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Operation TEAPOT

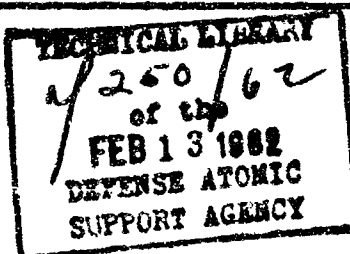
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February - May 1955

Project 8.4e

AIR TEMPERATURE MEASUREMENTS
ON VARIOUS SURFACES

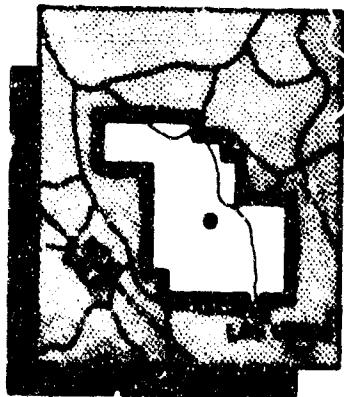
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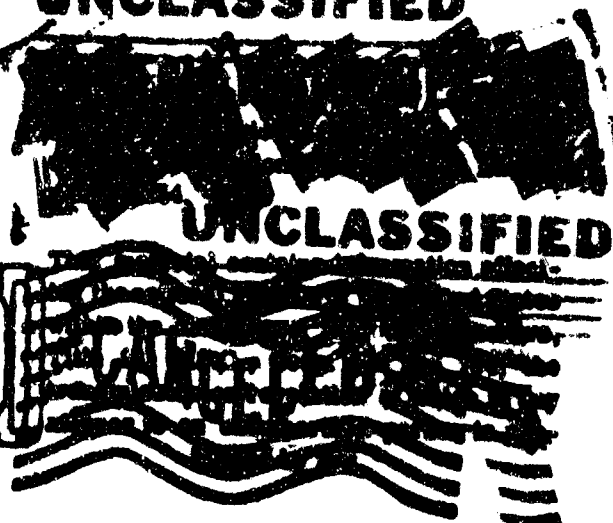
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WT-1149

OPERATION TEAPOT PROJECT 8.4a

Report to the Test Director

AIR TEMPERATURE MEASUREMENTS OVER SEVERAL SURFACES

E.C.I. Inn

U.S. Naval Radiological
Defense Laboratory
San Francisco, California

Issuance Date: September 3, 1957

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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' 11.0000" 136° 01' 10.7200"
2	Moth	22 February	0548	T-3	300-ft Tower	37° 03' 32.234" 136° 01' 10.0001"
3	Teale	1 March	0530	T-9b	300-ft Tower	37° 01' 31.0737" 136° 02' 31.0977"
4	Turk	7 March	0530	T-2	500-ft Tower	37° 00' 35.0544" 136° 01' 00.1073"
5	Hornet	12 March	0620	T-3a	300-ft Tower	37° 02' 35.0548" 136° 01' 31.0974"
6	Bee	22 March	0608	T-7-1a	500-ft Tower	37° 00' 41.0000" 136° 01' 35.0074"
7	ESB	23 March	1230	T-10a	87-ft Underground	37° 10' 00.1200" 133° 02' 37.7010"
8	Apple	23 March	0455	T-4	500-ft Tower	37° 00' 45.0000" 136° 00' 00.3040"
9	Wasp	29 March	1000	T-7-4‡	740-ft Air	37° 06' 11.0000" 136° 01' 12.7000"
10	HA	6 April	1000	T-5§	36,620-ft MBL Air	37° 01' 45.3043" 136° 00' 35.3034"
11	Post	9 April	0430	T-9c	300-ft Tower	37° 01' 10.0000" 136° 02' 00.0000"
12	MET	18 April	1115	F.	400-ft Tower	36° 45' 32.0001" 136° 00' 44.0000"
13	Apple 2	5 May	0810	T-1	500-ft Tower	36° 02' 11.0000" 136° 02' 00.0000"
14	Cucchini	15 May	0500	T-7-1a	500-ft Tower	37° 00' 41.0000" 136° 01' 35.0074"

* Approximate local time, PDT 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

Preshock air-temperature measurements in the vicinity of a nuclear detonation are reported. Although no data were obtained for close-in stations over water, asphalt, and desert, somewhat interesting but unusual results were obtained for stations of simulated terrain such as plots of ivy plants, fir boughs, wood, and concrete. The maximum air temperatures above ambient were found to be in excess of 1,500°C over all plots. Furthermore, an increase in maximum air temperatures with elevation was found over all plots. Results of supporting high speed photographic coverage and gas analysis of air above irradiated plots are reported. An attempt to explain the results is given despite the lack of sufficient data.

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

The help of the following is gratefully acknowledged:
R. W. Hillendahl, F. I. Laughridge, J. R. Nichols, AFC, USN, and A. L. Greig who contributed in a major way in the planning and installation of the test stations; S. B. Martin and C. P. Butler who provided much of the help in assembly and calibration of the Hivats; F. Sauer and S. Scea for many helpful discussions; and W. B. Plum, Project Officer, who was a source of constant encouragement.

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Chapter 1

INTRODUCTION

1.1 OBJECTIVE

This project was to obtain air-temperature data, its temporal history, and spatial distribution over simulated and natural ground coverings in the vicinity of a nuclear detonation prior to shock arrival. These measurements were then to be correlated with sound-velocity and air-blast measurements to provide some insight as to the origin and the mechanism of the formation of a precursor, in view of the suspected importance of the latter in causing anomalous air blasts associated with shock arrival. From a military tactical and operational viewpoint, it is important that a better understanding of the precursor be obtained, in order to provide a realistic basis for predicting the effects of nuclear detonations.

1.2 BACKGROUND AND HISTORY

Under certain conditions in nuclear detonations, a precursor pressure wave is formed which develops prior to shock arrival and considerably modifies the intensity of the air blast. Also, a layer of very highly heated air forms above the ground prior to shock arrival which has been related to the formation of the precursor. The first most extensive air-temperature measurements prior to shock arrival in the vicinity of nuclear detonations were made in Operation Tumbler (Reference 1). These were made in conjunction with air-blast measurements in order to establish any correlation which may exist between these parameters. Fine-wire aspirated thermocouples and resistance thermometers, as well as sonic-velocity methods, were used, all being mounted at various heights on 50-foot towers. The latter was stationed at several distances from ground zero. In general, extremely high temperatures were obtained (in some cases in excess of 1,000°C) for the air just above ground level up to a height of a few feet. Furthermore, the air temperature decreased rapidly with height, with the result that above 10 feet the temperature increase above ambient was relatively small. The observed heated layer of air may well provide one of the necessary conditions for the development of the precursor. Although no definite conclusion could be made about the mechanism of formation of the heated layer of air, it was the opinion that much of the heating was due to rapid convective heat transfer between preshock dust and the turbulent air (Reference 2).

One of the conditions important to the formation of the heated layer of air is the nature and characteristics of the underlying terrain in the vicinity of a nuclear detonation. It is clear that the latter would be important, especially if it played a major role in controlling the heat-transport mechanism. For example, preshock

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sonic velocity measurements (Reference 3) made by the Naval Electronics Laboratory (NEL) over an area covered by fir boughs appeared to give anomalously high results in Operation Upshot-Knothole. Furthermore, in the laboratory at the Naval Radiological Defense Laboratory (NRDL), the irradiation of organic samples with a simulated pulse of thermal radiation resulted in very-fine, high-speed flaming jets arising over the irradiated surface. It is thus possible to attribute much of the observed heating of the air in the field to a process such as that observed in the laboratory for comparably irradiated surfaces.

In view of the possible importance of the nature of terrain in precursor formation, air temperature measurements over a variety of simulated terrains would be highly desirable. Such measurements as these should then be correlated with those of air blast. It would be also helpful to determine the nature and amount of gaseous emanations arising from the irradiated plots of simulated terrain.

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Chapter 2

INSTRUMENTATION

2.1 BASIC CONSIDERATIONS

There have been a number of air and gas-temperature measuring techniques developed, some of which are described in Reference 4. Most of these devices were designed for temperature measurements of gases at constant or relatively slow-changing temperatures. For the measurement of preshock air temperatures in the vicinity of nuclear detonations, certain stringent requirements must be met in selecting and designing air-temperature measuring devices. Thus, it is desirable to use an instrument with a time constant of the order of 50 msec or less, with an adequate sensitivity over a wide range in temperature (ambient to about $2,000^{\circ}\text{C}$), and of simple design yet rugged enough to withstand rough handling in field installations.

The selection of the method of measuring air temperature was, therefore, based on the above considerations as well as on the experience gained with that used in Operation Tumbler; namely, aspirated fine-wire thermocouples (generally called high-velocity thermocouple or HiVat). Although in principle the design chosen was similar to that used previously, a number of modifications were made as will be described below.

2.2 HIVAT AND ASSOCIATED EQUIPMENT

The final design of the HiVat is shown in Figure 2.1, which consisted of the following components. A 1-mil diameter Pt - Pt $\text{Rh}_{0.10}$ thermocouple, T, was used, the junction being placed on the axis of pyrex glass tubes I and O, the air inlet and outlet tubes respectively. Tube I consisted of a piece of 8-mm outside diameter and 1-mm thick-wall pyrex glass tubing fused on to that of a 6-mm outside diameter and 1-mm thick-wall tube, the overall length being about $1\frac{3}{4}$ inches. Tube O was the same as the latter half, being about $\frac{7}{8}$ inches long. Thermocouple T was mounted on a very thin disk of mica, M, $1\frac{1}{4}$ inches in diameter, which had a hole cut out at its center about $\frac{3}{16}$ inch diameter and held in place (with the thermocouple junction centered in the hole) by means of a small amount of cement. The Pt wire of the couple was cemented on one face of the mica disk while the $\text{Pt}_{0.9}\text{Rh}_{0.10}$ wire was cemented on the opposite face. Thus, electrical contact of each wire was made with brass cylinders C_1 and C_2 when placed face-to-face against the mica disk as shown, at the same time the brass cylinders were electrically insulating C_1 from C_2 . Because of the relatively large masses of C_1 and C_2 , they both served as cold, or reference, junctions for the thermocouple. Tubes I and O were inserted in the $\frac{1}{4}$ -inch diameter holes

drilled through the axes of C_1 and C_2 respectively, tube I being held in place with an asbestos padding, A, and O with sealing wax, W. Screws S_1 and S_2 served not only to rigidly hold C_1 and C_2 together but also as binding posts for making connections to the external

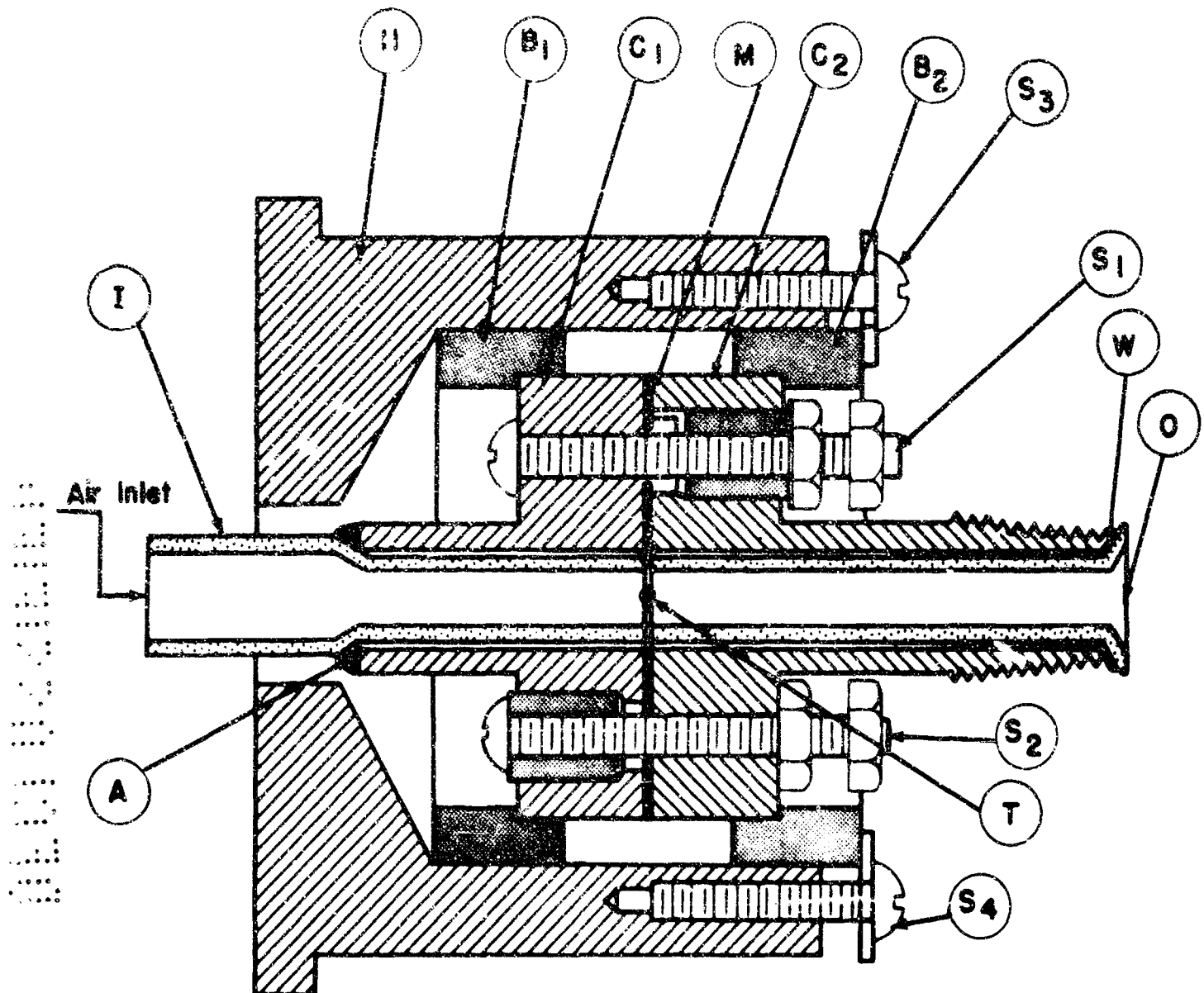


Figure 2.1 Components of HiVat and HiVat Mount.

circuit. Fiber washers were used to insulate S_1 and S_2 from C_1 and C_2 , respectively. Note that C_2 is threaded for making connections with UC fittings leading to the aspirating system.

The HiVat is thus mounted in an aluminum holder H and held in place by the fiber bushings B_1 and B_2 and screws S_3 and S_4 . The diameter of H was such that it could easily fit into a 2-inch pipe. The HiVats were removed from the holder when tested and calibrated in the laboratory.

The 1-mil Pt - Pt_{0.00Rh_{0.10}} thermocouple was fabricated in the laboratory by carefully welding the ends of the two wires using a small oxygen blowpipe burner. The performance of these thermocouples

was compared to that purchased from Baker and Company, Inc. They were found to give an almost identical temperature-versus-millivolt output relationship.

2.3 CALIBRATION OF HIVAT

In order to determine the reproducibility and accuracy of the HiVat, the following experiments were carried out in the laboratory. The results of these experiments therefore provided the basis of any corrections which should be applied to the measured temperatures in the field. In all these laboratory experiments, a Lindberg muffle furnace was used as the source of heated air. In sampling the latter from the oven, it was extremely important that none of the colder ambient air outside the furnace be entrained. The heated air was thus drawn through the HiVat by means of a compressed air aspirator, the sampling being controlled by an on-off solenoid valve. A hollow transite cylinder, inserted and sealed in a small port in the furnace, provided a convenient means for sampling the heated air. Thus, a 1-mil Pt - Pt_{0.90}Rh_{0.10} thermocouple was placed inside the transite cylinder so that its junction was about 1/8 inch from the inlet end,

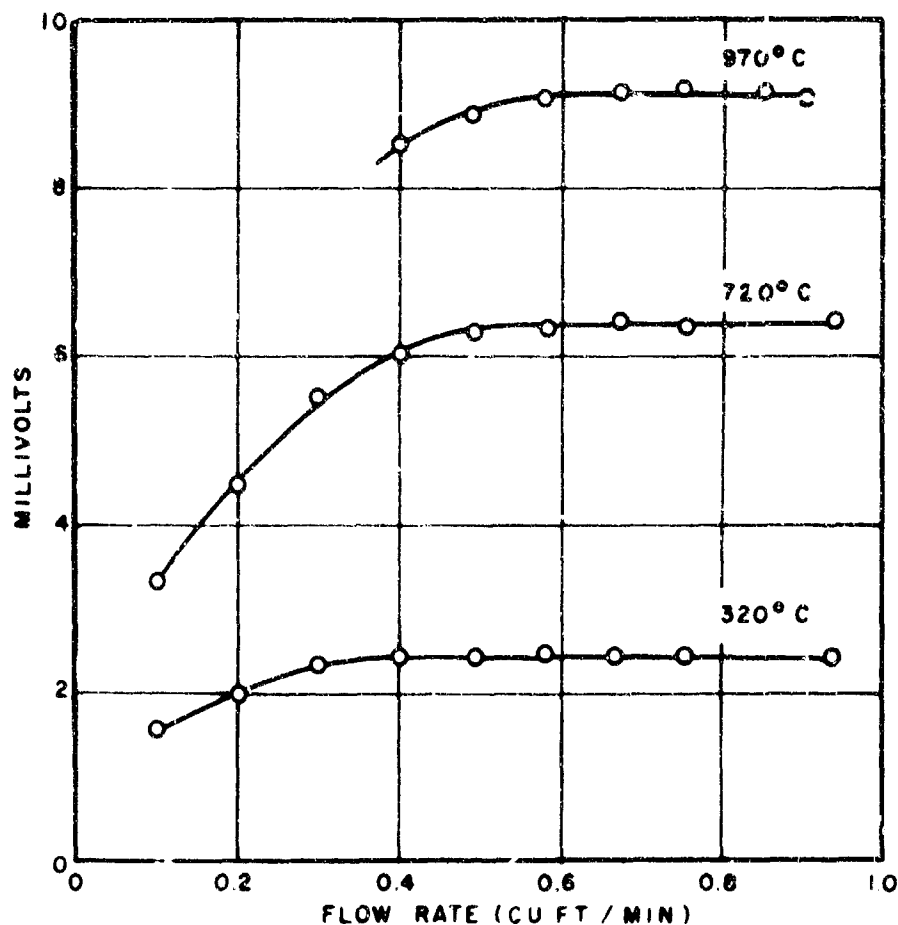


Figure 2.2 Response of HiVat as Function of Flow at Various Air Temperatures.

I, of the HiVat. The thermocouple response was measured by means of a Brown recorder.

Inasmuch as the performance of the HiVat is determined to a large extent by the effective convective heat transfer between the heated air and thermocouple, the response of the HiVat was measured as a function of air velocity or flow rate. The results are shown in Figure 2.2. Evidently, the HiVat response was independent of flow rate above 0.5 to 0.6 ft³/min. Therefore, it was decided to use flow rates between 0.6 and 0.7 ft³/min in all experiments and in the field measurements.

In order to determine the degree of precision required in centering the junction of the thermocouple in the HiVat, the air temperature profile was obtained by measuring the temperature at various points along two perpendicular diameters of the circular cross section of the stream of air in the region of the HiVat thermocouple. Although these measurements could not be made with precision, the results obtained appeared to be reasonably indicative, as shown in Figure 2.3. It is to be noted that the temperature profile was symmetric and fairly flat near the center of the stream.

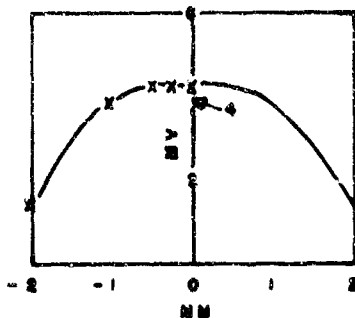


Figure 2.3 Temperature profile along a diameter of air stream passing thermocouple in HiVat. Origin of abscissa represents center of air stream. Temperature profile along a diameter perpendicular to the above gives identical curve, hence profile symmetric about origin. Air temperature at center about 510°C.

Thus, it was assumed that the air temperature in the moving stream was sensibly constant within a region at least 1 mm in diameter about the center of the stream.

Although it was found that the response of the laboratory-fabricated thermocouples was the same as calibrated standard Pt - Pt_{0.00} Rh_{0.10} thermocouples, it was felt that a further check on the calibration would be desirable. This was accomplished by determining the melting point of 1-mil diameter aluminum and gold wires with the HiVats. Thus, one of these wires was mounted in the HiVat parallel to the thermocouple and close enough so that both were within the region of constant temperature in the center of the air flow. Then, by increasing the air temperature, which was measured by the HiVat, the point at which the aluminum or gold wire melted was noted. The results are shown in Table 2.1.

The agreement between the accepted melting points and those measured in this experiment is remarkably good. In fact, the deviation from the accepted melting point for both aluminum and gold can be reasonably accounted for by calculating the heat conduction losses (assuming radiation losses small) along the wires (Reference 5).

To obtain some measure of the response time of the HiVat to a

sudden increase in air temperature from ambient to about 1,000°C, a Heiland Oscillographic Recorder (Type B galvanometers) was used. It was found that a conservative estimate of the response time was something less than 50 msec. However, it was felt that this was probably the response time of the solenoid valve used to control the sudden input of heated air into the HiVat and that the thermocouple response time was appreciably better than this. Unfortunately, there was no way of determining the response time to sudden decreases in air temperature, but it was assumed that this should not be very different from that of sudden increases in temperature.

The thermocouple was located downstream (Figure 2.1) about 1 3/4 inches from the point at which air enters the HiVat. A large number of experiments were carried out to ascertain how much the air was cooled in passing between these two points. The air temperature was measured before entering the HiVat with the thermocouple placed inside of the transite tube (see above) through which the air was sampled. The difference between this temperature and that measured by the HiVat then gave the cooling experienced by the air. To obtain reproducible results it was extremely important to prevent entrainment of the colder ambient air. It was found that for air temperatures up to about 1,000°C, the apparent temperature drop ranged from about 0 to 7

TABLE 2.1 RESULTS OF MELTING POINT MEASUREMENTS USING HIVATE

HiVat No.	Melting Temperature °C	
	Aluminum	Gold
0	716	1080
1	691	1077
2	691	1088
3	696	1074
4	698	1071
Average	698	1071
Accepted Melting Point, °C	660	1063

percent, although by far, most of the results gave 1 to 4 percent cooling. It is believed that much of this apparent cooling was due to inability to completely eliminate entrainment of cold ambient air. An average value of about two percent was applied as the cooling correction for all HiVats in subsequent field use.

In almost all the experiments relating to the calibration of the HiVats, the Brown recorder was used; in all field measurements, the Heiland Oscillographic recorder was used. Inasmuch as the latter is a current-measuring device, any change in resistance of the thermocouple wires necessarily implied a change in response and, therefore, sensitivity. Thus, a series of experiments were carried out to determine the change in sensitivity as a function of temperature using the Heiland recorder. It was found that the measured change in sensitivity compared very well with that calculated for the circuits used. Therefore, all field measurements were corrected for the combined effects of cooling and change in sensitivity. Depending on the circuits used, the latter correction amounted to almost 10 percent for the highest temperatures obtained. It may be conservatively estimated that the accuracy of air-temperature measurements using the HiVat and Heiland Oscillographic recorder was better than 10 percent.

Chapter 3

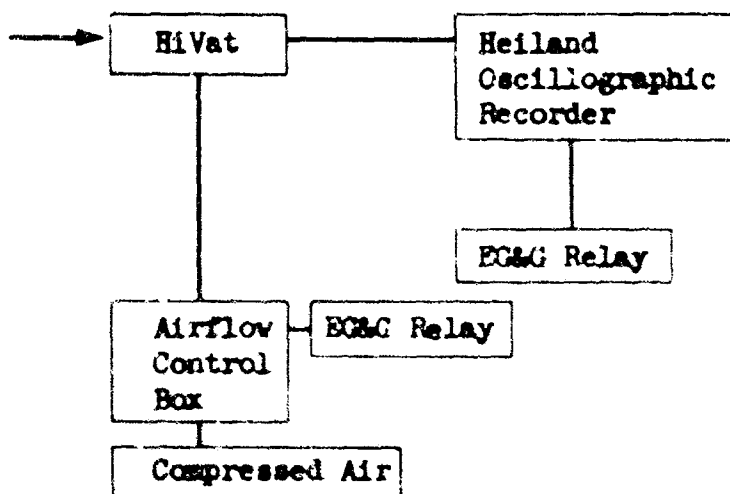
OPERATIONS

3.1 FIELD MEASUREMENTS

Air-temperature measurements were made at two different test sites, Yucca Flat (Shot 4) and Frenchman Flat (Shot 12). The measurements on Shot 4 were made to test the performance of the HiVats and associated instrumentation.

3.2 INSTRUMENTATION

The basic field instrumentation consisted of ten HiVats mounted on a 10 foot tower at elevations of 1/2, 1 1/2, 3, 6, and 10 feet, a system for controlled air flow through the HiVats, and a Heiland Oscillographic recorder. A schematic block diagram of the layout is shown below:



The tower consisted of a 10-foot-long, 8-by-3-inch channel iron. Bolted at right angles to this were 4-by-1 5/8-inch channel iron brackets, with 2-inch iron pipes 10 inches long welded to these for mounting the HiVats. Thus, three HiVats (spaced 12 inches apart) were mounted at 1/2-foot and 1 1/2-foot elevations, two at 3 feet and one each at 6 feet and 10 feet, with all HiVats pointing in a direction at right angles to ground zero. The recessed portion of the channel iron provided adequate protection from thermal radiation for all cables and rubber tubing leading to the HiVats.

The airflow control box consisted of a set of twelve compressed air aspirators, the suction end of ten of them being connected to the HiVat by means of 1/2-inch-diameter rubber tubing, the remaining two serving as spares. Each aspirator was regulated by means of needle valves on the high-pressure side; these were then connected in parallel

in sets of three. Each set was controlled by a solenoid valve, the latter in turn connected by means of 3/8-inch pressure tubing, to a tank of compressed air fitted with a reducing valve. Agastat holding relays controlled the energizing of the solenoid valves, the former being energized in turn by the closing of BO&G relays at minus 5 sec. The needle valves were adjusted to fixed positions so that the flow rate through the HiVats was approximately 0.7 ft³/min. This was determined by using a set of calibrated flowrators. The control box and compressed air tanks were placed in 6-foot diameter and 6-foot deep culverts, one for each tower, each culvert located some 15 feet from the latter and away from ground zero.

The Heiland recorders were placed in shelters about 20 feet deep. The approximate locations of these shelters are shown in Figure 3.1. The operation of each recorder was controlled by Agastat and BO&G relays similar to those used with the air aspiration control system.

3.3 SHOT 4

A 10-foot tower was instrumented at 1,500 feet from and due south of ground zero. The tower was located just at the base and due west of a 20-foot high mound, which enclosed the shelter for the Heiland recorder. Ten HiVats were mounted on the tower as follows: three each at 1/2-foot and 1 1/2-foot elevations from grade; two at 3 feet and one each at 6 feet and 10 feet, respectively, so that the field of view was at right angles to ground zero. Each HiVat was connected to a separate channel of a Heiland Oscillographic recorder.

3.4 SHOT 12

Air-temperature measurements were attempted along three different radial lines from ground zero. Thus, the water line was located on a radial line north, the desert line west, and the asphalt line south of ground zero. The layout is shown in Figure 3.1.

One station was located on the water line 1,000 feet from ground zero. On the asphalt line two stations were instrumented, one at 1,000 feet and one at 2,000 feet from ground zero, both on the same radial line. Similarly, there were two stations on the desert line, one at 1,000 feet and one at 2,000 feet from ground zero, situated in areas characteristic of terrain in Frenchman Flat. In addition to these, a series of five others, about 50 feet apart, were instrumented at 2,000 feet from ground zero on the desert line, each being located on 20 - by 30 - foot plots of simulated ground coverings as follows: concrete, fir boughs, ivy plants, wood, and organic soil. The surfaces of these plots were about 4 inches above the desert grade.

At each station, one 10-foot tower was instrumented as in Shot 4, except that the HiVat thermocouples at the same elevation were now connected in series. Furthermore, at the 1 1/2-foot elevation the three HiVats were mounted with the field of view 180 degrees from the rest of the HiVats but still at right angles from ground zero. Although it was attempted to mount the HiVats on towers at

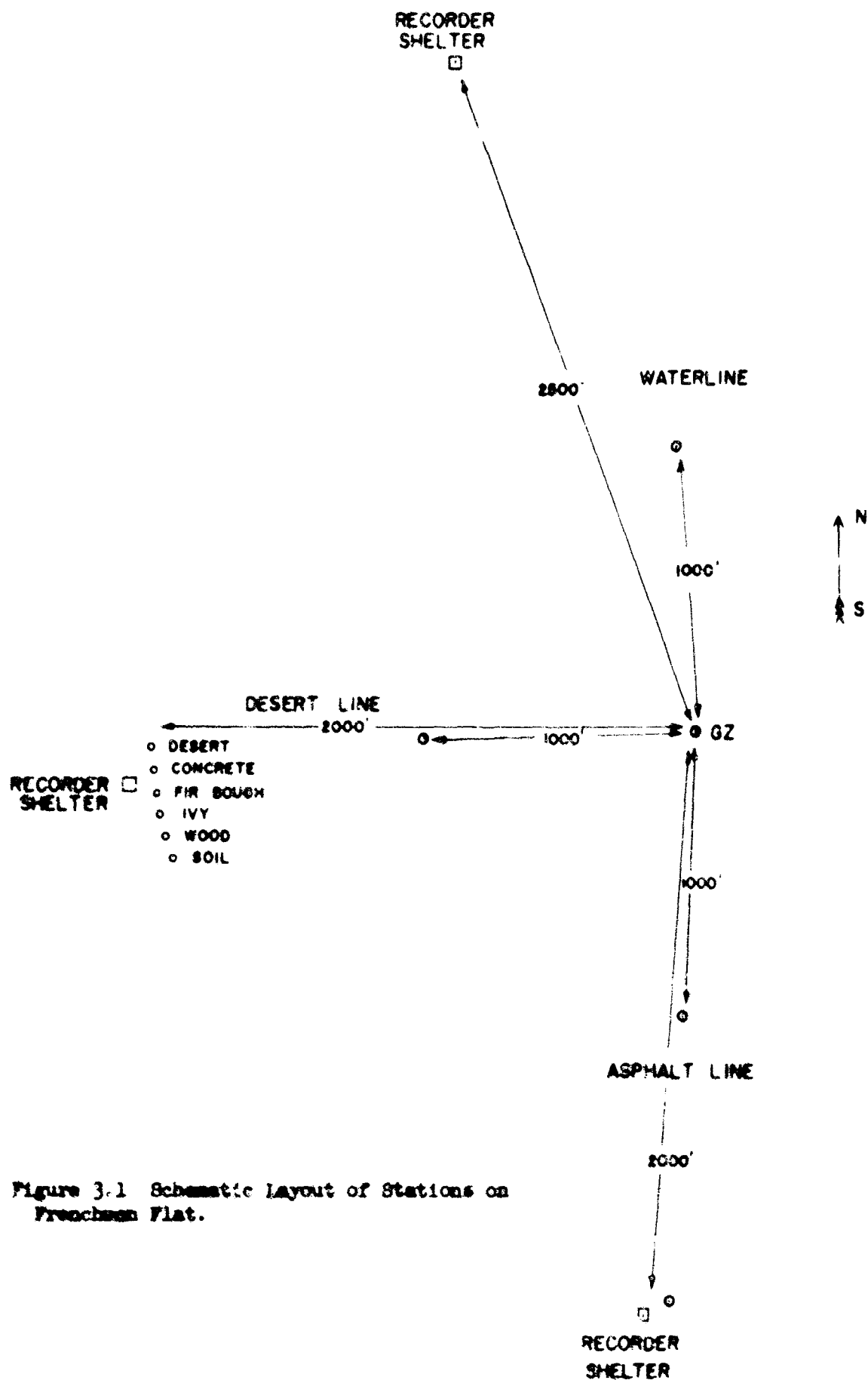


Figure 3.1 Schematic Layout of Stations on Frenchman Flat.

the same elevations over the surfaces at each station, the corresponding elevations differed at different stations. The exact heights will be indicated in the results.

The recording instrument shelters were located 2,500 feet from ground zero on the water line and 2,000 feet on the desert and asphalt lines. Although shielded two-conductor microphone cables were used to connect the thermocouples at the tower to the Heiland recorders in the shelters, the long lengths of the cables, especially for those from the 1,000-foot stations, may have presented some difficulties in electromagnetic pickup.

3.5 SUPPORTING OBSERVATIONS

A 5-mil diameter copper-constantan bare-wire thermocouple was mounted at an elevation of 1 1/2 feet on the 2,000-foot desert tower to obtain the ambient air temperature prior to zero time. The reference junction was placed in an ice-water bath.

In addition to air-temperature measurements, 16-mm (GSAP) cameras were installed at each station to provide photographic records of events prior to shock arrival. At each station, two cameras were placed in 2-foot-diameter, 20-foot-long corrugated-iron cylinders, the axis of each cylinder being at right angles to ground zero and pointing towards the respective towers. A 2-by-2-foot wooden target with contrasting horizontal 1/4-inch-wide lines and 2 inches between centers provided a convenient reference for the photographed region. The target, shielded from direct thermal radiation, was located about 13 feet from the tower and 10 feet from the camera. Thus, on the special plots the targets were located within and about 2 feet from the edges of the plots. The speed of the cameras was set at 64 frames/sec¹, one camera being set at optimum exposure and the other at one-half optimum. The operation of the camera was controlled by Agastat and EOAC relays in the same way as the aspirator system.

In order to determine the nature of any gaseous emanations from the irradiated surfaces prior to shock arrival, gas samplers were installed at the desert, fir-bough, ivy, wood, and asphalt stations. The gas sampler consisted of a 2-foot³ iron cylinder with a heavy-duty solenoid valve for controlling the period of sampling and a 1-inch intake pipe. The inlet end of the latter was located about 2 feet from the tower and at an elevation of about 1 1/2 feet. The energizing of the solenoid valve was controlled by Agastat and EOAC relays, the latter operating at -1 second. The period of sampling, therefore, extended from -1 second to the time of arrival of the shock, a blast switch de-energizing the solenoid valve. The gas samplers were located in the culverts along with the aspirator control box and compressed air bottles.

¹ Although the film speed was set for 64 frames/sec, the actual speed may be different during the detonation.

Chapter 4

RESULTS

4.1 SHOT 4

In Figures 4.1, 4.2, and 4.3 the results of air temperatures above ambient measured at 1/2-1 1/2- and 3-foot elevations, respectively, are plotted while Figure 4.4 shows results for the measurements made at 5 - and 10-foot elevations. It is to be noted that most of the heating of the air occurred between 0.05 and 0.3 seconds for all elevations.

There were no indications on the air-temperature galvanometer traces of shock arrival. However, from Naval Ordnance Laboratory (NOL) blast measurements, the time of shock arrival at 1,500 feet from ground zero was 0.27 seconds. This is indicated in Figures 4.1 through 4.4. Air-temperature data following shock arrival are considered unreliable.

As a whole, the results indicate a definite trend in decreasing air temperature with elevation, although for some as yet inexplicable reason the measurements at the 1 1/2-foot elevation show a lower temperature than the 3- and 6-foot measurements. However, at any instant of time there does not seem to be any well-defined temperature distribution with elevation. Furthermore, at each elevation the individual HiVats apparently indicate different temperature--time history. From curves a and b in Figure 4.1, the air temperature decreased rapidly to ambient prior to shock arrival.

The peak air temperatures measured were extremely high. In fact, at the 1/2 - and 3-foot elevations, peak temperatures approaching the melting point of the thermocouple (melting point of Platinum 1,773°C) were recorded. Although no basic thermal-radiation measurements were made, it is estimated that the total radiant exposure at the station was of the order of 500 cal/cm². It is therefore, not inconceivable that a part of this large amount of thermal energy was transferred to the air by some heat transfer process, resulting in the extremely high temperatures observed.

Another striking feature of the results of these measurements is the almost totally unrelated time-temperature history of the air sampled by the HiVats. For example, the results shown in Figure 4.1 are highly suggestive of the existence of rapidly rising discrete parcels of air. The breadth of these parcels of heated air appear to be less than the distance between HiVats, namely 12 inches. Furthermore, they seem to appear and rise randomly in time and the course they take in ascending vertically is also random. However, the maximum temperature of these air parcels appears to be about the same at the same elevation.

Although these measurements on Shot 4 were primarily made to test the performance of the HiVats, an enlightening interpretation can be made of the results obtained. For example, it would appear from the results that the air was not heated uniformly, at least at the station

where the measurements were made. In fact, the heated air seemed to consist of a random distribution of rapidly rising parcels of heated air in a medium of air at much lower temperatures approaching ambient. Furthermore, the time of appearance of these parcels of heated air was random. The height to which they rose and the course they took presumably depended on any larger scale lateral motion of air and entrainment of the cooler surrounding air. The existence of parcels of heated air would seem to imply the development of hot areas on the surface of the ground, the existence of the latter perhaps being related to the heterogeneity of the surface layers of the Yucca Flat soil. The effect on any large scale disturbance transmitted by the air would thus be a function of the density distribution of the parcels of heated air, i.e., an average temperature defined by the density distribution which in turn may be related to the effect of the parcels of heated air. It should be emphasized that the above interpretation is conjectural and is an attempt to try to formulate a plausible explanation of the results.

4.2 SHOT 12

4.2.1 Water Line Station. No air-temperature data were obtained for this station. The Heiland record showed that of the five air temperature channels, two indicated excessive electromagnetic pickup at shot time, although the galvanometers remained undamaged. However, no galvanometer traces could be found for the other three channels after zero time, indicating that the galvanometers were burnt out due to excessive pickup. Unfortunately, despite the shielding and use of twisted cables, strong electromagnetic pickup resulting presumably from the use of long lengths of cable (about 2,000 feet for each channel) prevented successful measurement of air temperatures at the 1,000-foot station on the water line.

4.2.2 Asphalt Line. At the 1,000-foot station, no air-temperature data were obtained. For some as yet unknown reason it appeared that the Heiland recorder was not in operation just prior to and during shot time.

At the 2,000 - foot station, the Heiland record indicated that there was no galvanometer deflection for all the air-temperature channels. This result may be due to either the air temperature remaining constant throughout or the HiVats being inoperative during shot time. It is almost inconceivable that the air temperature remained sensibly unchanged during and right after zero time. On the other hand, if the aspirators were inoperative so that no air was being drawn through the HiVats during and immediately after shot time, any rise in air temperature would not be recorded. However, there was no way of checking for any failure in the aspirating system. At best, from the records obtained at this station it was inferred that no air temperature data were obtained. On the other hand, photographic results, which will be described below, indicated probable high air temperatures at this station.

4.2.3 Desert Line. At the 1,000-foot station, again no air-

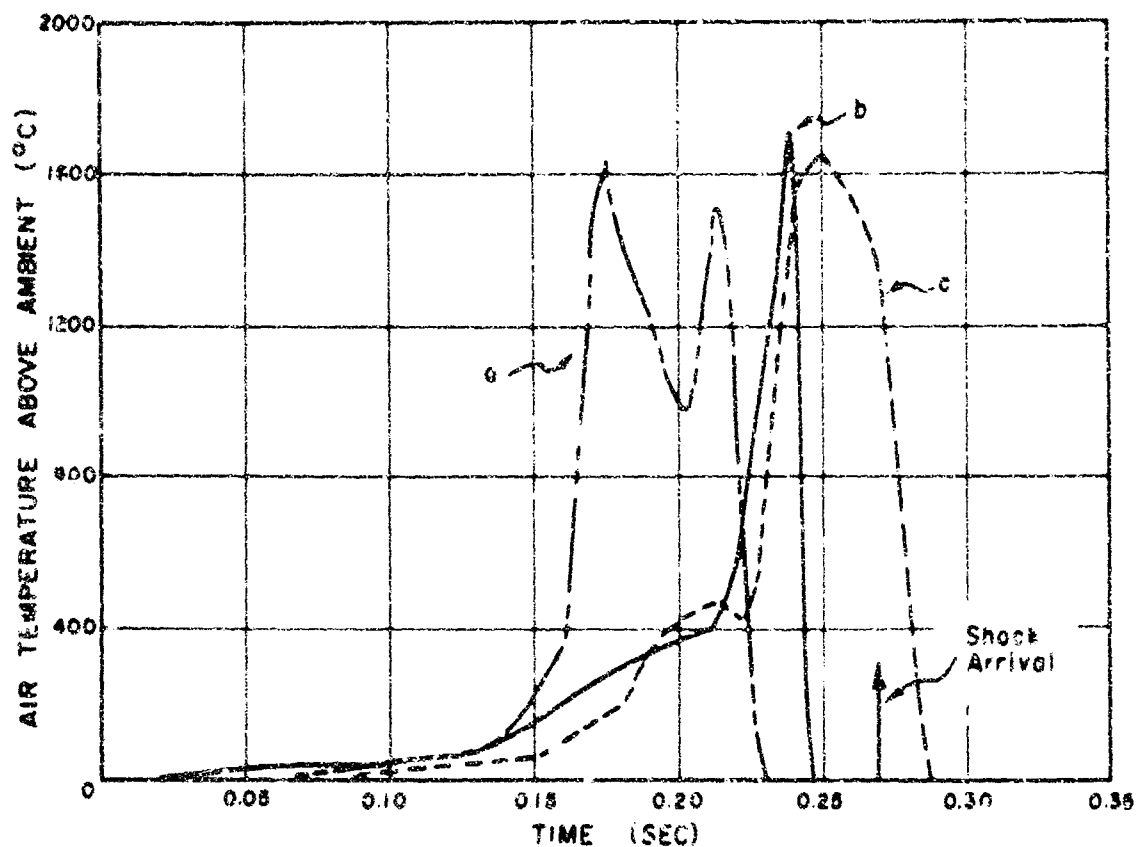


Figure 4.1 Air Temperature Above Ambient at 1/2 ft Elevation Above Grade; a,b,c, represent three different Hivats, Shot 4.

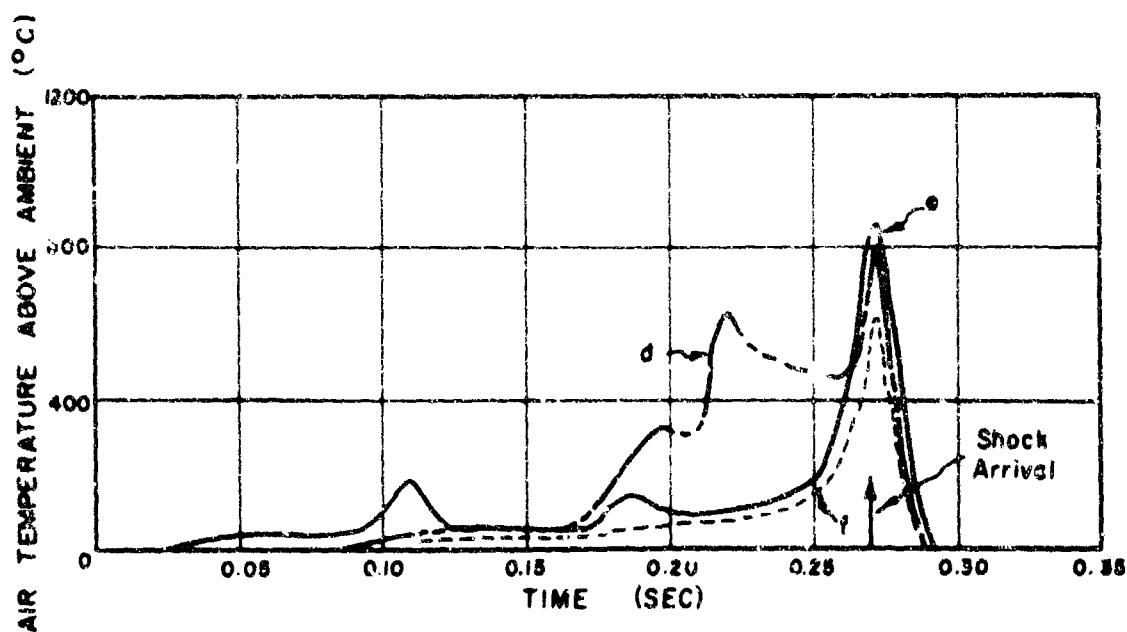


Figure 4.2 Air Temperature Above Ambient at 1 1/2 ft Elevation Above Grade; d,e,f represent three different Hivats, Shot 4.

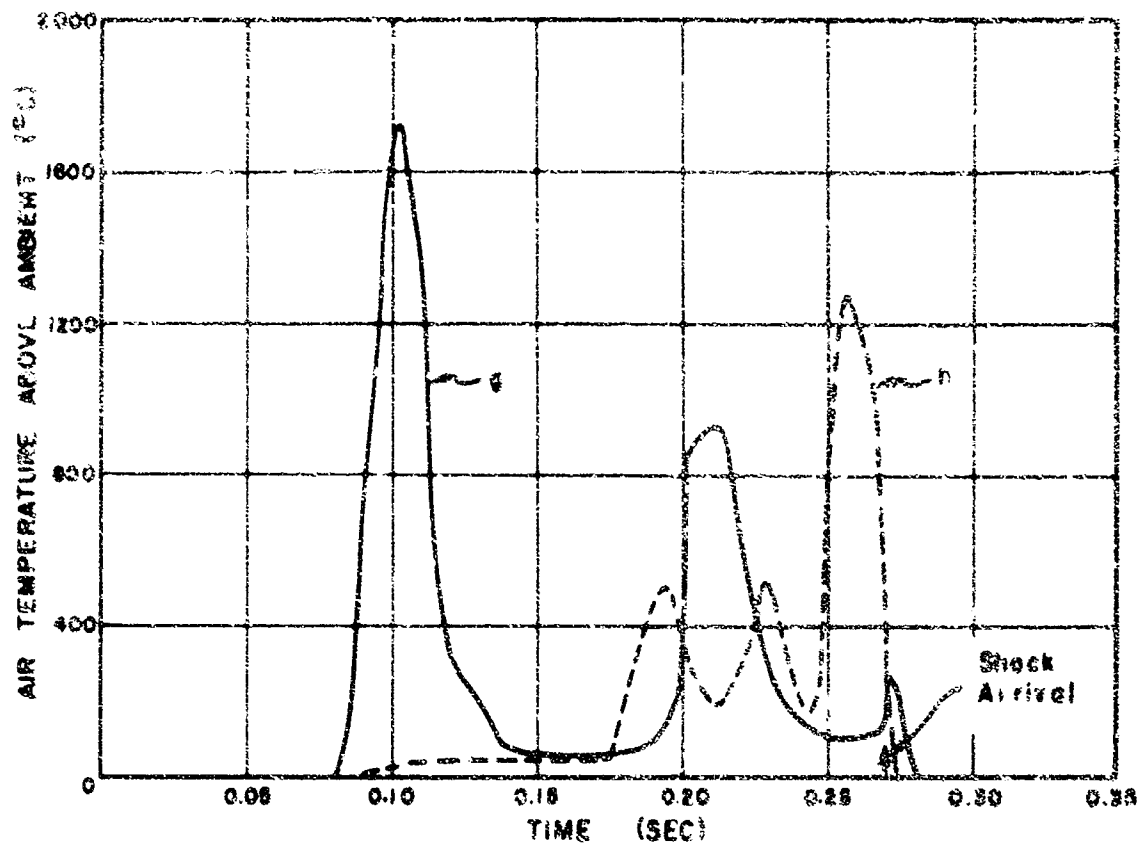


Figure 4.3 Air Temperature Above Ambient at 3 ft Elevation Above Ground; g, h represent two different HiVats, Shot 4.

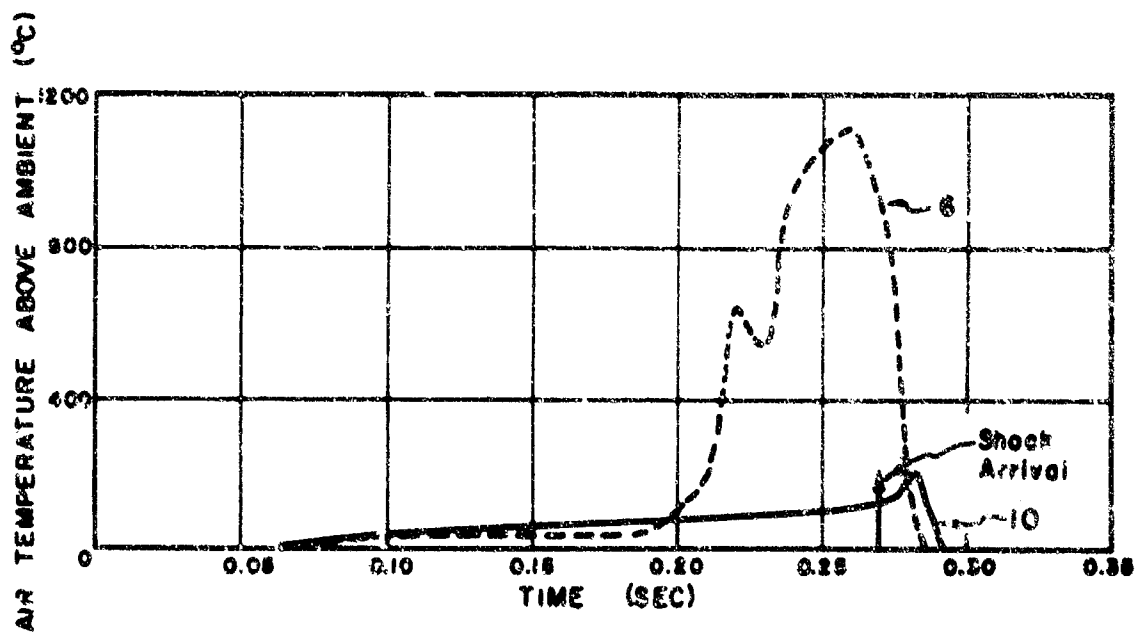


Figure 4.4 Air Temperature Above Ambient at 6 and 10 ft Elevation, Shot 4.

temperature data were obtained. The Heiland record indicated that the paper drive mechanism of the recorder jammed momentarily during and for a short while after zero time. As a result of this jamming, the traces of the galvanometer deflections were virtually superposed as to make reduction of the data impossible.

4.2.4 2,000-Foot Station. For the desert plot, no air temperature data were obtained. Again apparently for some unknown reason, the Heiland recorder was not in operation just prior to and during shot time.

At the organic soil plot, the air temperature data was inadvertently lost in the photographic development of the Heiland record.

For the concrete, ivy, fir-bough and wood plots, the air temperatures above ambient are shown in Figures 4.5 through 4.8, respectively. In Figures 4.7 and 4.8, the maximum air temperatures for some elevations were not obtained because the galvanometer deflections were off scale. No positive indication of shock arrival appeared on the air-temperature galvanometer traces. However, the results for shock arrival time obtained by Stanford Research Institute (SRI) at 2,000 feet from ground zero on the desert line and at elevations of 0 and 3 feet above grade was 0.452 seconds. This is indicated in Figures 4.5 through 4.8. Air temperature data following shock arrival are considered unreliable.

Examination of Figures 4.5 through 4.8 reveal a rather unusual result, in that the air temperature at all 1 1/2-foot elevations generally showed significant increase only at much later times than those at other elevations. It should be stated that the HiVats mounted at the 1 1/2-foot elevation at each station pointed in a direction 180 degrees from those mounted at all other elevations. It does not seem possible that this arrangement of mounting HiVats on all towers could be responsible for the unusual time history of the air temperature at the 1 1/2-foot elevations for all stations. By coincidence, the air-temperature measurements on Shot 4 also indicated something unusual at the 1 1/2-foot elevation, namely much lower maximum temperatures than at either the 1/2 or 3-foot elevations. On the other hand, the HiVats at the 1 1/2-foot elevation recorded air temperatures above ambient over a much longer period of time than at most of the other elevations for all stations.

A somewhat more interesting observation is that the maximum air temperature apparently increased with elevations, at least up to about 10 feet on all these stations. This is very striking over ivy, fir boughs, and wood, although perhaps not a totally unexpected result. In the case of concrete, it is difficult to explain such an increase in maximum temperature with increasing elevation. However, the temperature gradient over concrete is much smaller than over the other plots. A tentative explanation is that the results are strongly suggestive of flaming over the latter plots. Presumably, absorption of thermal radiation by the materials in the plot could cause rapid release of highly combustible gases which subsequently can ignite in air and thus produce flaming.

Another interesting thing is the rather short duration of recorded high air temperatures. This is apparent for most of the measurements on all plots. The rapid drop in temperature to ambient which occurs

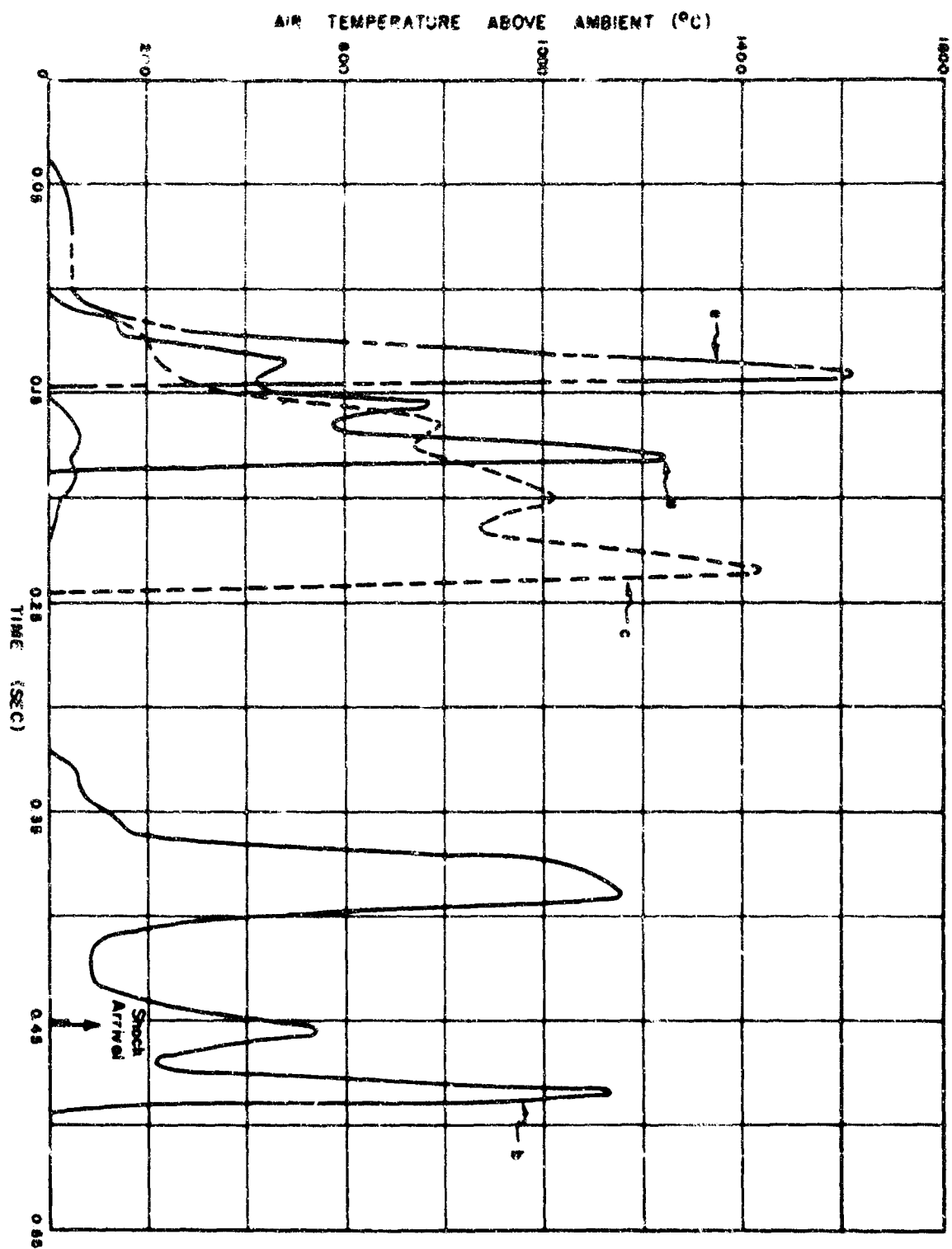


Figure 4.5 Air Temperature above Ambient over Concrete Plot; (a) 1/2 ft., (b) 1 1/2 ft., (c) 3 ft., (d) 10 ft. Elevation, Shot 12.

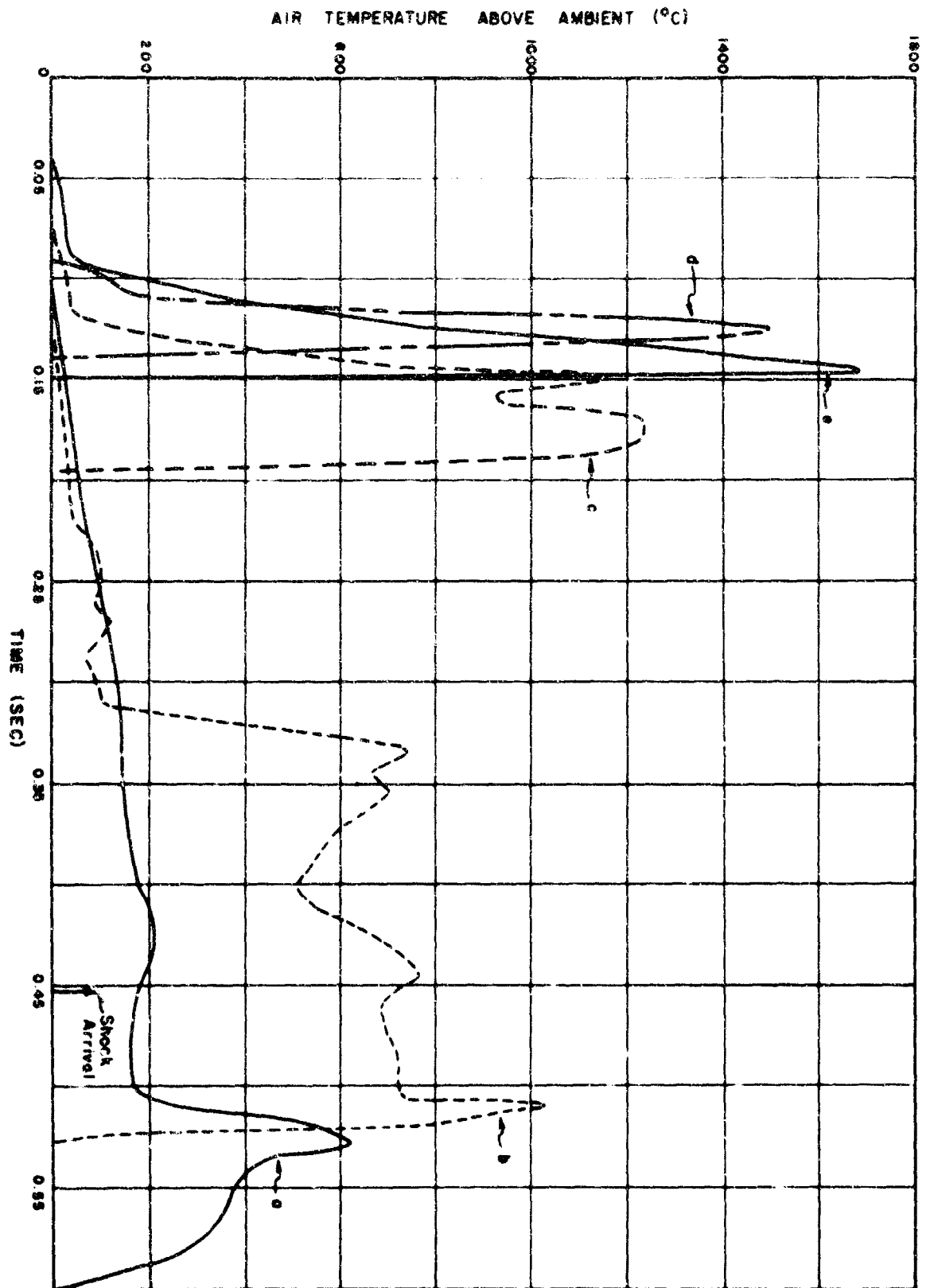


Figure 4.6 Air Temperature above Ambient over Ivy Plot; (b) top of Ivy leaves, (c) 1 ft, (d) 2 1/2 ft, (e) 5 1/2 ft, (f) 9 1/2 ft above top of Ivy leaves, Shot 12.

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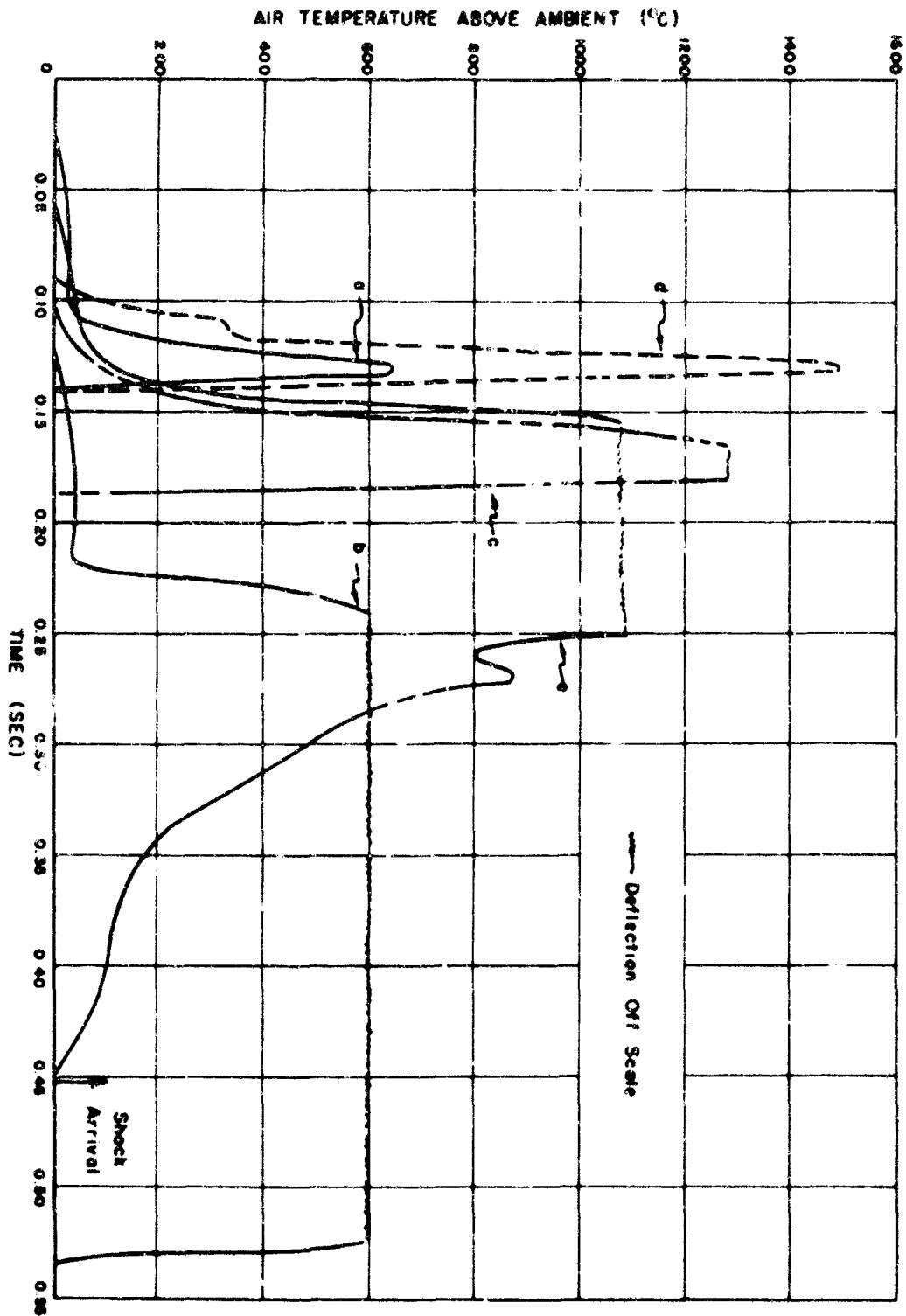


Figure 4.7 Air Temperature above ambient over Fir Bough Plot; (a) 0.4 ft, (b) 1.4 ft, (c) 2.9 ft, (d) 5.9 ft, (e) 9.9 ft above top of fir boughs, Shot 12.

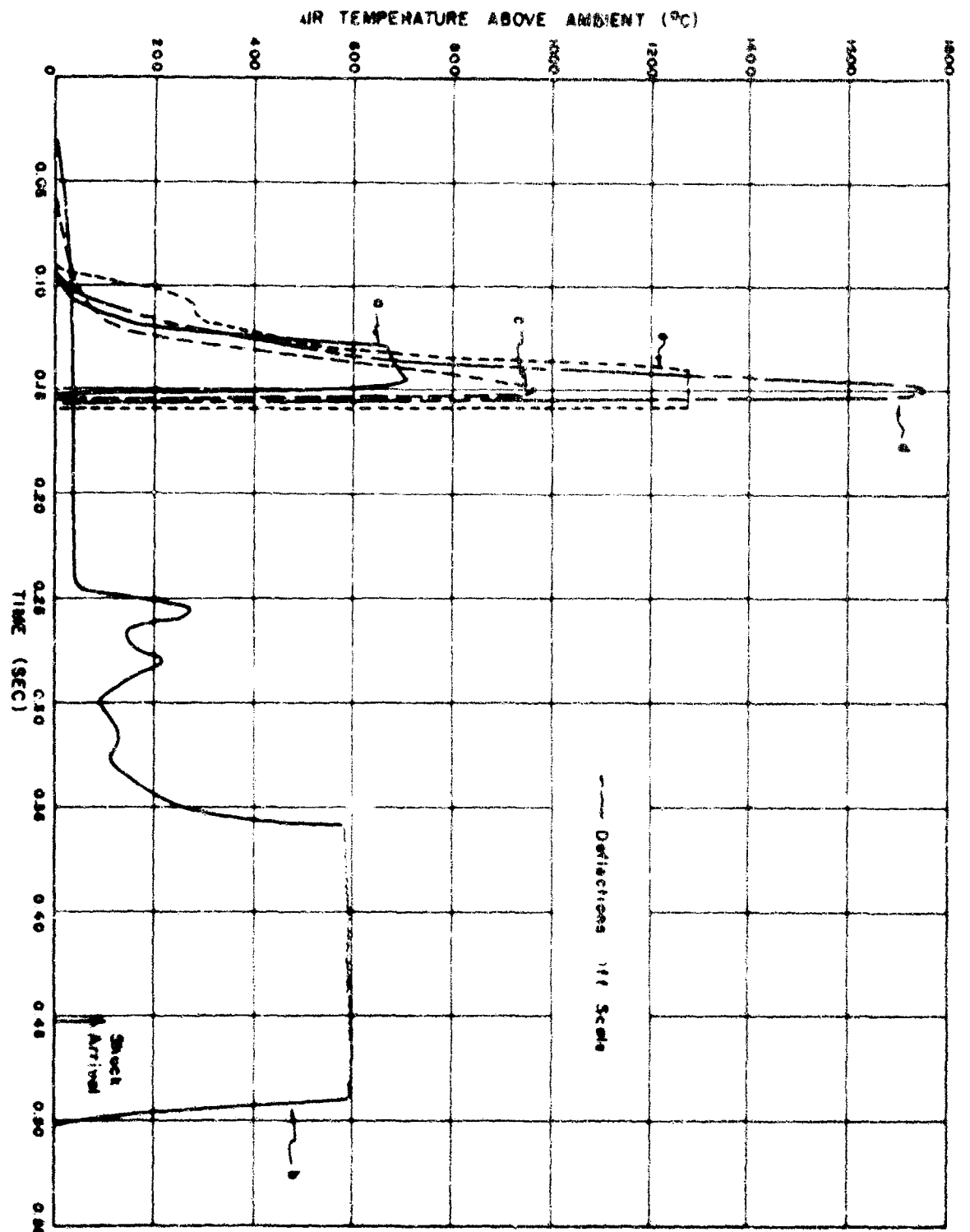


Figure 4.8 Air Temperature above Ambient over Wood Floor; (a) 0.4 ft, (b) 1.4 ft, (c) 2.9 ft, (d) 5.9 ft, (e) 9.9 ft above surface of wood, Shot 12.

appreciably prior to shock arrival appears to be somewhat inconsistent with the Shot 4 results. This will be further discussed below.

4.2.5 Gas Samples from Irradiated Plots. In Table 4.1 the results of the chemical analysis of the gas samples obtained over the five plots at the 2,000-foot stations are listed. The analysis was

TABLE 4.1 RESULTS OF ANALYSIS OF GAS SAMPLES IN VOLUME PER CENT OBTAINED IN SHOT 12

	Desert	Fir	Ivy	Wood	Asphalt
CO ₂	None Found				
CO					
H ₂					
CH ₄					
C ₂ H ₄					
unesturates					
O ₂	20.1	20.5	12.8	18.7	19.2
N ₂ *	79.9	79.5	87.2	81.3	80.8

*(by difference)

performed by the Army Chemical Center. The absence of products of oxidation or combustion, such as CO and CO₂, is somewhat surprising. It would seem more reasonable to assume that the analysis failed to quantitatively detect the presence of these products.

In the case of the oxygen content of the gas samples, the results immediately suggested removal of oxygen over the ivy, wood, and asphalt stations by some process such as combustion or flaming. On the other hand, over the desert and fir-bough stations the oxygen content was not different from that of normal air. This is to be expected for the desert station whereas for the fir-bough station one would expect results similar to that over ivy and wood.

4.2.6 Photographic Results. The photographic films from the cameras at all the 1,000-foot stations were fogged beyond any possibility of obtaining photographic records at these locations. Although measures were taken to shield all cameras from prompt radiation, apparently they were not enough to reduce fogging due to prompt radiation as well as that due to a high gamma field after shot time. In fact, early recovery of these films could not be made because the camera shelters

were very severely damaged, making it impossible to remove the cameras within the time allowed. Therefore, recovery of the films and cameras was made several days after such time when it became radiologically safe to work in these areas for an extended period of time. However, the developed films were fogged to the extent that no photographic images were discernible.

At the 2,000-foot stations, on the other hand, photographic records prior to shock arrival were obtained for all stations. These are shown in Figures 4.9 through 4.14. Certain general features are quite evident in these photographs, namely, the pronounced minimum in intensity prior to the second maximum, the buckling of the metal baffle between the dark and light portions of the background target due to intense thermal radiation, and the evolution of material from the irradiated surface between the target and camera.

For the desert, in Figure 4.9, photograph 5, there appears near the desert surface clouds or wisps of material being carried up into the air. On the time scale this is estimated to begin roughly 80msec after zero time. Succeeding photographs show the time history of the development of a rather tenuous and somewhat inhomogeneous distribution of these clouds. Furthermore, at some stage of development there is a suggestion of a filamentous nature of this rising material. It is believed that the latter consists of very fine particles being forced into the air by the explosive action due to rapid heating of occluded air trapped in the minute interstices of desert agglomerates. Such rapid heating of the occluded air presupposes rapid heat transfer of the absorbed intense thermal energy by the particles which comprise the desert surface. Although the convective heat transfer coefficient to static air is generally small, the amount of heat transferred per unit volume of occluded air and per unit time may be extremely large especially under conditions of very large surface to volume ratios.

For the asphalt, Figure 4.10 shows two sets of photographs, each taken from a different camera but at the same location. In the first case the exposure was set at predicted optimum and in the second case, a neutral filter was used to reduce the intensity by a factor of 2. Again, at about 70msec after zero time there appears to be definite indications of changes taking place at the asphalt surface and just above it. Furthermore, the material that is observed at and above the surface appears to be noticeably different from that above the desert. In fact, up to a height of about 2 inches from grade the material appears to be rather homogeneous, although at later times this is not so, and it is much denser than that over the desert plot. During the early stages of development it is difficult to decide whether the material is incandescent or consists of particles released from the highly irradiated asphalt surface. However, at later times it is certain that the material is incandescent and flames can be seen in the photographs. In fact, vigorous development of the flames appears to take place up to the time of shock arrival. Patches of smoke can be seen which appear black in the photograph, presumably because such smoke consists of highly absorbing material, e.g., carbon particles. (Note that in all photographs the field of view extends to an elevation of only about 18 inches above grade).

The photographs over the concrete plot in Figure 4.11 are some-



Figure 4.9 Photographic Sequence over Surface at
2,000 ft. Desert Station

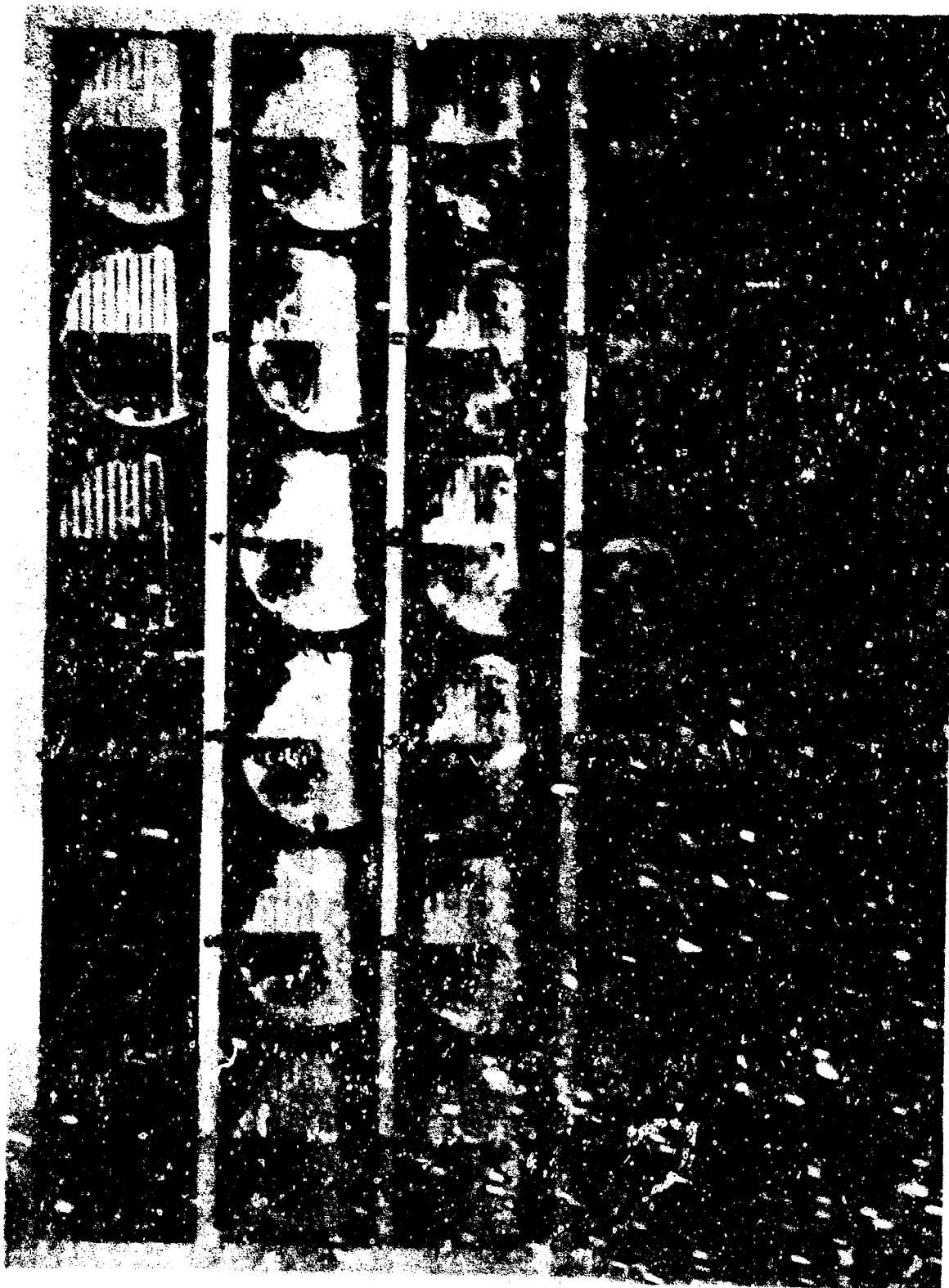




Figure 4.10 Photographic Sequence over Surface at 2,000-foot Asphalt Station. Upper Photo: Set at predicted optimum exposure. Lower Photo: Neutral filter used to reduce intensity by factor 2.



Figure 4.11 Photographic sequence over Concrete
Surfaces.

what similar to those for the desert. The development of a cloud of material at and above the surface of the plot appears to start at about 100 msec after zero time. The appearance of the cloud in the photographs is very similar to that over the desert; however, it is more copious and dense than that over the latter. It is remarkable that such clouds would form over concrete. One might expect this if it were assumed that just prior to zero time the concrete surface was covered with a layer of very fine desert dust. On the other hand, it is known from laboratory observations that irradiation of firebrick with intense thermal radiation will cause ejection of copious amounts of fine particles from the irradiated surface.

For the fir boughs, the photographs of Figure 4.12 show the same general phenomena that were observed over the other plots. Thus, at about 80 msec after zero time at the surface of the plot, material was forced into the air above. As in the case of the desert plot, the clouds are tenuous and patchy. It is not possible to infer whether these clouds are made up of discrete particles or concentrated gaseous or vapor emanations. The photographs for later times indicate what appears to be flaming, although being much less evident than over the asphalt surface. In fact, it seems that very little burning of the fir boughs takes place and that any appreciable flaming would apparently originate in the clouds above the plot. This would suggest release of combustible gases or vapors from the fir boughs upon irradiation with subsequent combustion and flaming in the presence of atmospheric oxygen.

In Figure 4.13 the photographs obtained over the ivy plot are shown. These are very similar to those over the fir-bough plot except perhaps with only very slight indications of flaming over the ivy.

For wood, the photographs in Figure 4.14 are very striking. About 80 msec after zero time "wisps" of material appear to rise from the wood surface. Then, about 30 msec later, a dark line appears just above the surface of the wood which later develops into what seems to be a mixture of flame and smoke. The latter becomes so extensive that the whole field of view of the camera is obscured.

The photographs obtained over the soil plot have been omitted because there was partial obscuration of the plot. However, they appeared very similar to those of the desert plot.



Figure 4.12 Photographic Sequence over Fir Bough
Plot

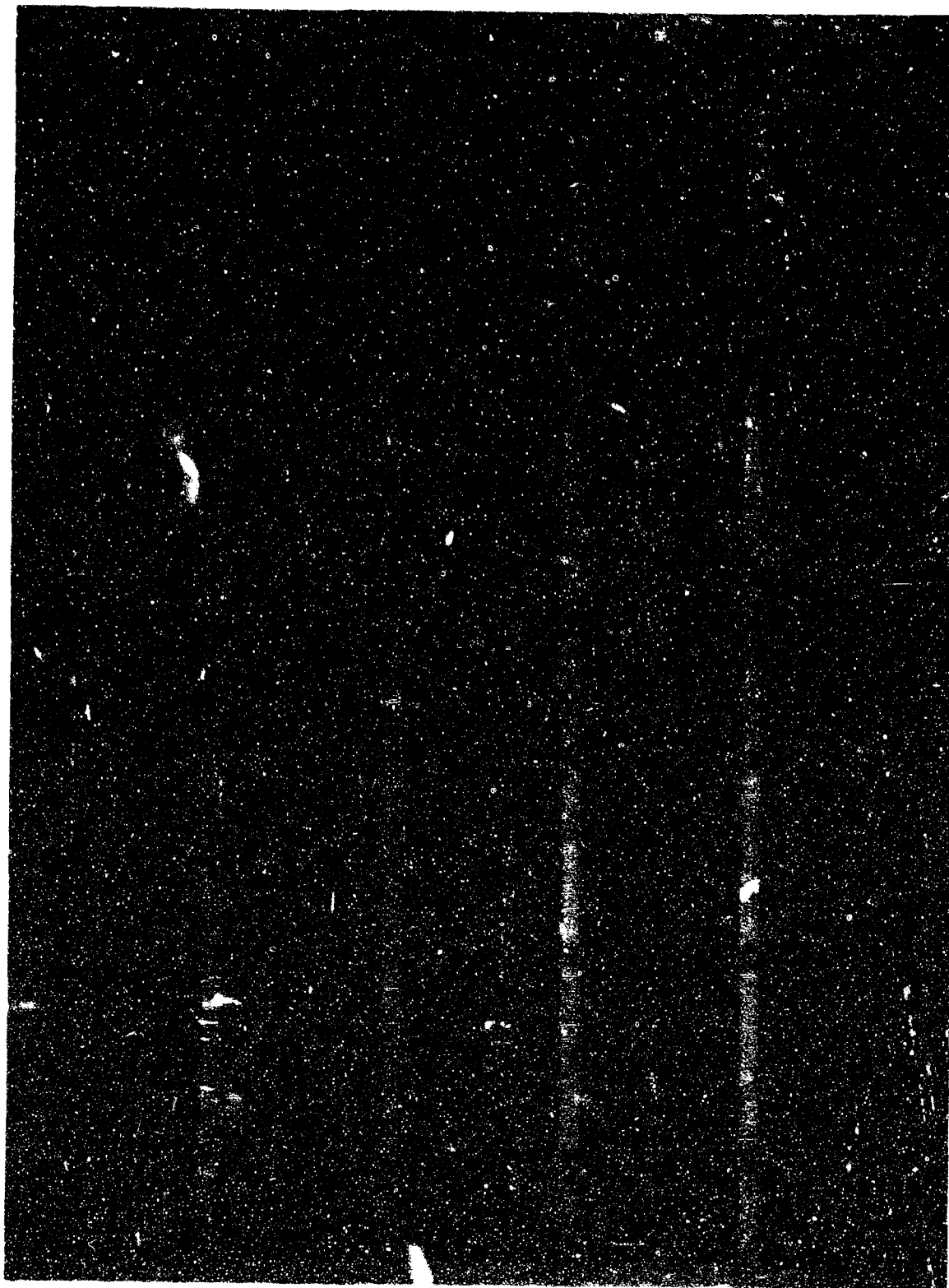


Figure 4.13 Photographic Sequence over Ivy Plot

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Figure 4.2.4 Photographic Sequence over Wood Plot

Chapter 5

DISCUSSION

It is unfortunate that no results were obtained from the air-temperature measurements over the desert, asphalt and water surfaces, which makes it almost impossible to relate air temperatures with precursor formation. However, the results obtained on Shot 4 and those over the special plots in Shot 12 may be helpful in providing some insight into the nature of the preshock air.

In Section 4.1, based on the results of Shot 4, a description and possible explanation of the nature of preshock air has already been discussed. It does seem likely that a similar description would apply to preshock air over the desert in Shot 12.

Thus, the photographs in Figure 4.9 seem to indicate that the air over the desert is not uniformly heated prior to shock arrival. This implies that there may exist patches, filaments, or parcels of intensely heated air distributed randomly in only slightly heated ambient air. Shock waves passing through such medium would therefore behave as if passing through it at some average air temperature determined by the distribution of heated parcels of air. The photographic results over concrete in Shot 12 appear to support the suggested existence of parcels of heated air. Thus, the air-temperature measurements indicate high temperature of brief duration, i.e., suggests pulses or parcels of heated air rapidly moving past the HiVat. It may be argued that fine dust particles, heated to very high temperatures upon irradiation, and which could be a major constituent of the clouds over the desert surface, may have been drawn into the HiVat and thus simulated high air temperatures of short duration. This is quite possible and, in fact, may well provide for one of the mechanisms of rapid heat transfer to the air resulting in the formation of parcels of heated air.

From the photographs obtained over the asphalt surface, it would seem that the air would be heated much more uniformly. The photographs indicate considerable combustion and vigorous flaming over the asphalt surface which should therefore heat the air above rather uniformly. Furthermore, the gas analysis also indicates removal of atmospheric oxygen in rather significant amounts, thus supporting combustion over the asphalt surface. Unfortunately, the photographs do not show the entire vertical extent of the flaming. A conservative estimate of the temperature in the flame and the air immediately above it would be of the order of $1,000^{\circ}\text{C}$ (inasmuch as most organic fuels yield flame temperatures of about $1,000$ to $2,000^{\circ}\text{C}$).

The similarity of the results for the concrete, fir-bough, ivy and wood plots suggests similarity in the nature of the air above the plots. The results for the concrete plot have already been discussed. In the case of the ivy and fir bough plots, apparently very little or no combustion takes place at the surface of the plots. It is suggested that gaseous emanations released by the intense

irradiation of these plots rise into the air above in patches or parcels which then absorb the incident radiation with possible subsequent combustion and flaring. Such a mechanism could well explain the high air temperatures of short duration observed. There does not appear to be any other mechanism which would bring about uniform air temperatures above these surfaces. The gas analysis indicates considerable combustion taking place over the ivy plot; however, over the fir-bough plot the oxygen content remained normal. The latter result could be explained by assuming that in the region where the air was being sampled, little or no combustion took place due to the random nature of the gaseous emanations from the fir boughs. In addition, the maximum air temperatures observed are of the order of those expected in combustion of organic fuels.

In the case of the wood plot, again, according to the gas analysis, appreciable combustion takes place. Presumably, oxygen is consumed in the burning of the surface layers of wood as well as combustion of any gaseous, ignitable material released from the wood. The photographs seem to indicate great quantities of a mixture of smoke and flame, which however, do not have the appearance of being steady and persistent as over the asphalt surface. Thus, the measured air temperatures do not indicate any uniform heating over the wood plot, much of this being probably due to the relatively small size of the plot as compared to that over the asphalt station.

The above discussions are by no means intended to be conclusive in view of the limited data obtained. However, it is felt that the above represent a possible qualitative description of the nature of pre shock air above such surfaces irradiated by intense thermal radiation from nuclear detonations.

Chapter 6

CONCLUSIONS and RECOMMENDATIONS

It is felt that the method of measurement of air temperatures reported here is a reliable one. Therefore, the recorded temperatures obtained in this operation do indeed indicate air temperatures at the locations of each instrument. The high temperatures obtained are somewhat in keeping with the results of previous test operations. However, an important difference has been observed in the time--temperature history of the heated air prior to shock arrival. The recorded high air temperatures of very short duration are indicative of marked inhomogeneities of the heated air. The existence of patches or parcels of heated air has been postulated to account for these observations. The effect on any large scale phenomenon, such as a shock front moving in such a medium, should therefore be related to some average temperature defined by the distribution of these parcels of heated air.

Despite the limited success in the measurement of air temperature over various types of terrain, it is felt that the equipment and technique used in this operation are well suited for air temperature measurements especially in view of the satisfactory results obtained on Shot 4. However, in any future measurements, utmost consideration should be given to the possibility of electromagnetic pickup interfering completely with the measurements. It is further suggested that other reliable methods be considered which will sample the air more extensively than the above in order that local inhomogeneities will be averaged out in the measurement.

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- 88 Commander, U.S. Naval Ordnance Test Station, Inyokern, China Lake, Calif.
- 89 Commanding Officer, U.S. Naval Medical Research Inst., National Naval Medical Center, Bethesda 14, Md.

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- 90-98 Chief, Bureau of Aeronautics, D/S, Washington 25, D.C. ATTN: AER-41-41/20
- 99 Director, U.S. Naval Research Laboratory, Washington 25, D.C. ATTN: Mrs. Katherine R. Omer
- 99 Director, The Material Laboratory, New York Naval Shipyard, Brooklyn, N. Y.
- 97 Commanding Officer and Director, U.S. Navy Electronics Laboratory, San Diego 52, Calif.
- 98-101 Commanding Officer, U.S. Naval Radiological Defense Laboratory, San Francisco, Calif. ATTN: Technical Information Division
- 102 Commander, U.S. Naval Air Development Center, Johnstown, Pa.
- 103 Commanding Officer, Clothing Supply Office, Code 1D-0, 3rd Avenue and 29th St., Brooklyn, N.Y.
- 104 CIRCPCAC, Fleet Post Office, San Francisco, Calif.
- 105-109 Technical Information Service Extension, Oak Ridge, Tenn. (Surplus)

AIR FORCE ACTIVITIES

- 110 Asst. for Atomic Energy Headquarters, USAF, Washington 25, D.C. ATTN: DCS/O
- 111 Director of Operations, Headquarters, USAF, Washington 25, D.C. ATTN: Operations Analysis
- 112 Director of Plans, Headquarters, USAF, Washington 25, D.C. ATTN: War Plans Div.
- 113 Director of Research and Development, DCS/D, Headquarters, USAF, Washington 25, D.C. ATTN: Combat Components Div.
- 114-115 Director of Intelligence, Headquarters, USAF, Washington 25, D.C. ATTN: AFOSI-IE
- 116 The Surgeon General, Headquarters, USAF, Washington 25, D.C. ATTN: Bio. Def. Br., Pres. Med. Div.
- 117 Asst. Chief of Staff, Intelligence, Headquarters, U.S. Air Force-Europe, APO 633, New York, N.Y. ATTN: Directorate of Air Targets
- 118 Commander, 897th Reconnaissance Technical Squadron (Augmented), APO 633, New York, N.Y.
- 119 Commander, Far East Air Force, APO 925, San Francisco, Calif. ATTN: Special Asst. for Damage Control
- 120 Commander-in-Chief, Strategic Air Command, Offutt Air Force Base, Omaha, Nebraska. ATTN: Special Weapons Branch, Inspector Div., Inspector General
- 121 Commander, Tactical Air Command, Langley AFB, Va. ATTN: Documents Security Branch
- 122 Commander, Air Defense Command, Fort AFB, Colo.
- 123-124 Research Directorate, Headquarters, Air Force Special Weapons Center, Kirtland Air Force Base, New Mexico, ATTN: Blast Effects Sec.
- 125 Commander, Air Research and Development Command, PO Box 1395, Baltimore, Md. ATTN: R&D
- 126 Commander, Air Proving Ground Command, Eglin AFB, Fla. ATTN: Adj./Tech. Report Branch
- 127-128 Director, Air University Library, Maxwell AFB, Ala.
- 129-130 Commander, Flying Training Air Force, Waco, Tex ATTN: Director of Observer Training
- 131 Commander, Crew Training Air Force, Randolph Field, Tex. ATTN: RCTB, DCS/O
- 132-139 Commandant, Air Force School of Aviation Medicine, Randolph AFB, Tex.
- 140-145 Commander, Wright Air Development Center, Wright-Patterson AFB, Dayton, O. ATTN: WDCB
- 146-147 Commander, Air Force Cambridge Research Center, US Henslow Field, Bedford, Mass. ATTN: CRATT-2

- 148-149 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, 1007th Special Weapons Squadron, Headquarters, USAF, Washington 25, D.C.
- 152-154 The RAND Corporation, 1200 Main Street, Santa Monica, Calif. ATTN: Nuclear Energy Division
- 155 Commander, Second Air Force, Barksdale AFB, Louisiana. ATTN: Operations Analysis Office
- 156 Commander, Eighth Air Force, Tinker AFB, Mass. ATTN: Operations Analysis Office
- 157 Commander, Fifteenth Air Force, March AFB, Calif. ATTN: Operations Analysis Office
- 158 Commander, Western Development, Div. (ARDC), PO Box 262, Eaglewood, Calif. ATTN: WDSB, Attn: R. D. Wells
- 159-163 Technical Information Service Extension, Oak Ridge, Tenn. (Surplus)

OTHER DEPARTMENT OF DEFENSE ACTIVITIES

- 164 Asst. Sec. for Defense, Research and Development, Dept. of Defense, 1415 AFB, Room 1110
- 165 U.S. Documents Office, Office of the U.S. National Military Representative, NATO, APO 14, New York, N.Y.
- 166 Director, Weapons Systems Evaluation Group, 2000 The Pentagon, Washington 25, D.C.
- 167 Armed Services Explosives Safety Board, 1700 Building 7-7, Gravelly Point, Washington 25, D.C.
- 168 Commandant, Armed Forces Staff College, Norfolk, Va. ATTN: Secretary
- 169-174 Commander, Field Command, Armed Forces Special Weapons Project, PO Box 1100, Albuquerque, N. Mex.
- 175-176 Commander, Field Command, Armed Forces Special Weapons Project, PO Box 1100, Albuquerque, N. Mex. ATTN: Technical Training Group
- 177-181 Commander, Field Command, Armed Forces Special Weapons Project, P.O. Box 1100, Albuquerque, N. Mex. ATTN: Deputy Chief of Staff, Weapons Effects Test
- 182-183 Chief, Armed Forces Special Weapons Project, Washington 25, D.C. ATTN: Documents Library Branch
- 184 Office of the Technical Director, Directorate of Effects Tests, Field Command, AFM/P, PO Box 1100, Manila Park, Calif. ATTN: Dr. E. B. Doll
- 185-186 Technical Information Service Extension, Oak Ridge, Tenn. (Surplus)

ARMED SERVICES COMMISSION ACTIVITIES

- 187-188 U.S. Atomic Energy Commission, Classified Technical Library, 1901 Constitution Ave., Washington 25, D.C. ATTN: Mrs. J. M. O'Leary For DCS
- 189-190 Los Alamos Scientific Laboratory, Report Library, PO Box 1663, Los Alamos, N. Mex. ATTN: Helen Johnson
- 191-192 Rand Corporation, Classified Document Division, Santa Monica, Albuquerque, N. Mex. ATTN: E. J. Smith, Jr.
- 193-194 University of California Radiation Laboratory, PO Box 408, Livermore, Calif. ATTN: Louis J. Craig
- 195-196 Weapon Data Section, Technical Information Service Extension, Oak Ridge, Tenn.
- 197-198 Technical Information Service Extension, Oak Ridge, Tenn. (Surplus)

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