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TECHNICAL REPORT

OCTOBER 1961

Contract No. DA 36-039 SC 87211

SEISMIC LOCATION OF
MISSILE IMPACTS
AT THE
WHITE SANDS MISSILE RANGE

Prepared for

United States Army Signal Supply Agency
Fort Monmouth, New Jersey



By

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TECHNICAL REPORT

SEISMIC LOCATION OF

MISSILE IMPACTS

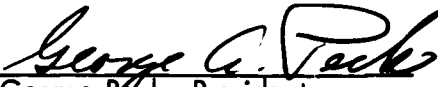
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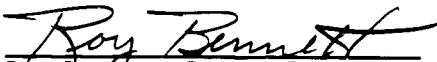
WHITE SANDS MISSILE RANGE

OCTOBER 1961

Contract No. DA 36-039 SC 87211

Approved by:


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ABSTRACT

In July 1961, Dresser Electronics, SIE Division of Dresser Industries conducted field tests with commercial seismic instruments to determine the feasibility of locating missile impacts on White Sands Missile Range. Results proved seismic refraction techniques reliable and accurate to within ± 30 ft. for location of missile impacts in a mile square area of the range. Time of impact could be calculated to within a few milliseconds.

The most useful signal path for accurate location of missile impacts was via the 7,300 ft. per sec. refractor. For impacts beyond the critical distance, the first arrivals were via the 14,100 ft./sec refractor layer.

The loss of data from many sensors located within 2,000 feet forward of the impact point was caused by air sonic boom noise.

A broader and deeper array would have enhanced accuracy in locating missile impacts several miles from the sensors.

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1.0 INTRODUCTION

This report covers a series of field tests which were designed to determine whether seismic methods using standard equipment were feasible for calculation of time and location of missile impacts on White Sands Missile Range. This work was based on earthquake location and sound ranging techniques which have been successfully used to locate the source of waves propagating through air, water, or earth. The difference in the arrival times of a wave at several sensors in an array are used to calculate the direction and distance to the energy source, and when the signal velocity is known the initial time of the event may be obtained.

A. Problem and Experiment Planning

Current seismic geophysical exploration techniques are designed to study composition and structural attitude of layers in the earth's sedimentary veneer. This technique requires accurate recording of the moment of detonation (time-break), arrival of the resulting longitudinal waves at the recording position, and knowledge of the propagation velocity of the intervening medium traversed. Standard electronic equipment has been developed for oil exploration which in this study was applied to the problem of locating missile impacts. The problems posed were: 1) obtainable accuracy; 2) range of detectability on the White Sands Missile Range area; 3) seismic ambient noise and signal-to-noise ratios; 4) the most effective sensor array; and 5) the most accurate method of data analysis.

Technical literature (1, 2, and 3)* indicates that time differences of wave arrivals at properly distributed geophones (sensors) may be resolved to indicate the

* See Ref. 1, 2, & 3 in Bibliography

location and time of a shock wave source. An array of sensors was selected based on the square array recommended by Schriever (1). Although sonic boom noise was considered, not enough details were known apriori to layout the array to minimize its effects. The array used was too narrow to provide accurate distance determination in the 4 to 12 mile range although it proved adequate for impacts in or close to the arrays.

B. Instrumentation

A modern, transistorized, truck-mounted seismograph system was used to record the data received from the controlled explosive detonations and missile impacts. The following pertinent, condensed characteristics of units forming the system are expanded in the brochures appended.

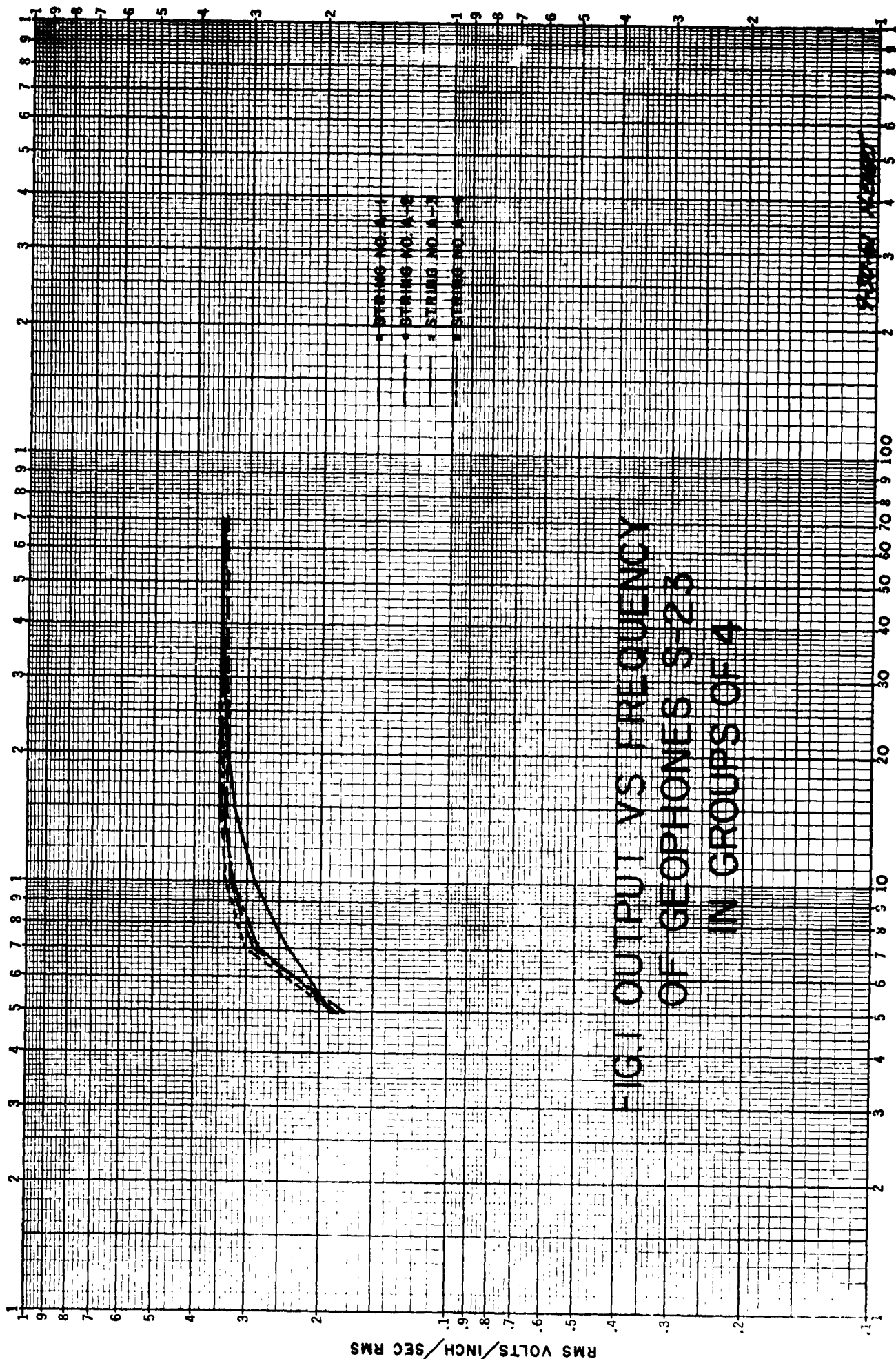
Sensors - Standard SIE S-23 geophones were used to detect earth motion at the recording arrays and refraction profile stations. This instrument is a velocity type generator consisting of a wire coil suspended by a spring in a magnetic system permanently attached to the case. The natural frequency is $7\frac{1}{2}$ cycles per second and the output vs. frequency curve is shown in Fig. 1.

Amplifiers - Standard SIE PT-100 seismic amplifier system combining 24 channels of transistorized TGA-1 amplifiers and control units were used. (A, Figure 2) Specifications of this equipment follow:

Frequency Response - to tape - within 3 db., 3 to 500 cps

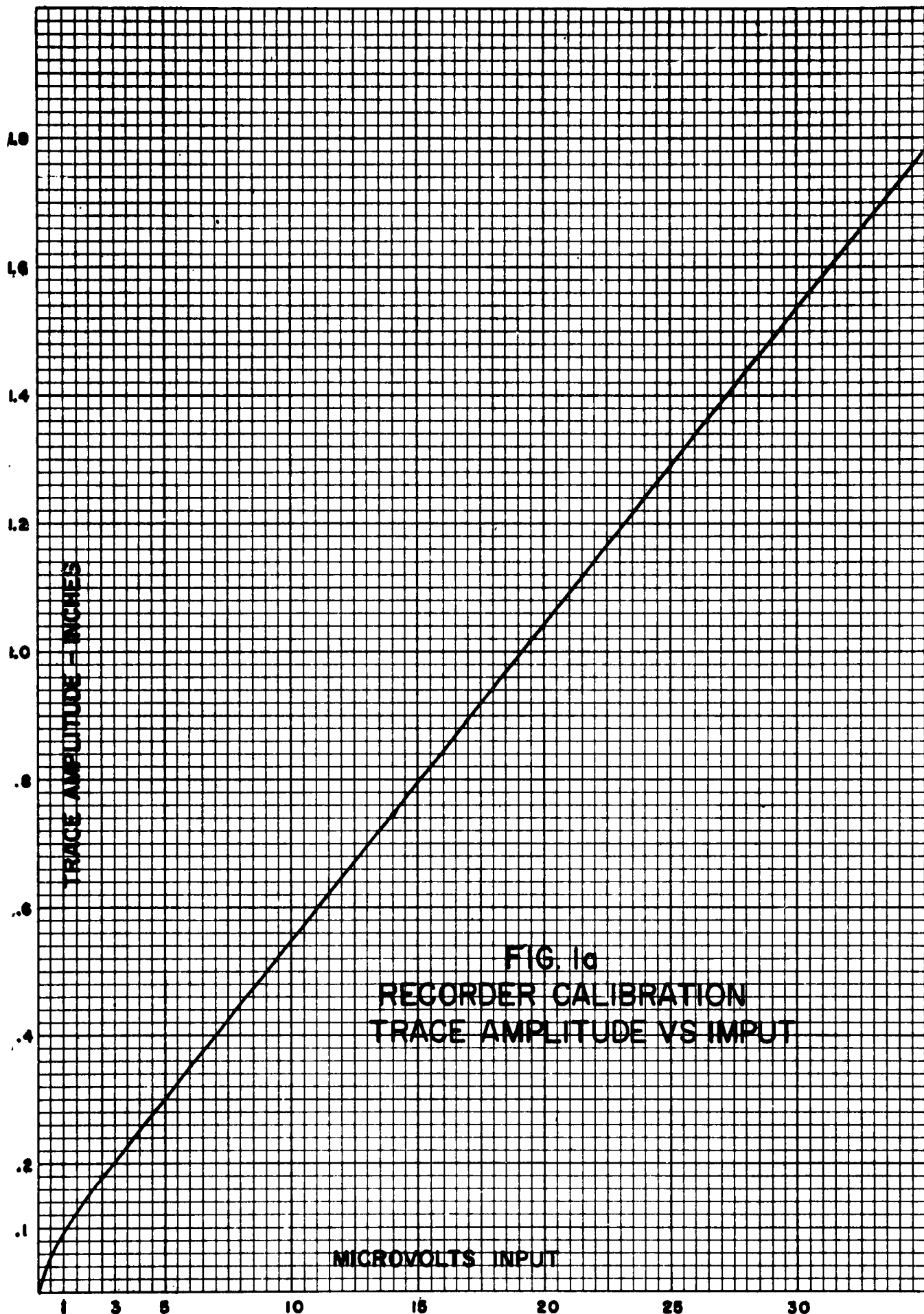
to galvanometer - within 3 db., 5 to 500 cps.

Automatic Gain Control (optional - equal output amplitude - 1 microvolt to 1 volt input.



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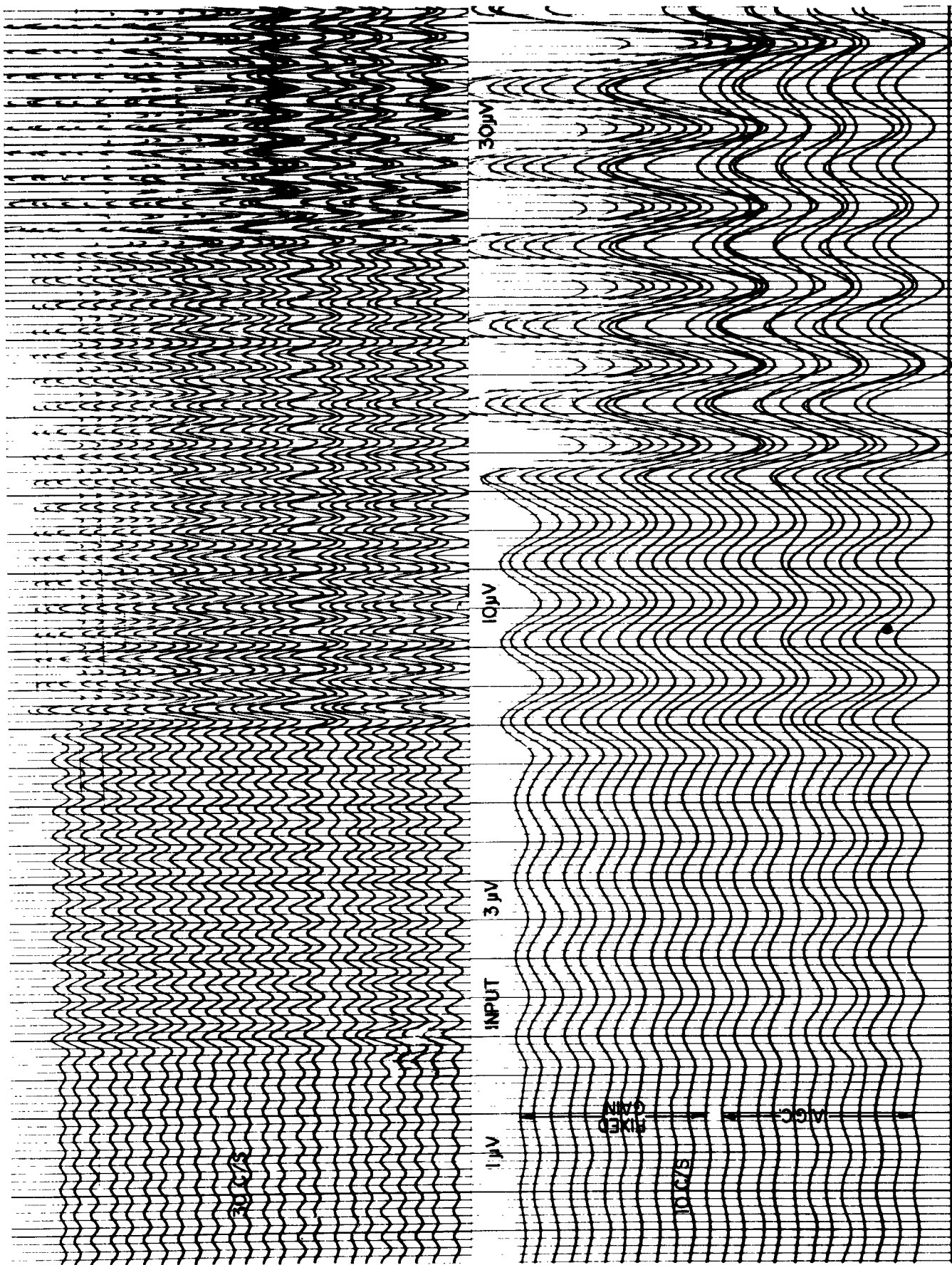


FIG. 1B TYPICAL RECORDER CALIBRATION — TRACE AMPLITUDE VS. INPUT VOLTAGE

Distortion:	Less than 0.5%
Outputs - Galvo:	Maximum deflection with 200 cps SIE galvanometer recorder 12 inches peak-peak.
Tape:	0.15 and 1.0 volt rms @ 22 K ohms
Filters - Passive, Constant K:	18 or 36 db/octave (B, Figure 2)
Cut-off Frequencies:	Lo-cut: out, 16, 20, 25, 31, 39, 50, 65, 82, 105 or 130 cps. Hi-cut: 24, 30, 37, 47, 60, 78, 100, 135, 175 or 220 cps.
Control Unit:	Gain and amplitude controls, integration controls to program oscillograph and magnetic tape recording.
Recording Oscillograph:	SIE TRO-6 (C, Figure 2)
Display:	Variable density variable area, wave form or combinations on photographic paper, 28 channels.
Galvanometers:	200 cps, undamped DC sensitivity - 3.4 in/ma at 1 foot; damping factor 0.65 critical.
Timing:	Flasher tubes imprint lines each 0.010 secs.
Accuracy:	1 part in 20,000
Paper Drive:	Selectable speed 3 to 30 in/sec. (D, Figure 2)
Magnetic Tape Recorder:	SIE PMR-20 frequency modulated system combining 24 TRM modulators, 24 TRD demodulators, MR-20 tape transport and MC-20 control unit.

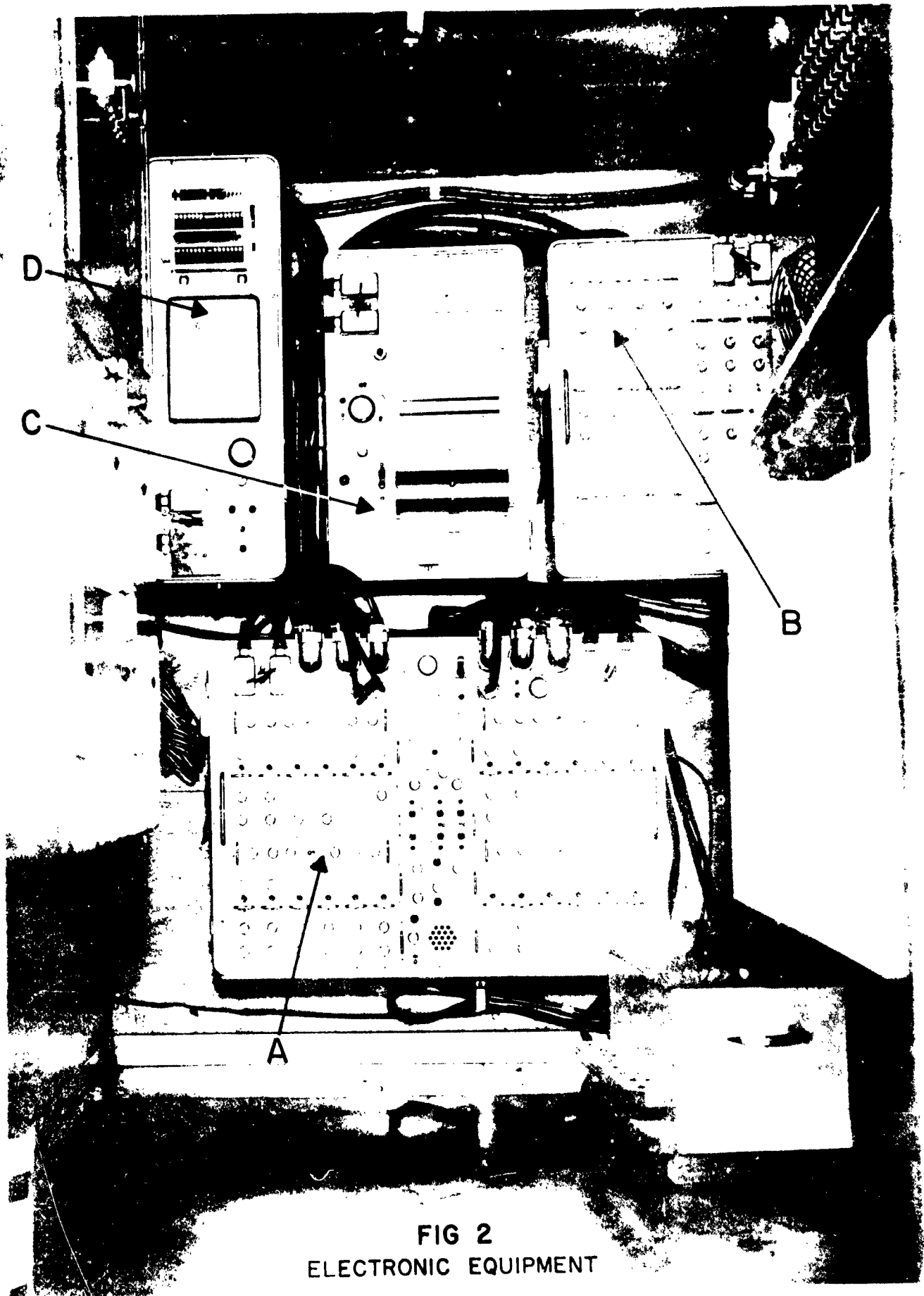


FIG 2
ELECTRONIC EQUIPMENT

Frequency Response:	Within 1 db 1 to 300 cps
Signal-to-noise Ratio:	60 db (rms-rms), 1 to 500 cycles
Harmonic Distortion:	Less than 1%
Absolute Timing Accuracy:	0.2 millisecond/sec. $\pm$ 1 millisecond
Relative Timing Accuracy:	$\pm$ 0.25 millisecond
Transfer Relative Timing Accuracy:	Within 1 millisecond
Input for Max. Record Level:	0.375 across 0.5 potentiometer
Max. Output Level:	2.2 volts at 3000 ohms, 300 microvolts at 200 ohms.

Recorder gain calibration was checked daily. Typical calibration data are shown in Figures 1a and 1b.

The normal tape speed of 7-1/2 in./sec. provides a 6 sec. recording on this drum-type transport. The speed of the transport was decreased to extend the recording time to 9 sec. for this application.

2.0 TEST PROCEDURE

A. Field Test Procedure for Collecting Data

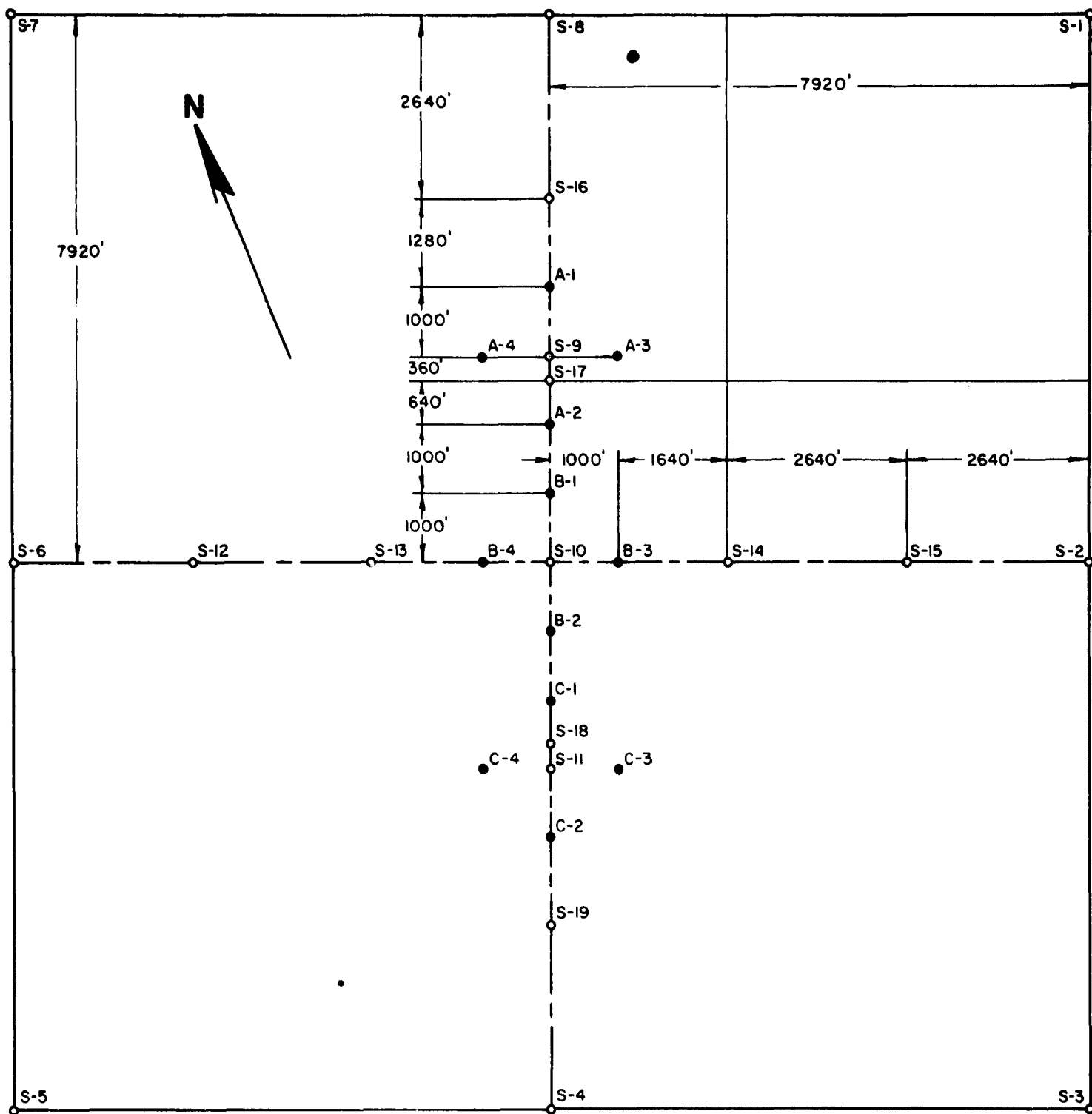
The choice of the test area was based on probable missile impact locations during the test period, August 17 to September 17, 1961. The area to be studied was 3 miles x 3 miles. This area consisted of slightly rolling topography with brush covered loose sand at the surface underlain by a layer of loosely cemented evaporites. It is typical of most of the Tularose Basin which lies between the San Andres and Sacramento Mountains. Subsurface sediments are flat lying lacustral non-marine shales and sandstones. The presence of evaporites at or near the surface strongly suggests an evaporite section at depth.

The experiment plan determined configuration of explosive shot point locations and recording arrays indicated in Figure 3. A Signal Corps survey team, headed by R. W. Boobar, located and flagged each location for subsequent use. Accuracy of 5 feet horizontally and 2 feet vertically was realized by careful surveying procedures and ties made to bench marks included in the WSTM coordinate system. The cooperation of Signal Corps and the survey team aided materially in the field tests by their accurate work resulting from competence, willingness and experience with the area and its survey control.

In addition to the above described configuration, stakes were spaced 115 feet apart between shot points S-2 to S-6 and S-4 to S-8 by chaining to these locations for the single sensors used in the reversed refraction profiles.

1. Recording Arrays

At each array location, designated A-1 to A-4, B-1 to B-4 and C-1 to C-4 in Figure 3, four S-23 geophones were connected in series, planted one foot deep



- GEOPHONES
- SHOT POINTS

TEST ARRAY & SHOT
LOCATIONS

FIG. 3

of shots required from each shot point. Explosive charges varied from 1 pound to 50 pounds, determined primarily by distance to the sensors.

4. Communication

Truck-mounted, two-way radios were used to provide communication between shot point and recorder and transmitted a detonation impulse on each shot recorded. During missile impact recordings, the WSMR G-2 timing signal was recorded on the bottom trace of each record.

5. Recording Missile Data

Absence of precise impact times handicapped the operator of the recording system used in this project. The magnetic tape recorder was capable of recording only nine seconds after modification from the standard six seconds storage. To use the conventional exploration equipment, the drum carrying the magnetic tape was allowed to run continuously during the missile flight. It recorded and erased ambient noise until a selected wave front arrival was viewed on the galvanometer screen of the recording oscillograph. At that moment the operator manually removed the recording head bank to avoid erasure. Terminal splice of the magnetic tape also reduced probable recovery of data. A reel-to-reel type recorder is recommended for future studies of this type; these are not used in conventional seismic exploration systems.

Film speed in the photographic oscillograph required a compromise to minimize the length of photographic paper to be handled in the developing process. At the same time sufficient spacing of the 0.010 second timing lines to permit interpolation of event timing to ± 0.001 second was required. The film speed used was 8 inches per second.

B. Analysis of Data

Preliminary data reduction procedure used on the square arrays was as follows:

1. Obtained first approximation of the impact location by

$$\tan^{-1} = (t_1 - t_2) / (t_4 - t_3) \text{ method.}$$

2. Distance measured from approximate impact location to each sensor.
3. Plotted Time vs. Distance curve using approximate distances and sensor arrival time differences. The sensor nearest the impact was used as time .000.
4. Line or lines of best fit were drawn through plot.
5. Corrected sensor times to agree with these lines.
6. Arcs from each sensor were drawn with radii equal to t multiplied by the appropriate velocity.
7. Isochronic circle of best fit was drawn tangent to these arcs; the center of this isochronic circle represented the impact point.
8. Calculated impact time by plotting corrected time-distance curve and subtracting intercept time (t_i) plus $\frac{D_c}{V}$ from t_o

D_c = corrected distance to nearest sensor recorded WSMR G-2

t_o = time of first arrival at nearest sensor recorded

t_i = intercept time

A discussion of the procedure used for data reduction step No. 1 through 8 follows:

Step No. 1

The tangent method (1) of finding the azimuth from first arrivals in a square array of sensors was used for preliminary calculations.

(1) See Ref. 1 in bibliography

Step No. 2

The location obtained in Step No. 1 was plotted on a scaled map so the approximate distances to each sensor could be measured or calculated from the appropriate coordinate system.

Step No. 3

Plot of the difference in arrival times at the various sensors in all arrays against the approximate distance as found in step No. 2 has the following advantages:

- a. Total variable time delays at each sensor are corrected by taking new time readings to the best fit line.
- b. Any unconformable points are at once obvious. This permits further check on the time pick of the points, evaluation of signal path, detection of later arrivals such as from multiple refracted signals, and a check on the correlative cycle used for each trace of the record.

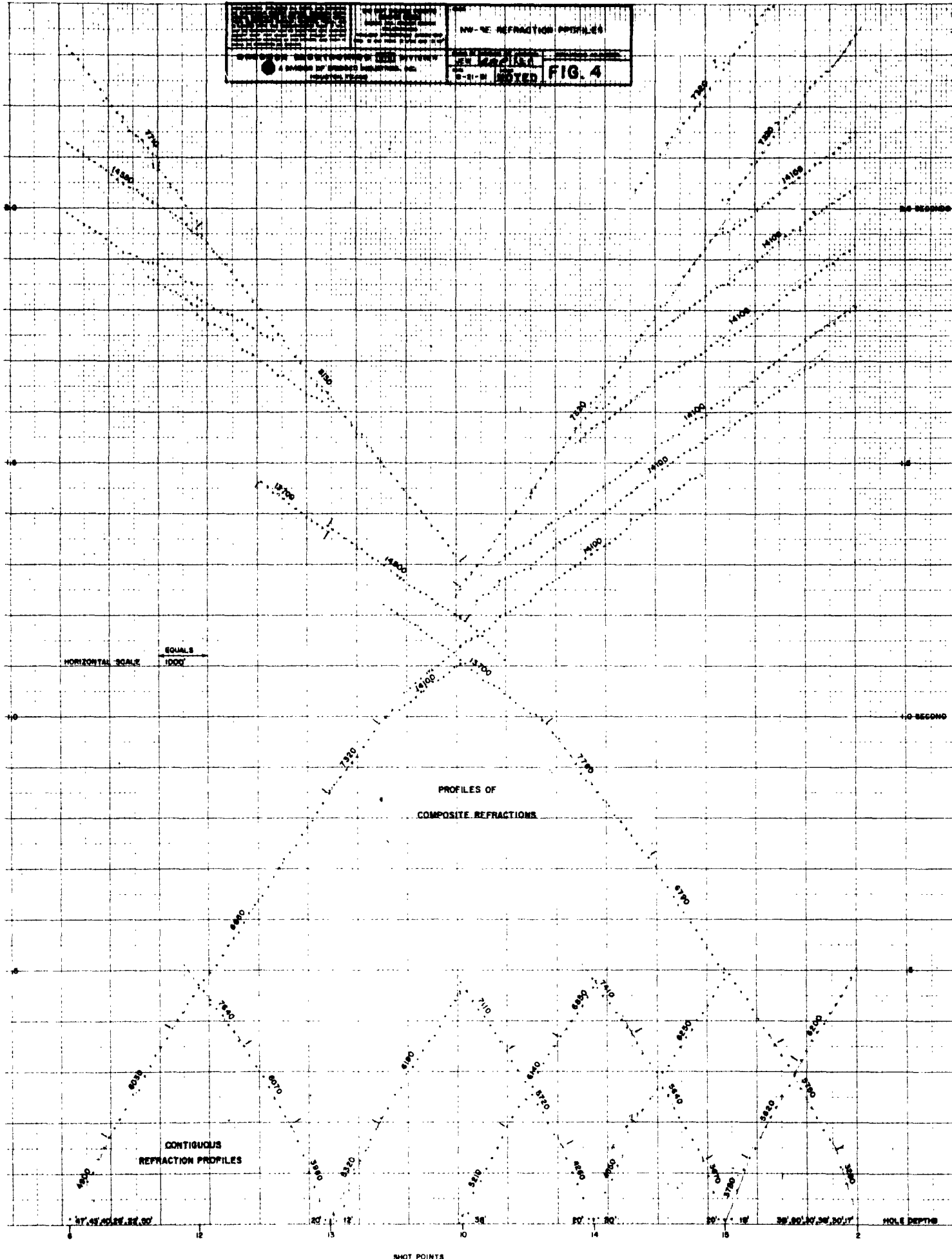
Step No. 4

The slope of the straight line of best fit to the arrival times of the sensors in each array should be close to one of the velocities shown on the T-D plots from the refraction data for the profile involved as shown in Figures 4 and 5. The dashed line in Figure 6 is the average of these profiles corrected for geophones planted 40 feet deep. If different velocity paths were transversed by the signals to adjacent geophones at different distances and azimuths these will be obvious on the T-D curve. In the case of signals arriving from opposite directions the points may fall on two parallel lines separated by a distance which is twice the error found in locating a point midway between the two sensors by the arc method described in steps 5 through 8.

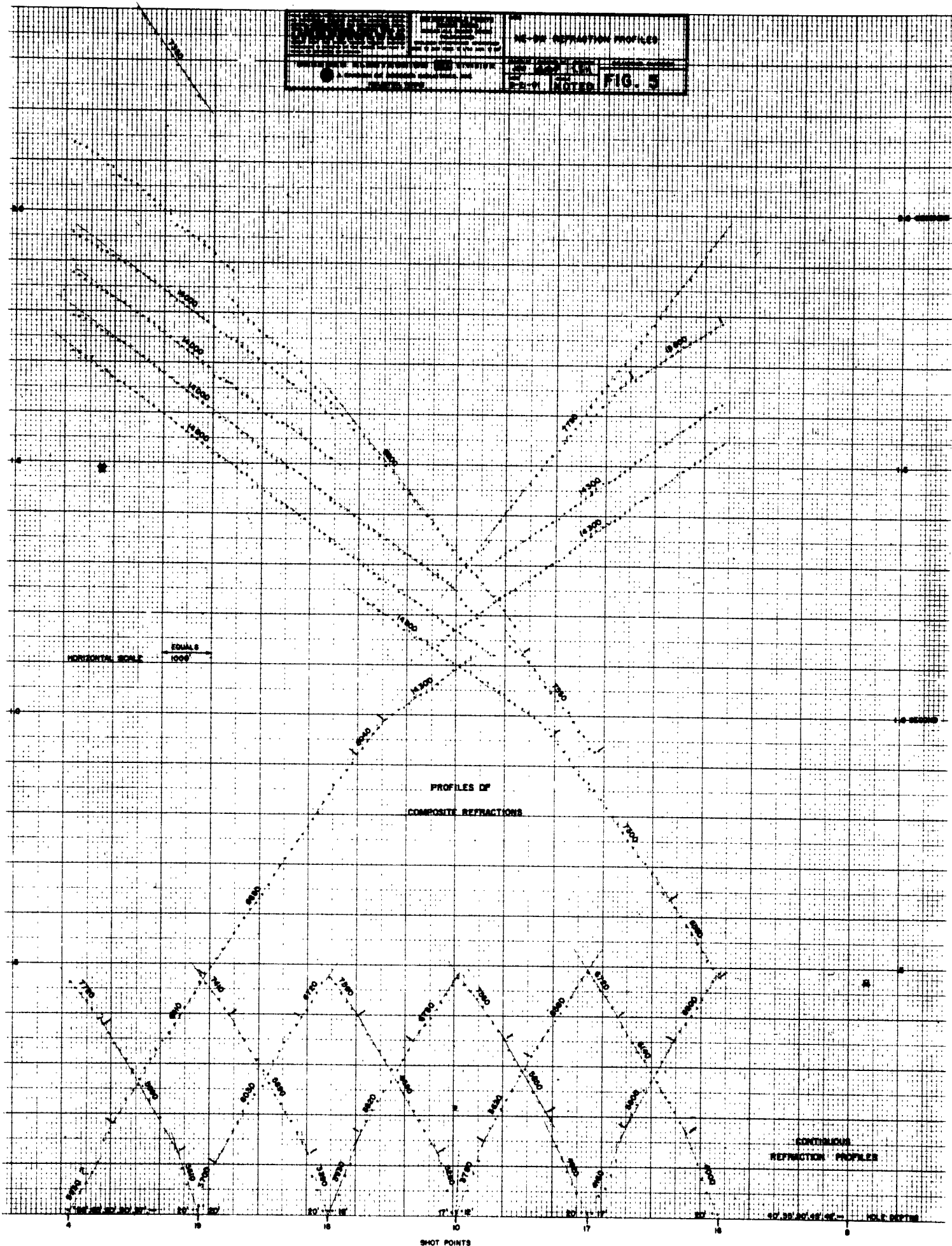
Step No. 5

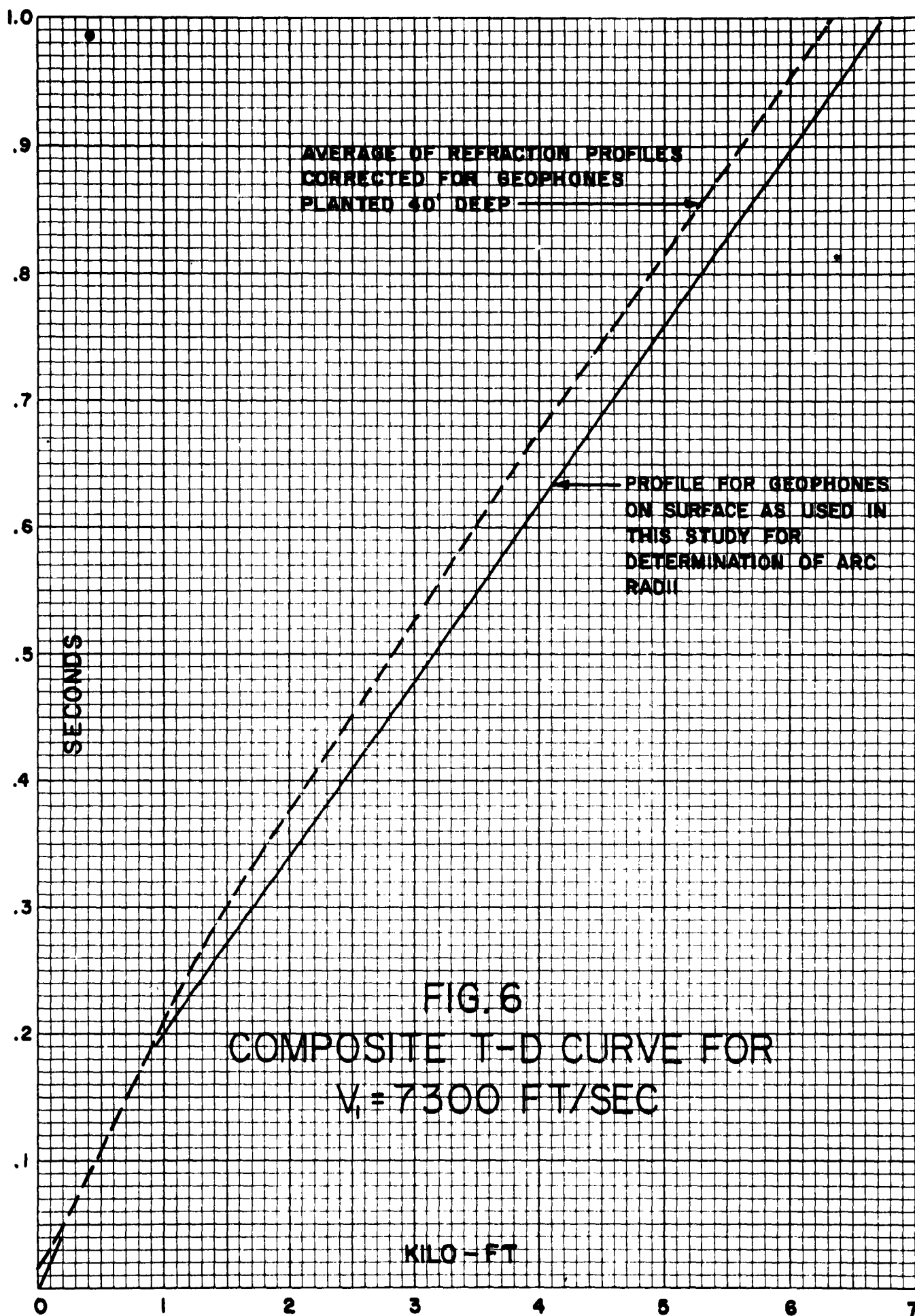
Using the straight line or lines obtained in Step 3 the corrected times for the plotted

NO. 1 NORTH-NE REFRACTION PROFILES DATE: 10/2/54 BY: J. H. M. CHECKED: J. H. M.	
SECTION: 4 SCALE: 1" = 1000' FIG. 4	

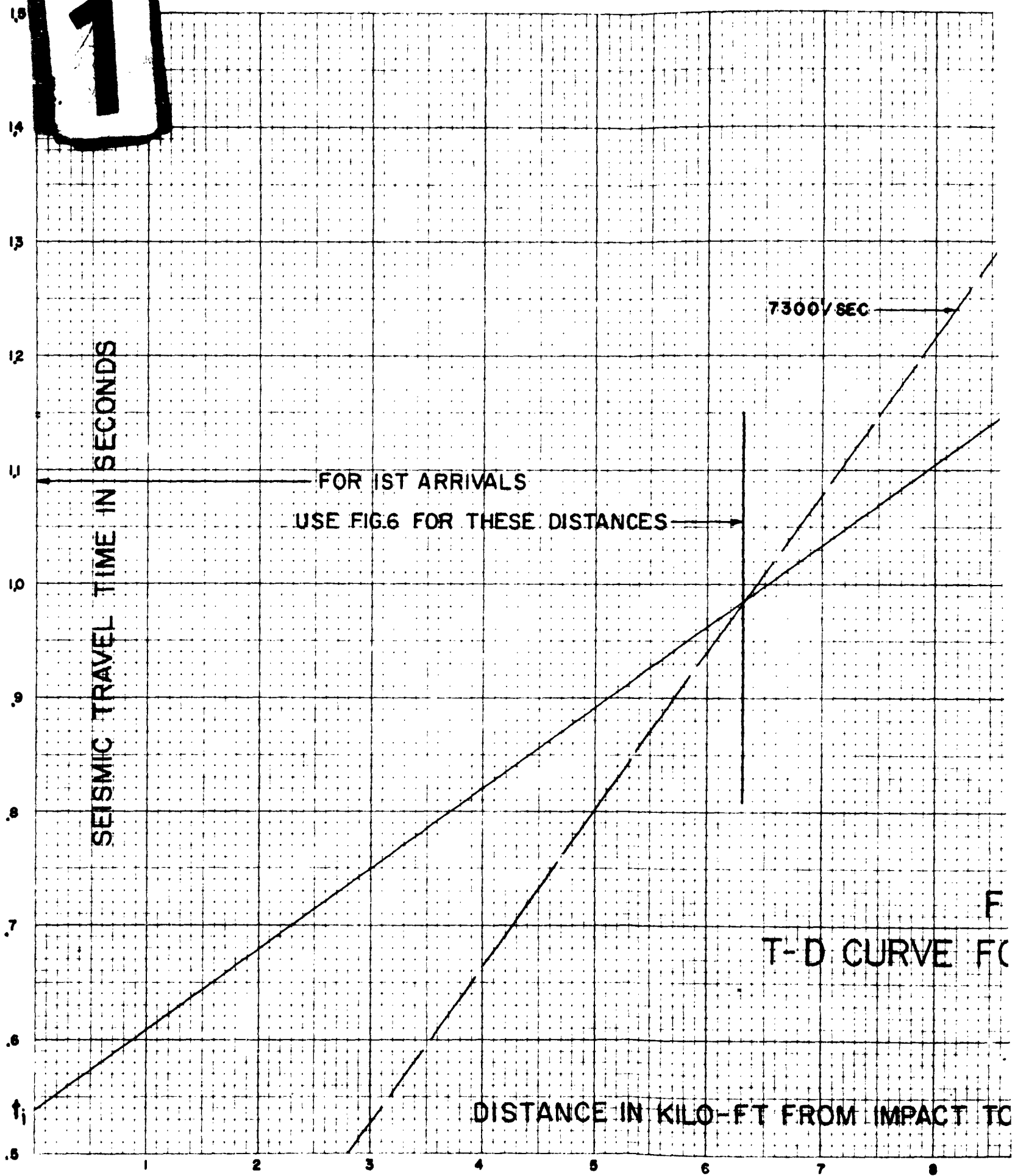


NAVY DEPARTMENT OF THE NAVY BUREAU OF NAVAL PERSONNEL 1600 REAR ADMIRAL ROAD WASHINGTON, D.C. 20374	REFRACTION PROFILES FIG. 5
	PROJECT NO. 100-100 DATE 10-1-60
	DRAWN BY 100-100 CHECKED BY 100-100





1



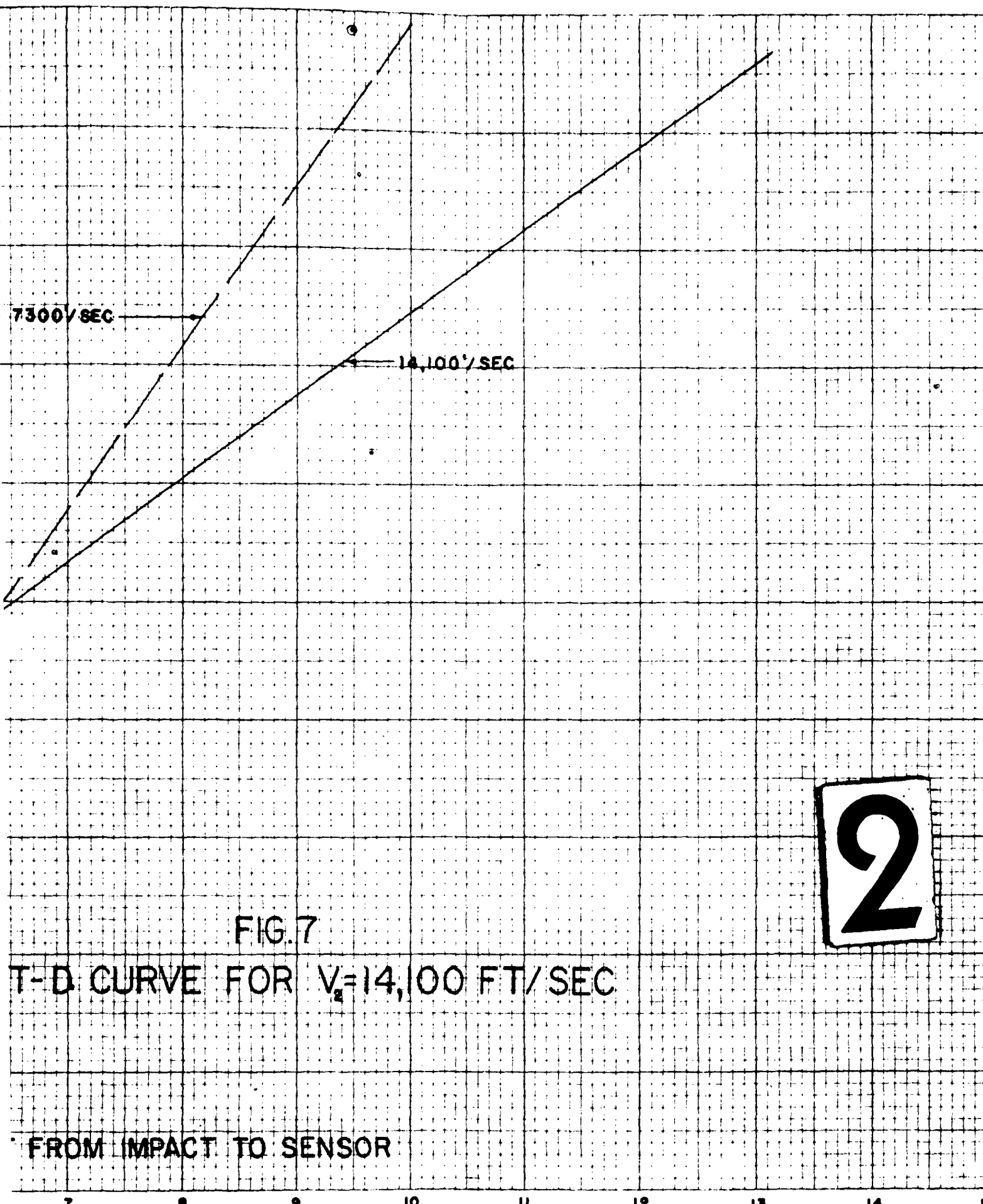


FIG. 7
T-D CURVE FOR $V_2=14,100$ FT/SEC
FROM IMPACT TO SENSOR

2

distance of each sensor were read and recorded. These new times have been corrected for individual differences in elevation between sensors or other topographical and geological irregularities.

Step No. 6

By subtracting the minimum time (lowest point on curve read in Step 5) from all other corrected times, time differences were obtained. These Δ times represent the time for the signal wave front to pass from the first sensor to other sensors. Distances used as construction radii for arcs drawn from each sensor were obtained from the corrected Δ times referred to the T-D curve (solid line) Figure 6. This solid line may be established either by computation or calibration and was used to correct for the additional travel time incorporated as a result of refractors of decreasing velocity near the impact area, which is inherent in this method of location where more than one refractor exists. In effect, this correction placed all distant sensors on the 7300' refractor from impact zone to critical distance.

Step No. 7

All arcs did not fall exactly tangent to one circle since 3 points establish a circle and 12 points are available. The better data received preference in fitting the isochronic circle. The center of this circle was marked as the calculated missile impact point.

Step No. 8

The time of impact to within a few milliseconds was calculated by the equation

$$\text{WSMR G-2 Time} = t_o - \left(\frac{D_c}{V} + t_i \right) .$$

Where t_o = Real Time of 1st Arrival

D_c = Corrected Distance

V = Velocity for Azimuth & Distance

t_i = Delay Time

A time-distance plot was made from the corrected distances to the sensors from the final calculated impact location. The best line through these points were extrapolated to intersect the ordinate at 0 distance. This is the intercept time (t_i). The distance (D) from the calculated impact position to the nearest sensor was measured and divided by the appropriate velocity (V). This total time $\frac{D}{V} + t_i$ may also be read from the T-D plot (Figure 6). This total was subtracted from the time of day observed on the WSMR G-2 timing trace corresponding to the first arrival at the nearest sensor (t_o) to obtain the real time of impact $T = t_o - \left(\frac{D}{V} + t_i \right)$.

C. Comparison of Procedural Methods

Schreiver's method (1) of using the square array to obtain the azimuth by the equation $\tan^{-1} = \frac{t_1 - t_2}{t_4 - t_3}$ is valid only if the wave front over one array is essentially plane as might be produced by a very distance source. This condition is not met by impacts into an array. While this method does make effective compensation for variations of velocity in the medium beyond the array it has no way of correcting for the close-in variations that may be caused by topography or differences in the propagation. These slight differences, even though only a few milliseconds, cause large errors in the azimuth. Further the loss of any one of the four sensor arrival times as a result of sonic boom or other reasons renders the tangent equation useless. An additional fault of this method is that one sensor may receive its first arrival via a different path and hence a different velocity than the other three which would vitiate the results. These errors are not obvious and will go undetected which results in large triangles of error for the impact point.

The hyperbolic method (3) used in the "Gee", "Loran", and "Decca" navigational aids systems has most of the same faults of the Schreiber method such as lack of accuracy when one arrival is in slight error. In these methods there is no method of self checking on each data point such as in the procedure using the isochronic circle. The hyperbolic method is based on differences in signal arrival times at three known points where the velocity of transmission has been uniform. The velocity of a seismic signal depends upon the velocity of the refractor. Figure 8 shows simplified composite signal paths for seismic signals in three layers each of which has homogeneous elastic properties. This figure shows the different velocities and signal paths followed by the first arrival before and beyond the first critical distance ($x_{c1} = 1000$ ft.) and beyond second critical distance ($x_{c2} = 6300$ ft.). In using the hyperbolic method where one sensor station is less than x_{c1} and another is more than x_{c1} or x_{c2} the velocities would not be the same by a factor of three; hence, the location would be grossly in error.

Another serious fault in the hyperbolic system similar to one in the tangent method is that for distant impacts the intersecting lines would be nearly parallel thus providing poor range accuracy.

This series of field tests and experience in reducing the data therefrom have proved that the method using an isochronic circle drawn tangent to arcs whose radii are equal to corrected time difference multiplied by the proper velocities reduces the many faults of the other systems.

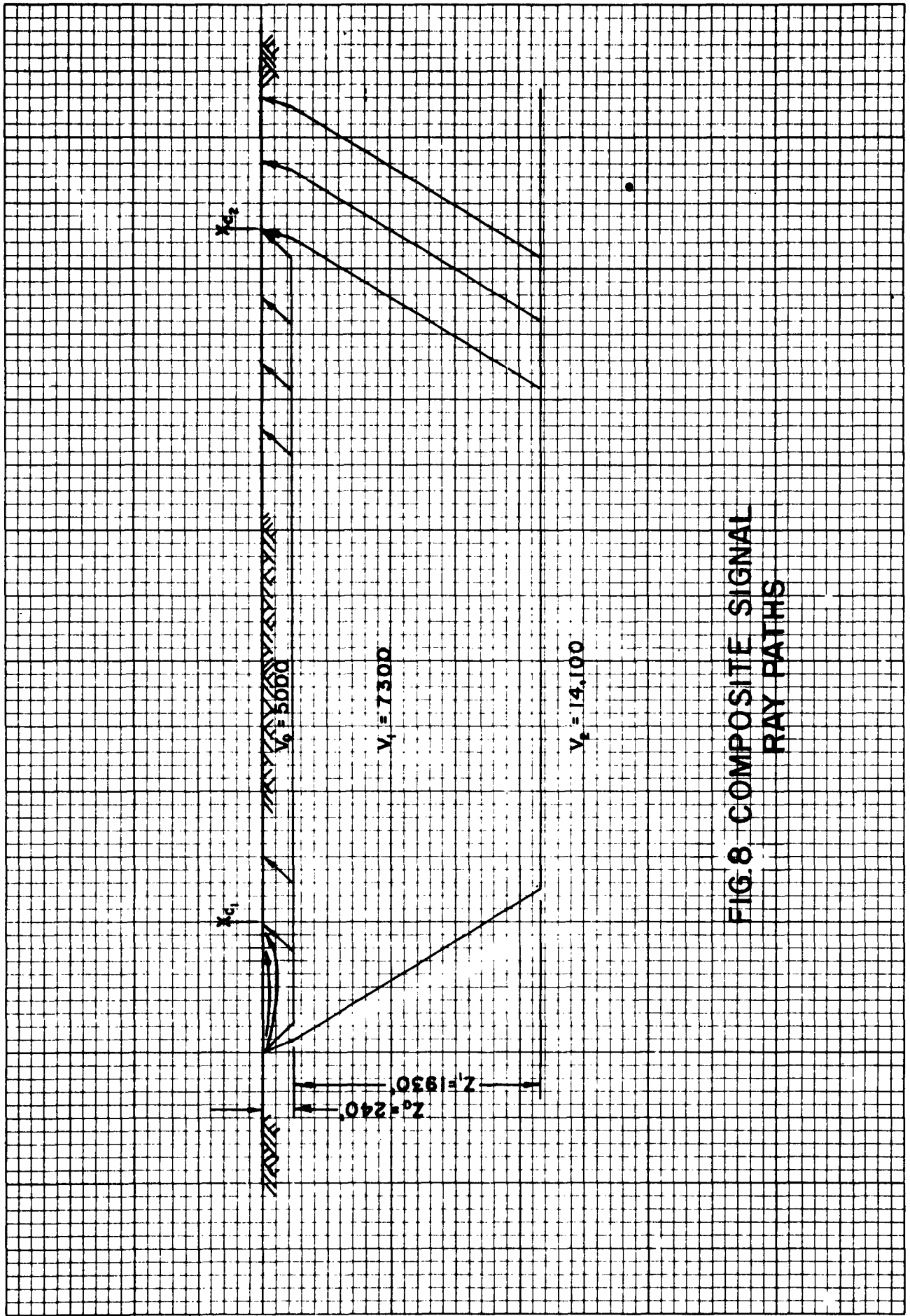


FIG. 8 COMPOSITE SIGNAL
RAY PATHS

3.0 RESULTS OF TESTS

A. Ambient Noise Level and Frequency Content

Studies of the ambient noise level on (non-AGC) traces from the various sensors in the arrays indicate that no serious problems exist from low signal-to-noise ratio. Table 1 shows the pre-trace maximum noise levels on all records of shots from the periphery of the area. All records were examined including those of the missile impacts, and with the exception of trace #10, which was driven by a noisy amplifier, all traces were below .10 inch amplitude of ambient noise. This represents about one microvolt output from the geophone or about 3×10^{-8} inches motion at 30 cycles per second.

In most cases the frequency of the ambient noise was random. Records from shot points S-2, S-4, and S-5 showed some evidence of 12, 5, and 30 cycle per second noise frequency.

The only noise adversely effecting the "P" waves from a missile impact is the sonic boom when it occurs within one second prior to the signal arrival. This occurred several times on impacts in the B-array. Planting the geophones 30' or 40' below the surface should reduce this noise.

B. Variation of Velocities

Velocity Variations in the Test Area are shown by the refraction profiles on Figures 4 and 5. Only those velocities shown on the composite curves Figure 6, 7, and 8 need to be used. Slight velocity variations of ± 100 ft./second will not affect the use of the system.

In order to show the velocities at 45° azimuths to the center lines of the arrays, shots were made into the arrays from each corner of the 3 mile square area. These T-D curves

TABLE 1

AMBIENT SEISMIC NOISE LEVEL AND FREQUENCY CONTENT

Shot Point	Max. Amb. Noise (inches)	CPS	Charge Weight	Hole Depth
S1	.05	-----	10#	58'
S2	.10 (4)*	12	10#	60'
S3	.05	-----	10#	54'
S4	.10 (1)	5	10#	54'
S5	.10 (3)	30	45#	43'
S6	.05 (3)	----	10#	68'
S7	.10 (3)	----	40#	54'
S8	.05	----	10#	68'

* Indicates trace number with most ambient noise

are shown in Figures 9, 10, 11, and 12. These data supplement the refraction profiles in Figures 4 and 5 and together provide a seismic velocity survey in 8 directions from each sensor. The slight variations of the points from the lines are probably due to local irregularities as well as experimental measurement and instrumental error.

C. Signal-to-Noise Ratio

The signal-to-noise ratios for various size charges shot into the arrays are shown in Table 2.

The type of ground that a missile strikes would have some influence on the S/N ratio; however, the worst condition should provide sufficient signal for detection for distances of several miles.

D. Seismic Frequencies

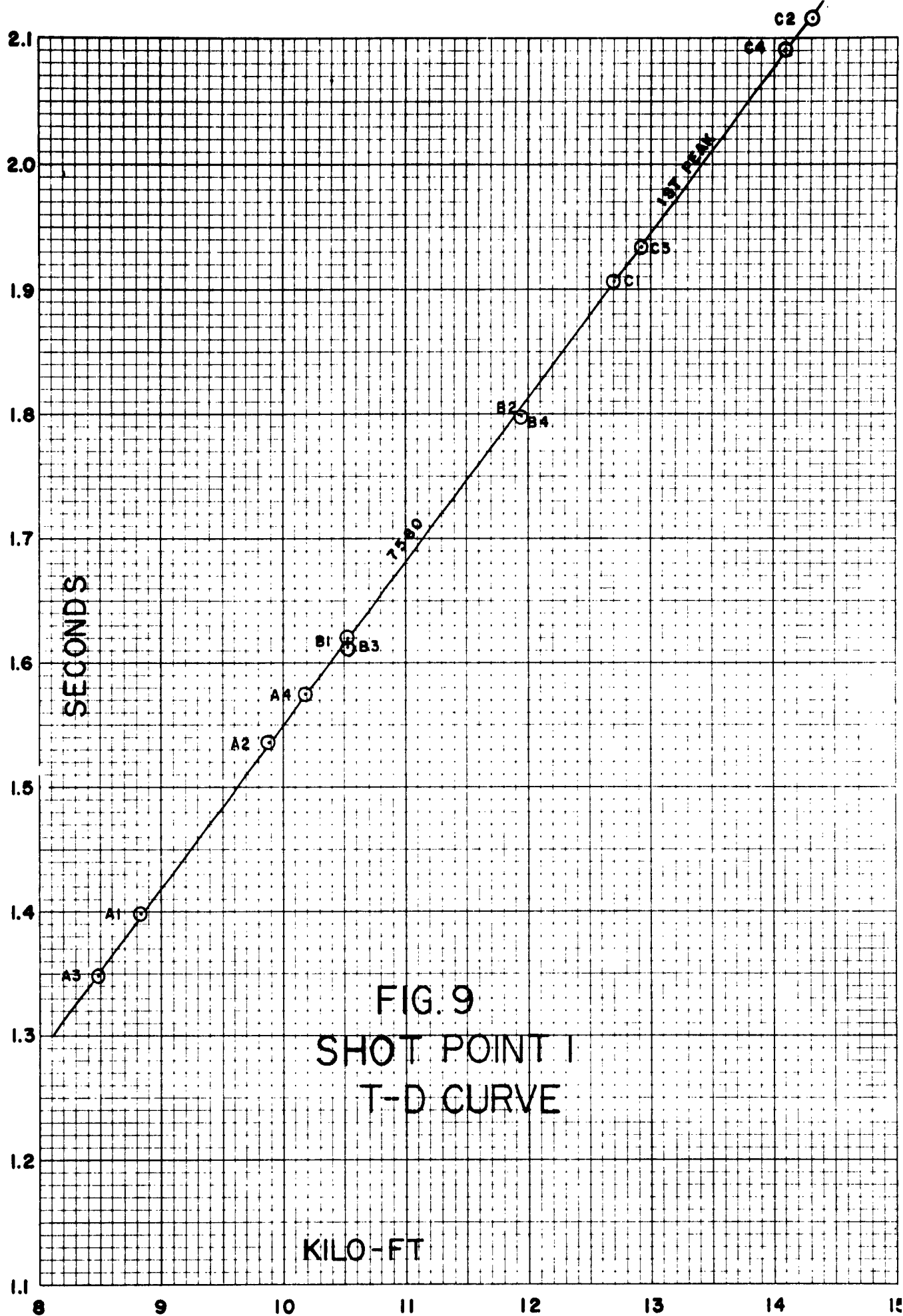
Data from the test conducted show that most useful frequency in the White Sands area for detection of the first arrivals of the primary waves is 20 to 30 cycles per second. For greater distances lower frequencies may be present because of lower attenuations associated with lower frequencies. For the purpose of missile impact location within a few square mile area the standard geophone used as a sensor and responding to 6 cycles per second and higher has proven satisfactory.

Other frequencies from waves shown on the record sections, but which were not useful in this project are as follows:

- a. The air coupled ground wave of approximately 15 cycles per second is measurable after 1.5 sec. and this wave disperses to below 8 cycles per second after 4 seconds. This wave travels at about 1100 feet/sec and shows on the record section as the slowest band of energy.

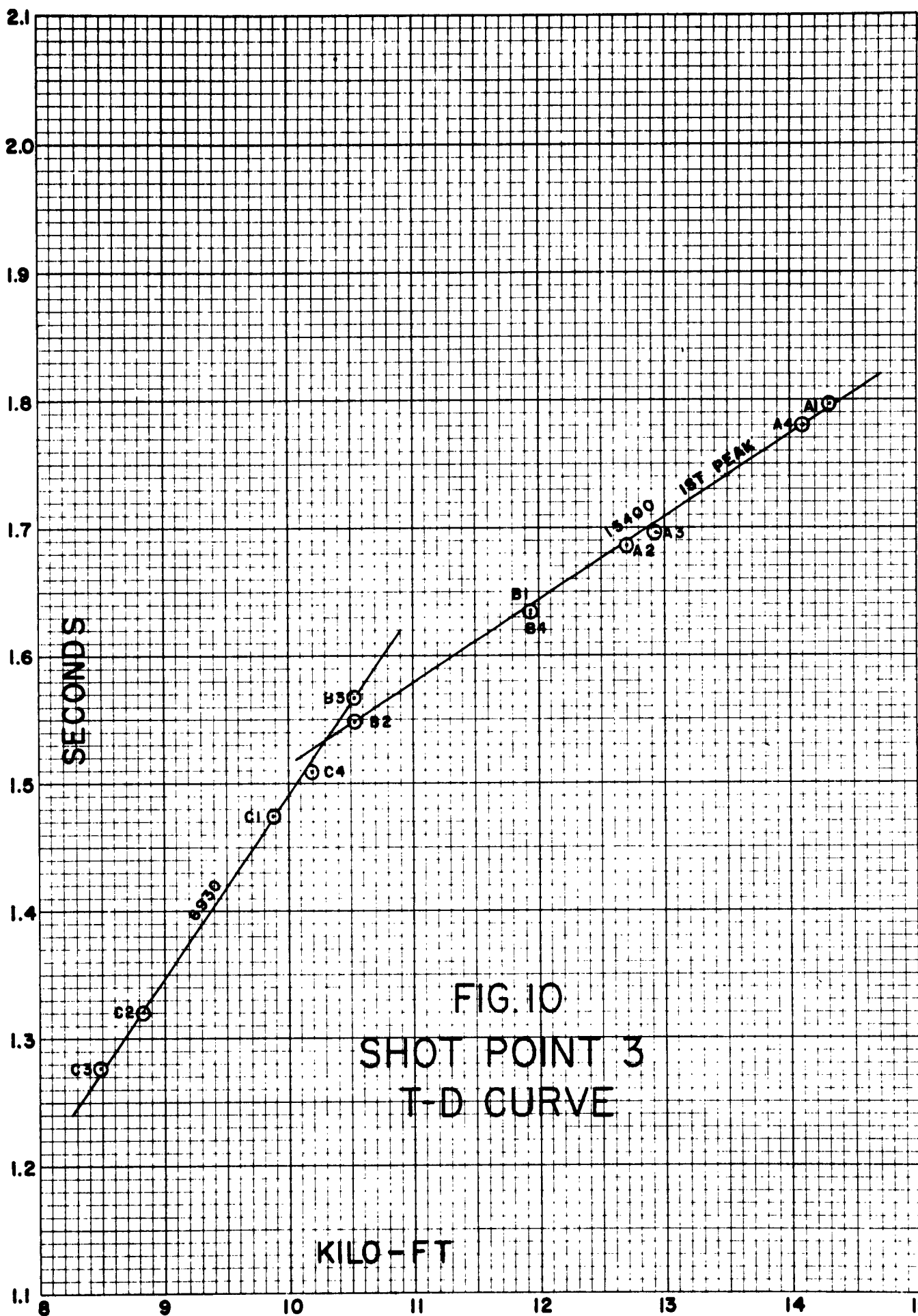
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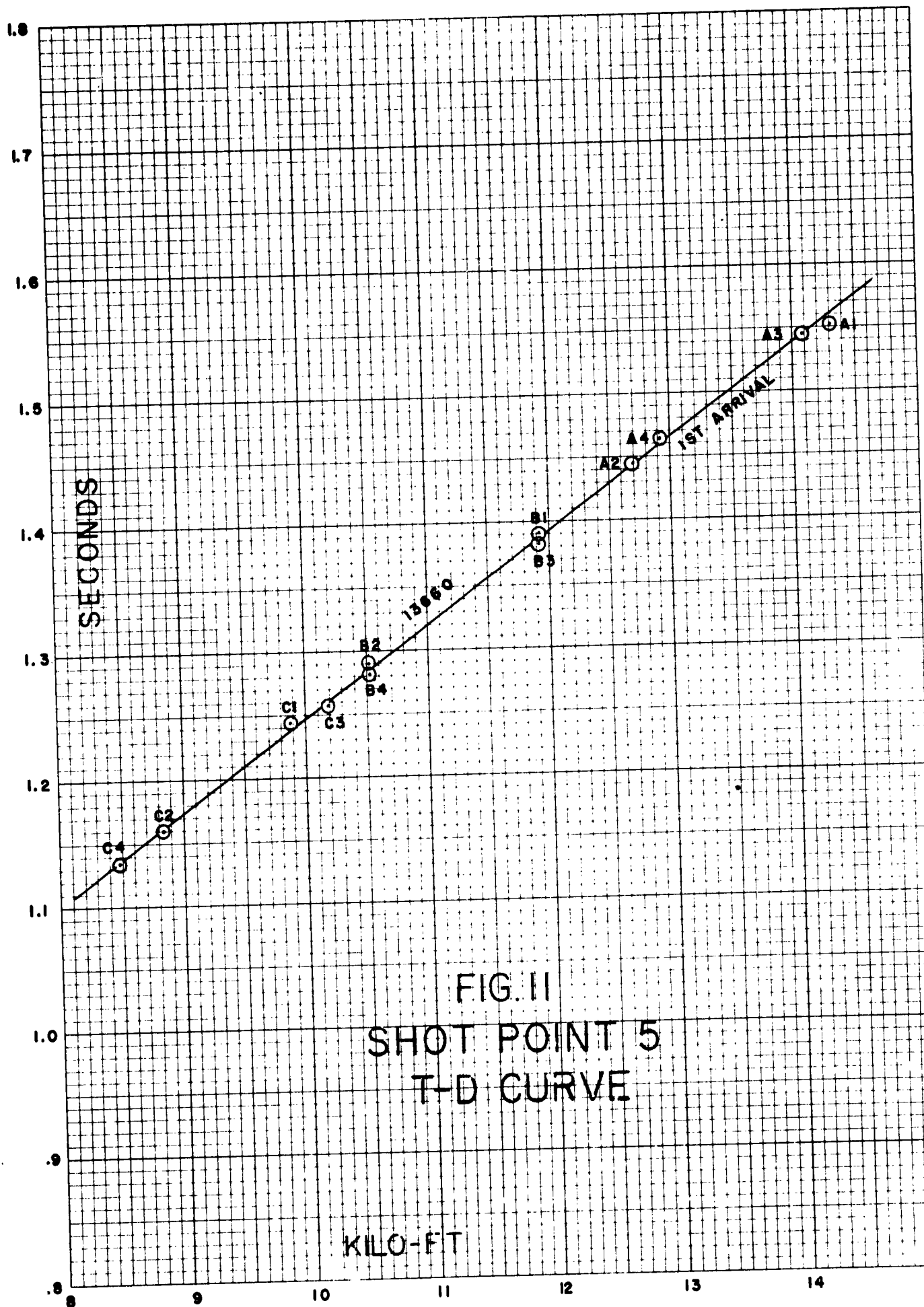
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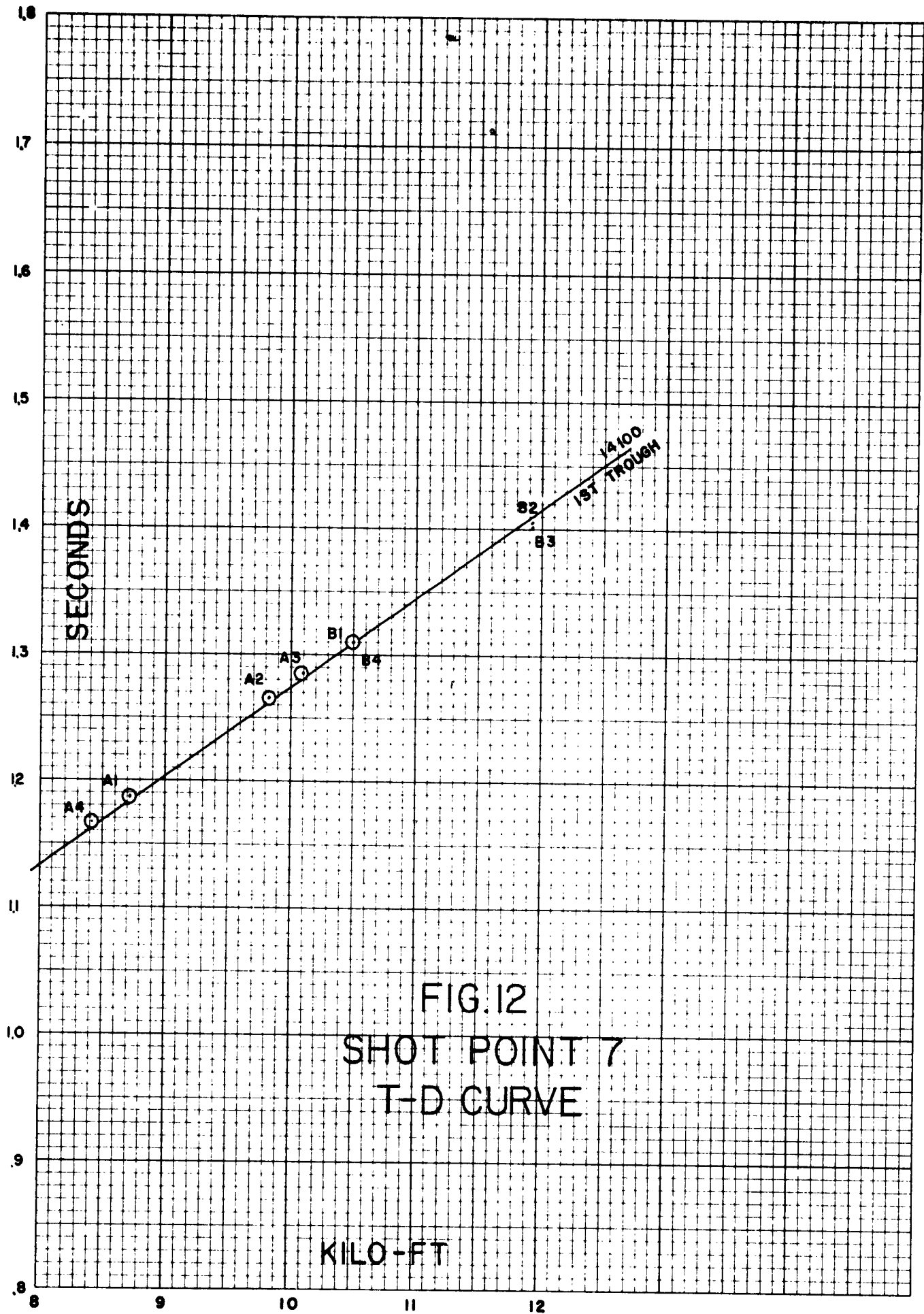


TABLE 2

SIGNAL-TO-NOISE RATIO FOR VARIOUS SIZE CHARGES

Shot Point	Charge Weight	Hole Depth	S/N - V_1	S/N - V_2	Distances to ~~g~~ Of Arrays-Ft.
S1	10#	58'	10/1	4/1	11,223
	40#	50'	20-30/1	4/1	11,223
S2	10#	60'		2-3/1	7,920
S3	10#	54'	20/1	5/1	11,223
	40#	40'	20/1	5/1	11,223
S4	10#	54'	20/1	5/1	7,920
S5	45#	43'		5-20/1	11,223
	10#	62'		5-15/1	11,223
S6	10#	68'		2-8/1	7,920
S7	40#	54'		2-10/1	11,223
	20#	73'		4-20/1	11,223
	10#	78'		6-30/1	11,223
S8	10#	68'	50/1	4-15/1	7,920

- b. Shear waves appear on the record section as energy bands having velocities between the air coupled ground wave and the first arrivals of the primary waves.

E. Signal Paths

The signal path most useful for computation of missile impacts as a seismic energy source is shown in Figure 8. In many cases the low velocity bed (7300 ft/sec) produced a strong later arrival because of less attenuation than the deeper high speed (14,100 ft/sec) layer. Note that the path, the velocity, and the intercept time for the first arrival changes with the distance from the sensor to the point of missile impact.

F. Accuracies in Computations of Locations

The limitations and accuracies of geophones, amplifiers, oscillographs, and timing instruments is well covered by the literature, see Ref. #4. Accuracies of instrumentation and reading traces are within $\pm$ one millisecond. Limits of accuracy in determining source location by this study are shown in Figure #13 (one of the folded inserts in the back cover) which shows the locations and calculated positions for all shots made into the arrays.

Table 3 shows the measured error in the location of shot points on the border of the area.

The maximum error was 180 feet $\pm$ 14 feet.

The minimum error was 25 feet $\pm$ 7 feet.

The average error was 118 feet $\pm$ 10 feet.

G. Range of Detectability of Explosive Shots

The range of detectability of explosive shots depends upon the shot size and attenuation of the signal in the medium. Table 4 shows the quality of signals obtained from various shots into the arrays.

The signal in all cases was satisfactory for the maximum range shot used in this test, which was 3 miles.

TABLE 3
ACCURACY-SHOT POINT LOCATIONS

Shot Point	Error
S-1	25'
S-2	180
S-3	180
S-4	130
S-5	170
S-6	120
S-7	120
S-8	80
S-12	110
S-13	70

Average Error = 118 ft.

Minimum Error = 25 ft.

Maximum Error = 180 ft.

TABLE 4
QUALITY OF SIGNALS FOR VARIOUS DISTANCES AND SHOT HOLE DEPTHS

Shot Point	Charge Weight	Hole Depth	Sensor Min. Dist.	Sensor Max. Dist.	Signal Quality
S1	10#	58'	8492	14312	good on all
	40#	50'			
S2	10#	60'	6920	9411	good on all
S3	10#	54'	8492	14312	good on all
	40#	40'			
S4	10#	54'	3920	10970	good on all
				11920	weak trace?
S5	45#	43'	8492	14312	all good
	10#	62'			
S6	10#	68'	6920	8872	all good
				9411	Weak but readable
S7	40#	54'	8492	12927	all good
	20#	73'		14100	
	10#	78'		14312	Weak but readable
S8	10#	68'	3920	10970	all good
				11920	weak

A plot of charge size vs. distance is shown on Figure 14. All traces recorded were usable. For any further shooting in this area the minimum size charge for given distances as shown by this curve is recommended.

The record sections shown in Figures 17 and 18 (folded inserts) illustrate the quality of seismic data recorded. Note in Figure 19 that the air sonic boom produces an arrival having a gradual negative first half cycle while the first arrival of a seismic signal has a sharp positive impulse.

H. Location of Missile Impacts

Impacts were recorded and analyzed based upon the background information obtained by the refraction survey.

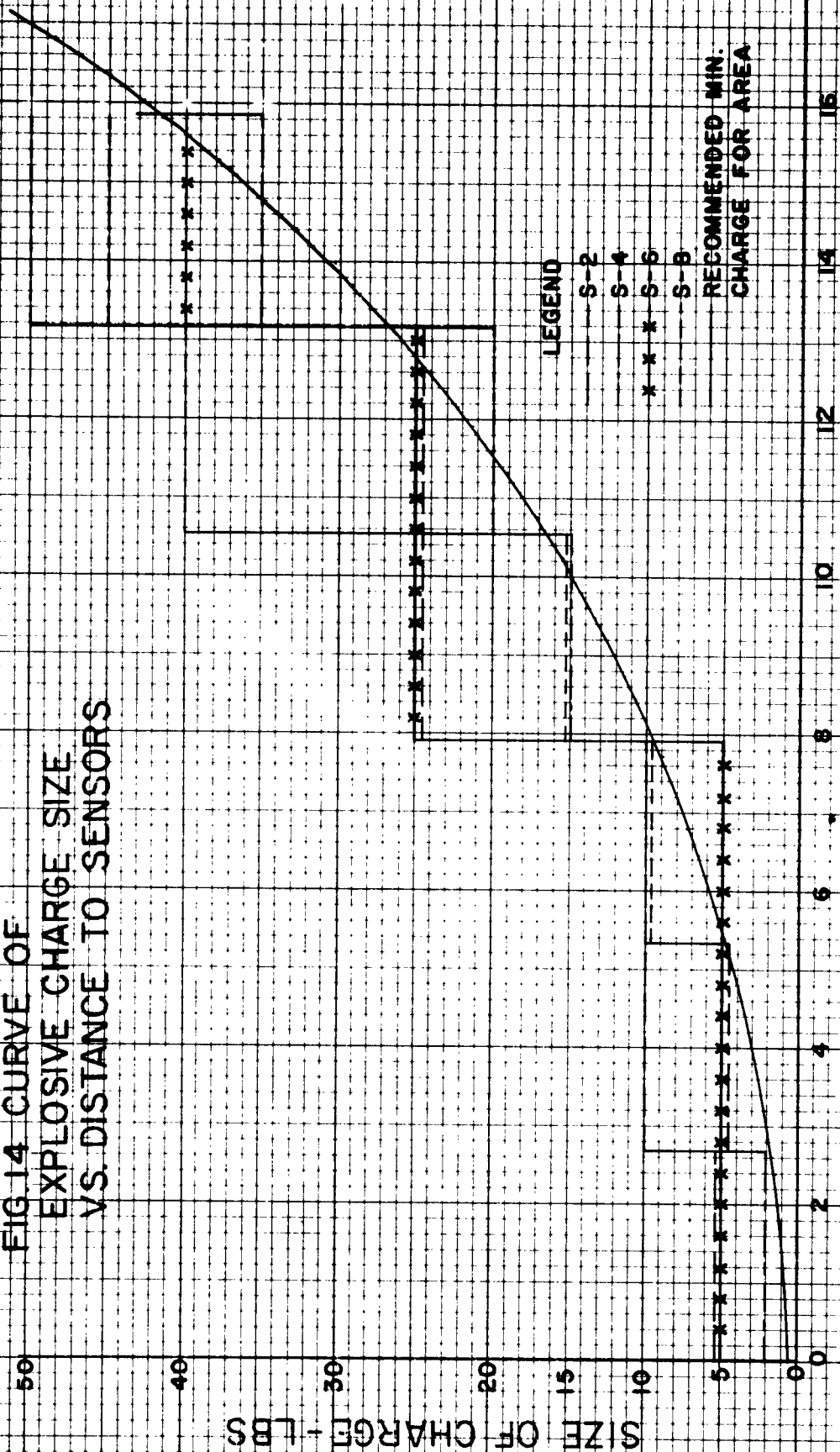
The locations of missile impacts are shown in Figure 16 (folded insert). The surveyed locations are shown as circles. The calculated positions based on the seismic signal are indicated by an X.

I. Accuracy of Missile Impacts

Table 5 shows the coordinate differences between the surveyed coordinates and the calculated positions. The average error in the Y direction was 22 feet and in the X direction 20 feet.

The accuracy was reduced on the distant impacts because the array design was not optimum. Complications in reading the records were caused by air noise arriving just prior to the P wave on many traces. On four missile impacts this air noise interfered with one or more sensors in an array. This lack of data made the $\tan^{-1} = \frac{1-2}{3-4}$ method useless.

FIG. 14 CURVE OF
EXPLOSIVE CHARGE SIZE
VS. DISTANCE TO SENSORS



DISTANCE FROM SHOT POINT IN KILO-FT

TABLE 5

ACCURACY OF MISSILE IMPACT LOCATIONS

Impact Number	DE/SIE Calculated Error in Ft.		Remarks
	x	y	
1	7	4	Good Data
2	17	?	Air Sonic boom inter- ference on R&C Array
3	13	25	Good Data
4	4	15	Good Data
5	5	41	Good Data
6	50	20	Air Interference
7	60	9	Good Data

Figure 15 is a proposed array which is designed to provide ± 50 foot accuracy within a 1 x 2 mile area and ± 200 foot accuracy on a 4 x 5 mile area. The diamond shaped layouts of the sensors are distributed around the center of the target which is sensor #7. Spacing of these sensors (#3 to #11) is such that all but one should be between the X_{c1} and X_{c2} velocity breaks permitting use of the 7300 ft/sec velocity and hence the composite T-D curve of Figure 6. They are also spaced to minimize the number that may be disturbed by a sonic boom. The outer 4 sensors (#1, 2, 12, and 13) are wide spread and would be effective for locating distant impact points.

Figure 15a is an alternate proposed array providing more accuracy over a smaller area. Since the outermost sensors are only 4000 to 6000 feet apart the distant impact locations would be less accurate than those obtained by proposed array #1.

J. Range of Detectability of Impacts

The maximum range of detectability is about 12 miles. Useable information was recorded on "A" array for one impact at this distance. However, reliable information with accuracies of a few hundred feet can be obtained no more than 5 or 6 miles with equipment as used for this test. More sensitive geophones planted deeper and used with higher amplification may be effective over a longer range.

Table 6 shows the peak-to-peak amplitudes of first arrivals as well as the missile energy ($1/2 MV^2$) at the time of impact for all missiles recorded.

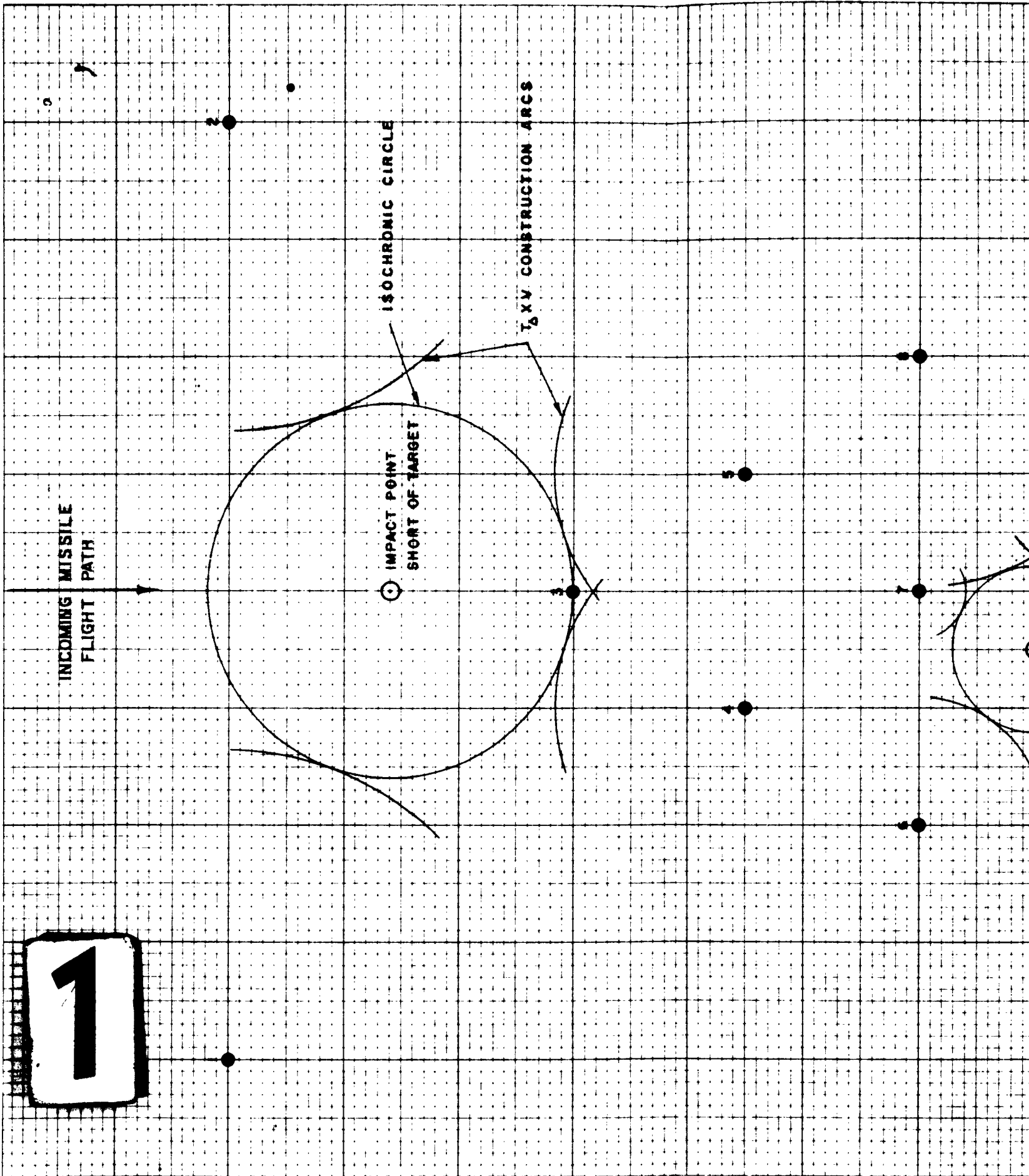
1

INCOMING MISSILE
FLIGHT PATH

ISOCHRONIC CIRCLE

① IMPACT POINT
SHORT OF TARGET

T_0 XV CONSTRUCTION ARCS



2

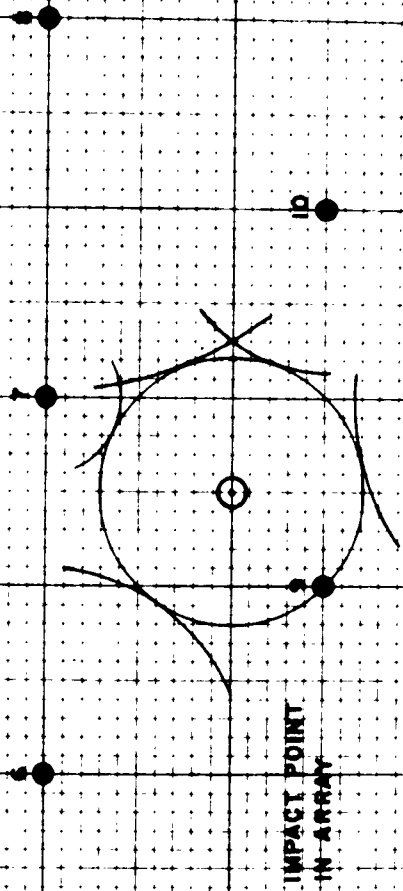


FIG. 15
PROPOSED ARRAY NO. 1
FOR ±150' ACCURACY ON 1X2 MILE AREA
AND ±200' ACCURACY ON 4X5 MILE AREA
SCALE 1" = 1000'

EUGENE DIETZGEN CO.
MADE IN U. S. A.

NO. 340R-10 DIETZGEN GRAPH. PAPER
10 X 10 PER INCH

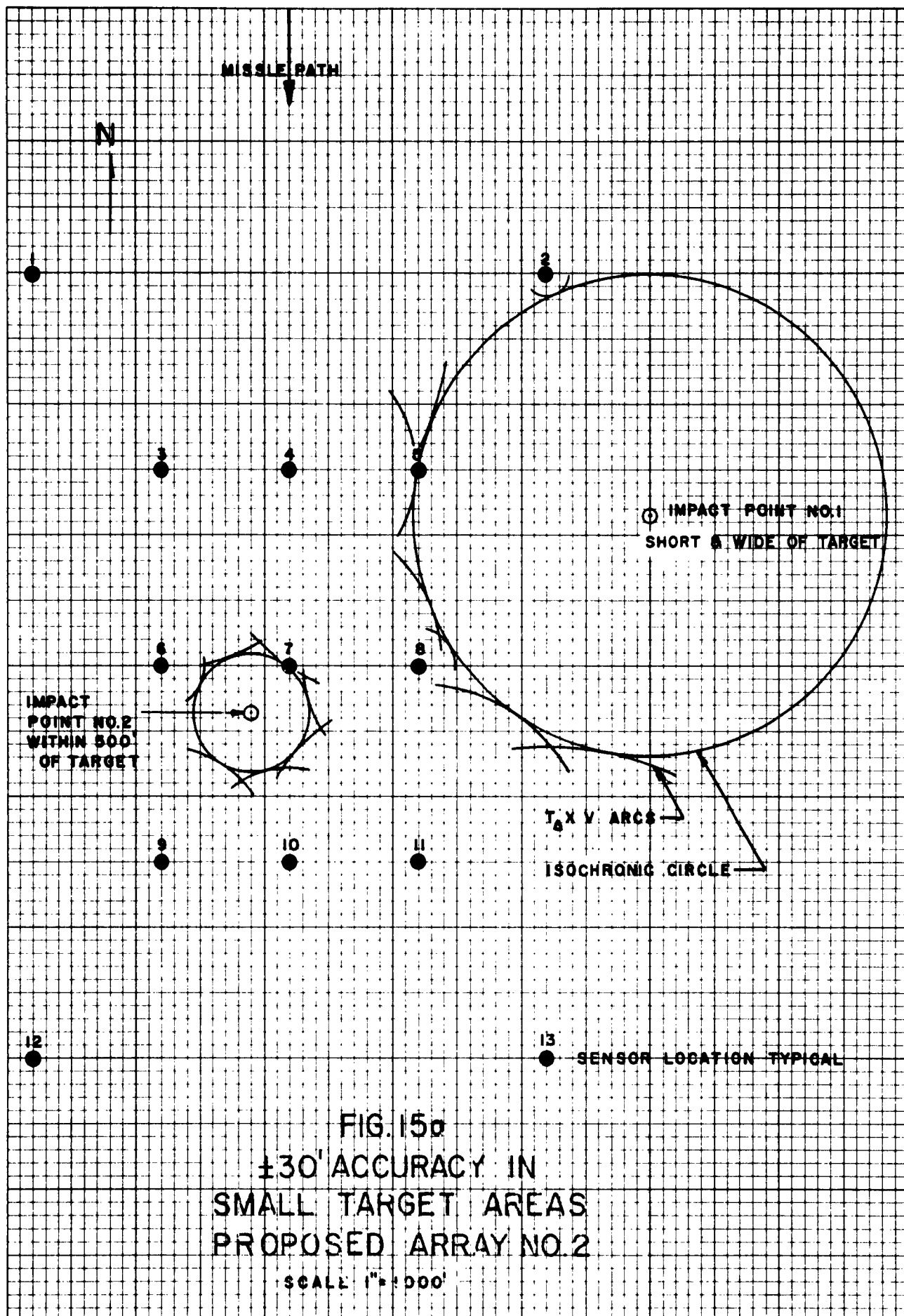


TABLE 6

1st. ARRIVAL AMPLITUDE VS. MISSILE ENERGY ON IMPACT

Missile No. 1		2 **		3		4		5		6		7	
	8.3×10^6	Ampl. inches	Dist. feet	Ampl. inches	Dist. feet	Ampl. inches	Dist. feet	Ampl. inches	Dist. feet	Ampl. inches	Dist. feet	Ampl. inches	Dist. feet
Sensbr													
A-1	.6+ 4100	.13	9460	.24	5040	.46	4620	.44	4560	.41	4670	.39	4350
A-2	*	.15	8710	.50	2040	.89	2620	*		*		1.15	2360
A-3	*	.13	9960	.48	4180	.57	3760	.67	3670	.97	3640	.89	3370
A-4	*	.22	8100	.42	4140	.38	3710	.30	3710	.56	3990	.54	3600
B-1	*	*	*	*	*	*	*	*	*	1.3+	1730	1.60+	1350
B-2	*	*	*	*	*	*	*	*	*	*	*	1.28	840
B-3	*	*	*	1.67	1500	1.72	1210	1.30	1080	.80	700	1.42	680
B-4	*	*	*	.71	1370	1.23	1130	1.40	1210	1.10	1780	1.25	1440
C-1	1.13 1950	*	*	.84	1000	1.33	1400	1.48	1460	1.45	1540	1.34	1740
C-2	.40 3940	*	*	.26	3000	.21	3400	.22	3460	.42	3450	.32	3700
C-3	.67 3200	*	*	.64	2270	.49	2630	.45	2630	.70	2430	.66	2770
C-4	.33 3060	*	*	.36	2210	.28	2610	.18	2710	.42	2950	.30	3070

* No readable value on trace because the air sonic boom interfered with 1st. arrival of "p" wave

** 1st. through amplitudes all others are 1st. peak amplitudes

+ Traces off of record

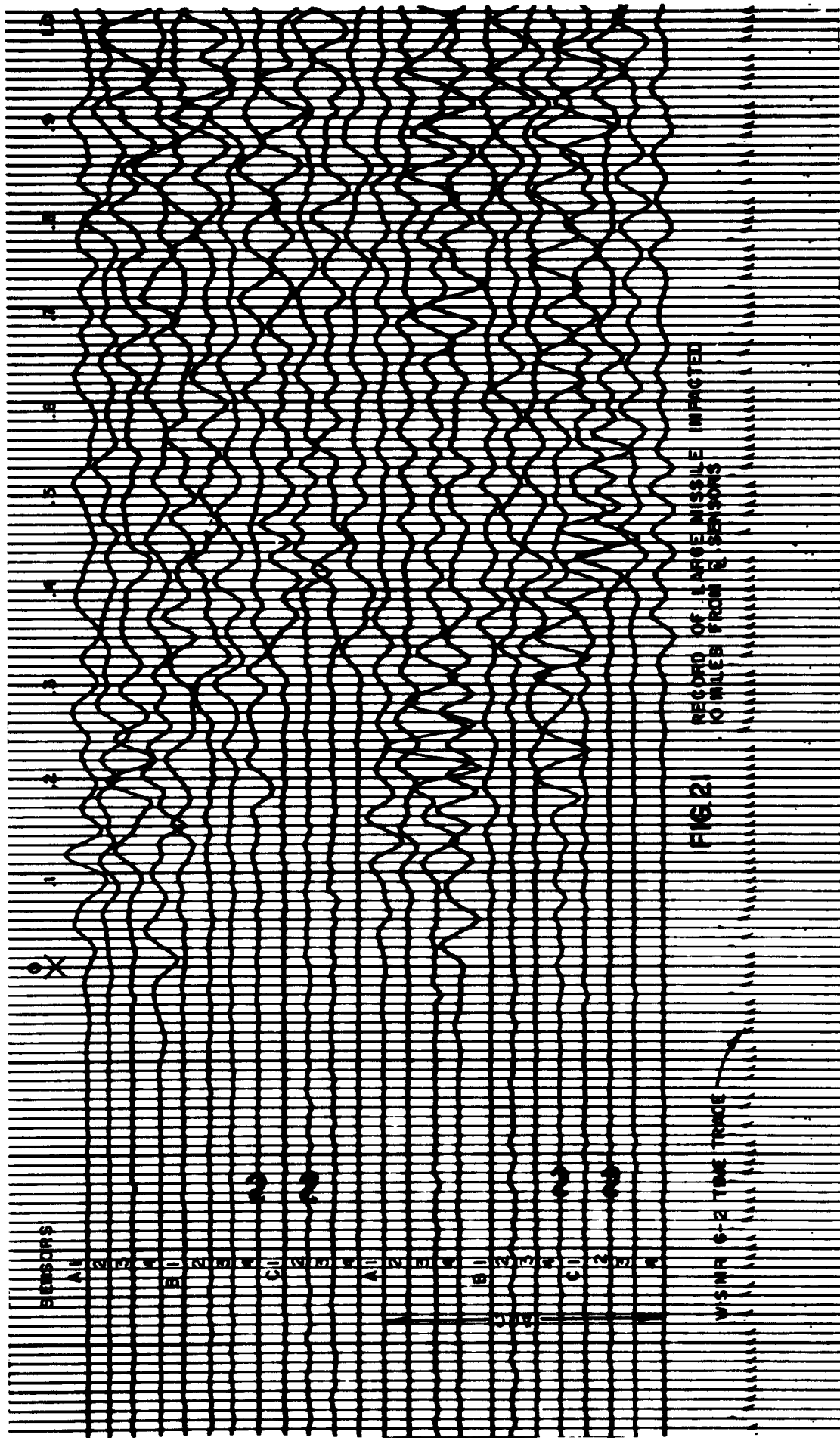
Impact Energy
 $\frac{1}{2} MV^2$ lb. ft.

4.0 CONCLUSIONS AND RECOMMENDATIONS

Energy released by explosive shots and missile impacts was transmitted through the earth by refraction paths in recognizable form to provide seismic "P" wave arrival times at multiple sensors. A computation method was developed to resolve the impact location relative to the sensor arrays and time of impact relative to established WSMR G-2 time base, using "P" wave time arrivals at three or more sensors and calibrated transmission characteristics of the area. Computer techniques could shorten computation time but the recorded data requires judgment to determine proper basic arrival times and paths due to energy arriving via multiple paths.

Maximum limit of detectability of missile impacts depends upon the impact energy, distance, and coupling. The weight and velocity of the missile body can be determined precisely but coupling variation between the earth and mass due to the angle of impact and variations earth material cause large differences in the seismic energy transmitted. Most of the recorded missiles were small that were impacted in the sensor array. They transmitted relatively large "P" waves to the outside sensors, a distance of about 4000 feet. No. 2 missile impacted near shot point 6 a distance of 9500 ft from sensor A-1 with strong 1st arrivals. One large missile impact was recorded ten miles away and resulted in satisfactory time arrivals. See Figure 21. Table 6 shows the trace amplitude VS missile impact energy on all data obtained during this test.

Experience developed during the short test period indicated that optimum location and design of the sensor arrays would reduce data loss caused by air sonic waves. An extension of range and accuracy of the location system would result from a broader array.



The following recommendations will result in substantial performance improvement over those as shown in this report which were obtained with equipment described in Appendix B.

- a. We recommend that sensor arrays similar to those shown in Figures 15 or 15A be permanently installed at strategic locations relative to ranges being instrumented. Sensors of each array may be connected to a recording point that can be occupied by a manned recording van. This will permit use of one mobile instrument van to occupy the most effective arrays relative to missile firing schedule and minimize costs of instrumentation.
- b. Instrumentation basically similar to that being used by the Department of Interior for earth crustal studies is recommended. The specifications of this system are substantially better for this application than the exploration equipment used during this test. The following proposed system components are fully described in Appendix C.

Amplifiers - SIE Model GTR-200 system

Magnetic tape recorder - SIE Model MR-200

Recording oscillograph - SIE Model TRO-6A or 10A

Sensors - Hall-Sears HS-10 or equivalent

- c. The isochronic circle method of data reduction is recommended with the procedure as follows:
 1. Plot arcs from four nearest sensors (least primary wave arrival times) using radii obtained from Figure 6.
 2. Fit best isochronic circle to these arcs; the center is the approximate impact location.
 3. Measure distances from approximate impact location to various sensors and plot time/distance graph.

4. Correct primary wave arrival times to time distance graph in 3 and plot arcs from sensors using distances obtained from lower solid curve on Figure 6 as radii.
5. Fit best isochronic circle to these arcs; the center is the impact location.
6. From Figure 6 determine the time corresponding to the isochronic circle radius by referring to the dashed upper curve. This time is equal to $(T_i + \frac{D}{V})$ and gives the impact time when it is subtracted from the real time of the first "P" wave arrival at the nearest sensor.

5.0 BIBLIOGRAPHY

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6.0 APPENDICES

ARRAY CALIBRATION SHOTS

APPENDIX A

SP No.	Record Stns.	Date	Time	Amplifiers		Tape No.	Explosive	
				Gain Set	Filter Set		Chg. (lbs)	Depth (feet)
S-1	A-B-C	8/2/61	1256	-5db	out-1/47	866	10	58
S-1	A-B-C	8/2/61	1330	-5db	out-1/47	867	40	50
S-2	A-B-C	8/2/61	1205	-5db	out-1/47	865	10	60
S-3	A-B-C	8/2/61	1115	-5db	out-1/47	863	10	54
S-3	A-B-C	8/2/61	1135	-5db	out-1/47	864	40	40
S-4	A-B-C	8/2/61	1045	-5db	out-1/47	862	10	54
S-5	A-B-C	8/1/61	1350	-5db	out-1/47	860	10	62
S-5	A-B-C	8/1/61	1620	-5db	out-1/47	861	45	43
S-6	A-B-C	7/31/61	1440	-10db	out-1/47	855	10	68
S-7	A-B-C	8/1/61	1155	-5db	out-1/47	857	10	78
S-7	A-B-C	8/1/61	1230	-5db	out-1/47	858	20	73
S-7	A-B-C	8/1/61	1308	-5db	out-1/47	859	40	54
S-8	A-B-C	7/31/61	1340	-10db	out-1/60	854	10	68
S-9	A-B-C	7/31/61	1305	-10db	out-1/60	None	5	38
S-10	A-B-C	7/31/61	1240	-10db	out-1/60	853	5	38
S-11	A-B-C	7/31/61	1155	-10db	out-1/47	852	5	38
S-12	A-B-C	8/3/61	1227	-5db	out-1/47	868	5	18
S-13	A-B-C	8/3/61	1246	-5db	out-1/47	697	5	18

I

Refraction Profiles

SP No.	Record Stns.	Date	Time	Amplifiers		Tape No.	Explosive	
				Gain Set	Filter Set		Chg. (lbs)	Depth (feet)
S-4	S-4-19	8/8/61	1200	AGC	out-1/47	515	2	58
S-19	S-19-4	8/8/61	1220	AGC	out-1/47	516	2	20
S-8	S-19-4	8/8/61	1300	AGC	out-1/24	517	50	40
S-8	S-18-19	8/8/61	1330	AGC	out-1/24	518	40	35
S-4	S-19-18	8/9/61	1001	AGC	out-1/24	520	5	65
S-19	S-19-18	8/9/61	1015	AGC	out-1/24	521	1	20
S-18	S-18-19	8/9/61	1025	AGC	out-1/24	522	1	20
S-4	S-18-10	8/9/61	1130	AGC	out-1/24	523	15	60
S-4	S-18-10	8/9/61	1145	AGC	out-1/24	524	15	60
S-18	S-18-10	8/9/61	1153	AGC	out-1/24	525	2	18
S-10	S-10-18	8/9/61	1205	AGC	out-1/24	526	2	17
S-8	S-10-18	8/9/61	1225	AGC	out-1/24	527	15	50
S-8	S-17-10	8/9/61	1425	AGC	out-1/24	528	10	45
S-17	S-17-10	8/9/61	1445	AGC	out-1/24	529	2	20
S-10	S-10-17	8/9/61	1500	AGC	out-1/24	530	2	12
S-4	S-10-17	8/10/61	0950	AGC	out-1/24	531	20	50
S-4	S-17-16	8/10/61	1045	AGC	out-1/24	532	45	37
S-17	S-17-16	8/10/61	1100	AGC	out-1/24	533	2	17
S-16	S-16-17	8/10/61	1115	AGC	out-1/24	534	2	20
S-8	S-16-17	8/10/61	1145	AGC	out-1/24	535	16	42

Refraction Profiles

SP No.	Record Stns.	Date	Time	Amplifiers		Tape No.	Explosive	
				Gain Set	Filter Set		Chg. (lbs)	Depth (feet)
S-8	S-8-16	Not Shot						
S-16	S-16-8	Not Shot						
S-4	S-16-8	Not Shot						
S-2	S-2-15	8/8/61	1036	AGC	out-1/47	513	5	17
S-15	S-15-2	8/8/61	1050	AGC	out-1/47	514	2	18
S-6	S-15-2	8/7/61	1450	AGC	out-1/47	512	40	50
S-6	S-14-15	8/7/61	1330	AGC	out-1/47	511	25	22
S-14	S-14-15	8/7/61	1310	AGC	out-1/47	510	2	20
S-15	S-15-14	8/7/61	1255	AGC	out-1/47	509	2	20
S-2	S-15-14	8/7/61	1245	AGC	out-1/47	508	10	30
S-2	S-14-10	8/4/61	1500	AGC	out-1/47	503	10	38
S-14	S-14-10	8/7/61	1145	AGC	out-1/47	507	2	20
S-10	S-10-14	8/7/61	1134	AGC	out-1/47	506	2	38
S-6	S-10-14	8/7/61	1102	AGC	out-1/47	505	25	28
S-6	S-13-10	8/4/61	1220	AGC	out-1/47	875	5	40
S-13	S-13-10	8/4/61	1300	AGC	out-1/47	501	1	12
S-10	S-10-13	Not Shot						
S-2	S-10-13	8/4/61	1320	AGC	out-1/47	502	25	30
S-2	S-13-12	8/4/61	1033	AGC	out-1/47	872	25	60
S-13	S-13-12	8/4/61	1100	AGC	out-1/47	873	1	20

Refraction Profiles

SP No.	Record Stns.	Date	Time	Amplifiers		Tape No.	Explosive	
				Gain Set	Filter Set		Chg. (lbs)	Depth (feet)
S-12	S-12-13	Not Shot						
S-6	S-12-13	8/4/61	1125	AGC	out-1/47	874	5	43
S-6	S-6-12	8/3/61	1525	AGC	out-1/47	871	5	47
S-12	S-12-6	Not Shot						
S-2	S-12-6	8/3/61	1445	Fixed- 12 AGC 13-24	out-1/47	870	35	38

APPENDIX B

ELECTRONIC EQUIPMENT BROCHURES AS USED IN THIS STUDY

PT

a new distortion-free transistorized seismic amplifier

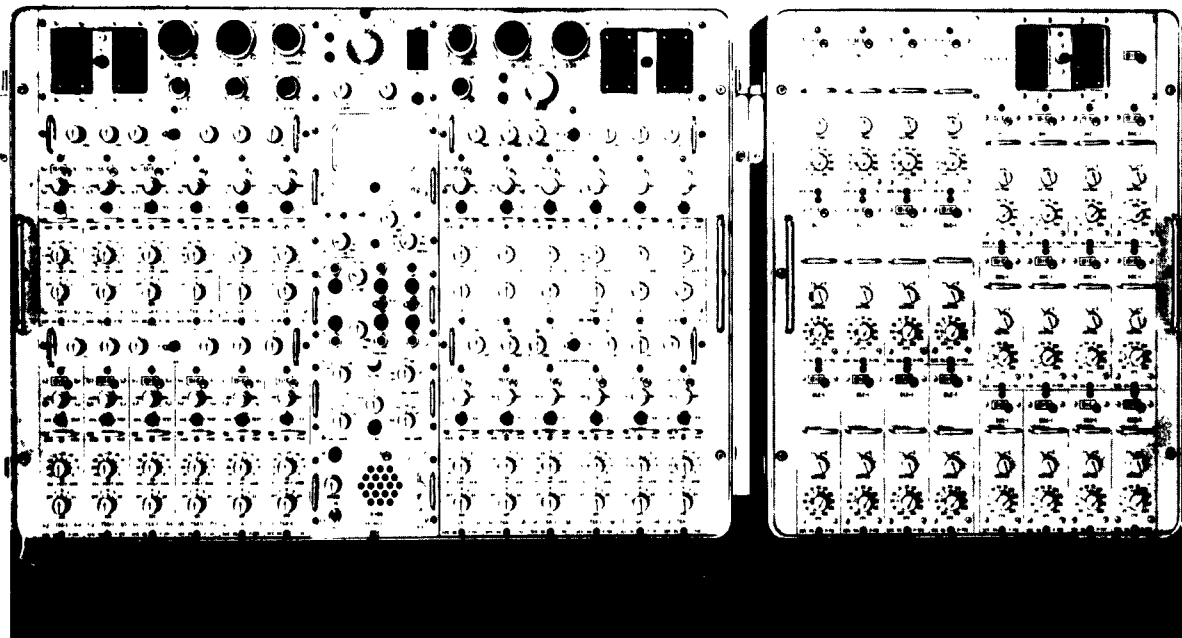
Unique AGC circuitry does away with balancing and matching problems—no diodes used.

Up to 1 volt controlled with negligible "burstout" distortion

AGC control for refraction shooting

Completely transistorized for low-power drain, small size and highest reliability

Novel gain control system meets all modern requirements for simplicity of operation with magnetic-recording—provisions for programmed gain control allow amplitude studies



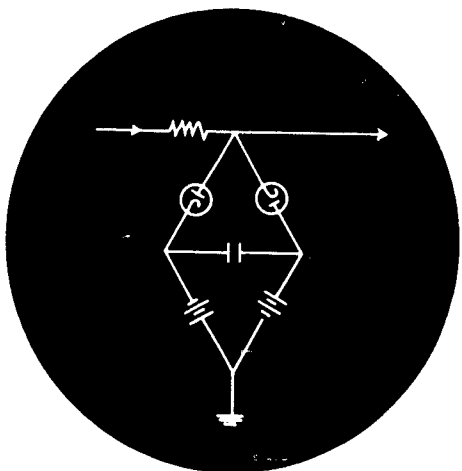
The ABC's of AGC

In a typical seismic amplifier the amplitudes of seismic signals are controlled by AGC circuits utilizing lossy elements. Most widely used in such lossy circuits is a diode bridge arrangement similar to the one shown.

If the elements of this bridge are "perfect" — and remain so — its most objectionable characteristic is that it distorts large signals applied across it. However, perfection is seldom achieved in actual practice. Deviation from the ideal almost always becomes wider as the amplifier is used in the field. The nagging problem of "diode-balancing" to minimize amplifier instability, d-c shift and distortion is one only too familiar to all operators.

It is obvious that a more ideal lossy element could provide greatly improved performance. Such an ideal element should: **1** Be pure resistance **2** Cause no interaction in the signal path when control voltage is applied **3** Have a large control range **4** Have a short time constant **5** Be a low noise element **6** Cause no distortion when the seismic signal is impressed across it **7** Be stable with respect to time and temperature

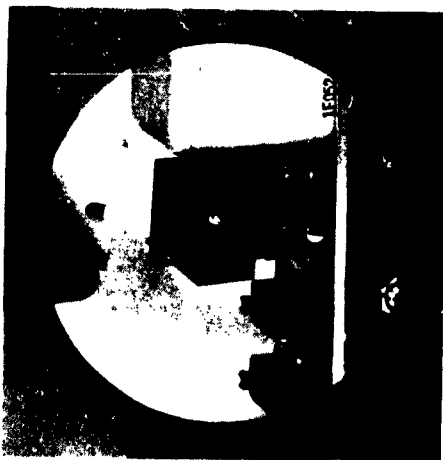
The unique AGC lossy element in the PT-100 satisfies ALL of these requirements. This brochure shows the performance thus made possible.



Unique lossy element — heart of the PT-100

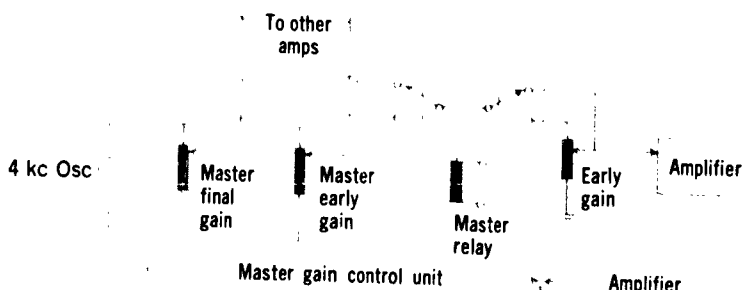
Heart of the PT-100 AGC lossy assembly pictured is a cadmium sulfide photo-conductive cell. Four of these cells, one for each of four amplifying stages in the amplifier, are all illuminated by a common small filament light bulb. Power for the bulb is derived from an AGC amplifier stage fed in a conventional fashion. Resistance — and hence loss across the element — is determined by the level of illumination to which the cell is exposed.

With this unique arrangement there is no direct electrical connection between the lossy elements nor between the elements and the AGC control circuitry. Coupling problems within an amplifier channel are eliminated. No critical matching or balancing of lossers is ever required as with conventional diode circuits. Furthermore, the cells are essentially pure linear resistances and do not distort voltages applied across them. Time and temperature stability is assured by encapsulating and proper circuit design.

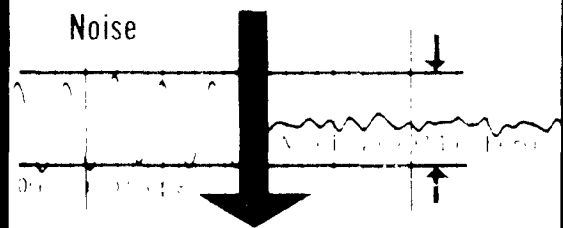
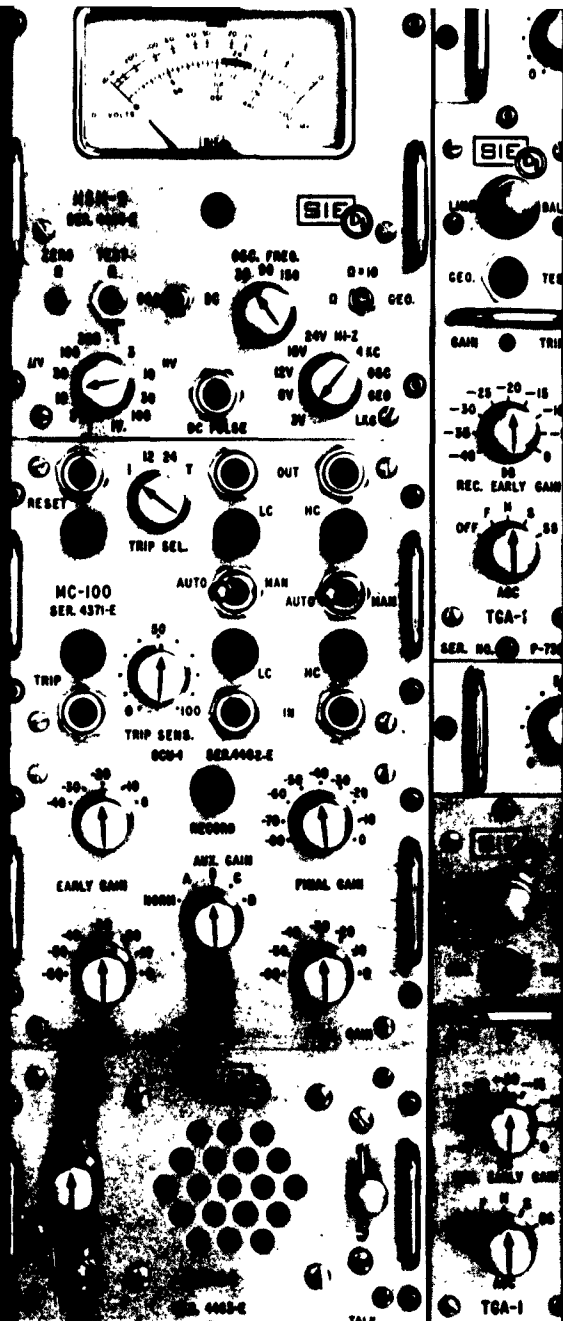
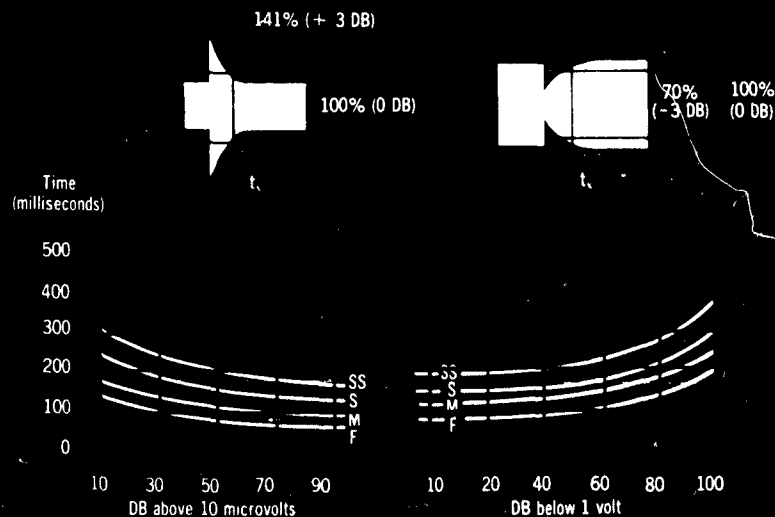
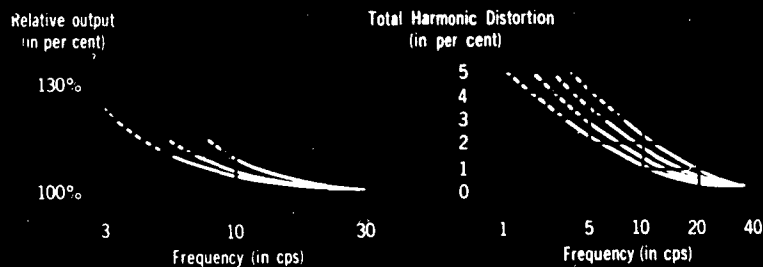
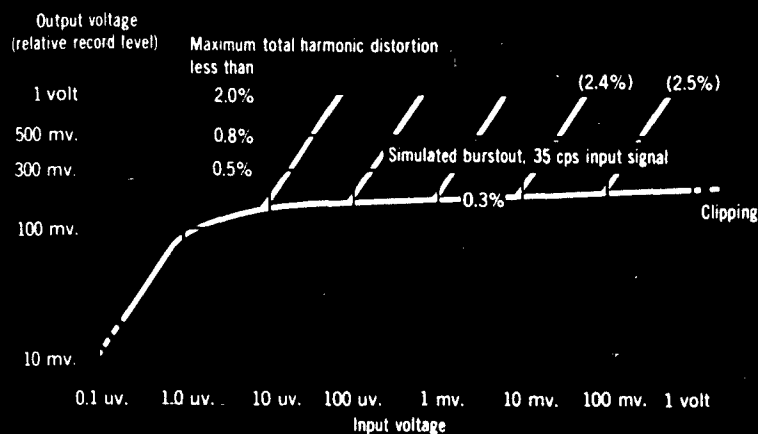


Gain control

Control of both suppression ("early gain") and sensitivity ("final gain") is achieved in the PT-100 by applying a 4 kc "rider" signal to the amplifier input. This "rider", (by-passing the high-cut filter through a 4 kc band-pass filter) results in AGC action to reduce the amplifier gain. This action is identical to that produced by a normal seismic signal. The result is stable, repeatable gain control directly proportional to amplitude of the "rider" signal. A single, master gain control can therefore be used to produce the same gain condition in all channels. Programmed gain control is also possible through use of an external 4 kc signal. Gain of all channels may be varied simultaneously merely by programming the amplitude of the external signal. This convenient, reliable and repeatable method of gain control eliminates the need for gain calibration each time it is used. The system is ideally suited for conducting amplitude studies of seismic energies. A specially-designed 4 kc generator for this application is available from SIE.

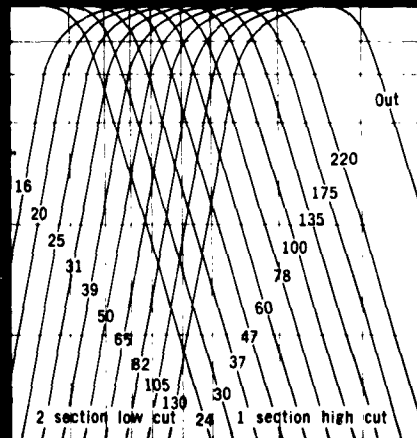
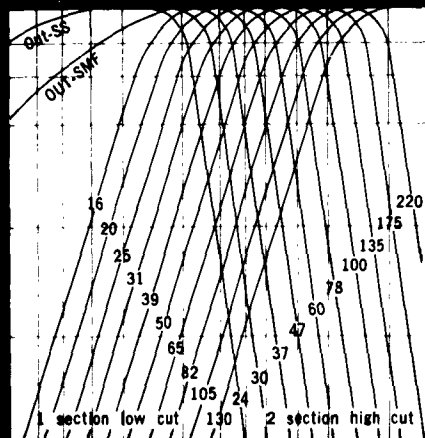
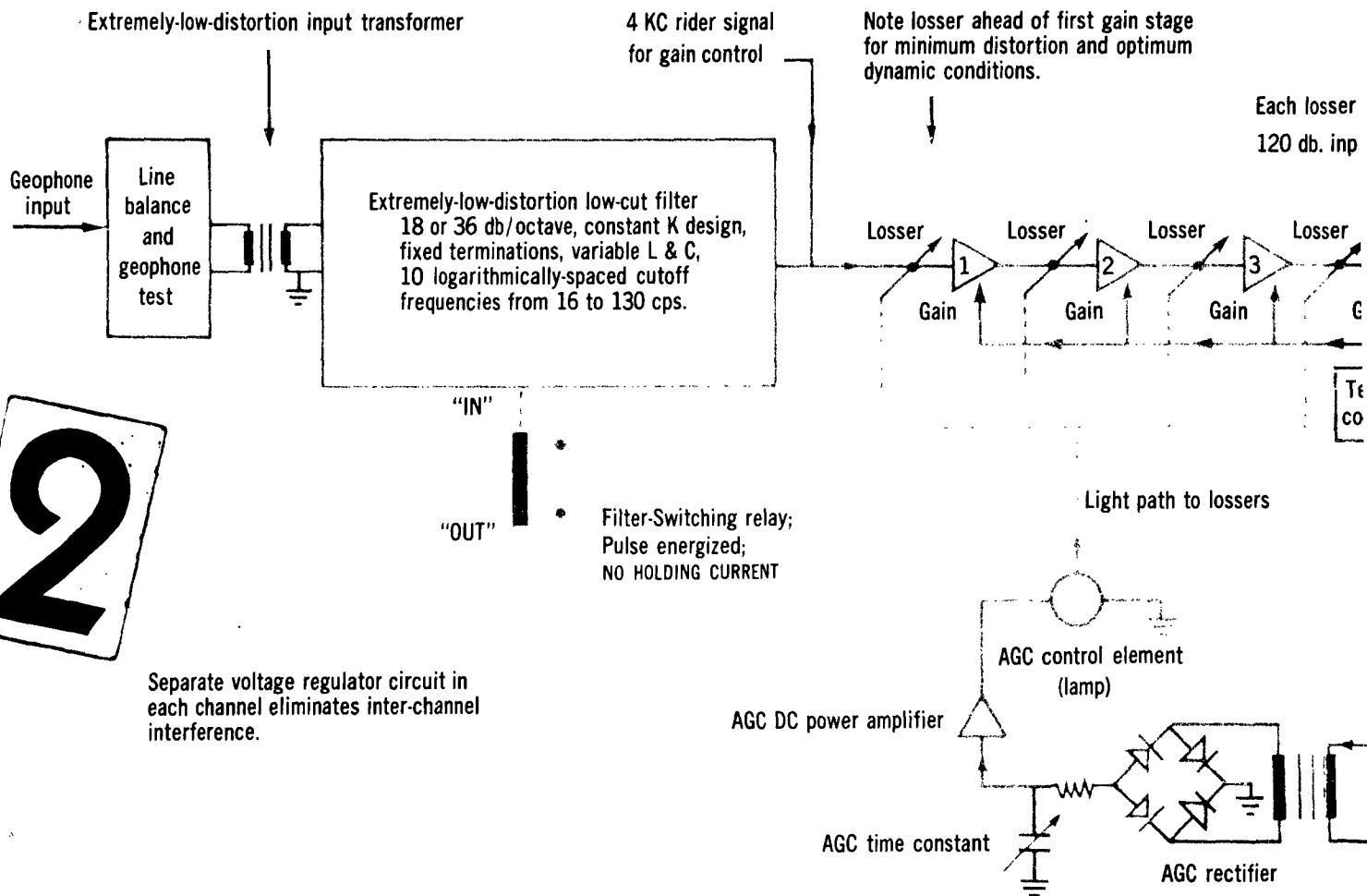


AGC action

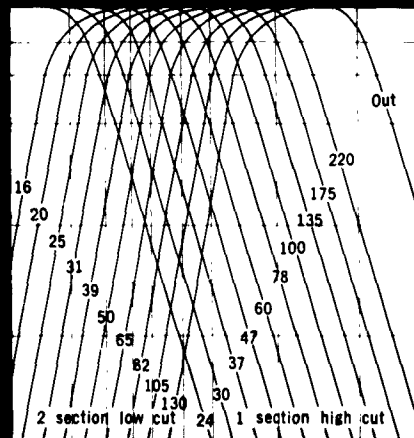
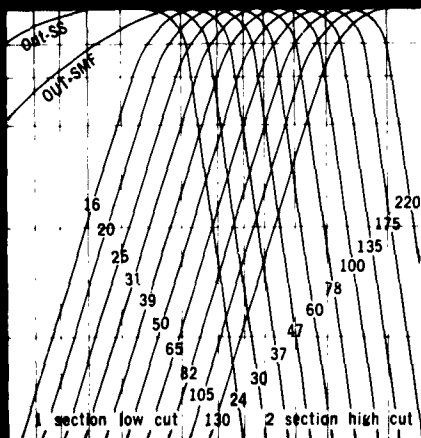
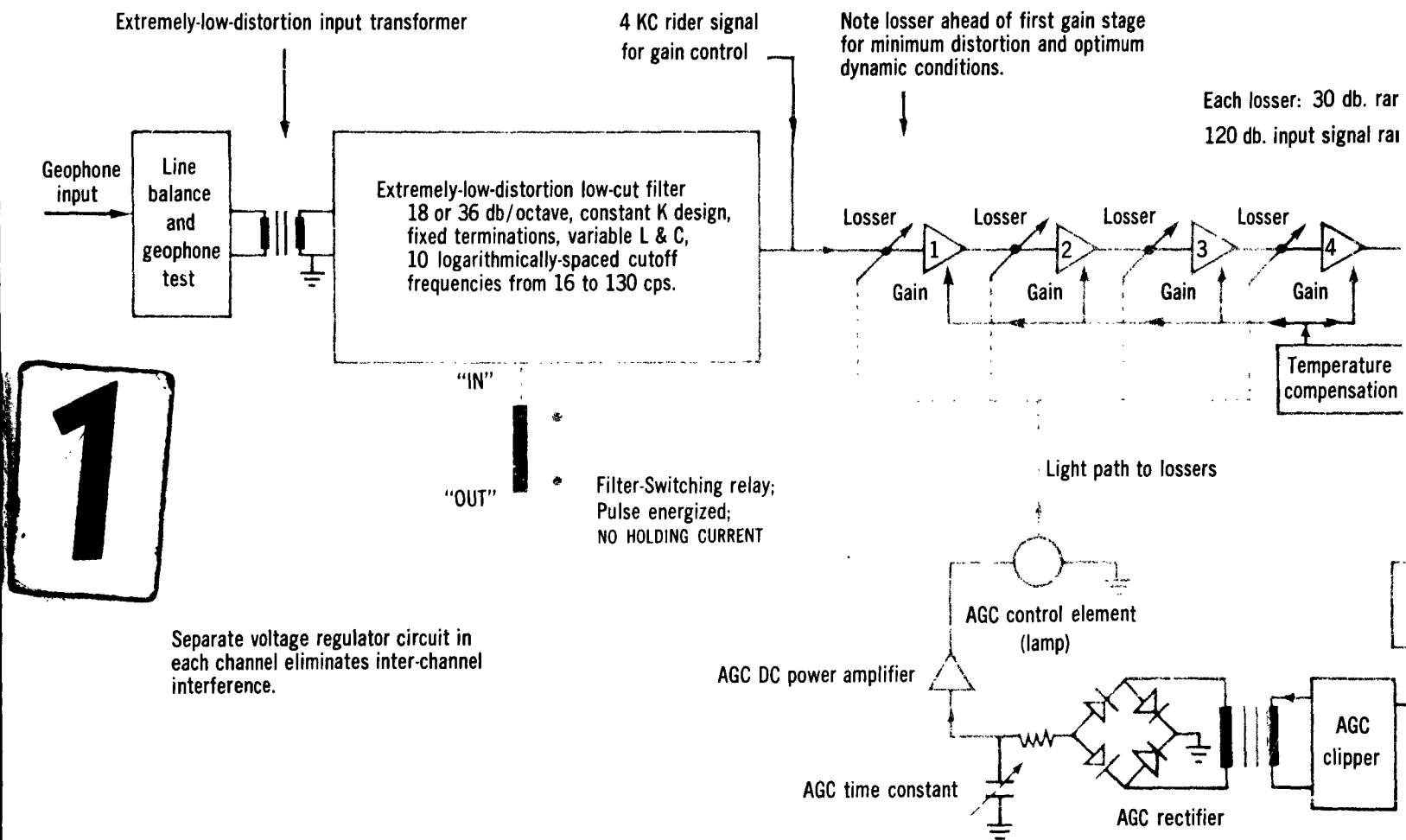


Within the pass band and at the impedance levels encountered in seismic amplifiers, modern transistors properly used provide better signal-to-noise ratios than vacuum tubes. Transistors also have the obvious advantage of freedom from hum and microphonics. They, unlike vacuum tubes, always produce the same low noise every time the amplifier is turned on. They are more stable with age than vacuum tubes. The oscillograph record shown illustrates the truth of these statements by displaying actual noise in a PT-100 channel. It represents noise present with a broad pass band of 3 to 125 cps. Noise is even less for normal filter settings.

Operation



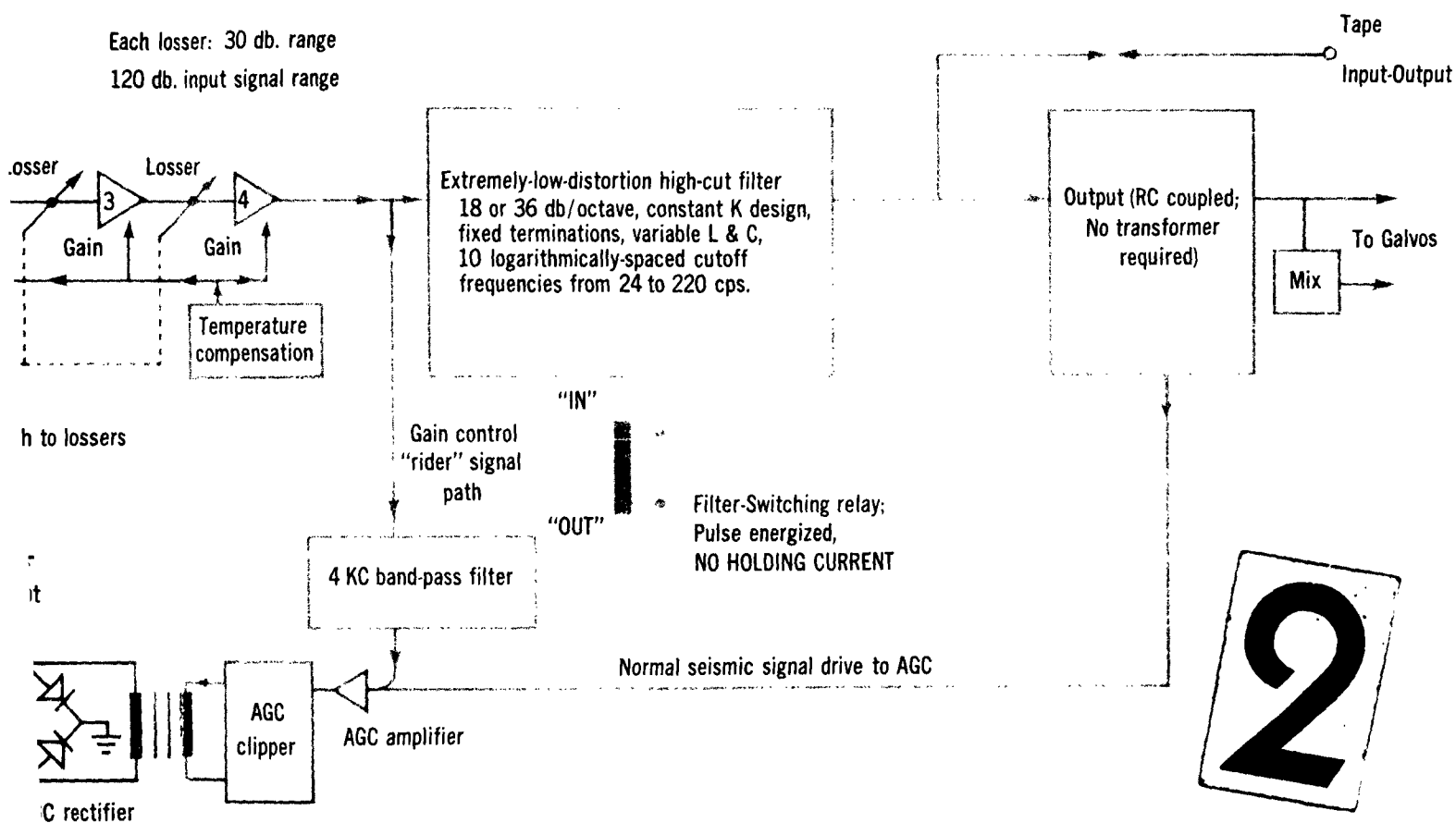
Operation



Filter

stage
imum

Each loss: 30 db. range
120 db. input signal range



Filtering

PT-100 SPECIFICATIONS

AMPLIFIER (Type TGA-1)

INPUT:

Impedance 500 ohms (shunted by 40 hy. primary inductance—negligible above 5 cps)

Dual line balance controls (capacitive and resistive) for high-line rejection.

FREQUENCY RESPONSE:

With AGC in OFF or S-S:

To Tape—within 3 db., 3 to 500 cps;

To Galvo—within 3 db., 5 to 500 cps.

With AGC in S, M, or F within 3 db. from 10 to 500 cps for both tape and galvo.

1 microvolt to 1 volt range, control down to 5 cps with AGC in S-S.

Four speeds: F—fast, M—medium, S—slow, SS—slow-slow, and OUT.

High-frequency self-balancing "rider" system; linear response to controlling signal from master gain or external source.

Individual early gain (suppression) controls.

Less than 0.5% including heavy reflection stand-out.

Approximately 0.15 microvolt peak-to-peak for normal filter settings, 0.30 microvolts for broad-band 3 to 500 cps.

OUTPUTS:

Galvo: Maximum deflection with 200 cps SIE galvo is 1.8" pk-pk for AGC level (1 millivolt input to amplifier), 12" pk-pk maximum for "burstout."

For dual recording the maximum deflections are approximately $\frac{2}{3}$ above values.

(AGC level is 75 millivolts rms, "burstout" is 200 mv, both at approximately 200 ohms—sufficient to drive a galvo and magnetic direct recording head.)

Hi Z Tape: 0.15 and 1.0 volt rms (suitable for driving all SIE and most other tape recorders) @ 22K-ohms for conditions as above.

TEMP. RANGE:

0° to plus 130° F.

FILTERS (Types DHC-1 and DLC-1)

TYPE:

Passive dual channel plug-in units, 18 or 36 db/octave, constant K.

Filter removal relays — Manual or Automatic

CUT-OFF FREQUENCIES:

(See previous graphs)

Lo-cut: "Out," 16, 20, 25, 31, 39, 50, 65, 82, 105 and 130 cps.

Hi-cut: 24, 30, 37, 47, 60, 78, 100, 135, 175, and 220 cps.

SYSTEM

RECORD PRESENTATION:

Dual outputs for simultaneous mixed and unmixed display; plug-in units for flexibility of percentage and method of mixing.

CONTROLS:

Master final and early gain controls for record; plus separate controls for playback.

Master-hi and lo-cut filter IN-OUT controls, manual or automatic.

Provisions for external program gain control.

Selection of geophone or magnetic drum control for trip function.

TEST FACILITIES:

Metering circuit for geophone lines OHMS and LEAKAGE, selection of individual channels for signal metering, monitoring of supply voltages, oscillator and gain control signal.

Internal test oscillator with calibrated attenuator and frequency selector.

Paralleling and dual record switch.

High gain uphole amplifier.

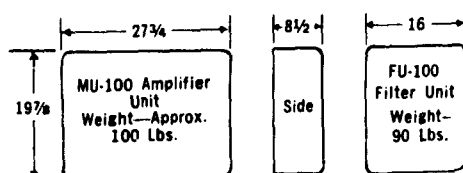
Built-in communication amplifier.

Complete interlock and control functions for integration with magnetic systems.

12 VDC; 8 amperes nominal, approximately 5 amperes momentary switching current for filter relays (50 ms). Power supply is self-contained in MU-100

AUXILIARY FUNCTIONS:

POWER REQUIREMENTS:



From completely portable to complex office-playback use . . . from refraction to high-frequency recording—the PT-100 will provide you new criteria by which to judge seismic records. From field recording to final cross-sections . . . SIE instrumentation sets the standard for the industry.

16
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Why another seismic amplifier?

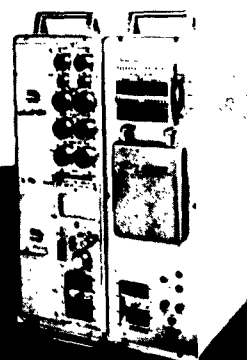
Here is an entirely new seismic amplifier—new for a reason. Even with the most painstaking care in design, construction and final checkout, practical seismic amplifiers have heretofore been far from ideal. Their AGC control has been poor over at least part of the dynamic operating range needed for modern recording techniques. They have suffered from undesirable distortion characteristics. And in cases where distortion was not obvious on the record, the situation was especially disturbing...critical "picks" could be made incorrectly or misplaced in time without the interpreter having any way to know of the error!

Now for the first time ALL the advantages of transistor circuits and compatible solid-state components have been utilized in one amplifier. Not only does the PT-100 feature increased reliability, low power consumption, compact design and light weight, but it has an entirely new AGC system. It is this unique AGC control that produces signal-handling capabilities in the PT-100 such that it will not overload in ANY area. And now it is possible to record *refraction with full AGC performance!*

A new gain control concept adds to the convenience and stability of the PT-100, also. Sufficient filter positions and cut-off slopes provide full-spectrum operation—refraction, reflection, and high frequency. Critical adjustments just don't exist in the PT-100. No longer is it necessary to replace parts such as vacuum tubes to keep channels balanced—transistors don't wear out. And most important, no longer is it necessary to wonder whether or not hidden distortion is destroying the accuracy of your "picks." The PT-100 provides improved standout for reflected and refracted signals...distortion-free!

These are the reasons why SIE has created "another" seismic amplifier. Proof of the claims exists partially in the data displayed in this brochure. Final proof is actual field performance. Call SIE for a demonstration. Find out for yourself how the PT-100 will provide you with today's most readable and reliable records.

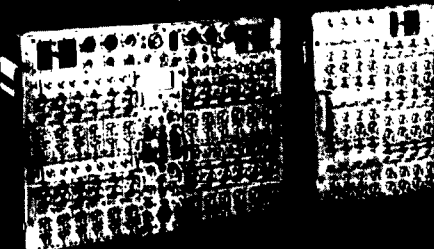
Transistorized for improved performance



PMR-20
PORTABLE HIGH-FIDELITY
FM MAGNETIC
RECORDING SYSTEM

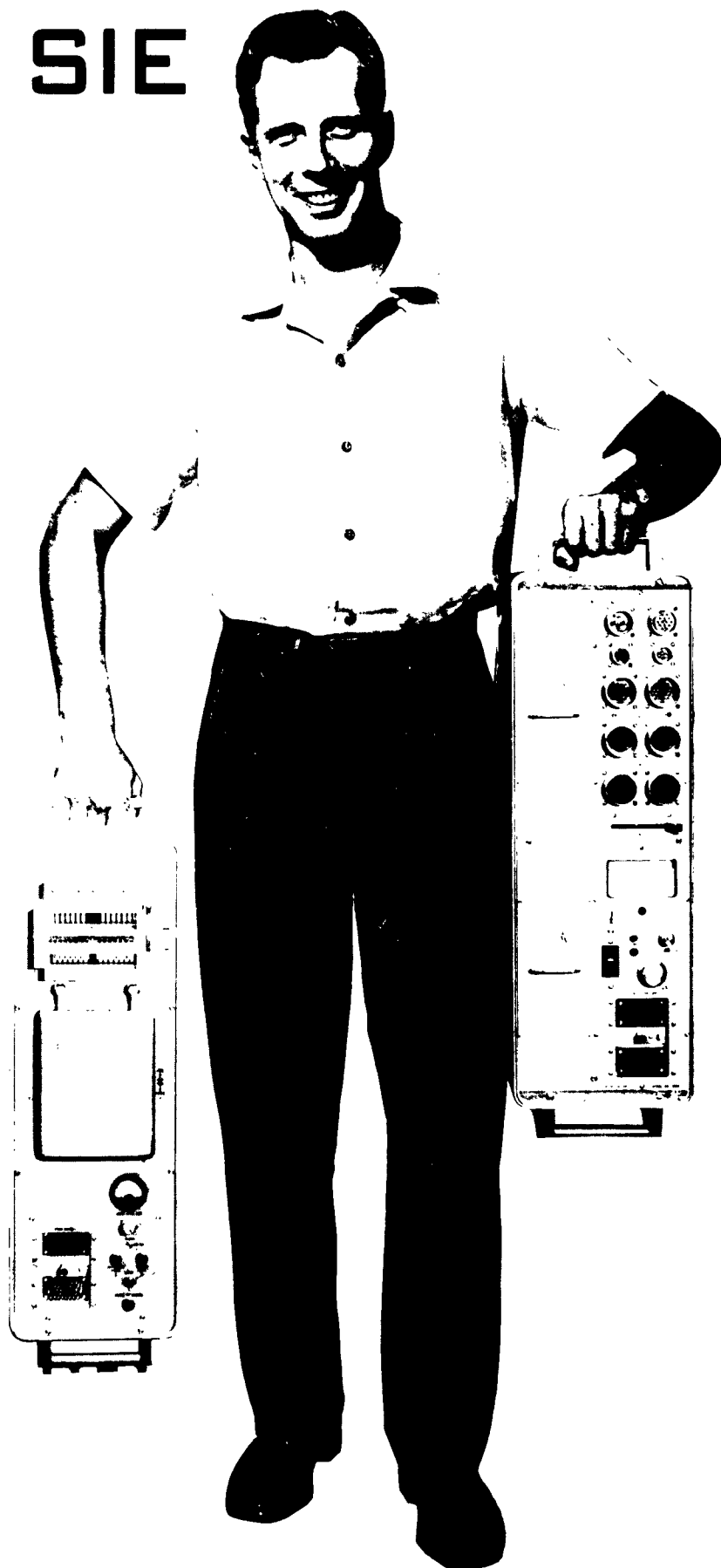


TRO-6 MULTI-DISPLAY
RECORDING OSCILLOGRAPH



PT-100 PORTABLE DISTORTION-FREE SEISMIC AMPLIFIER

SIE



Portable
magnetic
recording
system

SIE PMR-20 PORTABLE FM RECORDING SYSTEM

Features:

Wide range recording

Full spectrum for — reflection, refraction, high frequency recording
Frequency range beyond any AM system

Highest fidelity recording available

For present and future recording and analysis
Independent of tape quality
Lowest noise and distortion

Exceptional portability

Complete in two small lightweight packages
All-transistor circuitry for low power drain (Less than 1/10 of vacuum tube models)

Easily installed

Small enough for easy addition in any recording cab
Needs no extra batteries
Complete two-package system — nothing else to buy

Rugged construction for field dependability

Transistorized circuitry gives maximum reliability
Moisture-proof aluminum cases

Operational simplicity

Single push-button operation
Controls interlocked to prevent errors
Complete metering for proper signal levels

System compatible with standard geophysical equipment

Amplifier, trip and camera control incorporated

SEE SPECIFICATIONS ON PAGE 4 FOR DETAILED TECHNICAL FEATURES

BACKED BY COMPLETE SIE WORLD-WIDE SERVICE

Description:

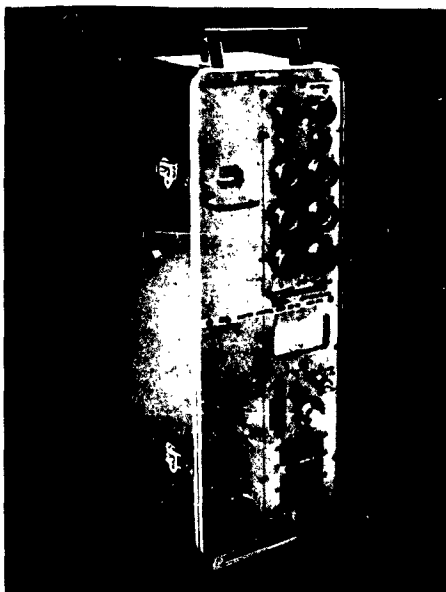
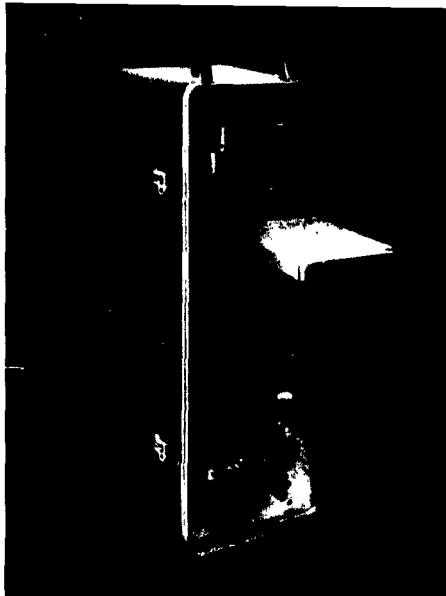
The SIE PMR-20 Portable FM Magnetic Recording System is a 28-channel all-transistorized record-playback system complete in two compact, lightweight units. It provides high-fidelity frequency modulated recordings of seismic data on standard SIE magnetic tapes from the output of standard geophysical amplifiers.

The two units are designated the MR-20 Recorder and the MU-20 Master Unit. The MR-20 houses the recording drum, drum drive system and recording head banks. Modulators, demodulators, switching and auxiliary electronics are contained in the MU-20 Master Unit. Also included in the Master Unit is a transistorized power supply which converts the 12 vdc from the external power source to the regulated levels required in all parts of the system.

In addition to 24 seismic data channels, time-break, up-hole, noise-cancelling and 100 cps timing reference channels are also included. Recording and playback modulation levels are read directly from the convenient front panel meter. Record-playback switching functions are accomplished from a single front-panel switch. Fixed or movable recording heads may be specified. Provision is incorporated for playing back tapes through the seismic amplifier or directly through the output transformer of the seismic amplifier. The complete two-unit system weighs only 107 lbs.

FM magnetic recording is used in the PMR-20 system to provide exceptionally high signal-to-noise ratio and wide frequency response, assuring maximum reproduction flexibility and eliminating effects of tape imperfections, wear or irregularities. The aluminum cases and covers are watertight. In the PMR-20, new standards in wide frequency range, low noise level, low distortion, and precise timing-accuracy characteristics are combined in a portable, low power drain, lightweight, low-bulk system of outstanding field dependability and simplicity.





MR-20 Recorder Unit

The **Tape Drum** is a lightweight, magnesium casting, rubber covered and supported on special precision bearings. The drum is driven at $7\frac{1}{2}$ " per second surface speed by a 400 cps hysteresis synchronous motor. A fabric belt double reduction from the drive motor followed by a capstan drive provides maximum speed constancy without critical adjustments, assuring a high signal-to-noise ratio.

Drum speed is magnetically monitored from a series of precision-machined notches in the drum periphery. At the correct drum surface speed, this magnetic "tachometer" generates a 100 cps signal in a reluctance pickup. The phase relation between this signal and a standard 100 cps signal (counted down from a precision 800 cps timing fork) is sensed by a servo-amplifier which controls the drive-motor. Drum speed accuracy is maintained to such a degree that timed events on successive records compare within 1 ms at any point.

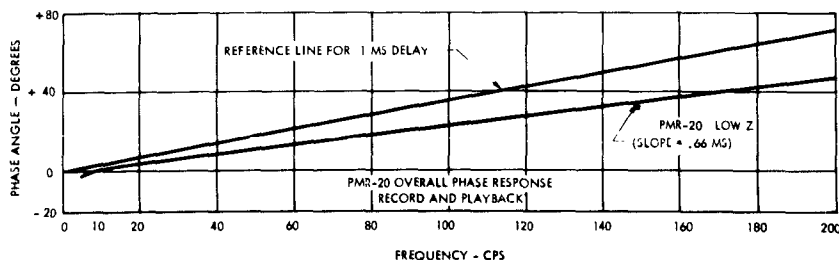
Recording Control is virtually automatic on the PMR-20 system. Use of a powerful drum drive permits cam-operated switches to be used to start the camera, initiate the recording cycle, fire the shot, trip the amplifier and other auxiliary functions. The amplifier trip cam is adjustable from the front panel.

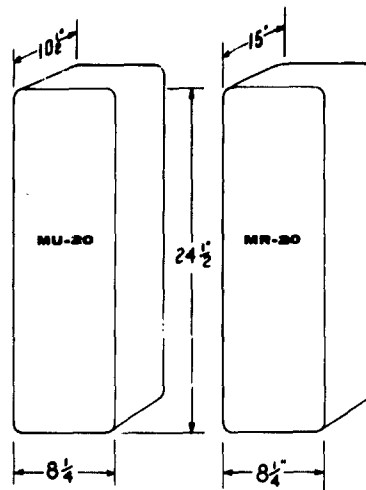
The **Recording Heads** are mounted in two banks of fourteen on plug-in chassis quickly and easily removable for inspection, cleaning or maintenance. Individual head suspension permits alignment and pressure adjustment to insure that each head tracks correctly and follows tape thickness variations freely. Fixed recording heads or movable heads with a ± 50 ms adjustment range for static corrections are available. Standard head spacing on the PMR-20 makes records compatible with other SIE FM recorders and with SIE GeoData seismic data reduction systems. The recording head assemblies are rigidly mounted to maintain their position relative to the recording drum, insuring that shot energy or "truck-bounce" cannot introduce tracking errors.

MU-20 Master Unit

The **Modulator** and **Demodulator** units, models TRM-1 and TRD-1 respectively, are two-channel units on plug-in linen-bakelite chassis. An aluminum stiffening bar through the longitudinal center separates the two channels, and an "L"-shaped bar at the front facilitates quick, easy plug-in removal and replacement of the chassis. Use of frequency modulation in the PMR-20 gives a high signal-to-noise ratio, excellent frequency response, and reduces the effects of tape imperfections or wear on recording fidelity. Carrier center frequency is 4000 cps, with upper and lower limits 7000 cps and 1000 cps respectively. The high deviation ratio insures a high signal-to-noise ratio. Carrier center-frequency adjustment is factory set, but provision is made for metering and re-adjustment if necessary. Input and output levels on the TRM-1 and TRD-1 can also be trimpot adjusted after the modulator and demodulator front panels have been removed. A novel magnetic multi-vibrator circuit in the modulator gives wide dynamic range and low distortion. The carrier frequency is filtered from the seismic signal by a single K-Section filter which has extremely linear phase shift, with a time delay of only .66 ms. Low frequency phase shift is extremely small (see graph). Frequency response is flat within 1 db from 1 to 300 cps.

The **MC-20 Control** section contains the modulation/voltage meter and its associated switching and a power circuit breaker. Provisions are made to indicate (1) modulation percentage, (2) playback level, (3) "A" voltage, (4) "B" voltage, (5) Hi Z recording level, (6) modulator center frequency and (7) a position which allows calibration of the meter by playing back a standard tape. The latter position can also be used to determine percentage modulation of any recorded tape or to indicate malfunctions.





Specifications:

Channels	24 geophysical 4 auxiliary (time-break, up-hole, 100 cps and noise-cancelling)		
Tape dimensions	4" x 45 1/4" (Standard SIE)		
Tape speed	7 1/2" sec.		
Useful Record Length	5 1/2 sec.		
Input for maximum recording level	0.375 volt across 0.5 megohm potentiometer		
Maximum output level	Hi Z: 2.2 volts (source impedance = 3000 ohms) Lo Z: 300 micro volts (source impedance = 200 ohms)		
Frequency response	1 cps to 300 cps — within 1 db Down 3 db at 500 cps		
Signal-to-noise ratio	60 db (rms to rms) with noise cancelling, 1 to 500 cps 54 db (rms to rms) without noise cancelling, 20 to 200 cps		
Harmonic distortion	Less than 1%		
Crossfeed	Below recording system noise level		
Absolute timing accuracy	0.2 ms per second + 1 ms.		
Relative timing accuracy	± 0.25 ms		
Transfer relative timing accuracy	Within 1 ms		
Time delay	0.66 ms		
Power requirement		Standby	Operating
	Record	2.5 amps	7 amps
	Playback	2.0 amps	5.5 amps
			12 vdc
Dimensions (without handles)	MR-20 Recorder Unit — 8 1/2"W x 24 1/2"H x 14 3/4"D MU-20 Master Unit — 8 1/4"W x 24 1/2"H x 10 1/2"D		
Weights	MR-20 Recorder Unit — 67 lbs. MU-20 Master Unit — 40 lbs.		

Specifications are in accordance with SEG standards — See Geophysics, v22, p922-931, and subject to change without notice.

SIE DIVISION

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APPENDIX C

ELECTRONIC EQUIPMENT BROCHURES AS RECOMMENDED

INSTRUMENTATION MAGNETIC RECORDING - REPRODUCING SYSTEM

SIE MODEL MR-200

Specifications

Transport: Ampex Model CP-100

Electronics: SIE Model MU-21 FM Record-Playback Unit

Channels: 14

Tape Dimensions: 1" width, 1.0 mil or 1.5 mil base

Reels: 10-1/2" Diameter Precision or Standard NAB Reels

Tape Speed: 3-3/4" Per Second

**Useful Record Length: 1.0 mil Base: 3600'
1.5 mil Base: 2500'**

Start Time: Approx. 3 seconds

Stop Time: Approx. 3 seconds

Tape Speed Deviation: $\pm 0.25\%$

Flutter and Wow: Approx. 0.84% Peak to Peak

Signal-to-Noise Ratio: Minimum Approx. 45 db, 1-300 cps

Input for Maximum Modulation: 0.375 Volt rms @ 0.5 Megohm

Frequency Response: 1 cps to 300 cps within 1 db

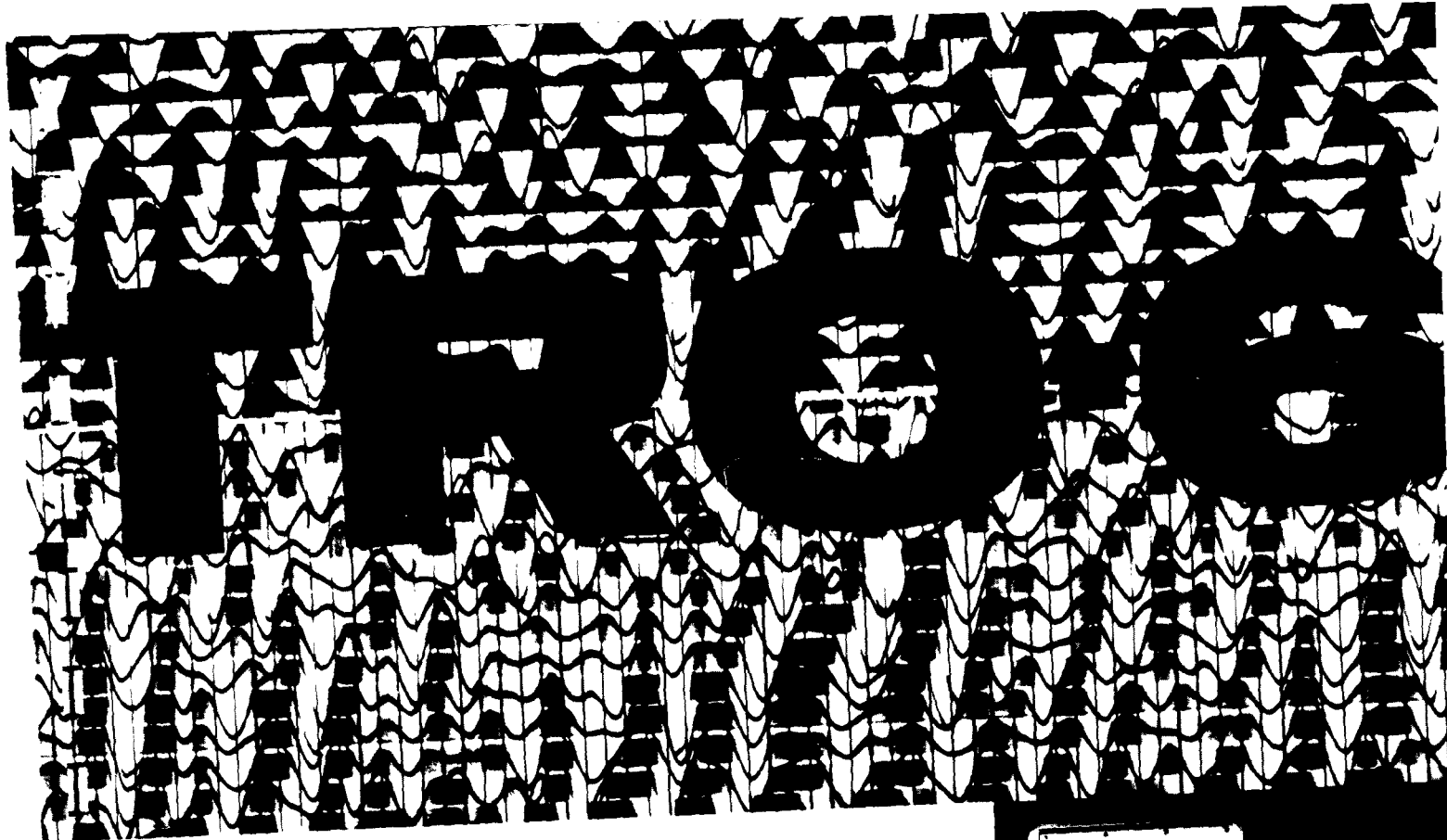
Maximum Output Level: 2.2 volts @ 10,000 ohms

Harmonic Distortion: Less than 2%

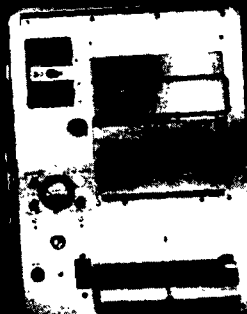
Power Requirements: 28 Volts DC, Approximately 400 Watts

**Dimensions: CP-100 - 11-13/16" H x 33-1/2" W x 19" D
MU-21 - 18-1/2" H x 8-1/2" W x 10-1/2" D**

**Weight: CP-100 - Approx. 150 lbs.
MU-21 - Approx. 30 lbs.**



**TRIPLE
RECORDING
OSCILLOGRAPH**



THE TRO-6 TRIPLE RECORDING OSCILLOGRAPH is the first geophysical camera to answer all your needs in one unit. The versatility of display and timing allows you to use the TRO-6 in applications ranging from simple conventional wiggle-trace field recording to the most complex office playback. Variable-density, conventional wiggle, or variable-density-and-wiggle combined are the usual modes of operation. A simple mechanical change provides variable-area or variable-area-and-wiggle displays. The same single galvo block is used in all cases.

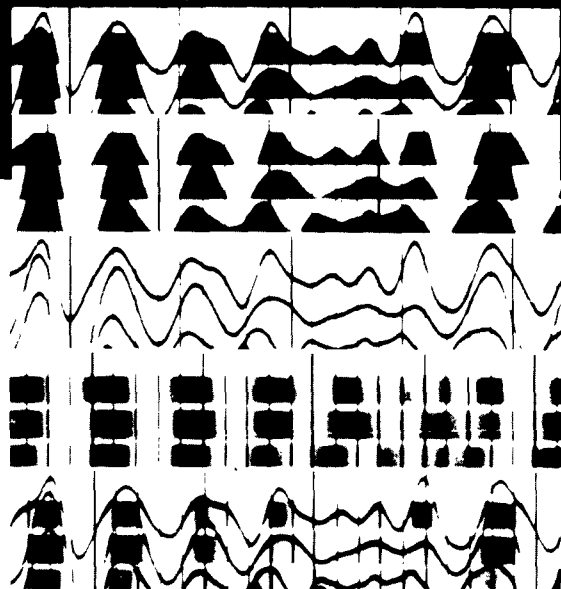
New standards of accuracy and repeatability in paper drive are produced by a synchronous drive motor. Since there are no motor brushes or governor contacts to generate "camera hash", power wiring location is not critical and the ultimate sensitivity of associated amplifiers can be realized. A solid-state power amplifier fed from a precision 400 c-p-s non-position-sensitive fork drives the motor. Drive speed is quickly and easily established by changing coupling gears.

Electronic flasher tube timing is usually employed.

Excitation may be from a 100 c-p-s external signal normally provided from magnetic playback systems or from the built-in precision transistorized fork-controlled drive circuitry. All timing line widths are individually adjustable for ease in record interpretation. A 400 c-p-s timing motor may be substituted for flasher tubes if desired.

All operator controls are carefully located for ease in operation. Designed with practical field operation in mind, hinged chassis design eliminates any need to remove the oscillograph from mountings or to disassemble any parts while making adjustments. Electrical centering for galvo traces is provided for ease of trace adjustment.

No longer is it necessary to have two or more cameras to supply the various oscillographic presentations and modes of operation demanded in modern geophysical record interpretation techniques. Evaluate the features of the TRO-6 as detailed in this brochure. Then call SIE for your personal examination of the pace-setting oscillograph described.



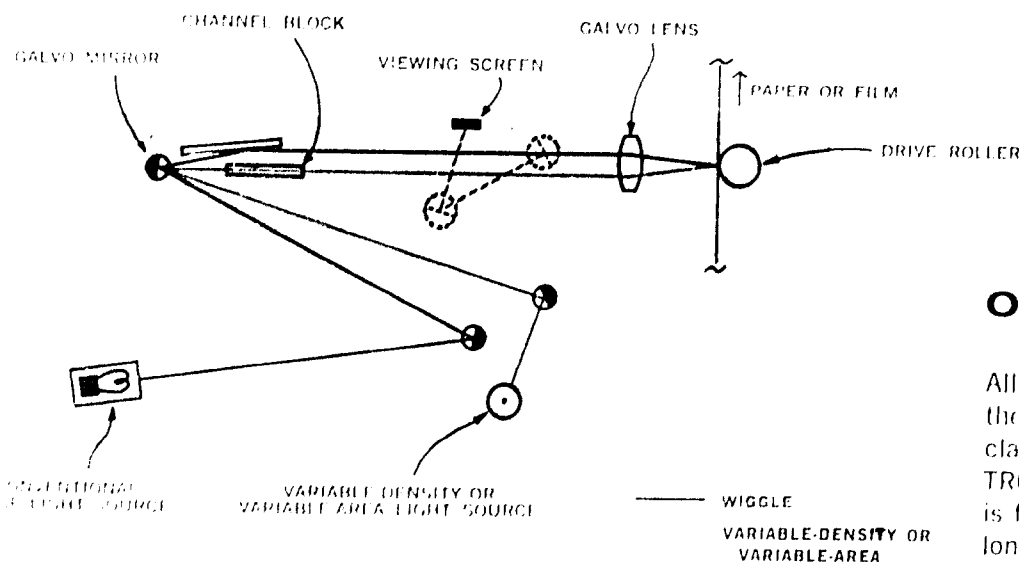
PRESENTATION

These full-size records illustrate the five types of display possible with the TRO-6. A novel optical system provides proper adjustments for all types of presentation. No compromises are required in settings even though only one galvo block is used.



PAPER DRIVE

Accuracy and consistency of paper drive is assured by a synchronous drive motor, a motor which does not generate electrical noise in associated equipment. Power is supplied from a built-in solid-state 400 c-p-s supply. Standard paper speed is twelve inches per second. However, four to twenty-four inches per second is available by means of quick-change gears. The standard reliable magazine design proven by hundreds of SIE cameras in the field is used on the TRO-6. A full-roll take-up magazine is also available.



TRO-6 OPTICAL PATH FOR GALVO TRACES*

OPTICS

All optical elements adjust from "outside" the camera. There are no hard to reach clamp screws and adjustments in the TRO-6. Cleaning of mirrors and lenses is facilitated by simple removal. No longer does photography need to suffer from lack of proper camera maintenance.

* Pat. Pend.

TIMING

The TRO-6 is designed for both field recording and tape playback. Flasher tubes can be driven from external signals or from a built-in transistorized amplifier. This amplifier is excited from a temperature-compensated tuning fork accurate to one part in 20,000. All line widths are individually adjustable. Normally they are set to provide varying degrees of emphasis for 0.01, 0.05 and 0.1 second. The two flasher

tubes are provided to insure absolutely uniform line density. A 100 c-p-s output is available for recording timing signals on tape.

Flasher timing may be replaced by a 400 c-p-s timing motor if desired. Motor drive is then provided by a solid-state amplifier which plugs in to replace the flasher amplifier. Automatic push-button timing motor starting is provided on the front panel.

SPECIFICATIONS

GENERAL

Display Variable-density, variable-area, conventional wiggle, variable-density-and-wiggle, or variable-area-and-wiggle superimposed.

PRESENTATION

Trace Width Approximately 0.18 inches, equally spaced.
28 traces cover 5.04 inches, 24 traces cover 4.32 inches.

Maximum Record Width Six inches (See note on TRO-10 below).

Material Either paper or film.

Galvo Frequency 125 c-p-s standard.

Viewing Wiggle traces viewed on front panel screen.

TIMING SYSTEM

Type Flasher tubes with internal or external timing generator; or 400 c-p-s timing motor.

Electronics Plug-in assembly for electronic drive for flasher or timing motor.

Output 100 c-p-s output signal available, approximately one volt from 5000 ohms source.

Accuracy 1 part in 20,000.

OPTICS

Adjustments All adjustments made from "outside". Elements removable for ease in cleaning. Flasher tubes adjust and lock in position.

Trace Position Electrical centering with solid-state built-in power supply.

PAPER DRIVE

Drive Motor 400 c-p-s synchronous with built-in power supply.

Speed Standard 12"/second. 4 to 24"/second available by quick-change gears.

POWER

Voltage 12 volts dc input, operates satisfactorily from 10½ to 13½ volts at camera input plug.

Current Stand by: (lights out) 1.5 amp.
Operating: 13 amps (with variable-density, wiggle and timing motor lamps. Less for single display and/or flasher timing).

Timing motor or electronic flash timing.

Solenoid-operated light shutter for providing title block space.

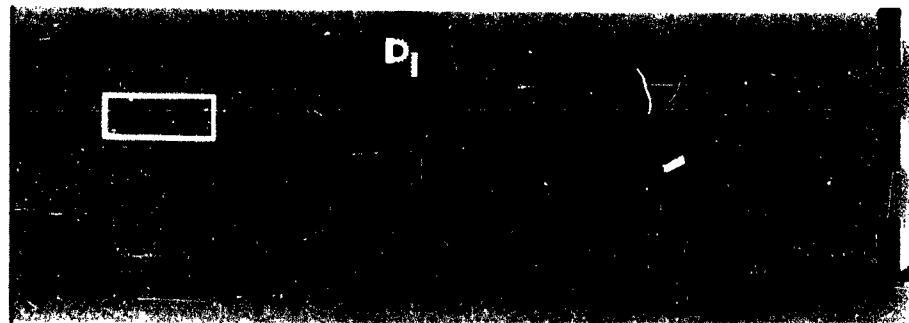
Full-roll, take-up magazine.

Note: The TRO-10, a 10" version of the TRO-6, is available on special order.

Size 20¾ high by 12¾ wide by 10¾ deep with lid, 7½ without lid.

Weight 50 pounds with lid, 48 pounds without.

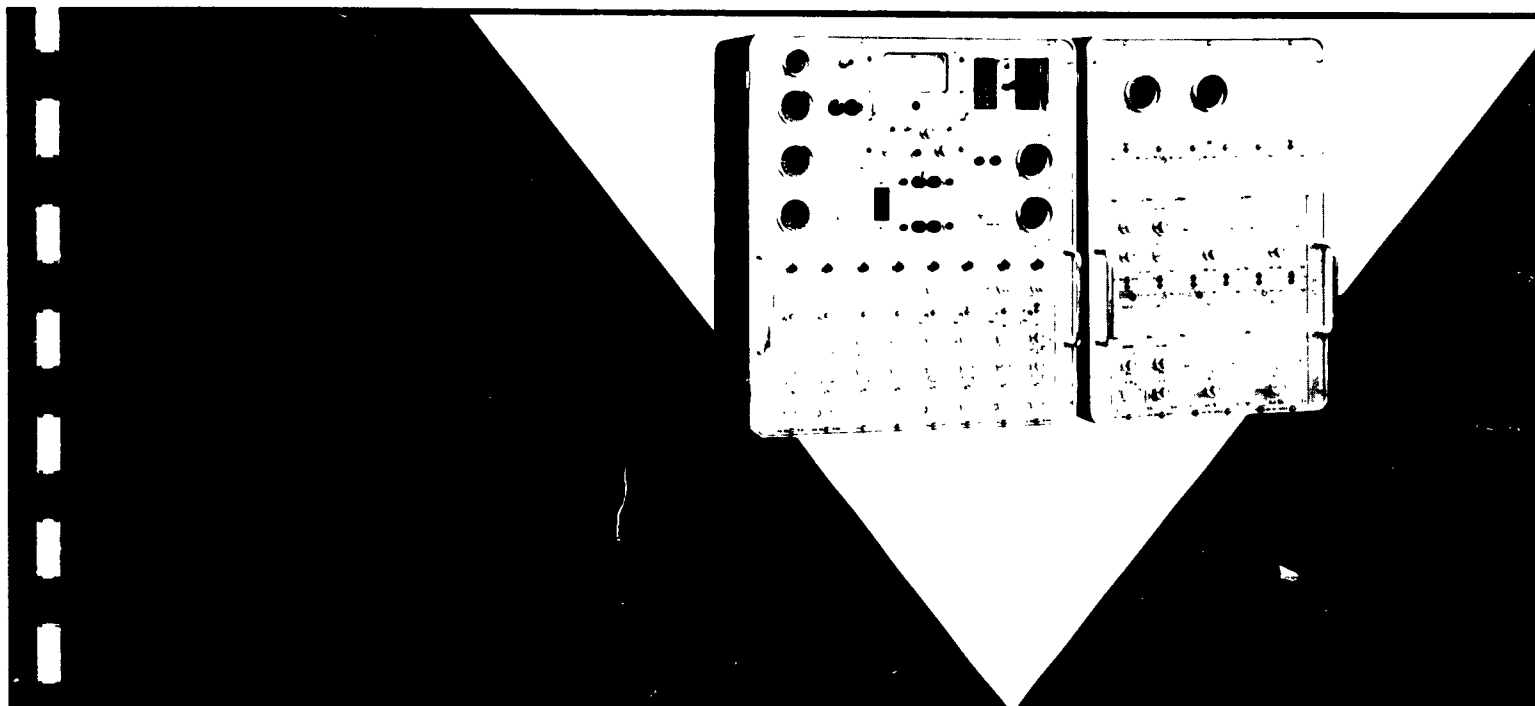
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GTR-200

GTR-200
VLF REFRACTION
AMPLIFIER

TRANSISTORIZED VERY-LOW FREQUENCY REFRACTION AMPLIFIER SYSTEM



GTR-200 VLF AMPLIFIER SPECIFICATIONS

AMPLIFIER TYPE TGA-2

Input: Transformer input. Impedance 1500 ohms resistive shunted by 350 henries. (approximately 1200 ohms resistive above 2 cps). Tap for higher impedance available.

Frequency Response: Broad band. Within 3 db. 1 to 300 cps. Separate hi-cut and lo-cut filter insertion relays.

Attenuation Controls: Step attenuator switch. 6 db steps. 0 to 42 db; switch for additional 42 db attenuation.

Distortion: Less than .5% at input levels up to 100 microvolts with no attenuation.
(Dynamic range 60 db, noise level to maximum undistorted signal.)

Noise: Approximately 12 microvolts peak-to-peak 1 to 26 cps.*
Approximately 17 microvolts peak-to-peak 1 to 100 cps.*
* Peak-to-peak ratio of noise to 1 microvolt RMS referred to input.

Outputs: Galvo: Dual output, 0 and -15 db.
Maximum deflection (200 cps SIE galvo) for input level of 1 microvolt RMS is 1" peak-to-peak from 0 db output.
Maximum deflection (200 cps SIE galvo) without distortion is approximately 40" from 0 db output, and approximately 8" from -15 db output.
Single level control feeding both outputs.

Hi-Z Tape: Dual output, 0 and -30 db.
Maximum output for input level of 1 microvolt RMS is 1 volts @ 10K ohms at 0 db output.
Maximum output for input level of 30 microvolts RMS is 1 volts @ 10K ohms at -30 db output.
Single level control feeding both outputs.

FILTERS TYPE DHC-2 AND DLC-2

Passive dual channel plug-in units, constant K.

Lo-Cut 18 db oct Out, 3 1/2, 7, 14 cps
Hi-Cut 18 and 36 db oct Out, 9, 13, 18, 26, 37, 100 cps.

SYSTEM

Controls: Master hi and lo-cut filter IN-OUT switches.
Individual channel dual capacitive and resistive line balance controls for high-line rejection.

Test Facilities: Metering circuit for geophone ohms and leakage, selection of individual channels for signal metering, monitoring of supply voltages and oscillator.
Input paralleling switch and selector for injection of oscillator signal into individual channels.
Internal test oscillator with calibrated attenuator and frequency selector.
Individual channel switches for geo test.

Auxiliary Functions: Compatible with all SIE oscillographs and SIE special magnetic recording equipment.
Inputs for magnetic tape playbacks, (signal injection ahead of filters).

Power Requirements: Total 8-channel system approximately .7 amp @ 24 VDC.

Dimensions: MU-200 Amplifier Unit (8 channels): 18 3/8"H x 16 1/4"W x 8 1/2"D
Approximately 68 lbs.
FU-200 Filter Unit (8 channels): 18 3/8"H x 12 3/4"W x 8 1/2"D
Approximately 39 lbs.

Temperature: 0° to 130 °.

SIE

DIVISION

DRESSER ELECTRONICS

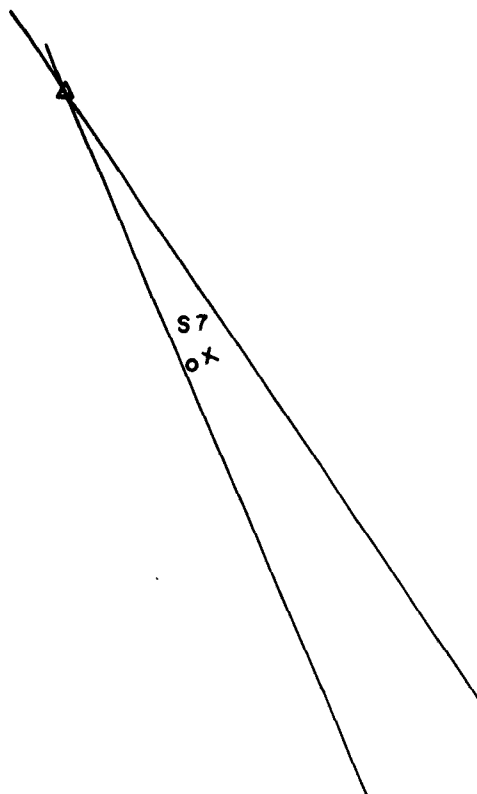
10201 Westheimer, Zone 42 / P. O. Box 22187, Zone 27 / Houston, Texas

PHONE: SUbset 2-2000

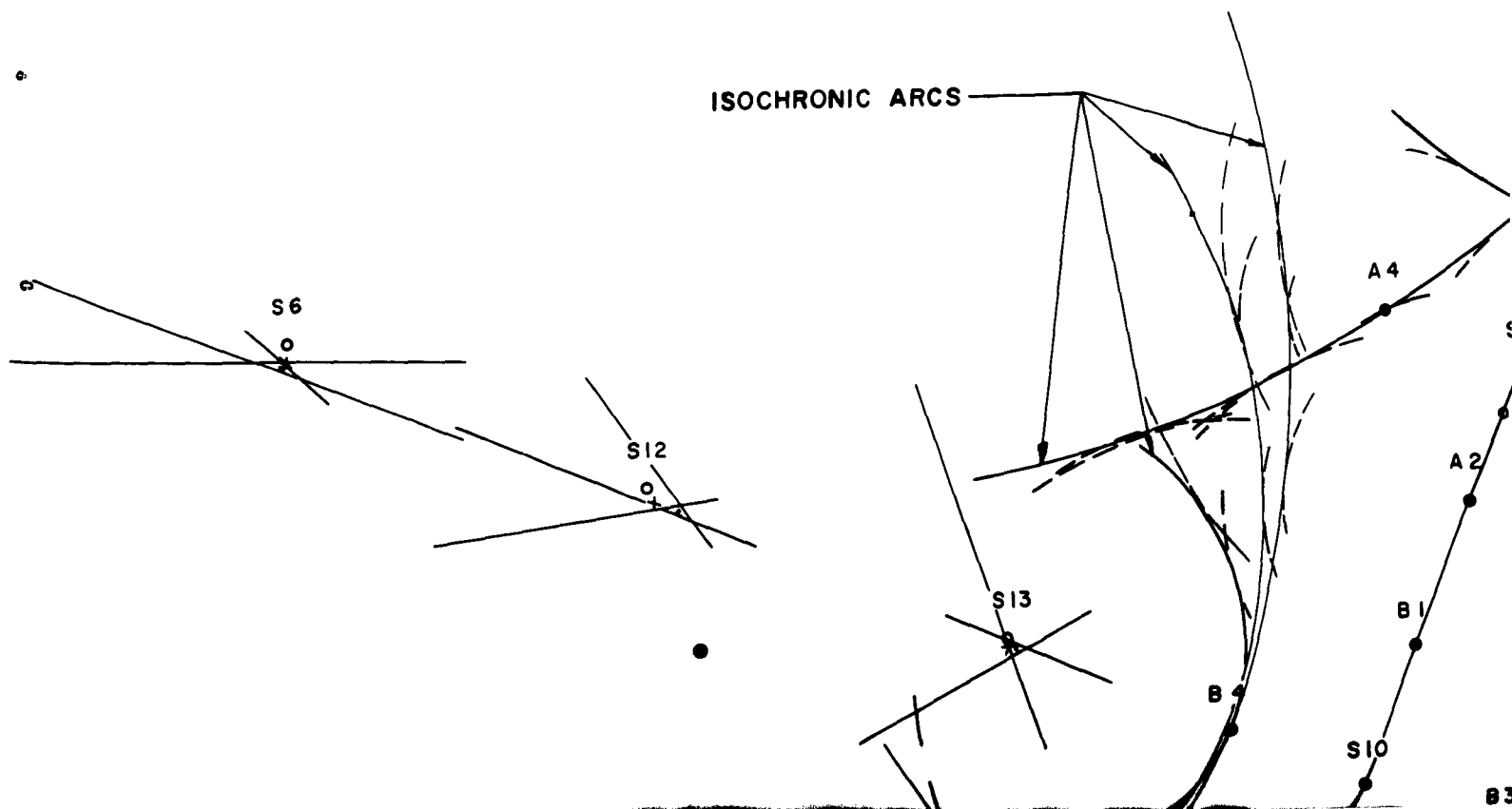
CABLE: SIECO HOUSTON

TWX: HO-1185

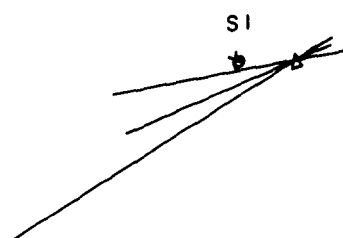
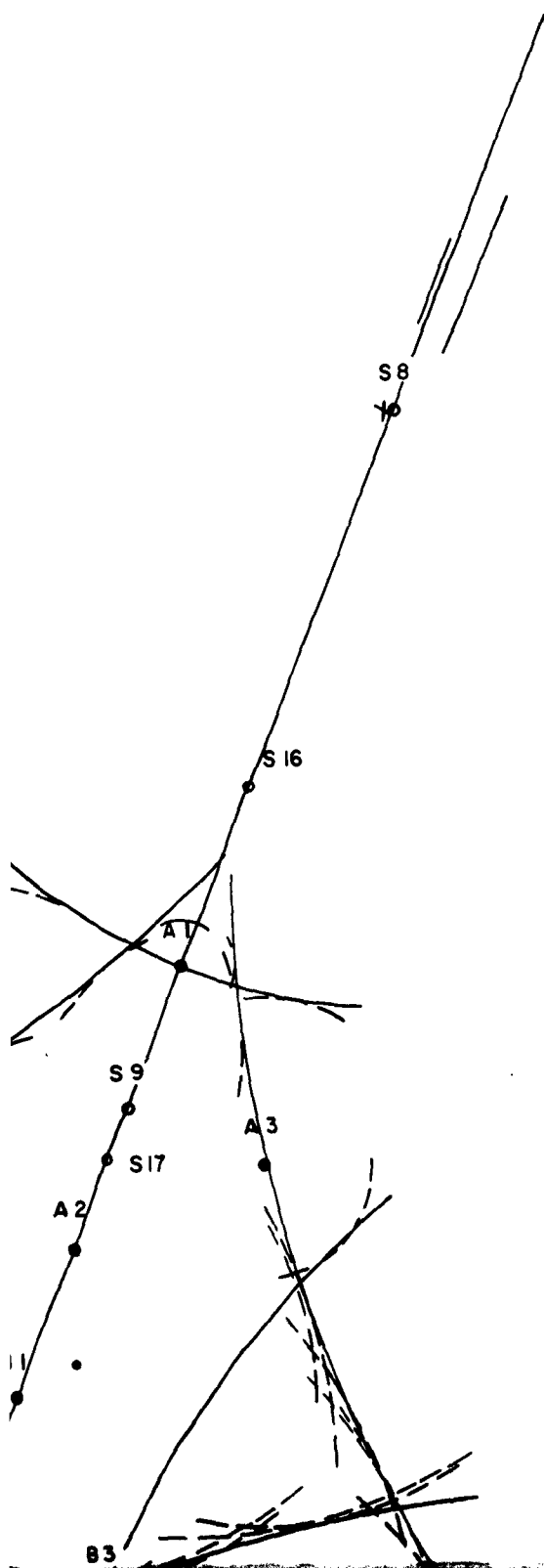
World-wide service. Offices in Canada, Europe and Mexico---agents throughout the free world

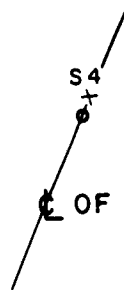
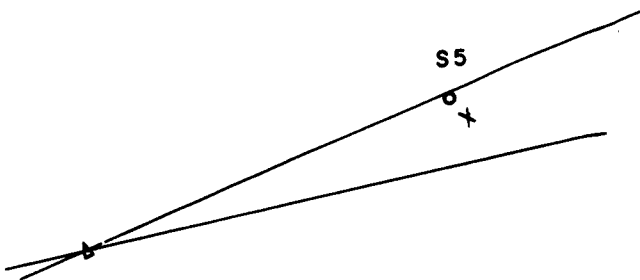


ISOCHRONIC ARCS



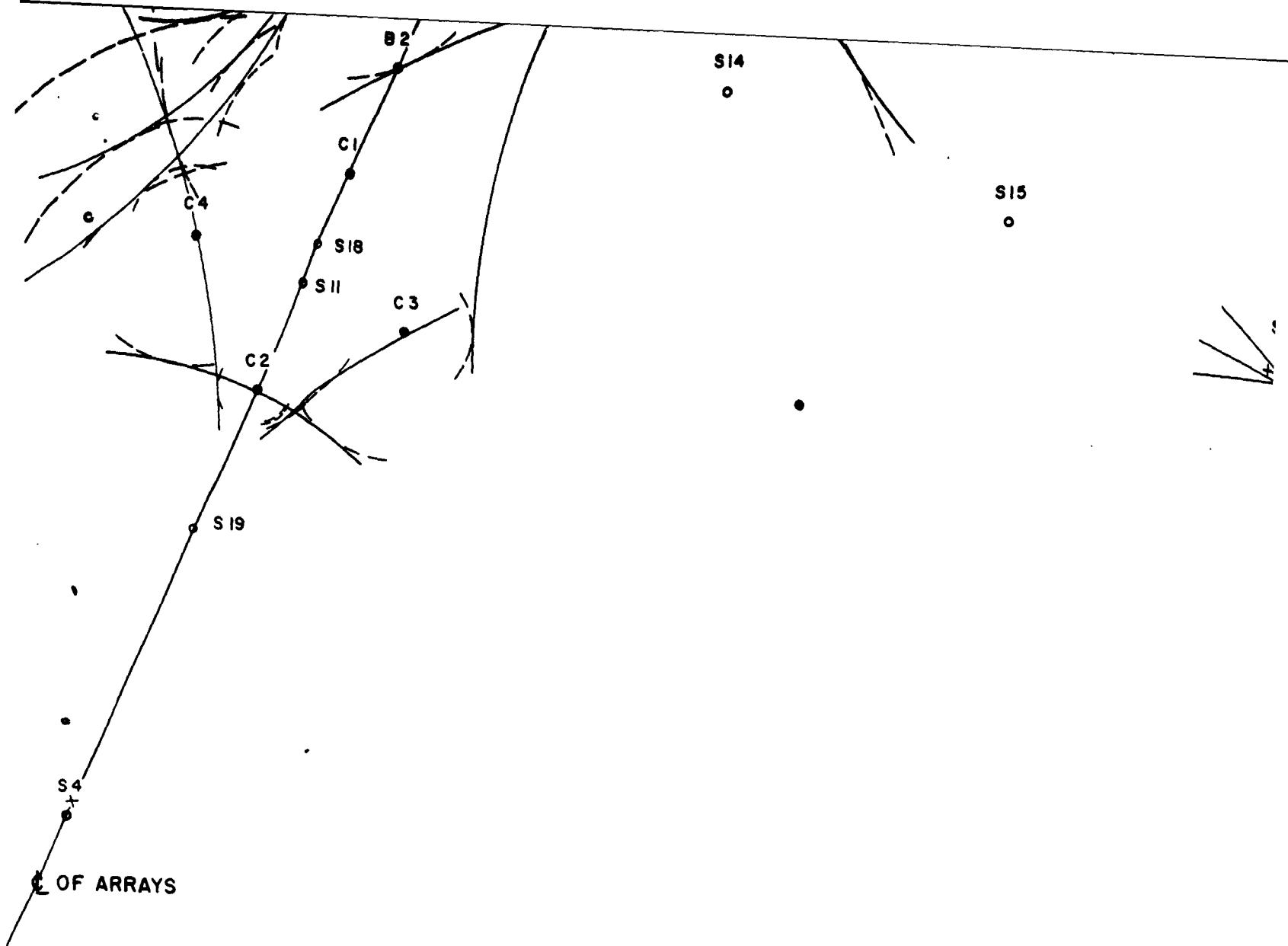
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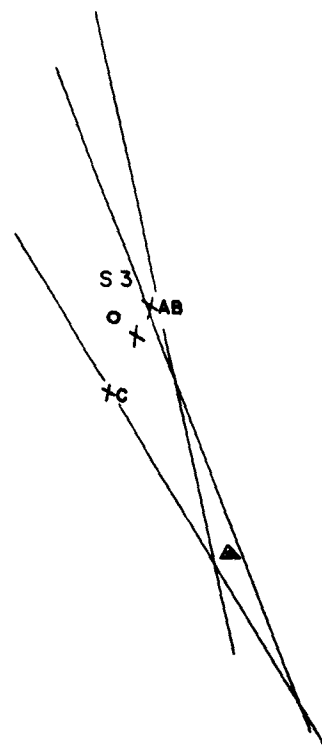


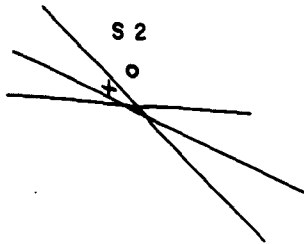
- = SHOT POINT
- = GEOPHONE
- X = CALCULATED POSITION
- △ = POSITION VIA $TAN^{-1} \frac{t_1 - t_2}{t_4 - t_3}$

3



4





5

THIS DRAWING, INCLUDING ALL NOVEL AND PATENTED OR PATENTABLE SUBJECT MATTER, EMBODIES CONFIDENTIAL INFORMATION OF THE SOUTHWESTERN INDUSTRIAL ELECTRONICS COMPANY, HOUSTON, TEXAS, AND IS LOANED WITH THE UNDERSTANDING THAT IT WILL NOT BE REPRODUCED NOR BE USED FOR ANY PURPOSE EXCEPT THAT FOR WHICH LOANED UNLESS WRITTEN PERMISSION IS GRANTED BY THE OWNER, AND THAT IT SHALL BE RETURNED ON DEMAND	DO NOT SCALE PRINTS REMOVE BURRS BREAK ALL SHARP EDGES TOLERANCES UNLESS OTHERWISE SPECIFIED DEC. $\pm .005$ FRAC. $\pm 1/64$ ANG. $\pm 30^\circ$	NAME CALCULATED POSITIONS OF SHOTS	
DRESSER ELECTRONICS SIE DIVISION A DIVISION OF DRESSER INDUSTRIES, INC. HOUSTON, TEXAS		DRAWN BY C.E.K. CHECKED BY <i>[Signature]</i> APPROVED <i>[Signature]</i> DATE 9-20-61 SCALE 1"=1000'0"	DRAWING NUMBER FIG.13



S7

o



S6

o



S12

o

S13

o

A4

B

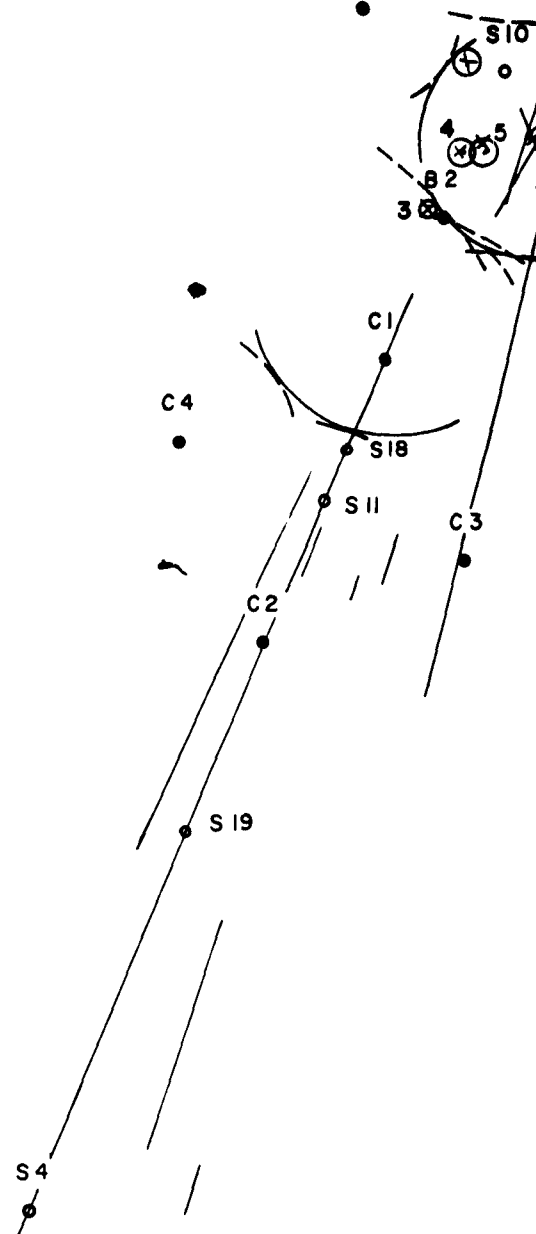


SI
o

2

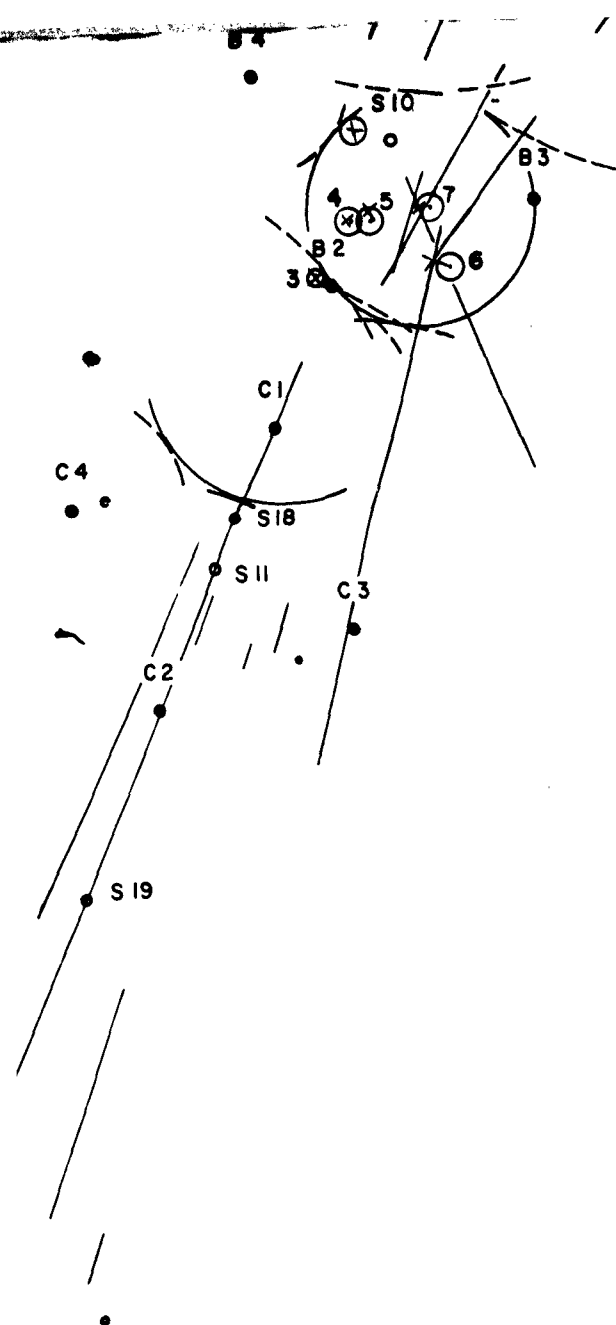
3

S5
o



- o = SHOT POINT
- = GEOPHONE
- ⊙ = MISSILE IMPACT PER COORDINATES FROM WSMR
- x = MISSILE IMPACT AS CALCULATED

THIS DRAWING INCLUDING ALL NOVEL AND PATENTED OR PATENTABLE SUBJECT MATTER, EMBODIES CONFIDENTIAL INFORMATION OF THE SOUTHWESTERN INDUSTRIAL ELECTRONICS COMPANY, HOUSTON, TEXAS, AND IS LOANED WITH THE UNDERSTANDING THAT IT WILL NOT BE REPRODUCED NOR BE USED FOR ANY PURPOSE EXCEPT THAT FOR WHICH LOANED UNLESS WRITTEN PERMISSION IS GRANTED BY THE OWNER, AND THAT IT SHALL BE RETURNED ON DEMAND.	DO NOT SCALE PRINTS REMOVE BURRS BREAK ALL SHARP EDGES TOLERANCES UNLESS OTHERWISE SPECIFIED DEC ± .005 FRAC. ± 1/64 ANG. ± 30°	NAME CAL OF
DRESSER ELECTRONICS SIE DIVISION A DIVISION OF DRESSER INDUSTRIES, INC. HOUSTON, TEXAS		DRAWN BY C.E.K. DATE 9-20-



4

ITED INPI. DUB- AND RILL FOSS TEN T IT	DO NOT SCALE PRINTS REMOVE BURRS BREAK ALL SHARP EDGES TOLERANCES UNLESS OTHERWISE SPECIFIED DEC. $\pm .008$ FRAC. $\pm 1/64$ ANG $\pm 30^\circ$		NAME CALCULATED POSITIONS OF MISSILE IMPACTS	
	DNICS S12 DIVISION ESSER INDUSTRIES, INC. N, TEXAS		DRAWN BY C.E.K.	CHECKED BY <i>[Signature]</i>
DATE 9-20-61		SCALE 1" = 1000' 0"	DRAWING NUMBER FIG. 16	

S3
o

STATIONS

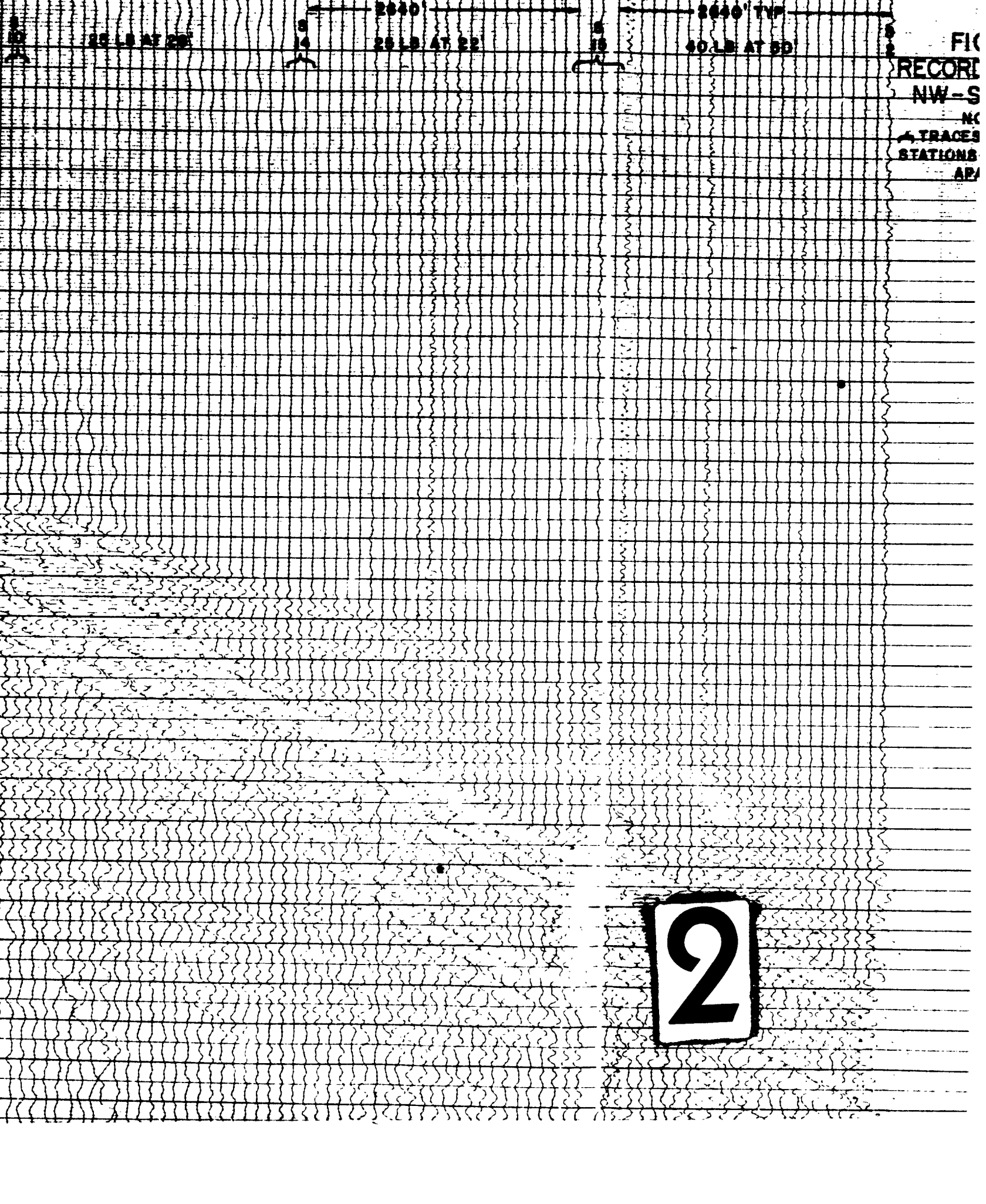
SIZE AND DEPTH

5 LB AT 47'

5 LB AT 45'

5 LB AT 40'

1



25 LB AT 25'

25 LB AT 22'

40 LB AT 50'

FIG
RECORD
NW-S
NO
4 TRACES
STATIONS
AP

2

FIG.17

RECORD SECTION

NW-SE LINE

NOTE

4 TRACES FROM SAME
STATIONS- SENSORS 118'
APART

25 LB AT 30'

25 LB AT 60'

25 LB

3

10 LB AT 30'

10 LB AT 30'

5 LB AT 17'

4

SIZE AND DEPTH

2 LB AT 55'

3
19

5 LB AT 65'

3
19

15 LB AT 60'

STATIONS

1

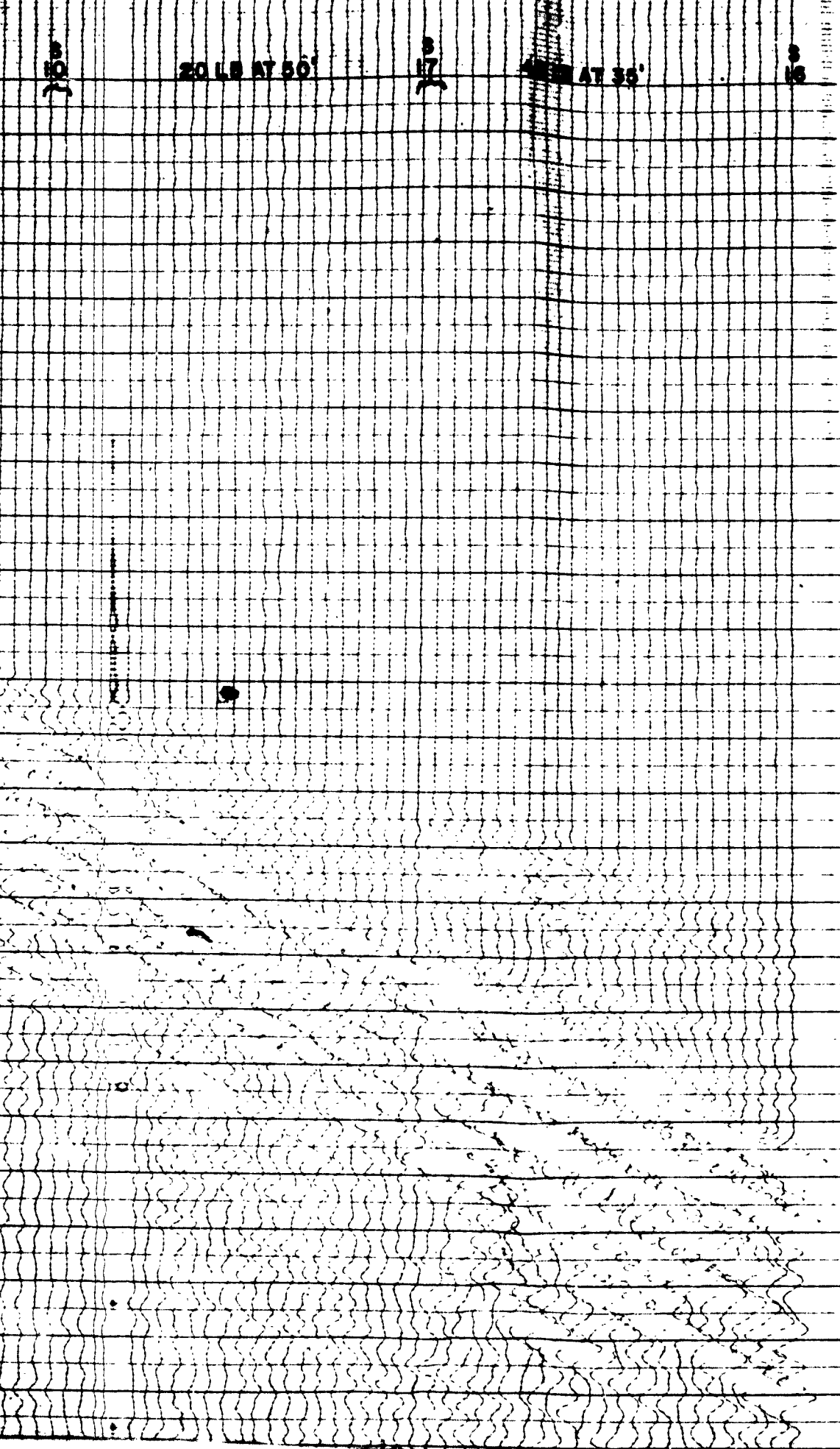


FIG. 18
REVERSED REFRACTIVE
RECORD SECTION
S4 TO S8 NE-SW LINE
THROUGH E OF AREA

2

.18
D REFRACTION
D SECTION
NE-SW LINE
H & OF ARRAYS

SOLE AT 40'

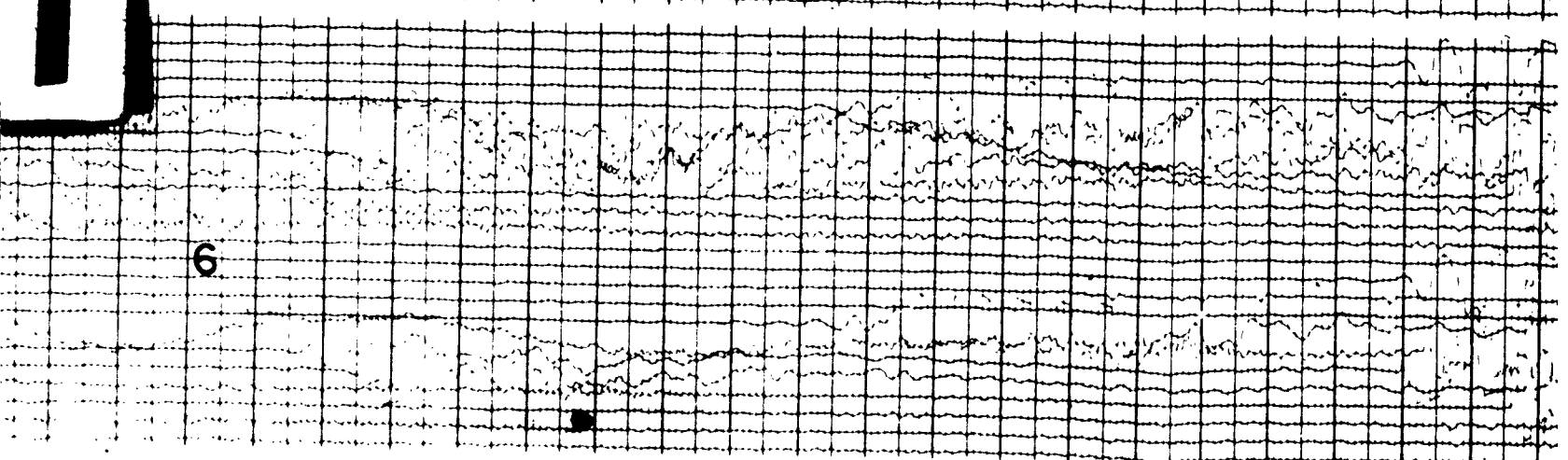
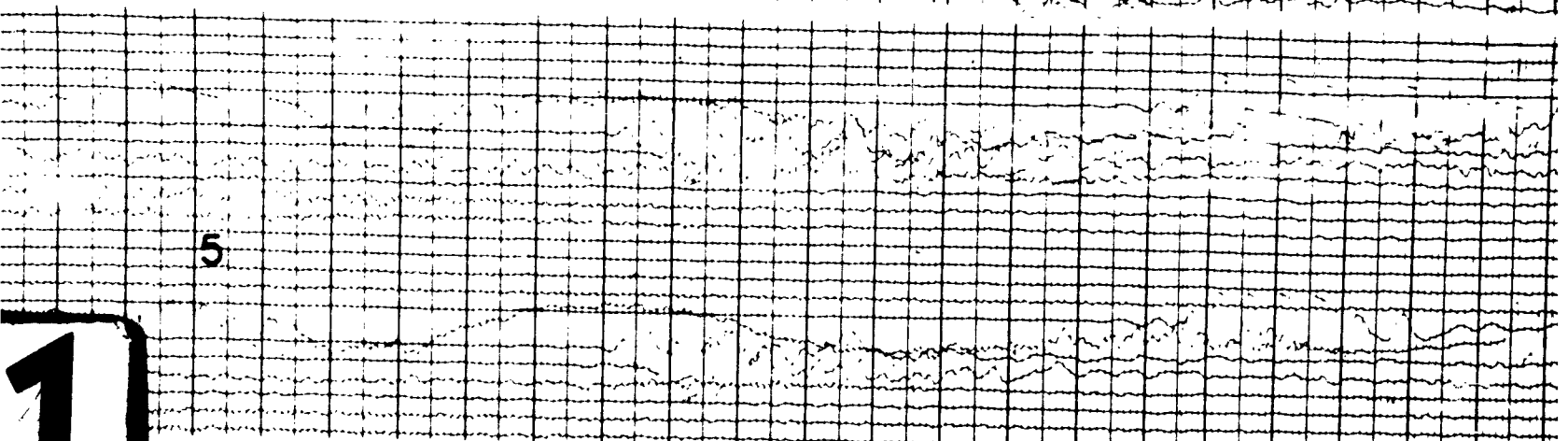
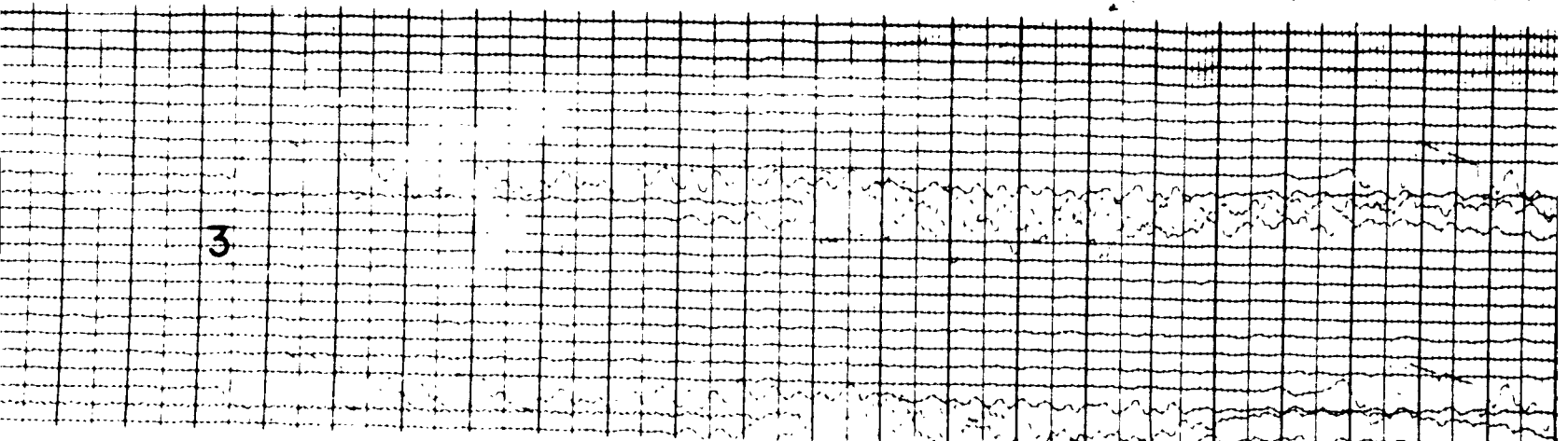
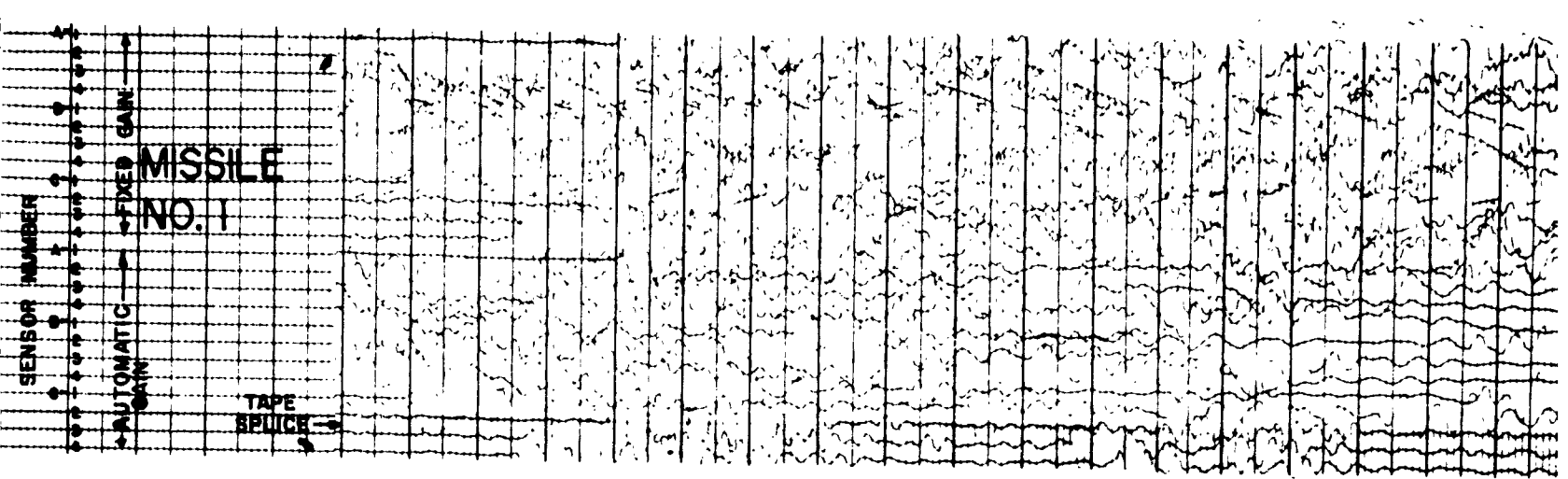
SOLE AT 55'

3

FILE AT 50

FILE AT 45

4



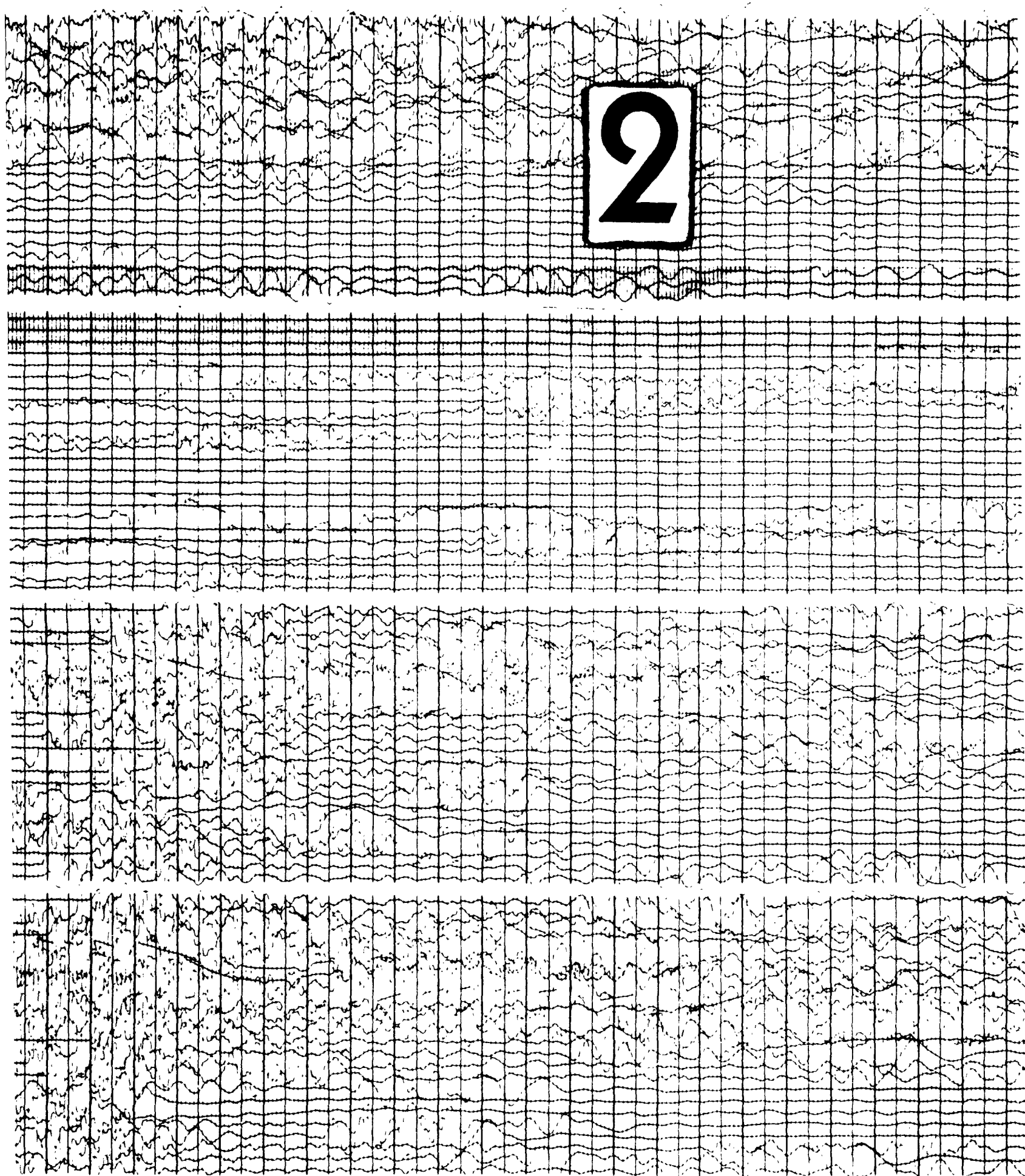
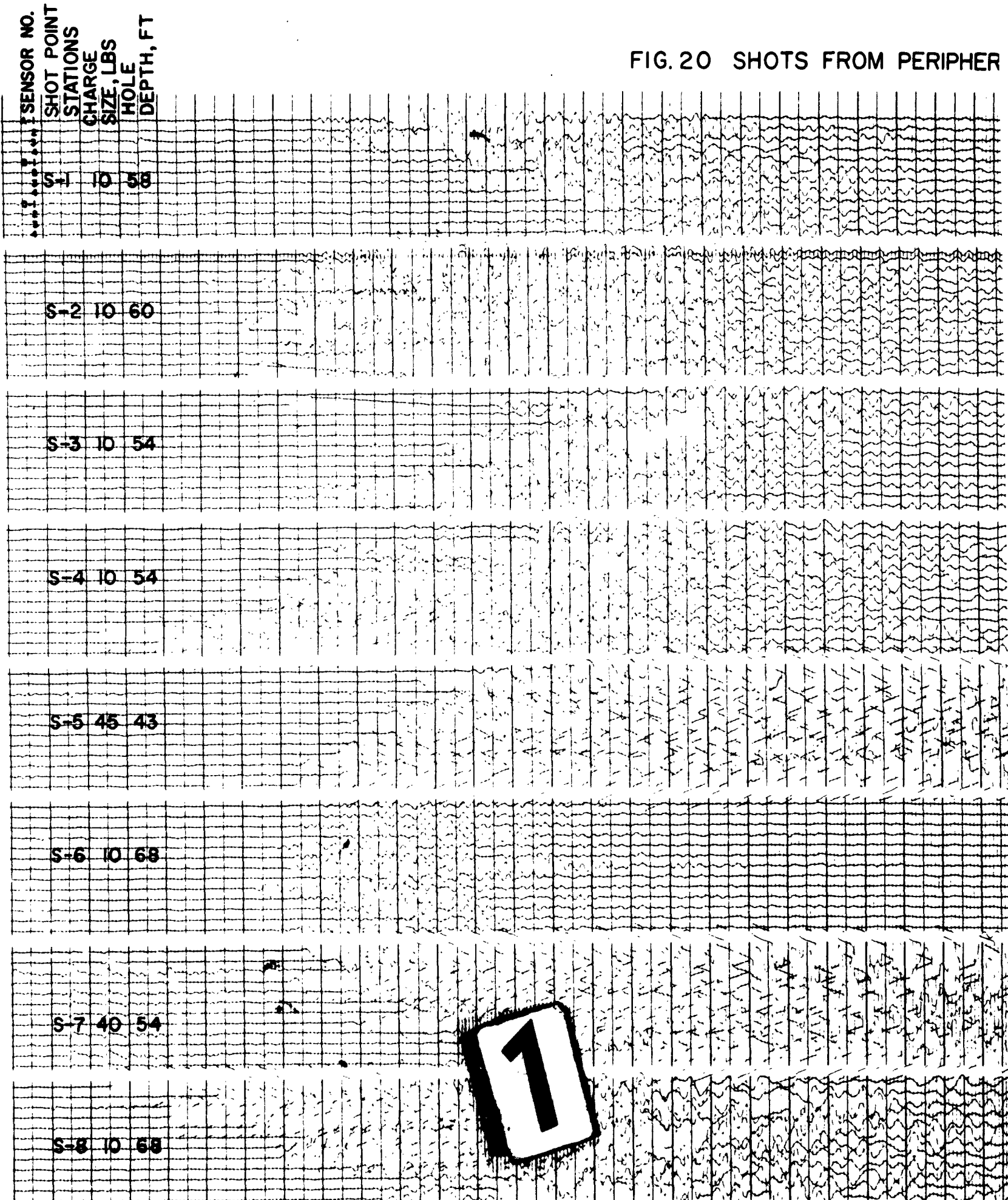


FIG. 19 RECORD SECTIONS OF IMPACTS •

3

FIG. 20 SHOTS FROM PERIPHER



OTS FROM PERIPHERY STATIONS INTO ARRAYS

