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# Operation

# UPSHOT-KNOTHOLE

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Project 6.12

DETERMINATION OF HEIGHT OF BURST AND GROUND ZERO

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**OPERATION UPSHOT-KNOTHOLE**

Project 6.12

**DETERMINATION OF HEIGHT OF BURST  
AND GROUND ZERO**

*REPORT TO THE TEST DIRECTOR*

by

Roland V. Tiede, Lt Col, USA  
Daniel F. Kelly  
Kenneth C. Burger

May 1955

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for Chief ISCM DNA*

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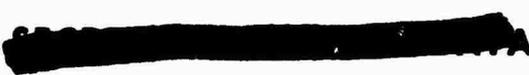
ABSTRACT

The purpose of this series of experiments was to test methods available to the field army for tactical determination of atomic burst location and yield over enemy-held terrain. Preliminary analysis indicated that the systems that should be tested were sound ranging, seismic height of burst determination, photographic flash ranging, and Bhangmeter type systems for yield determination.

Sound ranging was accomplished using standard equipment with modified techniques. Microphone arrays of dimensions which were small compared to the range were used to eliminate hyperbolic curvature corrections and to simplify meteorological corrections. A new system of meteorological corrections was employed. This system was based on approximating the maximum height reached by the sound which ultimately passes across the microphone array. It was determined that this technique gave far greater accuracy than conventional techniques at these long ranges. Most accurate locations were obtained on air bursts. For air bursts at ranges from 20,000 to 60,000 meters, angular standard deviations of 13.8 minutes of arc were obtained. For air bursts, the average radial location error expressed as per cent of range was 0.61 per cent. It was estimated that in a tactical situation these locations could be computed in less than 30 minutes.

Seismic height of burst determinations were attempted by the heat seismic and the seismic velocity methods. Both methods depended upon the travel time of the shock wave from the point of origin to ground zero. The heat seismic method used in addition a seismic signal generated by the heat radiated from the nuclear detonation, as postulated by earlier investigators. The velocity seismic method utilized additional seismic shocks for a determination of seismic propagation constants. Conclusive evidence as to the feasibility of either seismic method was not obtained.

Photographic flash ranging was accomplished using pinhole cameras and Polaroid film. The tactical requirement for speed in processing required the use of this film. The camera used was a modification of an experimental flash ranging camera [part of Flash Ranging Set AN/TVS-1 (XE-2)] with the conventional refractive optics replaced by a pinhole. A high speed shutter tripped by a blue box was employed. It was determined experimentally that a given pinhole aperture with a fixed delay time provided photographs of the fireball with adequate resolution for accurate angular measurements over a wide range of yields and



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distances. Average angular accuracies of 0.75 mils were obtained. It was estimated that ground zero locations and burst heights could be provided by this method under tactical conditions in 5 to 10 minutes.

Conventional Bhangmeters furnished yield determinations under non-line-of-sight conditions at ranges out to 40 miles with an accuracy of the order of 20 per cent or better. Attempts to utilize a Bhangmeter type instrument with a lead sulfide cell detector indicated that extensive investigation would be required to establish the correlation between yield and time to minimum in the light intensity-time curve for the spectral response of the lead sulfide cell. Attempts to modify a Mark III Type Bhangmeter by substituting a lead sulfide cell for the photo cell made possible successful time of flight measurements on the 280 mm gun when firing conventional ammunition. Design parameters were established for such a time of flight measuring equipment.

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FOREWORD

This report is one of the reports presenting the results of the 78 projects participating in the Military Effects Tests Program of Operation UPSHOT-KNOTHOLE, which included 11 test detonations. For readers interested in other pertinent test information, reference is made to WT-782, Summary Report of the Technical Director, Military Effects Program. This summary report includes the following information of possible general interest.

- a. An over-all description of each detonation, including yield, height of burst, ground zero location, time of detonation, ambient atmospheric conditions at detonation, etc., for the 11 shots.
- b. Compilation and correlation of all project results on the basic measurements of blast and shock, thermal radiation, and nuclear radiation.
- c. Compilation and correlation of the various project results on weapons effects.
- d. A summary of each project, including objectives and results.
- e. A complete listing of all reports covering the Military Effects Tests Program.

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CHAPTER 1

INTRODUCTION

1.1 OBJECTIVE

The objective of this project was to test methods available to the field army for tactical determination of atomic burst location and yield over enemy-held terrain. Effective exploitation of atomic weapons used in support of our ground operations requires that our ground commanders receive timely information relative to the damage inflicted upon the enemy. Reasonable assessment of this damage may be made by knowing the location of ground zero and height of burst relative to the target, the yield of the atomic weapon, and the target vulnerability with sufficient accuracy. Evaluation of the methods tested is based on feasibility, accuracy, speed, and availability of equipment suitable for use in the field.

1.2 BACKGROUND

A study to determine the army's capability to locate atomic bursts over enemy territory was begun by Army Field Forces Board No. 1 in 1952 as directed by Office, Chief of Army Field Forces. Consultation with the Signal Corps Engineering Laboratories indicated the desirability of joint participation by Army Field Forces and the Signal Corps in Operation UPSHOT-KNOTHOLE. It was determined that such tests should be limited to instrumentation which was or could, in a short time, be made available as standard equipment. The systems to be tested included photographic flash ranging and radar ranging for location of ground zero and height of burst under line of sight conditions. Sound ranging was to be tested for ground zero location at ranges in excess of those normally employed in locating enemy weapons and under non-line-of-sight conditions. An attempt was to be made to determine burst heights by seismic instrumentation. Study of the systems proposed for yield determination indicated that a system based on the fireball temperature versus time curve offered the greatest promise of permitting tactical yield measurements. Equipment for such a system had already been developed in the form of the Bhangmeter.

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The use of S-band tracking radar for location of the air-dropped weapons was discouraged by the Test Director because of the slight possibility of triggering the radar fuse. Inasmuch as radar was a part of the gunnery technique of the 280 mm gun, it was decided to delete radar from the tests to be included in this project.

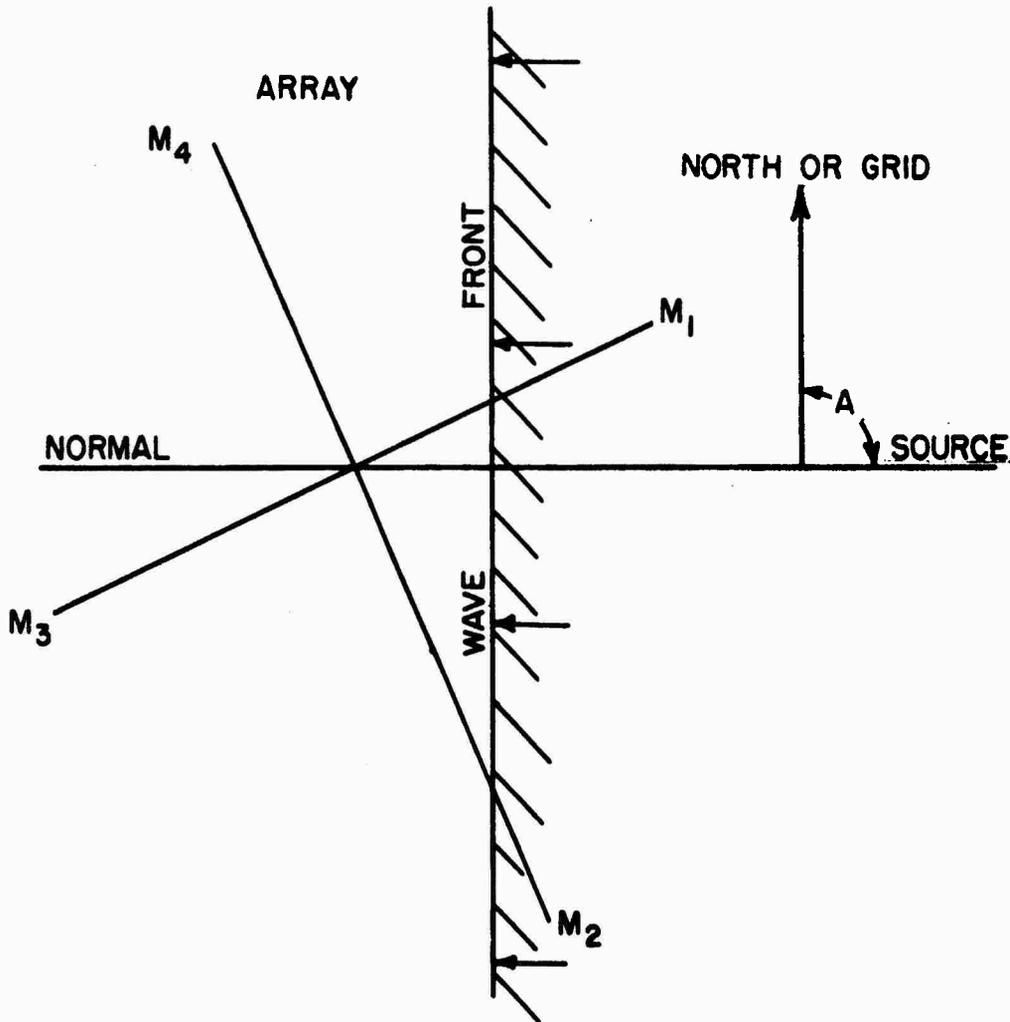
## CHAPTER 2

SOUND RANGING2.1 EXPERIMENT DESIGN2.1.1 Theoretical Considerations

Preliminary study of existing sound ranging methods <sup>1/</sup> indicated that the technique rather than the equipment must be modified to permit sound ranging on the atomic burst at ranges between 30,000 and 60,000 meters. Therefore, the configuration of microphones employed for sound ranging in the current tests differs significantly from the more conventional sound bases described in cited reference. This configuration (Fig. 2.1) was designed to eliminate the requirement for curvature corrections and to simplify meteorological corrections. If the distances  $\overline{M_1M_2}$ ,  $\overline{M_2M_3}$ , etc. (Fig. 2.1) are selected so as to be small compared to the distance to the sound source, the wave front across the array can be assumed to be plane. Making this assumption, it can be demonstrated that the following relations exist:

$$\begin{aligned} \tan(A-B_{13}) &= \frac{T_2-T_4}{T_1-T_3} \cdot \frac{\overline{M_1M_3}}{\overline{M_2M_4}} \cdot \frac{1}{\sin(B_{24}-B_{13})} - \text{Ctn}(B_{24}-B_{13}) \\ \tan(A-B_{12}) &= \frac{T_2-T_3}{T_1-T_2} \cdot \frac{\overline{M_1M_2}}{\overline{M_2M_3}} \cdot \frac{1}{\sin(B_{23}-B_{12})} - \text{Ctn}(B_{23}-B_{12}) \\ \tan(A-B_{23}) &= \frac{T_3-T_4}{T_2-T_3} \cdot \frac{\overline{M_2M_3}}{\overline{M_3M_4}} \cdot \frac{1}{\sin(B_{34}-B_{23})} - \text{Ctn}(B_{34}-B_{23}) \quad (2.1) \\ \tan(A-B_{34}) &= \frac{T_4-T_1}{T_3-T_4} \cdot \frac{\overline{M_3M_4}}{\overline{M_4M_1}} \cdot \frac{1}{\sin(B_{41}-B_{34})} - \text{Ctn}(B_{41}-B_{34}) \\ \tan(A-B_{41}) &= \frac{T_1-T_2}{T_4-T_1} \cdot \frac{\overline{M_4M_1}}{\overline{M_1M_2}} \cdot \frac{1}{\sin(B_{12}-B_{41})} - \text{Ctn}(B_{12}-B_{41}) \end{aligned}$$

If, within the required accuracy limits, the microphone configuration is exactly square, the distance ratio terms in Equation 2.1 reduce to unity and all of the angles reduce to 90°. Equation 2.1 then becomes



Definitions:

A = Azimuth Of Direction To Sound Source.

$M_1, M_2, M_3, M_4$  = Microphones.

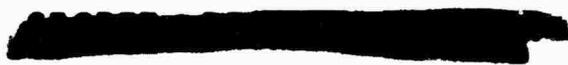
$B_{13}$  = Azimuth of Microphone 3 From 1 (i.e., Looking From  $M_1$  to  $M_3$ ).

$M_1 M_3$  = Distance Between  $M_1$  and  $M_3$ .

$T_1, T_2, T_3, T_4$  = Time Reading At Time Sound Wave Passes Across  $M_1, M_2, M_3, M_4$  Respectively.

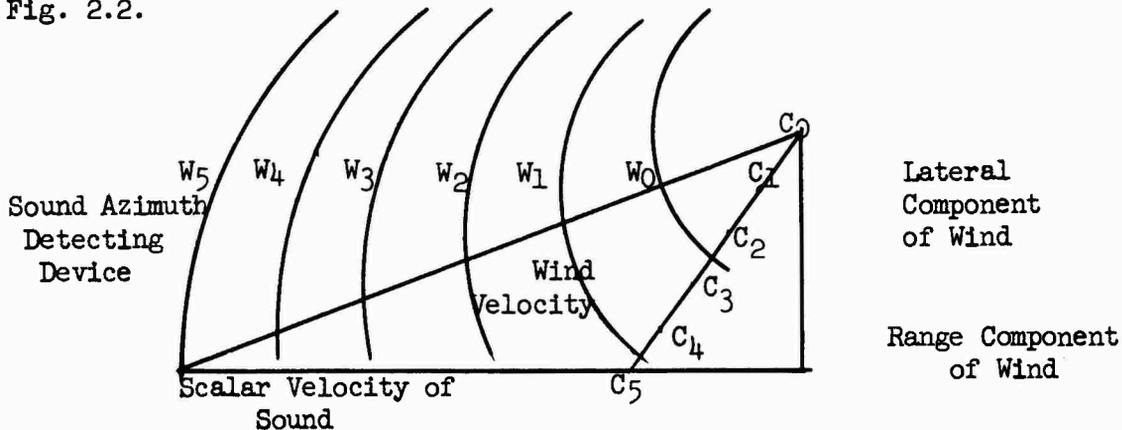
Fig. 2.1 The Square Microphone Array

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simple time interval ratios.

The azimuth, A, computed from Equation 2.1 must be corrected for wind, since the wave front is displaced by wind, so that the normal, i.e., the direction toward the apparent source, is directed downwind from the true source. This relationship is illustrated in Fig. 2.2.



$C_0, C_1, C_2 \dots$  Locus of successive apparent sound sources.

$W_0, W_1, W_2 \dots$  Wave fronts corresponding to successive apparent sources.

Fig. 2.2 Effect of Wind on Sound Wave

From Fig. 2.2 it is clear that the metro azimuth correction angle, M, can be computed from the relation,

$$\tan M = \frac{\text{lateral wind component}}{\text{velocity of sound (including range component of wind)}}$$

The wind components and sonic velocity are of course dependent on the temperature and wind structure of the atmosphere. The effect of the lateral winds, in particular, must be weighted according to the fraction of total time that the received portion of the sound wave front is propagated in each layer of the atmosphere. Such weighting requires that the sound path be approximated.

In dealing with propagation paths which are, in general, not line of sight, the sound must be refracted by the atmosphere or be diffracted over intervening sound barriers. The conditions under which sound is refracted back toward the surface of the earth are well known. 2,3/ These conditions are best ascertained by constructing criterion curves for sound propagation as illustrated in Fig. 2.3. Criterion curves are constructed by first plotting the scalar velocity

of sound, a, as given by the following relation:

$$a = \sqrt{\frac{\text{Virtual Temperature in } ^\circ\text{C} + 273.16}{273.16}} \quad 1088 \text{ f/s} \quad (2.3)$$

against altitude. In equation 2.3 virtual temperature refers to a temperature slightly higher than actual to take into account humidity effect and density. <sup>4/</sup> To this scalar velocity of sound is then added the range component of wind and the result is plotted against altitude for each sound array. As has been shown in references 2.3/, sound will be refracted downward when the velocity of sound is increasing with increasing altitude and the horizontal phase velocity of the sound thus refracted back to the surface of the earth will be identical with the velocity of sound at the maximum ordinate of the sound path. If one measures the horizontal phase velocity across any given microphone array, one needs only to follow up the criterion curve until an altitude is found for which sound velocity is identical to the phase velocity determined and in which region the sonic velocity is increasing with altitude. If the altitude thus obtained is greater than the altitude of the intervening sound barriers, it may safely be assumed that the sound "turned over" at the selected altitude. If no point on the criterion curve meets these conditions, then diffraction over the sound barriers is indicated. Figures 2.4 and 2.5 illustrate the type terrain over which sound was propagated in Operation UPSHOT-KNOTHOLE.

The exact trajectory of the sound is, of course, impossible to determine without exact knowledge of the space variation in the propagation constants. Nevertheless, it is clear for the case of refraction that the sound trajectory will be a curve and that the maximum ordinate of this curve has been determined. For the purpose of weighting the effect of lateral winds, it is convenient to assume that this curve is a vertical parabola passing through the origin of the sound, the center of the microphone array, and the maximum ordinate. Referring to Fig. 2.6 and noting that in practice the parabolas referred to are very flat, it is clear that the following relation exists:

$$\frac{t}{T} \approx \frac{d}{D} = \sqrt{\frac{h}{H}} \quad (2.4)$$

where t is the time spent traversing distance d and T the time between source and array. If h/H be called the zone altitude fraction, then for the condition of refraction, the weighting factors are proportional to the square roots of the zone altitude fractions. For the case of diffraction, straight line propagation may be assumed giving equal weight to each zone altitude fraction between successive barriers. The zone altitude fractions taken must be consistent with the maximum ordinates of the sound trajectories and the frequency of the atmospheric soundings taken.

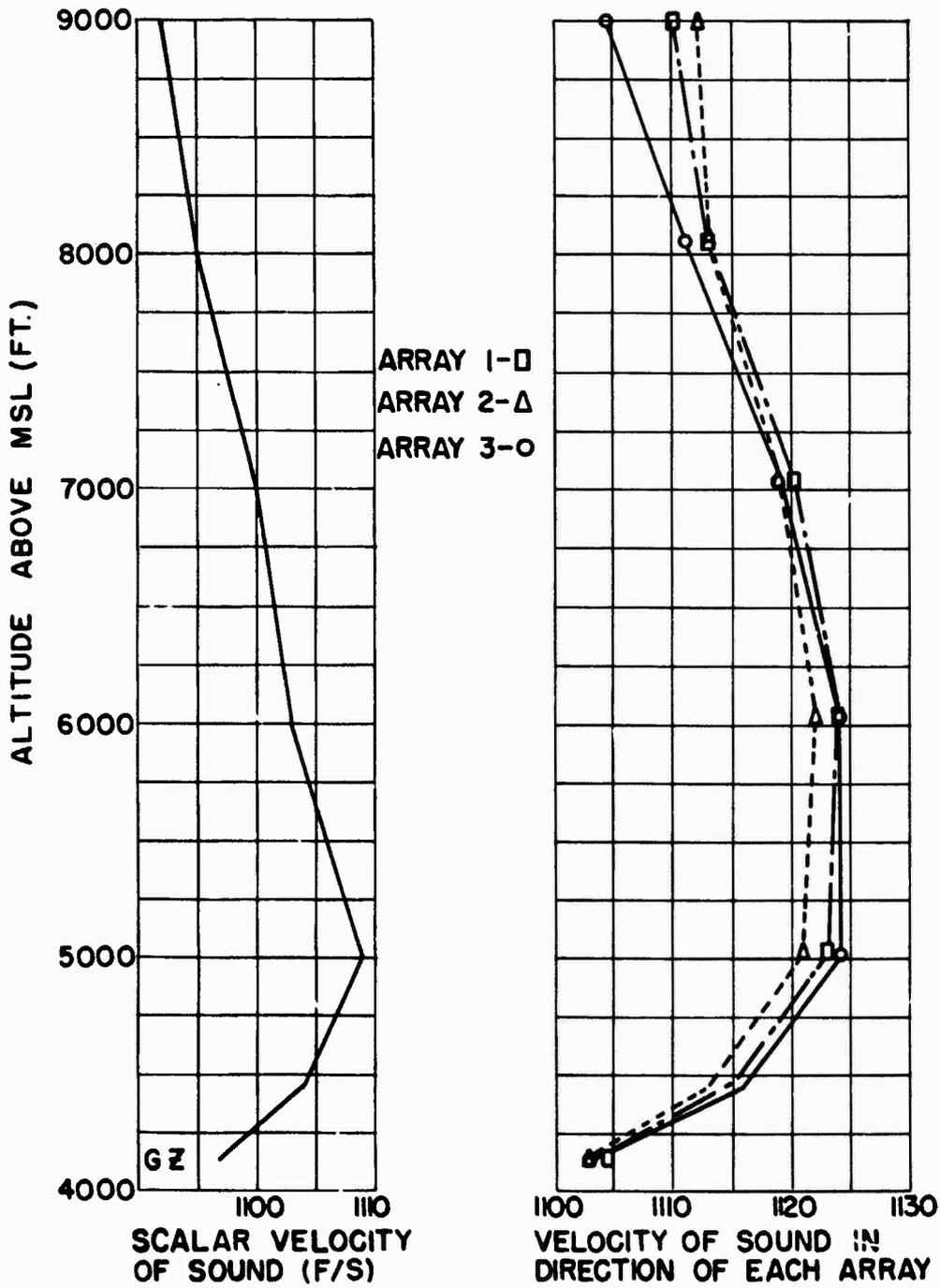


Fig. 2.3 Typical Criterion Curves

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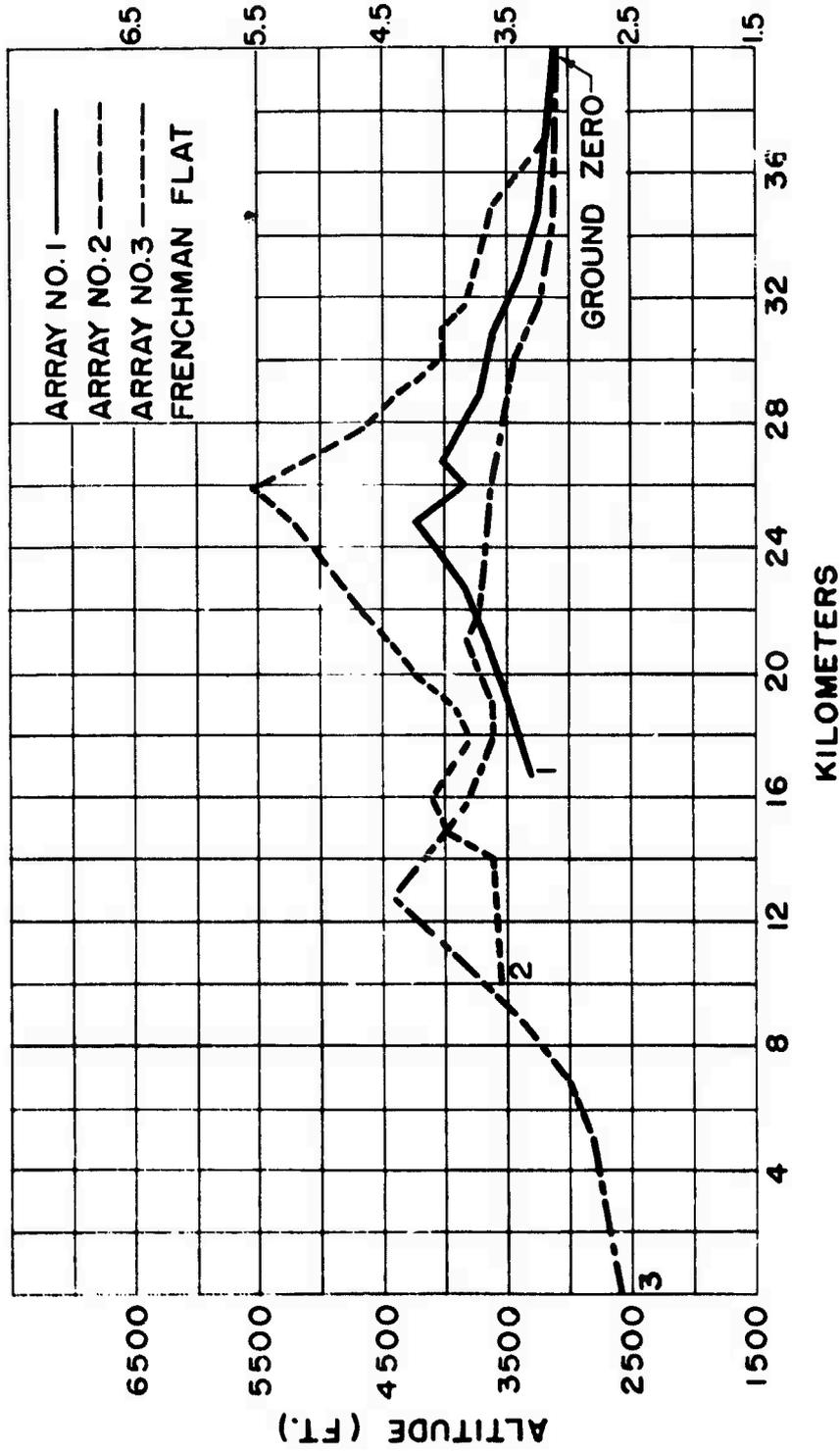


Fig. 2.4 Terrain Profile between Frenchman Flat Test Location and Microphone Arrays

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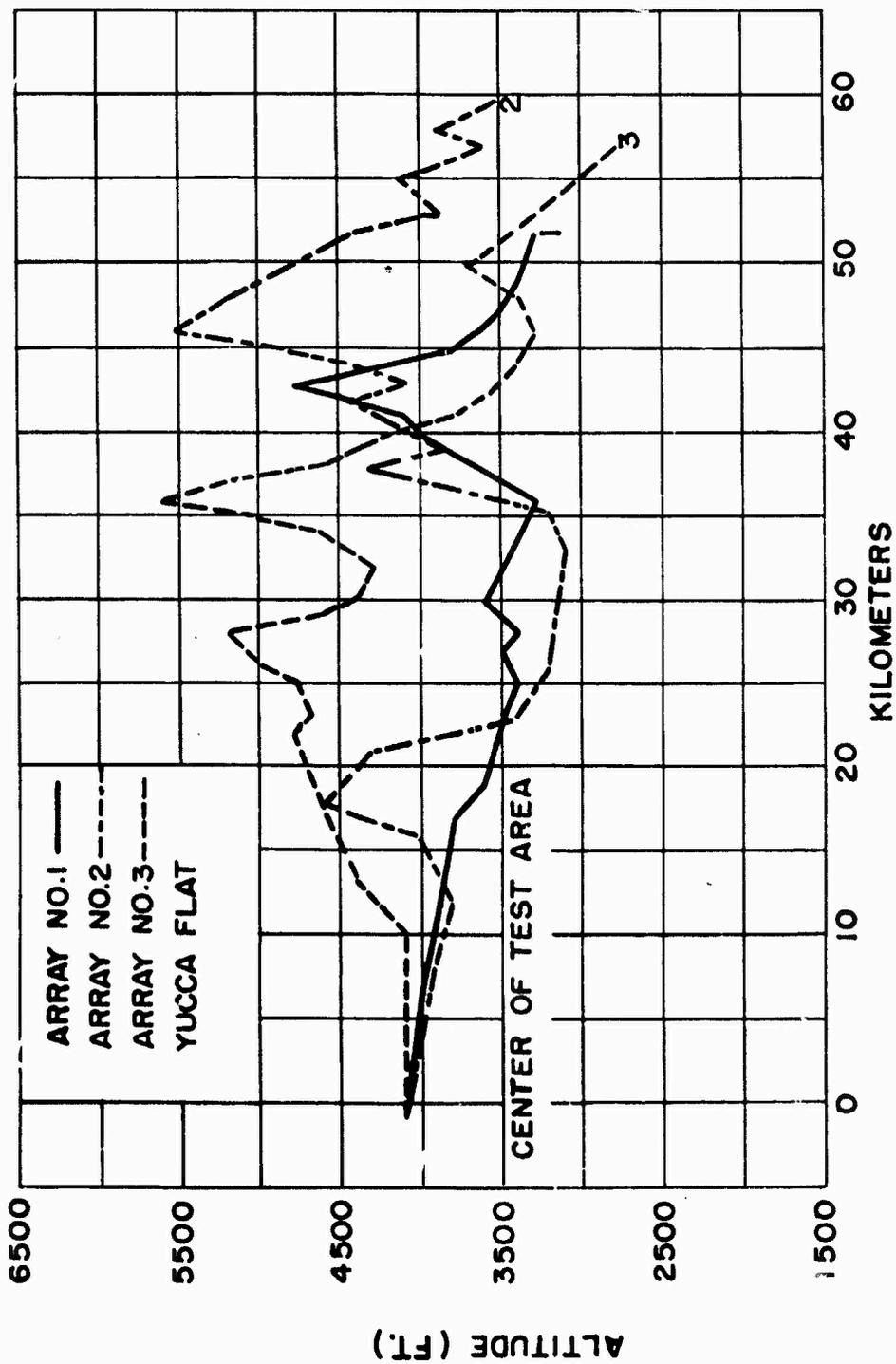


Fig. 2.5 Terrain Profile between Center of Yucca Flat Test Area and Microphone Arrays

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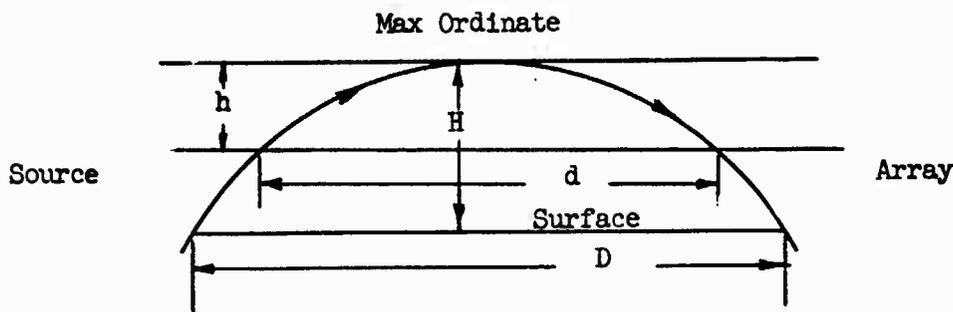


Fig. 2.6 Parabolic Sound Trajectory

### 2.1.2 Instrumentation (See Fig. 4.3)

The general layout of the sound ranging installations is indicated in Fig. 2.7. It will be noted from Fig. 2.7 that three separate microphone arrays were established and that each array consisted of four microphones. These microphones were installed at the corners of a square with sides 2 miles long within 1 part in 10,000. The array centers were separated by 18,323 meters, Array No. 1 to No. 2, and 24,864 meters, Array No. 1 to No. 3. The microphones used are standard army equipment. The nomenclature is: Microphone T-23, a component of Sound Ranging Set GR-8. Sound Ranging Set GR-8 is standard issue to Field Artillery Observation Battalions. It is described in detail in TM 11-2568 5/ and its employment in the field is described in FM 6-120. 1/ Microphones T-23 were installed in the prescribed manner using 25 cps acoustical plugs. Microphone covers were covered with an improvised wind baffle consisting of a 3 in. layer of straw held down by a net of wire fastened to stakes.

A recorder was installed in the vicinity of the center of each array. The recorders used are also components of Sound Ranging Set GR-8; the nomenclature is: Recorder BC-1337. These are six-channel recorders plotting output on teledeltos paper. A time reference with 0.01 sec divisions is printed on the record. An additional time reference common to all three recorders was provided by an electric timing clock at the center array. This clock provided electrical pulses at 5 sec intervals. Minutes were indicated by omitting every twelfth pulse. The output of the timing clock was placed on one of the spare channels of each recorder. All three recorders were controlled simultaneously from the center array by using Outpost Connecting Boxes BE-71, components of Sound Ranging Set GR-8.

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2.1.3 Experimental Procedures

On D-1 all equipment was thoroughly checked for cleanliness and operation. This included microphone checks and checks of all wire lines. Each array was then checked individually and finally the whole system was checked. There was normally sufficient wind to generate wind noise, which is a satisfactory criterion for proper operation. TNT charges of the order of 2000 lb were detonated at H-2 and H-1 hour in the general area of the atomic detonation for almost every shot in the series. Sound data were recorded for all such bursts. These bursts provided an excellent check of the attenuation settings for all channels. Settings which enabled these bursts to be detected over wind noise proved to be quite satisfactory. The sound "breaks" obtained from TNT detonations at these long ranges were not, however, clear enough to permit time interval readings and actual sound ranging.

At H-5 minutes the outlying arrays were alerted by telephone and all recorders were placed in "stand-by" to permit control from the Sound CP. At H-20 seconds all recorders were started simultaneously. This procedure was adopted after the first shot when all recorders started without closing the switch at the Sound CP. It was thought that the long wire lines between arrays may have picked up enough electromagnetic energy at the instant of detonation to throw the relays. However, later attempts to record this energy gave negative results. Signals from the common timing clock at the Sound CP were disconnected after approximately 1 minute of operation to reduce the possibility of "cross-talk" to the sound recording channels. Similarly, as the initial sound "break" appeared on each channel, the attenuation on that channel was increased to maximum to reduce the possibility of cross-talk. After the sound had been recorded on all four channels, each recorder was turned off individually.

Meteorological data were obtained from the visual stations established in the vicinity of the sound arrays and from the Air Weather Service, who provided data for the forward area. The Air Weather Service data included virtual temperatures aloft so that this temperature was taken from the AWS data for all shots except No. 10. For Shot 10 the virtual temperatures provided by the Artillery Test Unit were used. For all tower shots the wind data in the forward area were taken from the Air Weather Service report.

Wind data in the vicinity of the microphone arrays were taken from the visual metro station established at the center of Array 1 for Shots 1, 2, and 3. The visual metro station was moved to Station 6.12m (Fig. 2.7) for Shots 4-8. In addition to this station, two more visual metro stations were established for Shots 9 and 10. One of these was located in the vicinity of Microphone 1 of Array 2 to furnish local wind data for Array 2. The other was located at HM 96 in the vicinity of Array 3. The original metro station was moved to vicinity Camp Mercury Sewage Disposal Plant for Shots 9 and 10. The data from this latter station were used for local winds in the vicinity of Array 1.

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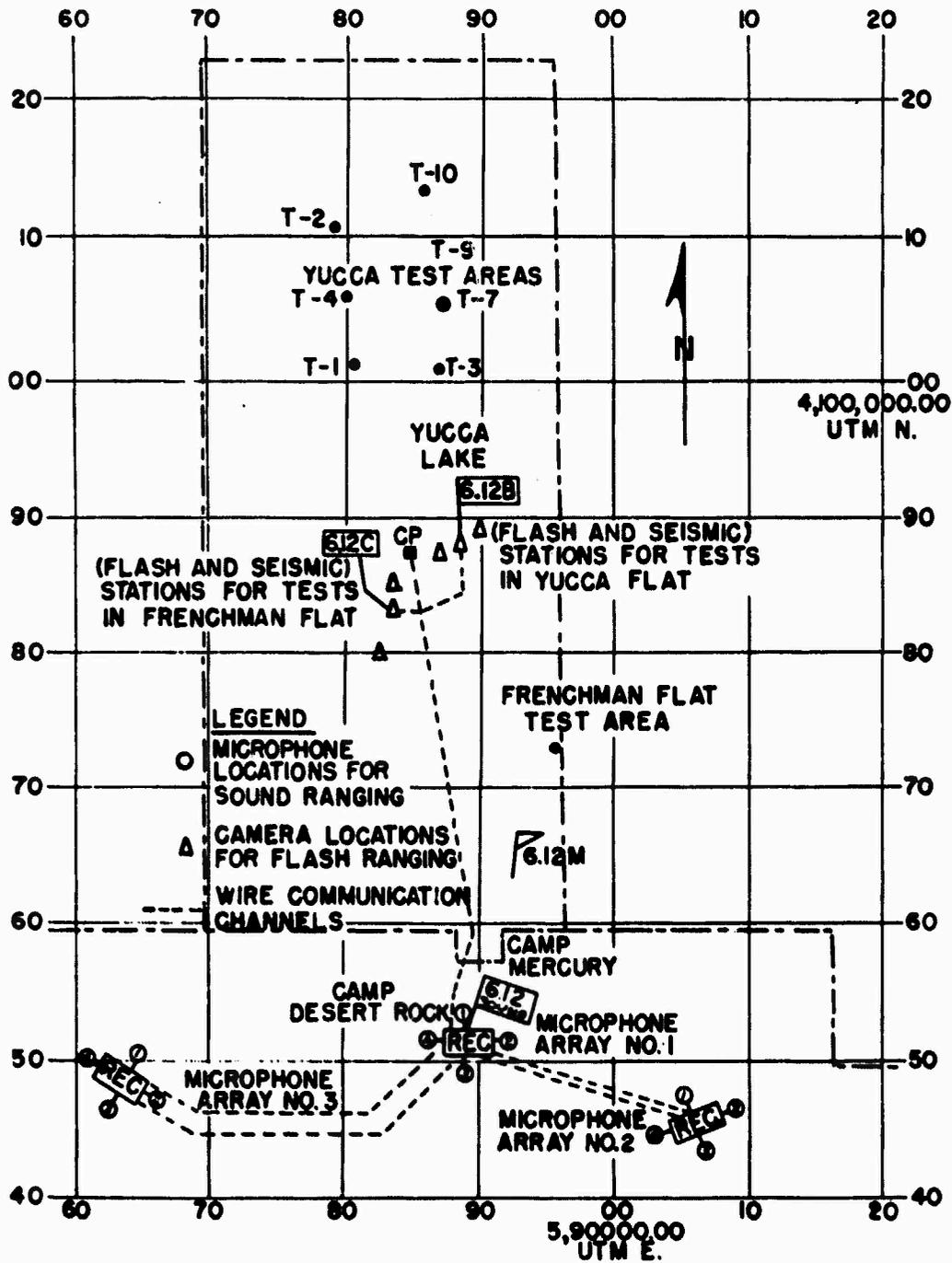


Fig. 2.7 General Layout of Project 6.12 Instrumentation

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## 2.2 RESULTS

Figures 2.8 and 2.9 represent the extreme variation in quality of the sound ranging records obtained. Figure 2.8 was recorded at Array No. 1 on Shot 6. It is interesting to note that the yield of this shot was 0.22 KT and that it was a tower shot. It is representative of the records from which it was most difficult to obtain exact sound arrival times. Figure 2.9 is representative of the best sound "breaks" obtained. This record was obtained during Shot 9 at Array No. 1. Shot 9 was an air dropped bomb with yield of 26 KT.

Table 2.1 is a tabulation of the distances from the centers of each microphone array to each burst, the angular errors of the metro-corrected sound azimuths from each array and the sound location errors. Table 2.2 indicates the errors for each shot and the variation in certain other parameters such as yield, quality of the sound records, delivery means, and the number of locations at which metro data were taken.

The results obtained by normal irregular base computations 1/ gave angular errors of the order of degrees rather than minutes so that this system was abandoned after Shot 4. Irregular base measurements were made with the aid of the common 5 sec time markers provided by the time clock at Array No. 1. The times and the coordinates for the four microphones in each array were averaged giving an averaged location and time for a microphone at the center of each array.

## 2.3 DISCUSSION

### 2.3.1 General

Analysis of the data obtained indicates that there are two principal classes of errors. The first class consists of those conditions which contribute to poor quality sound recordings. This, in turn, gave poor apparent sound azimuths caused by inaccurate time measurements. Among the factors contributing to poor sound records are height of burst, intervening terrain, yield, distance from the burst, and wind noise. It is clear from Table 2.2 that the one parameter among these which has the most effect on the quality of the records is height of burst. It is quite clear that the nearer the propagation path approaches line of sight the sharper the resulting sound "break." The sharpness of the sound break is of course dependent upon the relative energy of the higher sound frequencies. It is when the higher frequencies have been unduly attenuated that the very slow rise times, observed in Fig. 2.8 are achieved. This is, of course, also a function of the intervening terrain. From this point of view, the sound ranging sites available in the vicinity of Nevada Proving Ground left much to be desired. It is likely that less rugged terrain would permit more accurate sound ranging at lower heights of burst. Although yield will have some effect on the quality of the record, it is clear that meteorological conditions, particularly the magnitude and direction of the wind, will affect the quality of the sound records much more. In at least one instance, Shot 5, the relatively large

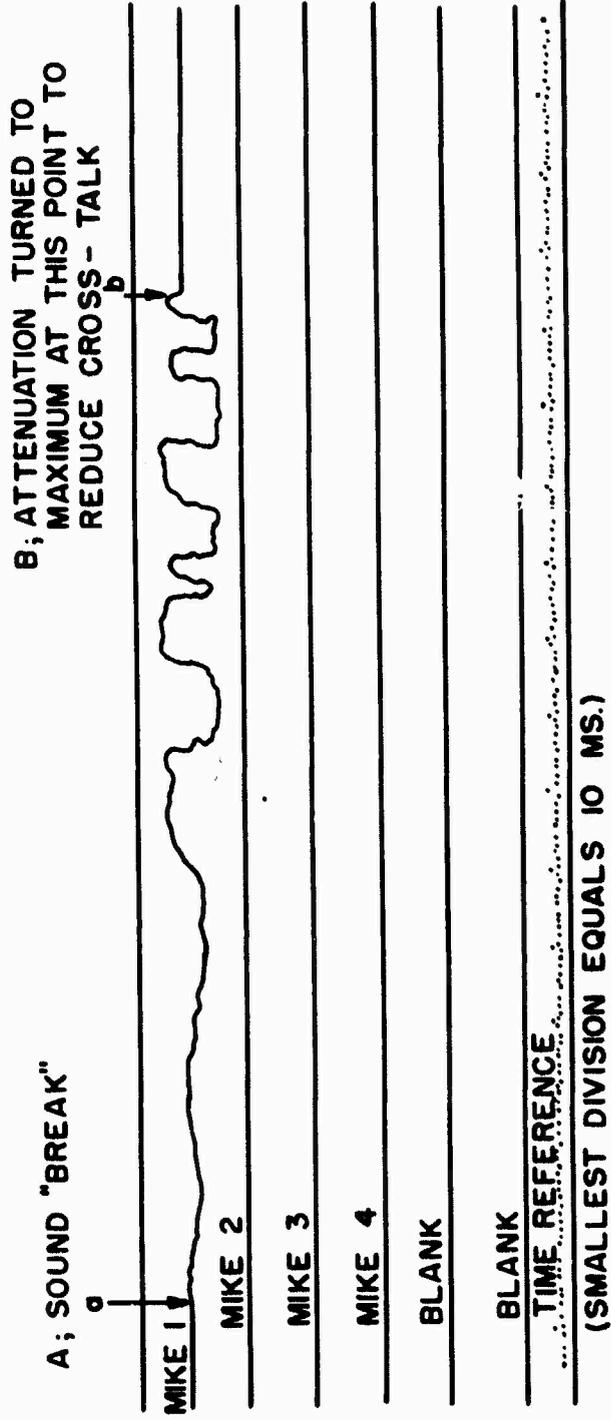


Fig. 2.8 Typical Sound Record Taken at Microphone Array No. 1 for Shot 6

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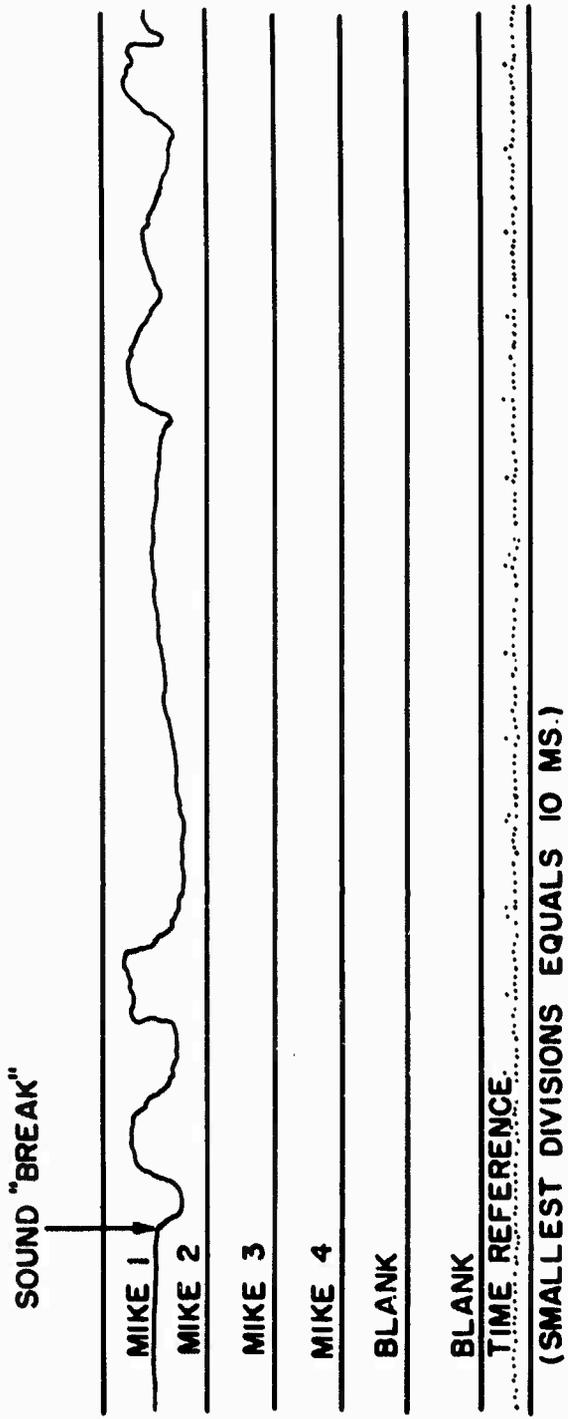


Fig. 2.9 Typical Sound Record Taken at Microphone Array No. 1, Shot 9

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TABLE 2.1 Composite Data on Shot Series by Array

SHOT	Sound Data											
	ARRAY 1		ARRAY 2		ARRAY 3		TRUE LOG OF G.Z.		SOUND ERROR			
	Dist	Az Error	Dist	Az Error	Dist	Az Error	E	N	E	N	Radial	
1 (17 Mar)	49,237	22'R	58,491	13'R	57,135	05'L	587054	4100426	+241	+339	416	
2 (24 Mar)	55,137	08'L	65,987	45'L	59,584	14'L	579736	4105643	-117	-1211	1221	
3 (31 Mar)	53,111	14'R	62,251	05'R	60,579	02'R	586763	4104294	-478	+480	678	
4 ( 6 Apr)	53,340	01'L	62,327	27'L	60,999	31'L	587294	4104530	-203	-65	213	
5 (18 Apr)	60,049	03'L	70,893	No Record	63,847	No Record	578356	4110393	No Record	No Record	No Record	
6 (11 Apr)	55,383	02'L	65,987	25'L	60,205	44'R	580645	4106031	+239	-1822	1841	
7 (25 Apr)	50,485	52'L	61,661	58'L	55,076	39'L	579790	4100935	-697	-747	1022	
8 (19 Ma.)	48,417	08'R	57,823	07'L	56,220	16'R	586675	4099594	+2522	-627	2628	
9 ( 8 May)	22,451	28'L	29,359	06'L	39,955	21'L	595550	4072538	+181	+120	217	
10 (25 May)	22,647	09'L	29,567	No Record	40,066	06'R	595407	4072562	-122	-189	225	

- NOTE:
1. Dist. in meters
  2. True Loc UTM Grid to Nearest Meter
  3. Sound Errors in Meters



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TABLE 2.2 Composite Results of Sound Locations

Shot	Yield	Delivery Means	Quality of Sound Record	No Of Met Stations	Angular Error Of Sound			Radial Error (Meters)
					Azimuth Array No.3			
					Array No.1	Array No.2	Array No.3	
1	16.2	300'Twr	Fair	2	22'R	13'R	5'L	416
2	24.5	300'Twr	Poor	2	8'L	45'L	14'L	1221
3	0.20	300'Twr	Good	2	14'R	05'R	02'R	678
4	11.	6022'Air	Good	2	01'L Air	27'L A	31'L A	213
5	23	300'Twr	Poor (Worst)	2	03'L	-	-	-
6	0.22	100'Twr	Fair	2	02'L	25'L	44'R	1841
7	43.4	300'Twr	Fair	2	52'L	58'L	39'L	1022
8	27	300'Twr	Fair	4	08'R	07'L	16'R	2628
9	26	2423'Air	Good (Best)	3	28'L Air	06'L A	21'L A	217
10	14.9	524'Gun	Poor	4	09'L Gun	- G	06'R G	225

yield was completely offset by the strong winds blowing from the arrays toward the burst. Strong local winds over the arrays also raise the noise level.

### 2.3.2 Meteorological Effects

The second (class) of error results from lack of sufficiently detailed knowledge of the variations in the atmosphere. Analysis of the metro data taken throughout the tests indicates that there were material point to point variations in the wind velocities and directions at altitudes less than about 2000 ft above the surface. It was not uncommon to find that in this altitude range winds would vary in excess of 90° in direction and 10 to 15 knots in velocity at the same time between points separated from 12 to 20 kilometers. At higher altitudes, on the other hand, there was fair agreement in wind velocities and directions even between stations separated by 50 kilometers. This condition made it possible to ignore the wind data taken by the Air Weather Service in the test area for the air burst. For the tower shots, however, the sound traversed the lower atmosphere twice and it was necessary to use the local wind structure in the test area to determine adequate corrections. In this connection, it should be noted that the variation in local winds between arrays was the most probable cause for the failure of the conventional irregular base computations to provide accurate results. The base assumption, insofar as meteorological conditions are concerned in irregular base computations, is that the metro conditions are the same across one sub-base. This condition was obviously untrue. Another invalid assumption of conventional sound computations, as described in reference 1, is that metro corrections are computed for an altitude of 600 ft above the surface. With sound barriers extending more than 2000 ft above the surface, it was obviously necessary to consider the effect of non-standard atmospheric conditions to much higher altitudes (Figs. 2.4 and 2.5).

### 2.3.3 Statistical Data

Table 2.3 indicates the magnitude of the mean angular errors, the angular standard deviations, and the average radial errors for all shots and for the air bursts only. The improvement in accuracy for the air bursts is striking. It should be noted that the air bursts represent more nearly tactical conditions insofar as employment of the atomic weapon in support of the field army is concerned. Air bursts in this sense means an appreciable height above ground and does not refer to a particular method of delivery.

TABLE 2.3

Summary, Sound Data					
Shots	Mean Angular Error	Angular Std Deviation	Angular Probable Error	Average Radial Location Error	
				Meters	% Range
1 thru 10	10'L	23'	15.5' (4.6 mils)	939	1.72
Air bursts only	14'L	13'	8.7 (2.5 mils)	218	0.61
Tower bursts only	7'L	27'	18.2' (5.3 mils)	1301	2.36

#### 2.3.4 Summary

The results of the sound ranging experiment may be summarized as follows:

(1) Sound ranging on atomic air bursts, using present standard equipment, is feasible at ranges out to at least 60,000 meters (37.2 miles).

(2) The order of accuracy of sound ranging on air bursts at these ranges is one part in 100 or better.

(3) The rugged terrain and lack of sufficiently detailed knowledge of the variations in the atmosphere preclude a general statement being made of the accuracy of location for low air or surface bursts. It would, however, be expected to be better than the 2.3 parts in 100 observed under the particular conditions of these tests.

(4) No valid measurements of the time required for location of the atomic burst could be made because of the limited personnel available to the project. It should be noted, though, that an installation of the size described in this report would probably be installed by a Field Artillery Observation Battalion on a corps front. With this personnel available, it is estimated that the location computations could be performed in 30 minutes or less.

## CHAPTER 3

### SEISMIC HEIGHT OF BURST DETERMINATION

#### 3.1 EXPERIMENT DESIGN

##### 3.1.1 Background

There have been no previous studies directed toward the determination of height of burst by seismic means. However, concurrently with the establishment of plans for this seismic test, it was learned that during the tests of Operation SNAPPER personnel engaged in general seismic studies believed they had observed a heat generated seismic wave. This factor was taken into consideration in planning this seismic test. With regard to general background on acoustic and seismic studies related to propagation and ground structure, the reports of Project 7.2 (JANGLE) and 7.5 (BUSTER), 6/ 7.4 (SNAPPER), 7/ and the report of the Geologic and Seismic Survey of Yucca and Frenchman Flats 8/ furnished basic information used in this test.

##### 3.1.2 Methods and Theoretical Considerations

The determination of height of burst by either of the two methods employed utilizes the travel time of the shock wave from its origin to ground zero. This travel time is primarily a function of the height and yield of the nuclear detonation. Thus, if the travel time is measured and the yield is known, the height can be calculated. Other factors which influence the travel time are the ambient temperature and atmospheric pressure. Complete data from which the time height curves, Figs. 3.1 and 3.2, have been computed and are contained in AFSWP Report WT-513, 9/ The effect of these factors on travel time and distances (height) are given there as follows:

$$t_1 = t_2 \quad \frac{C_2}{C_1} \left( \frac{W_1}{W_2} \right)^{1/3} \left( \frac{P_2}{P_1} \right)^{1/3}$$

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$$R_1 = R_2 \left( \frac{W_1}{W_2} \right)^{1/3} \left( \frac{P_2}{P_1} \right)^{1/3}$$

where the subscript 1 denotes the condition for case 1 and subscript 2 for case 2 (when data have been obtained experimentally), and

t = Travel Time

C = Velocity of Sound;  $\frac{C_2}{C_1} = \sqrt{\frac{T_2 + 273}{T_1 + 273}}$  (T = Temperature °C)

W = Weight of Charge (yield)

P = Atmospheric Pressure

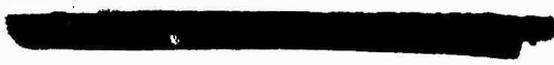
R = Distance (height)

3.1.2.1 Heat Seismic Method

The most direct method utilizes, in addition to the seismic wave generated by the shock impulse, the seismic signal thought to be generated by the heat radiated from the nuclear detonation. Upon contact with the ground, both the shock wave and the radiated heat generate seismic signals which have maximum energy at normal incidence. It is postulated <sup>7/</sup> that the heat seismic signal is generated by the intense short pulse of radiation occurring at the instant of detonation which suddenly heats the surface of the ground and the air immediately above it, producing a sudden downward pressure on a roughly circular area of the earth's surface centered on ground zero; the intensity of this pressure obviously decreases rapidly with distance from ground zero.

If a geophone were used to detect both the heat seismic and the shock seismic signals and these signals were recorded on a moving strip of paper, the time difference in arrival may be measured. This time difference would then be the actual travel time of the shock wave from its creation to ground zero. It should be noted that the measurement of the travel time would not be affected by the seismic structure since the time difference is independent of the particular path traveled as long as both seismic paths are identical.

The assumption that the two seismic paths are identical is not valid at points close to ground zero, but at distances greater than 10 kilometers the two paths become more and more nearly identical. This is due to the difference in method of generation between the thermal seismic and the shock seismic. The thermal seismic is generated simultaneously over a circular area of the earth's surface centered on ground zero while the shock seismic is generated over this area as a function of time from ground zero. Therefore, thermal and shock seismic signals traveling in the surface layer close to ground zero do not have a common point of origination. However, at greater distances



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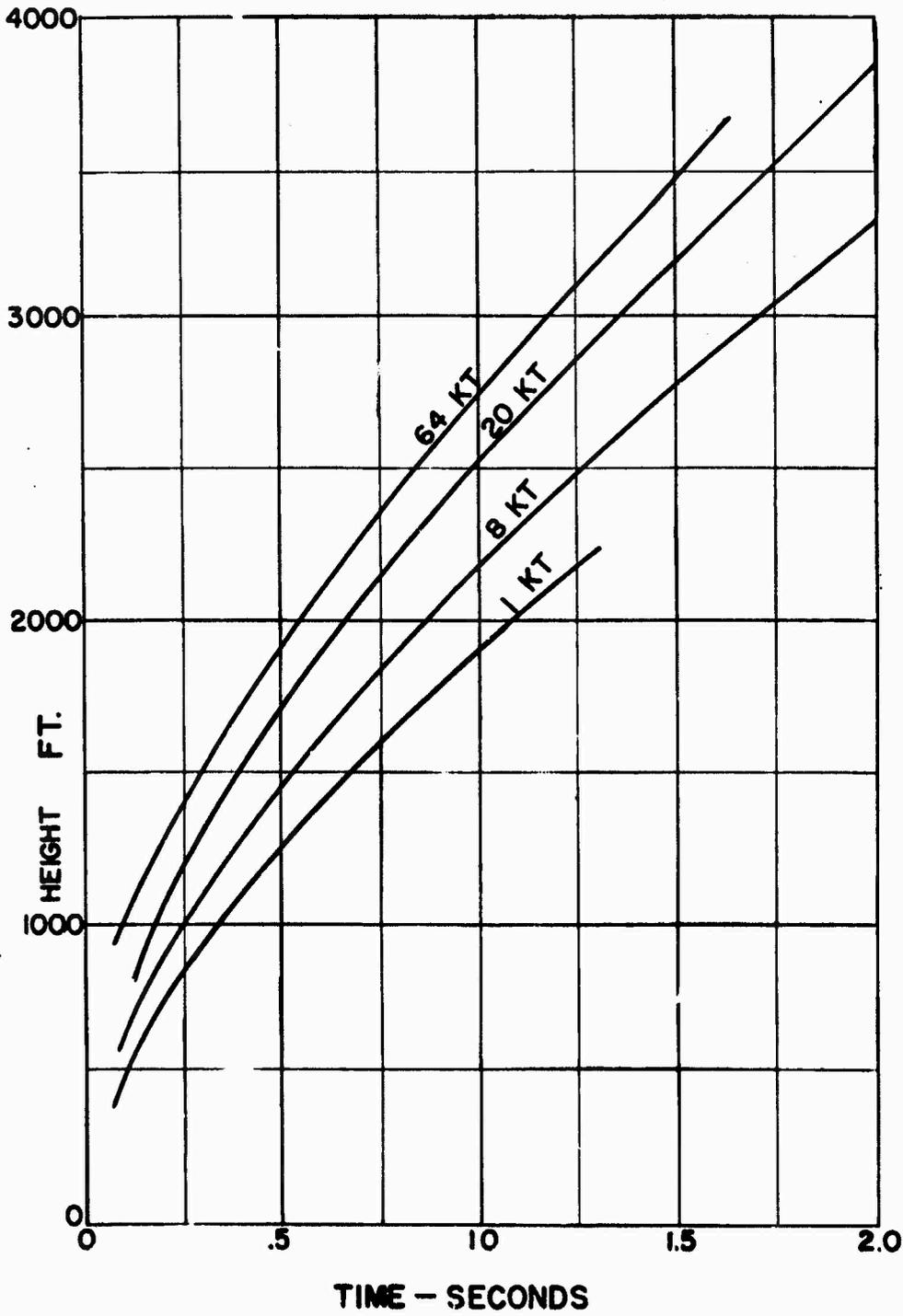
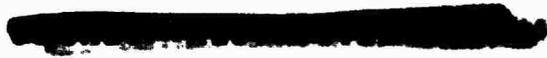


Fig. 3.1 Height of Burst vs Shock Wave Travel Time

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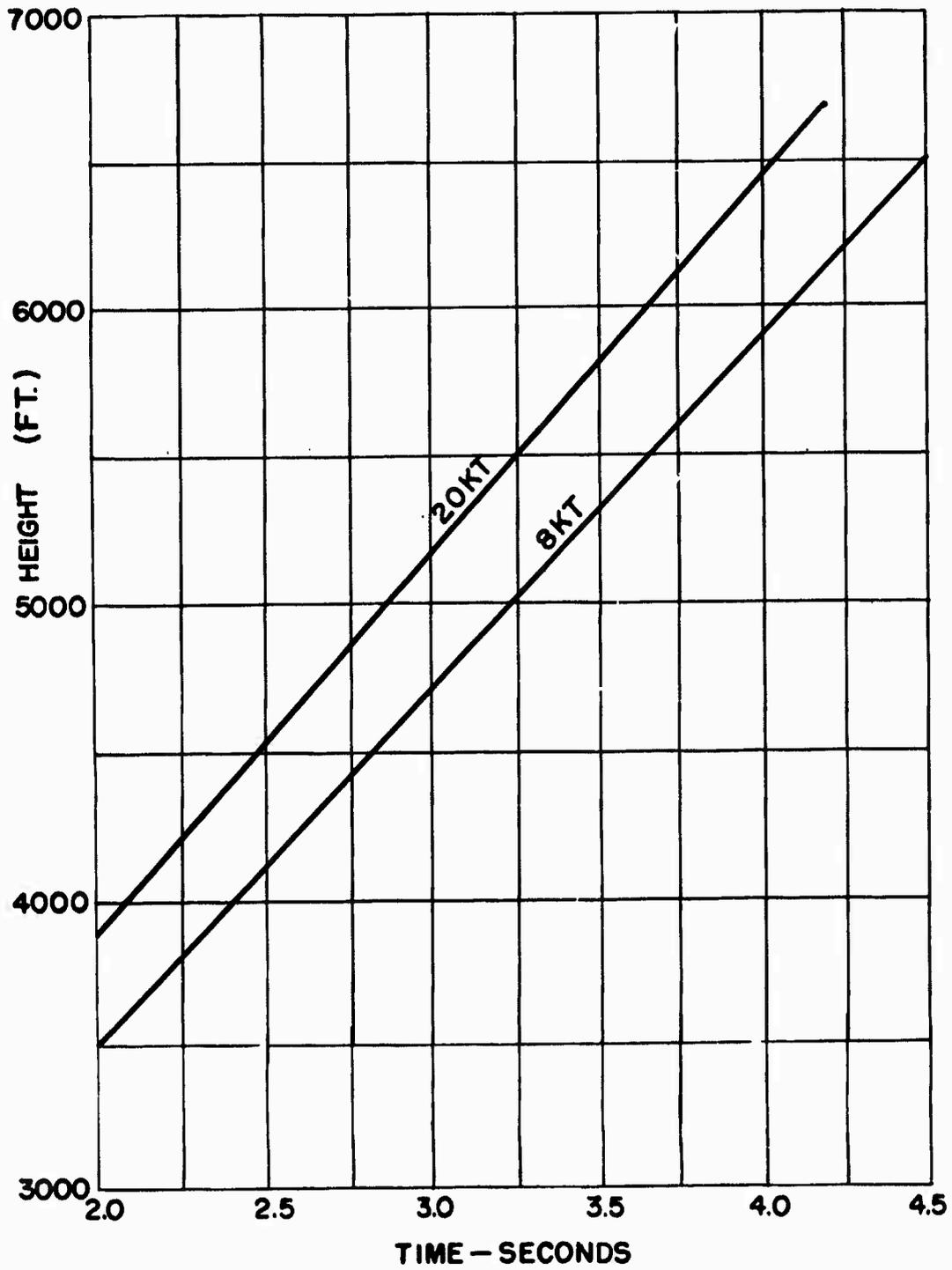


Fig. 3.2 Height of Burst vs Shock Wave Travel Time

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the initial signals received are not these surface signals but signals which have passed thru to the higher velocity sub-surface layers and have been refracted or defracted up to the seismic detector. These signals do have a primary common point of generation which is ground zero.

### 3.1.2.2 Seismic Velocity Method

This method measures the total time of the shock and seismic wave travel from detonation to geophone. Additional data as to seismic velocity are required from other sources. Knowing the seismic velocity, the seismic travel time from ground zero to geophone can then be computed and subtracted from the total time. Tactical application of this method would involve firing a high explosive shell into the ground at the approximate location of the target and then measuring the seismic travel time from the instant of shell burst to seismic arrival. The latter time, corrected to ground zero, would then be subtracted from the total, leaving the shock wave travel time between the burst point and ground zero. If the high explosive shell exploded exactly at the nuclear ground zero, the height data would have maximum accuracy. In the event that the shell exploded at some distance from ground zero, an error dependent on the variation in seismic propagation constants would be introduced. For identical earth structures the error would be a minimum. Under average conditions a separation of 500 meters between the shell burst and nuclear ground zero would not cause an error in excess of 10 per cent in height of burst after correcting for the displacement of the high explosive detonation.

### 3.1.3 Instrumentation (See Fig. 4.3)

Although there was no standard tactical equipment which completely fulfilled the requirements of this project, it was decided to utilize as many tactical components as possible. Commercial seismic exploration geophones were used for detection of the seismic signals and Recorder BC-1337, component of Sound Ranging Set GR-8, 5/ was used to record the seismic signals. These geophones required preamplifiers and the amplifiers of Microphones T-23 (also components of Sound Ranging Set GR-8) were used for this purpose. It was found that additional sensitivity was required, so that for the later tests additional amplifiers were constructed. The band pass of the whole system covered from 2 to 10 cycles per second. During some phases of the test, some channels had a high frequency cut off of 60 cps.

During the latter portion of the tests additional equipment having still more gain and greater dynamic range was constructed in an effort to verify the existance of a heat seismic signal. This equipment utilized the same geophones and preamplifiers, but was fed through a new amplifier to an Esterline-Angus Recorder. This system had a band pass of 0.2 cps to 0.4 cps, but would record frequencies up to 10 cps. This instrumentation suffered from two limitations. The time resolution was poor due to the slow speed of recording of the Esterline-Angus Meter. Moreover, the gain of the system was so high

that the burst of electromagnetic energy induced in the wire lines at time zero acted to paralyze the recording pen and mask the seismic signal for long periods of time.

The usual number of geophones employed with the GR-8 recorder was four. In the Yucca Flat area these were placed on the corners of a 1 mile square. In the Frenchman Flat area the configuration was approximately a straight line (pointing toward ground zero) of four geophones with an approximate separation of 1 mile (see Fig. 3.3). The Yucca Flat array was used for Shots 1 through 7 and the Frenchman Flat array for Shots 8 through 11 except as noted below. In addition, one Esterline-Angus recording system, located at FF-M-4, was used for Shot 8. This same arrangement was used for Shot 10 plus an additional Esterline-Angus system located near the center of Microphone Array No. 1, Fig. 2.7. In all tests the approximate distance to ground zero was between 10 and 20 kilometers, except for the location at Microphone Array No. 1. Each of the geophones was buried approximately 1 ft and was sensitive to the vertical component of the seismic signal.

The nature of the Recorder BC-1337 is such that a limited dynamic range of writing is available due to stops on the mechanical styluses. For Shots 9, 10, and 11 a modification was made to increase the dynamic range. The output of a single geophone and its associated amplifiers was fed simultaneously into the various channels; the individual channel gains being set over a wide range to permit viewing of signal amplitudes. Due to the limited number of available channels, the output from only one geophone was recorded for these three shots.

A blue box fiducial marker was used to obtain time zero and its output was connected to one of the channels of the GR-8 recorder. The blue box was actuated by the light emitted by the nuclear detonation, and the signal recorded was delayed less than 0.01 sec. In addition, the long lines to the geophones picked up the electromagnetic signal emitted at time zero and this was also recorded. This signal coincided, in most cases, with the blue box signal, but some departures up to 0.1 sec were noted. These discrepancies have not been explained satisfactorily. A second "flash" detector, consisting of a 6 in. parabolic reflector and a lead sulfide cell, was employed to give them zero for the high explosive detonations.

3.1.4 Procedures

The general procedure was to set the gains of the channels at the maximum permitted by the local ambient noise conditions, record during the detonation of high explosive charges at H-2 and H-1 hours, and then to record the detonation of the nuclear device. Departures from this general procedure were made as necessary to take into account changes in gain setting required for differences in yield and distance, etc.

3.2 RESULTS AND DISCUSSION



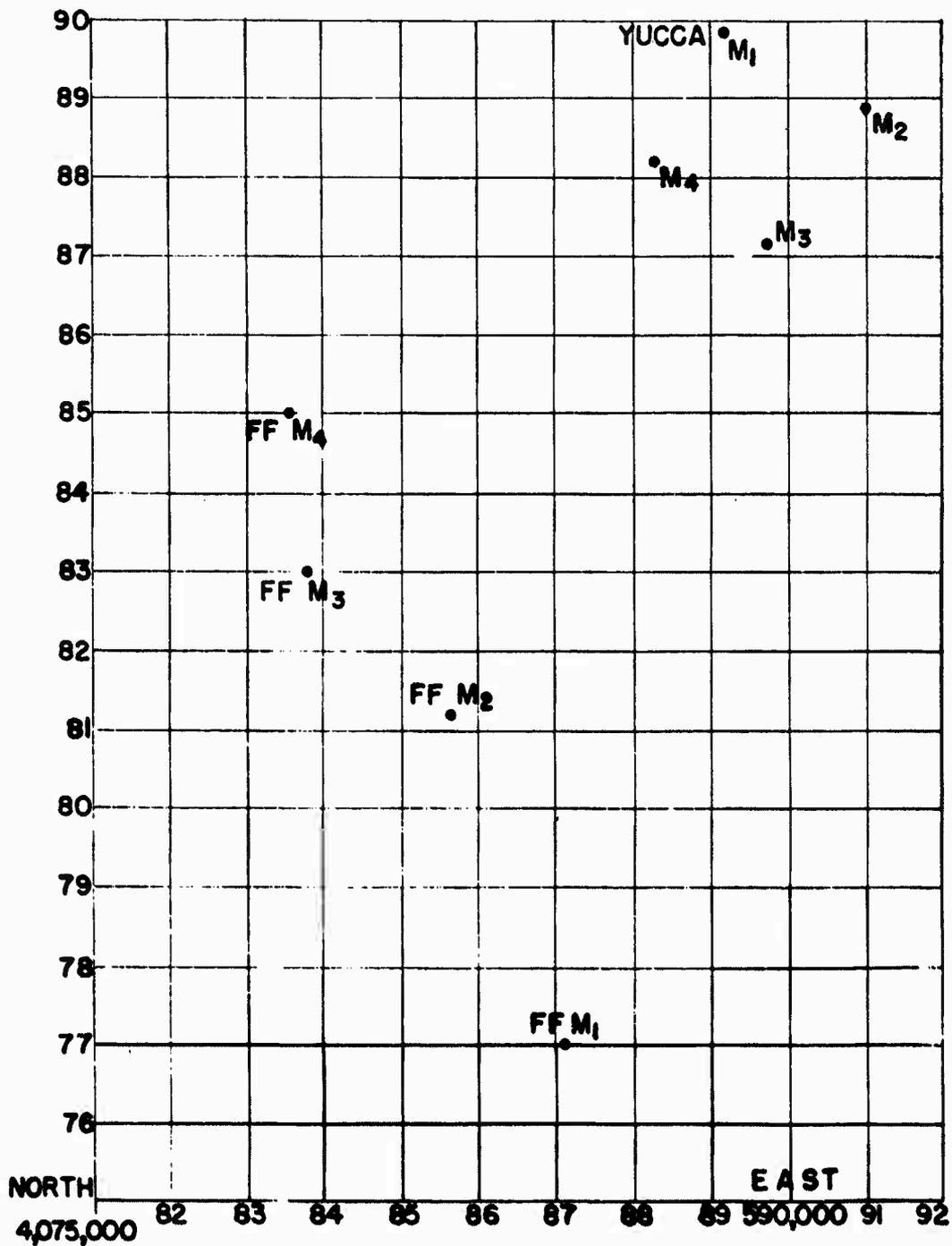


Fig. 3.3 Geophone Locations - UTM Grid Coordinates

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3.2.1 General

The duration of the seismic signal trains varied somewhat. However, a typical record lasted for approximately 1 min and started at a very low level, building up to a maximum in about 15 to 20 sec, and then slowly decaying to the background level.

In this experiment, the portion of the seismic signal train that was of interest was restricted to the initial arrival inasmuch as only this portion is significant for determining the instant of shock wave impact at ground zero. At the distances involved, 10 to 20 kilometers, the maximum energy in the initial signals was in the region 5 to 7 cps. This applied to all shots. In the central and later portions of the signal trains the predominant signal frequency became lower and lower. One cycle per second appeared to be the lowest frequency of appreciable amplitude. The response of the equipments used covered the range 0.2 to 60 cps.

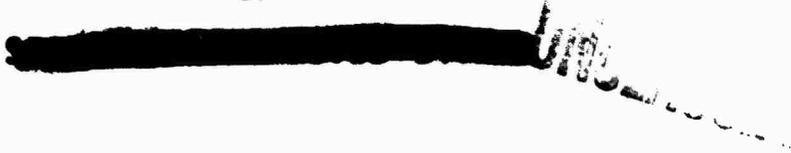
There is evidence on Shots 10 and 11 of a seismic forerunner, a signal arriving in advance of the main body of energy. This signal appears as a single unidirectional pulse and precedes the main signal by a time sufficiently long to preclude its being the associated heat seismic (see Fig. 3.4).

3.2.2 Heat Seismic Method

None of the signals found on the records could be positively identified as being thermally induced. This does not, of course, prove that such signals do not exist, but it does indicate that the particular equipment employed in this test was not capable of identifying such signals, if present, at distances of 10 to 20 kilometers. Changes were made in equipment frequency response and sensitivity without success. Additional tests with high heights of burst would be required to resolve the question as to the existence of a heat generated seismic shock. For Shot 10, however, a signal does appear 0.08 sec prior to the major seismic shock (Fig. 3.4). If this figure is used as a basis for calculating burst height, on the assumption that it has been thermally induced, the resulting height of burst is 600 ft, only 75 ft greater than the true value. For Shot 11, a signal has been noticed which precedes the seismic forerunner by 0.36 sec (Fig. 3.15). Assumed to be a heat seismic, this would be equivalent to a height of burst of 1500 ft, 166 ft higher than the official height of 1334 ft.

3.2.3 Seismic Velocity Method

The results of this method indicate that the technique can be employed to determine height of burst with adequate accuracy in the Nevada Proving Ground test areas. However, the basic seismic velocities used in these calculations were obtained from atomic tower shots. No positive evidence was obtained that the detonation of high explosive charges in the test area could be detected on the equipment used in the test. This does not mean that such explosions cannot be detected. It may be that the soil structure in the vicinity of the



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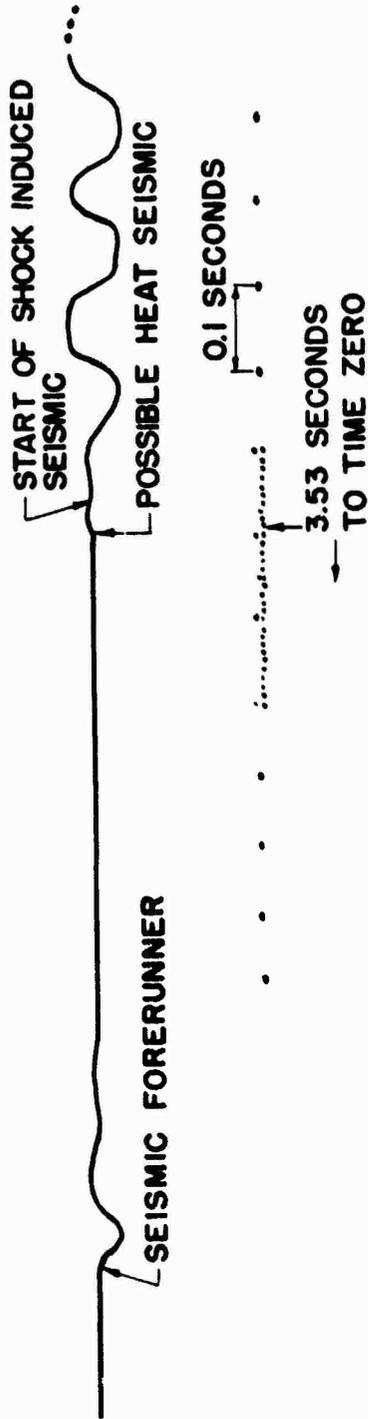


Fig. 3.4 Portion of Seismic Record from Shot 10

high explosive charges damped out the high explosive induced seismic signals or the equipment used may not have been optimum for the reception of such signals.

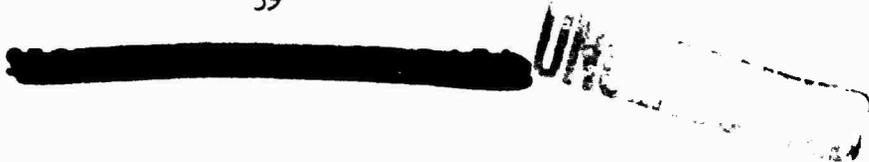
The height of Shot 4 was determined using seismic velocities established from Shot 3 (tower) and was calculated to be 610 ft, assuming a yield of 11 KT for Shot 4. This height departs 118 ft, or 2 per cent, from the actual height of 6022 ft.

There were no tower shots in the Frenchman Flat area during this series of tests, and therefore no direct seismic velocities were obtained. However, using Shot 10 data as the basis for determining the seismic velocity (assumed height of 500 ft and yield of 20 KT), the height of Shot 9 (assumed yield of 26.9 KT) was calculated to be 2580 ft, which is 157 ft, or 6 per cent, higher than the official height of 2423 ft. Except for Shot 11, for which there was no suitable seismic reference, these were the only air delivered shots of the series and consequently the only shots to which the seismic velocity technique was applicable. The unsuitability of tower shots is due partially to the fact that these shots are close to the ground and provide only very small times of travel of the shock wave from origin to ground. As the system is dependent on the relative error in this time, fixed errors cause a large relative error for low heights of burst. A second factor which introduces errors for tower shots is the unknown effect of the tower itself on the generation of seismic signals. This series of tests has demonstrated that the technique is workable if calibration of seismic velocities is determined from another atomic burst. Additional tests to determine the conditions under which seismic signals can be detected, using conventional artillery shells or other small explosive charges, are required before a final evaluation of the complete system can be made.

3.2.4 Summary

The failure to obtain reference seismic velocities from the detonation of high explosive charges (2000 lb of T.N.T.) at 10 to 20 kilometer distances tentatively indicates that the seismic velocity method of height determination is tactically infeasible. The measurements made do show; however, using seismic velocities obtained from atomic tower shots, that the systems is capable of determining height of bursts to an accuracy of 150 ft. In a situation where no extrapolation of the seismic travel time had to be made (i.e. where data were available from a previous burst having the same ground zero) the accuracy would be 10 to 40 ft, depending on yield and height of burst. The greater accuracy being obtained with lower yields and/or higher bursts. In general this ultimate accuracy would not be realized due to errors in determination of the seismic travel time caused by the necessity to extrapolate data from a distant point.

The limited number of air bursts in this series of tests, the small number of seismic recording channels, and the low signal level of the possible heat seismic signals, prevented definite conclusions from being reached regarding the feasibility of the heat seismic method. If the signals selected are truly due to the heat of the



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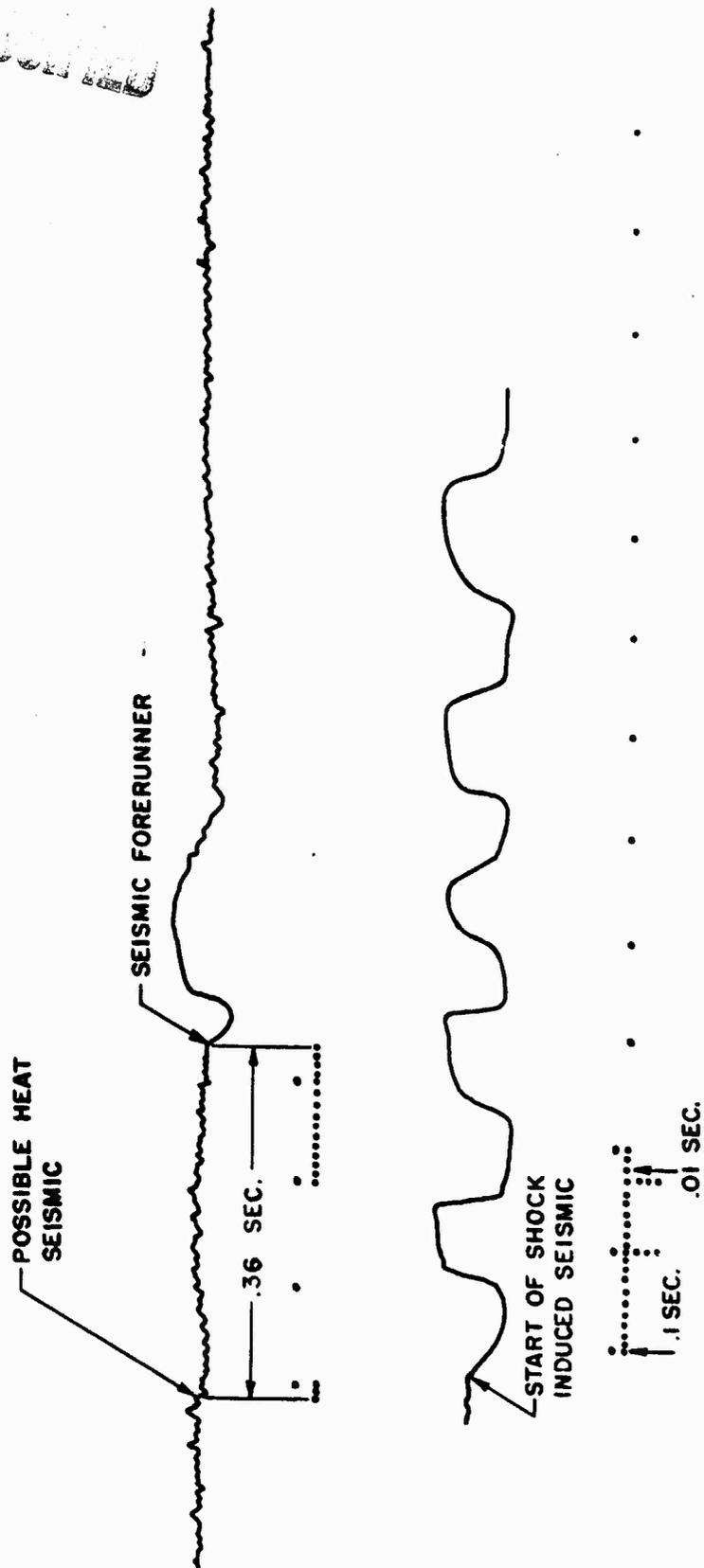


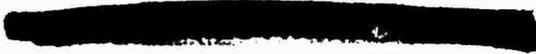
Fig. 3.5 Portions of Seismic Record from Shot 11

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atomic explosion, the accuracy of height determination by this technique is approximately 150 ft and is of possible tactical value. There is evidence of a seismic forerunner on the records for Shots 10, and 11. This seems to be a phenomenon analogous to the precursor in air described for the TUMBLER Four Shot. 9/ Computations have shown, however, that this cannot merely be a seismic wave generated by a shock precursor.

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## CHAPTER 4

### FLASH RANGING

#### 4.1 EXPERIMENT DESIGN

##### 4.1.1 Background

The purpose of this phase of Project 6.12 was to investigate the feasibility of flash ranging techniques for the tactical location of height of burst and ground zero of an atomic detonation. Inasmuch as the system to be employed had to be tactical and thus be capable of obtaining the desired data within a few minutes, the use of Polaroid film, with its rapid development process, was indicated. Since the success of this whole experiment was dependent on the performance of the Polaroid film in this application, the immediate objectives of the test became two in number:

(1) The determination of whether Polaroid film with its inherent limitations could be used in this application of fireball photography. It was feared that the relatively limited latitude of the film and its inherent rapid growth of image size when photographing high intensity light sources might require shutter speeds that could not be attained in a simple equipment, or might require the use of undesirable filters.

(2) A determination of whether pictures produced by a successful Polaroid system, used in combination with a superimposed grid, would provide sufficient instrument accuracy to warrant application of the technique to the burst location problem.

At the time Army Field Forces first indicated an interest in the development of a method for the tactical determination of the location and the height of burst of a nuclear detonation, the Signal Corps laboratories were engaged in the development of an outpost camera for use in a flash ranging system, known as Flash Ranging Set AN/TVS-1(XE-3), for the location of enemy artillery. In view of the capabilities of the system under consideration and the fact that with relatively minor changes it would be possible to apply the same flash ranging system to

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the location of atomic bursts, it was proposed to test a modification of this system.

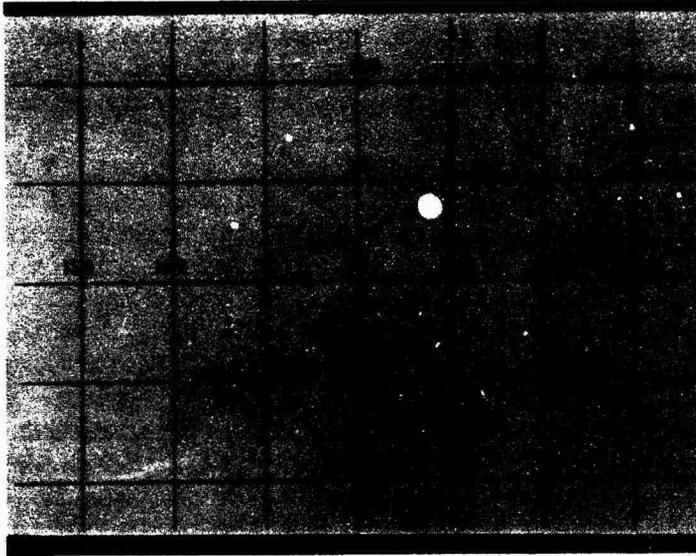


Fig. 4.1 Typical Flash Ranging Picture of Fireball with Grid Lines in Background

4.1.2 Design Considerations

Flash ranging as performed by the Artillery is the procedure employed in detecting targets by visual observation and determining the location of such targets by the intersection of "fix" rays from two or more observation posts. From this description it is quite apparent that the technique involves the location of known observation posts through survey and the determination of the location of targets by triangulation, using the baselines between observation posts, and the measured azimuths and elevation angles to the target from each observation post. Aside from this brief statement on flash ranging, this report will not concern itself with the details of techniques involving the selection of appropriate baseline lengths, the orientation of the base relative to the zone of observation, the accuracy of locations, or the orientation system. Complete coverage of these matters and other tactical considerations is contained in Department of the Army Field Manual FM 6-120. 1/

In photographic flash ranging, a grid system is superimposed on the photograph of the viewed area. This grid system is designed for the focal length of the camera such that distances on it represent angular measurements from the optical axis. Using this grid system, the angular departure of the target from the optical axis may be read horizontally and vertically. Application of these departure angles in the proper sense to the known azimuth and elevation of the camera axis provides



angular location of the target. The image of the grid lines is normally placed on film by means of a fogging light which produces a uniform partial exposure (see Fig. 4.1) except where the shadow of the grid lines appear, the grid being located as close as possible to the focal plane.

Obviously the photographic conditions involved in the location of artillery weapons are the direct opposite of those conditions associated with the atomic burst. In the preparation of artillery propellants every effort is made to reduce the intensity of the flash to a minimum. Therefore, in attempting to photograph the flash associated with the firing of an artillery piece, it is necessary to use large light gathering optics. However, in the case of a nuclear detonation, the light associated with the phenomenon is of tremendous brightness, and successful photography can employ only a small portion of this energy. In order to meet these new conditions the modifications required in the camera system involved the conversion from the somewhat conventional optics and shutter system to a satisfactory system for the new application. An examination of all available reports on earlier test series failed to disclose any experiments of a similar nature which might provide background information that could serve as a guide in the design of an adequate camera system for photography of the fireball. Most of the concern associated with the photographic problem centered about use of Polaroid film and its particular properties; namely, its high speed, its high contrast, its relatively narrow latitude, and the halations and growth of image which are evident in this film in the photography of intense light sources when optimum exposures are not used. In view of the lack of information from previous reports, most of the data concerning the atomic flash and the problems of photography associated with the acquisition of a good fireball picture were obtained from TM 23-200 10 and from discussions with personnel of Edgerton, Germeshausen and Grier (EG and G). Meeting with EG and G personnel proved very informative in the light of their wide experience in the field of photography associated with atomic tests. From these sources of information it was quickly ascertained that standard cameras such as Aerial Camera (K-20) or the standard Army Graflex Camera (TL-47), for instance, with conventional "f" numbers and shutter speeds, could not be used without the addition of high density filters. In view of the tactical requirement associated with this equipment, an effort was made to keep the unit as simple as possible. In this respect, there appeared to be no more simple type of camera than a pinhole camera. Theoretical considerations indicated that the resolution of pinhole cameras was more than adequate for the film to be used. In addition, since there was an abundance of energy available, the possibility of successfully using a pinhole camera with a slotted shutter to give the proper speed appeared to be good.

Having decided on a pinhole aperture, the next consideration involved the delay time after zero time at which the photograph should be taken. Inasmuch as the size and symmetry of the image would contribute directly to the accuracy with which the location could be determined, it was felt that the picture should be taken at an early time before the fireball had lost its symmetry. Recognizing the possible growth of

image from overexposure in the first few milliseconds, particularly on high yield weapons, it was recommended by EG and G that an experimental starting point for the exposure should be the time for minimum temperature on the temperature-time curve for a given weapon. It was felt that the exact values of shutter speed, delay time from time zero for shutter opening and the "f" number required for the system used in conjunction with Polaroid film, could best be determined experimentally. Provisions were made to permit variations in all of these parameters for the tests. As later indicated in this report, the resultant experimentation proved that photography in the region of the light minimum was not an essential requirement. The film proved to be far less critical in this respect than had been anticipated, and good photography resulted when taking exposures as early after time zero as the combined delay of the blue box (3 - 4 msec) and the mechanical shutter (1 - 3 msec) would permit.

Having established the type of lens and shutter system, it was next necessary to determine a nominal focal length, field of view, and grid system that would provide angular accuracy of 1 mil or better. This figure had previously been stated by Army Field Forces as a satisfactory angular accuracy for the location of the target. Consistent with this thinking, it was decided to assign a value of 0.01 in. to an angular mil on the film surface. This figure was chosen as being about the smallest value which could be easily read with a magnifying reader and still permit estimation of 0.2 mil. The choice of this value established the nominal focal length of the camera at 10 in. and determined that the 2-7/8 in. x 3-3/4 in. film format of the Polaroid positive would cover a field of view of approximately 250 mils x 380 mils, allowing for the mounting of a grid system holder in the aperture directly in front of the film plane. At minimum ranges of the order of 15,000 meters from a flash, this provided a more than adequate coverage in azimuth of 5700 meters at the target site and 3750 meters in height.

#### 4.1.3 Instrumentation

##### 4.1.3.1 Location of Baselines

In order to test the system proposed, it was decided to establish a somewhat tactical baseline consisting of three observation posts at which the camera instrumentation would be located. The stations were located and surveyed in at locations described in Appendix A by Army Field Forces survey teams to an accuracy estimated to be of the order of one part in 5000.

Ideally, these observation posts should have been chosen in accordance with the location of the target and the distance from it at which an adequate length baseline could be located. However, in this series of shots, since the location of ground zero varied with each shot and since the selection of each site for test operations was subject to approval for obvious safety reasons, it was decided to compromise with optimum baselines and their locations for each shot and to locate a single base for as many shots as possible. The first eight shots of Operation UPSHOT-KNOTHOLE were all scheduled for detonation in

the Yucca Flat test area, so a compromise baseline for all of these shots was established across the south end of Yucca Lake running in a generally east west direction. These stations were located approximately 1 mile apart. (See Fig. 2.7.) Coordinates are given in Appendix A. For the KNOTHOLE shots scheduled for Frenchman Flat, a better tactical baseline of somewhat longer dimensions was established running generally north and south in the area south of the Control Point Station some 9 miles west and north of the Frenchman Flat target area.

4.1.3.2 Equipment

As indicated earlier in this report the exact performance of the combination of the pinhole camera and the Polaroid film could not be accurately predicted. Therefore, to permit ample experimentation, auxiliary equipment in the nature of time delay circuits, various density filters, a selection of pinhole sizes, various size shutters and springs to provide a variety of shutter speeds, were made available for use in the tests.

For the purpose of acquiring additional data on the fireball photography, a number of Graflex cameras, PH-47, were also used.

Tripping signals for the cameras were provided by conventional blue boxes (Battery, Model MK-3, Type No. 3170, 3-4 msec delay), a number of which were made available to this project.

4.1.3.3 The Tactical Observation Post (See Fig. 4.4)

The complete instrumentation for the tactical Observation Post (OP) consisted of a blue box, the pinhole camera unit, a variable delay box, a fogging unit, and a pocket size film reader.

For orientation data, a sighting stake of known azimuth was located in the general direction to the target such that it could be photographed in the same field of view as the actual target or could be located relative to the target picture by consecutive pictures taken at known azimuth readings on the camera mount.

4.1.3.4 Auxiliary Equipment

In addition to the tactical instrumentation, three Graflex cameras (PH-47- ( ), each located at one of the outposts, were connected through a time synchronization system known as Shutter Assembly Set A-N/GVA. These cameras were tripped by a blue box at the central observation post, which acted through the AN/GVA switchboard to trip the camera at all the observation posts. These cameras were equipped with heavy neutral density filters (Kodak ND-2). The blue box actuated the shorting switch in the AN/GVA in the order of 3 to 4 msec. However, due to delays in the circuitry of the AN/GVA, the actual camera exposure did not result for 20 to 60 msec, depending on the camera solenoid and the line length to the particular camera.



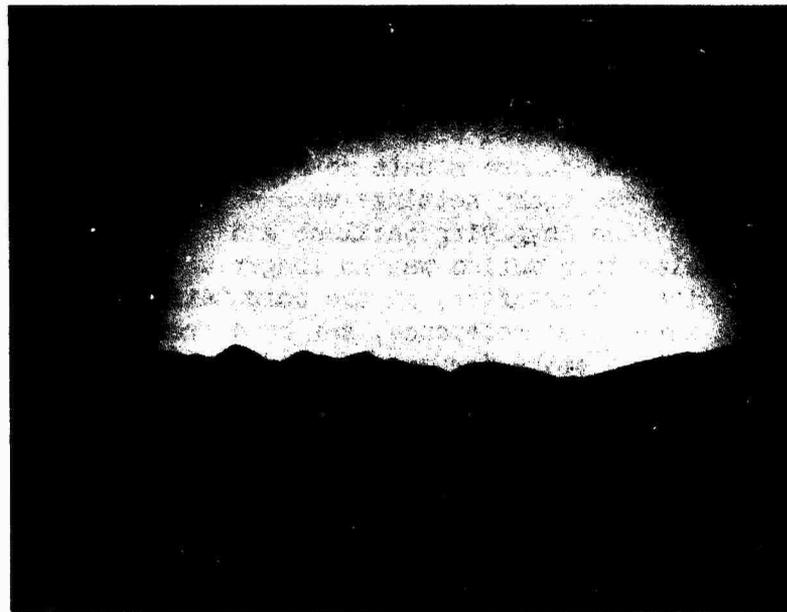
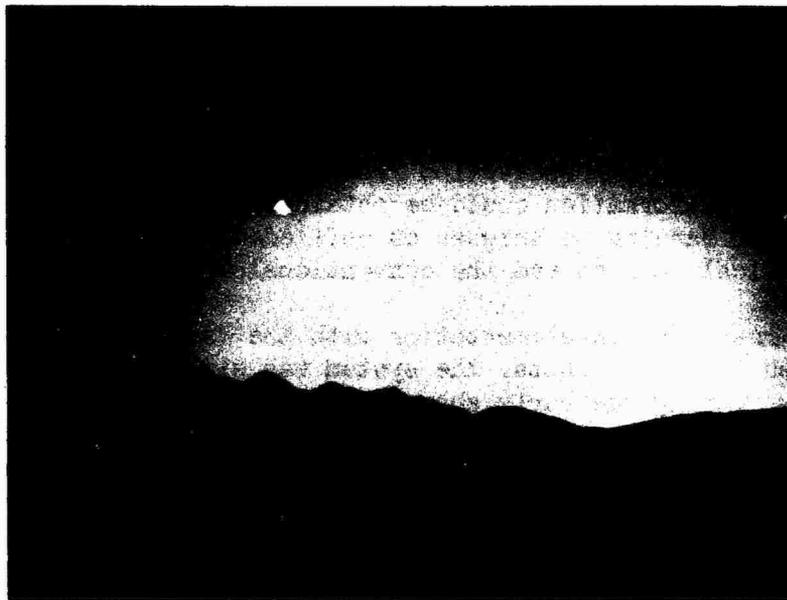


Fig. 4.2 Typical Skyglow Associated with Defiladed Nuclear Flash

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#### 4.1.4 Operations

Participation in all shots except Shot 8 involved the employment of flash ranging techniques utilizing the equipment and baselines described above. On Shot 8 it was decided that instead of returning to the Yucca area for line of sight observation it would be of interest to Project 6.12 to attempt an observation from the Frenchman Flat area to determine if some information could be obtained on the feasibility of employing flash ranging techniques on defiladed flashes. In this test both the tactical cameras and the conventional Graflex Cameras (PH-47) were employed.

As a result of experimentation with the variable instrumentation parameters on the early shots, the system was simplified after the fourth shot. During the early shots it was noted that the image of the fireball did not change to any noticeable extent in quality and very little in size when the adjustable delay times between time zero and the trip time of the camera were varied from the shortest time attainable to a time representing the time to minimum for the particular yield bomb being photographed. For these comparisons the actual time of shutter opening was maintained in the order of 5 msec. In view of the fact it no longer appeared necessary to attempt to place the time of exposure at the minimum of the temperature time curve of the bomb, it was possible to eliminate the delay box. In all tests after Shot 4 the blue box relay signal was used directly to trip the camera shutter.

Comparison of the photographic flash azimuth and elevations with the values obtained from survey disclosed that the errors in the elevation angles were large compared with the errors in azimuth. Investigation of the individual camera mounts revealed that in all cases the elevation motion and the scale settings were unreliable because of mechanical imperfections involving backlash and slippage of the elevation scale. The elevation motion was no longer used for angular measurement after Shot 4. Thereafter, in the computation of elevation data for all shots, a zero level reference, set by a transit, appeared on the azimuth orientation stake for use in reading elevation angles from the film.

#### 4.2 RESULTS

The results obtained from this series of shots are presented in the following group of tables. For the most part the data are self-explanatory.

From Table 4.1 it is evident that the computed azimuths from the individual observation posts are of an order better than 1 mil. The average error for all the angles determined during this series from the three observation posts is 0.75 mils.

From an examination of Table 4.2, it can be seen that the accuracy of location determination is dependent on the relationship of the baseline length to the target range. Shots 2 and 5, which represented the poorest ratio of range to baseline, resulted in the poorest position determination, whereas the results of the triangulation from the Frenchman Flat baseline on Shot 9 provided the best results of the series, as

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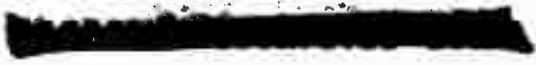


TABLE 4.1 Tabulation Of Ground Zero Computations For UPSHOT-KNOTHOLE Series  
Using Flash Baselines in Yucca Flat and Frenchman Flat Areas

Shot	UTM Coordinates True Location		Computed UTM Coordinates		Radial Error in Meters	Range from Blast to Middle OP of Base in Meters	Error of Range (%)	Number of Triangles Solved to Determine Mean Coordinate
	N	E	N	E				
1*	4,100,425.78	587,053.95						
2*	4,105,643.34	579,736.29	4,105,816.2	579,667.7	185.9	19,812	0.94	1
3*	4,104,294.13	586,763.33	4,104,136.3	586,756.4	157.9	16,650	0.95	1
4*	4,104,530.50	587,292.60	4,104,510.7	587,317.3	32.0	16,732	0.19	3
5*	4,110,392.74	578,356.30	4,100,546.0	578,311.2	159.8	20,240	0.79	3
6*	ONLY 1 STATION					24,694		None
7*	4,100,934.67	579,790.45	4,100,977.0	579,768.7	47.6	15,670	0.30	3
9**	4,072,527.30	595,550.17	4,072,546.4	595,538.3	22.4	16,023	0.14	3
10**	ONLY 1 STATION					16,023		None

\* Yucca Baseline  
\*\* Frenchman Baseline

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TABLE 4.2 Data Comparing True and Computed Azimuths for Each OP Throughout Series

Shot	Range from Target to Middle OP in Meters	OP No. 1		Diff in mills	OP No. 2		Diff in mills	OP No. 3		Diff in mills
		True Az in mills	Comp Az in mills		True Az in mills	Comp Az in mills		True Az in mills	Comp Az in mills	
1	Not computed	Not computed	Not computed		Not computed	Not computed		Not computed	Not computed	
2	19,812	Not computed	Not computed		5940.2	5940.9	0.7	5857.5	5859.0	1.5
3	16,650	6395.8	6395.3	-0.5	Not computed	Not computed		6208.4	6206.6	-1.8
4	16,732	0027.0	0028.8	0.8	6334.1	6335.9	1.8	6244.8	6245.5	0.7
5	20,240	6042.6	6042.8	0.2	5974.5	5975.4	0.9	5908.4	5909.5	1.1
6	24,694	Not computed	Not computed		Not computed	Not computed		5908.5	5909.5	-1.0
7	15,670	5916.3	5915.8	-0.5	5809.5	5809.9	0.4	5705.4	5705.5	0.1
9	16,023	2425.8	2425.9	0.1	2325.1	2324.4	-0.7	2125.3	2125.4	0.1
10	16,023	2417.6	2418.3	0.7	Not computed	Not computed		Not computed	Not computed	

Shots 1-7 - Yucca Area Baseline  
9-10 - Frenchman Flat Baseline

Accuracy Measures for All OP's - All Shots  
Average Error: 0.75 mills  
Mean Deviation: +0.26 mills  
Standard Deviation: 0.84 mills  
Probable Error: 0.56 mills

TABLE 4.3 Tabulation of Elevation Determination for UPSHOT-KNOTHOLE Series  
From Baseline in Yucca Flat and Frenchman Flat Areas

Shot	Elevation True	Elevation Computed	Difference in feet	Number of Elevation Determinations Averaged	Range from Center OP to Target in Meters	Elevation Error in Terms of Range (%)
1 **	-	-	-	-	-	-
2 **	4608.37	4663.6	65.2	2	19,812	0.1
3 **	4163.83	4463.8	323.8	2	16,650	0.6
4 **	10213.00	10306.0	93	3	16,732	0.2
5 **	4791.70	4749.9	-41.8	3	24,694	0.05
6 **	4250.86	4276.2	25.3	1*	19,565	0.04
7 **	4537.54	4530.7	-6.8	3	15,670	0.01
9 ***	5500.7	5573.5	72.8	3	16,023	0.1
10 ***	3601.7	3643.9	42.2	1*	17,627*	0.07

\* True range between OP and target assumed for this determination since no fix was possible.

\*\* Baseline Yucca

\*\*\* Baseline Frenchman Flat

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TABLE 4.4 Fireball Diameters

Shot	Official Yield	Maximum Fireball Diameter (ft)	Computed Size of Fireball at Time of Photography Determined from Individual OP's Diameter (ft)	
			OP 1	OP 2
1 (17 Mar)	-	-	-	-
2 (24 Mar)	24.5	1070	-	850
3 (31 Mar)	0.20	220	280	-
4 ( 6 Apr)	11.0	790	570	580
5 (18 Apr)	23	1115	890	810
6 (11 Apr)	0.22	220	-	510
7 (25 Apr)	43.4	1360	860	920
9 ( 8 May)	26.	1100	800	740
10 (25 May)	14.9	925	685	-

The above table shows comparison of size of fireball as determined from film records from the individual observation stations and the maximum fireball size as computed from formula  $R_1 = W_1^{1/3}$  where  $R_2 = W_2$

$R_1$  and  $R_2$  are radii in ft and  $W_1$  and  $W_2$  are yields in KT. Maximums are computed for each shot, assuming 500 ft radii for 20 KT bomb as indicated in AFSWP publication, TM 23-200. It can be seen that the flashes photographed from the individual stations generally were obtained prior to the attainment of the fireball maximum size, except for Shots 3 and 6. On these small yields the maximum fireball probably occurred prior to shutter opening, and the pictures taken on these shots are larger and probably are not the true fireball. \*The images on this shot appear to be slightly overexposed, apparently due to an excessively high fogging level plus the excessive image exposure time.

would be expected, since this provided the most advantageous ratio of baseline to range.

It can also be seen that as the number of observation posts recording data was increased from two to three, the resultant positional determination improved. This improvement would be expected since it is possible to average the location data from three triangles instead of just one. This improvement can be noted even between Shots 2 and 5, which occurred in the same general area and had the poorest relationship of baseline to range.

#### 4.3 DISCUSSION

##### 4.3.1 General

From an examination of the data presented in Table 4.4, showing the size of burst as determined from the flash ranging photographs compared to the maximum fireball size for the corresponding shot, certain interesting conclusions can be drawn. It is noted that over a wide range of yield values the sizes of the images recorded were consistently smaller than the fireball maximum size for the given yield. Had the film shown any tendency toward rapid growth of image for overexposure, the consistency of image size would not have been maintained for various size yields. Of additional note in the discussion of film performance is the fact that the images obtained were for the most part quite sharp except in a few cases where high fogging levels were used on the grid line. Therefore, it appears that the Polaroid film (Type 41) used on these tests proved more than adequate. It is apparent that, in view of the fine symmetry associated with the fireball in the early stages, at the time these pinhole pictures were taken, it would be possible to determine the center of the image with acceptable accuracy even for relatively high values of overexposure.

As indicated earlier in this report, an attempt was made on Shot 8 to observe a defiladed shot to determine if it would be possible to determine the location and height of burst by locating the center of a halo of reflected sky light in the photo. Actually the pinhole system, as earlier described, provides no variable exposure ranges to adequately perform this task. In an attempt to acquire a satisfactory picture, time exposures were taken. These were automatically initiated by blue boxes and terminated by a manual operation. In all cases the sky was uniformly overexposed and evaluation on these pictures was impossible. However, on Graflex Camera PH-47 pictures taken at  $1/400$ th sec and  $f:32$  a symmetrical sky glow was obtained. It was impossible to determine from these particular pictures the degree of accuracy that might result from attempted interpretation, since the Graflex camera had neither elevation or azimuth scales nor a grid system. Despite the fact that these pictures could not be evaluated and in view of the limited application of the line of sight techniques employed and evaluated in this report, it was felt that some analysis of the defiladed observation should be made. In order to make this evaluation, direct view Graflex pictures of some of the shots which had been taken through filters were examined. Among these shots it was noted that some were

taken at such exposures that the sky-glow associated with the flash was photographed and that this halo would have been recorded had the fireball center of the flash been hidden by a hill or other obstacle. While these pictures were taken with the same Graflex camera mentioned above and did not have scales or a grid system, it was possible to locate the true center of the fireball on the film negative by reason of its high intensity causing a defined reversal in the negative. Thus from these pictures, it was possible to extrapolate from the circular halo of the sky glow and compare an estimated location of the fireball center with the true position determined by the film reversal. By using several prints of the shots in which this halo appeared, it was possible to gain some indication of the type of position location that might be expected by observation on a defiladed flash. It was found by this analysis that the elevation position could not be determined in most cases. However, due to the general symmetry of the flash in azimuth it was possible to locate the azimuth position accurately to within  $\pm 2$  mils. On the basis of this very limited evaluation, it appears that there may be some merit in attempting photographic flash ranging on defiladed nuclear flashes. Of course, the effectiveness of such flash ranging would be very sensitive to the choice of proper exposure which, in turn, would be dependent on the amount of defilade of the weapon. It is believed that the problems of photography involved here are much more critical than in direct observation of the fireball.

#### 4.3.2 Summary

The results obtained during this series of tests indicate that the photographic flash ranging system employed in this experiment is quite adequate for the tactical location of height of burst and ground zero when line of sight conditions exist. As can be seen from the results, the azimuths to the targets obtained from the individual observation posts resulted in an average error for all shots of 0.75 mils. Not only does this figure meet the requirement that had been stated, but it is doubtful that any attempt to go much beyond this order of accuracy would be practicable because of the vastly increased complexity in the equipment that would result from such problems as film distortion and reading inaccuracies.

In view of the successful photography obtained during these tests using Polaroid Type 41 film, it is evident that this film has the properties required for this application. There is, furthermore, little doubt that this film could be used in conjunction with a pinhole camera to photograph, and therefore to do satisfactory flash ranging, on bombs of much higher yield.

The photographic flash ranging system employed in this test is highly satisfactory from the point of view of speed in providing burst locations. Locations of ground zero and height of burst could be obtained under tactical conditions in 5 to 10 minutes.

The equipment used in this project is not standard equipment. It is estimated, however, that this equipment could be made available to Army Field Forces in less than one year.

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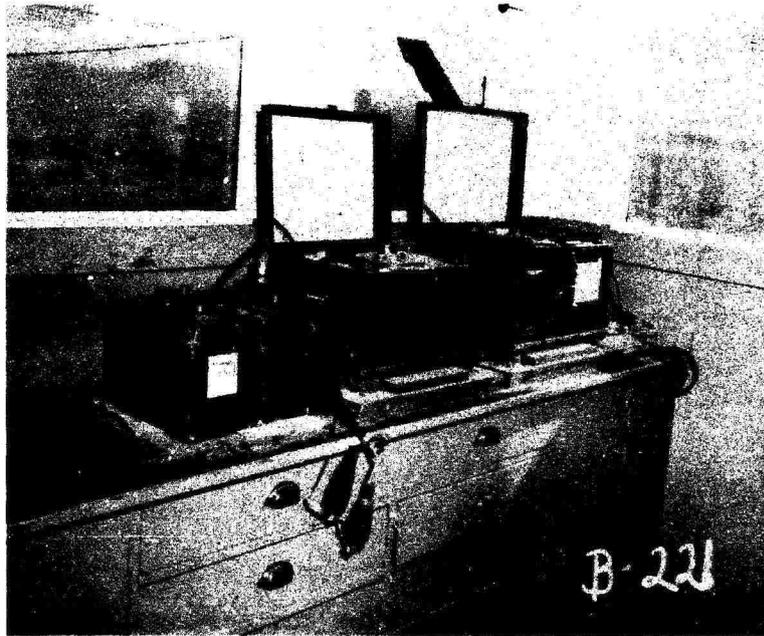


Fig. 4.3 Interior View of Van showing Sound Ranging Set GR-8 which was used for Sound and Seismic experiments.

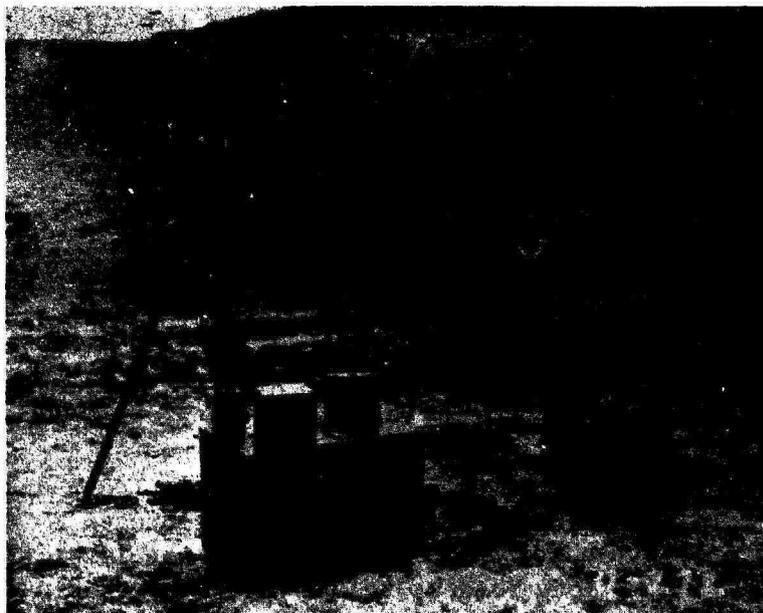


Fig. 4.4 Typical Flash Ranging Outpost Installation showing modified AN/TVS-1 Camera, with activating "Blue Box." Also shown is standard Graflex Camera and Pulse Synchronizing Shutter Set AN/GVX-1.

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## CHAPTER 5

### LONG RANGE YIELD DETERMINATION

#### 5.1 EXPERIMENT DESIGN

##### 5.1.1 Background

Most of the methods employed for the accurate determination of yield do not, by their nature, lend themselves to tactical use. Of the better known methods of yield determination, the Bhangmeter appears to be the best tactical form of equipment. This method of yield determination utilizes the correlation between yield of the bomb and the time at which a first minimum occurs in the light intensity curve. The light output of the flash is observed by a visible light sensitive detector which presents a time-intensity curve of this light output on a cathode-ray scope photographed by a Land Polaroid camera. The time to the minimum is readily counted in milliseconds and this value is used for an approximate value by substituting in the formula:

$$\text{Approximate Yield} = \frac{(\text{time in milliseconds})^2}{10}$$

For the purpose of these tests it was planned to borrow one Bhangmeter for tactical use by Army Field Forces personnel to determine the yield at distances up to 30 or 40 miles.

It was felt that the determination of yield at longer distances of the order of 100 or more miles would also be of interest. To insure operation at such ranges, it was believed that the substitution of a more sensitive cell than the photocell employed in the Bhangmeter would result in a more sensitive instrument than the standard EG and G model. Since atmospheric attenuation due to scattering has less effect on infrared radiation at long ranges, the possibility of using energy in the infrared region was considered. An examination of the fireball temperature curve revealed that the temperature at the minimum for a 20 KT bomb approached 2000° Kelvin. For black body radiation at this temperature, the peak radiation would occur at a wave length of 1.5 microns, with predominance of emitted energy at wave lengths in excess of 1 micron. In view of these considerations it was decided to

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construct a Bhangmeter-type equipment utilizing the very sensitive lead sulfide photoconductive cell which has peak sensitivity at 2 microns.

### 5.1.2 Equipment

The detector for this equipment consisted of a 2 x 2 mm Ektron lead sulfide cell, manufactured by Eastman Kodak Company, placed at the focal point of 4.5 in., f/0.9 parabolic, first surfaced collector. The output of the cell was coupled to a low-level preamplifier through a resistance capacitance network. This output was then fed to a logarithmic compression circuit and then to an oscilloscope whose sweep was triggered by the flash detected by the lead sulfide cell and which was intensity modulated at 1000 cps. The information presented on the cathode ray tube was photographed by a Land Polaroid camera.

### 5.2 RESULTS AND DISCUSSION

On the first two shots of the series, an attempt was made to use the lead sulfide system at short ranges of the order of 8 to 12 miles. On the first shot the received energy burned out the cell. On the second shot, with the parabolic collector removed, the signal from the cell failed to trigger the oscilloscope despite the apparent high level light output from the detonation. Inasmuch as the cell is known to be quite sensitive, having an equivalent noise input of the order of ( $10^{-8}$  watts/cm<sup>2</sup> for 5 millivolts of noise), it was suspected that the failure was due to the tremendous energy associated with the flash. In view of the capabilities of the cell at low energy levels, it was decided to try the unit from a distant point on the third shot.

This equipment and a conventional Bhangmeter were moved to a location approximately 80 miles (Nellis Air Force Base, North Las Vegas) from ground zero for Shots 3 and 4. For these experiments the cell was remounted in the detector housing at the focal point of the collector, and the receiver collecting area was reduced to one-fourth of the maximum area. At this location the two equipments were oriented in the general direction of ground zero and elevated toward the sky. The expected signal was to be totally dependent upon sky reflection because of the presence of a range of mountains between the location and the target. On Shot 3, which was of very low yield, the time to minimum of the light intensity-time curve occurred at approximately 6 m sec, which was 2 msec longer than the time to minimum recorded on EG and G Bhangmeters used in the test area. The EG and G Bhangmeter used them the same location as the lead sulfide detector failed to trigger because of the low light level.

On Shot 4, both the lead sulfide cell system and conventional EG and G Bhangmeter successfully operated from the Nellis AFB location.. However, a great difference in the times to minimum from the two systems resulted. The conventional Bhangmeter recorded approximately 12 msec, whereas the lead sulfide system recorded a time to minimum in excess of 21 msec. It was apparent that further investigations, beyond the scope of this project, would be required to investigate a correlation between the infrared time to minimum and the yield. Thus, it was decided to

abandon this investigation.

During Shots 5 through 9, lead sulfide cell systems were used as a matter of interest to observe the flashes from the relatively short ranges of from 8 to 15 miles. In these observations using various combinations of optical filters and electronic gains with and without compression circuits the best signal obtained from any system during these tests was only about 1/50 of the maximum signal normally recorded for the same system before saturation using flash bulb sources at close range. The wave form noted on these shots was sawtooth in nature with a rapid rise to a much reduced amplitude than would be expected before saturation, followed by a sloping decay of from 30 to 40 msec. On the basis of the repeated occurrence of this phenomenon, which was not understood, it appeared that the cells performance might be quite different under extremely high intensity radiation than under lower intensity sources. It was not possible with the limited experimental equipment available and the time element to obtain more complete data for an analysis of this observation. Subsequent discussions with the leaders in the field of lead sulfide development and investigation work, revealed that the performance described might be explained on the basis of known information concerning lead sulfide cells. The cells performance is quite dependent on the temperature of the cell which conceivably could have undergone marked changes due to the intense radiation. In addition a photoelectric effect could have been generated opposite to the photoconductive signal under certain temperature conditions which would have reduced the expected signal.

### 5.3 SUMMARY

The conventional Bhangmeter consistently gave information which permitted estimation of the yield size to within a 20 per cent accuracy.

The lead sulfide type Bhangmeter may be capable of indicating yield of the detonation. At short ranges, under intense radiation, the performance of the lead sulfide cell cannot be explained from the data available.

### 5.4 TIME OF FLIGHT DETERMINATION

#### 5.4.1 Instrumentation

Time of flight measurements were made on spotting rounds during test firing of the 280 mm gun. The basic equipment used for tests on 15, 22, and 23 May was the Mark III Bhangmeter, manufactured by EG and G. A lead sulfide photocell mounted at the focal point of a 4 1/2 in. f/0.9 parabolic collector was substituted for the conventional photohead supplied by EG and G. The timing clock in the Bhangmeter was started by an electrical signal initiated at the Fire Direction Center (FDC). This signal was obtained from a relay in the firing circuit of the gun. The burst of the round was detected by the lead sulfide cell and, after amplification, applied to a trigger circuit in the Bhangmeter indicator unit which caused the timing clock to be photographed at this instant.

#### 5.4.2 Results

Measurements made on 15 May at a range of 3500 yd from the burst were successful. The equipment was moved to a location 1000 yd to the right flank of the gun for the firing on 22 May. Measurements made on rounds, before the direct rays of the sun caused the background noise to increase by a factor of 100, were successful. The shock wave from the muzzle blast jarred the detector enough at this location to modulate the background noise, thus causing the indicator unit to be triggered. Upon resetting the indicator unit before the burst occurred, the detector did detect the burst and trigger the indicating unit at ranges of 12,000 yd. However, because of premature triggering of the indicator unit on the latter rounds, time of flight measurements were successful on the first three rounds only.

The equipment was moved to a location 3600 yd to the right of the gun for the firing on 23 May. The operation of the detector was successful at this location for ranges of 20,000 yd. However, the timing clock in the EG and G indicator unit failed and no time of flight measurements were possible.

The basic equipment was changed for the firing on 25 May. A 100 cps tuning fork supplied timing pulses to a Berkeley Decimal Scalar. The circuitry controlling the Scalar was arranged such that an electrical signal from the FDC started the Scalar and the burst of the round, as detected by the lead sulfide cell, stopped the counter. The time of flight of a round was indicated directly on the counter to hundredths of a second. No time of flight measurements were possible on this date due to the absence of the initial signal from FDC.

#### 5.4.3 Discussions

The work on time of flight measurements during this period, while not entirely successful in giving the actual time of flight of all the rounds fired, did demonstrate the soundness of using a lead sulfide cell for detecting the burst of spotting rounds at long ranges. The failure of the timing clock in the EG and G Bhangmeter indicated that a more reliable timing unit should be used. Sufficient information was obtained to establish the design parameters for a complete system for accurately determining the time of flight of a projectile.

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## CHAPTER 6

### CONCLUSIONS AND RECOMMENDATIONS

#### 6.1 CONCLUSIONS

##### 6.1.1 Sound Ranging

(1) Sound ranging on atomic bursts using present standard equipment is feasible out to at least 60,000 meters (37.2 miles).

(2) The order of accuracy of sound ranging on air bursts at these ranges is one part in 100 or better.

(3) The estimated time required to locate ground zero by means of sound ranging is 30 minutes or less.

##### 6.1.2 Seismic Height of Burst Determination

(1) The absence of detectable seismic signals from large TNT explosions is conclusive evidence that the seismic velocity method is not feasible at tactical distances.

(2) The feasibility of determining height of burst of atomic bursts by the heat seismic method has not been clearly established.

##### 6.1.3 Flash Ranging

(1) Photographic flash ranging using equipment of the type described is capable of locating ground zero and height of burst with an angular accuracy of better than 1 mil (3.3 minutes) under line of sight conditions.

(2) The possibility of employing photographic Flash Ranging on defiladed nuclear flashes appears promising insofar as an azimuth determination is concerned, however, it is very doubtful that elevation angle determinations to any degree of accuracy can be achieved from the sky glow.

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(3) Photographic flash ranging is capable of furnishing ground zero locations and heights of burst within 5 to 10 minutes after an atomic detonation.

(4) The photographic flash ranging equipment employed in this test is relatively simple and can be readily procured.

6.1.4 Long Range Yield Determination

(1) Of the systems currently available for yield determination, the Bhangmeter is the nearest approach to a tactical device.

(2) The Bhangmeter is capable, generally, of providing yield information within 20 per cent of the accepted values at distances to 40 miles and under non-line-of-sight conditions.

(3) Substitution of a lead sulfide cell in the Bhangmeter may extend these capabilities, but would require extensive investigation to establish the correlation between yield and time to first minimum in the light intensity-time curve for its spectral response.

6.2 RECOMMENDATIONS

6.2.1 Seismic Height of Burst Determination

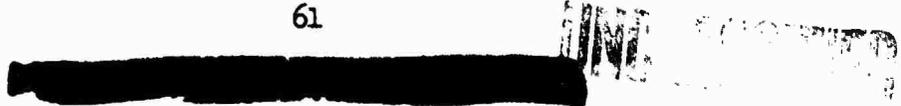
Inasmuch as the data accumulated in the experiments described in this report were inconclusive in determining or refuting the existence of a usable heat seismic signal, it is recommended that additional field tests be performed with equipment specifically designed for detection of such a signal. These tests should be performed to determine whether the heat seismic exists, what its characteristics are and whether such a signal might be satisfactorily employed for height of burst determination, assuming that there still exists a need for such a determination not satisfied by other means.

6.2.2 Long Range Yield Determination

Pending the existence of a requirement for long range yield determination of the order of 100 to 300 miles. It is recommended that the possibility of employing infrared sensitive cells in a Bhangmeter type of instrument be investigated.

6.2.3 Lead Sulfide Cells

In view of the apparent failure of lead sulfide cells to perform in the expected fashion under the high illumination levels experienced at ranges from 8 to 15 miles from the nuclear flashes, it is recommended that research centers interested in lead sulfide cell development and improvement undertake a program to investigate lead sulfide cells and their performance under high illumination conditions if the performance of the cells cannot be justified on the basis of known facts at this time.



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APPENDIX A

SURVEY CONTROL

A.1 GENERAL

The trig list comprising the remaining pages of this appendix contains the locations of the survey control points established by survey teams of the Army Field Forces Test Detachment in connection with Project 6.12, Operation UPSHOT-KNOTHOLE. All horizontal control is given in Universal Transverse Mercator coordinates; vertical control is in feet above mean sea level. This survey was based on first, second, and third order control points established by the U. S. Coast and Geodetic Survey, U. S. Geological Survey, and the Corps of Engineers. In addition to stations established by Army Field Forces Test Detachment personnel, there is a list of locations of weapons test sites. These latter locations were computed from the geographic grid coordinates furnished by Silas Mason Co., civilian contractors.

The accuracy of the locations established by Army Field Forces Test Detachment is one part in 5000 relative to the first order Coast and Geodetic control points. The accuracy claimed for the test area site locations established by Silas Mason Co. is one part in 25,000 relative to the first order Coast and Geodetic control points on which the test area locations were based. On this basis, it is estimated that the overall accuracy of the locations of the sound and flash ranging bases relative to the true weapon locations is one part in 10,000 or better.

All stations in the attached list, except for the weapon test area sites, have been permanently marked with "Fort Sill" type markers. These consist of a short length of 1/2 in. steel pipe imbedded in a concrete block. Into the pipe is placed a 2-ft steel rod to which is welded a steel flag. The station designation indicated herein is painted on this steel flag.

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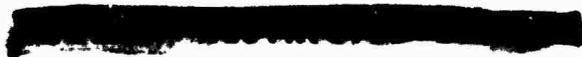


TABLE A.1 Coordinates of Control Points and Microphones of Sound  
Base Desert Rock Area

<u>STATION</u>	<u>E</u>	<u>N</u>
KRAMER (CP-1)	92348.50	52902.19
METRO	88410.55	51705.38
D.P.	85459.49	48104.98
MAC (CP-5)	91907.52	50693.00
SIGNAL MT. (CP-3)	02250.83	48689.89
CHARLES (CP-2)	93206.72	42613.06
BILL (CP-4)	98724.49	42083.89
	<u>ARRAY NO. 1</u>	
MIC 1	88901.38	53484.84
MIC 2	91055.11	51092.88
MIC 3	88663.15	48939.15
MIC 4	86509.42	51331.11
	<u>ARRAY NO. 2</u>	
MIC 1	04997.93	47155.74
MIC 2	07915.06	45795.46
MIC 3	06554.78	42878.33
MIC 4	03637.65	44238.61
	<u>ARRAY NO. 3</u>	
MIC 1	64987.38	51086.97
MIC 2	65820.44	47077.95
MIC 3	62711.42	46244.89
MIC 4	61878.36	49353.91

D.P.: Dynamite point for purpose of checking microphones.

Metro: Rear metro station.

TABLE A.2 Coordinates of Microphones of Seismic Base and  
Flash Outpost Yucca Flat Area

<u>STATION</u>	<u>E</u>	<u>N</u>	<u>ALT. FT.</u>
MIC 1	89211.35	89825.67	
MIC 2	90648.29	88783.13	
MIC 3	89711.32	87367.94	
MIC 4	88324.34	88285.84	
OP-1	86834.29	87232.59	3938.6
OP-2	88374.27	87825.06	3939.4
OP-3	89723.69	88697.32	3961.1

TABLE A.3 Coordinates of Control Points, Flash Outpost, and  
Mic of Seismic Base, Frenchman Flat Area

<u>STATION</u>	<u>E</u>	<u>N</u>	<u>ALT. FT.</u>
BROWN (CP-7)	90842.10	69772.02	
BURK (CP-6)	90897.58	73098.34	
JIM (CP-10)	94064.49	71890.08	
JUNE (CP-9)	94373.86	69750.47	
TOM (CP-8)	91399.59	64913.84	
BOB (CP-11)	94548.85	65202.87	
GUN	92342.97	63376.56	
PT. 28	95388.05	65418.57	
PT. 22	89044.54	66729.85	
PT. 13	92287.16	63396.49	
PT. 11	92313.60	63312.43	
OP-1	83553.13	85148.48	4026.4
OP-2	83417.75	82994.77	3835.82

TABLE A.3 (Cont'd)

<u>STATION</u>	<u>E</u>	<u>N</u>	<u>ALT. FT.</u>
OP-3A	82524.73	79734.73	3797.11
MIC 1	85645.58	81242.87	
MIC 2	84086.63	81720.04	
MIC 3	83907.49	83026.39	
MIC 4	85358.12	83023.66	
OP-3	82612.17	79859.78	3714.84

TABLE A.4 Coordinates of Weapons Test Area Sites Computed From Geographic Coordinates Furnished by Silas Mason Company

<u>STATION</u>	<u>SHOT</u>	<u>E</u>	<u>N</u>	<u>ALT. FT.</u>
T-3	1	587053.95	4100425.78	4025.00
T-4	2	579736.29	4105643.34	4308.27
T-7-5a	3	586763.33	4104429.13	4163.83
T-7-3	4	587121.34	4104508.38	4191.00
T-2	5	578356.30	4110392.74	4491.70
T-4a	6	580645.16	416030.71	4250.86
T-1	7	579790.45	4100934.68	4237.54
T-3a	8	586675.24	4099593.79	4008.74
F	9	595554.75	4072793.18	3077.7
F	10	595554.75	4072793.18	3077.7

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