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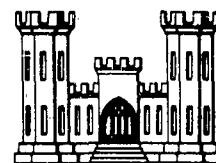


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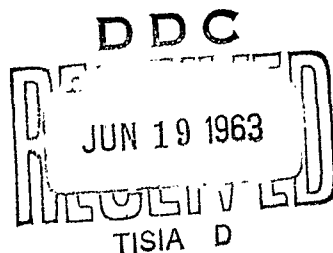


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SOIL DENSITY STUDIES IN CONNECTION
WITH DETECTION OF UNDERGROUND
NUCLEAR EXPLOSIONS

FINAL TECHNICAL REPORT
1 NOVEMBER 1962

U S Army
Engineer Research And
Development Laboratories



FORT BELVOIR, VIRGINIA

SOIL DENSITY STUDIES IN CONNECTION
WITH DETECTION OF UNDERGROUND NUCLEAR EXPLOSIONS

Part I - Nuclear Techniques

Part II - Thermal Techniques

Packrat, Hardhat and Gnome Events

FINAL TECHNICAL REPORT
1 November 1962

Submitted in Accordance with Requirements of
Program Vela/Uniform T/182
(Air Force Technical Applications Center Project 7.7)

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PREFACE

Part I of this report was prepared by Mr. Dwight L. Gravitte and Sp/5 Leonard M. Young of the Basic Sciences Section, Mine Detection Branch, U. S. Army Engineer Research and Development Laboratories. Part II was prepared by Mr. Stanley L. Carls and Sp/5 Leonard M. Young of the Basic Sciences Section. Both parts were reviewed and approved by Messrs. Stephen E. Dwornik, Project Director, and Charles N. Johnson, Jr., Chief of the Basic Sciences Section, Mine Detection Branch, U. S. Army Engineer Research and Development Laboratories, Fort Belvoir, Virginia.

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PART I

NUCLEAR TECHNIQUES

I. INTRODUCTION

1. Objective. - To determine (a) if density changes occurring in soils where underground nuclear explosions have taken place can be detected by measurements with nuclear density-measuring instruments; (b) if these changes can be used to indicate differences between blast and non-blast areas; (c) if density differences occur from day-to-day after detonation. A fourth objective is to indicate areas of research and development to advance the state-of-the-art in equipment and techniques which might make the method favorable for detection of areas where underground nuclear explosions have occurred. This report covers tests conducted at the Nevada Test Site and at Carlsbad, New Mexico. The work at the Nevada Test Site was conducted in connection with the Packrat Event during 7 - 17 November 1961 (pre-shot) and 27 November - 6 December 1961 (post-shot), and in connection with the Hardhat Event during 11 - 14 February 1962 (pre-shot) and 15 February - 2 March 1962 (post-shot). The work at Carlsbad, New Mexico, was conducted in connection with Operation Gnome of the Plowshare Program during 8 - 9 December 1961 (pre-shot) and 11 - 19 December 1961 (post-shot) and 3 May 1962 (post-shot).

2. Background. - The report on the nuclear detonations under Rainier Mesa in Operation Hardtack II pointed out that there was extensive upheaval and subsequent settling of the soil in the area of the underground explosion which indicated a probable change in density of the disturbed soil. Soil density changes might be expected to be detectable by suitable instrumentation such as nuclear density gauges which have been developed to measure the density of material moving along a conveyor belt. Such a gauge moved over the soil should detect relative density changes in the soil.

II. INVESTIGATION

3. Theory. - The density of the soil in the vicinity of the blast should be altered as a consequence of (a) the shock wave on soil compaction and (b) mechanical heaving. If these density changes are of sufficient magnitude for reliable detection and exceed variations in density due to natural causes, density measurements taken before and after the explosion can be used to indicate areas where underground blasts have occurred.

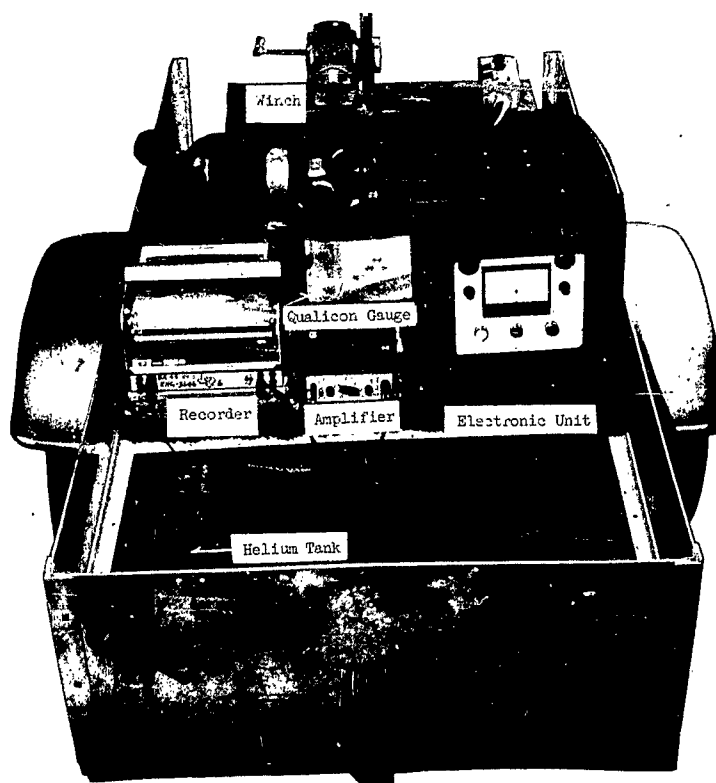
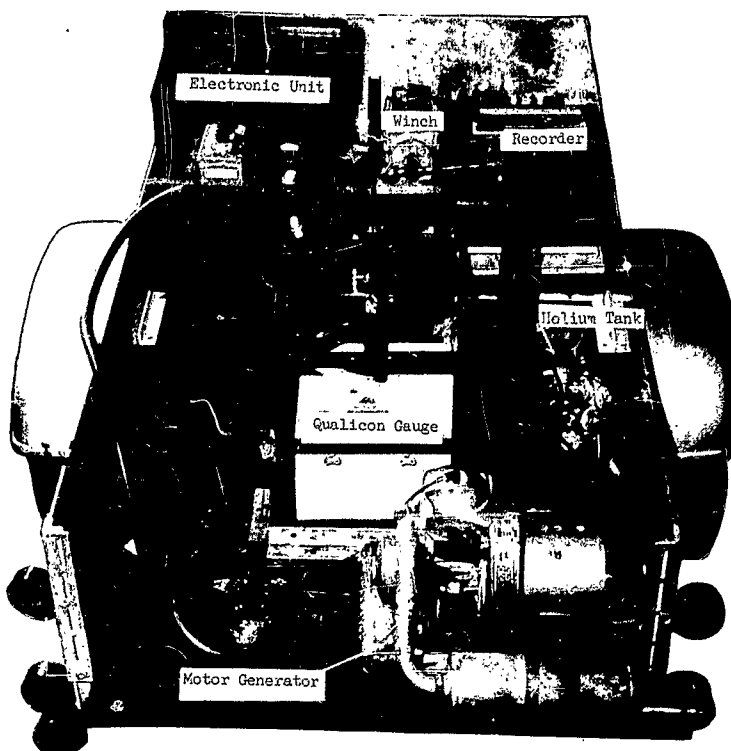


Figure 1

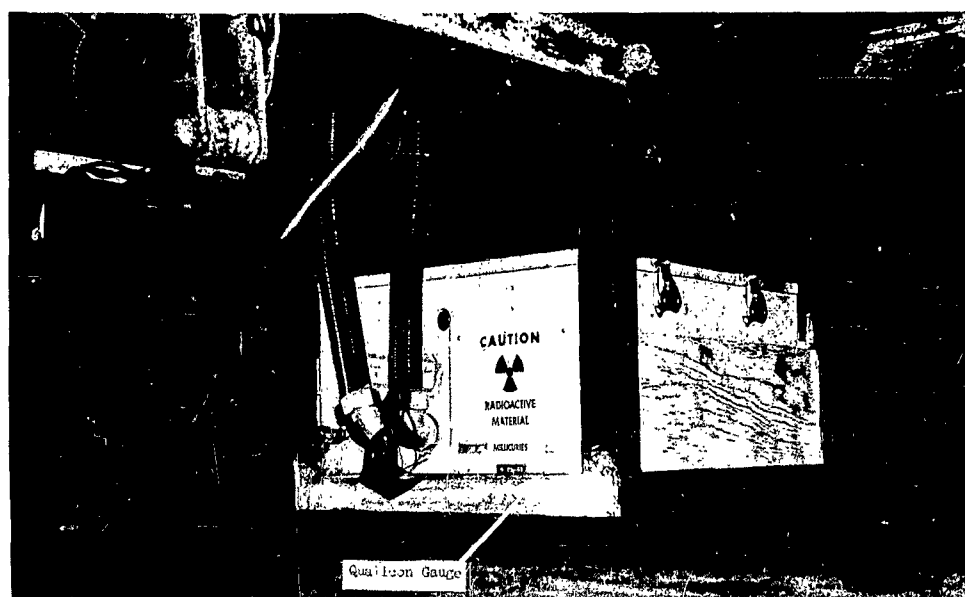
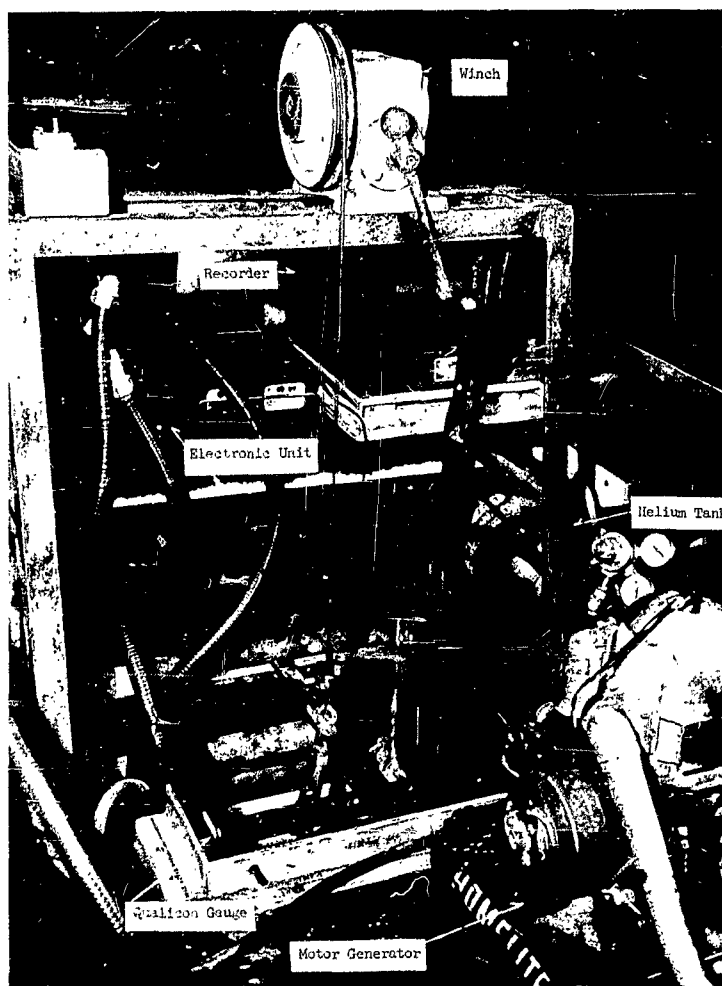


Figure 2



Figure 3

4. Instrumentation. - Two commercial nuclear density gauges manufactured by Nuclear Chicago Corporation were used in the measurements: (a) the Qualicon 502 (bulk density) gauge, trailer-mounted as shown in Figures 1 and 2, for continuous measurement of the relative density of the soil; and (b) the hand-carried model P-22 surface density gauge (Figure 3) for measurement of in-place (point-by-point) density of the soil. Both gauges read an average density (wet) of soil to a depth of 3 to 8 inches. The principle of operation of both instruments is identical: gamma rays from a Cesium 137 source contained in one end of the gauge penetrate the soil, are scattered by the soil material, and are detected by a detector in the other end of the gauge which responds only to gamma rays. The detector in the Qualicon 502 gauge (continuous reading) is an ionization chamber; and in the P-22 gauge (point-by-point measurement), a Geiger tube. The Qualicon 502 gauge was used only for the Packrat Event whereas the P-22 gauge was used for all phases of the work, both at Nevada Test Site and at Carlsbad, New Mexico.

The Qualicon 502 gauge has an adjustable sensitivity and provision for ionization current suppression so that the desired span and range of the gauge may be set to the desired level. The sensitivity of the P-22 gauge is approximately 200 counts per minute for a difference of one pound per cubic foot in density, and, in routine use, accuracies within -0.5 pounds per cubic foot can be obtained.

The principle parts of the Qualicon 502 gauge system are the source-detector head and the readout unit, the latter being comprised of a panel meter for visual readout and a recorder. The winch shown in Figure 2 provides a means of raising or lowering the source-detector head as required. In operating position, the source-detector head was one and one-half inches from the ground. When not in operation, the head was raised to the floor level of the trailer and secured in place.

The P-22 probe, shown in Figure 3, consists of a source-detector head and a decade scaler, the latter being a self-contained electronic scaler and power supply for use with nuclear radiation detectors.

5. Procedure:

a. Nevada Test Site

(1) Continuous Relative Density Measurements for Packrat. - Preparatory to taking measurements, the Qualicon 502 gauge was standardized in a relatively isolated area over a smooth soil that was characteristic of the soils to be measured. This standardization procedure consisted of establishing an operating zero point for the panel meter and



Fig. 4. Panoramic view of test site.

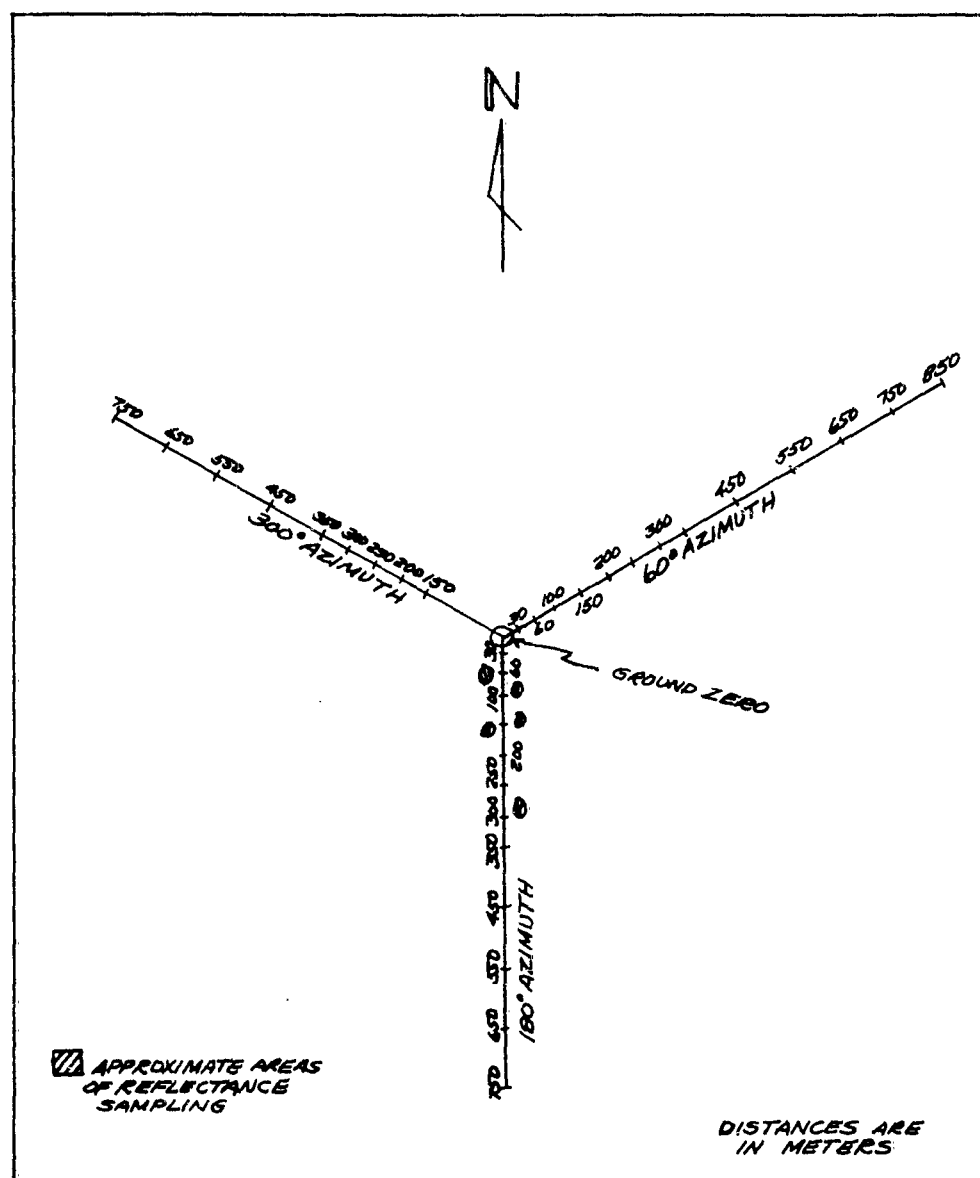
the recorder relative to the operating position of the source-detector head over the soil. Used in this manner, the gauge reads relative and not absolute density. The Qualicon 502 gauge was then operated along two traverses before and after the shot; one east, and the other north from ground zero. Both pre-shot traverses extended from about 150 feet to 1600 feet from ground zero. The post-shot north traverse began about 350 feet from ground zero because of the crater (approximately 600 feet in diameter and 50 - 75 deep) created by the explosion; the post-shot east traverse began about 450 feet from ground zero in order to avoid rainwater puddling. Chart recordings were made of the relative density measurements corresponding to the continuous movement of the gauge over the soils. The data from the chart recordings were reduced to give an average relative density value over a 50-foot interval by graphical integration of successive portions of the recording, representing 50 feet of movement along the ground, and dividing this integrated area by the 50-foot interval (each 50-foot interval overlapped the adjacent interval by 25 feet).

(2) In-Place (Point-by-Point) Density Measurements for Packrat. - Measurements were made at selected positions before and after the shot with the hand carried P-22 density gauge. Measurements began at 300 feet from ground zero (approximately on the lip of the crater) and were made at 50-foot points out to 750 feet from ground zero in a north, northwest, south and northeast direction. Measurements in the east direction began at 200 feet and were made at 50-foot points to about 1700 feet from ground zero. Density values of the P-22 gauge were determined by the average of two readings for each data position.

(3) In-Place (Point-by-Point) Density Measurements for Hardhat. - Density measurements were made with the P-22 density gauge on NE and SE traverses from ground zero at Area 15 Test Site before and after the shot at points carefully selected and precisely located. The latter was accomplished by spray painting the outline of the source-detector head on the soil so that the head could be replaced exactly in the same location each time a reading of the point was required.

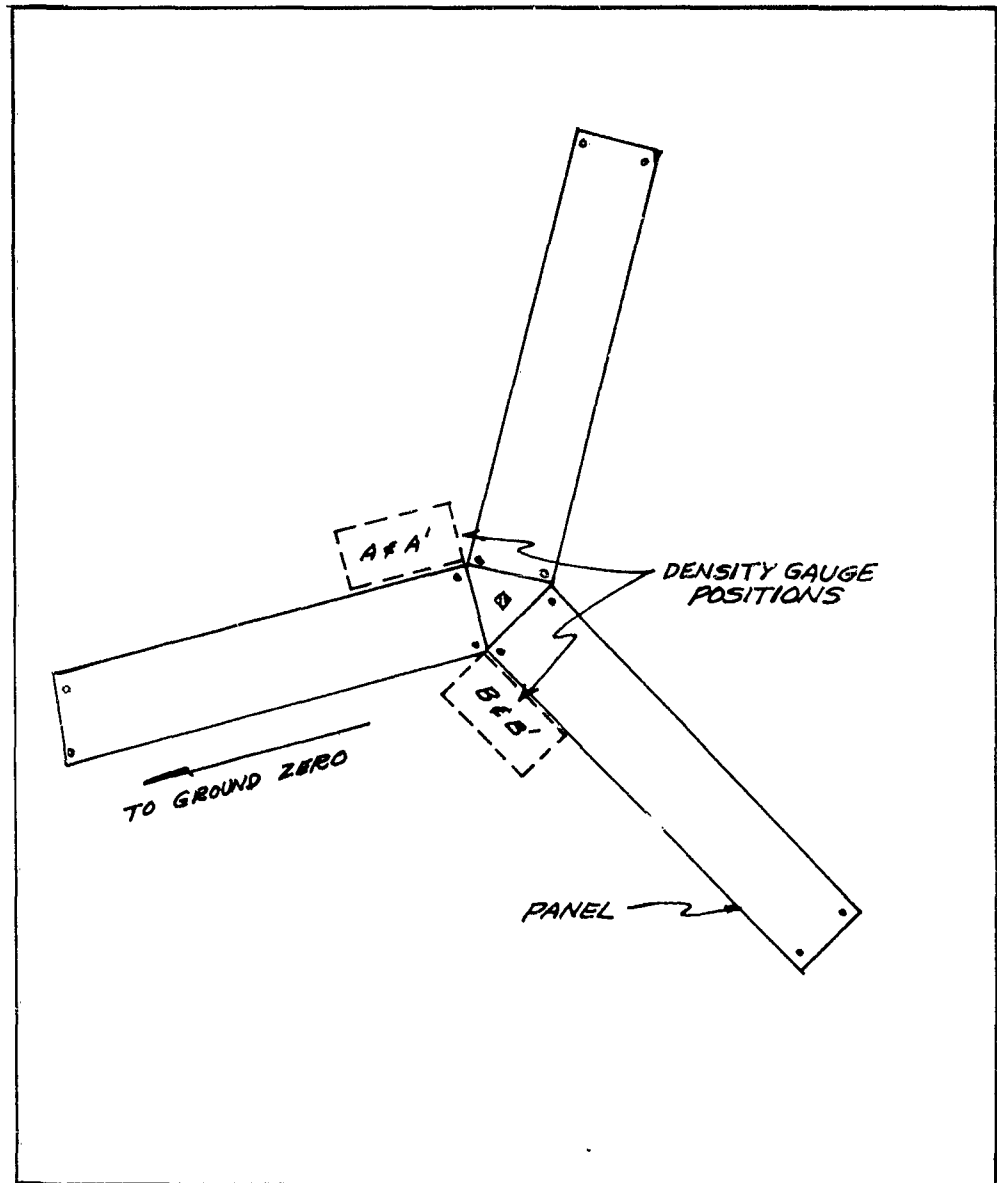
Figure 4 is a pre-shot panoramic view of the test site area looking from ground zero, with the two traverses used (NE and SE) indicated.

On the southeast traverse the measurements started at 60 feet from ground zero, the second measurement point at 100 feet, and subsequent points every 30 feet (130, 160, . . .) to 600 feet. From 600 feet to 1200 feet from ground zero, the points were spaced at 50-foot intervals. On the northeast traverse, the points started at 90 feet from ground zero and ran to 600 feet at intervals of 30



SKETCH OF HORIZONTAL MOTION
TARGET LINES USED FOR SAMPLING

FIGURE 5



TYPICAL HORIZONTAL MOTION TARGET

FIGURE 6

feet. From 600 feet to 1200 feet from ground zero, the points were spaced at 50-foot intervals. On both traverses, post-shot points were extended to 1600 feet using 25-foot intervals, starting at 1200 feet from ground zero.

The density values for a particular point were obtained by averaging two readings from the P-22 surface density gauge.

b. Carlsbad, New Mexico (Gnome)

All pre- and post-shot measurements were made with the P-22 density gauge along three lines of horizontal motion targets that radiated from ground zero at azimuths of 60° , 180° and 300° . Readings were collected at each target from a minimum of 30 meters to a maximum of 850 meters distance from ground zero (Figure 5). In each case, the positioning of the P-22 density gauge was determined by orienting it with the panels comprising the target (Figure 6).

For each placement of the P-22 gauge a pair of consecutive readings was taken; e.g., "A"; the instrument was then turned 180° and another pair of readings; e.g., "A" was recorded. Generally, only pairs that came within 400 counts per minute of each other were recorded, although there are exceptions in the earlier traverses. Because of time limitations only two pairs of readings were taken at each target on the 300° traverse.

Pre-shot data were collected on 8 and 9 December 1961, and post-shot data on 11 and 12 December 1961, along all three lines of targets. Concurrent spectral reflectance work made it necessary to limit subsequent post-shot data collecting to the 180° azimuth. Unfortunately, the horizontal motion targets were removed on 18 December. Results for the traverse of 19 December are, therefore, not uniformly satisfactory owing to disturbance of the soil and obliteration of some instrument locations.

The procedure followed for soil density post-shot measurements on 3 May 1962 was analogous to that described for the work conducted during December 1961. However, the complete obliteration of the old horizontal motion target sites made impossible precise placement of the P-22 density gauge head on the pre-shot data points.

Data were collected only along the 60° and 180° azimuths, beginning 60 to 75 meters from ground zero and sampling every 25 meters out to 200 meters. From 200 meters density was sampled every 50 meters out to 500 meters. Two pairs of readings were taken at each station; no attempt was made to utilize the November-December

sample sites. The area within a 60 meter radius of ground zero had been greatly disturbed by human activity and was highly unsuitable for data gathering.

6. Results

a. Packrat Event

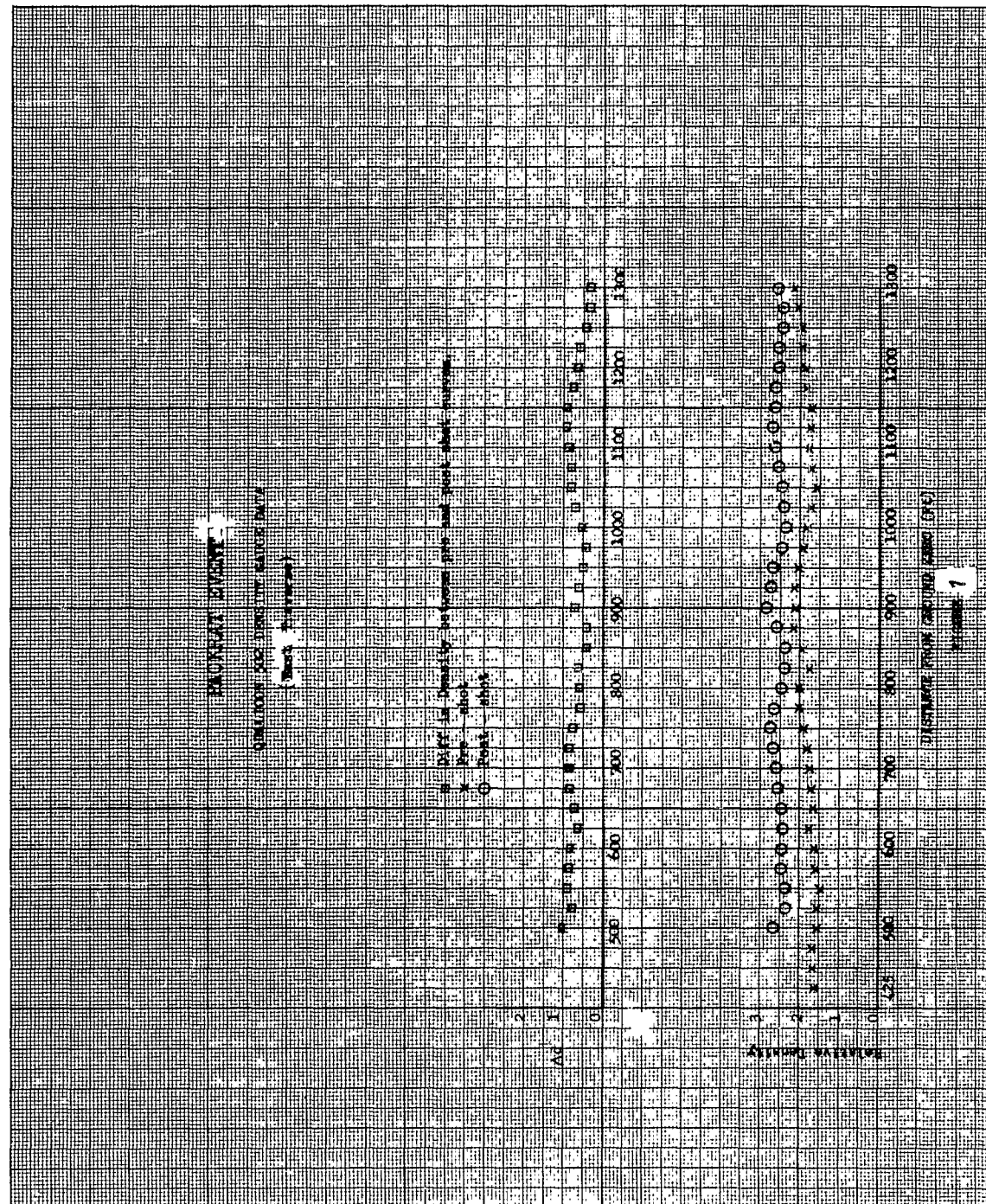
The data obtained for Packrat are graphically presented in Figures 7 and 8. The Qualicon 502 gauge data represented relative density values for pre- and post-shot runs in an east (Figure 7) and in a north (Figure 8) direction. Also shown on these two figures are the differences (Δd) between the relative density of the post-shot and pre-shot data. The slight increase in density difference along the east run, as ground zero is approached, is considered of little significance, inasmuch as this increase could have been caused by a very slight difference in detector head height over the two runs. Data taken along the north traverse indicate that although there was a very slight increase in density difference between post- and pre-shot measurements as ground zero was approached, there was no reliability indicative trend in density difference.

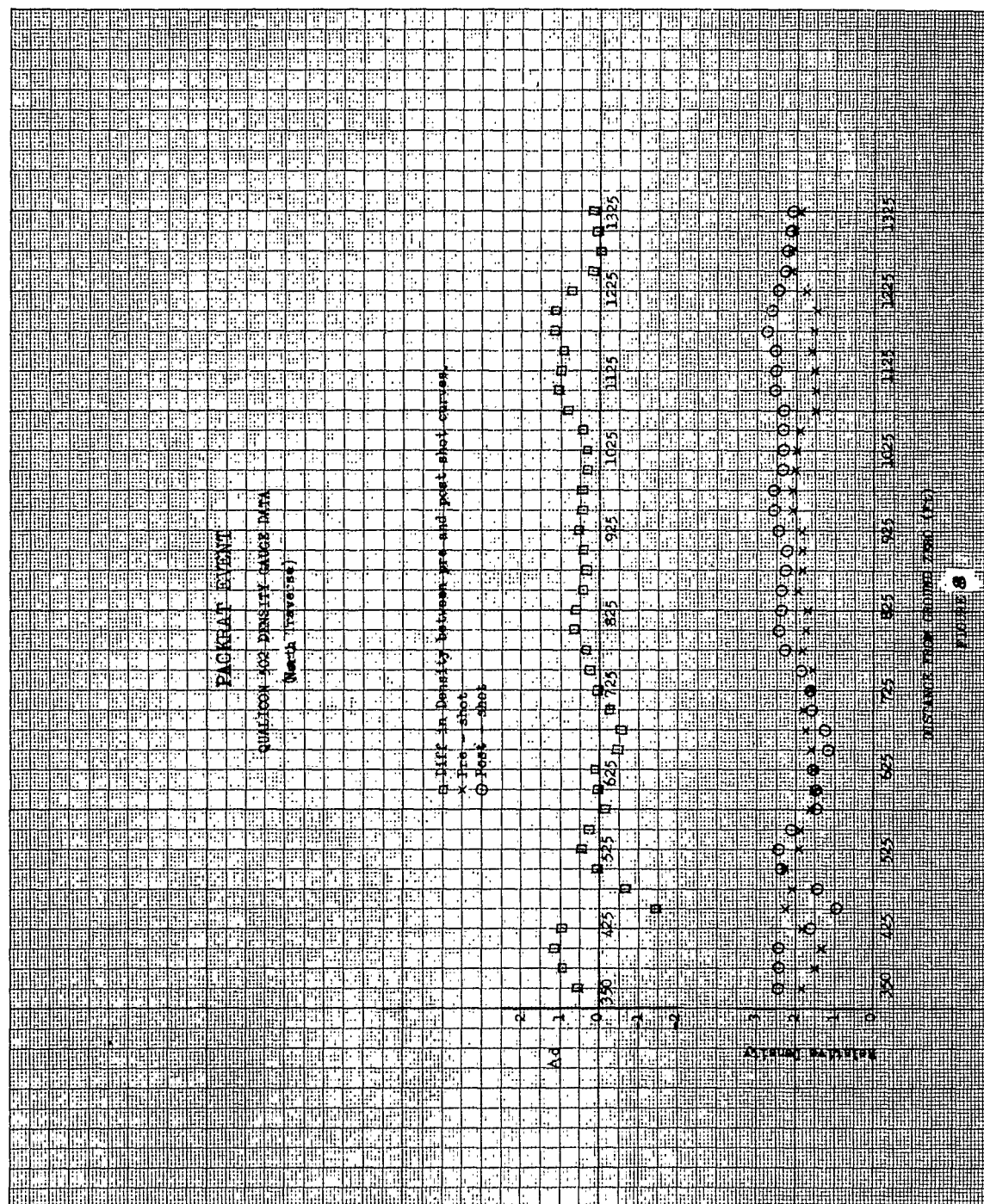
Figures 9 and 10 show the differences between the in-place post-shot and pre-shot density data obtained with the P-22 gauge. The point-by-point measurements made along the east traverse showed a general trend toward decrease density differences between 1600 and 300 feet from ground zero. The few measurements made within the crater, at 250 and 200 feet from ground zero (taken before access to the crater was prohibited), indicated that the density had decreased significantly in the region where the soil had been violently disturbed in the collapse of the soil around ground zero. Measurements made at points south, northwest, and north from ground zero showed a trend toward a very slight increase in density difference as ground zero was approached. No trend was recognizable along the northeast traverse.

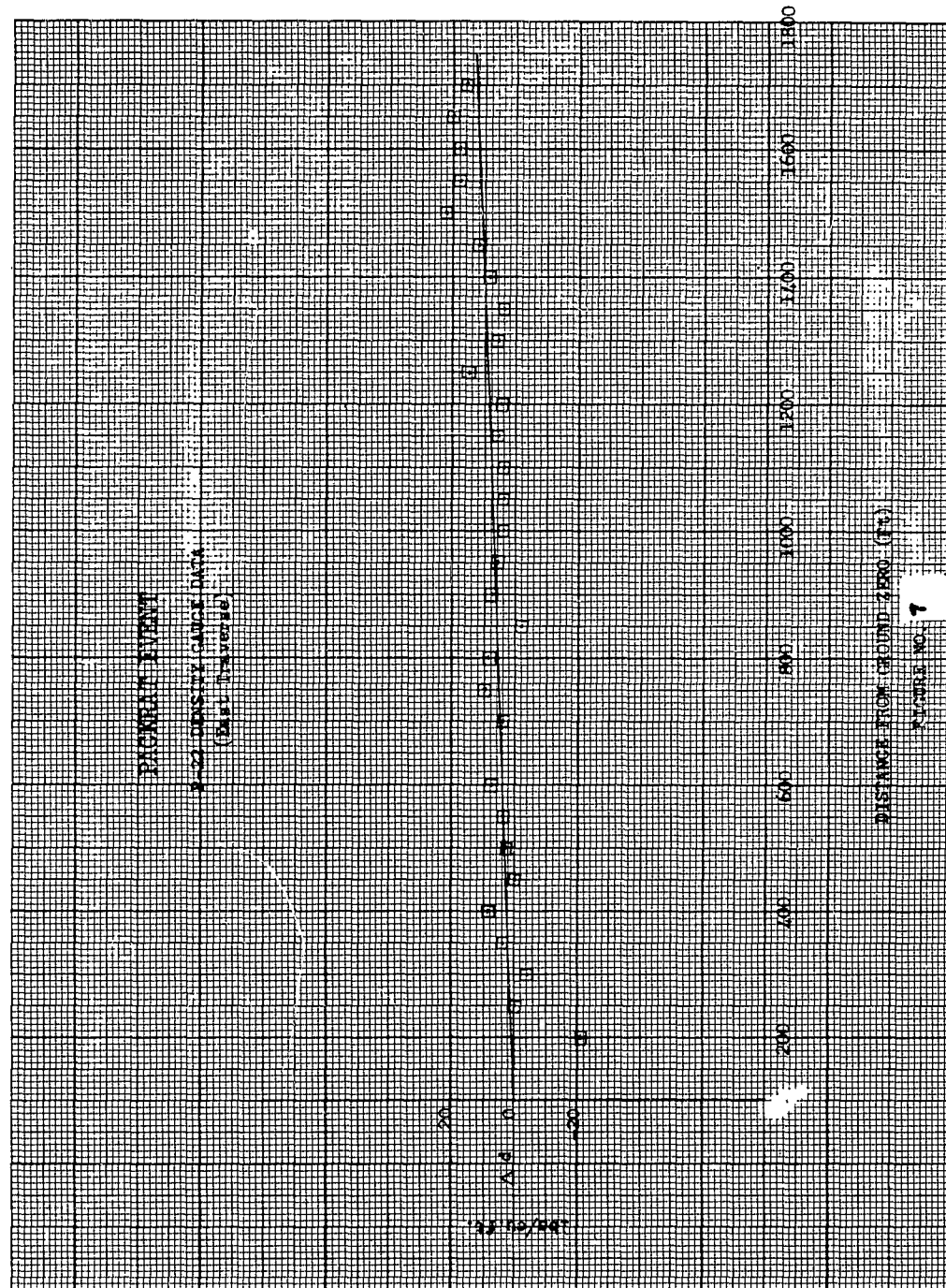
Figures 7 through 10 indicate that in the area tested the density changes occurring in the soil due to the Packrat explosion were slight and they were not positively identifiable by measurements with either the Qualicon 502 or the P-22 probe.

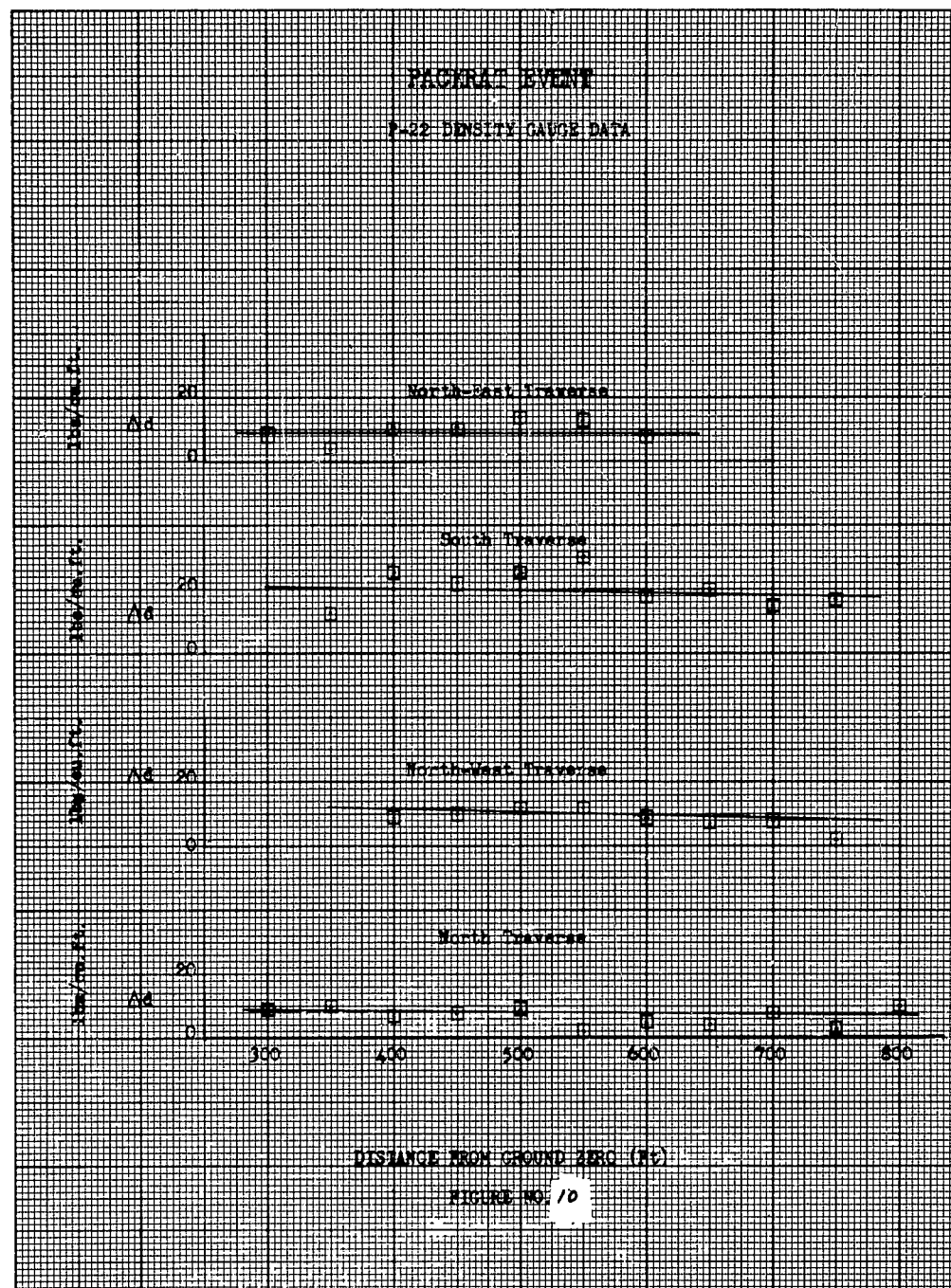
b. Hardhat Event

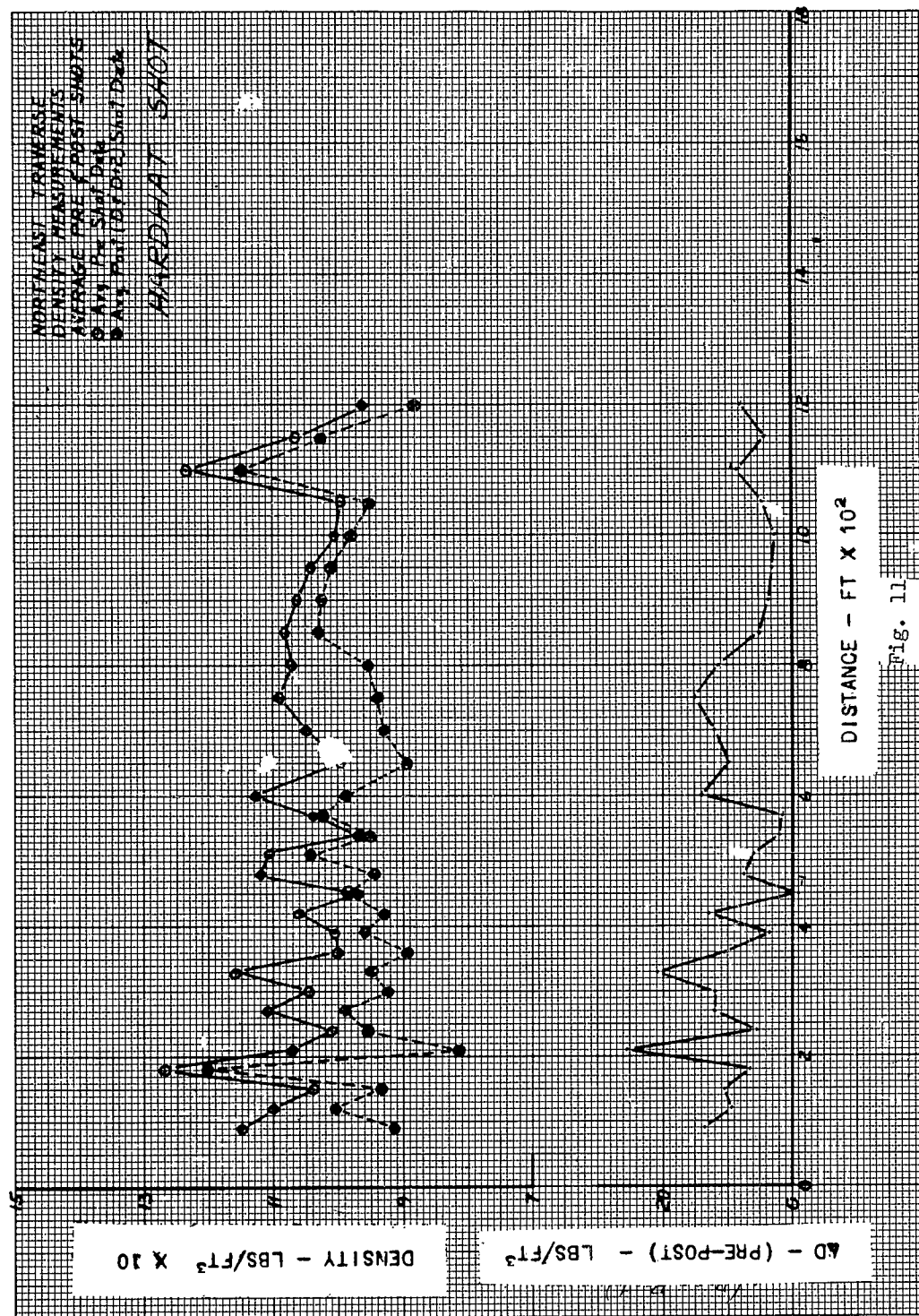
Figures 11 and 12 are the averages of pre-shot and the first two days' post-shot density data as well as the differences (Δd) between pre- and post-shot density data for both traverses. Only the first two days' post-shot runs were used because they were the only post-shot runs not exposed to snowfall, and consequently best indicate any ground disturbance because of the underground

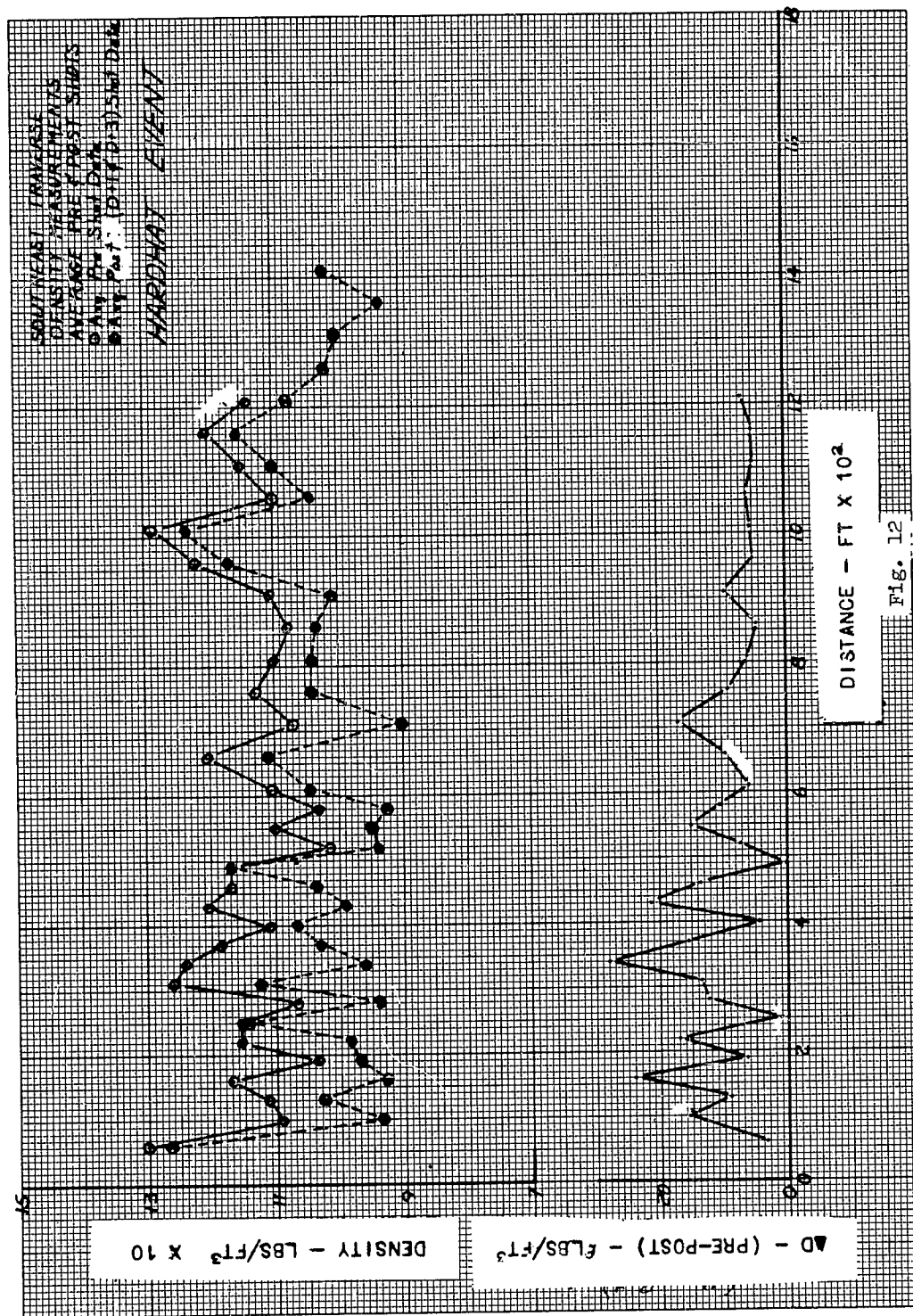


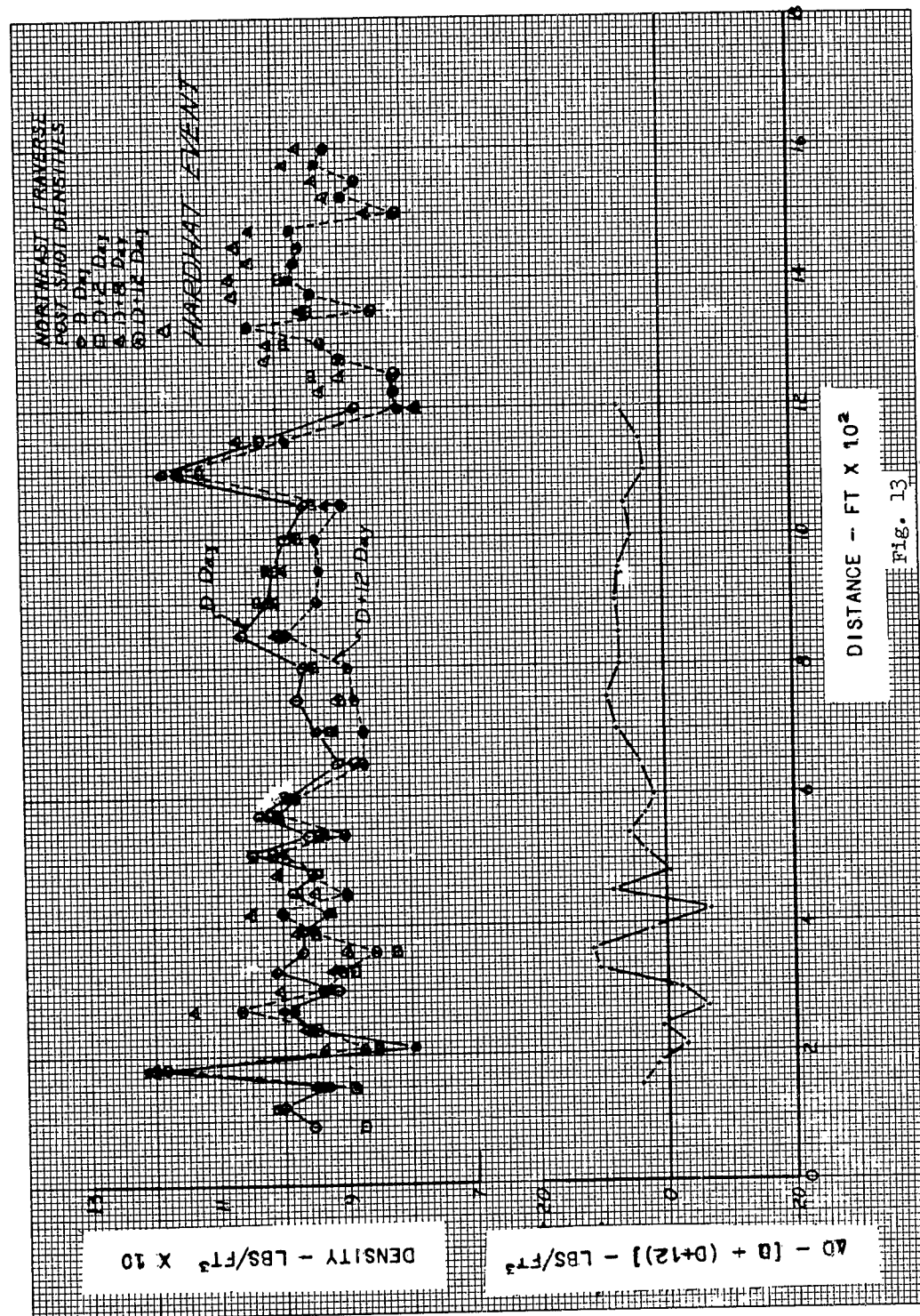


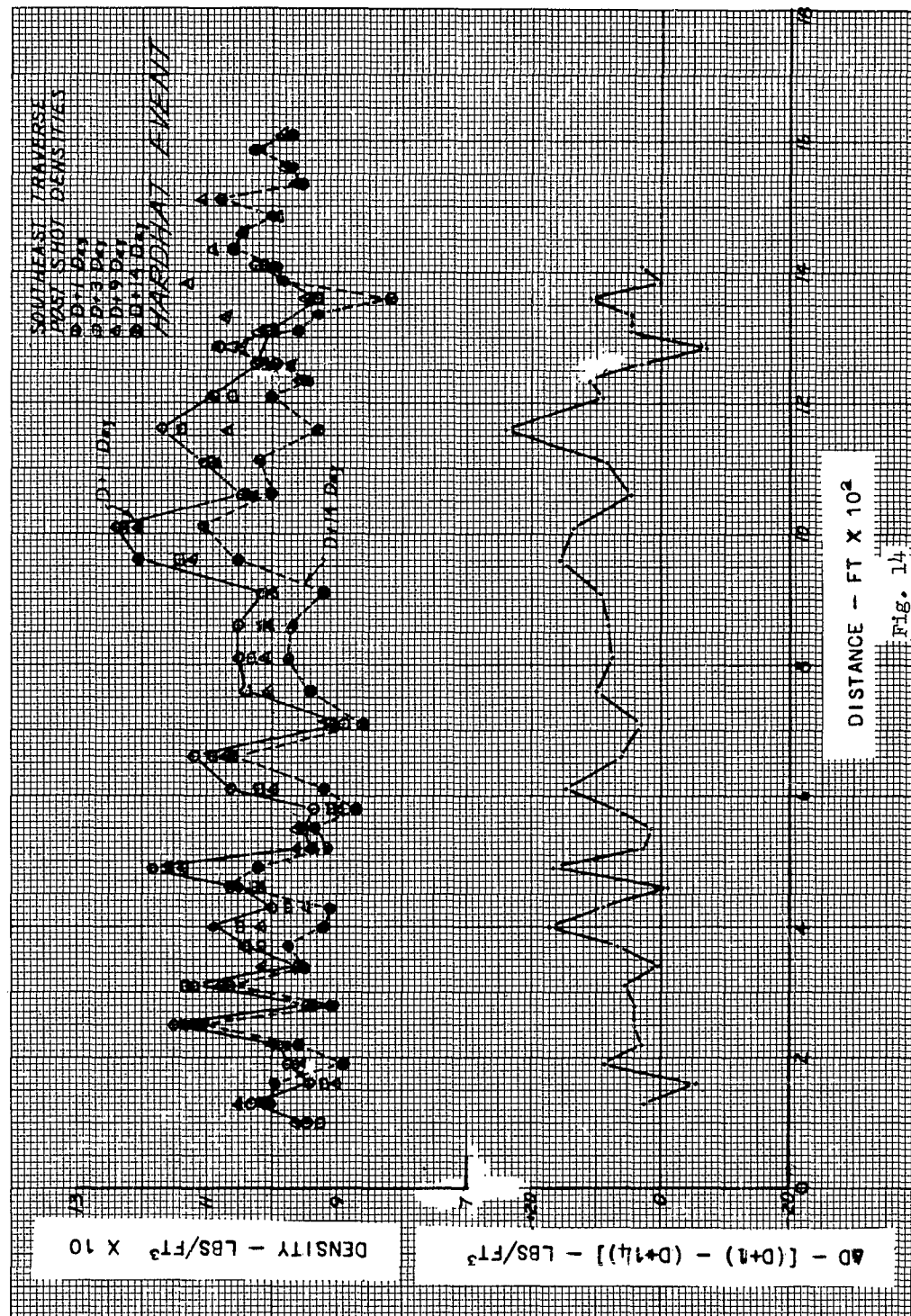












nuclear explosion. Both figures indicate a post-shot density generally lower than the pre-shot density for each traverse. The ΔD curves indicate a slight trend toward decreasing density change from ground zero outward along either traverse.

Figures 13 and 14 show variations in post-shot data at intervals up to 12 days after the detonation for both traverses. These data show the effects not only of changes in ground structure after the explosion, but also the effects of snowfall, melting, drying and cracking of the soil during the post-shot interval. The solid curve represents the first day's (D) post-shot data, and the dashed curve the last day's (D+12) post-shot data. The difference between the first and last day's soil density (ΔD) is shown on the lower half of each figure. The post-shot density changes from day-to-day are extremely erratic and inconsistent, and the effects of soil moisture changes and weathering (causing cracks in the soil) have obscured the disturbances caused by the detonation.

c. Operation Gnome, Carlsbad, New Mexico

Figures 15 through 19 are plots of soil density versus distance from ground zero. The values of soil density for station "A" were obtained by averaging P-22 density gauge values of the "A" and "A'" positions. A similar procedure was followed for the station "B" plots. The legend indicates the number of days data were collected before and after the Gnome Event; i.e., D-1 is one day before detonation; D+1 is one day after detonation, etc.

All plots show a decrease in soil density following the underground blast. This change is evident from the immediate vicinity of ground zero out to at least 850 meters. In addition, plots of the 180° traverse indicate that within a ten day period after the detonation, the soil tended to regain its original density.

Results of the work performed during May 1962 are shown in Figures 20 and 21, which are also plots of soil density versus distance from ground zero. The pre-shot densities are shown on the graphs, so that comparisons may be conveniently made.

III. DISCUSSION

7. Packrat Event

a. General

The pre-shot data were taken two to three weeks prior to the explosion at a time when the soil was very dry and dusty. One week before the shot, heavy rain fell for about 24 hours, and on the

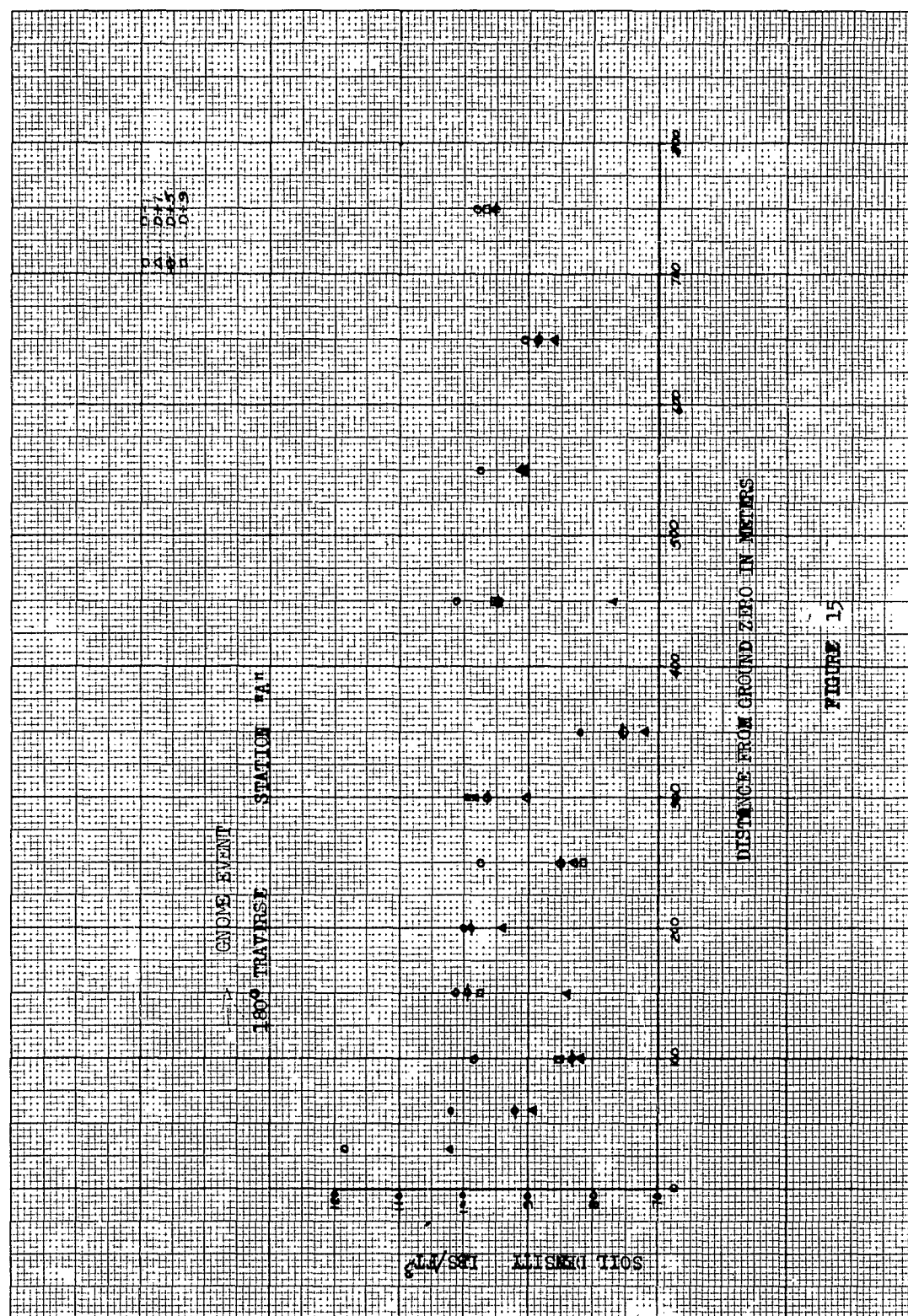


FIGURE 15

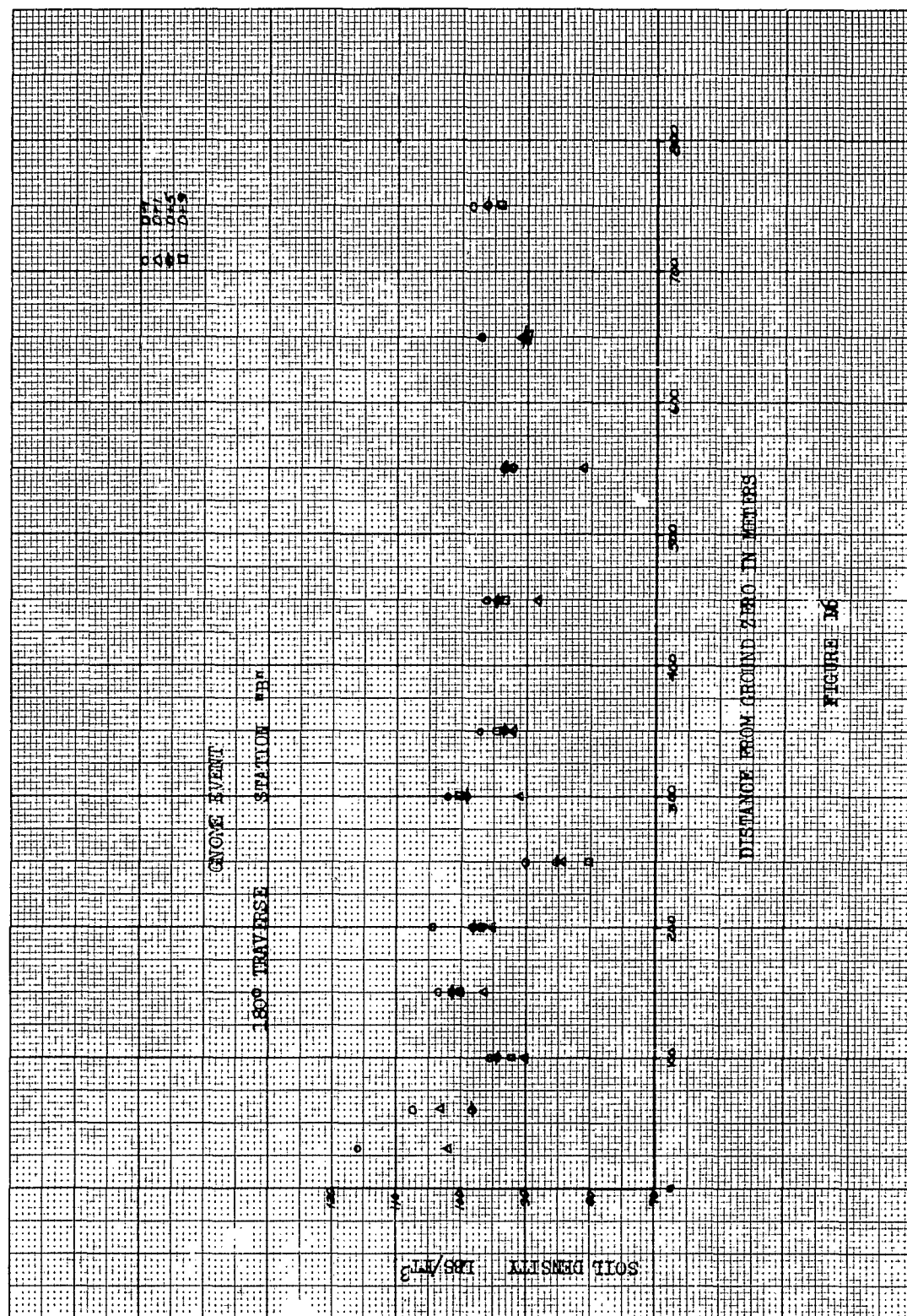
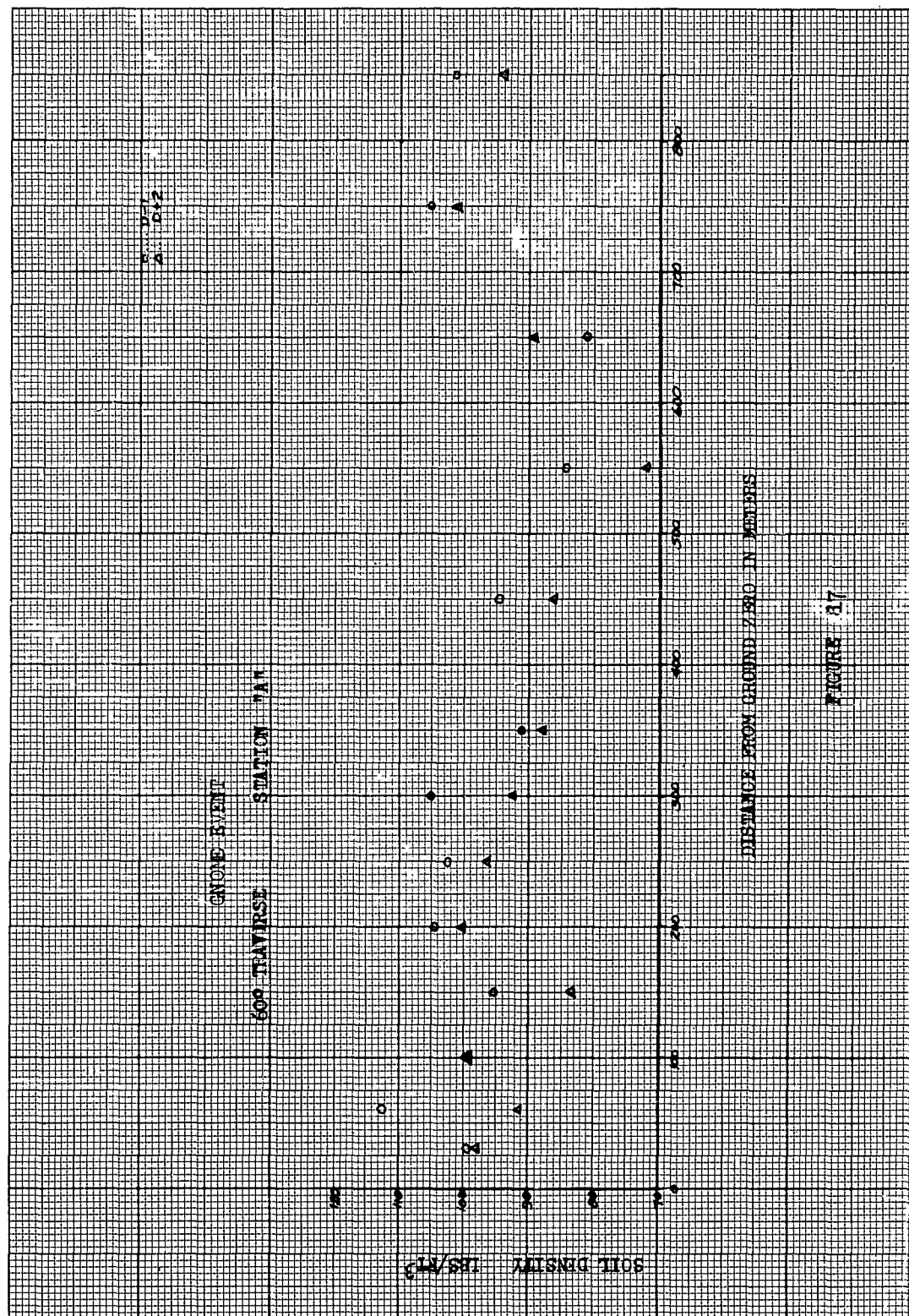
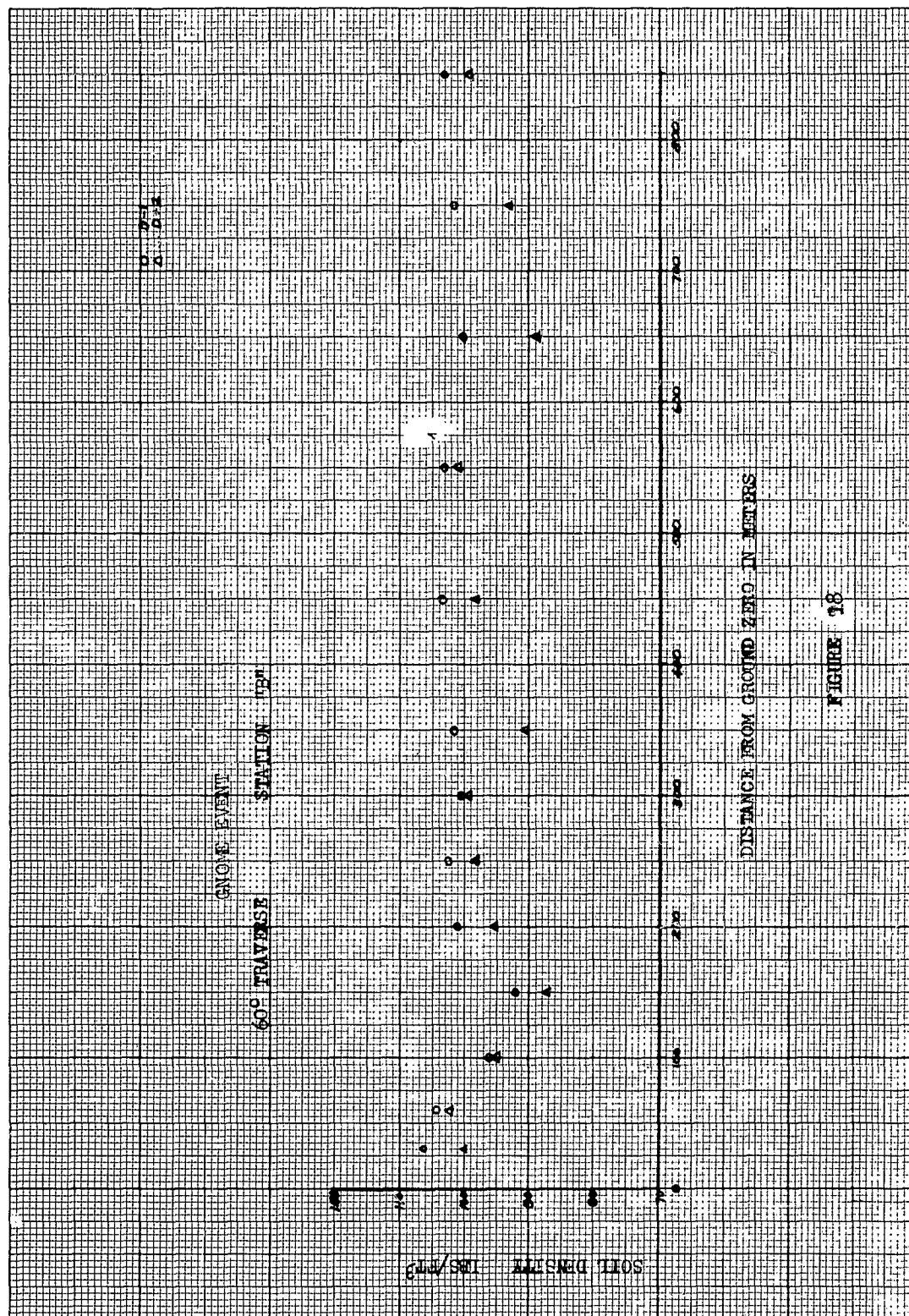


FIGURE 16





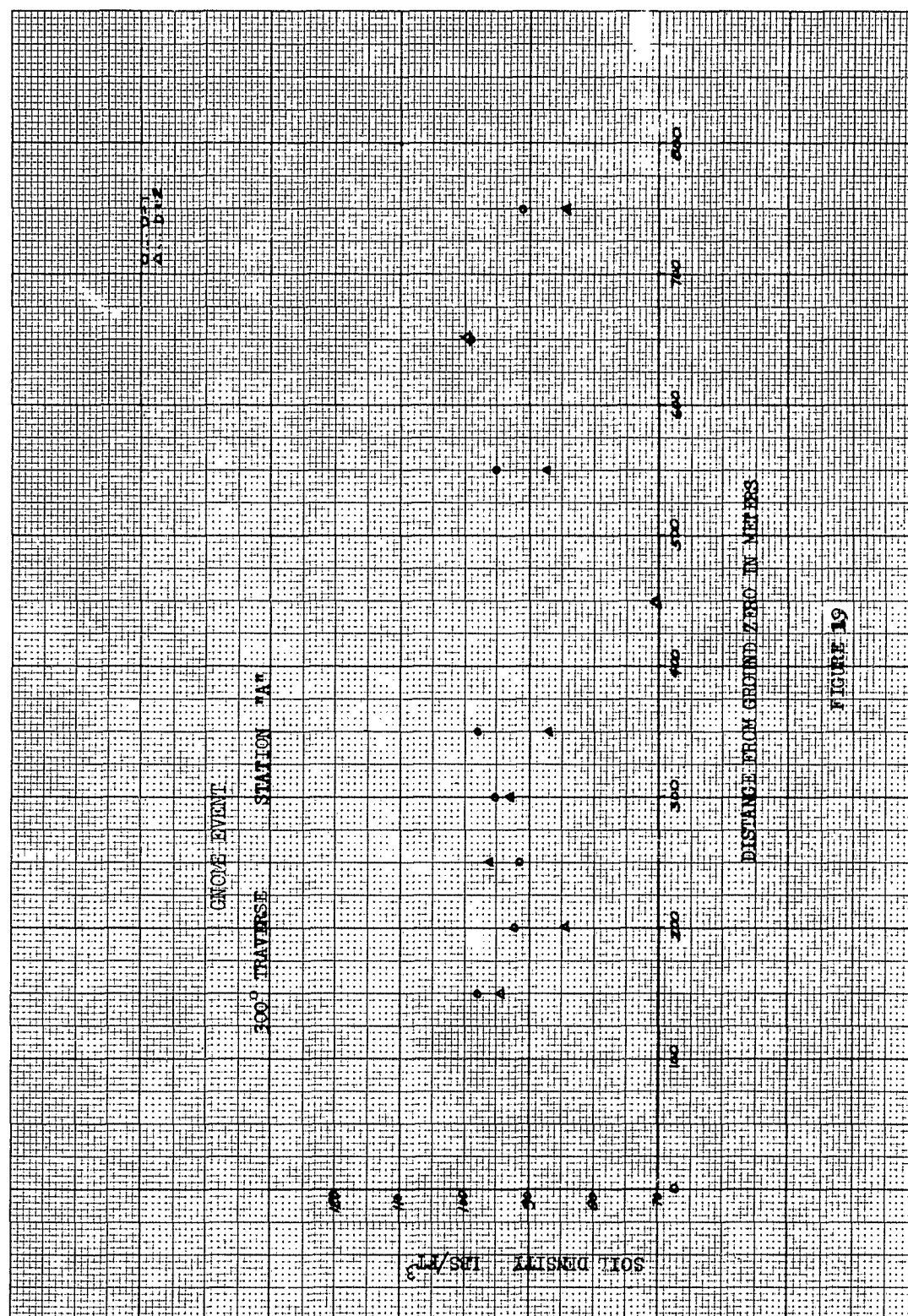


FIGURE 19

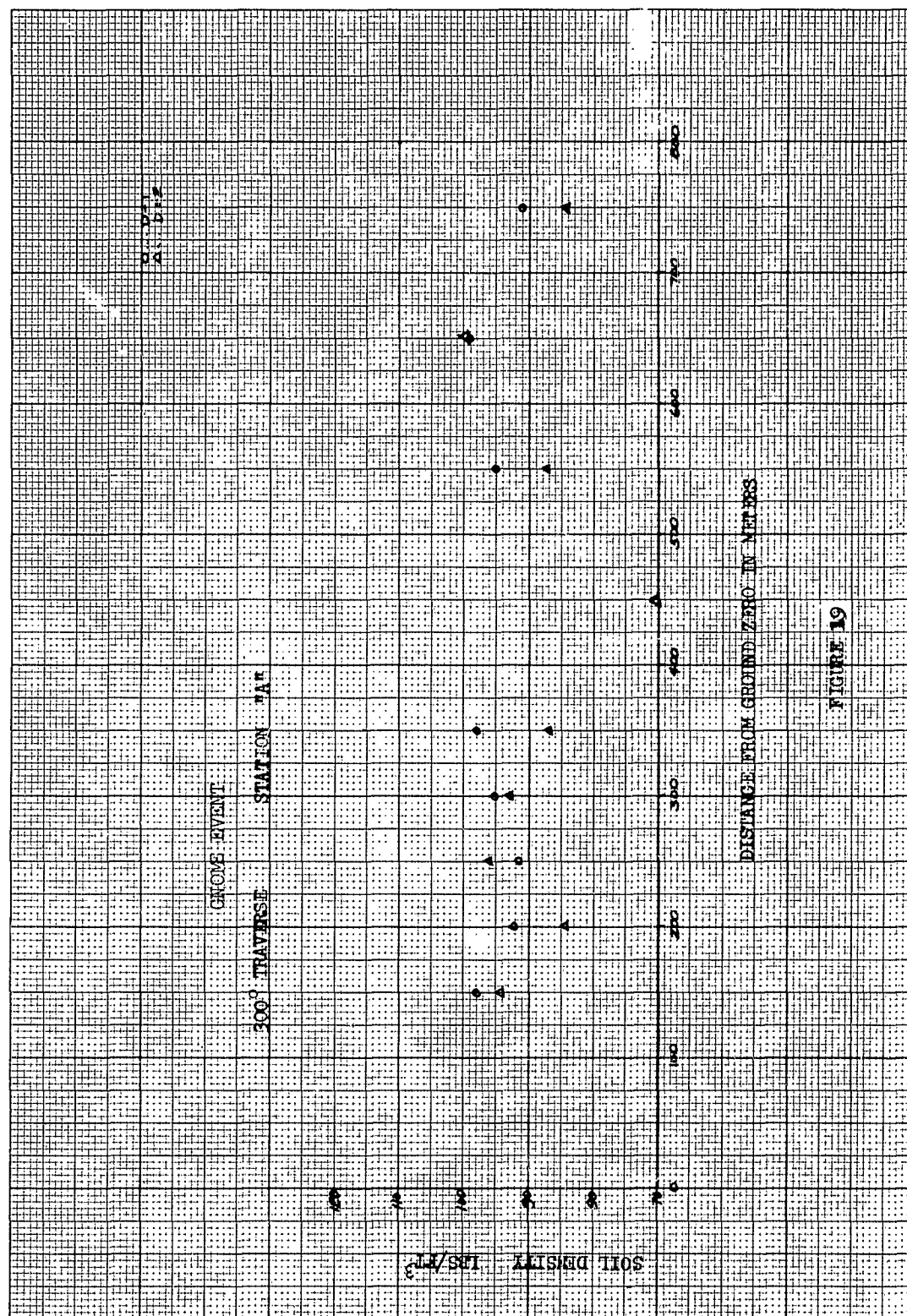


FIGURE 19

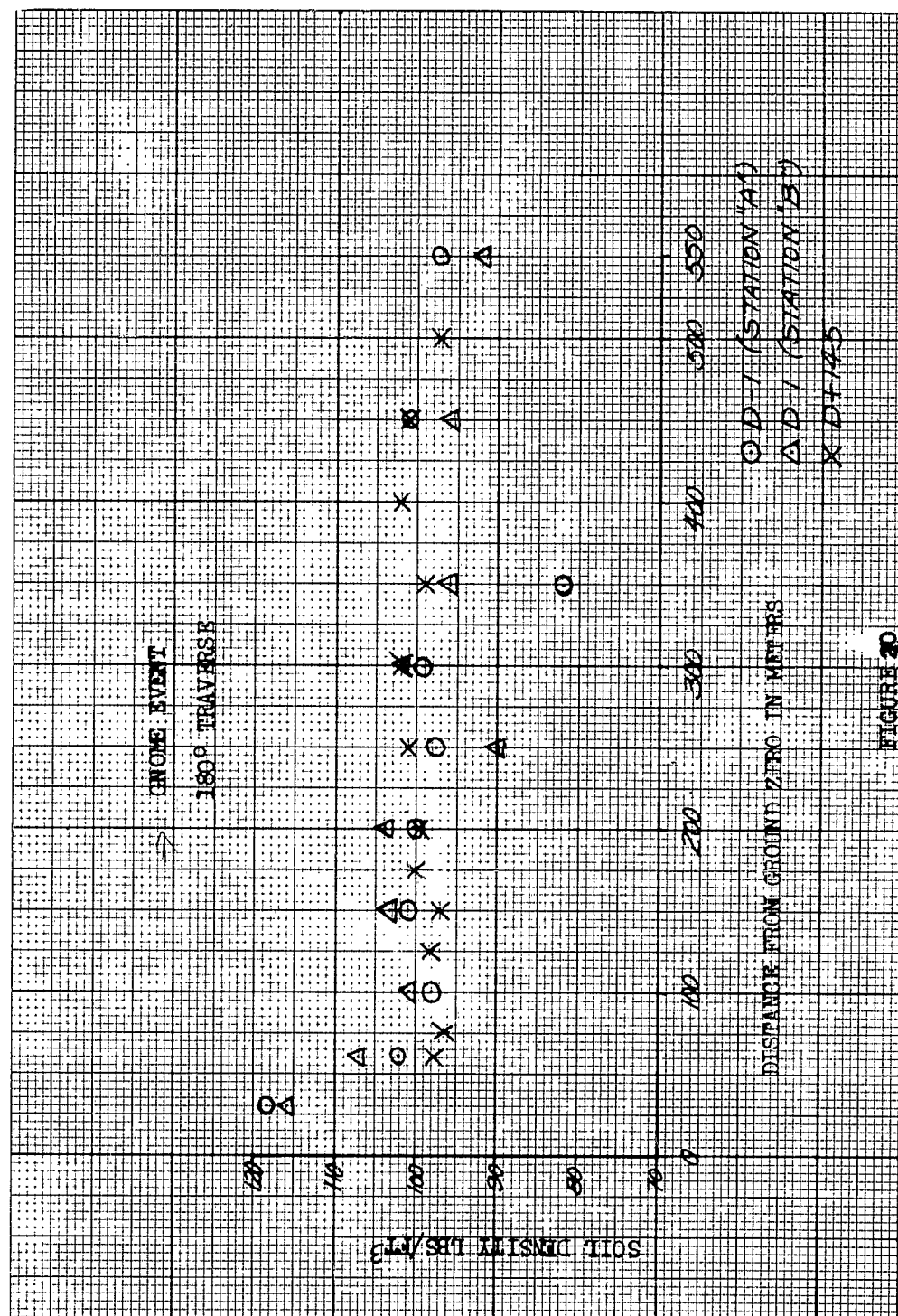


FIGURE 20

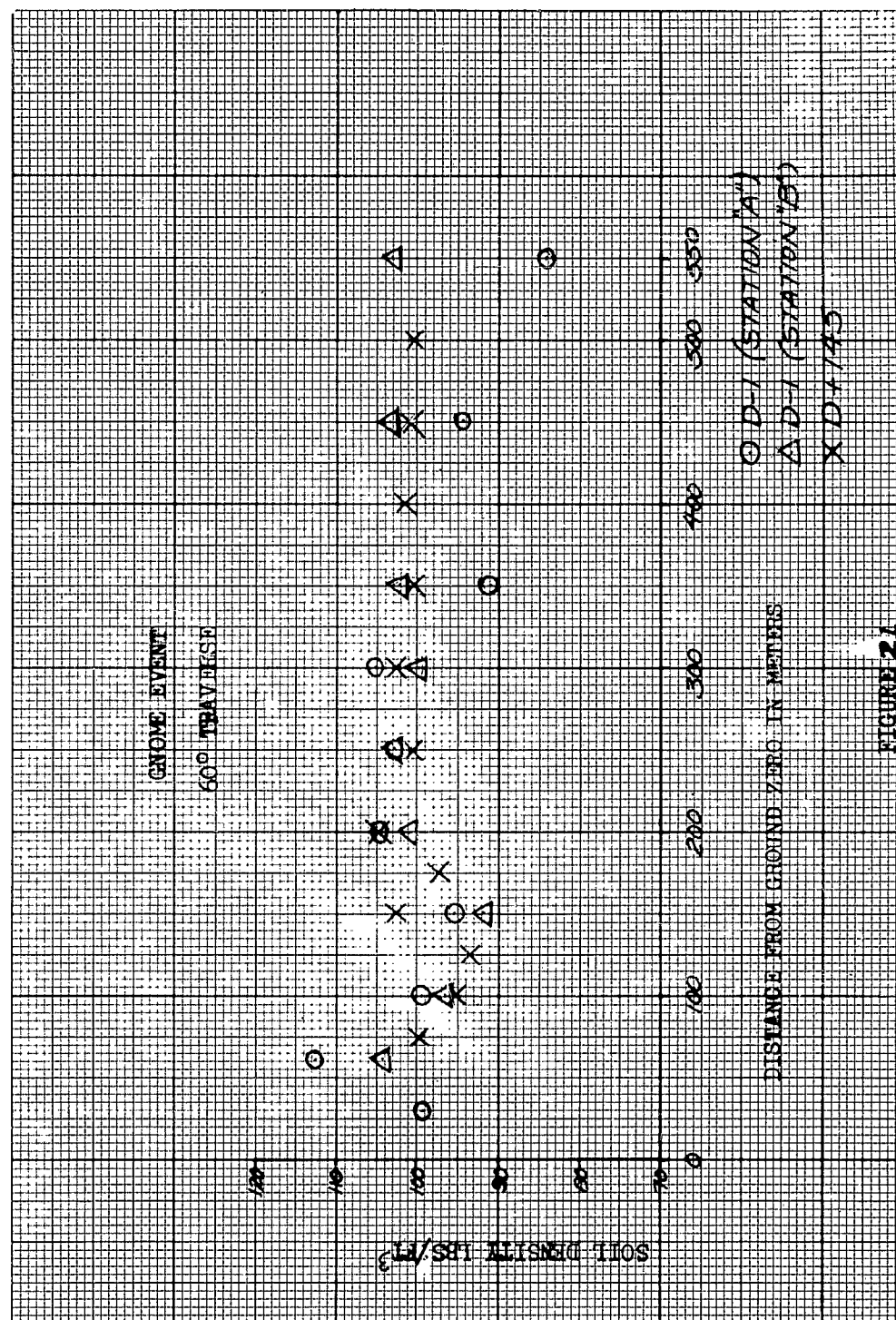


FIGURE 21

day preceding the shot, heavy rain fell for about 16 hours. Wetting the soil increases its density and tends to obscure density changes occurring between pre- and post-shot measurements. However, it is still possible to determine if density changes have occurred along a given traverse, if one assumes a uniform moisture distribution. If the density differences between pre- and post-shot decreases as ground zero is approached, this would indicate that an underground blast occurred.

b. Continuous Measurements of Soil Density

A major difficulty in interpreting the continuous measurements is due to Qualicon 502 density gauge's great sensitivity to variations in height above the soil. A variation in the detector head height (either increasing or decreasing) of one-half inch causes a 20% change in the recorded measurement; a one-inch variation causes a 40% change, and a one and one-half inch variation causes a 60% change. The apparent density fluctuations depicted graphically (Figures 7 and 8) are believed entirely caused by terrain irregularities rather than true density variations. The height of the detector head varied as much as three inches as it was conveyed over the two traverses. Due to these characteristics, relative density rather than absolute density was measured by the Qualicon 502 gauge.

Because of this extreme sensitivity to surface micro-relief, it appears unlikely that the Qualicon 502 gauge can ever be used effectively to detect density differences due to an underground explosion. In order for this instrument to be effective in detecting the presence of underground explosions, the variations in the density due to the explosion would have to be greater than those due to instrument height variations. The requirements for height stability are extremely severe as evidenced by the fact that only slight variations from a consistently level terrain cause large variations in relative density measurements. Most areas are not likely to be absolutely level and free of growth. There is no practical way to overcome the effects of surface microrelief and height variation on the performance of the Qualicon 502 gauge.

Where there are no height variations and there are appreciable density differences, such as going from an asphalt road to smooth soil, the gauge gives striking and accurate indication of density differences.

c. In-Place Measurements of Soil Density

There are two factors that make it difficult to make a significant interpretation of the P-22 gauge data: (a) the large density differences between the post- and pre-shot data as a result of rainfall between the two data-taking periods, and (b) the variation

in density differences from point-to-point. The variation in density differences from point-to-point are due to variations in soil texture and structure, and in some cases, lack of intimate contact between the detector probe and the soil surface (i.e., air spaces). Variations were greater along the roadway where intimate contact could not be made due to the hardness and roughness of the dirt road.

Although curves have been drawn through the data points of the traverses to indicate trends in density change, the data points are quite scattered about the curves and the trends, if truly recognizable or valid, are inconclusive. It is strongly suspected that appreciable density changes did occur between ground zero and 300 feet outward in all directions, since a crater 600 feet in diameter and 50 to 75 feet deep was created by the explosion. With the exception of two readings taken at 200 and 250 feet respectively from ground zero on the east traverse before access to the crater area was prohibited, density measurements could not be made directly over the crater. There were visual indications of violent disturbance of the soil in the form of cracks in the soil as far as 900 feet from ground zero. The effect of these cracks on the density were not measurable because they constituted only a minute part of the total soil volume affecting the instrument reading.

In order for the P-22 gauge to be effective in detecting density differences due to an underground explosion, the changes in the soil density due to the explosion would have to be greater than the indicated variation due to differences in the soil texture, structure, moisture content and the amount of air space between the detector head and the soil surface. With the exception of moisture effects, the effect of these factors can be held almost constant if precisely identical locations for measuring post-shot and pre-shot data are maintained. If all these factors are maintained constant, then changes in density observed between pre- and post-shot are due to the explosion. Conditions of the test were such that both moisture content changes and minor pre- and post-shot instrument position changes adversely affected the measurements. In the practical case, when only post-shot data would be taken, density differences from point-to-point due to the underground blast would have to be great enough to enable the establishment of an unquestionable trend in density difference of the soil as ground zero is approached, a trend which could not be explained by any of the foregoing natural phenomena, and which must, therefore, be attributed to an underground explosion.

8. Hardhat Event

Two factors make difficult a significant interpretation of the density data; (1) the destruction of precise location points for measurement, which occurred because of heaving and subsequent movement of the soil resulting from the underground nuclear explosion as

illustrated in Figure 22 (cracks and soil disturbances from the underground explosion were visually detectable as far out as 1500 feet from ground zero), and (2) the abundance of snow during the post-shot interval (D+4 to D+12) in contrast to the pre-shot interval in which there was no snow. After the shot, both traverses were laid again and the measurement points re-established as near to the pre-shot points as possible. They were marked precisely, using paint as before, and used throughout the collection of post-shot data.

Before the shot, the weather was sunny and clear and continued so for three days after the shot. On the fourth day, a six-inch snow covered the ground and all points in both traverses. Snow still covered the points through the seventh day, but on the eighth day the snow had melted enough to allow data to be taken again. Snow again fell on the tenth day and though partially melted, still covered the traverses on the eleventh day. The twelfth day and throughout the remaining measurement period, the weather was sunny and clear. Thus during most of the post-shot period, the ground was alternately dry and then moist from the effects of melting snow. These changes in moisture unquestionably affected the density data. When the soil became exposed and began drying, cracks began to appear on the surface which made air spaces between the recording head and the surface and caused false density readings for a particular point.

As is shown in Figures 11 and 12, a definite decrease in soil density did occur between pre- and the first two days' post-shot data. These differences are attributed to the underground nuclear explosion.

If no pre-shot data were available for comparison with the first two days' post-shot data (the dashed curves of Figures 11 and 12), the possibility of detecting the site of an underground explosion is very remote. A very slight density decrease is observed in the first two days' post-shot density data as ground zero is approached, but the points are quite scattered about the curves and the trends in density change, if recognizable at all, are difficult to define. Without the pre-shot data, the first two days' post-shot data is really not sufficiently pronounced to establish that a density change did occur along a traverse. There is a possibility that if the traverses had been extended to approximately 3000 feet from ground zero, one would have encountered truly undisturbed soil which could be used as a basis of comparison and thus enable recognition of the disturbed soil near ground zero in the first two days' post-shot data.

Interpretation of post-shot data taken after the first two days is complicated by the effects of snowfall, by the moisture added to the soil by melting snow, and by the partial drying and cracking of the soil between snowfall and melting cycles. Consequently, data



Fig. 22 Disturbed Soil After Hardhat Detonation

points of Figures 13 and 14 for intervening days between the first and last post-shot records are not only quite scattered between the curves but also fall above and below the curves. The interval of 12 days represented in the curves of Figures 13 and 14 show that in general the soil became less dense (and not more dense as expected from settling) between the first and last day's data. The effects of weather (wetting, drying, cracking) thus have not only obscured any reliable indication of a density change occurring in any traverse on a given day, but have also obscured density differences which may have taken place because of settling between the first day's post-shot data and the last day's data.

9. Gnome Event

Soil density data collected during December 1961 for the Gnome blast are suggestive rather than conclusive. The soil density decreased out to approximately 800 meters. Cracks in the ground appeared out to at least 250 meters, but had no effect upon density measurements taken over them. Based on collection of data along the 180° azimuth, there is an apparent tendency for the soil to recover its original density after a few days. For any given post-shot traverse no trend towards increase or decrease of density values with respect to ground zero exists, except within the first 100 yards.

The more recent studies performed during May of 1962 indicate that soil density along the 60° and 180° traverses is now remarkably uniform. The density is most uniform along the 180° traverse, where, in fact, the values are even more uniform than the values obtained in December 1961. This is most apparent in the 0-100 meter region. The lack of uniform density along the December traverse may have been a result of poor instrument placement; at that time it was not realized how sensitive the P-22 gauge was to minor variations in positioning. It is also possible that pre-shot construction activities may have radically altered the natural density around some of the sites.

There is, on the whole, a recognizable agreement between pre-shot and the most recent soil density values (Figure 20). Extreme differences, such as occur at 350 meters, are perhaps a result of local soil variations.

The 60° traverse also exhibits both a reasonably close agreement between recent and pre-shot density values, and a uniformity of recent soil density. However, the uniformity is poor at a distance less than 150 meters from ground zero.

It is difficult to directly correlate this data with the Gnome event. The close numerical agreement between pre-shot values

and the latest soil density values at distances greater than 150 meters from ground zero suggests that density differences occur in the 0-150 meter region. One must look for significant trends. However, in the case of the 180° azimuth, the soil density is now more uniform in this region than when the pre-shot data was taken. In the case of the 60° azimuth both pre-shot and recent soil density values have about the same degree of non-uniformity. Such a contrast makes it difficult to determine which situation, if either, is a result of the Gnome detonation, and to what degree normal sampling variations enter into the picture. Nonetheless, it is apparent that post-shot soil density alone is an insufficient means of detecting the Gnome event.

IV. CONCLUSIONS

10. General

a. The continuous-reading Qualicon 502 bulk density gauge cannot be used effectively to detect density differences in the soil because of extreme sensitivity to height variations and soil micro-relief. There is no practical way to overcome this restriction in use.

b. The P-22 surface density gauge is suitable for detecting soil density differences, but is highly sensitive to the amount of air space between the detector head and the soil surface. This effect can be overcome by careful selection and precise location of measurement points and firm placement of the detector head in contact with the soil surface.

c. Effects of normal variations in local soil texture, structure and moisture content (weather conditions) will present serious problems in the use of any soil-density-measuring instrumentation for detection of underground explosion areas and may invalidate their use.

11. Packrat Event

a. The density changes in the soil greater than 300 feet from ground zero (outside the crater) were not great enough to be detectable with either type of instrumentation used in these tests.

b. Within a 300 foot radius from ground zero (inside the crater) the density changes were visually detectable. No conclusion based on density measurements in this area can be made, as access for measurement was prohibited.

c. Cracks in the soil due to the underground explosions, although visually detectable out as far as 900 feet from ground zero, were not detectable with the instrumentation because the cracks constituted only a minute part of the total soil volume affecting the instrument reading.

12. Hardhat Event

a. A change in soil density was observed between pre-shot and the first two days' post-shot data between ground zero and 1200 feet from ground zero which is attributed to the effect of the underground nuclear explosion.

b. Post-shot recordings alone, as experienced under the conditions of this test, cannot be used to indicate the site of an underground nuclear explosion.

c. Post-shot recordings, under the conditions of this test, indicate that the soil appeared to become less dense with passage of time because of the effects of drying and cracking of the soil.

13. Gnome Event

a. Soil density increased from ground zero out to 850 meters as a result of the Gnome detonation.

b. Beginning a few days after the explosion, the soil density in the vicinity of the Gnome event returned to its original state.

c. Post-shot density data is in itself insufficient evidence for the Gnome detonation.

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PART II

THERMAL TECHNIQUES

I. INTRODUCTION

1. Objective. - To determine if density changes occurring in soils where underground nuclear explosions have taken place can be detected by thermal imaging techniques in order to differentiate between blast and non-blast areas.

2. Background. - The report on the nuclear detonation under Rainer Mesa in Operation Hardtack II pointed out that there was extensive upheaval and subsequent settling of the soil in the area of the underground explosion indicating a probable change in density of the disturbed soil. Detection of soil density changes by thermal imaging has been brought out by mine detection research at USAERDL. Buried land mines have been found to be detectable under certain conditions by thermal imaging which shows that temperature differences exist between mined and unmined domains, from the changes occurring in the thermal conductivity and in the heat capacity of the soil which has been loosened by the operation of burying the mines. Since a similar loosening of the surface soil occurs above an underground blast area, it is reasonable to expect changes in thermal properties which can be detected by thermal imaging methods. This report covers investigations at the Nevada Test Site. Preliminary measurements were made at the Orchid and Blanco areas during 24 - 27 June 1961. Later tests were conducted at the Packrat test site during 7 - 17 November 1961 (pre-shot) and 27 November - 6 December 1961 (post-shot).

II. INVESTIGATION

3. Theory. - The density of the soil in the vicinity of the blast will be altered as a consequence of the effects of (1) the shock wave on soil compaction; and (2) mechanical heaving. Because of lowered soil density, both the specific heat and the thermal conductivity of the soil will also be reduced. Thus the temperature of the disturbed soil will rise faster and to higher values during daylight hours and will drop faster and to lower values during night hours than the temperature of undisturbed soil. As a result, a disturbed area, such as exists above a blast site, can be expected to exhibit some degree of thermal contrast with the surrounding, undisturbed area.

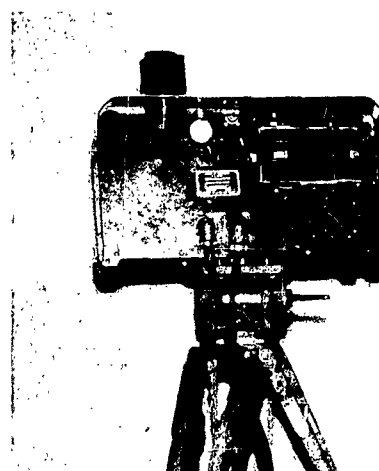
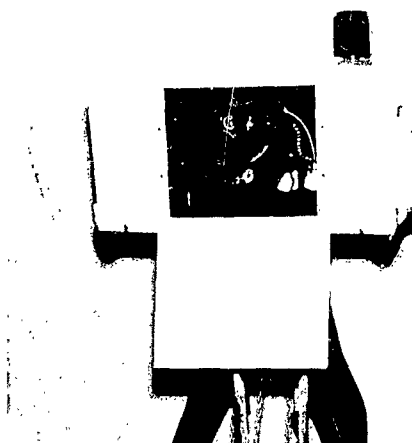


Figure 23

4. Instrumentation. - The Thermograph T-2, developed by USAERDL, was used to obtain thermal images. This instrument, shown in Figure 23, is a field device for forming thermal images of objects and terrain by detecting self-emitted infrared radiation and converting it into a visible image. Basically, the thermograph is a mechanical-scanning radiometer. Infrared radiation is collected by an optical system consisting of a fixed, 8-inch, paraboloidal mirror and an 8.5- x 12-inch, plane-surface, scanning mirror. This mirror system provides an instantaneous field of view of approximately 1.5 milliradians. The radiation is focused on two germanium-immersed thermistor bolometers; one of which (low frequency) is for the sensing of the gross details of the scene, and the other (high frequency) is for the sensing of finer details. A mechanical system drives the plane scanning mirror in both horizontal and vertical motions, giving a field of view of 10 degrees vertically by 20 degrees horizontally. The system scans at the rate of 100 square degrees of target area per minute, or the total field of view in two minutes. The infrared radiation collected from the target area is converted by the bolometers into electrical signals which are processed through an electronic system. During the processing, the signals are amplified to a level where they can be used to intensity-modulate a glow tube. Light from the modulated glow tube is swept mechanically by a mirror at precisely the same rate and relative motion as the original scanning mirror, thus producing a two-dimensional pictorial representation of the field of view on polaroid photographic film. The picture therefore corresponds to the infrared pattern of the objects within the field of view of the instrument.

Maximum sensitivity of the system is the noise equivalent temperature of the detecting section. For targets around 25°C, the noise equivalent temperature is (a) for the low-frequency channel, 0.26°C, (b) for the high-frequency channel, 0.14°C. The detector time constants are (a) for the low-frequency channel, 2.3 milliseconds and (b) for the high-frequency channel, 1.4 milliseconds. Additional characteristics of the thermograph T-2 are given in the Appendix. An additional polaroid camera, attached to the top of the case of the thermograph, was used to provide visible views of the terrain for comparison with thermally-recorded images.

5. Procedure. - The thermal imaging equipment was transported to the test sites in the USAERDL mobile lab (modified 3/4-ton, 4 x 4, M-37 army truck). The mobile lab gave working space for the operators, storage for supporting equipment, and an elevated platform from which to operate. The equipment was also operated from a surveyor's tripod on the ground to enable operation of the equipment from positions inaccessible to the vehicle.

The preliminary field work during June 1961 consisted of preparing panoramic thermal and visible images of Orchid ground zero

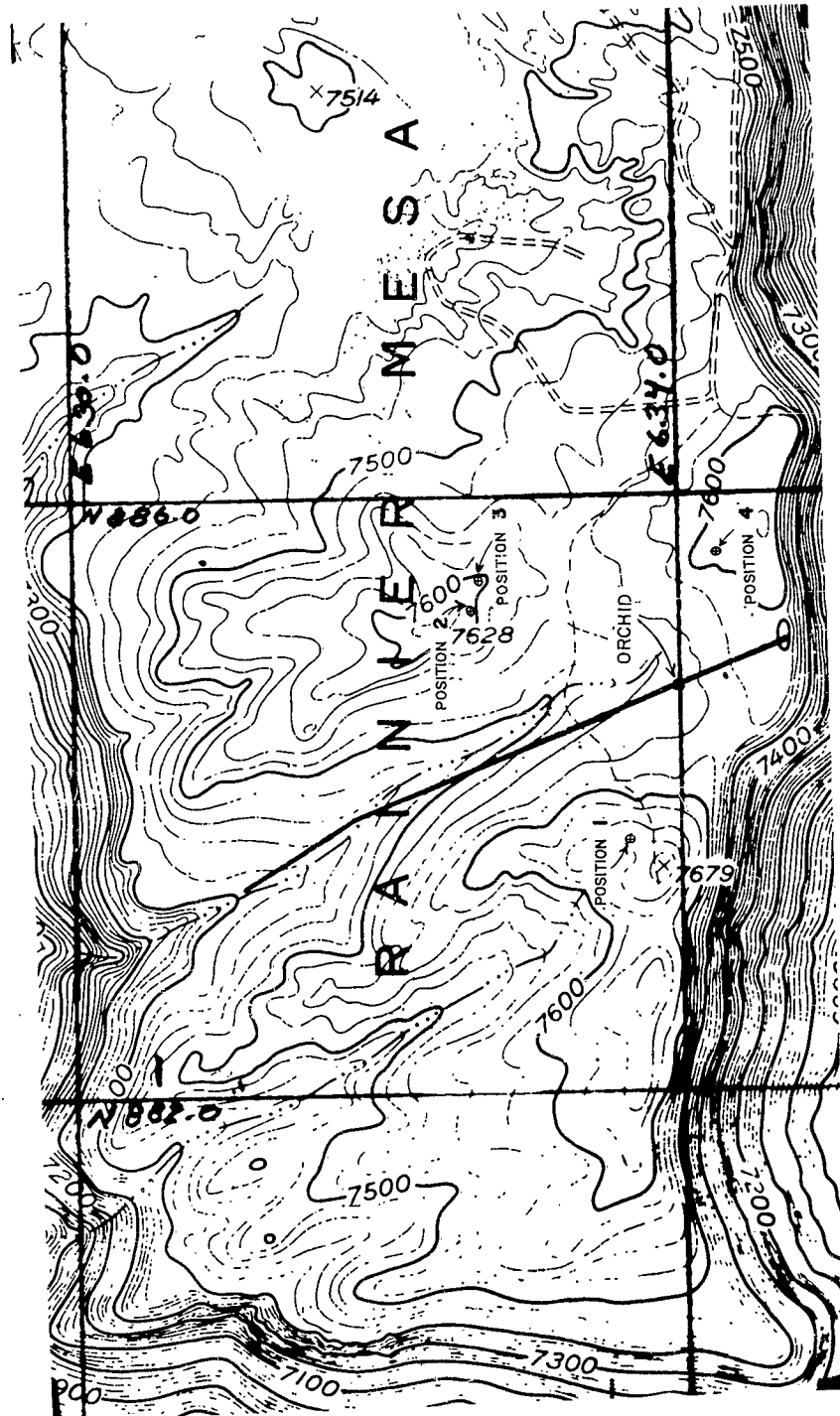


Figure 24

and the surrounding terrain from positions 1, 2 and 4 (Figure 24). Similar panoramic thermal images were taken from position 3, viewing the Blanco area, in order to provide an indication of the general type of thermal patterns which might be expected after an underground blast. Most thermal records were made during the daytime; however, a limited number were made at night to determine temperature patterns after dark. The thermal images were analyzed to determine normal target and background thermal patterns and contrasts.

Surface temperature readings, using surface thermometers, were made of light-colored red rock, gray soil and dead tree trunks. Air temperatures were recorded at the time of each thermal imaging.

Measurements of an actual underground blast (operation Pack-rat) were conducted during November and December 1961. Panoramic thermal and visible image records were made from the top of the mound over Bunker 3-330 during mid-afternoon two days before the shot. This position is approximately 900 feet due north of ground zero. Post-shot thermal and visible images were made from the same position during both mid-afternoon and midnight hours on the day following the shot.

The thermal image records were studied for thermal pattern changes between pre-shot and post-shot conditions and for evidence of areas of thermal contrast between a blast area and surrounding unaffected background.

6. Results. - Figures 25, 26 and 27 are panoramic visible and thermal views taken from Orchid viewing positions 1, 2 and 4. In general, the thermal images show excellent detail and terrain features can be easily recognized. Figure 28, taken from position 3, shows a thermal image of the Blanco area and discriminates between live and dead trees on the edge of the area. Thermal images indicate live vegetation temperatures less than air temperatures. The live trees are also cooler than the dead trees in the daytime and appear darker on the thermal image.

Daylight temperatures measured were:

<u>DATE</u>	<u>TIME</u>	<u>AIR (^oF)</u>	<u>Gray Soil</u>	<u>Light Colored Rock</u>	<u>Dead Tree Trunk</u>
25 Jun 61	10:50	95	109	106	---
25 Jun 61	11:20	98	116	109	102
25 Jun 61	14:35	82	88	90	89



Figure 25

Orchid from position No. 1

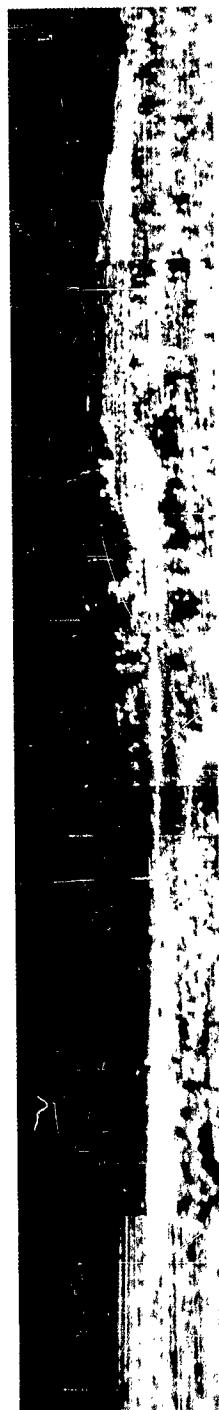


Figure 26

Orchid from position No. 2



Figure 27

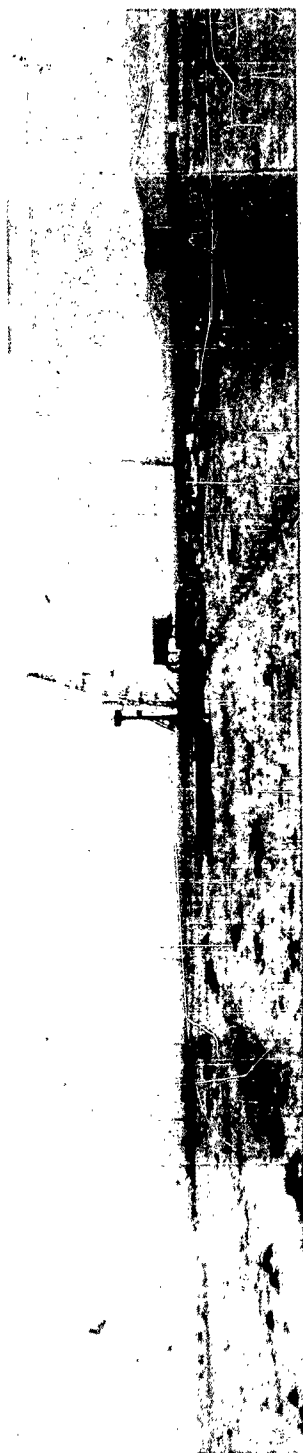
Orchid from position No. 4



44

Figure 28

Blanco from position No. 3



PRE-SHOT (48 HOURS) VISIBLE SCENE



PRE-SHOT (48 HOURS) DAYTIME THERMAL IMAGE

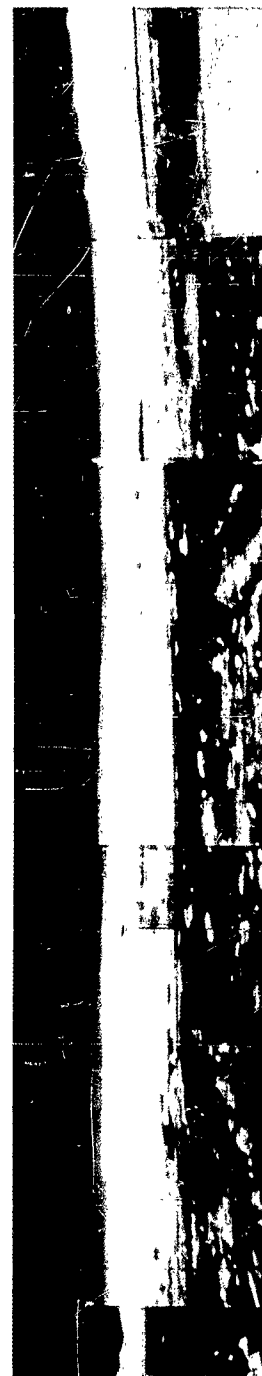
FIGURE 29



POST SHOT (24 HOURS) VISIBLE SCENE



POST SHOT (24 HOURS) THERMAL IMAGE DURING DAY



POST SHOT (36 HOURS) THERMAL IMAGE DURING NIGHT

FIGURE 30

Figures 29 and 30 show the results obtained during the Packrat event. The panoramic visible and thermal composite views in Figure 29 are of ground zero 48 hours before the shot. Figure 30 shows similar views 24 and 36 hours after the shot. It is evident in the pre-shot images that the area is one of considerable man-made activity. The drill rig, lights, vehicles, shocks and many motors operating in the area are obvious in the Figure 29 thermal image record. In Figure 30, made after the shot, the depression caused by the explosion is detectable on thermal imaging records as a cool area during the day and as a warm area at night.

III. DISCUSSION

7. Orchid Tests. - The thermograph records show high background temperatures and large thermal contrasts of objects in the test area. These contrasts made choice of instrument settings for studies of specific objects in the background difficult during daylight hours. The problem of choosing proper instrument settings was confined mostly to attempts to observe relatively small temperature differences between cool objects (such as vegetation) when they had to be viewed against the very hot soil and rock background. For detailed study of an area, several thermal images of the same scene but with different thermograph settings were valuable. The varying gain and contrast emphasized different aspects and details of the scene viewed.

Roads, paths and work areas were quite evident in the thermal images as hot areas. Often paths which were not visible to the eye from the viewing position are obvious on the thermal image. The high detectability of these features was due to high surface temperatures resulting from lack of plant cover and the presence of a thick layer of fine dust (low specific heat) on the soil surface.

8. Operation Packrat

a. Detection of Blast Site. - Although the depression caused by the underground blast shows up on the thermal images as a cool area during the daylight hours, it could be seen much better by either conventional photography or by the unaided eye. At night the crater appears as a warm area in the thermal images. One also notes in the recorded thermal image that the distant background beyond the depression is obscured by the rising warm air. It is rather doubtful, however, if either of these effects is sufficiently pronounced for recognition of the blast site without a prior knowledge of its position. The blast at the Packrat was the only one studied by ground-based thermal imaging equipment. Since a large crater was formed by this blast, we still do not know if a blast area can be recognized by such equipment in the absence of large topographic effects. Airborne thermal scanners with

similar resolution and sensitivity would offer better results than any ground-based instrument because of the more advantageous viewing angle possible.

b. Temperature Contrast. - The temperature contrast between the crater and the surrounding terrain was probably due to the exposure of moist earth on the sides of the crater where breaking occurred with the collapse of soil surface over ground zero. The soil had greater than normal moisture since there had been several days of rain before the shot. Because moist earth has a greater heat capacity than dry soil, moist earth heats slower during the day and cools slower at night than dry soil. The side of the depression which was visible from the thermal viewing position was also more oblique to the sun's rays than the flat surrounding desert. This, coupled with the lower reflectivity of the moist earth, could contribute to the cooler day-time appearance.

IV. CONCLUSIONS

9. Conclusions

a. Although extreme background temperature contrasts may present thermal imaging problems, satisfactory imaging of a test area can be accomplished with good image detail during both day and night observations.

b. The Packrat blast site was detectable on T-2 thermal images during both day and night.

c. While detection with thermal imaging equipment was successful, a much better view of the Packrat site was possible with conventional photography and the unaided eye during daylight. At night the thermal images from a ground-based system such as the T-2 are only a marginal value without a prior knowledge of the general test site.

d. Since a crater was formed by the only explosion tested, no conclusion can be made concerning the value of thermal imaging equipment for detection of underground explosions in the absence of topographic changes.

e. Future thermal imaging operations should be conducted with airborne devices because of the superior viewing angle offered.

APPENDIX

Characteristics of the Thermograph T-2

The following is an outline of the principal characteristics of the Thermograph T-2:

1. Infrared Detectors

- a. Type of detectors: Germanium-immersed
Thermistor bolometers
- b. Number of detectors: Two
- c. Size of active detector flakes: 0.1 x 0.1 mm

2. Detector Time Constant

- a. Low-frequency channel - 2.3 milliseconds
- b. High-frequency channel - 1.4 milliseconds

3. Detector Responsivity*

- a. Low-frequency channel - 6,370 rms volts/rms watt
- b. High-frequency channel - 3.270 rms volts/rms watt

4. Optical System

- a. Scanning System: Scanning system with fixed 8-in. diameter, f/1.5, paraboloidal, primary mirror and a rectangular (8.5-in. by 12-in.), plane-surface scanning mirror.
- b. Interceptor Mirror: A (3/4-in. by 3/4-in.) plane-surface mirror is fixed in the radiation path to divert a portion of the collected radiation to the low-frequency channel detector.
- c. Instantaneous field of view: Approximately 1.5 milliradians.

*Responsivity for these immersed detectors is a relative value obtained by using a point source chopped at 20₂ cps and dividing the radiant power in watts falling on the detector by n where n is the refractive index of germanium. For the purpose of this measurement, n is taken as 4.

d. Total field of view: Fixed horizontal scan of 10 degrees; adjustable vertical scan of either 5 degrees or 10 degrees.

5. Bandwidth - Frequency sharing system: 0 to 400 cps

6. Weight - Approximately 160 lbs.

7. Power Requirements

a. 300 watts at 110 volts, 60 cps

b. Line Voltage Source: In field operations, the system is operated from a $\frac{1}{4}$ -ton, jeep-type vehicle, 24-volt, d-c system converted to 110 volts, 60 cps. The system may also be operated from any 110-volt, 60-cps line supply.

8. Recording Speed - System scans at the rate of 100 square degrees of target area per minute.

9. Operating Mode

a. Field Operations: The Thermograph T-2 is mounted on, transported by and powered from a jeep-type vehicle.

b. Other Operations: The Thermograph T-2 may be removed from the vehicle and powered from a tripod wherever there is a source of 110-volt, 60-cps power.

10. Noise Equivalent Temperature for Targets Around 25°C

a. Low-frequency channel: 0.26°C

b. High-frequency channel: 0.14°C