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AN IMPROVED METHOD FOR APPROXIMATING DEPTH AND POSITION OF BOTT--ETC(U)
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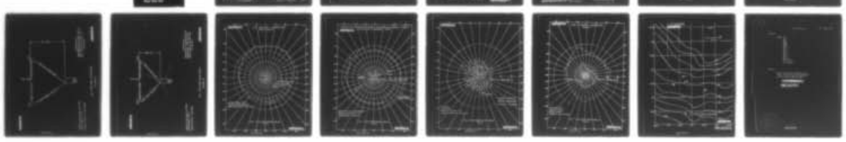

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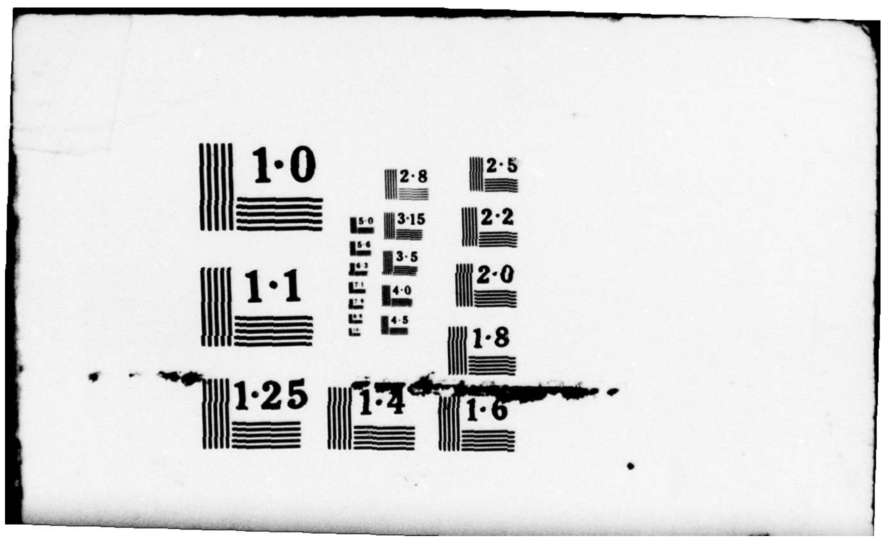
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(12) 20p. (6)

# An Improved Method for Approximating Depth and Position of Bottomed Modules.

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MOST Project

USL Problem
No. 1-556-00-00

by

(10) F. G. Weigle [redacted] B. Sussman

USL Technical Memorandum No. 913-046-61

(11) 2 Jul[redacted]61

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## INTRODUCTION

Reference (a) describes a preliminary method used to determine the position and depth of a bottomed hydrophone or module by means of acoustic signals. The following procedure was used. A number of M-1 rifle shots were fired directly above the area in which the array was located (as obtained from Raydist information at time of planting), and the shot instants and the instants of receipt from the module were noted. The minimum time delay obtained was used to get a first estimate of the depth of the array. A circular run at a radius of 1000 yards from the array position was then made, and time delays again measured. Using the computed depth and the measured time delays, the horizontal ranges to the module position were computed, and the results plotted on polar coordinate paper. The Raydist range vs bearing data were also plotted on the same sheet. From the displacement of the centers of these two circles, an improved module position was found. By repeating the circular runs, this position estimate could be successively improved. When the position was adequately known, a final series of shots, as nearly directly over the module as possible, was used to obtain the depth more accurately.

## NEW METHOD

(9) Technical memo.,

In a more recent method of measurement, a single series of shots is fired in a circle with a known diameter around some fixed reference point. It is preferable (but not absolutely necessary) that the circle be located so that the module is somewhere within it. As in the previous method, the time delay for each shot position is measured. These are then converted into slant ranges and from these the position and depth of the module may be calculated, as follows:

From Figure 1 it can be seen that for any point within a circle (but not at the center) the diameter through this point will join it to the closest point and farthest point on the circumference. A similar statement is true if the point is located outside or on the circle. (These statements may be proven very simply using plane geometry.)

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A profile view of the configuration is shown in Figure 2. Since PB is the shortest line from P to the circumference, and since the depth $h$ is constant, $a$ must be the shortest slant range. Similarly $b$ which is 180° from $a$, is the longest slant range. Thus all three sides of triangle ABC are known. The angle A, depth $h$, and distance OP may now be computed quite easily as illustrated below.

## ILLUSTRATION

Table I is part of a table of measurements used to locate one of the modules. Shots were fired at 5° intervals, and the circle diameter was 2000 yards. The pertinent data of table I have been entered in the triangle of Figure 2. Note that diameter AB is given by the sum of the Raydist ranges at 90° and 270°. Thus

$$AB = AP + PB = 980 + 1020 = 2000 \text{ yards.}$$

Using the values of Figure 3, we have, from the law of cosines,

$$\cos A = \frac{b^2+c^2-a^2}{2bc} = \frac{(2110)^2+(2000)^2-(1332)^2}{2\times 2110\times 2000}$$

$$= \frac{6.68\times 10^6}{8.44\times 10^6} = 0.7912$$

$$A = 37^\circ 42'$$

$$h = b\sin A = 2110\times 0.6116 = 1290 \text{ yd}$$
$$= 645 \text{ fm}$$

$$l = b\cos A = 2110\times 0.7912 = 1669 \text{ yd.}$$

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Hance the module is located 1669 - 980 = 689 yards from the reference point on a bearing 090.

## ACCURACY

The method just described is preferable to the previous method, since it requires only a single series of shots for the determination of both the depth and location of the module. No preliminary information is required other than a very rough idea of the location of the module. The calculations are also much simpler, since the slant ranges are used directly for computing all required quantities. In addition, the depth determination is more accurate, since in the earlier method there never was any assurance that any shot was directly over the module. Thus the depth calculated by that method would as a rule be too large.

The accuracy of the method will, of course, depend on the accuracy of the data abtained. Thus reliable navigational information and accurate sound velocity data are needed for good results.

In addition to the above sources of error, there is one more which arises from the finite number of shots used to form the circle. Assuming that all the experimental data are perfectly accurate, the solutions obtained with this method will be exact if the location of the shot nearest the module lies on the diameter drawn through the module at P, as point B in Figure 1. However, the location of the shots may be such that the nearest point is actually at B'. Under this condition, the depth and location computed by the method described will be in error.

The magnitude of the maximum error will depend on the spacing of the shots. In the tests under discussion, shots were placed $5^{\circ}$ apart on a circle with 1000 yards radius. Thus the maximum value of angle BOB' is $2.5^{\circ}$. Using this value, and the measured values given in Figure 2 for the sides of the triangle, the errors in depth and location were computed. The error in depth was negligible (less than 1/2 yard). The computed position, however, was P' instead of P, where arc PP' is situated practically on a circle with center at O. The distance PP' is 31.6 yards, and this is the maximum position error for the triangle of Figure 2. To reduce this maximum error, either the shots should be spaced closer than $5^{\circ}$, or more than one determination should be made.

Neither method described above will compete with more sophisticated micro-location schemes in which travel times to several module locations are observed simultaneously and thence their relative placement determined and in which consideration is also given to the fact that different average velocities will obtain for modules located at differing depths.

## APPLICATIONS

The revised technique described in this memorandum was applied to two sets of measurements taken on the six modules described in reference (a). The first of these was taken about June, 1960[1] and the second in November, 1960. The first set of data had been used to compute depth and position by the older method, thus permitting comparison of results obtained by the two techniques. The data will be divided into two parts for purposes of discussion. First that related to modules at locations 2, 4, 5, and 6 will be discussed. Modules 1 and 3 will be treated separately.

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[1]This set of measurements was actually spread over a period of time, and not all were made in June. For convenience, they will be referred to as the June measurements.

Table II shows depth and location estimates for modules 2, 4, 5, and 6, using the data of June 1960. As may be seen, the two sets of results are in good agreement. The differences are within experimental error. In particular, it should be noted that the new depths are in every case somewhat smaller than the old depths. This is to be expected, as explained above. As a further check, all solutions of Table II were also obtained graphically, as shown in Figures 3 to 6. The results agree with those of the table within one yard. Based on the discussion given, the new solutions are considered the more reliable.

The results of analyzing the data obtained in November, 1960 are shown in Table III. The same four modules as in Table II are listed there, and the positions are given as displacements from those of Table II. Comparison of the results in the two tables shows that the differences in depth are not too great, ranging from four to 30 fathoms. However, the differences in position are very large, and an explanation must be sought. There are several possible sources of error, and these will be examined in turn.

As stated above, the inherent error in position due to the geometry of the tests is of the order of 30 yards, assuming perfect navigation information. Possible errors in sound velocity information may add somewhat to this figure. But these sources of error are certainly not sufficient to account for the large displacements obtained.

Another possibility is that the modules have actually moved. However, other considerations indicate that this is almost certainly not the case. For example, orientation plots and directivity patterns taken on these four modules during the same period yielded results which are comparable to earlier measurements. Further, the units sound normal and show no signs of flooding. It is extremely unlikely that any unit would be unaffected had it been dragged 150 to 300 yards along the bottom.

The most plausible cause of the observed discrepancies remaining for consideration is some type of navigational error. Specifically, if an error were made in calibrating the Raydist system, it would result in a systematic error in all the reported reference points based on this calibration. Such errors in reference location would cause similar errors in apparent module location. On the other hand, such errors would not affect depth determination, since in both methods described in this memorandum the depth is calculated without using the reference location. A glance at Table II will show that, for the four modules in question, the above statements describe the actual discrepancies. Thus all four modules are displaced by distances of the same order of magnitude (180 to 290 yards) and in the same general direction ($135^{\circ}$ to $207^{\circ}$). The depth differences, on the other hand, are very small. Thus it would appear that the discrepancies noted between the two tables is very probably due to an error in Raydist calibration.

This, of course, puts the results of all past Raydist measurements in doubt, and at least one additional set of measurements will be required to resolve the matter. While it is impossible to say for certain which of the two sets of data is more reliable, it is considered more likely that it is the earlier (Table II). This conclusion is based on the manner in which the tests were conducted. The earlier runs were made at widely spaced intervals, and were treated individually. Thus, errors in these data would tend to be random. The later runs, however, were all conducted within one 48-hour period, and the readings were all based on a single Raydist calibration. Hence, in this case errors in position would tend to be comparable for all modules, as was the case with the actual data.

We now turn to a discussion of the modules at locations #1 and #3.

No acoustic position determination was made for module #1 during the June measurements. The only information available concerning this module prior to the November measurements was the original Raydist Plant position at 31° 54' 52" N, 65° 11' 13.5" W. The result of the November circle on this module indicates a "corrected" position displaced 645 yards along 135.5°. Thus the new position of the hydrophone would be 31° 54' 39" N, 65° 10' 58" W. However, in view of the previous discussion, it is likely that this new position is in error by 200 or 300 yards, and should not be relied upon until further checks are made.

Module #3 is unique in that the November tests displace it along 012°, rather than towards the southeast as is the case for the other modules. This would indicate that the original Raydist position may have been in error, as well as the calibration for the November measurements. In addition there is a distinct possibility that this unit has moved or was dragged from its original position. One indication of this is that the orientation plot run in November (Figure 7) does not look like the earlier one (Figure 8).

Again, the directional pattern of this unit taken in November (Figure 9) does not look like the previous one (Figure 10). As a matter of fact, the November plot has no recognizable pattern at all. This suggests either that some portion of the steering has failed or that the module has been physically damaged. Because of this, it may be that the unit is no longer usable as a steered array. But for possible future use of even the single hydrophone, further measurements should be made in order to determine its position more accurately.

## SUBSEQUENT MEASUREMENTS

At the earliest opportunity following the November measurements the Raydist reference buoy locations were re-established and found to have indeed shifted. With the speculations suggested earlier thus confirmed, appropriate corrections were applied to positional data and additional measurements made on both position and depth by the subject method. For purposes of information a revised summary of statistics concerning the first six modules thru the period covered by this memorandum is given in Table IV and Figure 11.

F. S. Weigle M.C.

F. S. Weigle and B. Sussman

B. Sussman

LIST OF REFERENCES

Ref (a): F. S. Weigle and W. H. Thorp, "Summary of measurements at Tudor Hill Laboratory, Bermuda, USL Technical Memorandum No. 913-09-61, dtd 27 Feb. 1961.

Table I

| Shot No. | Bearing(deg) | $\Delta t$ (sec) | Slant Range, yd. | Raydist Range, yd. | |
|---|---|---|---|---|---|
| 2 | 085 | .820 | 1338 | 1015 | |
| 3 | 090 | .816 | 1332 | 1020 | Shortest |
| 4 | 095 | .824 | 1345 | 1010 | |
| 38 | 265 | 1.288 | 2102 | 970 | |
| 39 | 270 | 1.293 | 2110 | 980 | Longest |
| 40 | 275 | 1.287 | 2100 | 990 | |

Table II

| Module Location Number | Original Correction to Raydist Plant Position | New Correction to Raydist Plant Position | Original Depth Estimate(fm) | New Depth Estimate(fm) |
|---|---|---|---|---|
| 2 | 146 yds along 111° T | 145 yds along 105° T | 555 | 545 |
| 4 | 310 yds along 290° T | 315 yds along 288° T | 607 | 595 |
| 5 | 250 yds along 290° T | 235 yds along 310° T | 827 | 815 |
| 6 | 200 yds along 225° T | 190 yds along 230° T | 530 | 505 |

Table III

| Module Location No. | Displacement from previous best acoustic position | | Depth-June Data | Depth-Nov. Data |
|---|---|---|---|---|
| 2 | 180 yds | along 135° | 545 fath. | 541 fath. |
| 4 | 290 yds | along 145° | 595 fath. | 565 fath. |
| 5 | 140 yds | along 150° | 815 fath. | 797 fath. |
| 6 | 220 yds | along 207° | 505 fath. | 480 fath. |

Table IV

Revised Summary Sheet
Showing Final Positions and Depths of 6 Modules and Argus Island

| Location No. | Position | Depth in Fathoms | Type Cable | Date Planted 1960 | Notes |
|---|---|---|---|---|---|
| 1 | 31° 54' 42.0"<br>65° 10' 58.0" | 632 | 3 Quad | 15 June | One pair brought out for each leg. One pair for shcok mtd. single hydrophone. One pair for rigidly mtd, single hydrophone. (At top for both). Vertical steering Leg A appears defective. Cliff behind module. Steers 170°. No turning motor. |
| 2 | 31° 55' 01.5"<br>65° 11' 49.0" | 532 | 12 Quad | 23 July | Steers 213°. C and D legs are strings of separate hydrophones, 1 pair each hydrophone. 1 Pair for Leg A and 1 pair for Leg B. $C_1$ and $D_1$ both have heavy thumping. Unusable. $D_4$ has thump occasionally but usable. Has steering motor separate. |
| 3 | 31° 53' 53.0"<br>65° 11' 46.5" | 1030 | 1 Quad | 11 Sept | Steers 070°. Has steering motor. Two leads brought out for module. Two leads brought out for combination of motor and single element located on bottom rear left arm. (Pattern on this module completely deteriorated). (Single element now unusable.) |
| 4 | 31° 54' 56.3"<br>65° 12' 12.5" | 556 | 1 Quad | 23 Sept. | Steers 300°. Has turning motor. Two leads for module. Two leads for combination motor and single element on top rear right armD. This module has continual pop-pop noise, and occasional metallic squeak. |



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Table IV (Cont'd)



| Module Location No. | Position | Depth in Fathoms | Type Cable | Date Planted 1960 | Notes |
|---|---|---|---|---|---|
| 5 | 31° 54' 30.0"<br>65° 11' 58.5" | 792 | 12 Quad | 30 Sept. | Steers 320°. Has steering motor. Appears to be in box canyon with 75° aperture from from 177° to 252°. Legs A and B are strings of individual elements with 1 pair brought out for each element. One pair for Leg C and one pair for Leg D. |
| 6 | 31° 55' 13.0"<br>65° 11' 53.0" | 486 | 1 Quad | 24 Sept | Steers 190°. Has steering motor. One pair for module. One pair for combination motor and single hydrophone located top rear right arm D. (Single hydrophone no longer usable) |
| Argus Island | 31° 56' 56.8"<br>65° 10' 45.2" | | | | Position from Raydist survey, Mar. 1, 1961. |

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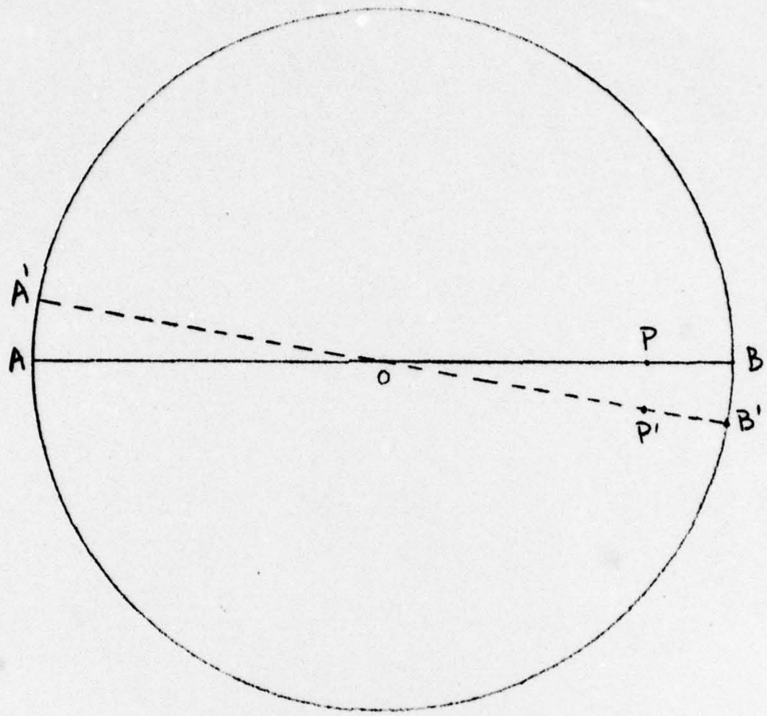


FIGURE 1

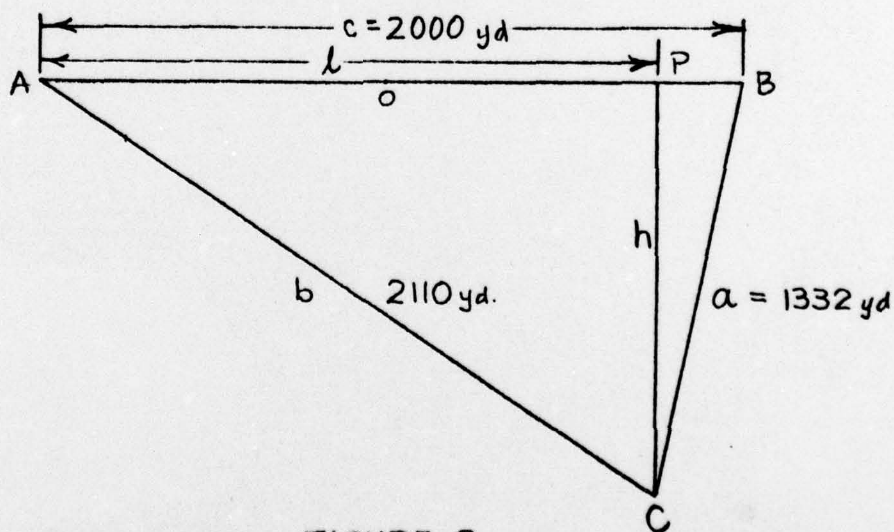


FIGURE 2

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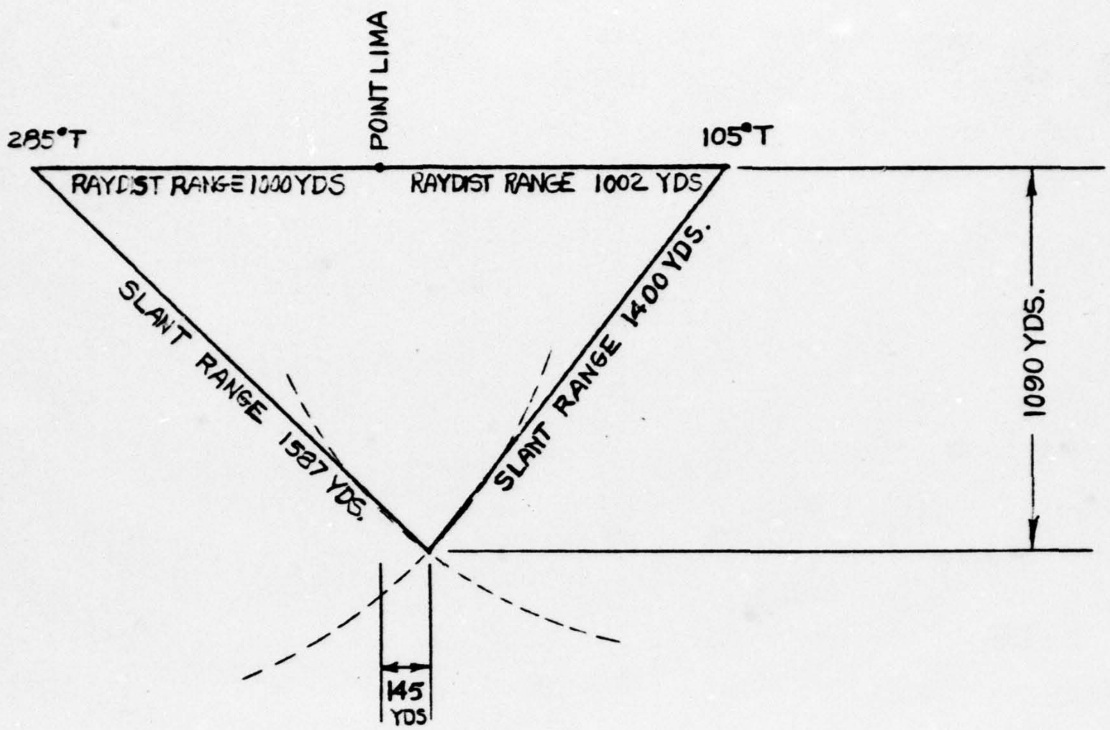


MODULE IS DISPLACED 145 YARDS ALONG BEARING 105°T

MODULE DEPTH IS 1090 YARDS

LOCATION № 2
DETERMINATION OF MODULE DEPTH AND DISPLACEMENT FROM 1000 YARD RADIUS CIRCLE OF 26 AUG 1960
16 FEB 1961

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FIGURE 3

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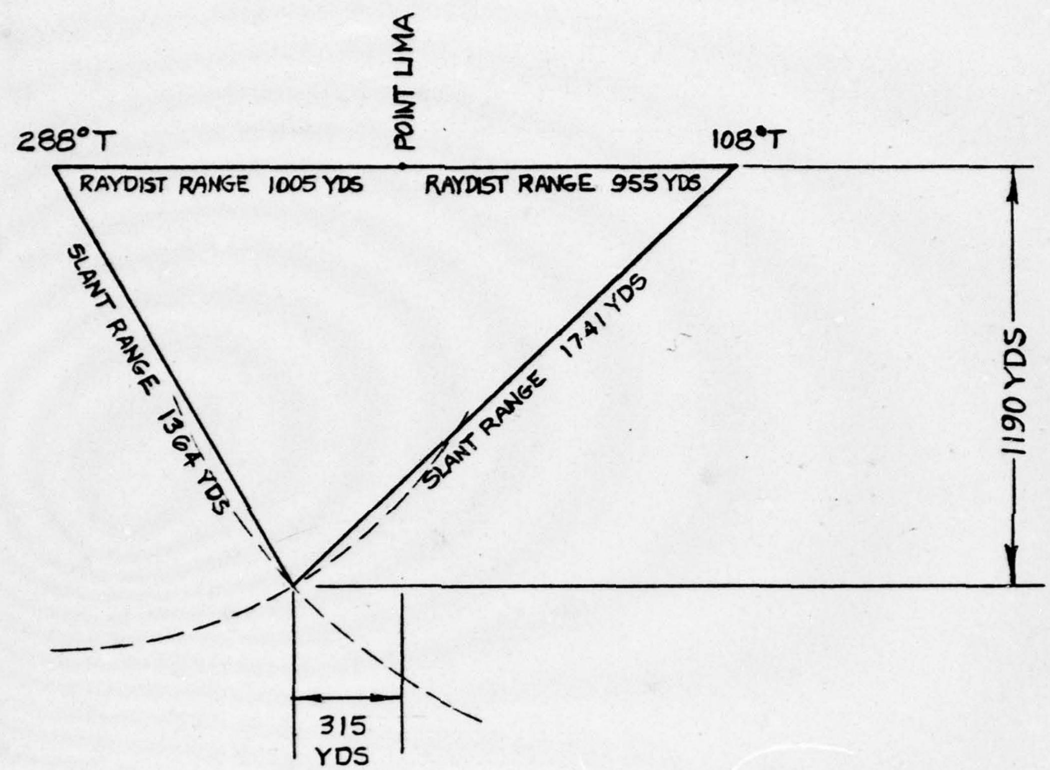


MODULE IS DISPLACED 315 YARDS
ALONG BEARING 288°T

MODULE DEPTH IS 1190 YDS

LOCATION Nº 4

DETERMINATION OF MODULE DEPTH
AND DISPLACEMENT FROM 1000
YARD RADIUS CIRCLE OF 26 SEPT '60

15 FEB 1961

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FIGURE 4

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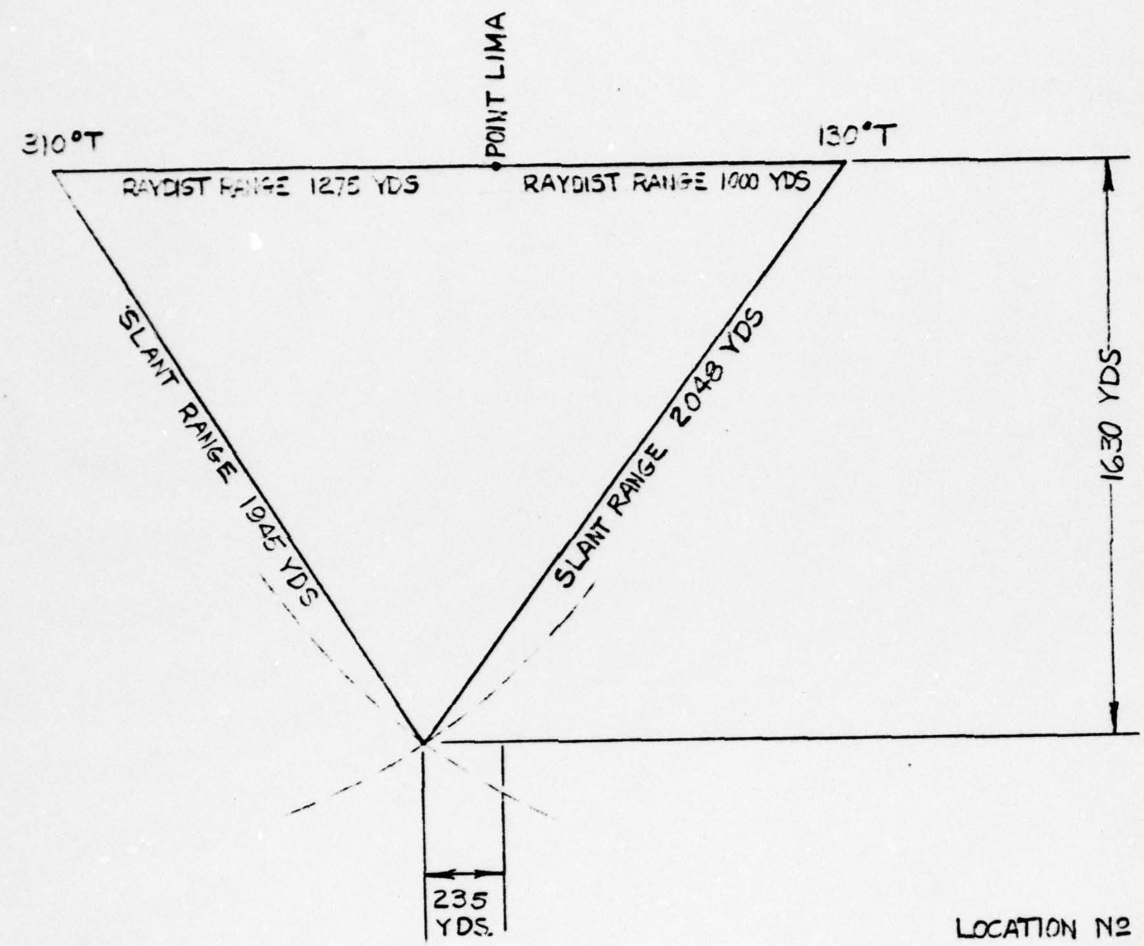


MODULE IS DISPLACED 235 YARDS
ALONG BEARING 310°T

MODULE DEPTH IS 1630 YARDS

LOCATION Nº 5
DETERMINATION OF MODULE DEPTH
AND DISPLACEMENT FROM 1000 YD.
RADIUS CIRCLE OF 14 OCT 1960
16 FEB 1961

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FIGURE 5

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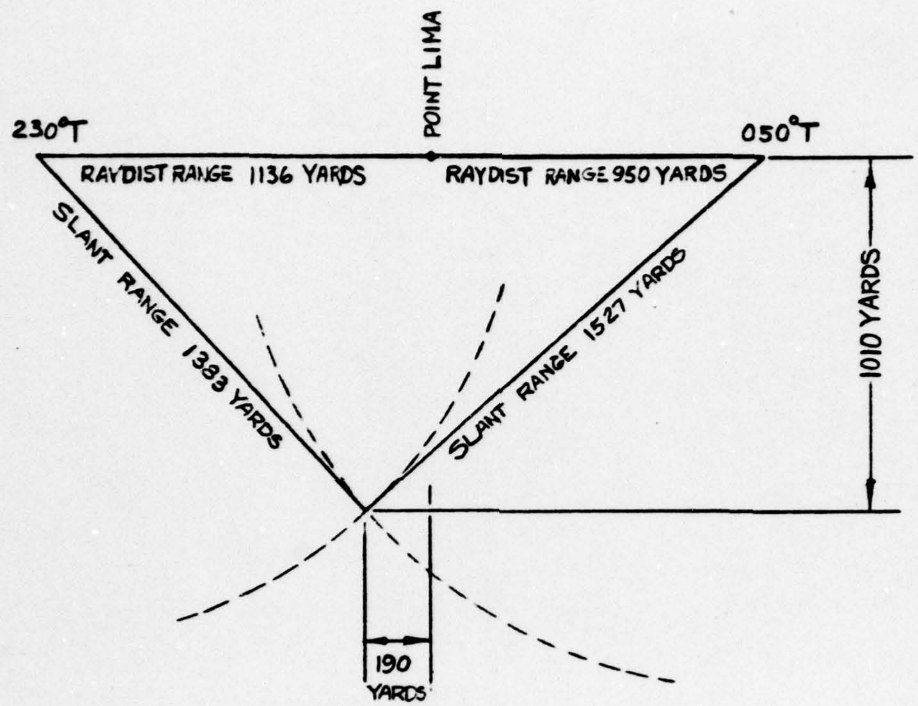


MODULE IS DISPLACED 190 YARDS
ALONG BEARING 230°T

MODULE DEPTH IS 1010 YARDS

LOCATION Nº 6
DETERMINATION OF MODULE DEPTH AND
DISPLACEMENT FROM 1000 YARD
RADIUS CIRCLE OF 30 SEPT 1960
16 FEB 1961

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FIGURE 6

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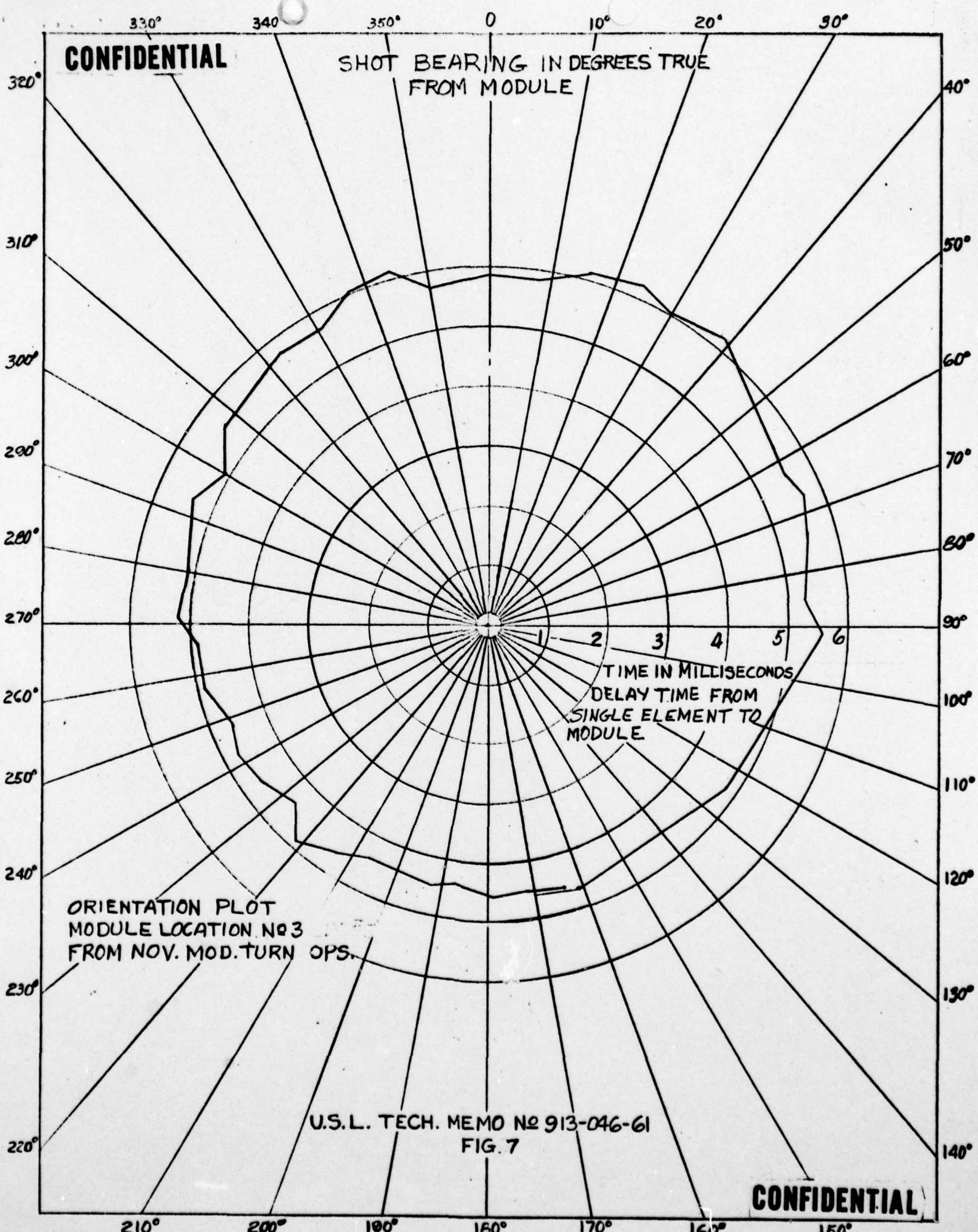


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FIG. 7

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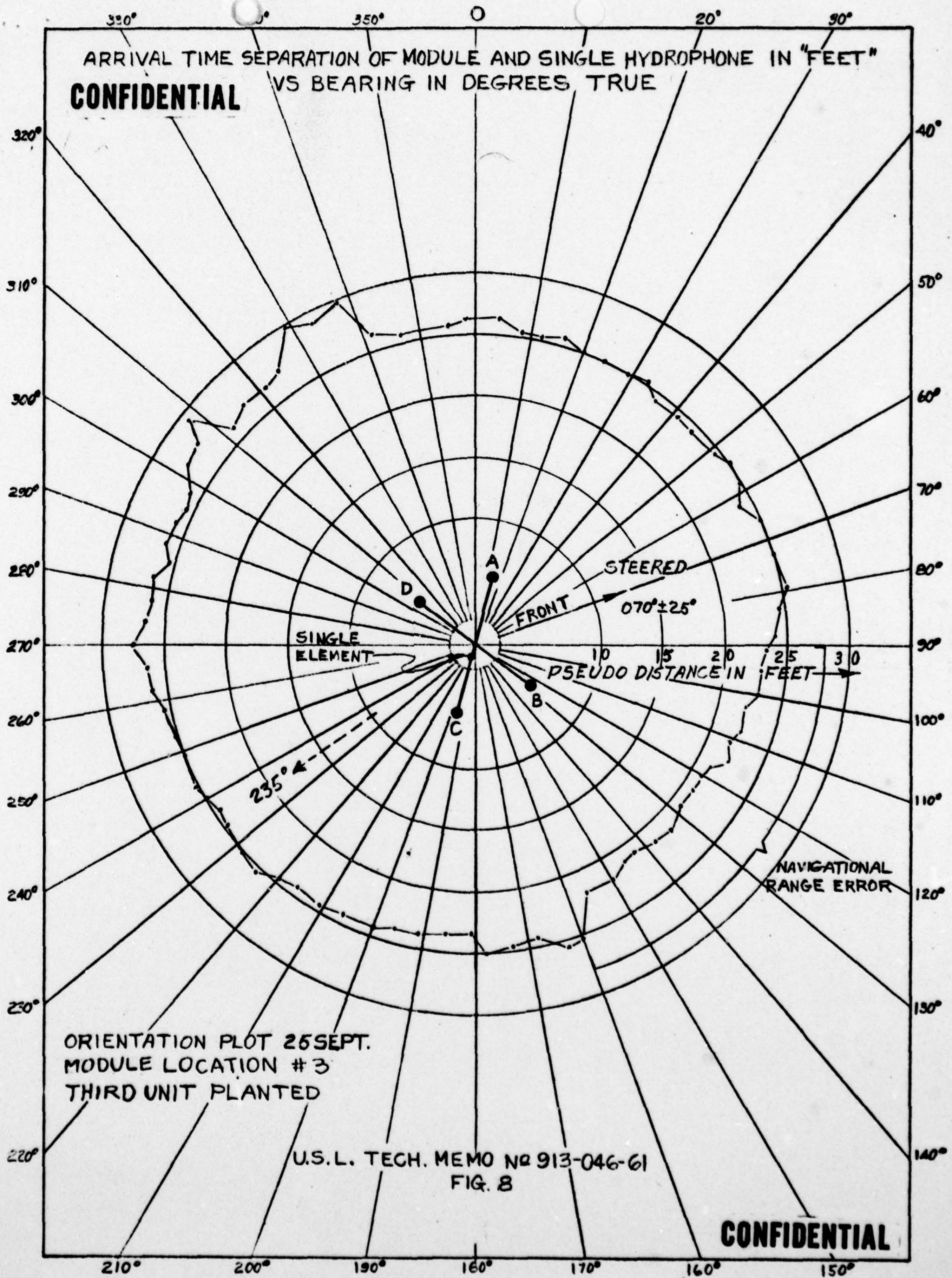


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FIG. 8

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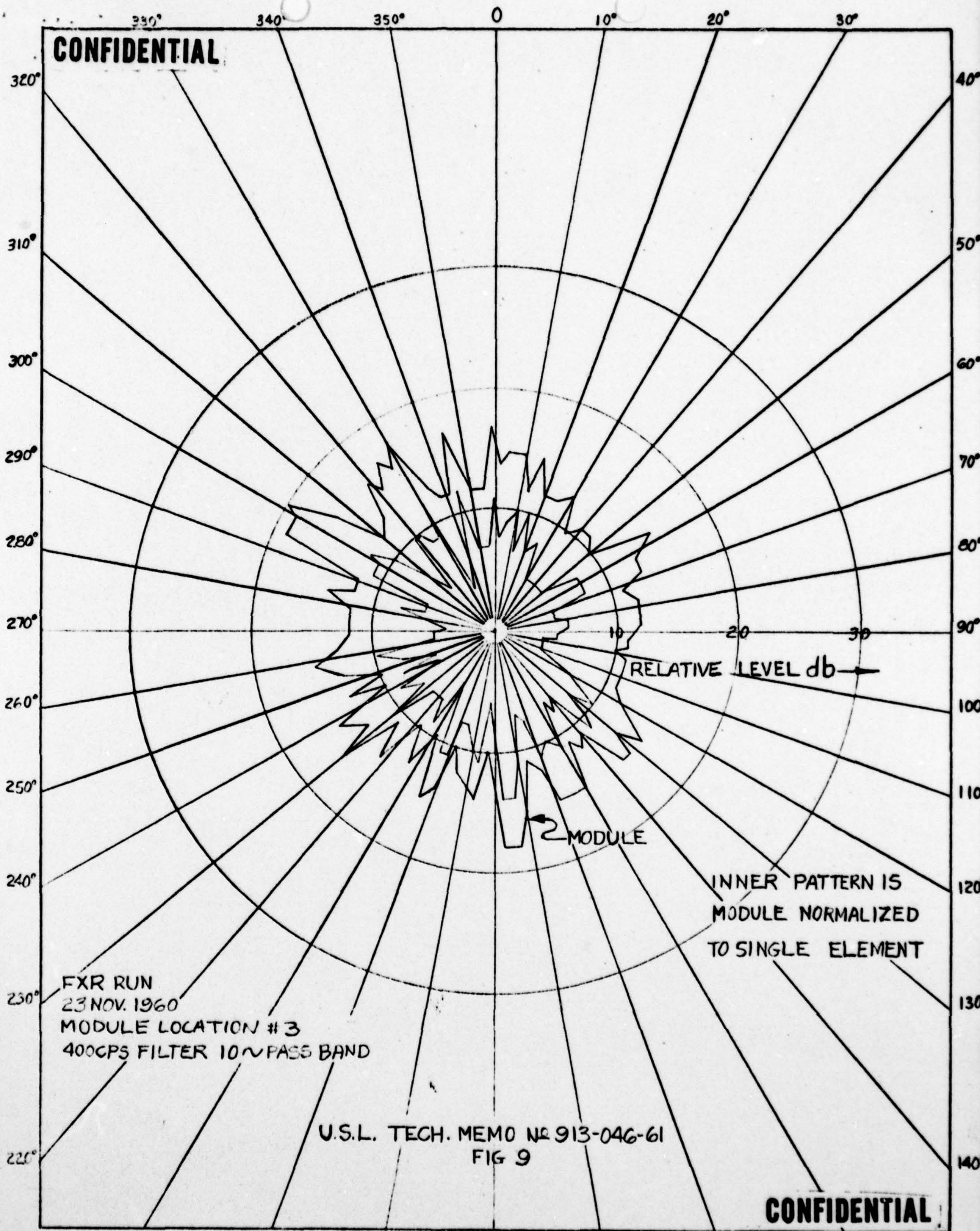


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FIG 9

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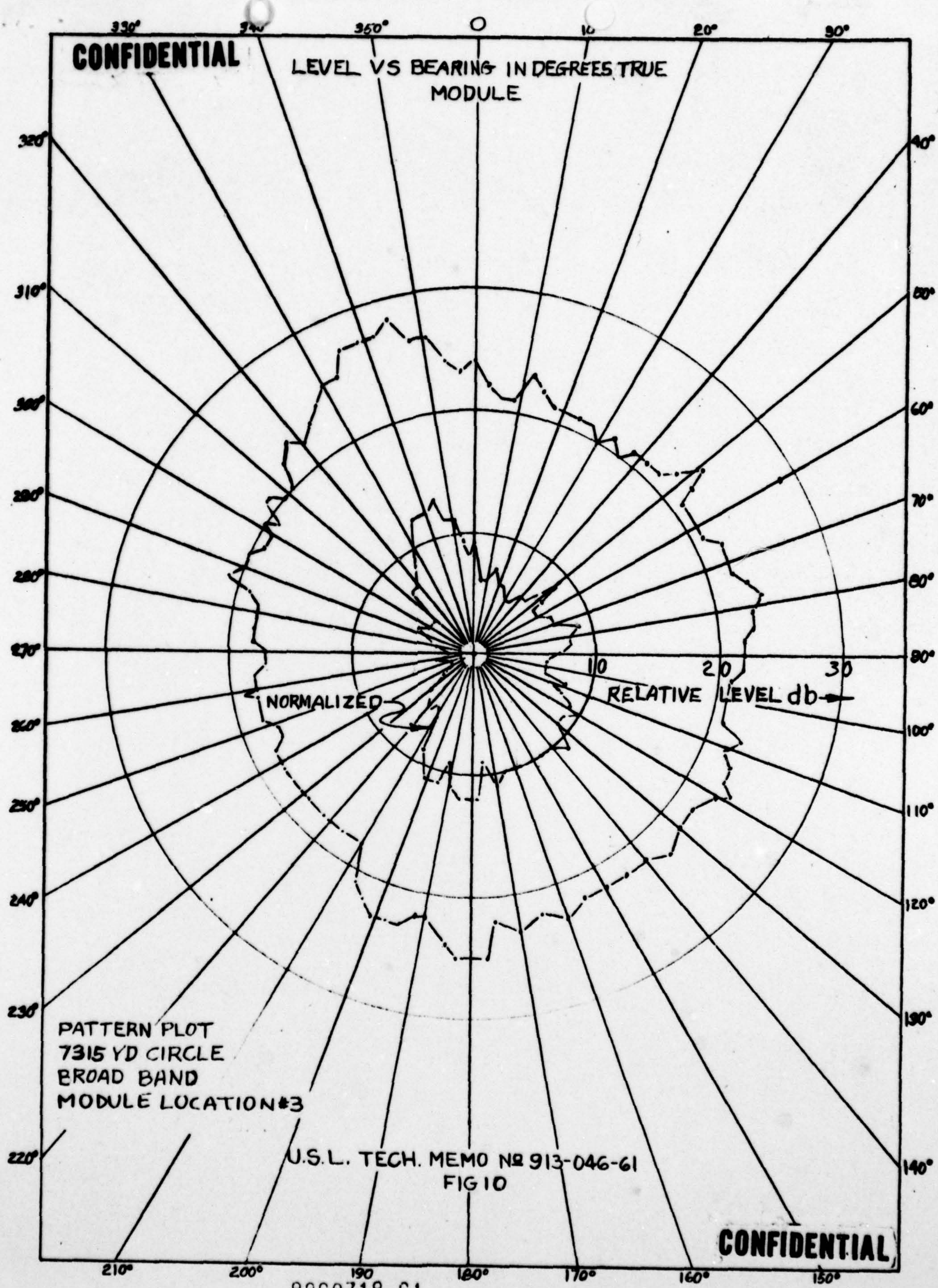


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FIG 10

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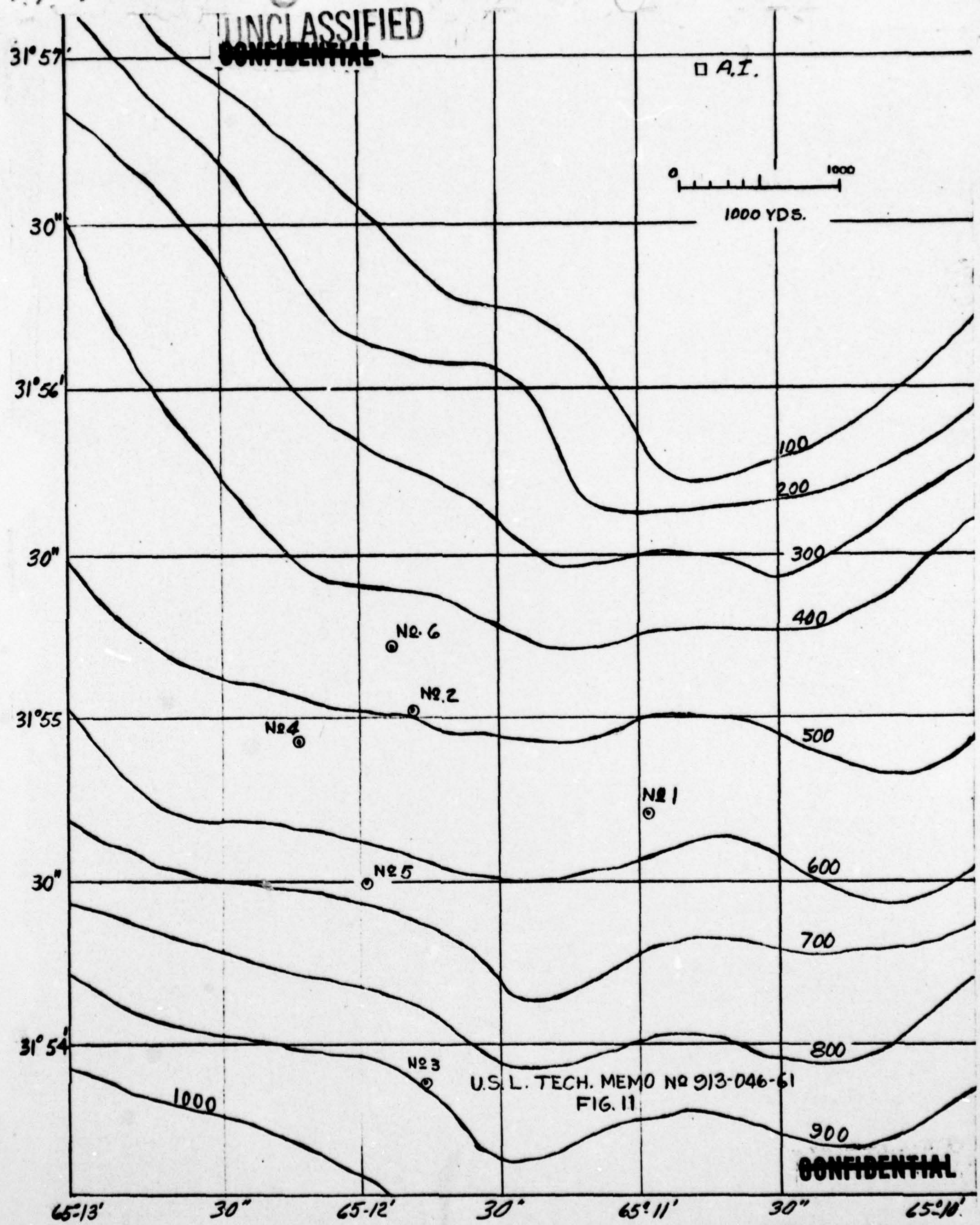


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FIG. 11

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