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NEVADA TEST SITE

February – May 1955

Project 8.4a

THERMAL MEASUREMENTS FROM AIRCRAFT IN FLIGHT

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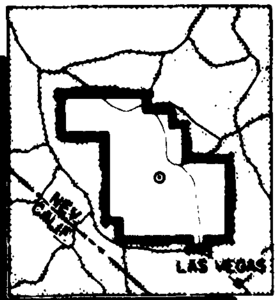

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WT-1145

OPERATION TEAPOT—PROJECT 8.4a

Report to the Test Director

THERMAL MEASUREMENTS FROM AIRCRAFT IN FLIGHT

R.P. Day
A. Guthrie

Naval Radiological Defense Laboratory
San Francisco, California

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SUMMARY OF SHOT DATA, OPERATION TEAPOT

Shot	Code Name	Date	Time*	Area	Type	Latitude and Longitude of Zero Point
1	Wasp	18 February	1200	T-7-4†	762-ft Air	37° 05' 11.6856" 116° 01' 18.7366"
2	Moth	22 February	0545	T-3	300-ft Tower	37° 02' 53.2554" 116° 01' 15.6967"
3	Tesla	1 March	0530	T-9b	300-ft Tower	37° 07' 31.5737" 116° 02' 51.0077"
4	Turk	7 March	0520	T-2	500-ft Tower	37° 08' 18.4044" 116° 07' 03.1579"
5	Hornet	12 March	0520	T-3a	300-ft Tower	37° 02' 26.4043" 116° 01' 31.2074"
6	Bee	22 March	0505	T-7-1a	500-ft Tower	37° 05' 41.2880" 116° 01' 26.5474"
7	ESS	23 March	1230	T-10a	67-ft Underground	37° 10' 06.1283" 116° 02' 37.7010"
8	Apple	29 March	0455	T-4	500-ft Tower	37° 05' 43.9200" 116° 06' 09.9040"
9	Wasp'	29 March	1000	T-7-4‡	740-ft Air	37° 05' 11.6856" 116° 01' 18.7366"
10	HA	6 April	1000	T-5§	36,620-ft MSL Air	37° 01' 43.2642" 116° 03' 28.2824"
11	Post	9 April	0430	T-9c	300-ft Tower	37° 07' 10.6965" 116° 02' 03.0060"
12	MET	15 April	1115	FF	400-ft Tower	36° 47' 52.6887" 116° 55' 44.1006"
13	Apple 2	5 May	0510	T-1	500-ft Tower	36° 03' 11.1096" 116° 06' 09.4037"
14	Zucchini	15 May	0500	T-7-1a	500-ft Tower	37° 05' 41.2880" 116° 01' 26.5474"

* Approximate local time, PST prior to 24 April, PDT after 24 April.
† Actual zero point 36 feet north, 426 feet west of T-7-4.
‡ Actual zero point 94 feet north, 62 feet west of T-7-4.
§ Actual zero point 36 feet south, 397 feet west of T-5.

ABSTRACT

The purpose of this phase of Project 8.4 was the measurement of thermal radiation received at aircraft locations in the vicinity of nuclear detonations at Operation Teapot. Specifically, certain physical characteristics of the thermal radiation received at the delivery aircraft on the high-altitude detonation were recorded. In addition, calorimeters and radiometers for the measurement of radiant energy and irradiance were supplied to Projects 5.1, 5.2, and 8.1 for installation in test aircraft and drones of these projects. Calibrations and installation assistance were also provided. This report deals primarily with the measurements made from the high-altitude detonation delivery aircraft.

The B-36 delivery aircraft for the high-altitude event was instrumented for measuring the thermal radiant energy, the peak irradiance of and the time to second maximum, and the broad-band spectral distribution of the thermal pulse. The instrumentation used included 10-junction Minneapolis-Honeywell thermopiles, a special 20-junction calorimeter, a photocell, and a very-thin, blackened-silver-foil instrument. Gun-sight-aiming-point (GSAP) cameras with wide-angle lenses were used in conjunction with these instruments.

On the basis of the results obtained, the Minneapolis-Honeywell thermopiles will satisfactorily measure thermal radiant energies of the order of 0.01 cal/cm^2, and the 20-junction calorimeter and thin-foil instrument can be used for energies of the order of 0.1 cal/cm^2.

At shot time the aircraft was located 21,500 ± 300 ft slant range from the point of detonation at an altitude of 46,775 ft MSL. Its ground speed was 294 mph. All equipment performed satisfactorily. The radiant energy received on the aircraft was approximately 0.18 cal/cm^2, which leads to a thermal yield of 1.0 KT and a thermal efficiency of 31 percent. The radiant energy is subject to possible correction due to the fact that no images were obtained on the GSAP films, which could be attributed to aircraft orientation at shot time. The limits of error due to this factor are discussed. The time to second maximum was about 45 msec.

Scaling on the basis of the relationship $t_{max} = 0.032 W^{\frac{1}{2}}$, where t_{max} is the time to second maximum, in seconds, and W is the yield, in KT, gives a yield value of 2.0 KT as compared to 3.2 ± 0.2 KT, which is the suggested yield. Comparison with the ground measurements made on the correlation shot, Wasp', indicates that, as the altitude increases, the thermal radiation is emitted in a shorter time, the peak of the second thermal pulse occurs at earlier times and the apparent color temperature increases. The thermal efficiency, as determined by the aircraft measurements, appears to be no greater than that of Wasp' and is likely smaller.

FOREWORD

This report presents the final results of one of the 56 projects comprising the Military Effects Program of Operation Teapot, which included 14 test detonations at the Nevada Test Site in 1955.

For overall Teapot military-effects information, the reader is referred to "Summary Report of the Technical Director, Military Effects Program," WT-1153, which includes the following: (1) a description of each detonation including yield, zero-point environment, type of device, ambient atmospheric conditions, etc.; (2) a discussion of project results; (3) a summary of the objectives and results of each project; and (4) a listing of project reports for the Military Effects Program.

PREFACE

This report covers the participation of the Naval Radiological Defense Laboratory (NRDL) in connection with thermal radiation measurements made from aircraft at Operation Teapot. It represents only a small portion of the total effort expended by the NRDL in making thermal radiation measurements at this operation. The other measurements are discussed in the reports covering Projects 8.4b, through 8.4f. Data obtained with thermal instruments supplied by NRDL to Projects 5.1, 5.2, and 8.1 are covered in the reports for those projects.

The authors wish to acknowledge the cooperation and assistance of the 4925th (Atomic) Group, and in particular, R. W. Knox, as well as the operational crew for the B-36 aircraft. Thanks are due the personnel of the Thermal Radiation Branch, NRDL, for assistance in the design, calibration, and installation of the instrumentation and in the reduction of the data. In particular, R. W. Hillendahl, Frank I. Laughridge, and R. L. Hopton made substantial contributions in connection with the design of the more sensitive instruments used on the B-36 aircraft.

The successful installation and operation of the thermal instruments used on aircraft in connection with Projects 5.1, 5.2, and 8.1 were due in large part to the cooperation and technical assistance of the following groups: Wright Air Development Center personnel and the contractors; Radiation, Inc., and Cook Research Laboratories for Projects 5.1 and 5.2, respectively, and personnel from both the Naval Air Experimental Station at Philadelphia, Pa., and from the Naval Air Special Weapons Facility in connection with Project 8.1.

CONTENTS

TABLES

Chapter 1

INTRODUCTION

1.1 OBJECTIVES

The principal objective of this phase of Project 8.4 was to measure, from a B-36 type aircraft, the pertinent physical characteristics of the thermal radiation associated with a low-yield, high-altitude nuclear detonation. The required measurements comprised the radiant energy received, the peak irradiance, the time to second maximum, and the broad-band spectral distribution of the total radiant energy. Such information should be useful for predicting some of the characteristics of nuclear warheads for anti-aircraft purposes.

The secondary objective was to provide an instrumentation service to other projects, i.e., Projects 5.1, 5.2, and 8.1. This involved supplying calorimeters and radiometers for test aircraft and drones to study radiant energy and irradiance received by aircraft positioned in the vicinity of nuclear detonations.

1.2 BACKGROUND AND THEORY

1.2.1 NRDL Participation in Aircraft Thermal Measurements. The Naval Radiological Defense Laboratory (NRDL) has made a number of measurements from aircraft of the radiant energy, the peak irradiance, the time to second maximum, and the broad-band spectral distribution of the thermal radiation from nuclear detonations during Operations Tumbler-Snapper (Reference 1), Upshot-Knothole (Reference 2), Ivy (Reference 3) and Castle (Reference 4). Consequently, there is some information available regarding these characteristics of the thermal radiation of nuclear weapons from about 1 KT to several megatons. In some cases these measurements were made to determine the operational criteria of aircraft and in other cases to derive more basic data which would allow extrapolation to situations other than those prevailing at the time of the measurements.

The high-altitude event provided a unique opportunity to determine the variation of the thermal characteristics of a nuclear detonation with altitude. Instrumentation of the drop aircraft was undertaken on this event because it provided an opportunity to make measurements at a higher energy range than was available on the ground and provided an opportunity for comparison with similar measurements made on the surface near ground zero. These measurements were of additional interest, since with both the source and the receiver at high altitude, the atmospheric attenuation is different than at lower elevations and is influenced very little by the presence of the reflecting desert floor.

Arrangements for making the measurements from the B-36 type drop aircraft were made at Albuquerque with the 4925th (Atomic) Group of the Air Force Special Weapons Center (AFSWC) organization (Reference 5).

1.2.2 Service to Other Agencies. While making preparations for the above types of measurements during Operation Teapot, a number of requirements were placed on this project in connection with aircraft thermal-radiation measurements for a number of other projects. Project 8.1, being carried out by personnel from the Naval Air Experimental Station at Philadelphia, requested instruments and technical assistance in connection with the operation of their Navy AD planes (Reference 6). Wright Air Development Center (WADC) also requested (Reference 7) essentially the same type of assistance in connection with two of their projects, viz., Projects 5.1 and 5.2. The first of these projects involved the instrumenting of four F-80 drone planes, whereas the second project involved two manned F-84F type jet planes. The bulk of the instrumentation on Project 5.1 was performed by the contractor, Radiation Inc., of Orlando, Fla. On Project 5.2 the instrumentation was carried out by Cook Research Laboratories of Skokie, Ill.

Chapter 2
EXPERIMENT DESIGN

In the case of the B-36 drop aircraft, it was necessary to develop more sensitive instruments than the standard MK-6F instruments (Reference 2) since the delivery aircraft was to be positioned at 50,000 ft altitude at the time of drop and the mean slant range at time of detonation was estimated to be about 20,000 ft. This geometry, together with an anticipated yield of about 3KT on Shot 10 (HA), gave an estimated thermal energy of less than 0.30 cal/cm^2. The instruments were designed to provide information leading to a value of the lethal thermal volume. Some details regarding these sensitive instruments are given in Section 2.1. Standard instrument holders and MK-6F calorimeters and radiometers were used in conjunction with oscillographic recorders and supplied to Projects 5.1, 5.2, and 8.1. The actual type of oscillographic recorder used varied from project to project. In all cases where thermal radiation instruments were used on aircraft, GSAP cameras were mounted adjacent to these instruments. These cameras were to be used to provide information regarding the orientation of the thermal instruments with respect to the line joining aircraft and point of detonation at time of detonation.

All the thermal instruments were calibrated at NRDL prior to the operation by exposure to the Mitchell high-intensity thermal radiation source (Reference 8) using techniques identical to those described elsewhere (Reference 1). Several series of calibration runs were made prior to shipment of the instruments to the Nevada Test Site. The procedure provided for recalibration of the instruments on the same source upon their return to NRDL.

The electrical calibrations were accomplished by introducing standard millivolt signals in series with the final field circuits a few hours before scheduled shot time. Electrical calibrations were checked in the same way after each shot.

Details regarding the thermal instruments used in Projects 8.1, 5.1, and 5.2 will not be given here, but they can be found in the respective reports for these projects. These same reports also include the results obtained during the operation.

2.1 DROP AIRCRAFT THERMAL INSTRUMENTATION

Only the B-36 aircraft designated as the drop aircraft was provided with thermal instruments. It was assumed that, if difficulties developed in connection with this aircraft, it would be possible to transfer the thermal instrumentation to the standby aircraft prior to the shot. As noted above, it was necessary to use special thermal instruments, because of the anticipated low thermal energies involved.

These special instruments had 90° fields-of-view and included the following items:

1. Nine of these sensitive instruments were 10-junction Minneapolis-Honeywell thermopiles (Reference 9). These were mounted in standard MK-6F instrument cases and had a sensitivity of about 480 mv/cal/cm^2. The decay rate for heat loss was about 260 percent per second.

2. One special 20-junction calorimeter was built for these measurements. This consisted of 20 blackened-silver buttons 0.25 in. in diameter and 10 mils thick. Each button had a copper-constantan thermocouple soldered to the back with these thermocouples connected in series to the recorder. The whole assembly was contained in a standard MK-6F instrument case. This particular instrument had a sensitivity of about 40 mv/cal/cm^2 and a decay rate for heat loss of about 35 percent per second.

TABLE 2.1 THERMAL INSTRUMENTATION ON B-36 DROP AIRCRAFT

Instrument Position	Instrument No.	Instrument Type	Filter
1	TF-1	Thin foil	Q
2	MH-1*	10 Junction	Q + ND-1**
3	MH-2	10 Junction	0-52 + ND-1
4	MH-3	10 Junction	3-69 + ND-1
5	MH-6	10 Junction	4-76 + ND-1
6	∅-1	Photocell	Q + ND-2
7	XX-2	20 Junction	Q
8	MH-7	10 Junction	Q + ND-1
9	MH-8	10 Junction	0-52 + ND-1
10	MH-9	10 Junction	3-69 + ND-1
11	MH-10	10 Junction	2-58 + ND-1
12	MH-5	10 Junction	7-56 + ND-1

* MH designates Minneapolis-Honeywell thermopile.

** ND designates neutral density 1.0 Kodak Wratten gelatin filter (lacquered). 0-52, 3-69, 2-58, 4-76 and 7-56 are designations used by Corning Glass Works for their filters. Q refers to a quartz filter.

3. The last special instrument used had a very-thin blackened silver foil less than 1 mil in thickness with a copper-constantan thermocouple soldered to the back of it. This instrument was designed to measure the temperature of the silver receiving disc just prior to the time of detonation. This measurement was made possible by by-passing the brass cold junction in the calorimeter with the constantan lead wire and taking it, instead, to a constantan stud and from there, using special shielded copper-constantan lead wire, to an ice bath. In this manner the voltage recorded on the Heiland oscillograph represents the difference between the temperature of the ice bath and the temperature of the receiving disc. The data obtained can be used to correct the receiving disc for its change in heat capacity as a function of temperature and to correct the thermocouple junction for its change in thermal EMF as a function of the temperature of the junction. This same instru-

ment is also capable of measuring the total radiant energy delivered by the thermal pulse, sc it serves a dual purpose. This unit was also contained in a standard MK-6F case. This instrument had a sensitivity

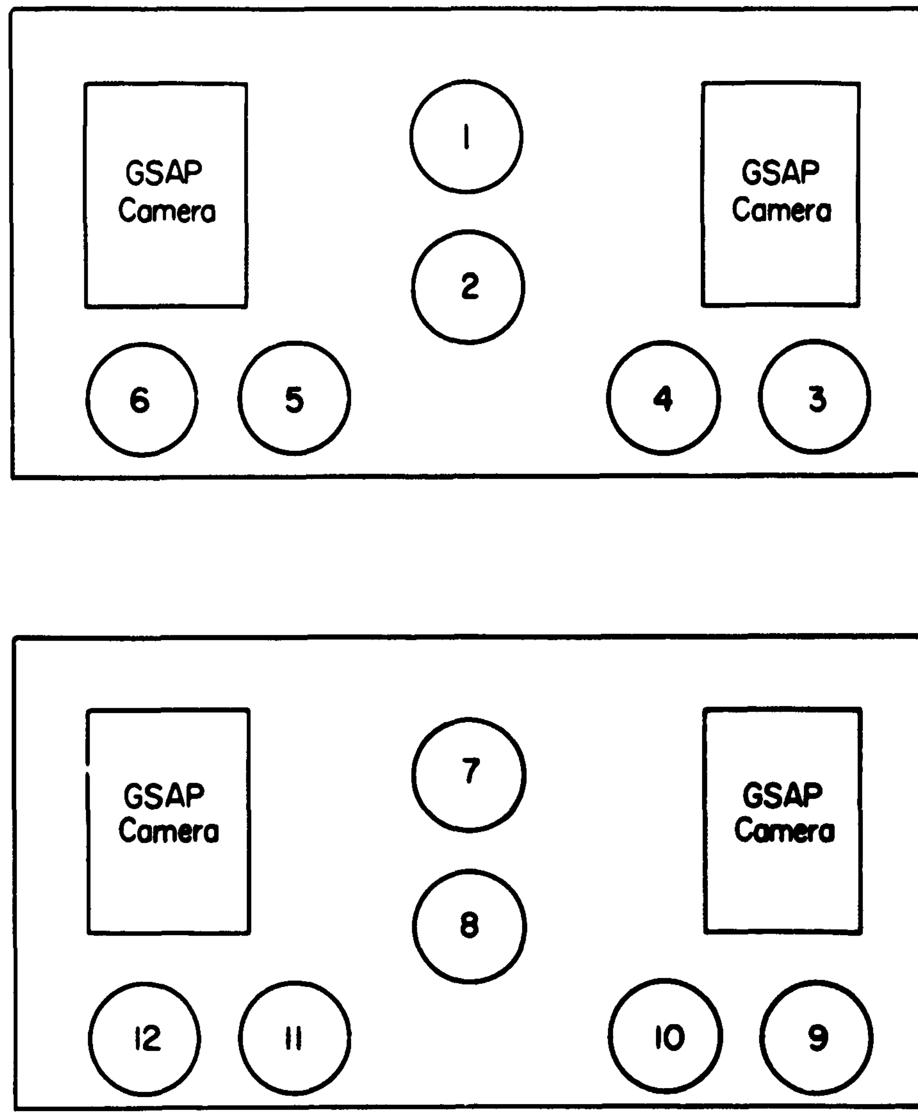

Figure 2.1 Drop aircraft station layout.

of around 27 mv/cal/cm^2 and a decay rate for heat loss of about 90 percent per second. The remaining instrument used was a photocell to give a direct measurement of the time to second maximum.

The instruments were all designed to measure the thermal radiant energy at the aircraft. The output of each instrument, as recorded by the Heiland oscillograph, appears as a trace of a quantity proportional to the thermal energy versus time. Application of the appropriate calibration factors and the making of corrections for the decay rate of heat loss lead directly to values of the thermal radiant energy. Application of a suitable differentiation process to the resulting curves of thermal energy versus time also gave values for the times to second maximum and for the peak irradiances. The instruments differ primarily in sensitivities and decay rates of heat loss. All the instruments described were contained in two standard instrument holders (Reference 2), oriented to look at the fireball at zero time and mounted

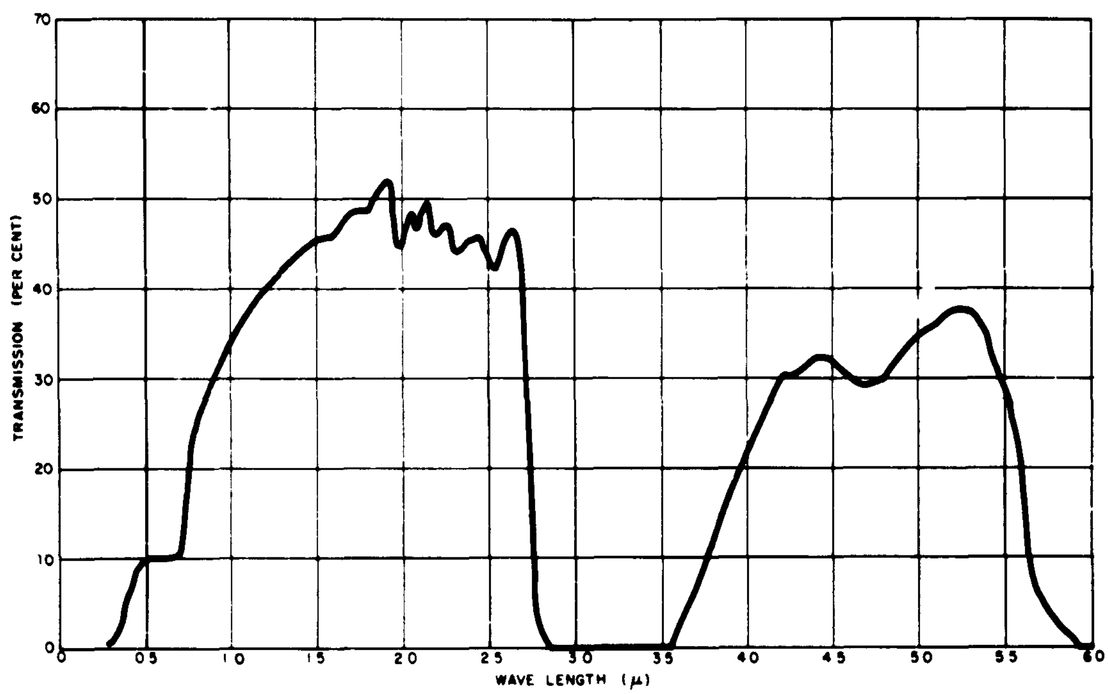

Figure 2.2 Transmission of Kodak Wratten gelatin ND-1 filter (lacquered).

in the tail of the aircraft. Two Heiland Model 500B oscillographic recorders were provided to record the signals.

Figure 2.1 is a schematic layout showing the positions of the various instruments in the holders, while Table 2.1 gives details regarding the individual instruments. Column 1 refers to instrument positions as given in Figure 2.1. The meanings of Columns 2 and 3 are self-evident. Column 4 gives the filter designations.

The type of nuclear device used on Shots 9 and 10 was of higher yield than originally anticipated. This made it necessary to use ND-1 neutral density filters with the Minneapolis-Honeywell thermopiles so that the galvanometer deflections would not go off scale. The type of filter used had to be decided late in the project preparations and final calibrations had to be made back in the Laboratory. The Kodak ND-1 type of neutral density filter was an unfortunate choice because of the way in which its transmission depends on wave-length. This is shown in Figure 2.2. The transmission values, in percent, for the Corning filter types 0-52, 3-69, 2-58, 7-56 and 4-76 are taken as 92, 90, 88, 88 and 80 respectively, while the value for quartz is taken as 92.

Each instrument holder was provided with two GSAP cameras, oriented in the same manner as the thermal instruments. These cameras were provided with 17-mm-focal-length wide-angle lenses by the 4925th (Atomic) Group. NRDL supplied microfile film, and made the necessary provisions for development. All power and recording circuits were installed to the Heiland and camera junction boxes by the 4925th (Atomic) Group.

2.2 PROJECT 8.1 THERMAL INSTRUMENTATION

This project was concerned with separating the direct fireball radiation from the ground-reflected thermal energy and involved the use of three Navy AD type planes. Each plane was provided with a total of 12 thermal instruments, six in each of two modified NRDL instrument holders. Each of these holders contained five MK-6F calorimeters and one MK-6F radiometer, all with 90°-fields-of-view. The instruments and filters were chosen to measure total radiant energy, broad-band spectral distribution, peak irradiance, and time to second maximum. One instrument holder was oriented so that the instruments looked directly at the fireball, while the second instrument holder was or'ented so that the instruments looked directly down at the ground. Recording was done on Century oscillographic recorders. It was intended that only two planes would be used on the events of interest, the third plane being on a standby status.

2.3 PROJECT 5.1 THERMAL INSTRUMENTATION

This project involved the study of destructive loads on aircraft in flight and made use of a total of four F-80 drone planes. All of these planes were provided with thermal instruments, which were standard MK-6F calorimeters and radiometers. Each plane had two pods, one under each wing, used for instrumentation purposes. One pod had two MK-6F 90°-field-of-view calorimeters and one MK-6F 90°-field-of-view radiometer mounted in it. The signals from these instruments were telemetered to a ground station and recorded on a Consolidated oscillographic recorder. The second pod was provided with two MK-6F 90°-field-of-view calorimeters. The signals from these instruments were recorded on a Consolidated oscillographic recorder mounted in the plane. All thermal instruments had quartz filters and were oriented to point at the fireball at zero time.

2.4 PROJECT 5.2 THERMAL INSTRUMENTATION

This project was concerned with studying thermal effects on fighter-type aircraft in flight. Two F-84F jet aircraft were involved.

Each of these aircraft was provided with three thermal instruments, two calorimeters and one radiometer. All of these instruments were standard MK-6F 90°-field-of-view instruments with quartz filters; they were oriented to look at the fireball at zero time. The signals were recorded on a Consolidated oscillographic recorder located in the aircraft.

Chapter 3
RESULTS

At shot time the B-36 delivery aircraft was traveling with a ground speed of 294 mph at 296° from true north and at an altitude of 46,775 ft mean sea level and a slant range with respect to point of detonation of 21,500 ± 300 ft. The calorimeter receiving junction temperature was -35°C. Records were obtained on all instruments, and all GSAP cameras operated. In order to reduce the data to usable form, calibration and correction factors are applied that depend upon the instrument, the method of calibration, and the particular data desired. Because of the low thermal energies anticipated, which set the types of instruments involved, the problem of reducing the data becomes quite involved without using machine computation. This arises from the fact that using sensitive instruments results in a high rate of heat decay. This is particularly true of the Minneapolis-Honeywell instruments. These instruments also displayed a zero drift (cold-junction heating) that will change the shape of the pulse depending on the amount of heat that is conducted to the cold junctions. In this particular case the maximum amount of heating of the cold junctions was 0.43 mv, which represents 0.009 cal/sq cm.

The decay rate of the heat loss of the Minneapolis-Honeywell (MH) thermopiles is not consistent among the various instruments, this heat loss being found to be a function of the temperature rise of the receiver. Normally these thermopiles have such a high rate of heat loss that they will tend to follow the pulse of the source, so it becomes difficult to measure the rate of heat loss from the shot record. A measurement of this heat loss was made in the laboratory using a Bouser climatic-simulator unit at -30°C (similar to the conditions in the field) by exposing the instruments to a square-wave pulse of thermal energy equivalent to that received in the field and then measuring the decay and plotting it as a function of the temperature of the receiver. This information can then be related to the field data and the proper heat-loss corrections applied to the data. A few decay points may be obtained from the shot record, so one may graph the time versus heat loss and only extrapolate the curve over a very short range. The nonlinearity of the thermocouple was neglected, since the receiver only had a temperature rise of less than 10°C and the linearity of the thermocouple is good over such a short range.

A voltage was introduced into the circuit both at room temperature (20°C) and in the Bouser Unit at -30°C to determine if there was a change in the line resistance to the circuit at the lower temperatures. There was no change noted on any of the instruments, so it was concluded that the electrical calibrating voltage introduced into the circuit at both ends of the shot roll was applicable during flight and the recording period for the bomb data.

Although all four of the GSAP cameras operated, the developed film was completely blank. Two of the cameras were operated at 16 and two at 32 frames per second. These speeds were chosen due to the early starting time of the recording circuits. To compensate for the long exposures, Microfile film was chosen because of its slow speed and its long latitude. Microfile film is also capable of receiving up to 5000 roentgens of gamma radiation before serious fogging appears.

Although the GSAP cameras were equipped with wide angle lenses (17.5° half-angle, 17 mm focal length), it is quite possible that the drop aircraft could have been oriented in such a manner, due to side load winds or the trajectory of the weapon, that the point of detonation appears outside the field-of-view of the lens. In this case, it is doubtful that an image would appear due to the slow speed of the film. Of course, the possibility that the cameras were inadvertently operated some time before or after shot time cannot be entirely eliminated. Assuming that the absence of a fireball image on the film is due to the

TABLE 3.1 - CALORIMETER RESULTS - HA

Instru. Posit.*	Use Code	Filter	Calorimeter No.	Total Engy Under Filter (cal/cm²)	Total Engy Incident (cal/cm²)
1	TE	Q	XX-2	0.13	0.14
7	TE	Q	TP-1	0.17	0.18
8	TE	Q + ND-1	MH-1	0.015	0.19
3	TE	Q + ND-1	MH-7	0.016	0.20
4	SP	0-52 + ND-1	MH-8	0.016	—
9	SP	0.52 + ND-1	MH-2	0.015	—
5	SP	3-69 + ND-1	MH-9	0.012	—
10	SP	3-69 + ND-1	MH-3	0.012	—
6	SP	2-58 + ND-1	MH-10	0.011	—
12	SP	7-56 + ND-1	MH-5	0.005	—
11	SP	4-76 + ND-1	MH-6	0.003	--
2	-	Q + ND-2	ϕ-1	—	--

* See Figure 2.1.

orientation of the aircraft then the angle between the line of sight of the camera and the point of detonation must be considered to be greater than 17.5 degrees. It is not possible to make the necessary cosine corrections for the actual angle involved although one can set limits of error. These limits are discussed in Chapter 4 of this report together with the effect on the results obtained.

Still pictures were also taken of the instrumentation and recording system by Lookout Mountain Laboratory personnel. However, these pictures were not entirely satisfactory, so only diagrams can be given to depict instruments and recording stations.

A summary of the thermal energies received at the aircraft for the various instruments and their associated filters is given in Table 3.1. These results represent thermal energies received by the instruments. Column 1 shows the position of each thermal instrument referred to in Figure 2.1. Column 2 gives the code indicating the type of measurement being made by the instrument; Column 3 gives the filter designations; Column 4 gives the instrument designation which is determined by the sensitivity; Column 5 gives the thermal energy received by the receiving element after passing through the filter, and Column 6 gives the thermal energy incident on the filter.

Column 6 is obtained from Column 5 by correcting for the filter loss. The values listed in Columns 5 and 6 have been corrected for the changes in the thermoelectric power of the thermocouple and the heat capacity of the receiver elements due to the low temperature encountered only in the cases of the XX-2 and TF-1 instruments.

Owing to the method of construction of the MH thermopiles, namely laying Chromel-P and constantan thermocouple wires over each other and then flattening them together to form the receiver, it is impractical to determine the heat capacity for the receiver, since there will be varying amounts of the two thermocouple wires in each receiver.

Referring again to Column 2 (Use Code) TE refers to an instrument used to measure total thermal energy and SP refers to an instrument used to measure a broad-band spectral region. In Column 3, the filter designations are those defined in Table 2.1.

From Table 3.1, there appears to be good agreement between the incident thermal energy values obtained with the TF-1, MH-1, and MH-7

TABLE 3.2 DIFFERENTIATED CALORIMETER RESULTS - HA

Instru. Posit.*	Calorimeter No.	Peak Irradiance Under Filter ($cal/cm^2/sec$)	Peak Incident Irradiance ($cal/cm^2/sec$)	Time to Second Max (t_p) (sec)
1	XX-2	1.21	1.29	0.046
7	TF-1	2.31	2.47	0.045
8	MH-1	0.223	2.61	0.043
3	MH-7	0.219	2.74	0.046
4	MH-8	0.197	—	0.049
9	MH-2	0.247	—	0.044
5	MH-9	0.134	—	0.051
10	MH-3	0.156	—	0.045
6	MH-10	0.150	—	0.049
12	MH-5	0.064	—	0.045
11	MH-6	0.052	—	0.046
2	ϕ-1	—	—	0.045

* See Figure 2.1

instruments. However, the latter two instruments used ND-1 neutral density filters for which the transmission varies considerably with wavelength. Consequently, it is necessary to assume some type of spectral distribution for the thermal radiation in order to make the necessary transmission corrections. The method which has been used is discussed in Section 3.2 of this report. Because of uncertainties in this procedure, only the thermal energy value measured by the TF-1 instrument, 0.18 cal per cm^2, is used in subsequent computations. For the same reason, total incident energy values are not quoted for those instruments using both Corning filters and ND-1 filters. The XX-2 instrument behaved in an erratic manner which was due to a poor thermocouple connection.

In Table 3.2, Column 3 gives the peak thermal irradiance values as measured at the receiving buttons of the instruments. Column 4 is obtained by adjusting the numbers in Column 3 for filter losses. Although the peak incident irradiance values for the TF-1, MH-1, and MH-7 instruments are in fair agreement, only the value for the TF-1 instrument, 2.47 cal per cm^2 per sec, is used in subsequent calculations because of uncertainties associated with correcting for the ND-1 filters. For the same reason, peak incident irradiance values are not given for instruments using Corning and ND-1 filters. Again, the erratic behavior of the XX-2 instrument is apparent. The values listed in Columns 3 and 4 include low temperature corrections only in the cases of the XX-2 and TF-1 calorimeters. Column 5 gives the times to second maximum and there is fair agreement between the values obtained by different instruments. The average value of the time to second maximum is 0.045 seconds, using only the quartz filter instruments and the photocell.

There are a number of correction factors which have not been applied to these data. The motion of the aircraft while thermal energy is being received must be considered. However, owing to the low yield of the nuclear device involved, as well as the relatively low speed of the aircraft, the correction is negligible. The thermal energy values quoted above assume negligible atmospheric attenuation. For the altitude and slant range involved, this is believed to be a valid assumption. A final factor to be considered is the orientation of the instruments with respect to the point of detonation. How large a cosine correction must be introduced into the results due to this factor is indeterminate owing to the negative results for the GSAP film. However, the limits of error due to this factor are discussed in Chapter 4.

The photocell (instrument Ø-1) gave a time to second maximum of about 45 msec. This is to be compared with a value of 43.7 msec obtained with the bolometer equipment at the ground station (Reference 10). The MH thermopiles gave varying results with regard to times to second maximum, which probably is due to the fact that these instruments were originally designed as null-type instruments and have a time constant of the order of 2 seconds, according to the manufacturer. Their transient time constant has not been measured; but it is felt, on the basis of the technique of construction of the thermopiles, that after the proper corrections have been applied to the data, this type of instrument should give results consistent with the MK-6 field instrument. For this low-yield weapon, the response of the recording galvanometer is being approached; since the cold junction is being heated by conduction down the thermocouple wires, one would expect the galvanometer response to lag the pulse and the shape of the output to change as the cold junction is heated. The most serious of these two variations would be the response of the galvanometer, since the diameter and length of the thermocouple wire is such that the cold junction is not receiving heat until after the time to second maximum in this particular case.

Figure 3.1 shows a plot of total incident thermal energy versus time for the TF-1 calorimeter. No attempt has been made to include any of the instruments using ND-1 filters because of the difficulties in correcting for transmission. It will be seen from Figure 3.1 that 95 percent of the total incident thermal energy is received in 0.22 seconds. Figure 3.2 shows a plot of thermal irradiance versus time which was obtained by differentiating the curve of Figure 3.1. Again, curves have not been included for the instruments using ND-1 filters

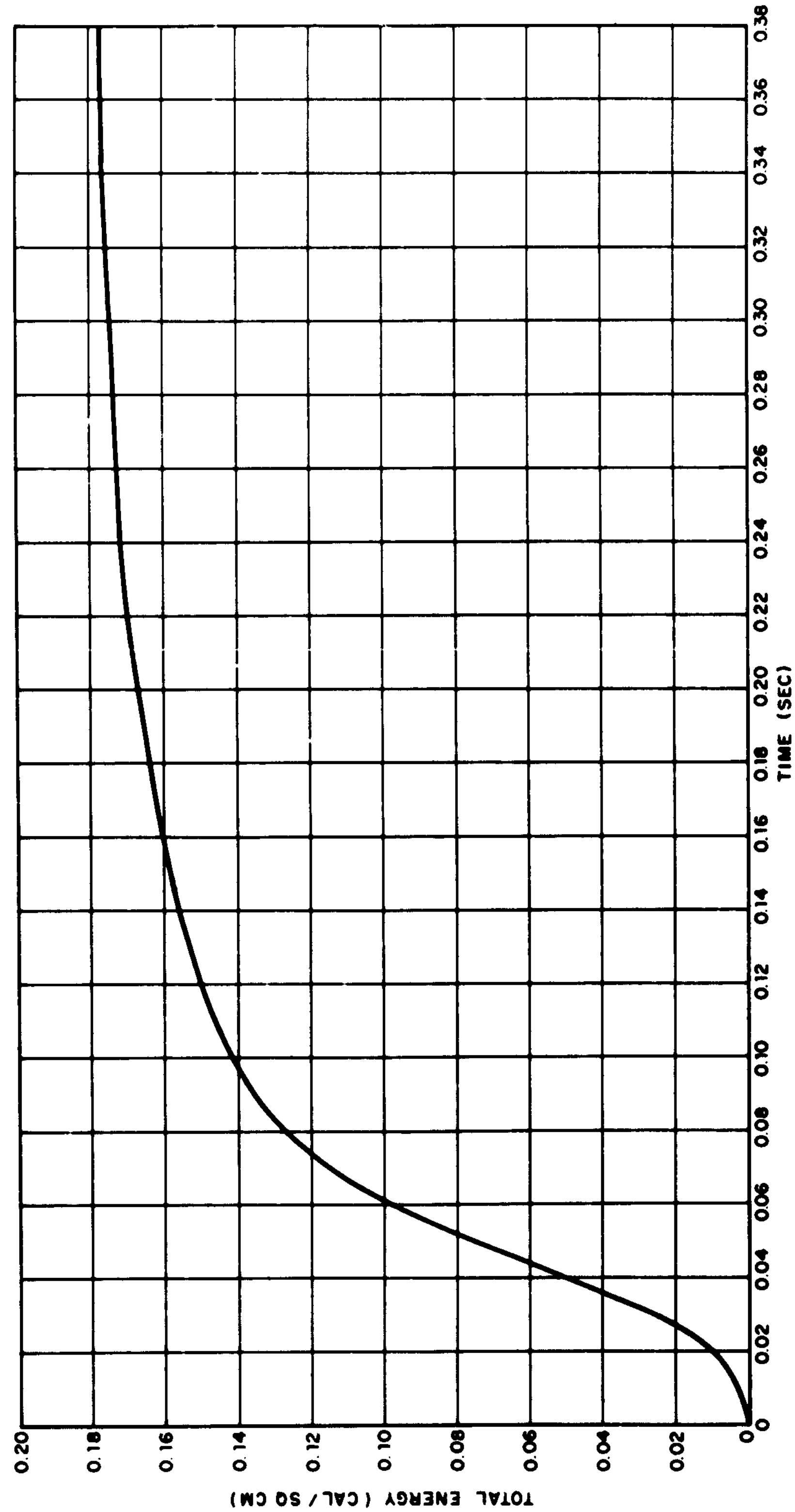

Figure 3.1 Total incident thermal energy versus time (TF-1 calorimeter).

because of the difficulties in correcting for transmission. From Figure 3.2 it will be seen that the peak irradiance is 2.47 cal per cm^2 per sec and the time to second maximum is 0.045 sec. The irradiance drops to 5 percent of peak irradiance in about 0.195 sec.

3.1 SCALING CONSIDERATIONS

A number of weapon-yield scaling considerations have been developed as a result of previous operations (Reference 11). Unfortunately, the data on relatively low yield devices, say less than 5 KT, are extremely meagre and data on high-altitude shots are essentially non-existent.

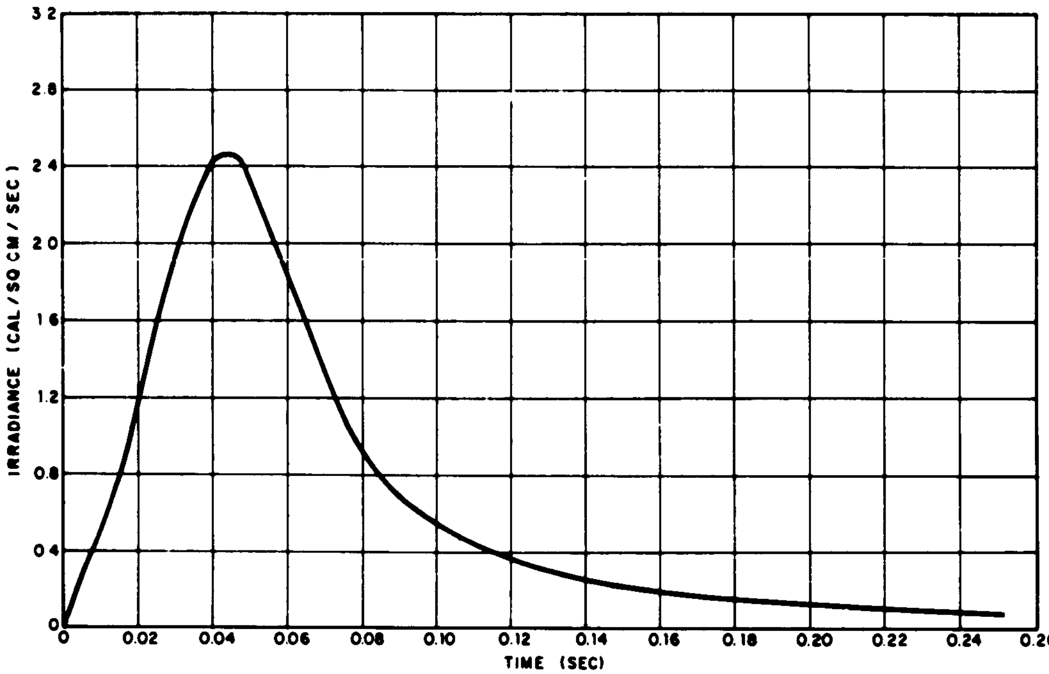

Figure 3.2 Thermal irradiance versus time (TF-1 calorimeter).

Consequently, the scaling laws available are based primarily on measurements made at lower altitudes and are primarily applicable to devices of yield greater than about 10 KT. Factors such as scattered radiation, atmospheric attenuation, cloud obscuration, and ground-reflected energy have less effect on the time to second maximum than on some of the other scaling relationships. Consequently, the only scaling relationship applied here is that relating weapon yield and time to second maximum, viz., $t_{max} = 0.032 W^{\frac{1}{2}}$, where t_{max} is in seconds and W is in kilotons TNT equivalent. This relationship gives a value for W of 2.0 KT as compared to 3.0 ± 0.2 KT, which is the suggested yield.

The thermal yield can be calculated by using the thermal energy values at the zero time position of the aircraft and integrating these over a sphere. In this case the thermal energy values measured by the instruments have been used because of the slow speed of the aircraft and the low yield of the device. This method ignores the effect of a number of variables, such as cloud obscuration and scattered radiation. Using an atmospheric transmission of 95.4 percent (Reference 12) over a slant range of 21,500 ft to correct the energy incident on the aircraft,

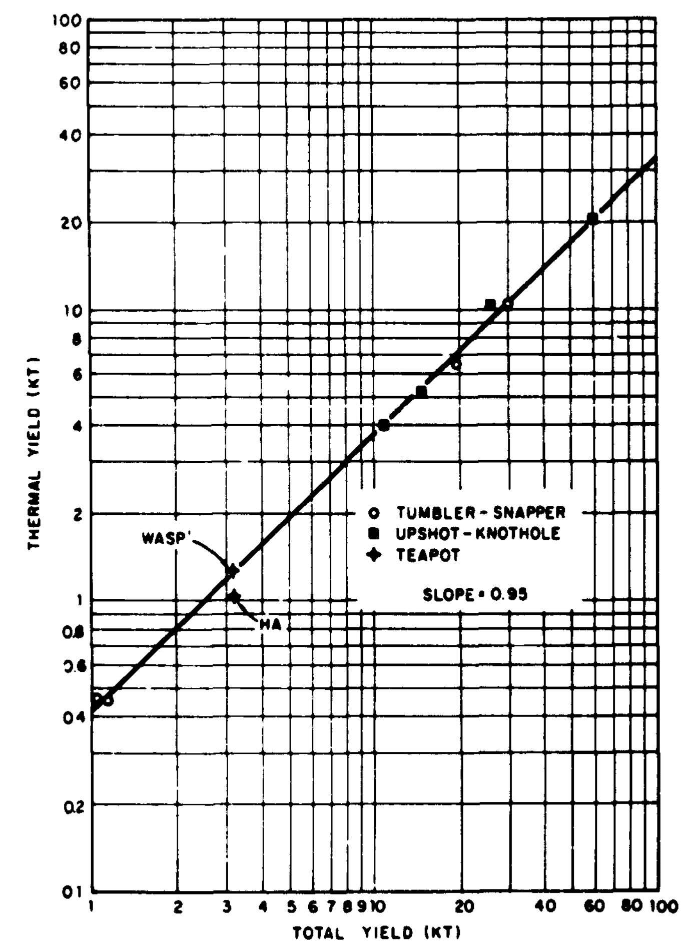

Figure 3.3 Thermal yields versus total yield for several air bursts.

one arrives at a thermal yield of 1.0 KT which corresponds to a thermal efficiency of 31 percent. The principal uncertainty in these values arises from lack of adequate information regarding the aircraft orientation at shot time.

Figure 3.3 is a plot of thermal yield versus total yield for various air drops of Operation Tumbler-Snapper (Reference 1), Upshot-Knothole (Reference 2), and Teapot. Shot 10 (the gun shot) of Operation Upshot-Knothole is included in this plot. The best fit appears to be a line of slope 0.95. It will be noted that the high altitude shot, of Operation Teapot, falls well below this line. However, any correction due to aircraft orientation or a lower atmospheric transmission than that assumed will tend to raise this point on the plot. It should be noted that the correlation shot in Operation Teapot, Shot 9 (Wasp'), appears to fall on the line.

Figure 3.4 shows another plot of thermal yield versus total yield which includes tower and surface bursts as well as air bursts and covers a range of total yield from around 1 KT to around 15 MT. It will be noted that the line giving the best fit has a slope of 0.90. In spite

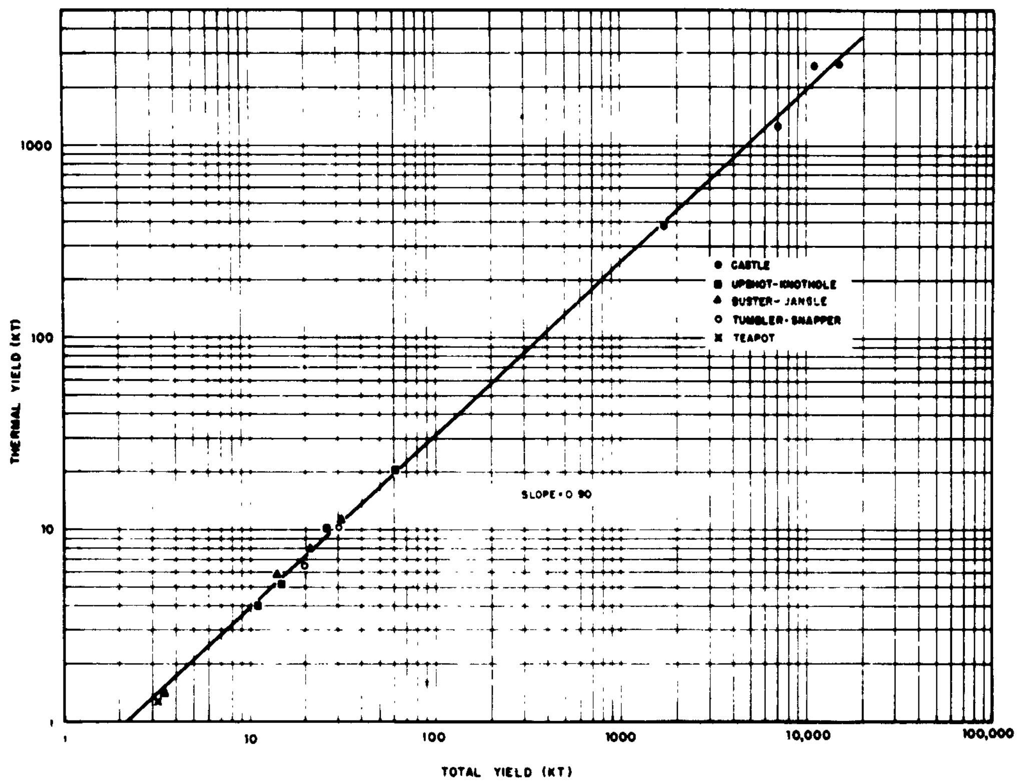

Figure 3.4 Thermal yield versus total yield for a variety of burst conditions and yields.

of the wide range of conditions represented in this plot, the line best fitting the data has a slope which does not differ drastically from the case of air bursts only, at least from the viewpoint of certain operational requirements.

Figure 3.5 shows a plot of slant range versus calories per cm^2 per KT for the same air bursts as in Figure 3.3. Incident thermal energies are used so there is no correction for atmospheric attenuation. The line which fits the data best has a slope of about -0.47. Both the HA and Wasp' shots of Operation Teapot appear to fit this line within

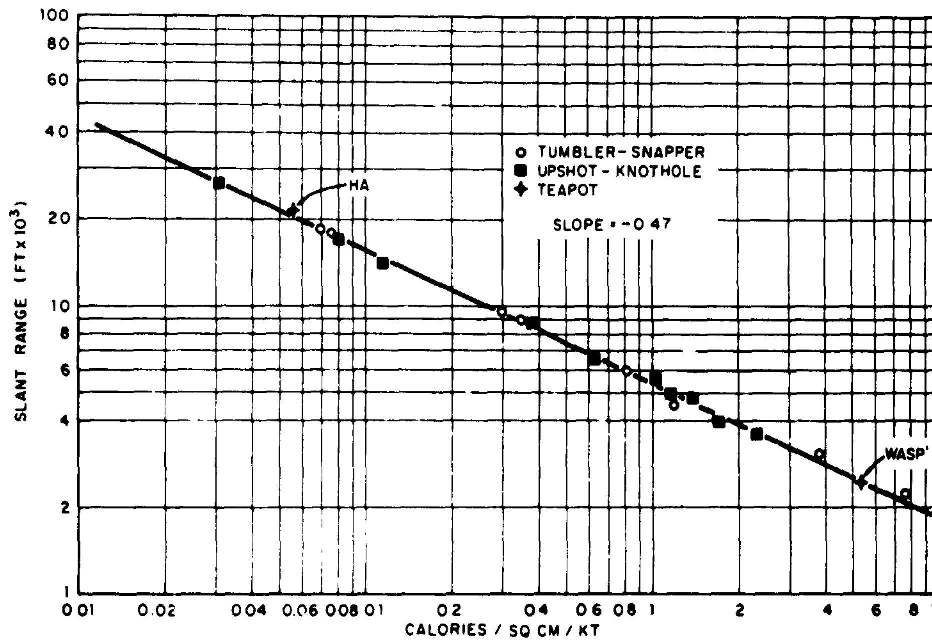

Figure 3.5 Slant range versus thermal energy per KT for several air bursts.

experimental error. Figure 3.6 shows a similar plot which includes the wide range of conditions of detonation and of yield as in the case of Figure 3.4. The line which appears to fit the data best has a slope of -0.45. In this case the difference in the slopes of the lines best fitting the data is negligible whether one includes only air bursts or a wide range of conditions.

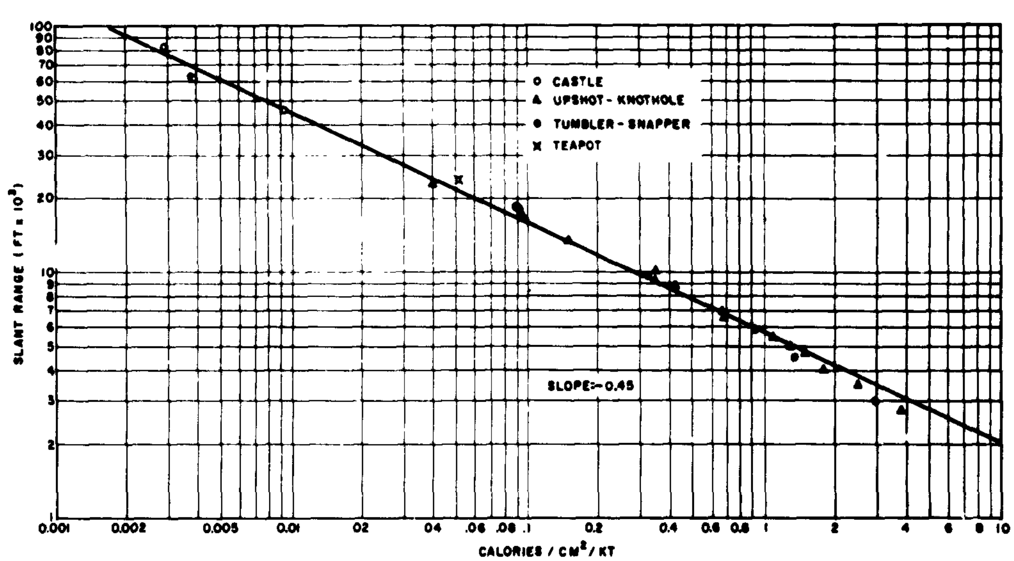

Figure 3.6 Slant range versus thermal energy per KT for a variety of burst conditions and yields.

3.2 SPECTRAL CONSIDERATIONS

The data obtained from the calorimeters utilizing the Corning and ND-1 filters are difficult to analyze because of the transmission characteristics of the ND-1 filters. The full designation of these filters is Kodak Wratten neutral density gelatin filters (lacquered). They were used to reduce the energy impinging on the receiving elements so that the resultant voltage would not drive the galvanometers off scale. The need for a neutral density filter was not apparent until just prior to shot day and this was the only type that could be obtained on such short notice. It was necessary to measure the transmission

TABLE 3.3 THERMAL ENERGIES UNDER FILTERS VERSUS TIME - HA SHOT

Th Energy Under Filter (cal/cm²) TIME (sec)	TF-1 Q	MH-1 Q+ND-1 x10⁻³	MH-7 Q+ND-1 x10⁻³	MH-2 0-52+ND-1 x10⁻³	MH-8 0-52+ND-1 x10⁻³	MH-3 3-69+ND-1 x10⁻³	MH-9 3-69+ND-1 x10⁻³	MH-10 2-58+ND-1 x10⁻³	MH-5 7-56+ND-1 x10⁻³	MH-6 4-76+ND-1 x10⁻³
0	0	0	0	0	0	0	0	0	0	0
0.01	0.004	0.4	0.5	0.4	0.5	0.2	0.2	0.2	0.1	0
0.02	0.012	1.3	1.0	1.4	0.8	0.9	0.6	0.7	0.3	0.2
0.03	0.028	3.1	2.6	3.3	2.1	2.2	1.6	1.7	0.9	0.5
0.04	0.051	5.4	4.4	5.5	3.9	3.8	2.8	3.1	1.5	1.0
0.05	0.074	7.6	6.6	7.9	5.8	5.7	4.2	4.6	2.2	1.5
0.06	0.094	9.5	8.8	10.0	7.8	6.8	5.5	6.1	2.8	2.0
0.07	0.109	10.9	10.6	11.6	9.5	8.0	6.7	7.3	3.2	2.3
0.08	0.118	11.9	11.7	12.4	10.7	8.7	7.7	8.2	3.6	2.5
0.10	0.131	12.9	13.1	13.6	12.1	9.7	8.9	9.4	4.0	2.7
0.12	0.139	13.6	13.9	14.2	13.0	10.4	9.6	10.0	4.4	2.9
0.14	0.145	13.9	14.5	14.6	13.7	10.8	10.2	10.5	4.6	3.0
0.16	0.148	14.2	14.9	14.9	14.2	11.2	10.6	10.8	4.8	3.0
0.18	0.151	14.3	15.2	15.2	14.5	11.4	10.9	11.0	4.9	3.0
0.20	0.155	14.5	15.4	15.3	14.8	11.6	11.4	11.2	5.0	3.0
0.24	0.158	14.5	15.7	15.3	15.2	11.8	11.5	11.4	5.1	3.0
0.28	0.161	14.6	15.7	15.3	15.4	11.8	11.5	11.4	5.1	3.0
0.32	0.165	14.6	15.7	15.3	15.6	11.8	11.5	11.4	5.1	3.0
0.36	0.166	14.6	15.7	15.3	15.6	11.8	1 .5	11.4	5.1	3.0
∞	0.166	14.6	15.7	15.3	15.6	11.8	11.5	11.4	5.1	3.0

characteristics upon return to the laboratory and the results are shown in Figure 2.2. Its short wavelength cut-off tends to limit its use to total energy measurements of high temperature black body radiators.

An attempt has been made to correlate the measurements made with instruments using Corning and ND-1 filters with that made with the TF-1 instrument by determining an apparent color temperature for the fireball. In this report, "color temperature" is defined as the temperature of a Planckian radiator which most nearly matches the radiation from the source at all wavelengths. The technique used (Reference 13) was to assume several black body color temperatures and to multiply the intensities at several wavelengths by the transmission of the various filters in each instrument system at these wavelengths and then plot the resulting values against wavelengh. By integrating each black body curve and comparing the value obtained to the area under the resulting curve for each instrument system, it is possible to make a reasonable estimate of the apparent color temperature of the fireball. This was done and it was found that each of the instruments gave a fireball color temperature of around 12,000°K. The two Minneapolis-Honeywell instruments designated as total energy calorimeters, viz., MH-1 and MH-7, gave values comparing quite favorably with the TF-1 calorimeter total energy measurements, once their filter combinations had been related to a 12,000°K black body radiator.

Table 3.3 shows the data used in applying the technique discussed above. The thermal energies, as measured by the receiving elements of the instruments and corrected only for heat losses, are shown as functions of time for various instruments. The XX-2 calorimeter is not included because of its erratic behavior. The captions at the tops of the columns give the instrument types and filters, which have been previously defined. The data listed in this table, together with the filter transmissions as functions of wavelength and curves for several black body color temperatures were used in arriving at an average color temperature of about 12,000°K or perhaps a little lower.

Chapter 4
DISCUSSION

One possible source of error in some of the results quoted in Chapter 3 stems from the fact that no image was obtained on the GSAP camera films. If this were due to the orientation of the aircraft at shot time, then the thermal radiation must have been incident on the instrument receiving elements at an angle between 17.5° and 45°, measured from the normals to these elements. This follows because of the 35° field-of-view of the cameras and the 90°-field-of-view of the instruments. It is probable that the error in angle is nearer the 17.5° because of the fact that the thermal energy and irradiance values measured from the aircraft agree reasonably well with the ground station values after suitable corrections for distances and atmospheric attenuation. In any case the cosine corrections necessary for angle errors of 17.5° and 45° are 1.05 and 1.41, respectively. Consequently, the thermal energy and irradiance values should be increased by a factor of 1.05 for a directional error of 17.5° and by a factor of 1.41 for a directional error of 45°. There should be a negligible effect on the time to second maximum and the ratio of peak irradiance to total thermal energy.

It is unfortunate that, due to circumstances, it was necessary to use the ND-1 neutral density filters since the transmission of these filters depends strongly on wavelength (see Figure 2.2). The technique used to correlate the results obtained from the instruments using Corning and ND-1 filters with that from the TF-1 calorimeter leads to reasonable results. Certainly, it appears that the apparent color temperature is considerably higher than in the cases of devices detonated at much lower altitudes. This is corroborated by the measurements made from ground stations on shots HA and Wasp' (Reference 13). Of course, the 12,000°K quoted in the results is not intended to be considered as a highly accurate number. However, all indications are that the apparent color temperature is above 10,000°K.

4.1 COMPARISON OF GROUND AND AIR MEASUREMENTS

A number of thermal measurements were made by Project 8.4b on the high-altitude shot from two ground stations, one located at the ground zero position and the other at station 410. The details of these measurements are included in the report for the project (Reference 13). A comparison of some of the thermal radiation characteristics for the ground and B-36 aircraft measurements is given in Table 4.1.

The thermal energy measurements made from the B-36 aircraft may be subject to question due to the failure to obtain images on the GSAP films. Any errors in these measurements would introduce the same percentage errors in the thermal yield and thermal efficiency. Assuming the absence of film images to be due to aircraft orientation, then the thermal energy value could range between 0.19 and 0.25 cal per cm^2. The thermal yield would be in the range 1.07 KT to 1.44 KT and the thermal efficiency in the range 0.33 to 0.45. The upper limits are certainly too high because, for the angular error involved, the receiving buttons would have received negligible energy. Any error in the assumed atmospheric transmission would also affect these quantities. However, one would expect such an error to have a greater effect on the

TABLE 4.1 COMPARISON OF GROUND AND AIR MEASUREMENTS ON HA

Station	Slant Range (ft)	Thermal En. Incid. to Sta (cal/cm^2)	Thermal Yield (KT)	Thermal Eff.	Time to 2nd Max.	Peak Irrad. ÷ total En.
B-36	21,500	0.18	1.02	0.31	0.045	14.3
G2	32,565	0.0606	0.89	0.27	0.043	11.2
410	47,175	0.0284	0.95	0.29	none	none

ground station measurements due to the greater distances involved and uncertainty regarding atmospheric conditions near the earth's surface.

The time to second maximum and the ratio of peak irradiance to total thermal energy should not be affected by aircraft orientation or assumptions regarding atmospheric transmission. It is very unlikely that the aircraft orientation would have changed drastically while thermal energy was being received due to the short time involved. From Table 4.1 it will be seen that there is excellent agreement between ground station and aircraft measurements of the time to second maximum. The difference in the values of the ratio of peak irradiance to total thermal energy can possibly be attributed to the instrumental difficulties associated with measuring small physical quantities. This is particularly true of the ground stations because of the distances involved.

4.2 EFFECT OF BURST ALTITUDE

It is unfortunate that arrangements could not be made for this project to make aircraft measurements on Wasp'. The result is that in order to determine the effect of altitude on thermal radiation characteristics

TABLE 4.2 EFFECT OF ALTITUDE - HA MEASUREMENTS FROM B-36 AIRCRAFT

Shot	Altitude MSL (ft)	Time to 2nd Max. (sec)	Thermal Efficiency	Peak Irradiance ÷ Total Thermal Energy
HA	46,775	0.045	0.31	14.3
Wasp'	4,933	0.073	0.40	6.3

it is necessary to use the ground station measurements made by Project 8.4b on Wasp'. Table 4.2 shows some thermal radiation measurements as made on HA from the B-36 aircraft and on Wasp' from ground stations. It is clear that the second thermal pulse peaks at an earlier time for HA than for Wasp'. Also, the ratio of peak irradiance to total thermal energy is considerably greater for HA that for Wasp'. The difference in the ground station and aircraft measurements on HA does not alter this fact. The thermal efficiency value quoted for HA is as measured on the aircraft with no correction for possible aircraft orientation. It appears likely that any error introduced by this factor will not raise the thermal efficiency of HA above that of Wasp'.

If one attempts to apply the scaling law $t_{max} = 0.032 W^{\frac{1}{2}}$ relating the time to second maximum in seconds to the yield in KT, a high value for Wasp' and a low value for HA are obtained as compared to the suggested yields. This is not too unexpected in view of the fact that this scaling law was derived from measurements on devices of higher yield than Wasp' and HA. As a matter of fact, the application of this scaling law to Shots 1 and 2 of Operation Tumbler-Snapper and Shot 3 of Operation Buster-Jangle (Reference 14), all of which are devices with yields less than 5 KT, gives yields considerably higher than the accepted values. It is apparent that the peak of the second thermal pulse occurs at earlier times as the altitude of detonation increases. If one uses the time in which 95 percent of the thermal energy is received, then the values obtained for HA and Wasp' are about 0.22 sec and 2.4 sec respectively. Also the times at which the irradiance drops to 5 percent of the peak irradiance are about 0.19 sec and 0.5 sec respectively.

Chapter 5
CONCLUSIONS and RECOMMENDATIONS

5.1 CONCLUSIONS

The principal conclusions that can be drawn from the results obtained in this project are: (a) significant differences were obtained in the thermal radiation characteristics of nuclear devices detonated at different altitudes. In particular, the effect of a higher altitude is to shift the emission of thermal radiation to a shorter time scale as compared with the low altitude correlation shot, with the peak of the second thermal pulse occurring at an earlier time. Also, the thermal radiation emitted by the device at the high altitude is emitted at a higher temperature. Due to technical difficulties, it is not possible to draw definite conclusions regarding the effect of altitude on thermal yield. All indications point to the thermal yield of the high altitude device being less than or equal to that of the correlation device.
(b) The special measuring instruments developed for this project operated in a generally satisfactory manner. The most sensitive of these instruments will measure thermal radiant energies of the order of 0.01 cal per cm^2.

5.2 RECOMMENDATIONS

The amount of information available regarding the thermal radiation characteristics of relatively low yield devices, say less than 5 KT, is quite meagre. Further thermal measurements are required for these low yield devices in order to arrive at appropriate scaling relationships for total yield. Additional thermal measurements should be made to obtain more definitive data on the effect of altitude. In this connection it would be highly desirable to use devices of the same type as were used for the HA and Wasp' shots so as to reduce the number of variable elements. It should be possible to detonate such devices at altitudes up to around 80,000 ft and still obtain useful thermal measurements from aircraft.

Although the special instruments used on the HA shot performed in a generally satisfactory manner, more familiarity should be gained with their performance. Attention must be paid to the calibration procedures involved, particularly in the case of the Minneapolis-Honeywell instruments. Efforts should be devoted to simplifying the design and fabrication techniques involved in the thin-foil (TF-1) instrument and the 20-junction calorimeter. If neutral density filters are needed then efforts should be made to locate filters for which the transmission is fairly constant over the wave-length region of interest.

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61 Chief of Naval Operations, D/N, Washington 25, D.C. ATTN: OP-03EG
62 Director of Naval Intelligence, D/N, Washington 25, D.C. ATTN: OP-922V
63 Chief, Bureau of Medicine and Surgery, D/N, Washington 25, D.C. ATTN: Special Weapons Defense Div.
64 Chief, Bureau of Ordnance, D/N, Washington 25, D.C.
65- 66 Chief, Bureau of Ships, D/N, Washington 25, D.C. ATTN: Code 348
67 Chief, Bureau of Yards and Docks, D/N, Washington 25, D.C. ATTN: D-440
68 Chief, Bureau of Supplies and Accounts, D/N, Washington 25, D.C.
69- 70 Chief, Bureau of Aeronautics, D/N, Washington 25, D.C.
71- 72 Chief of Naval Research, Department of the Navy Washington 25, D.C. ATTN: Code 811
73 Commander-in-Chief, U.S. Atlantic Fleet, U.S. Naval Base, Norfolk 11, Va.
74- 77 Commandant, U.S. Marine Corps, Washington 25, D.C. ATTN: Code AO3H
78 President, U.S. Naval War College, Newport, R.I.
79 Superintendent, U.S. Naval Postgraduate School, Monterey, Calif.
80 Director, USMC Development Center, USMC Schools, Quantico, Va.
81- 82 Commanding Officer, U.S. Fleet Training Center, Naval Base, Norfolk 11, Va. ATTN: Special Weapons School
83 Commanding Officer, U.S. Fleet Training Center, Naval Station, San Diego 36, Calif. ATTN: (SPWP School)
84 Commanding Officer, Air Development Squadron 5, VX-5, China Lake, Calif.
85 Commanding Officer, U.S. Naval Damage Control Training Center, Naval Base, Philadelphia, Pa. ATTN: ABC Defense Course
86 Commander, U.S. Naval Ordnance Laboratory, Silver Spring 19, Md. ATTN: R
87 Commander, U.S. Naval Ordnance Test Station, Inyokern, China Lake, Calif.
88 Commanding Officer, U.S. Naval Medical Research Inst., National Naval Medical Center, Bethesda 14, Md.
89- 93 Chief, Bureau of Aeronautics, D/N, Washington 25, D.C. ATTN: AER-AD-41/20
94 Director, U.S. Naval Research Laboratory, Washington 25, D.C. ATTN: Mrs. Katherine H. Cass
95 Director, The Material Laboratory, New York Naval Shipyard, Brooklyn, N. Y.

96 Commanding Officer and Director, U.S. Navy Electronics Laboratory, San Diego 52, Calif.

97-100 Commanding Officer, U.S. Naval Radiological Defense Laboratory, San Francisco, Calif. ATTN: Technical Information Division

101 Commander, U.S. Naval Air Development Center, Johnsville, Pa.

102 Commanding Officer, Clothing Supply Office, Code 1D-0, 3rd Avenue and 29th St., Brooklyn, N.Y.

103 Commander-in-Chief Pacific, Pearl Harbor, TH

104-108 Technical Information Service Extension, Oak Ridge, Tenn. (Surplus)

AIR FORCE ACTIVITIES

109 Asst. for Atomic Energy Headquarters, USAF, Washington 25, D.C. ATTN: DCS/O

110 Director of Operations, Headquarters, USAF, Washington 25, D.C. ATTN: Operations Analysis

111 Director of Plans, Headquarters, USAF, Washington 25, D.C. ATTN: War Plans Div.

112 Director of Research and Development, DCS/D, Headquarters, USAF, Washington 25, D.C. ATTN: Combat Components Div.

113-114 Director of Intelligence, Headquarters, USAF, Washington 25, D.C. ATTN: AFOIN-IB2

115 The Surgeon General, Headquarters, USAF, Washington 25, D.C. ATTN: Bio. Def. Br., Pre. Med. Div.

116 Asst. Chief of Staff, Intelligence, Headquarters, U.S. Air Forces-Europe, APO 633, New York, N.Y. ATTN: Directorate of Air Targets

117 Commander, 497th Reconnaissance Technical Squadron (Augmented), APO 633, New York, N.Y.

118 Commander, Far East Air Forces, APO 925, San Francisco, Calif. ATTN: Special Asst. for Damage Control

119 Commander-in-Chief, Strategic Air Command, Offutt Air Force Base, Omaha, Nebraska. ATTN: OAWS

120 Commander, Tactical Air Command, Langley AFB, Va. ATTN: Documents Security Branch

121 Commander, Air Defense Command, Ent AFB, Colo.

122-123 Research Directorate, Headquarters, Air Force Special Weapons Center, Kirtland Air Force Base, New Mexico, ATTN: Blast Effects Res.

124 Commander, Air Research and Development Command, PO Box 1395, Baltimore, Md. ATTN: RDDN

125 Commander, Air Proving Ground Command, Eglin AFB, Fla. ATTN: Adj./Tech. Report Branch

126-127 Director, Air University Library, Maxwell AFB, Ala.

128-135 Commander, Flying Training Air Force, Waco, Tex. ATTN: Director of Observer Training

136 Commander, Crew Training Air Force, Randolph Field, Tex. ATTN: 2GTS, DCS/O

137-138 Commandant, Air Force School of Aviation Medicine, Randolph AFB, Tex.

139-144 Commander, Wright Air Development Center, Wright-Patterson AFB, Dayton, O. ATTN: WCOSI

145-146 Commander, Air Force Cambridge Research Center, LG Hanscom Field, Bedford, Mass. ATTN: CRQST-2

147-149 Commander, Air Force Special Weapons Center, Kirtland AFB, N. Mex. ATTN: Library

150 Commander, Lowry AFB, Denver, Colo. ATTN: Department of Special Weapons Training

151 Commander, 1009th Special Weapons Squadron, Headquarters, USAF, Washington 25, D.C.

152-153 The RAND Corporation, 1700 Main Street, Santa Monica, Calif. ATTN: Nuclear Energy Division

154 Commander, Second Air Force, Barksdale AFB, Louisiana. ATTN: Operations Analysis Office

155 Commander, Eighth Air Force, Westover AFB, Mass. ATTN: Operations Analysis Office

156 Commander, Fifteenth Air Force, March AFB, Calif. ATTN: Operations Analysis Office

157 Commander, Western Development Div. (ARDC), PO Box 262, Inglewood, Calif. ATTN: WDSIT, Mr. R. G. Weitz

158-162 Technical Information Service Extension, Oak Ridge, Tenn. (Surplus)

OTHER DEPARTMENT OF DEFENSE ACTIVITIES

163 Asst. Secretary of Defense, Research and Engineering, D/D, Washington 25, D.C. ATTN: Tech. Library

164 U.S. Documents Officer, Office of the U.S. National Military Representative, SHAPE, APO 55, New York, N.Y.

165 Director, Weapons Systems Evaluation Group, OSD, Rm 2E1006, Pentagon, Washington 25, D.C.

166 Armed Services Explosives Safety Board, D/D, Building T-7, Gravelly Point, Washington 25, D.C.

167 Commandant, Armed Forces Staff College, Norfolk 11, Va. ATTN: Secretary

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

169 Commander, Field Command, Armed Forces Special Weapons Project, PO Box 5100, Albuquerque, N. Mex. ATTN: Technical Training Group

170-174 Commander, Field Command, Armed Forces Special Weapons Project, P.O. Box 5100, Albuquerque, N. Mex. ATTN: Deputy Chief of Staff, Weapons Effects Test

175-185 Chief, Armed Forces Special Weapons Project, Washington 25, D.C. ATTN: Documents Library Branch

186-190 Technical Information Service Extension, Oak Ridge, Tenn. (Surplus)

ATOMIC ENERGY COMMISSION ACTIVITIES

191-193 U.S. Atomic Energy Commission, Classified Technical Library, 1901 Constitution Ave., Washington 25, D.C. ATTN: Mrs. J. M. O'Leary (For DMA)

194-195 Los Alamos Scientific Laboratory, Report Library, PO Box 1663, Los Alamos, N. Mex. ATTN: Helen Redman

196-200 Sandia Corporation, Classified Document Division, Sandia Base, Albuquerque, N. Mex. ATTN: H. J. Smyth, Jr.

201-203 University of California Radiation Laboratory, PO Box 808, Livermore, Calif. ATTN: Clovis G. Craig

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

205-215 Technical Information Service Extension, Oak Ridge, Tenn. (Surplus)