curves for Calorimeters and Radiometers, Shot 10

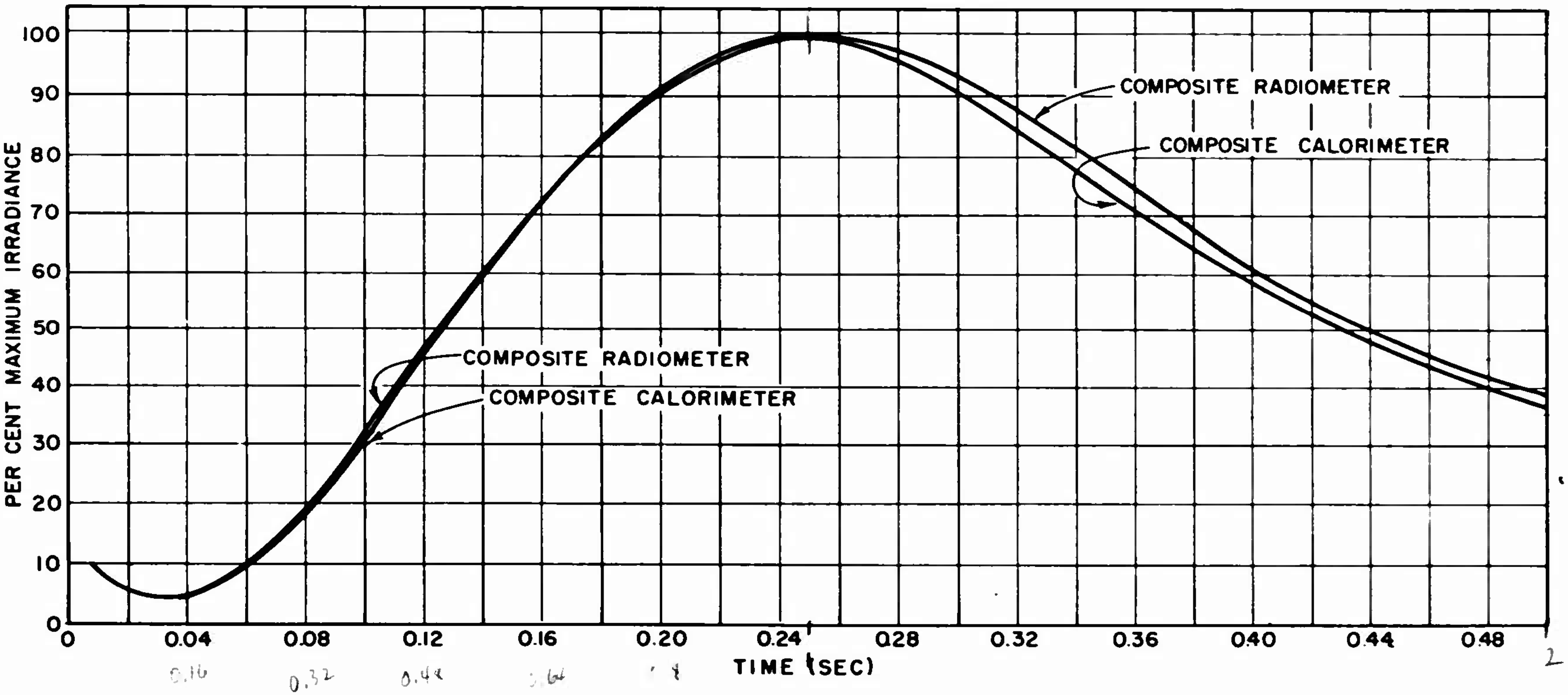


Fig. 4.11 Irradiance vs Time Curves for Calorimeters and Radiometers, Shot 11

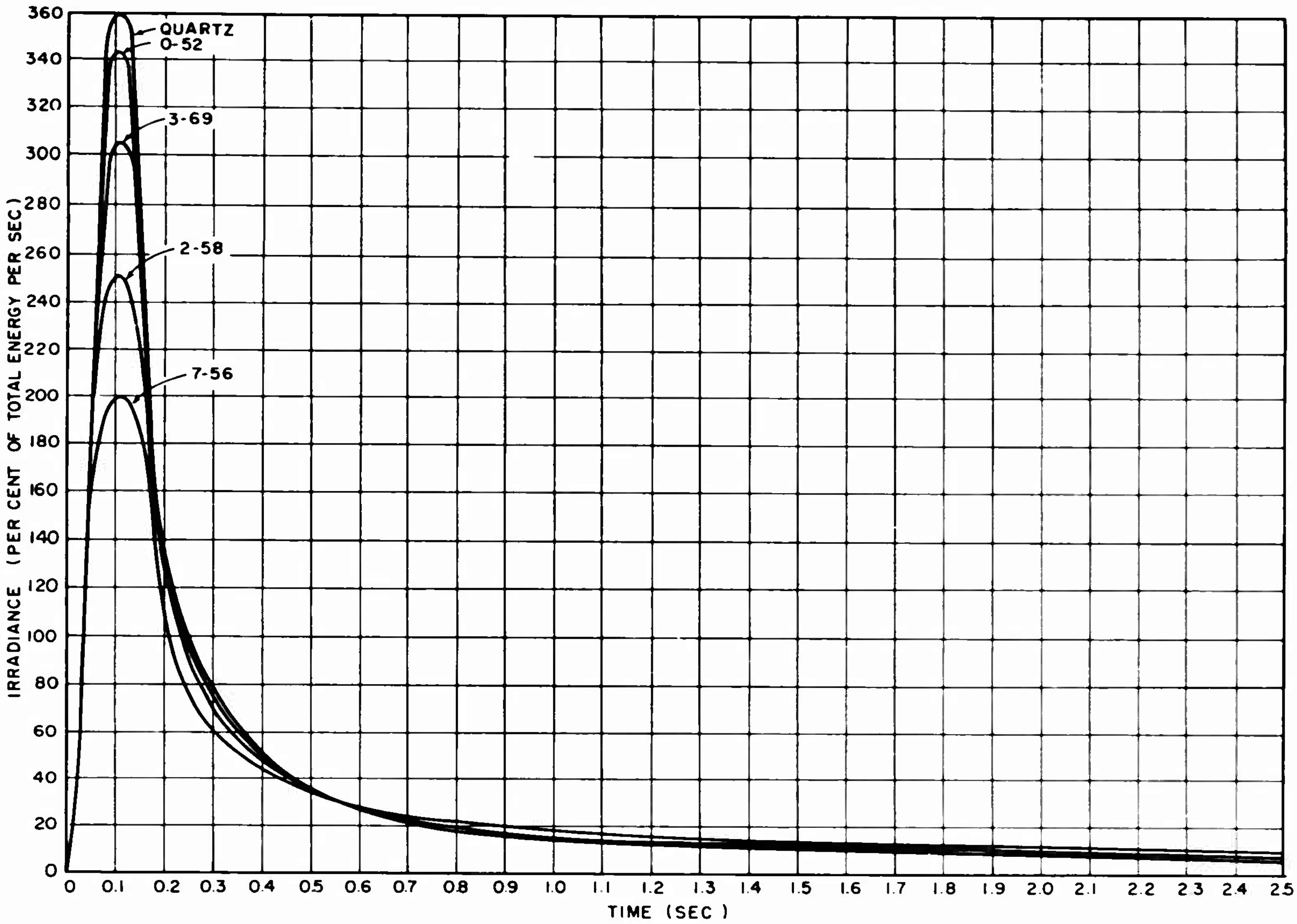


Fig. 4.12 Irradiance vs Time Curves for Calorimeters Used in Spectral Investigations, Shot 4

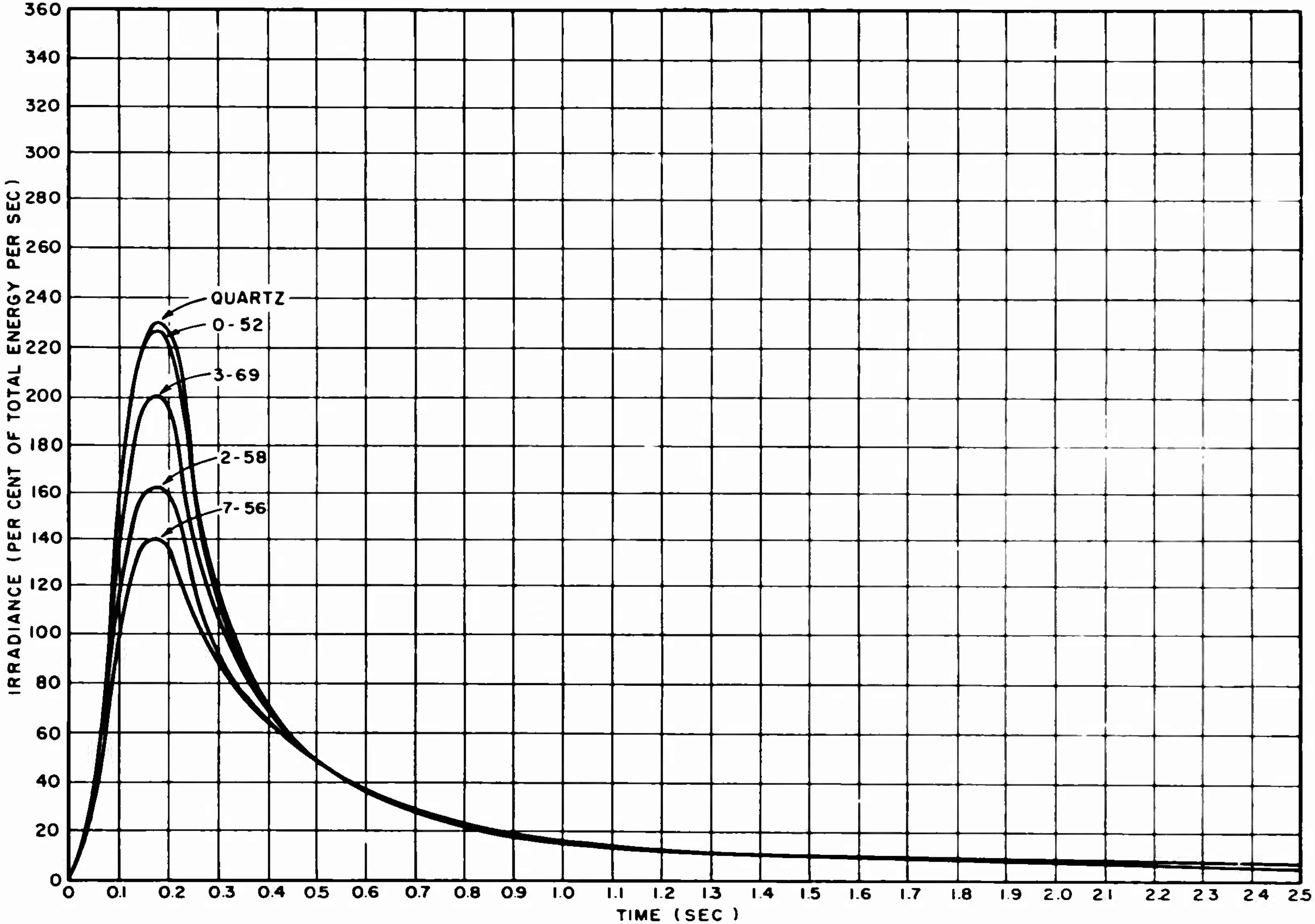


Fig. 4.13 Irradiance vs Time Curves for Calorimeters Used in Spectral Investigations, Shot 9

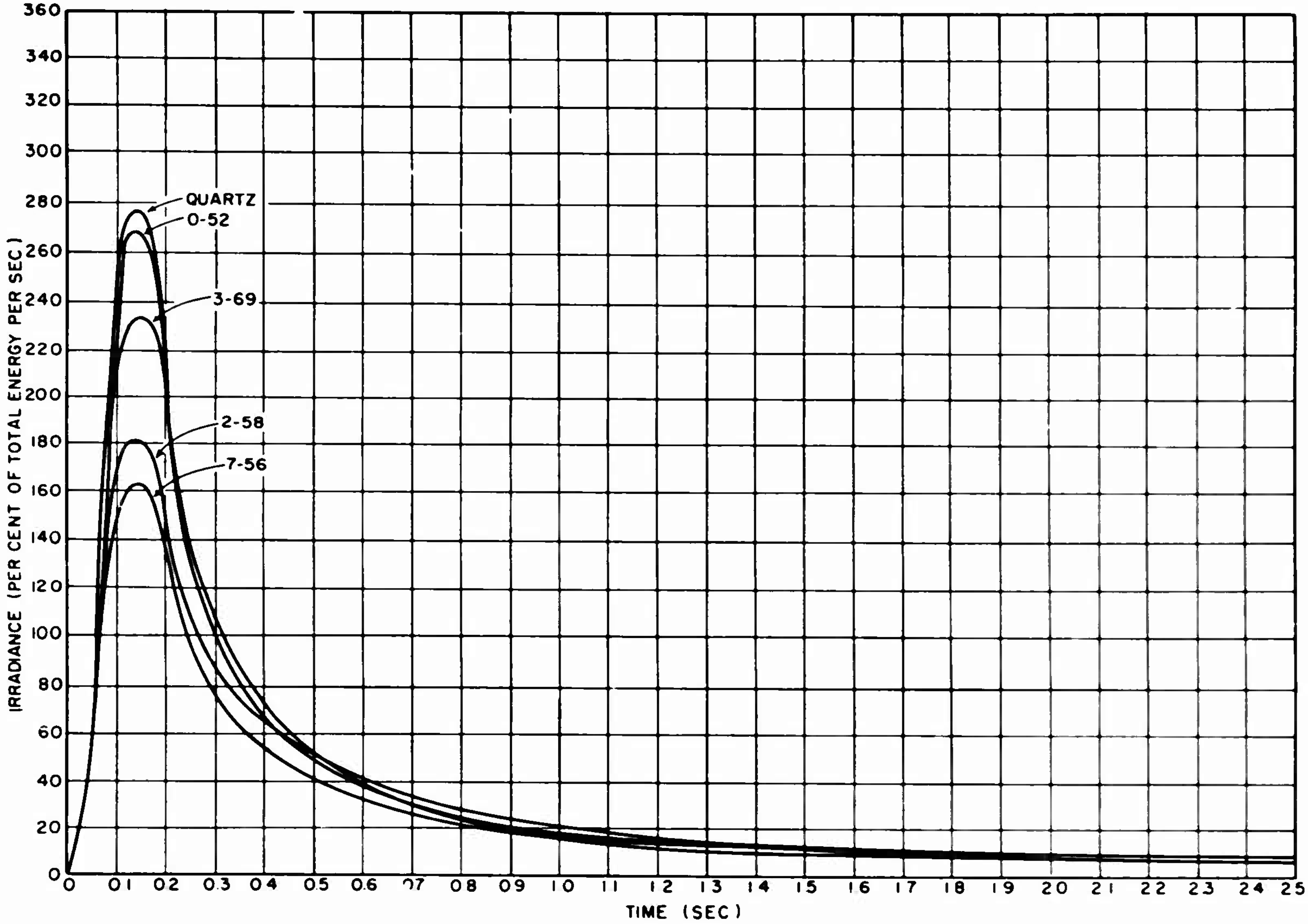


Fig. 4.14 Irradiance vs Time Curves for Calorimeters Used in Spectral Investigations, Shot 10

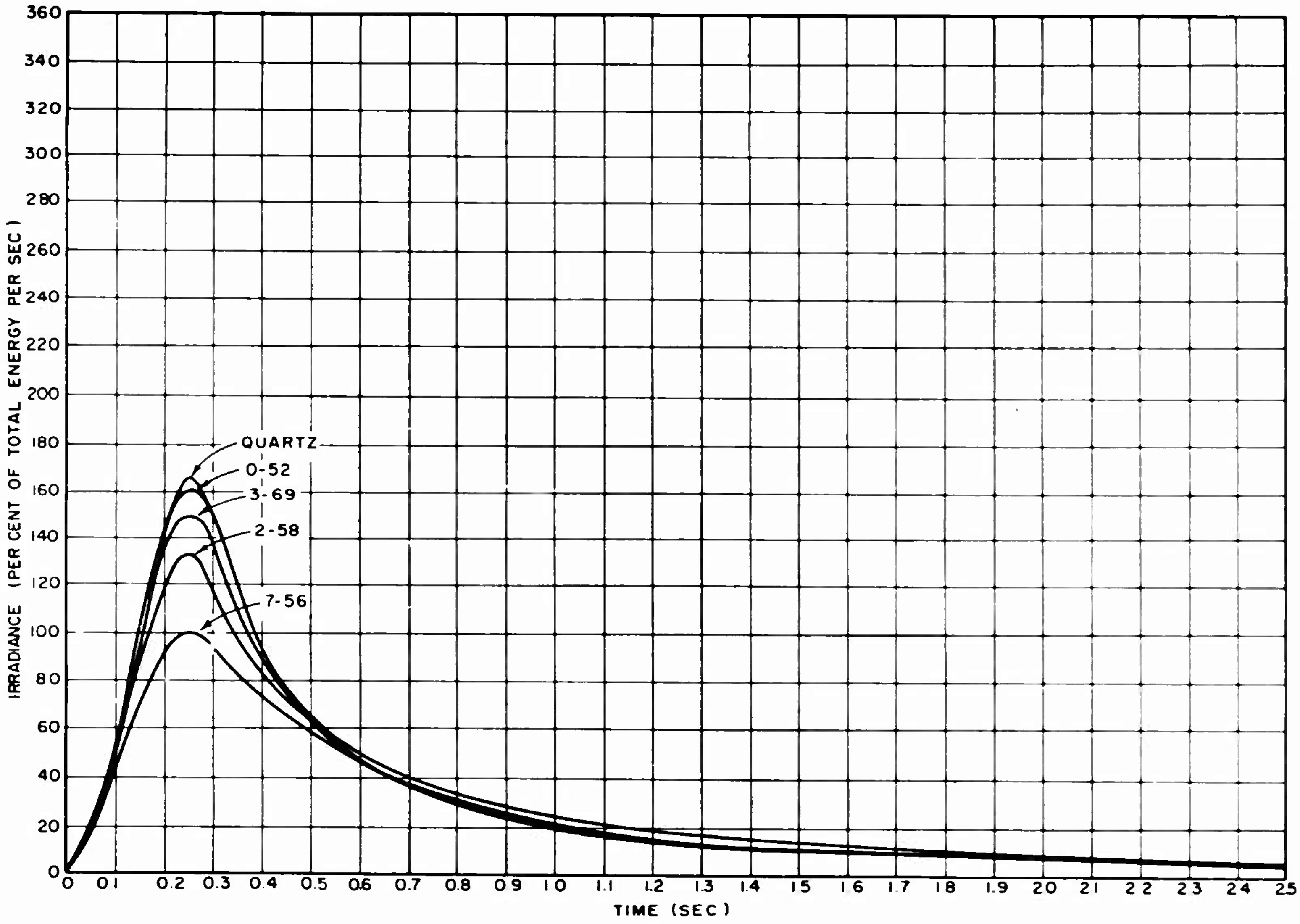


Fig. 4.15 Irradiance vs Time Curves for Calorimeters Used in Spectral Investigations, Shot 11

TABLE 4.2 Per Cent of Total Energy in the Transmission Range of the Filters Used in UPSHOT-KNOTHOLE

Filter Type	Spectral Range of Transmission (Å)	Per Cent of Total Energy				6000°K
		Shot 4	Shot 9	Shot 10	Shot 11	Black Body
		Ground Stations				
Quartz	2200 - 45000	100	100	100	100	99
0-52	3600 - 25000	90	99	93	99	88
3-69	5300 - 25000	65	71	75	76	66
2-58	6400 - 25000	52	53	54	56	52
7-56	9500 - 25000	21	22	21	21	26
		Aircraft Stations				
Quartz	2200 - 45000	100	100			99
0-52	3600 - 25000	86	97			88
3-69	5300 - 25000	64	69			66
2-58	6400 - 25000	45	57			52
7-56	9500 - 25000	28	29			26

90° field-of-view instruments. These values are listed as the average station energies.

The field-of-view and air scatter experiments were made in an attempt to obtain semi-quantitative measurements of the radiation scattered to an instrument by the air between the instrument and the point of detonation. Some measurements of the first type were made at previous operations. However, this is the first attempt to measure the air scatter directly. As noted earlier in this report, the air scatter instruments were designed so that no direct fireball radiation would be received. A number of the instruments listed in Tables 3.2 through 3.5 did not give valid results and these particular instruments are not included in Table 4.3. Presumably the difficulty here arose from the fact that these instruments saw a part or all of the fireball due to a difference between the actual and predicted points of detonation. Referring to Table 4.3, it will be noted that the air scatter contribution was approximately 10 per cent or less of the average station energy. With regard to the field-of-view measurements, some consideration should be given to the instruments designated by the Use Code TE with a field-of-view of 180° as well as to those designated by FV. The data listed in

TABLE 4.3 Field-of-view, Air Scatter, Ground Reflectance, and Albedo Measurements at Ground Stations

Use Code	Angle of Field of View (Deg)	Angle from Horizontal (Deg)	Elevation (ft)	Filter	Data Serial No.	Total Energy Incident (cal/sq cm)
		Shot 4, Station 7-204, Slant Range 6785 ft, Air Zero Angle 62.5°. Av. Station Energy = 7.0 cal/sq cm.				
AS	90	+64	50	Quartz	9-26	0.41
AL	90	-90	35	Quartz	9-30	1.3
AL	90	-90	35	Quartz	9-36	1.4
TE	180	+64	50	None	9-32	6.2
		Shot 4. Station 7-208, Slant Range 8605 ft, Air Zero Angle 44.3°. Av. Station Energy = 4.1 cal/sq cm.				
AS	90	+46	10	Quartz	9-40	0.28
AL	90	-90	35	Quartz	9-42	0.62
AL	90	-90	35	Quartz	9-47	0.61
TE	180	+46	10	None	9-39	4.0
		Shot 9, Station F-202, Slant Range 3535 ft, Air Zero Angle 42.2°. Av. Station Energy = 60.6 cal/sq cm				
AL	90	-90	35	Quartz	10-5	10.5
AL	90	-90	35	Quartz	10-6	10.5
GR	90	+44	50	Quartz	10-11	13.7

TABLE 4.3 Field-of-view, Air Scatter, Ground Reflectance, and Albedo Measurements at Ground Stations (Continued)

Use Code	Angle of Field of View (Deg)	Angle from Horizontal (Deg)	Elevation (ft)	Filter	Data Serial No.	Total Energy Incident (cal/sq cm)
		Shot 9, Station F-208, Slant Range 4715 ft, Air Zero Angle 30.3°. Av. Station Energy = 36.1 cal/sq cm				
AL	90	-90	35	Quartz	10-23	5.4
AL	180	-90	35	None	10-24	6.5
GR	90	+31	50	Quartz	10-17	2.1
		Shot 9, Station F-210, Slant Range 5585 ft, Air Zero Angle 25.2°. Av. Station Energy = 26.7 cal/sq cm				
TE	180	+25.8	50	None	10-30	27.1
TE	180	+25.8	50	None	10-31	24.6
		Shot 9, Station F-295, Slant Range 9820 ft, Air Zero Angle 14.3°. Av. Station Energy = 7.9 cal/sq cm				
AS	90	+14.2	10	Quartz	10-37	0.87
AL	90	-90	10	Quartz	10-38	0.50
AL	90	-90	10	Quartz	10-40	0.54
GR	90	+14.2	10	Quartz	10-36	7.7

TABLE 4.3 Field-of-view, Air Scatter, Ground Reflectance, and Albedo Measurements at Ground Station (Continued)

Use Code	Angle of Field of View (Deg)	Angle from Horizontal (Deg)	Elevation (ft)	Filter	Data Serial No.	Total Energy Incident (cal/sq cm)
		Shot 10, Station F-202, Slant Range 2465 ft, Air Zero Angle 11.1°. Av. Station Energy = 51.5 cal/sq cm.				
AL	90	-90	35	Quartz	10-74	4.2
AL	90	-90	35	Quartz	10-75	4.0
GR	90	+11.3	50	Quartz	10-72	15.0
		Shot 10, Station F-208, Slant Range 3945 ft, Air Zero Angle 6.9°. Av. Station Energy = 25.0 cal/sq cm.				
AL	90	-90	35	Quartz	10-86	2.0
AL	180	-90	35	None	10-87	2.6
GR	90	+7.1	50	Quartz	10-80	4.1
		Shot 10, Station F-210, Slant Range 4940 ft, Air Zero Angle 5.5°. Av. Station Energy = 17.3 cal/sq cm				
TE	180	+ 5.7	50	None	10-93	17.4
TE	180	+ 5.7	50	None	10-94	17.2

TABLE 4.3 Field-of-view, Air Scatter, Ground Reflectance, and Albedo Measurements at Ground Station (Continued)

Use Code	Angle of Field of View (Deg)	Angle from Horizontal (Deg)	Elevation (ft)	Filter	Data Serial No.	Total Energy Incident (cal/sq cm)
		Shot 10, Station F-295, Slant Range 9430 ft, Air Zero Angle 3.1°. Av. Station Energy = 4.4 cal/sq cm.				
AS	90	+3.0	10	Quartz	10-100	0.11
GR	90	+3.0	10	Quartz	10-99	0.39
FV	20	+3.0	10	Quartz	10-101	3.7
FV	20	+3.0	10	Quartz	10-103	3.7
		Shot 10, Station F8.10F, Slant Range 13,925 ft, Air Zero Angle 2.2°. Av. Station Energy = 1.7 cal/sq cm.				
AS	90	+2.1	10	Quartz	10-112	2.0
TE	180	+2.1	10	None	10-116	2.0
FV	20	+2.1	10	Quartz	10-115	1.7
FV	20	+2.1	10	Quartz	10-117	0.54
		Shot 11, Station 1-356, Slant Range 16,960 ft, Air Zero Angle 4.5°. Av. Station Energy = 5.0 cal/sq cm.				
FV	20	+4.5	10	Quartz	9-66	4.2
FV	20	+4.5	10	Quartz	9-67	4.5
		Shot 11, Station 8.12-1, Slant Range 26,810 ft, Air Zero Angle 2.8°. Av. Station Energy = 1.9 cal/sq cm.				
FV	20	+2.6	10	Quartz	9-78	1.6
FV	7	+2.6	10	Quartz	9-84	1.1

Table 4.3 again indicate that substantially all thermal energy arriving at a given point will be recorded by an instrument having a 90° field-of-view and with its axis aligned to pass through the point of detonation. It should be noted that the instrument designated by the Data Serial Number 10-117 apparently did not receive direct fireball radiation and the result given should be disregarded. In reviewing the field-of-view and air scatter measurements, geometrical considerations become of considerable importance. As will be noted from the table, some of the instruments could be aligned so that they received no ground-reflected energy. In other cases this was not true and, consequently, estimates of this energy contribution must be obtained from the ground reflectance measurements.

In view of the fact that the bulk of the thermal energy measurements made by the USNRDL during several past operations have been made using instruments with a standard 90° field-of-view, it is of considerable interest to determine how much of the energy received by these instruments is due to ground reflection. In making the measurements reported in Table 4.3 efforts were made to minimize the air scatter contribution as well as to eliminate the direct fireball radiation. Here, again, geometrical considerations are very important, particularly in view of the fact that the actual point of detonation differed to some extent from the predicted point of detonation.

In the case of the albedo measurements, standard 90° instruments were used in most cases. These instruments measured the energy reflected by a known ground area, for which the incident thermal energy was known from other measurements. This information, together with geometrical considerations, makes it possible to arrive at ground albedo values.

With regard to the aircraft, a number of instruments with different fields-of-view were used (see Fig. 3.3). However, as has been discussed earlier in this report, rather special geometries had to be used because of the limitations set by the design of the aircraft. Examination of the GSAP camera films obtained during the operation shows that the orientations of the aircraft for all shots on which measurements were made were such that no correction factors need be used. Consequently, it is feasible to make a more detailed analysis of the aircraft field-of-view results making use of Fig. 3.3, and Tables 3.6 and 3.7. However, it is felt that conclusions regarding this type of measurements should be withheld until such time as a study can be made of all such measurements, both from this operation and previous operations.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

The results obtained indicate that the objectives of the project have been fulfilled. In general, all of the equipment performed in a satisfactory manner. The new designs (MK-6F) of 90° field-of-view disk calorimeters and of foil radiometers were found to be entirely satisfactory for use both on ground stations and on aircraft. The 180° field-of-view calorimeters appear to be adequate for giving information regarding relative thermal energy values as a function of direction at a given location under a smoke layer. However, the data concerning absolute energy values as obtained with this type of instrument must be examined critically because of the fact that the receiving disk is not protected by a filter.

The data obtained on thermal energy and irradiance as functions of distance and time for the various weapons appear to be entirely consistent with the results obtained in previous operations. Emphasis must be placed on the importance of the atmospheric transmission coefficients, particularly for the more distant measuring stations. In view of the fact that the method of determining values for these coefficients makes use of an essentially zero angle field-of-view as compared with the usual 90° field-of-view for the thermal measuring instruments, a small correction for this factor must be introduced in order to arrive at final thermal energy values. Also, a small correction for the atmospheric water vapor content must be applied to the attenuation coefficients. For the distances involved at this operation, the total correction due to both these factors amounts to only a few per cent. In order to make it possible to directly compare the results of this operation with those obtained at previous operations, these corrections have not been included here.

With regard to the thermal energy measurements made under the smoke layers on Shot 10, a high degree of attenuation was produced by both the black and white smoke layers (over 95 per cent in each case). Although at first glance the white smoke might appear to be somewhat more effective in attenuating the thermal energy, no such conclusion should be drawn on the basis of the limited measurements made. The actual concentration of the smoke layers used, as well as local variations in distribution, would have a very decided effect on the results observed.

Various relationships for scaling total yields have been proposed (5) on the basis of operations preceding UPSHOT-KNOTHOLE. The data from this latter operation appear to fit these proposed relationships quite satisfactorily. The time to second peak, t_p , in seconds fits, within experimental error, the relationship $W = 850\ t_p^2$, where W is the total yield in KT of the weapon. The pulse shape beyond the second peak fits the general relationships derived in the scaling considerations for all shots of this operation.

These scaling relationships were derived on the basis of BUSTER, TUMBLER-SNAPPER ,and IVY. In view of the fact that the only thermal measurements available to date for high yield weapons are on IVY, it might appear that undue weight has been given to these measurements. However, the pulse shape obtained can be considered to be fairly reliable. Consequently, the value of t_p for the weapons of this operation can be looked upon with a reasonable amount of confidence. Scaling the weapon yield from t_p or R_p has the advantage that uncertainties in such factors as the atmospheric attenuation, the atmospheric water vapor content, and the instrument calibration factor enter the considerations only to a minor degree, if at all. This is not the case when scaling is attempted from the measurement of thermal energy at a given distance from the point of detonation. In the latter case the above factors must be introduced directly into the computations. The geometry relating ground surface, point of detonation, and aircraft position has a decided effect on the per cent of total energy received by the aircraft due to ground reflection. Although Shots 4 and 9 were detonated over different terrain (Yucca Flat and Frenchman Flat) it is not felt that the reflectance coefficients for these areas are so different as to radically affect the numbers obtained. Previously obtained data regarding the ground reflection contribution to the energy incident on aircraft are quite meager. The only other shot which probably can be compared with one of the shots of this operation is Shot 4, Operation TUMBLER-SNAPPER. In this case, the weapon was detonated at a height above ground level of 1060 ft and the aircraft was at a slant range from the point of detonation of 18,885 ft. The slant ranges for Shot 4 of TUMBLER-SNAPPER and Shot 9 of UPSHOT-KNOTHOLE are reasonably close together. Although the heights of burst for these two shots were different (1062 ft and 2423 ft) and they were detonated over different areas, the ground-reflected contributions to the thermal energy are much the same for these shots, viz., 50 per cent for Shot 4, TUMBLER-SNAPPER and 45 per cent for Shot 9, UPSHOT-KNOTHOLE.

The standardized MK-6F field calorimeters and radiometers proved to be very rugged and reliable both with regard to performance at ground stations and on aircraft. In addition, the standard instrument holders adopted for use in the aircraft installation proved both convenient and rugged. The standard MK-6F instruments together with the aircraft instrument holders provide a very convenient package for making measurements from aircraft.

5.2 RECOMMENDATIONS

Considerable data are now available for the range of weapons from 1 KT to about 50 KT. However, even for this range of yields the effects produced by various environmental conditions are not well known. Situations involving the presence of smoke layers, cloud layers, and snow-covered ground introduce unknown factors into the considerations. Consequently, it is recommended that an attempt be made to determine the effects of such factors on the physical characteristics of the thermal radiation incident at selected points. While it is true that such measurements may apply to a special field condition and might not be generally applicable to diagnostic work, the number of practical situations of interest is small and it is felt that actual measurements for a few typical cases would be better than pure speculation. It is felt that these field measurements should be conducted as an extension of a long range laboratory program concerned with the same phenomena. It is not believed that complete reliance should be placed on measurements made in the laboratory and at sites other than those used for atomic weapon tests. In general, primary emphasis should probably be placed on making thermal measurements in order to gain a better understanding of certain associated phenomena, including the obscuration effects noted above as well as ignition and precursor wave phenomena.

With regard to higher yield weapons, particularly in the megaton region, the knowledge of the physical characteristics of the thermal radiation is inadequate. Also, here the effect of the factors noted above becomes of even greater importance. The paucity of knowledge concerning the thermal radiation associated with high yield weapons makes it desirable to carry out field measurements for both surface and air bursts. In spite of the obscuring effects associated with surface bursts, ground station measurements will provide some useful information with regard to the casualty-producing capabilities of such weapons particularly at larger distances. The characteristics of the pulse at early times may be pertinent to scaling considerations.

There is some indication that the operational limitations for aircraft may be set by the thermal radiation rather than by other factors. As accurate a knowledge as possible of the physical characteristics of the thermal radiation, as well as the contributing effect of the earth's reflection and fog or cloud layers, should be acquired in this case, because of the fact that they may be important factors in determining the feasibility of delivering very high yield weapons. Measurements of atmospheric transmission as a function of height above the earth's surface should be made. Practically all measurements to date have been concerned with horizontal paths fairly near the earth's surface. The types of measurements recommended could well be carried out as part of a long range program with checks obtained at tests of atomic weapons. Even in the case of relatively low yield weapons, the above type of information should be extended, particularly with reference to the operation of aircraft in enemy atomic anti-aircraft defenses. Here, high altitude bursts will be of importance.

Summarizing the general recommendations discussed above, specifically, measurements of the pertinent physical characteristics of thermal radiation should be made at tests of atomic weapons in order to:

1. Provide supporting data for studies concerned with phenomena associated with thermal radiation, such as the precursor wave.

2. Determine the effect of scattering and attenuating media, particularly fogs and cloud layers.

3. Provide basic data which will be instrumental in determining the operational capabilities of aircraft and can also be applied to scaling considerations.

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75- 76 Chief, Bureau of Ships, D/N, Washington 25, D.C. ATTN: Code 348
77 Chief, Bureau of Yards and Docks, D/N, Washington 25, D.C. ATTN: D-440
78 Chief, Bureau of Supplies and Accounts, D/N, Washington 25, D.C.
79- 80 Chief, Bureau of Aeronautics, D/N, Washington 25, D.C.
81 Chief of Naval Research, Department of the Navy Washington 25, D.C. ATTN: LT(jg) F. McKee, USN
82 Commander-in-Chief, U.S. Pacific Fleet, Fleet Post Office, San Francisco, Calif.
83 Commander-in-Chief, U.S. Atlantic Fleet, U.S. Naval Base, Norfolk 11, Va.
84- 87 Commandant, U.S. Marine Corps, Washington 25, D.C. ATTN: Code AO3H
88 President, U.S. Naval War College, Newport, R.I.
89 Superintendent, U.S. Naval Postgraduate School, Monterey, Calif.
90 Commanding Officer, U.S. Naval Schools Command, U.S. Naval Station, Treasure Island, San Francisco, Calif.
91 Commanding Officer, U.S. Fleet Training Center, Naval Base, Norfolk 11, Va. ATTN: Special Weapons School
92- 93 Commanding Officer, U.S. Fleet Training Center, Naval Station, San Diego 36, Calif. ATTN: (SPWP School)
94 Commanding Officer, Air Development Squadron 5, VX-5, U.S. Naval Air Station, Moffett Field, Calif.
95 Commanding Officer, U.S. Naval Damage Control Training Center, Naval Base, Philadelphia 12, Pa. ATTN: ABC Defense Course
96 Commanding Officer, U.S. Naval Unit, Chemical Corps School, Army Chemical Training Center, Ft. McClellan, Ala.
97 Joint Landing Force Board, Marine Barracks, Camp Lejeune, N.C.
98 Commander, U.S. Naval Ordnance Laboratory, Silver Spring 19, Md. ATTN: EE
99 Commander, U.S. Naval Ordnance Laboratory, Silver Spring 19, Md. ATTN: EH
100 Commander, U.S. Naval Ordnance Laboratory, Silver Spring 19, Md. ATTN: R
101 Commander, U.S. Naval Ordnance Test Station, Inyokern, China Lake, Calif.
102 Officer-in-Charge, U.S. Naval Civil Engineering Res. and Evaluation Lab., U.S. Naval Construction Battalion Center, Port Hueneme, Calif. ATTN: Code 753
103 Commanding Officer, U.S. Naval Medical Research Inst., National Naval Medical Center, Bethesda 14, Md.

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104	Director, U.S. Naval Research Laboratory, Washington 25, D.C. ATTN: Code 2029
105	Director, The Material Laboratory, New York Naval Shipyard, Brooklyn, N.Y.
106	Commanding Officer and Director, U.S. Navy Electronics Laboratory, San Diego 52, Calif. ATTN: Code 4223
107-110	Commanding Officer, U.S. Naval Radiological Defense Laboratory, San Francisco 24, Calif. ATTN: Technical Information Division
111-112	Commanding Officer and Director, David W. Taylor Model Basin, Washington 7, D.C. ATTN: Library
113	Commander, U.S. Naval Air Development Center, Johnsville, Pa.
114	Director, Office of Naval Research Branch Office, 1000 Geary St., San Francisco, Calif.
115	Officer-in-Charge, U.S. Naval Clothing Factory, U.S. Naval Supply Activities, New York, 3rd Avenue and 29th Street, Brooklyn, N.Y. ATTN: R&D Division
116-122	Technical Information Service, Oak Ridge, Tenn. (Surplus)

AIR FORCE ACTIVITIES

123	Asst. for Atomic Energy, Headquarters, USAF, Washington 25, D.C. ATTN: DCS/O
124	Director of Operations, Headquarters, USAF, Washington 25, D.C. ATTN: Operations Analysis
125	Director of Plans, Headquarters, USAF, Washington 25, D.C. ATTN: War Plans Div.
126	Director of Research and Development, Headquarters, USAF, Washington 25, D.C. ATTN: Combat Components Div.
127-128	Director of Intelligence, Headquarters, USAF, Washington 25, D.C. ATTN: AFOIN-1B2
129	The Surgeon General, Headquarters, USAF, Washington 25, D.C. ATTN: Bio. Def. Br., Pre. Med. Div.
130	Deputy Chief of Staff, Intelligence, Headquarters, U.S. Air Forces Europe, APO 633, c/o PM, New York, N.Y. ATTN: Directorate of Air Targets
131	Commander, 497th Reconnaissance Technical Squadron (Augmented), APO 633, c/o PM, New York, N.Y.
132	Commander, Far East Air Forces, APO 925, c/o PM, San Francisco, Calif.
133	Commander, Strategic Air Command, Offutt Air Force Base, Omaha, Nebraska. ATTN: Special Weapons Branch, Inspection Div., Inspector General
134	Commander, Tactical Air Command, Langley AFB, Va. ATTN: Documents Security Branch
135	Commander, Air Defense Command, Ent AFB, Colo.
136-137	Commander, Air Materiel Command, Wright-Patterson AFB, Dayton, O. ATTN: MCAIDS
138	Commander, Air Training Command, Scott AFB, Belleville, Ill. ATTN: DCS/O GTP
139	Commander, Air Research and Development Command, PO Box 1395, Baltimore, Md. ATTN: RDDN
140	Commander, Air Proving Ground Command, Eglin AFB, Fla. ATTN: AG/TRB
141-142	Commander, Air University, Maxwell AFB, Ala.
143-150	Commander, Flying Training Air Force, Waco, Tex. ATTN: Director of Observer Training
151	Commander, Crew Training Air Force, Randolph Field, Tex. ATTN: 2GTS, DCS/O
152	Commander, Headquarters, Technical Training Air Force, Gulfport, Miss. ATTN: TA&D

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153-154	Commandant, Air Force School of Aviation Medicine, Randolph AFB, Tex.
155-160	Commander, Wright Air Development Center, Wright-Patterson AFB, Dayton, O. ATTN: WCOESP
161	Commander, Air Force Cambridge Research Center, 230 Albany Street, Cambridge 39, Mass. ATTN: CRW, Atomic Warfare Directorate
162	Commander, Air Force Cambridge Research Center, 230 Albany Street, Cambridge 39, Mass. ATTN: CRQST-2
163-165	Commander, Air Force Special Weapons Center, Kirtland AFB, N. Mex. ATTN: Library
166	Commandant, USAF Institute of Technology, Wright-Patterson AFB, Dayton, O. ATTN: Resident College
167	Commander, Lowry AFB, Denver, Colo. ATTN: Department of Armament Training
168	Commander, 1009th Special Weapons Squadron, Headquarters, USAF, Washington 25, D.C.
169-170	The RAND Corporation, 1700 Main Street, Santa Monica, Calif. ATTN: Nuclear Energy Division
171-177	Technical Information Service, Oak Ridge, Tenn. (Surplus)

OTHER DEPARTMENT OF DEFENSE ACTIVITIES

178	Asst. Secretary of Defense, Research and Development, D/D, Washington 25, D.C.
179	U.S. National Military Representative, Headquarters, SHAPE, APO 55, c/o PM, New York, N.Y. ATTN: Col. J. P. Healy
180	Director, Weapons Systems Evaluation Group, OSD, Rm 2E1006, Pentagon, Washington 25, D.C.
181	Asst. for Civil Defense, OSD, Washington 25, D.C.
182	Armed Services Explosives Safety Board, D/D, Building T-7, Gravelly Point, Washington 25, D.C.
183	Commandant, Armed Forces Staff College, Norfolk 11, Va. ATTN: Secretary
184-189	Commanding General, Field Command, Armed Forces Special Weapons Project, PO Box 5100, Albuquerque, N. Mex.
190-191	Commanding General, Field Command, Armed Forces, Special Weapons Project, PO Box 5100, Albuquerque, N. Mex. ATTN: Technical Training Group
192-200	Chief, Armed Forces Special Weapons Project, Washington 25, D.C.
201-207	Technical Information Service, Oak Ridge, Tenn. (Surplus)

ATOMIC ENERGY COMMISSION ACTIVITIES

208-210	U.S. Atomic Energy Commission, Classified Technical Library, 1901 Constitution Ave., Washington 25, D.C. ATTN: Mrs. J. M. O'Leary (For DMA)
211-213	Los Alamos Scientific Laboratory, Report Library, PO Box 1663, Los Alamos, N. Mex. ATTN: Helen Redman
214-215	Sandia Corporation, Classified Document Division, Sandia Base, Albuquerque, N. Mex. ATTN: Martin Lucero
216-217	University of California Radiation Laboratory, PO Box 808, Livermore, Calif. ATTN: Margaret Edlund
218	Weapon Data Section, Technical Information Service, Oak Ridge, Tenn.
219-280	Technical Information Service, Oak Ridge, Tenn. (Surplus)

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