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SHIP-SHORE DIVISION - CENTIMETER WAVE SECTION

30 November 1945

MORTAR LOCATION BY MARINE CORPS RADAR

Lt. (jg) R. R. Crane

- Report R-2652 -

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Preliminary Pages ... a-d
Numbered Pages 14
Tables 4
Plates 25
Appendices 2

NRL Problem S1146 T-S

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ABSTRACT

Radar equipments operating on L, S, and X frequency bands were tested for suitability for use as mortar locators. The L-band radar was the Mark 20 Mod. 2, the S-band radar was the SO-7M, and the X-band radar was the SO-12M. These three were found suitable for adaptation as mortar locators. The tests were made at ranges up to 12,000 yards and under conditions simulating as closely as possible battle conditions. Mortar shells of 60 and 81 mm. diameters were fired at various angles of departure. The larger shells presented better targets and the higher angles of departure gave better target pick-up above land return. Vertical polarization of the radar beam was found to be slightly better than horizontal polarization on the basis of echo strength. The beam shape, pulse width and range and bearing indication of these three radars were such that the order of accuracy was the SO-12M, SO-7M, and the Mk.20 Mod.2. Also, the beam shape produced sharper cut off above land return in the same order. The maximum range on mortar shells for the SO-12M and the SO-7M was approximately double the range for the Mk 20 Mod. 2. The SO-7M presentation was clearer and the signal strength greater than the SO-12M at the longer ranges. In other desirable features of a mortar locator, with one exception (see below), the three equipments were about the same. Considering overall performance, the SO-12M and the SO-7M were about equally suited for mortar location and were more suitable than the Mk. 20 Mod. 2. If emphasis is placed on operation through rain and foliage the Mark 20 Mod. 2 was better than the SO-12M and the SO-7M.

CONTENTS

TABLES AND PLATES

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INTRODUCTION

1. The purpose of the problem of Reference (a) was to test the suitability of L-, S-, and X-band radar equipments for detection of mortar shells. The addition to the problem, as outlined in Appendix 3., gave the procedure to be used in more detail and also expanded the scope of the original problem for the purpose of laying the groundwork for design of a future mortar locator.

2. Tests were conducted at Quantico, Virginia. Twelve radar locations were used, spotted around one mortar position. A total of 54 tests were run, and an average of 10 to 15 mortar shells were fired per test run.

3. The L-band radars used were the Mark 20 Mod 1 and a simulated Mark 20 Mod 2 obtained by modifying the Mark 20 Mod 1. The S-band radar used was the SO-7M, and the X-band radar used was the SO-12M.

4. The SO-7M and the SO-12M were modified before the tests as follows: (See Plates 11 through 18 and 23 and 24).

(a) In order to make it possible to rotate the antenna reflector through 90 degrees so that the long dimension would be vertical, a shaft was welded at right angles with the existing shaft. The new shaft was made approximately one foot longer, but had the same outside diameter so that it could fit into the pedestal. The difference in lengths was necessary since the reflector is two feet higher than wide. The reflector was braced to the shaft to maintain sufficient rigidity.

(b) The original waveguide was cut, and a piece approximately one foot long was inserted to bring the nozzle of the waveguide to the centerline of the parabola. When it was desired to obtain vertical polarization a new piece of waveguide with a 90 degree twist could be inserted.

5. The systems were carefully tuned, and the sensitivities of the systems were periodically checked by echo signal strength of distant aircraft throughout the test. It was found necessary that the sensitivity of the systems be at the optimum value to insure detecting the mortar shell with the radars.

6. Data was collected to obtain information on the following factors:

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(a) Effect of radar site and of trees.

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(b) Effect of weather.

(c) Mortar shell trajectories.

(d) Types of mortar shell.

(e) Position and shape of radar beam for maximum accuracy and for optimum signal return.

(f) Polarization of radar beam.

(g) Maximum ranges of radars.

(h) Accuracy of radars in spotting the mortar.

(i) Technique.

DESCRIPTION OF TESTS.

7. Position #0 - 250 yards. (See Plates 1, 2, 3, and 21). The three radars were situated on a slight incline surrounded by trees and bushes, but with an open view to the mortar site and to the path of the mortar shell. The shell was above the horizon for about one-half its flight. Preliminary tests were made at this site. They were of short duration (2 hours) and unsatisfactory for all three radars; in the case of the Mark 20 Mod 1 because of its minimum range of 1500 yards, while the SO-7M and SO-12M were unsatisfactory because of land clutter. It is possible that this land clutter might have been eliminated by adjusting the antenna elevation angle, but the method later employed of adjusting the antenna pedestal jack to elevate the antenna was not then known. This radar position was considered impractical in view of the radar mortar locator's tactical use.

8. Position #1 - 2,150 yards. The three radars were situated on a hill sloping down toward the mortar. About 250 yards away, on a line toward the mortar, was a fringe of trees which obstructed the initial path of the mortar shell trajectory. There were no other obstructions to the radar beam along this path, with the exception that initially the SO-12M was situated so that a tree, 200 yards distant and projecting through the radar beam, was directly in the line of sight to the mortar. Signals were weak but definite. The SO-12M was moved in order to have a clear beam path, and the results improved distinctly.

9. At this site all three radars picked up the shells, but the SO-7M and the SO-12M were unsatisfactory until a method to elevate the antenna by adjusting the antenna elevation jack was discovered. Trials were made with both horizontal and vertical polarization on all three equipments, and with the long dimension of the antenna in both the vertical and the horizontal position on the SO-7M and the SO-12M. It was necessary to place a wire screen over the antenna reflector to insure that it would reflect equally well when the beam was either vertically or horizontally polarized. (See Plate 20). This was due to the fact that the reflecting surface is, normally, metal slats running parallel to the longer dimension of the antenna dish. The metal screen was later discarded, as described in paragraph 21.

10. With the long dimension of the antenna in the horizontal position and using horizontal polarization (normal position and polarization), no mortar shells were picked up on the SO-7M and SO-12M. There was excessive land clutter which could not be eliminated by increasing the antenna elevation angle. This position of the antenna was not used again.

11. With the long dimension of the antenna in the vertical position and using vertical polarization, results were fairly satisfactory but no quantitative data were taken. The SO-7M performed better than with the long dimension vertical and using horizontal polarization, but the performance of the SO-12M was approximately the same under both conditions.

12. Position #2 - 1840 yards. The three radars were situated on a hill 500 yards from the nearest trees along the path to the mortar site. The mortar shell trajectory was above the horizon by approximately 300 yards at the maximum.

13. Only the SO-12M picked up the target at this site, due, it is believed to its narrow beam angle in the vertical and horizontal plane. The beam was sufficiently narrow to minimize ground clutter while operating at an elevation angle low enough to pick up the mortar shell. Various antenna elevation angles and both types of polarization were tried with all three radars.

14. Position #3 - 4800 yards. The radars were situated on the down slope of a hill with respect to the mortar site. There was a direct line of sight to the mortar

[redacted]

position, but the up slope of the hill at that time and the fairly high horizon behind the mortar caused such strong land return that the mortar shell echo was blanked out. No radar picked up an indication of the target. Both vertical and horizontal polarization were used with various antenna elevation angles. Land echoes were strong on all three equipments.

15. Position #4 - 3100 yards. The radars were situated on a slight hill about 500 yards from the nearest trees in the direction of the mortar site. At that range the trees projected about 30 feet above the antenna height. Mortar shells cleared the horizon by approximately 600 yards at normal mortar elevation.

16. No quantitative tests were carried out at this position since there was no cummunication, and also because it had been decided that only information obtained with the mortar firing at the radars, within a plus or minus 20 degrees azimuth would be useful, i.e., sufficiently close to actual battle conditions. This direction of mortar fire was not obtained in this position nor in positions # 0, 1, and 2, but was obtained in position #3. The mortar shell presents a different reflecting surface at different azimuths. Position #5 and following positions were chosen to satisfy this condition, i.e., with the mortar firing at the radars within a plus or minus 20 degrees azimuth. Some shells were fired and picked up clearly by all the radars at position #4.

17. Position #5 - 2500 yards. The radars were situated on a hill about 300 yards from the nearest trees in the direction of the mortar site. About two-thirds of the trajectory of the mortar shell at a normal firing angle was above the intervening terrain, and the mortar shell maximum ordinate was approximately 400 yards above the horizon.

18. The Mark 20 Mod 1 was modified by temporary additions to resemble effectively the Mark 20 Mod 2, i.e., a sector scan and an off-center PPI were installed. The Mod 2 of the Mark 20 was designed specifically to adapt this equipment for use as an intermin mortar locator. Tests were continued using the Mark 20 Mod 2 and the SO-7M and SO-12M. These three equipments were used for the remainder of the tests.

19. The results were fair at this site for the SO-12M and the Mark 20 Mod 2. The SO-7M was blanked out by a strong land return which could not be eliminated. The SO-12M was

[redacted]

free from this strong land return by virtue of its narrow beam in the vertical plane, which permitted adjusting its antenna angle so that the radar beam would pass above the land yet low enough to pick up the mortar shell. A strong land return with the Mark 20 Mod. 2 was avoided by increasing the antenna elevation angle, while the high power provided sufficient sensitivity to detect the shells with the receiver sensitivity reduced. With these adjustments the mortar shell could be clearly seen on the off-center PPI. However, the echo itself was more clearly defined on the SO-12M than on the Mark 20 Mod. 2.

20. Position #6 - 4100 yards. The radars were situated at the base of a slight incline with respect to the mortar. The rise to the base of the trees which were about 200 yards away was 30 mils; the rise to the top of the trees was about 40 mils (readings taken from the antenna height). This site was chosen with more attention to radar characteristics than any of the earlier sites. Calculations made by Mr. W. T. Rea of Bell Telephone Laboratories to determine the ideal site for the Mark 20 Mod 2, utilizing the reflected land wave as well as the direct return, indicate that the ideal site is a 10 mil rise over bush or prairie land, i.e., a contour presenting a smooth surface to L-band frequencies and continuing for at least 200 yards in the mortar site direction. This site actually had a 40 mil rise in 350 feet from the base of the radars.

21. The mortar shell was picked up under varied conditions of mortar fire angle, and with both 81 mm and 60 mm shells. Horizontal polarization was used, but again the change from vertical polarization was not noticeable for the SO-7M and SO-12M. The Mark 20 Mod 2 signals, as measured roughly on the A-scope, showed a 3 db drop when using horizontal instead of vertical polarization. The wire screens on the SO-7M and SO-12M previously mentioned in paragraph 9 were removed to determine whether they had introduced any appreciable loss. This removal was possible because it was decided to use vertical polarization exclusively for the remainder of the tests, since it was found slightly better than horizontal polarization. With the wire screens removed the signal strength of the mortar shell did not improve noticeably, but it was noticed that for both the SO-7M and the SO-12M, especially the latter, the time during which the mortar shell echo was seen on the scope decreased. Apparently the screens had to some extent widened the beams.

22. The interval of time from the mortar shell firing

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to the first pick-up on the Mark 20 Mod 2 was measured. The minimum time was about 3.5 seconds. At a later date at this same position this time was measured for the SO-7M and the SO-12M. In addition the time of the second pick-up. i.e., the signal return from the mortar shell as it drops back down through the radar beam, was measured. The time that the shell was in the radar beam, was estimated for the SO-7M, but for the SO-12M this time was too short, usually the shell being picked up on only 1 or 2 sweeps. A comparison of these results can be seen in Table 4 and Plates 4, 5 and 6.

23. The antenna pedestal, elevation jack burred and jammed. This was partly caused by the method of adjusting the antenna elevation angle, which places an additional strain on the jack. This was corrected by re-grinding the bearing joint, placing a steel washer at the base of the joint, and using graphite as a lubricant.

24. The Mark 20 Mod 2 was placed behind leafy foliage about 8 feet thick and 5 to 10 feet from the antenna. The effect on the operation was found to be negligible, by clearing away the foliage and continuing the tests. At a later date the SO-7M and SO-12M were set up behind similar foliage, and the mortar shell could not be picked up at all. (See Plate 22)

25. Two days' tests were carried out at this position with the Mark 20 Mod 2. On the last day of the tests the SO-7M and SO-12M were returned to this site and tested further. The results were very satisfactory, and from them several plots were made. (See Plates 4 through 10). These latter tests utilized all the experience gained in three weeks' practice, as well as a good radar site.

26. In these tests with the SO-7M and SO-12M, a technique for picking up the mortar shell using sector scan and then stopping on the "up-pip" or "down-pip" in bearing and watching for the echo to come in was used. It was found satisfactory and a definite improvement over continuous sector scanning which tires the operator and also causes the mortar shell echo to appear at different positions in its trajectory. Using this method on the SO-12M and the SO-7M, the "up-pip" was always clear and easily distinguishable. On the SO-12M the "down-pip" was occasionally picked up when on the "up-pip" bearing. On the SO-7M the echo could be seen moving down the sweep as the shell progressed toward the radar. (See Plates 4 through 10).

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27. A definite effort was made with both the SO-7M and the SO-12M to determine the best antenna elevation and the lowest elevation angle at which the mortar shell could be picked up. The results are listed in Plates 4, 5 and 6.

28. Position #7 - 1900 yards. The radars were situated on a hill in an open clearing. There were trees about 500 yards away on another ridge in the direction of the mortar site, rising about 60 mils above the antenna level. Tests were made at this location both in the clearing and behind trees. The Mark 20 Mod 2 did not operate due to maintenance faults.

29. In the open the SO-7M operated slightly better than the SO-12M, with respect to signal strength. Both radars observed H. E. shells bursting on a ridge close by. The echo from the burst was distinct, and particles could be seen flying in all directions.

30. The radars were moved behind a fringe of trees about 50 to 75 feet away and projecting 30 to 50 feet above the radar antennas. Sky could be seen through the trees although the fringe was several trees deep. The SO-7M could still pick up the mortar shell, but the echo was definitely weaker. The SO-12M could not pick up the shell at all.

31. Position #8 - 6850 yards. The radars were situated in an open space with very little masking. The radars were over 1000 yards away from the closest trees. At this range the Mark 20 Mod 2 did not pick up any shells, while the SO-7M and SO-12M performed satisfactorily. It appeared that the Mark 20 Mod 2 had reached its maximum range. Signal strength on the SO-7M and the SO-12M was good.

32. Position #9 - 9100 yards. The radars were situated in an open plain about 600 yards from a high hill in the mortar site direction. The hill had about a 5 mil rise above the SO-7M and SO-12M antennas.

33. The results were satisfactory on the SO-7M and the SO-12M, but the Mark 20 Mod 2 did not pick up the mortar shell. The results were not quantitative since there was no communication. The shell echo on the SO-7M was picked up on the 20 mile scale and came in clearly. The signal on the SO-12M was comparatively weak, but still definite. The fact that any echoes were picked up is remarkable since there was

a 50 mil mask, and the range was 9100 yards. However, the shells were fired at a maximum ordinate, rising approximately 1000 yards, and cleared the mask. Both radars operated with approximately 120 mil antenna elevation angle, it having been determined that this angle gave optimum signal return. (No accurate instrument was available to measure this angle at this site. An inclinometer was used at other sites.)

34. Position # 10 - 12000 yards. The SO-7M and the SO-12M were situated in an open clearing and 200 yards from trees which formed a 30 mil mask. Mark20 Mod 2 was situated at the base of a 20 mil incline about 200 yards in length bordered by trees. The mortar shells reached well above the horizon. There was no communication, and since the Mark 20 Mod 2 had picked up no shells at 6800 and 9000 yards, these positions were chosen to provide a closer range of about 5000 yards for the Mark 20 while tests were continued at 12000 yards on the SO-7M and SO-12M.

35. The SO-7M and SO-12M were able to pick up scattered echoes. Because of the lack of communication, the results were not quantitative. The very weak return on the SO-7M and the SO-12M indicated that 12000 yards is approximately their maximum range. The echoes were so weak as to be of no practical value. The SO-7M again had the clearer presentation.

36. Position #11 - 5150 yards. The radars were situated in a clearing. Three hundred yards away in the direction of the mortar site was a fringe of trees about 50 feet high. Results were satisfactory for all three radars. The SO-12M had maintenance trouble with its mechanical antenna drive which was corrected. Times of first pick-up of the shell were taken, and were very similar to the results recorded in Table 4.

37. Tests were made in a rain storm. The rain began about 1500 as the three radars were operating in one test. All three radars were picking up the target satisfactorily prior to the rain. The rain storm varied from very heavy rain and gusts of wind, through medium or light rain, to a drizzle, and stopped, passing through each stage evenly in time, and lasting about 40 minutes. Rounds were fired during each stage. The gain was cut down in all radars to eliminate rain clutter as much as possible.

38. The Mark 20 Mod 2 performed well in all rain conditions except for the first five minutes when, it is

[redacted]

believed, ionization of the rain drops caused the saturation noise noted. Echoes were seen through heavy rain satisfactorily. The SO-7M picked up scattered echoes during the light rain drizzle, Also, with rain between the radar and the mortar but not encompassing the mortar shell, the shell was picked up in a medium rain. The SO-12M was unable to pick up the target at any time during the rain.

39. The experimental data, Tables 1, 2, 3, give a fair indication of the test results. Only on the last two days of testing, 6 July and 9 July, were the tests conducted mainly from the standpoint of picking up targets. At other times experimentation with antenna elevation angle, poor slighting-in, or inexperienced observers caused the number of picked-up targets to be small with relation to the number of rounds fired.

ANALYSIS OF TESTS

40. The radar site should be chosen bearing these facts in mind:

(a) The antenna beam width in the vertical plane should be known, with S- and X-band equipments the antenna angle should be such that the lower edge of the antenna beam at the half-power point will clear by about 10 mils the highest intervening mask.

(b) The approximate range and bearing from the target should be known, so that the mask to the radar beam will not be so high as to render the radar useless.

(c) A masking effect that cuts out strong land return but does not prevent the radar from picking up the mortar shell fairly low down in its trajectory is ideal; for example, about a 30 mil mask in 300 yards and at a range of 4000 yards from the mortar.

(d) Defilade will not affect the radar operation if conditions (a), (b) and (c) are remembered.

(e) Only the L-band equipment gains much by choosing a site to utilize the reflected wave. An ideal site for L-band radars is one which gives about a 10 mil rise and presents a fairly smooth surface to that frequency, for example, sand, bush, etc.

[redacted]

(f) Foliage does not interfere appreciably with L-band (this does not include tree trunks). S- and X-band equipment will not work through heavy foliage. All three equipments will operate fairly well at short ranges through thin foliage. Thus some thin non-metallic camouflage placed over the radars would be permissable.

41. The Mark 20 Mod 2 will operate in any weather. The SO-7M, will operate fairly well through a drizzle or light rain. The SO-12M will not operate through rain.

42. The mortar shell trajectory has little effect on signal return. Its major effect is simply that if a low angle of fire is used, the mortar shell will be farther from the mortar when it rises into the radar beam and is detected. If the trajectory is very flat, the shell might not be detected at all. (See Appendix 2). The geometry of mortar location must be clearly understood by the mortar locator crew captain.

43. The types of mortar shells have the obvious effect of increasing or decreasing the signal return for larger or smaller shells except when the size of the shell is near 2, or less. The type mainly used in these tests was the M43 Training or H. E. (81 mm), which is smaller than the average Jap mortar shell and much smaller than the largest Jap mortar shell in use. (a 320mm projectile.) (See Plate 25).

44. As previously stated, the shape in space of the radar beam should be clearly held in mind by the operators. They should remember that the lowest antenna elevation angle at which the target may be picked up is the best for optimum accuracy, but that the best angle for signal return is usually higher. The radar beam should be aimed well above the mask, and moved down in reasonable increments until the lowest angle has been reached, if time permits. The radars should be pointing approximately at the mortar site to facilitate adjustment of the antenna angle.

45. For SO-7M and SO-12M, the problem of polarization was not solved except to indicate that both horizontal and vertical polarization gave about the same results. The Mark 20 Mod 2 tests indicated that vertical polarization was slightly better on L-band. It is believed from other tests that the type of polarization has a greater effect with lower frequencies.

46. (a) The maximum range on the SO-7M and SO-12M was

approximately 10,000 yards. Strong echoes were received on the SO-7M, at 9100 yards, with weaker but still definite echoes received on the SO-12M at this range. At 12,000 yards, both the SO-7M and SO-12M again picked up occasional echoes from the mortar shells but too weak to guarantee pick-up under battle conditions.

(b) The maximum range on the Mark 20 Mod 2 was approximately 6000 yards on 81 mm mortars. The Mark 20 Mod 2 used in these tests was a temporary field modification of the Mark 20 Mod 1. However, since an "A" scope was available, this range was considered fairly conclusive.

47. There are a series of errors which affect the accuracy with which radars can locate mortars. In these tests all errors were not equally emphasized and consequently the actual results are not conclusive; however, Plates 4, 5 and 6 give the results of one day's tests. The actual error is due mainly to "sighting-in" error, since other results are consistent and the major apparent error lies in the poor bearing indication.

(a) Error #1 - Radar Error: This is the range and bearing error inherent in a particular radar. From systems-test work this error for the SO-7M and SO-12M is approximately plus or minus 200 yards in range and plus or minus 1 degree in bearing.

(b) Error # 2 - Sighting-in Error: This is the error developed in the process of locating the radar site and bearing indication with respect to a definite reference; for example, an accurate map. It depends upon the expertness of the survey team used and/or the compass installed on the radar itself. The alignment is between the radar and mortar or artillery it governs.

(c) Error #3 - Variable Range Error: This is the error introduced by the estimate from pick-up position of the height at which the mortar shell is picked up with respect to the earth beneath it. If a mean angle, for example, 65 degrees, were assumed for the mortar elevation angle, this error would vary as the mortar elevation differed from 65 degrees. This error could be decreased by experienced mortar men aiding at the radar.

(d) Error #4 - Variable Bearing Error: This

[redacted]

error is also a result of the estimate of the height at which the mortar shell is picked up. It can be decreased to a very small amount if the up and down pips are picked up for the same mortar shell, and if this is done repeatedly.

48. A technique (for two or more men) for picking up the mortar shell, after a plausible site has been chosen is:

(a) Knowing approximately the mortar location, i.e., range ± 1000 yards - bearing ± 15 degrees, estimate the height of the mask presented and set the antenna elevation angle to clear the mask by about 10 mils.

(b) After the gear has warmed up, sector scan through the 30 degrees within which the mortar is located until a pip is picked up. If none is picked up, increase the sector scanned and alter the antenna angle as described in paragraph 24. When a target is picked up, sector scan over it and obtain its range and bearing.

(c) Stop sector scanning on the bearing of the up pip. Get accurate range information in this position.

(d) Sector scan again and search for the down pip and/or mortar burst, utilizing any information of sector being shelled, etc.

(e) If firing continues, return to the up-pip point and, as described in Paragraph 24, ascertain the lowest point at which the mortar shell can be picked up. Using the antenna elevation angle, known radar beam width and target range from the radar, a good approximation of the mortar shell height at this point may be made.

(f) Knowing the mortar shell height, range and bearing, and considering the target of the mortar, possible mortar sites and intervening terrian, drop a line from this height to the earth at an estimated mortar firing angle and position the mortar. Another method of finally getting on the target is: If friendly fire can be identified, adjust the fall of the friendly fire so that it coincides with the observed position of the enemy shell on the scope. This latter method has been very effective in the field, expecially with equipments having a large probable error, of the order of ± 200 yards.

49. Some desirable qualities of a mortar locator are:

[redacted]

(a) An overall radar accuracy of the order of 0.5 percent in range; plus or minus 2.5 mils in bearing; and plus or minus 3 mils in elevation.

(b) A minimum dependable range, under all conditions, of 5000 yards.

(c) Radar information which will give the most accurate position of the enemy mortar in the fastest and simplest way.

(d) Since the lowest height at which the mortar shell can be detected directly affects the ultimate accuracy of the mortar locator the radar beam should be as close to the intervening terrain as possible. Consequently good discrimination against land targets is needed, possibly MTI or a narrow beam. A method for discrimination against other moving targets is also needed.

(e) (d) suggests another quality immediately, that is the adaptability of the system for ground target search.

(f) A simple and precise method for orientation of the radar.

(g) Ease of operation is emphasized, since the equipment may be operated under fire where a complicated operating technique would be impossible.

(h) Because of the tactical uses of the Marine Corp troops, (attack and high mobility) the unit must have high mobility. It must be easily installed and re-installed and it must be light weight, air transportable and pack transportable.

(i) These tactical uses also imply that the equipment be even more sturdy and more weather-proof than in previous designs.

(j) The system must possess certain safety features to protect the operating personnel as much as possible. The mortar locator radar will be vulnerable to enemy attack and easily spotted because of the nature of microwave propogation and the close range to the enemy at which the radar must be situated. Separation of the antenna and controls has already been used; it permits the operating

[redacted]

personnel to dig in some distance from the antenna.

50. There are three fundamental problems involved in obtaining the qualities listed. They are: frequency, beam shape, and polarization.

(a) The best frequencies, excluding weather and foliage consideration, would be X-band or higher. Including weather and foliage, some compromise point between L-band and S-band would be desirable; or two frequencies, an L-band and K-band. The K-band equipment could satisfy the majority of the desirable qualities much better than the L-band.

(b) The beam would narrow in the vertical plane and in the horizontal plane to have sufficiently accurate bearing and elevation indication. Two beams, forming a "V" in the vertical plane, separated by a constant elevation and sector scanned rapidly together, (as in the Army's TPQ-2) might be used. The narrow beam is also advantageous in discriminating against other targets.

(c) The radar beam polarization should be adjustable. Vertical polarization is better for mortar detection, but this advantage decreases with an increase of frequency; at X-band little advantage is apparent. It is reported, however, that land targets can be more easily picked up with horizontal polarization, for this seems to give less land return while still picking up the target.

REFERENCE:

(a) BuShips ltr S-S67-5(919) Ser. S-002624/8Fc5 of 9 June 1945 to Director NRL (Secretary Radio Problem Prioirties Board)

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APPENDIX

1. An addition to the SO-7M of a scetor scanning mechanism was tried after field tests were completed. A simple mechanical system added to the antenna switch allows the radar to scan through a sector of thirty degrees. A gear reduction motor was mounted on a bracket to the side of the indicator case. A flywheel on the motor shaft was attached to a crank which operated the antenna control switch on the indicator panel. The crank threw the switch alternately clockwise and counterclockwise. A list of the parts necessary is - induction motor with gear reducer, 110 V AC, output speed 36 rpm; a bracket for supporting motor; flywheel; crank adjustable to correct for drift; and a switch. (See Plate 19).

2. Paragraph #42 does not mean to imply that the aspect of the mortar shell with respect to the radar source does not affect power reflected by the shell. Investigation by other research groups has indicated that a variation in excess of 20 db (inflected power) may be experienced as an 81 mm M43 mortar shell aspect is changed and if the frequency of the radar is such that $\lambda/2$ is appreciably less than the diameter of the shell.

3. <u>Tests at Quantico</u>

The addition to this problem as listed by Major Hazel USMC at Quantico, Virginia, June 20, 1945 follows:

(a) Set up radars (SO-7M, SO-12M and Mark 20 Mod 1) and mortar battery to simulate as closely as possible combat conditions; i.e. with mortar shells approaching radar in trajectories whose planes make angles with line of observation of minimum safe values up to forty-five (45) degrees.

(b) Conduct tests at ranges up to 10,000 yards, if possible.

(c) Use 81 mm mortars for most of the tests, as this is closest to widely used enemy mortars, but include sufficient data with 60 mm mortars to make comparisons.

(d) Vary angle of elevation of mortars as follows:
1 Tests at 45 degrees.
2 Tests at 65 degrees.
3 Tests at 85 degrees.

[redacted]

(e) Make a few tests with SO-7M and SO-12M horizontally polarized. If these confirm previous observations that vertical polarization is better, collect remaining data with latter polarization.

(f) With vertical polarization on SO-7M and SO-12M make tests as follows:

1) With long dimension of antenna horizontal (using screen over reflector - smoothed out in comparison with $1/4\ \lambda$)

2) With long dimension of antenna vertical (remove screen to get undistorted beam unless experience shows this is negligible)

(g) Tests should be made with all three equipments during wide varieties of weather conditions including rain. Careful records should be kept with sufficient data to compare the equipments' operation under these varying conditions.

(h) Maintain vigilant check of comparative performance of the three equipments on aircraft targets so that data on mortars can be properly interpreted.

Test	Posi-tion	Date 1945	Diam. of Shell mm.	Type	El. Angle	Mag. Azi-muth	Range of Shell Approx.
1	1	6/21	81	M43T	55.75	230	550 yds.
2	"	"	81	M43T	65	230	1,125
3	"	"	81	M43T	74.5	230	775
4	"	"	81	M43T	65	230	1,125
5	"	"	81	M43T	74.5	230	775
6	2	6/22	60/80	T/M43T	57.5	230	550/700
7	"	"	81/60	M43T/T	74.5	230	775
8	"	"	81/60	T/T	74.5	230	1,120
9	"	"	60/81	T/M43T	57.5	230	550/700
10	3	6/25	81	M43T	65	230	775
11	"	"	81	M43T	65	230	1,120
12	"	"	81	M43T	78.75	190	550
13	"	"	81	M43T	78.75	190	550
14	5	6/27	81	M43T	74.5	226	775
15	"	"	81	M43T	74.5	226	775
16	"	"	81	M43T	74.5	226	775
17	6	6/28	81	M43T	74.5	241.5	750
18	"	"	81	M43T	85	241.5	200
19	"	"	81	M43H.E.	74	241.5	800
20	"	"	81	M43T	74	241.5	750
21	"	"	81	M43H.E.	65.75	220	400
22	"	"	81	M43T	65.75	220	400
23	6	6/29	81	M43T	74.5	240	750
24	"	"	81	M43T	65	240	400
25	"	"	60	T	74.5	240	750
26	"	"	60	T	65	240	1000
27	7	7/2	81	M43H.E.	74.5	230	800
28	"	"	81	M43H.E.	74.5	230	800
29	"	"	81	M43H.E.	65	230	400
30	"	"	81	H.E./T	74.5	230	800/750
31	8	7/3	81	M43T	74.5	240	750
32	"	"	81	M43T	65	240	1050
33	"	"	81	M43T	85	240	250
34	"	"	81	M43H.E.	74.5	240	525
35	"	"	60	H.E.	82.5	240	600
36	"	"	81	M43T	84.5	240	450
37	9	7/4	81	M43T	84.5	240	450
38	"	"	81	M43T	84.5	240	450
39	"	"	81	T/H.E.	74.5	151	750/800
40	"	"	60	T	80	151	300
41	10	7/5	81	M56	74.5	157	800
42	"	"	81	M43T	84.5	157	450
43	"	"	81	M43H.E.	74.5	157	750
44	"	"	60	H.E.	84.5	157	600
45	"	"	81	M43H.E.	74.5	157	525
46	"	"	60	,H.E.	74.5	157	400
47	11	7/6	81	M43H.E.	84.5	224	525
48	"	"	60	T	84.5	224	450
49	"	"	81	M43H.E.	74.5	224	800
50	"	"	60	T	74.5	224	700
51	"	"	60	T	84.5	240	550
	6	7/9	81	M56H.E.	74.5	245	800
	"	"	81	M43T	65	245	1150
	"	"	81	M56	74.5	245	800

DECLASSIFIED

60 mm H.E. - H.E.M83A1
60 mm T - TM69

Fired	Up	Dn	Up	Dn	Up	Dn	Up	Dn	Up	Dn	Up	Dn	Vert.	Hori.
10	-	3	8	2	4	5	-	4	4	4	3	3	*	
10	6	3	10	8	7	3	3.5	2.5	4	4	3	3	*	
10	6	10	10	10	6	2	1.5	4.2	4	4	3	3	*	
10	10	5	8	2	-	-	3.5	3.0	2.5	2.5	-	-		*
10	9	10	7	9	9	9	3.5	4.5	2.5	2.5	4	4		*
5/5	1	3	-	-	-	-	2	2	-	-	-	-		*
10/5	-	2	-	-	-	-	-	2	-	-	-	-		*
10/5	-	1	-	3	-	-	-	1	-	1	-	-	*	
15	12	-	-	-	-	-	2.2	-	-	-	-	-	*	
10	-	-	-	-	-	-	-	-	-	-	-	-	*	
5	-	-	-	-	-	-	-	-	-	-	-	-		*
5	-	-	-	-	-	-	-	-	-	-	-	-		*
5	-	-	-	-	-	-	-	-	-	-	-	-	*	
10	5	-	-	-	-	-	1.8	-	-	-	-	-	*	
10	2	-	-	-	3	1	1.8	-	-	-	3.5	3.5	*	
10	1	-	-	-	8	8	1	-	-	-	2	2	*	
10	1	2	-	2	10	10	1	1	-	1	3.5	3.5	*	
10	10	5	-	8	10	10	1.8	1.5	-	3	3	3	*	
10	3	5	6	-	10	10	1	1.2	2.5	-	3	3	*	
10	1	11	-	-	10	10	1.1	1.2	-	-	1.5	1.5		*
10	-	-	10	2	-	-	-	-	2.5	1.3	-	-	*	
10	4	3	10	-	-	-	1.2	1.2	3.5	-	-	-	*	
10	1	7	8	7	9	9	1.5	1.5	4	4	2.5	2.5	*	
10	out	out	8	8	out	out	-	-	4	3.5	-	-	*	
10	out	out	9	8	out	out	-	-	3	2.5	-	-	*	
10	out	out	9	9	out	out	-	-	3	3	-	-	*	
10	2	-	10	-	out	out	1	-	3	-	-	-	*	
10	10	9	10	6	out	out	1.5	1.5	4	3.5	-	-	*	
5	5	5	5	5	out	out	2	2	4	4	-	-	*	
10/5	3	3	8	7	out	out	1.5	1.2	3	2.5	-	-	*	
10	2	-	9	-	-	-	1	-	1	-	-	-	*	
10	-	-	10	-	-	-	-	-	1	-	-	-	*	
10	9	9	7	-	-	-	3	3.2	2	-	-	-	*	
10	6	9	10	-	-	-	1	2	2	-	-	-	*	
10	3	5	8	3	-	-	2	2	2	2	-	-	*	
10	9	9	10	9	-	-	2	2	2.5	2.5	-	-	*	
30	11	7	8	-	-	-	2.5	3	4	0	-	-	*	
30	5	4	15	-	-	-	2.5	3	4	-	-	-	*	
5/5	-	-	2	-	-	-	-	-	3	-	-	-	*	
5	-	-	2	-	-	-	-	-	1	-	-	-	*	
10	c	c	c	c	c	c	2	2	2	2	2	2	*	
15	c	c	c	c	c	c	2	2	2	2	2	2	*	
15	c	c	c	c	c	c	2	2	2	2	2	2	*	
15	n.o	n.o	n.o	n.o	n.o	n.o	-	-	-	-	-	-	*	
30	n.o	n.o	n.o	n.o	n.o	n.o	-	-	-	-	-	-	*	
30	n.o	n.o	n.o	n.o	n.o	n.o	-	-	-	-	-	-	*	
7	out	out	7	7	7	-	-	-	5	2.5	3	-	*	
13	out	out	12	11	12	12	-	-	4	2.5	3	3	*	
12	out	out	12	12	10	10	-	-	4.2	4.2	3	3	*	
14	10	7	1	7	9	9	2.5	2.8	2	2.5	3	3	*	
24	-	-	3	2	20	20	-	-	2	2.5	2.5	2.5	*	
19	18	13	19	19	-	-	3.5	3.5	4	4	-	-	*	
23	16	19	23	23	-	-	2	2	4	4	-	-	*	
10	-	-	-	-	-	-	-	-	-	-	-	-	*	

Shells Picked Out
Out -- Out of order
n.o. - Not Operating
c - contact but no definite number
n.d. - No data

Signal Strength
Strong Signal - 5
Medium Signal - 3
Weak Signal - 1

Ant. Pol.
For SO-7M and SO-12M only

Test	12M Up	12M Dn	7M Up	7M Dn	MK20 Up	MK20 Dn	12M Up	12M Dn	7M Up	7M Dn	MK20 Up	MK20 Dn	Range of Mortar	Bearing of Mortar
1	-	2500	2200	2200	2700	2700	-	273	280	280	265	275	2150	260
2	2200	2400	2500	2500	2700	2700	272	264	260	260	265	275	"	"
3	2200	2400	2200	2200	2700	2700	270	264	274	260	265	270	"	"
4	2200	2400	2150	2150	-	-	270	264	272	272	-	-	"	"
5	2200	2500	2250	2500	2600	2600	271	262	265	272	262	260	"	"
6	1700	1850	-	-	-	-	169	172	-	-	-	-	1840	170
7	-	1950	-	-	-	-	-	174	-	-	-	-	"	"
8	-	1950	-	2100	-	-	-	174	-	176	-	-	"	"
9	1650	-	-	-	-	-	168	-	-	-	-	-	"	"
10	-	-	-	-	-	-	-	-	-	-	-	-	4800	020
11	-	-	-	-	-	-	-	-	-	-	-	-	"	"
12	-	-	-	-	-	-	-	-	-	-	-	-	"	"
13	-	-	-	-	-	-	-	-	-	-	-	-	"	"
14	2600	-	-	-	-	-	53	-	-	-	-	-	2500	038
15	2600	-	-	-	2250	1650	53	-	-	-	n d	n d	"	"
16	2600	-	-	-	2250	1650	53	-	-	-	n d	n d	"	"
17	4000	3900	-	4000	3950	3930	60	72	-	73	n d	n d	4100	062
18	4100	4100	-	4100	n d	n d	75	73	-	70	n d	n d	"	"
19	4000	3500	4000	-	3420	4000	70	70	70	-	n d	n d	"	"
20	4000	3500	-	-	n d	n d	700	70	-	-	n d	n d	"	"
21	-	-	4000	2900	-	-	-	-	70	74	-	-	"	"
22	4200	4000	4000	-	-	-	70	70	70	-	-	-	"	"
23	4000	3800	4000	3800	-	-	80	80	73	73	n d	n d	"	"
24	-	-	4000	3500	-	-	-	-	72	73	-	-	"	"
25	-	-	4000	3800	-	-	-	-	72	72	-	-	"	"
26	-	-	4000	3600	-	-	-	-	72	72	-	-	"	"
27	1100	-	1900	-	-	-	70	-	59	-	-	-	1900	051
28	1950	1800	1850	1250	-	-	70	68	60	62	-	--	"	"
29	1200	1200	1850	1200	-	-	74	72	60	66	-	-	"	"
30	1200	1200	1850	1500	-	-	74	72	60	62	-	-	"	"
31	6600	-	6600	-	-	-	67	-	71	-	-	-	6850	060
32	-	-	6600	-	-	-	67	67	71	-	-	-	"	"
33	6800	6700	6650	-	-	-	72	73	-	-	-	-	"	"
34	6800	6600	6700	-	-	-	72	74	71	-	-	-	"	"
35	6800	6600	6800	6600	-	-	72	73	71	71	-	-	"	"
36	6800	6600	6800	6600	-	-	72	73.5	71	71	-	-	"	"
37	9000	8900	9200	-	-	-	331	332	329	-	-	-	9100	321
38	9200	8900	9200	-	-	-	331	332	328	-	-	-	"	"
39	-	-	9500	-	-	-	-	-	328	-	-	-	"	"
40	-	-	9100	-	-	-	-	-	329	-	-	-	"	"
41	-	-	-	-	-	-	-	-	-	-	-	-	1200	329
42	-	-	-	-	-	-	-	-	-	-	-	-	"	"
43	-	-	-	-	-	-	-	-	-	-	-	-	"	"
44	-	-	-	-	-	-	-	-	-	-	-	-	"	"
45	-	-	-	-	-	-	-	-	-	-	-	-	"	"
46	-	-	-	-	-	-	-	-	-	-	-	-	"	"
47	out	out	5200	4900	5300	-	out	out	63	63	-	-	5150	053
48	out	out	5200	4950	-	-	out	out	63	63	-	-	"	"
49	out	out	5200	4550	-	4780	out	out	62	63	-	-	"	"
50	5200	4700	5200	4500	-	-	63	64	62	63	-	-	"	"
51	-	-	-	-	-	-	-	-	-	-	-	-	"	"
52	4115	3800	4080	3885	-	-	71	72	66	68	-	-	4100	062
53	4070	3540	4100	3565	-	-	71	72	68	70	-	-	"	"
54	-	-	-	-	-	-	-	-	-	-	-	-		

out - Out of order
n d - No data

Table 4 Timing Results

TEST	ROUND	SO-12M Time secs. up	SO-12M Time secs. down	SO-12M Ant. El. ∠ ⌀	SO-7M Time secs. up	SO-7M Time secs. down	SO-7M Ant. El. ∠ ⌀	Mk 20 - Mod 2 Time secs. up	Mk 20 - Mod 2 Time secs. down	Mk 20 - Mod 2 Ant. El. ∠ ⌀
49	1						140	3		120
	2				6-11		140	3	15-20	120
	3				5-11	12-16	140	3.2/	21-23	150
	4				3-9		140	2	17-21	150
	5				4-10	10-15	140		21 1/2	150
	6				5-11	25-30	130	8.5	20 1/2	150
	7				3-9	25-30	130	5		150
	8				3-9	20-24	130			150
	9				6-13	24-29	130	1.8		150
	10				6-13	22-26	130	6		150
	11				5-12	25-30	130			150
	12				5-10	20-25	130			150
52	1			60			130			
	2			60			130			
	3			60			150			
	4	3.5		60			130			
	5		23.5	45			130			
	6	3.5	24.5	50			120			
	7	3.5	24.0	66			130			
	8	3.5	24.5	78	4.5	19.5	130			
	9	4.5	23.5	78	3.5	15.5	130			

At this same site, Pos. #6, Mk 20 Mod 2, had a min. Time of pick up ≅ 3.5 sec. Ant. El.∠ ≅ 150 ⌀

Av. P. U. Time ≅ 4.5 sec.
Av. A. E.∠ ≅ 165⌀
(Test 19)

[redacted]

Table 4 (Cont'd)
Timing Results

TEST	ROUND	SO-12M Time secs. up	SO-12M Time secs. down	SO-12M Ant. El. ∠ ø	SO-7M Time secs. up	SO-7M Time secs. down	SO-7M Ant. El. ∠ ø	Mk 20 - Mod 2 Time secs. up	Mk 20 - Mod 2 Time secs. down	Mk 20 - Mod 2 Ant. El. ∠ ø
52	10	5.5	22.5	88	2.0	19.5	130	as before		
	11	4.5	21.5	100	3.3	22.5	135			
	12	5.5	24.5	100	2.5	27.5	135			
	13	2.5	23.5	60	3.5	21.5	135			
	14	2.1	23.5	55	3.5	22.5	135			
	15	3.0	23.5	55	5.5	27.5	135			
	16			75	3.0	21.5	135			
	17	1.5	24.5	75			135			
	18	2.6		75	3.5	18.5	135			
	19	2.5		75	3.1	19.6	135			
	20	3.5		75	2.5	18.5	135			
53	1	4.5	19.5	97			130			
	2		21.5	97	4.1	16.5	130			
	3		19.5	97	3.5	16.5	130			
	4	5.3	16.5	120	3.5	16.5	130			
	5	4.5	16.5	110	3.7	16.7	130			
	6	4.0	16.5	100	4.0	17.0	130			
	7	3.0	16.5	90	3.4	16.0	130			
	8		13.5	80	4.0	16.5	130			

Table 4 (Cont'd)
Timing Results

TEST	ROUND	SO-12M Time secs. up	SO-12M Time secs. down	SO-12M A. E. ∠ ø	SO-7M Time sec. up	SO-7M Time sec. down	SO-7M A. E. ∠ ø	Mk 20 Mod 2 Time sec up	Mk 20 Mod 2 Time sec down	Mk 20 Mod 2 A. E. ∠ ø
	9	2.5	17.7	80	4.2	17.0	130	As before		
	10	2.1	17.5	70	3.5	16.0	130			
	11	2.3		60	4.5	17.5	130			
	12			50	4.0	16.5	130			
	13			50	3.5	14.5	130			
	14	2.4	17.5	70	3.5	15.5	130			
	15	4.7	17.5	70	3.5	17.5	130			
	16			70			130			
	17	2.3	18.0	70			130			
	18	2.7	18.5	60	2.0	15.5	130			
	19	3.5		50	2.7	13.0	130			
	20	1.5	16.5	60			130			

[redacted]

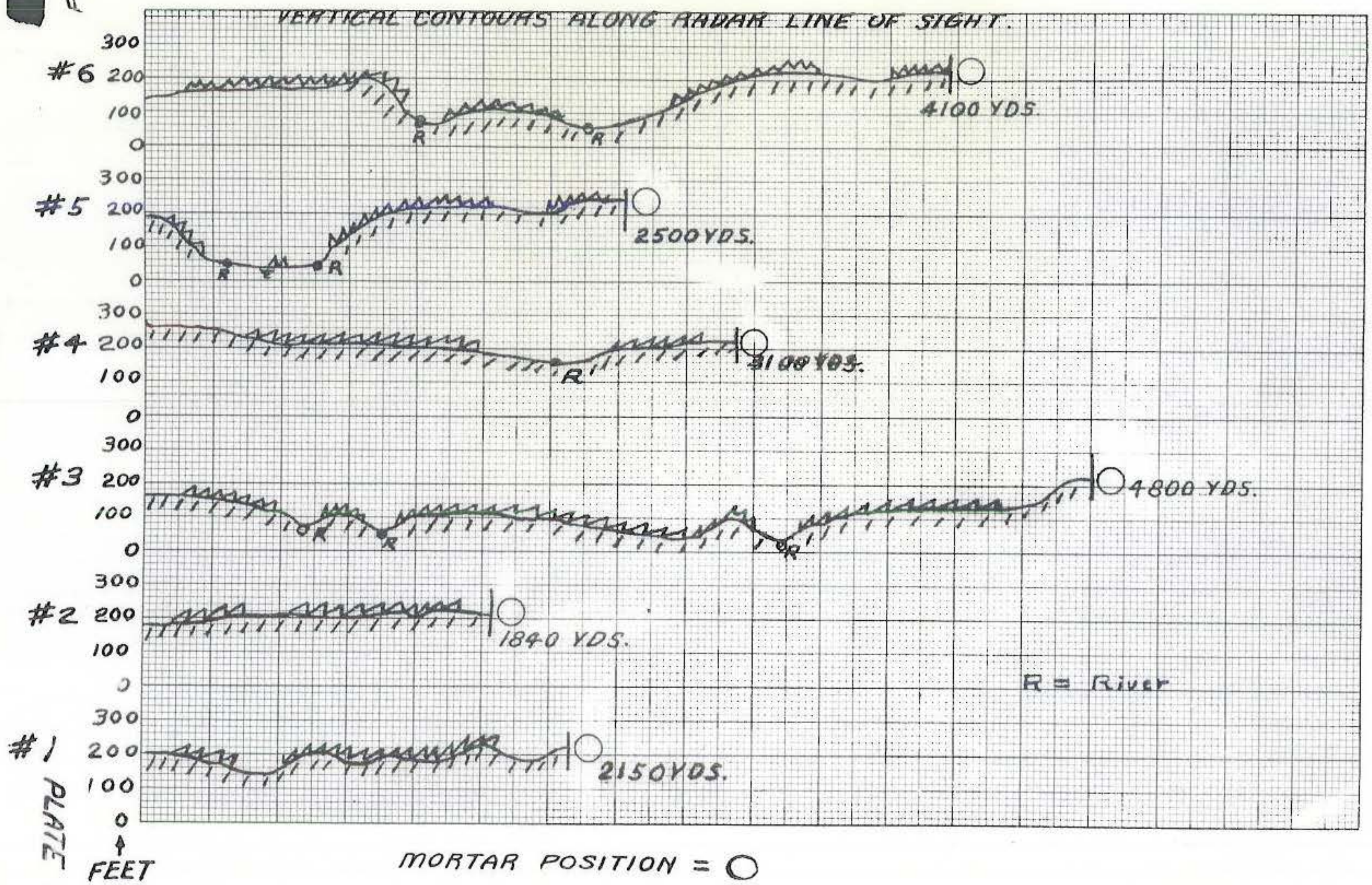

VERTICAL CONTOURS ALONG RADAR LINE OF SIGHT.
#6
#5
#4
#3
#2
#1
300
200
100
0
FEET
R
4100 YDS.
2500 YDS.
3100 YDS.
4800 YDS.
1840 YDS.
2150 YDS.
R = River
MORTAR POSITION = ○

PLATE 1

[redacted]

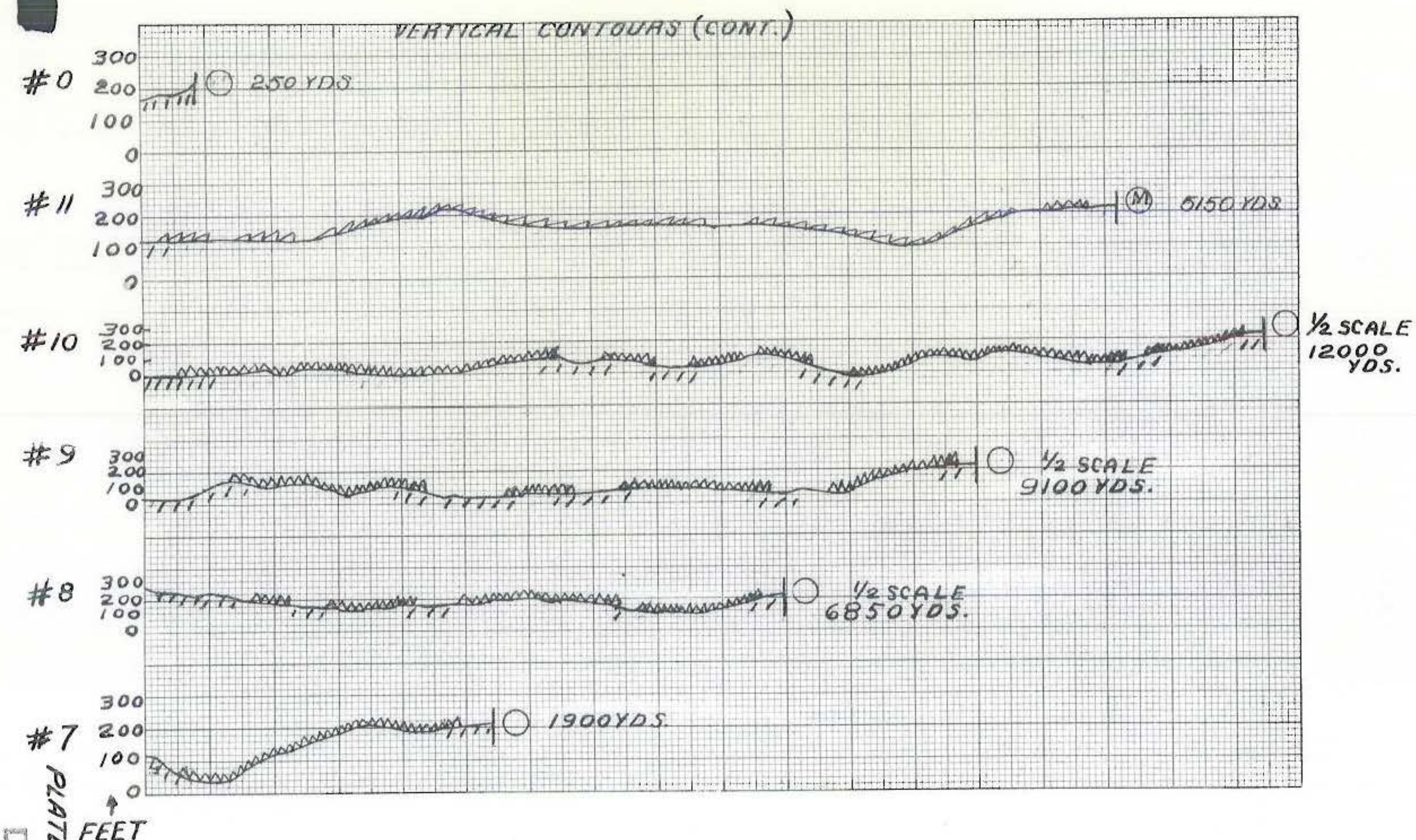
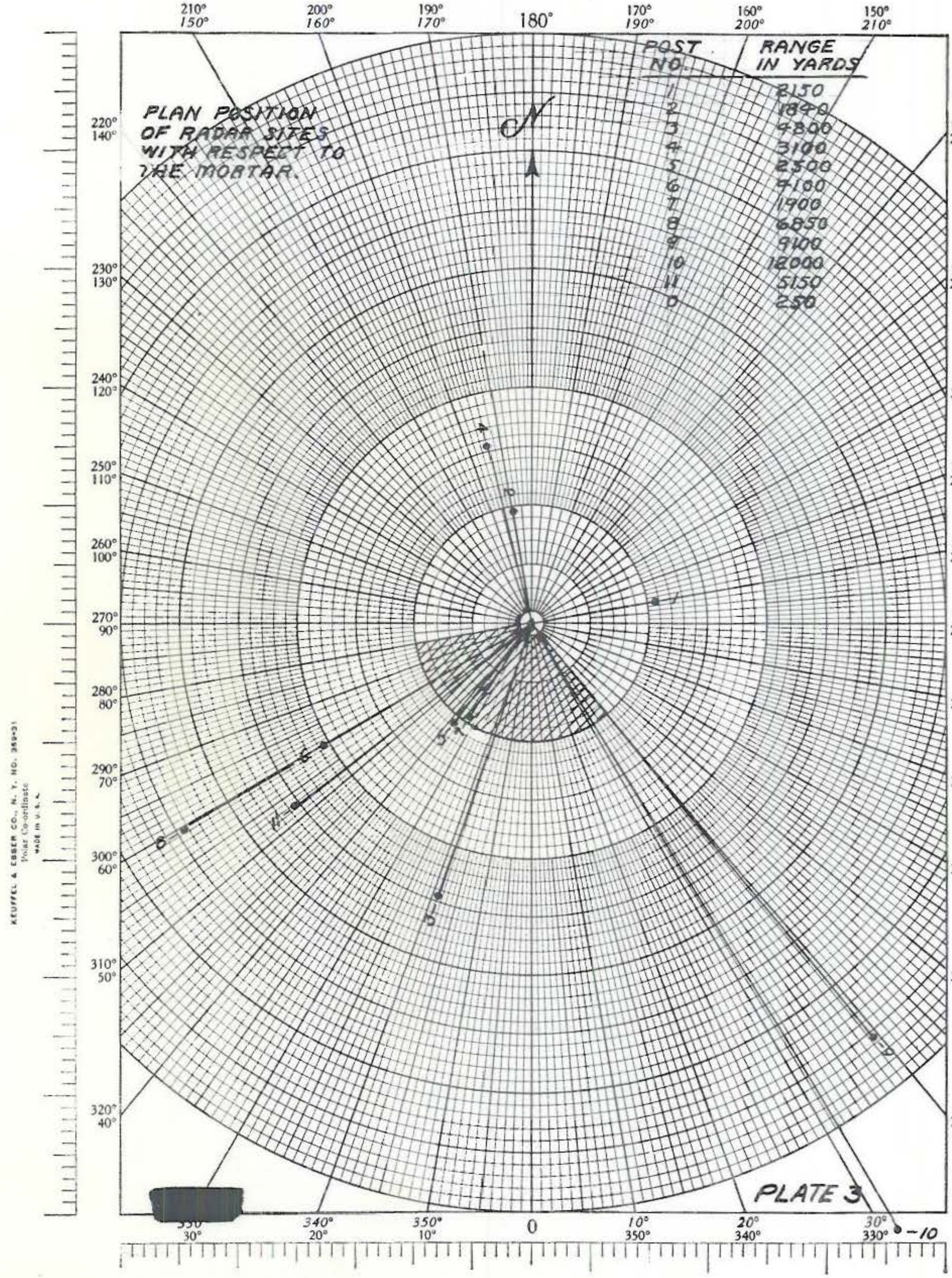


PLATE 2

DECLASSIFIED


PLAN POSITION
OF RADAR SITES
WITH RESPECT TO
THE MORTAR.
POST NO.
RANGE IN YARDS
1 2150
2 1840
3 4800
4 3100
5 2500
6 4100
7 1900
8 6850
9 9100
10 12000
11 5150
0 250
N
180°
0
PLATE 3
KEUFFEL & ESSER CO., N. Y. NO. 358-21
Polar Co-ordinate
MADE IN U.S.A.

RADAR BEAM PLOT POS. #6
So-12m TEST 53

TIME 1st PICK UP ≅ 2 SEC. (SECTOR SCAN)
MAX. RANGE = 4070 YDS.

TIME 2nd PICKUP ≅ 18 SEC.
MIN. RANGE = 3540 YDS.

NOTE: CALCULATION OF MORTOR SHELL POSITION AS INDICATED BY 1, 2, 3 SEC., ETC. WAS MADE WITH OUT CONSIDERING ANY EFFECT BUT GRAVITY.

VERTICAL $S = t(V \sin\theta) - \frac{1}{2} g t^2$

HORIZ. $S = t(V \cos\theta)$

t = TIME (SEC.)

V = VEL. (ft/sec.)

$g = 32\ ft/sec.^2$

LEGEND:
LOWEST BEAM POS. FOR ECHO = 70 ⊕
BEST BEAM POS. FOR ECHO = 100 ⊕
1½° BEAM WIDTH IN VERTICAL

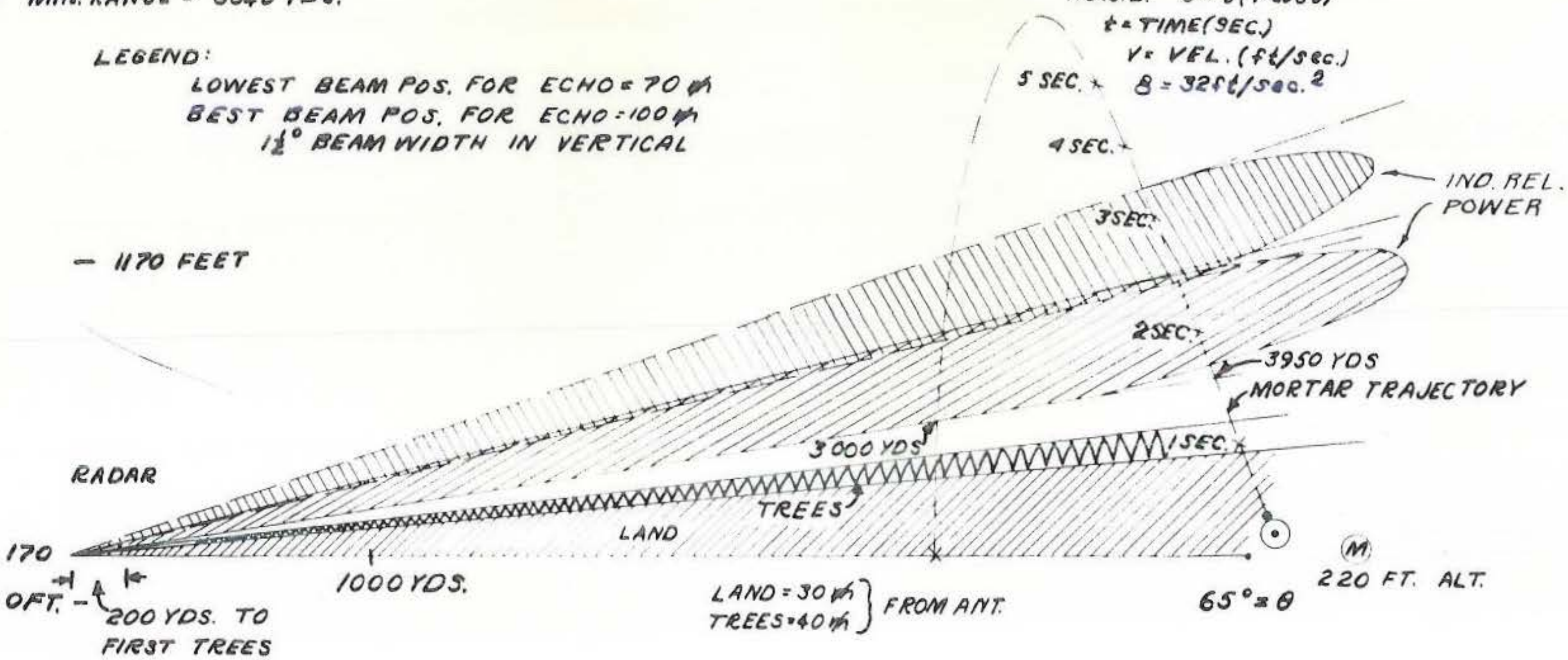


PLATE 4

[redacted]

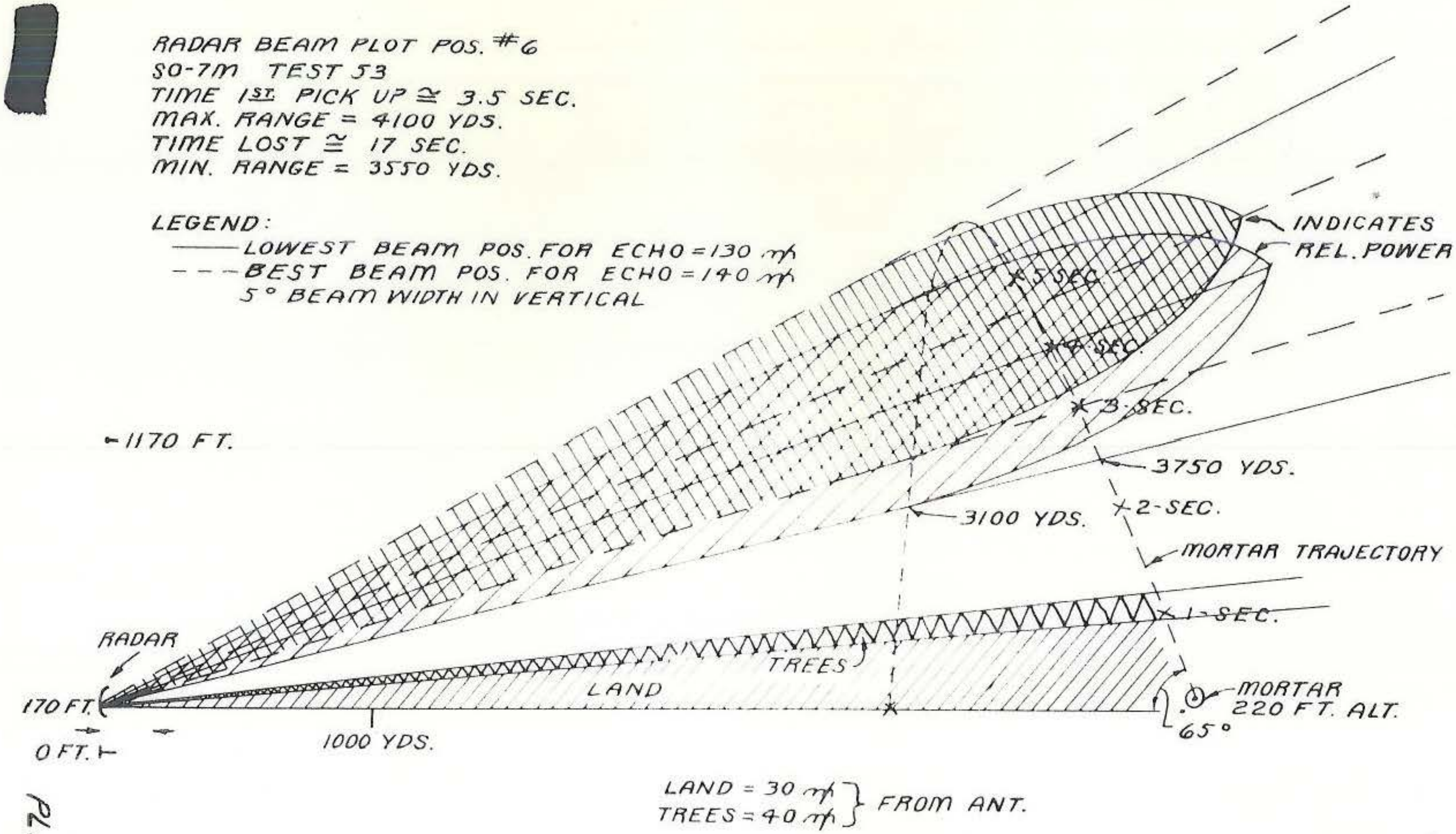


PLATE 5

[redacted]

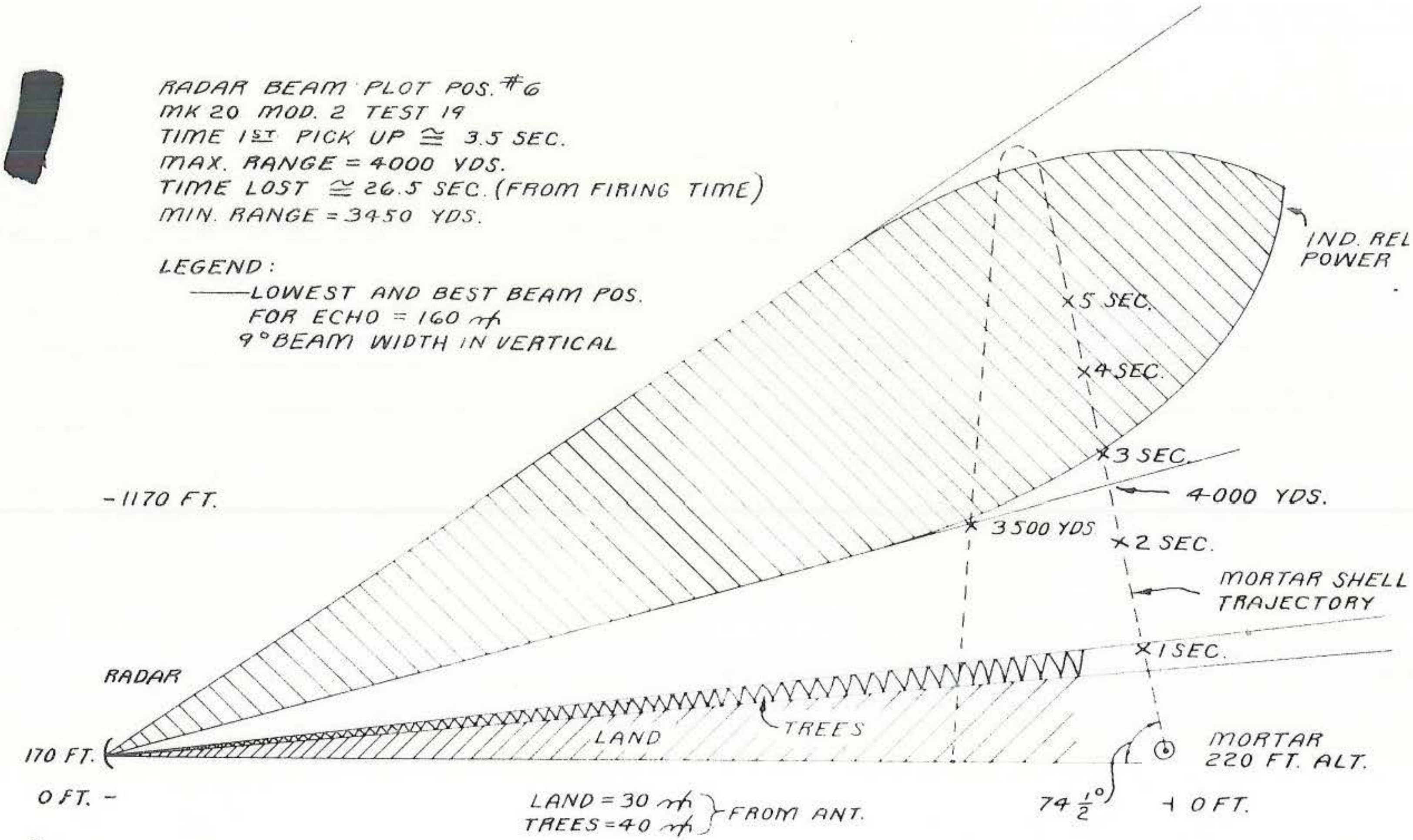
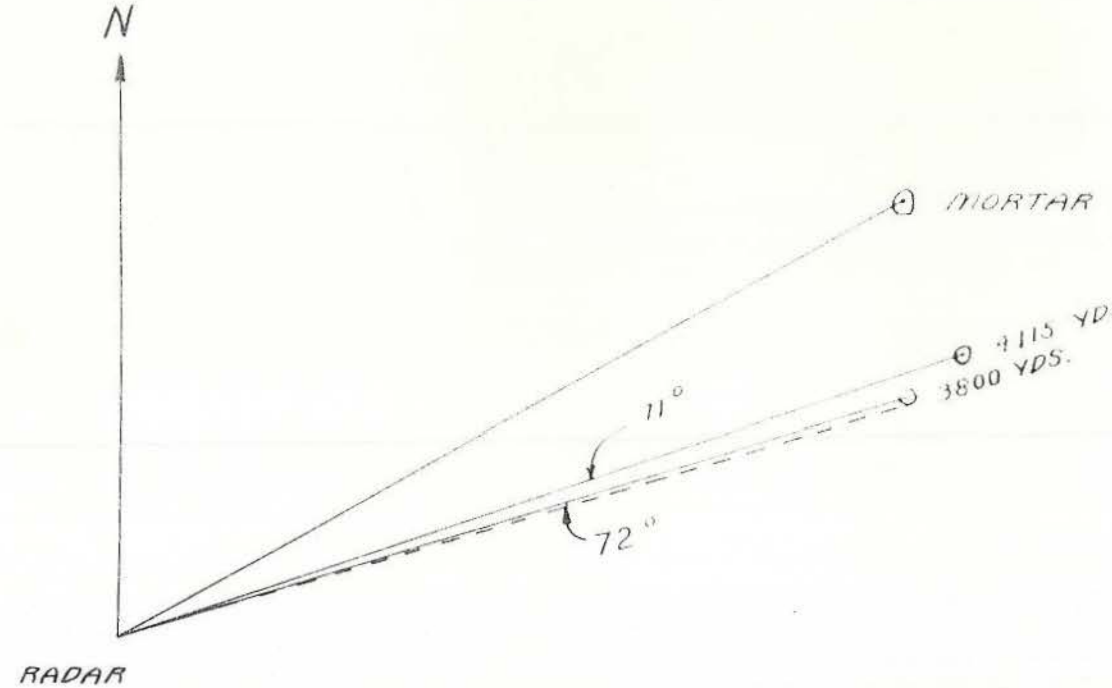


PLATE 6



SO-12M

POSITION # 6

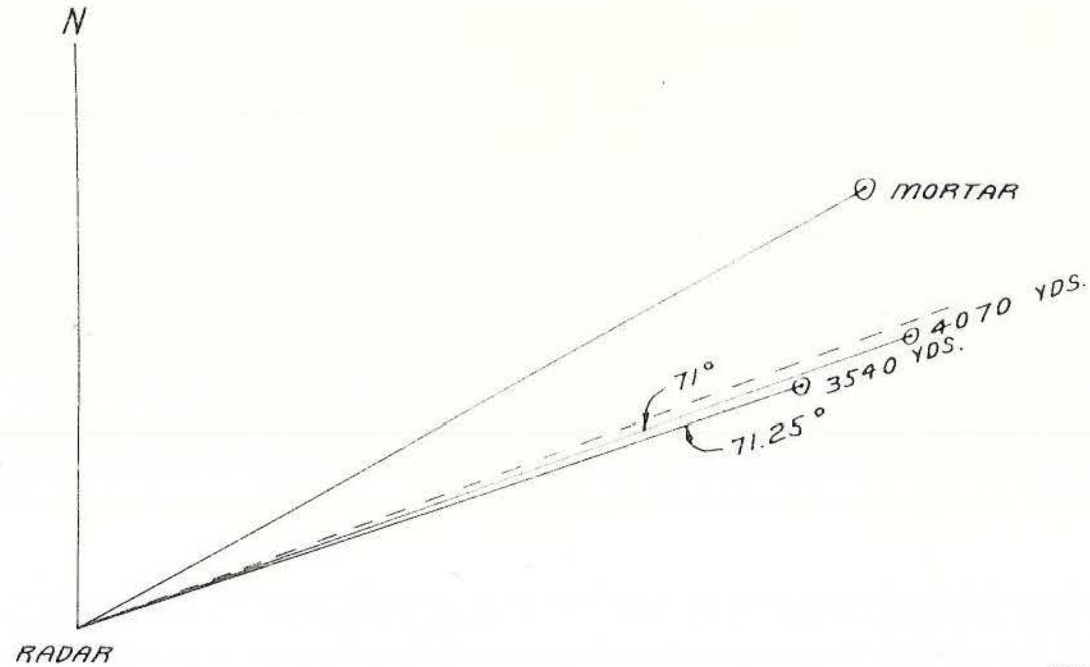
TEST 52

UP PIP

MAXIMUM RANGE 4150
MINIMUM RANGE 4100
MAXIMUM BEARING = 72.5°
MINIMUM BEARING = 71°

ACCURACY PLOT

PLATE 7



UP PIP

MAXIMUM RANGE = 4125
MINIMUM RANGE = 4000
MAXIMUM BEARING = 71°
MINIMUM BEARING = 70°

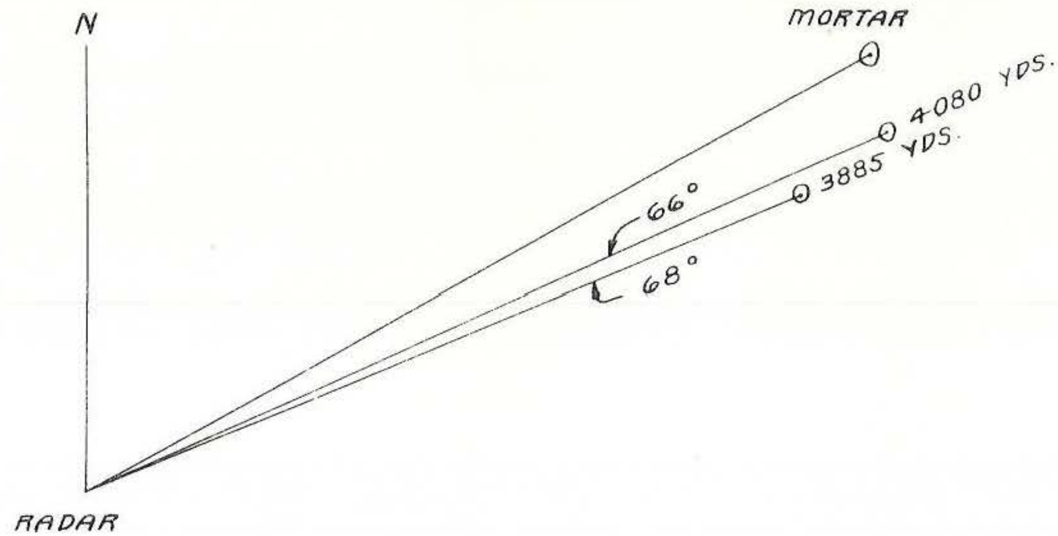
ACCURACY PLOT

POSITION #6
SO-12 M
TEST 53

PLATE 8

DECLASSIFIED

[redacted]



UP PIP

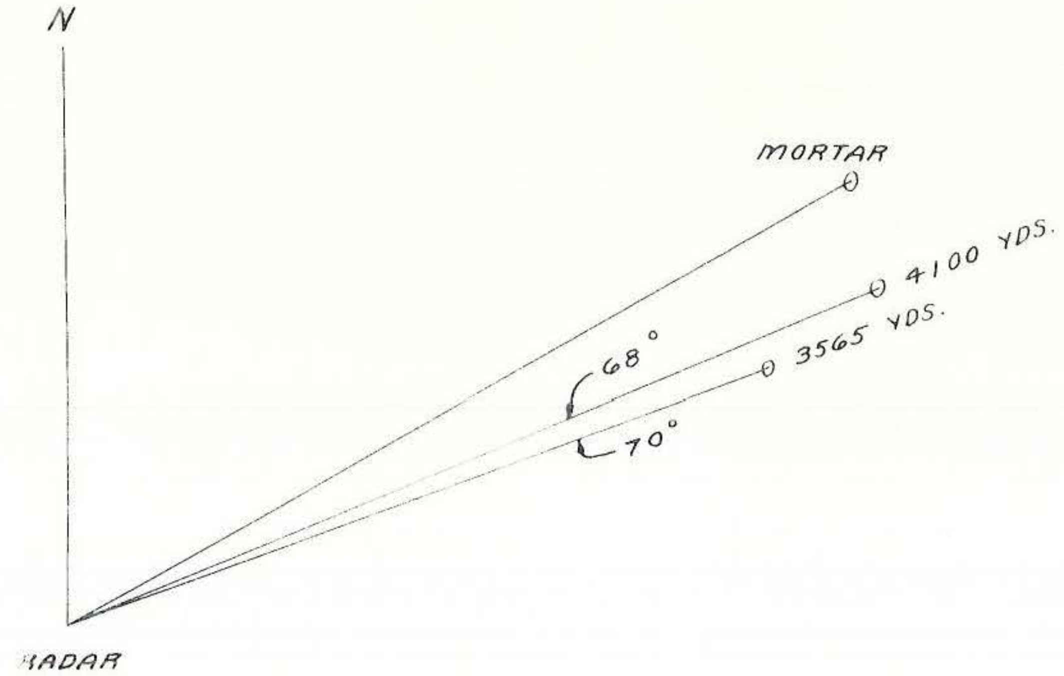
MAXIMUM RANGE = 4100
MINIMUM RANGE = 4000
MAXIMUM BEARING = 66°
MINIMUM BEARING = 66°

ACCURACY PLOT

POSITION #6
SO-7M
TEST 52

PLATE 9

DECLASSIFIED



SO-7M

POSITION # 6

TEST 53

UP PIP

MAXIMUM RANGE = 4100
MINIMUM RANGE = 4100
MAXIMUM BEARING = 68°
MINIMUM BEARING = 68°

ACCURACY PLOT

PLATE 10

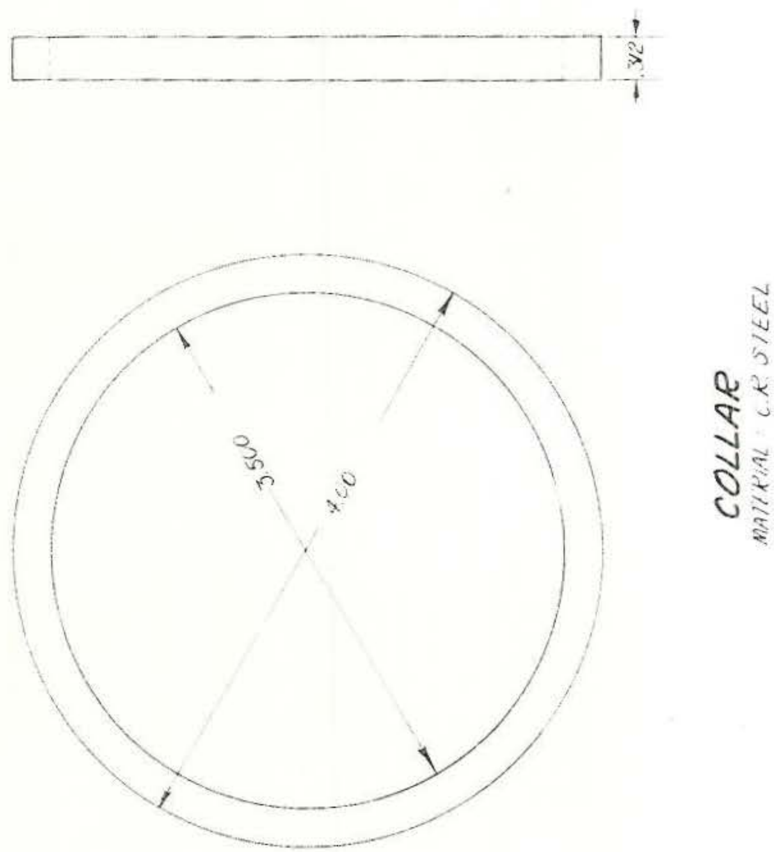


PLATE 11

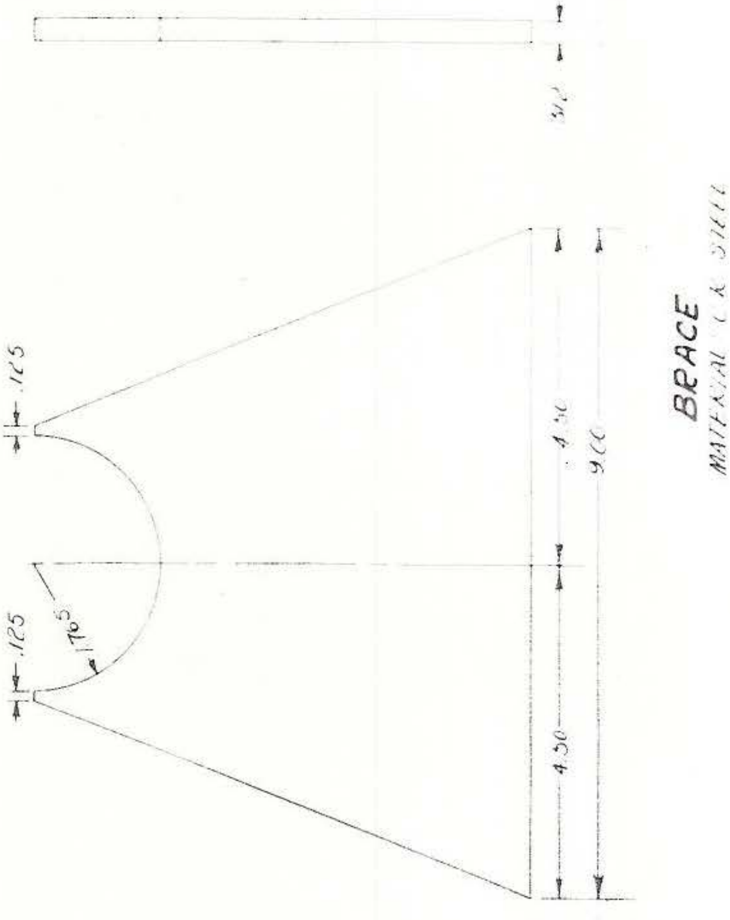


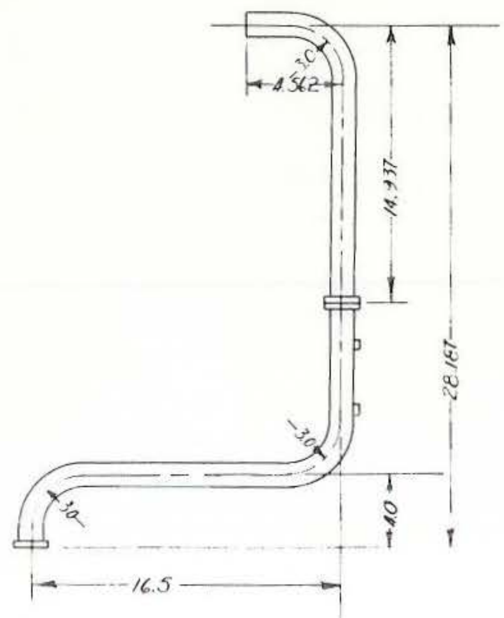
PLATE 12

DECLASSIFIED

[redacted]

[redacted]

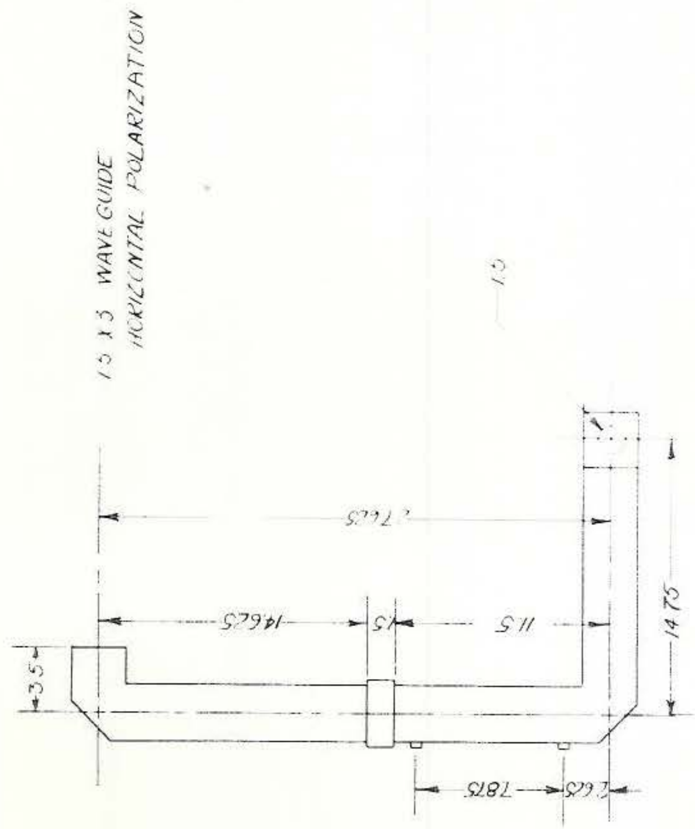
.625 X 1.25 WAVEGUIDE
HORIZONTAL POLARIZATION



X-BAND WAVEGUIDE ASSEMBLY

PLATE 13

DECLASSIFIED

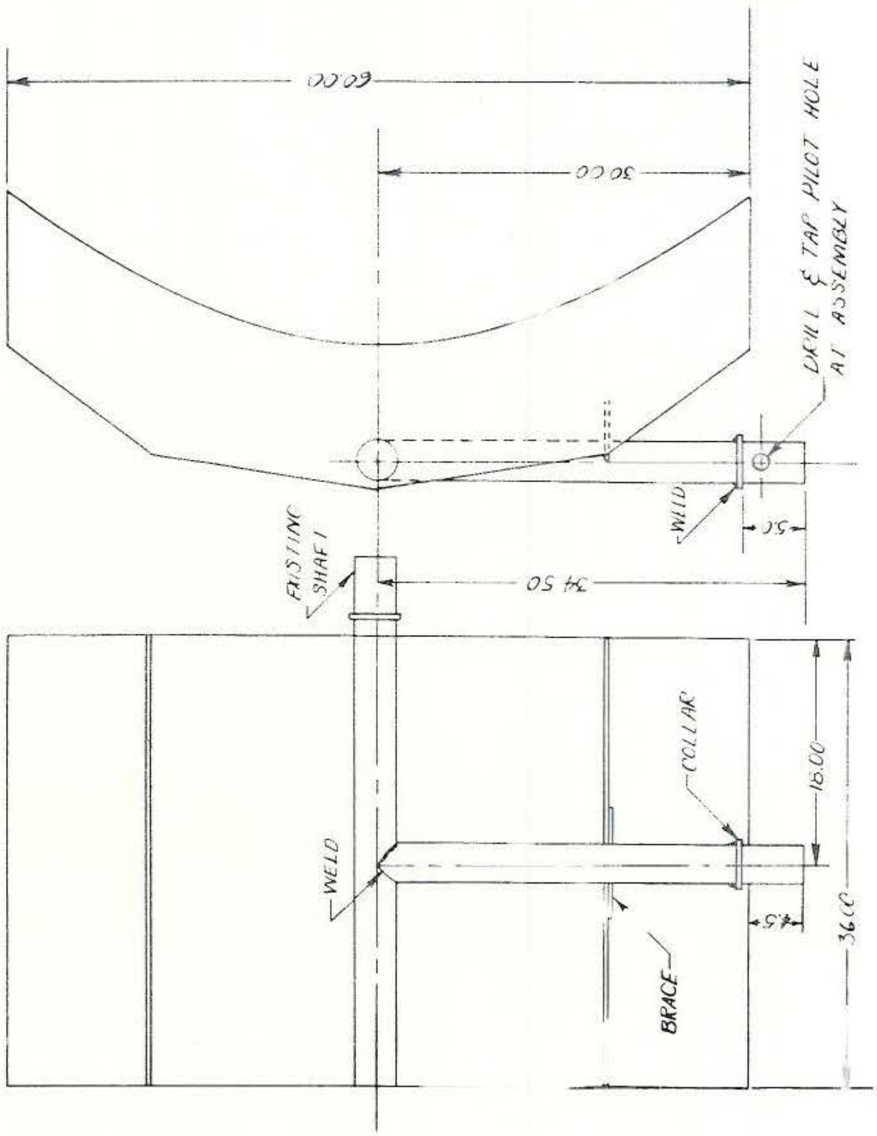


S-BAND WAVEGUIDE ASSEMBLY

PLATE 14

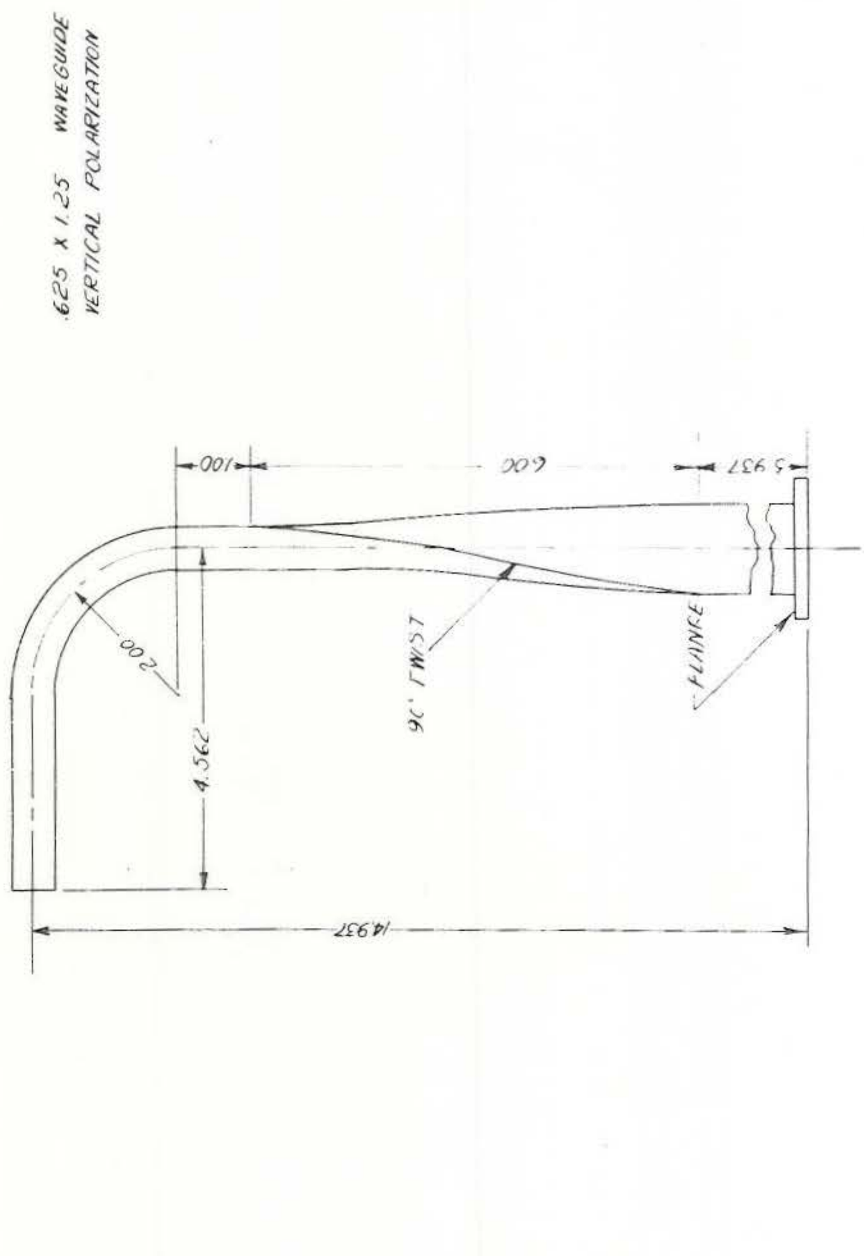
[redacted]

DECLASSIFIED



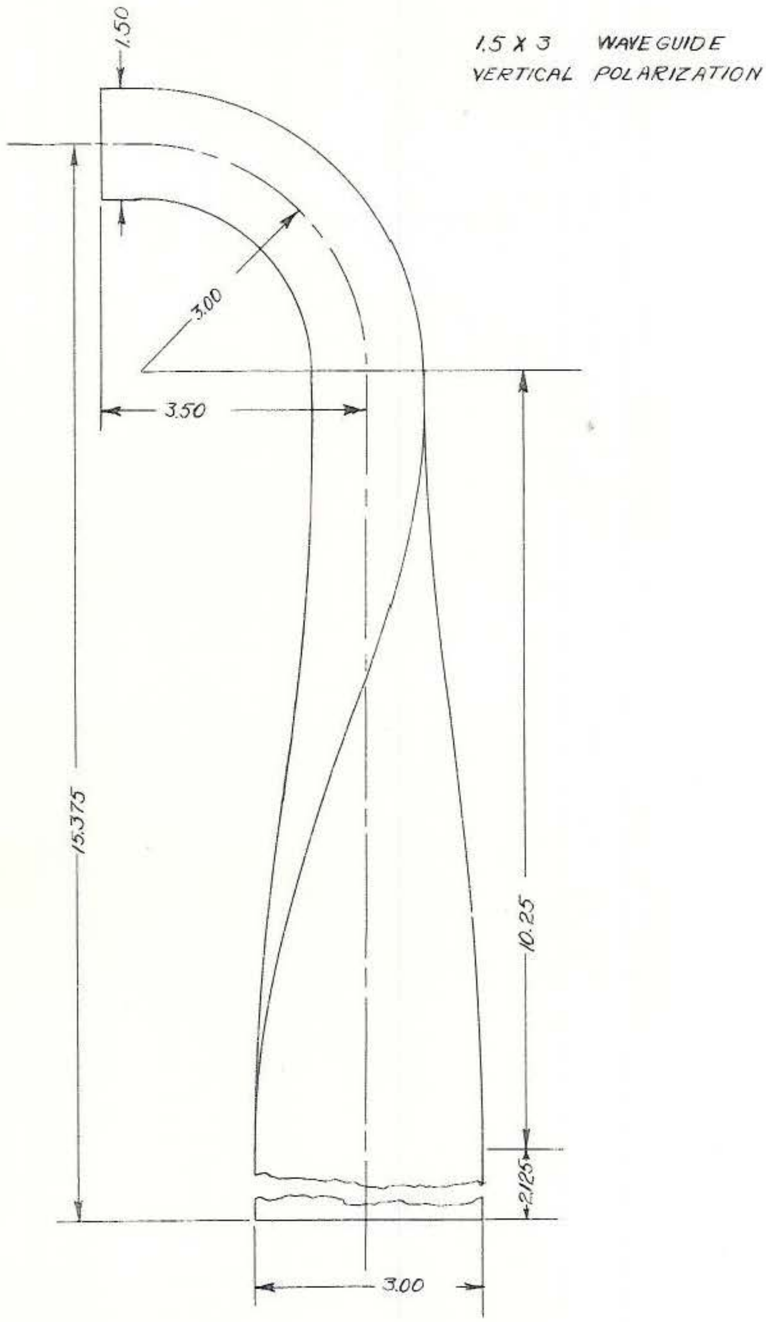
REFLECTOR ASSEMBLY

PLATE 15



X-BAND WAVEGUIDE BENDS

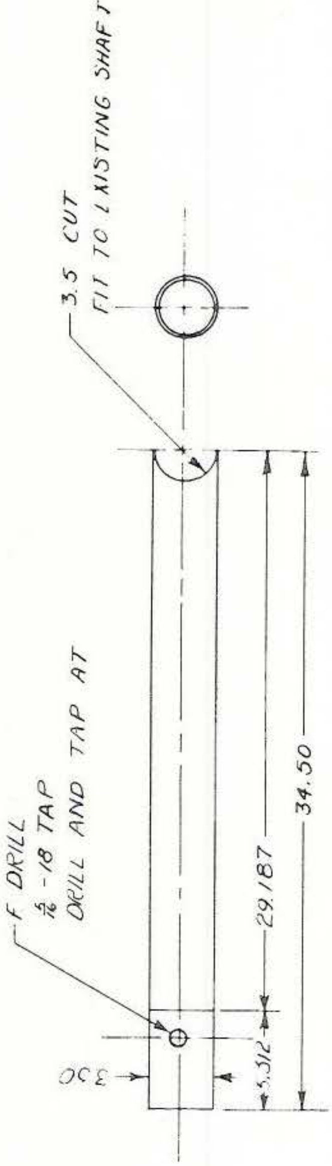
PLATE 16



WAVE GUIDE TWIST

PLATE 17

[redacted]

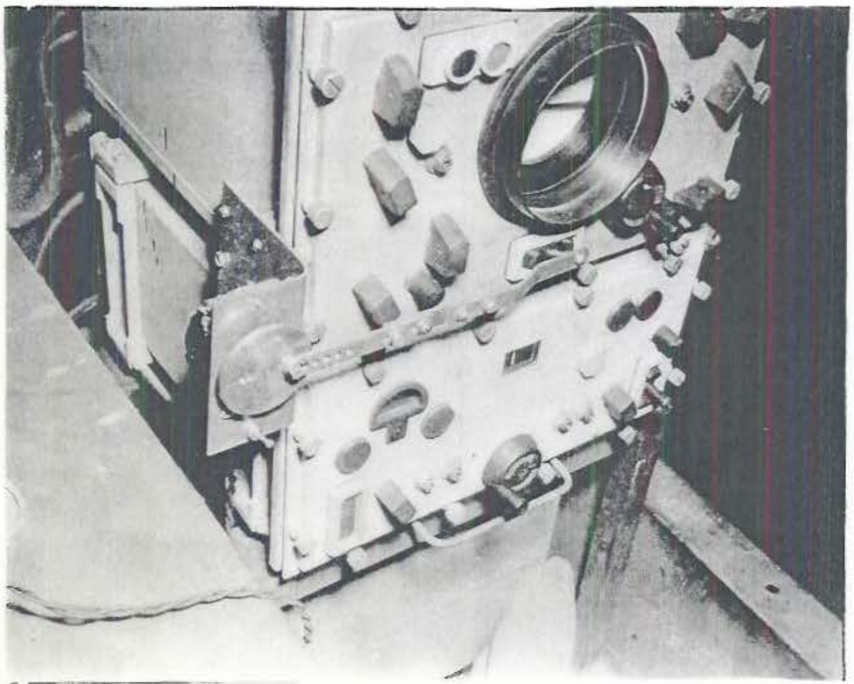


SHAFT
MATERIAL: CR STEEL PIPE
3.50 OD .125 WALL
NO. REQ'D: 1

PLATE 18

[redacted]

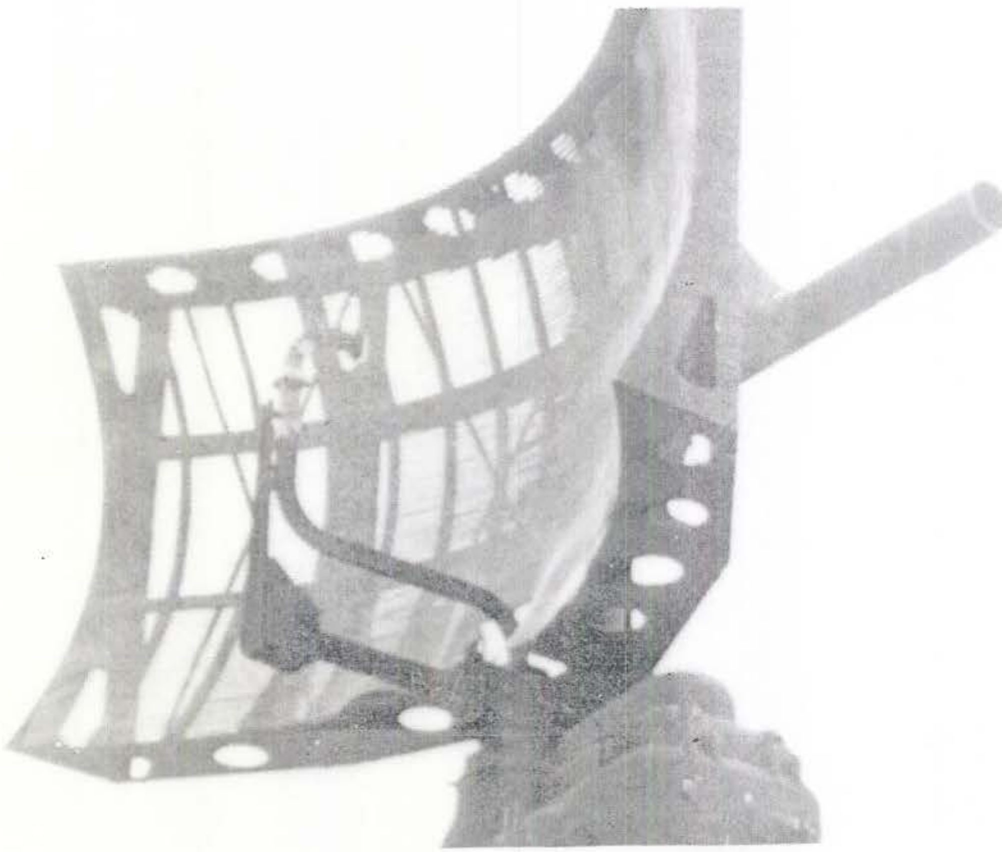
DECLASSIFIED



FRONT VIEW OF SO-7M
MODIFIED FOR SECTOR SCAN

DECLASSIFIED

[redacted]



SO-12M ANTENNA
SHOWING WIRE SCREEN

DECLASSIFIED

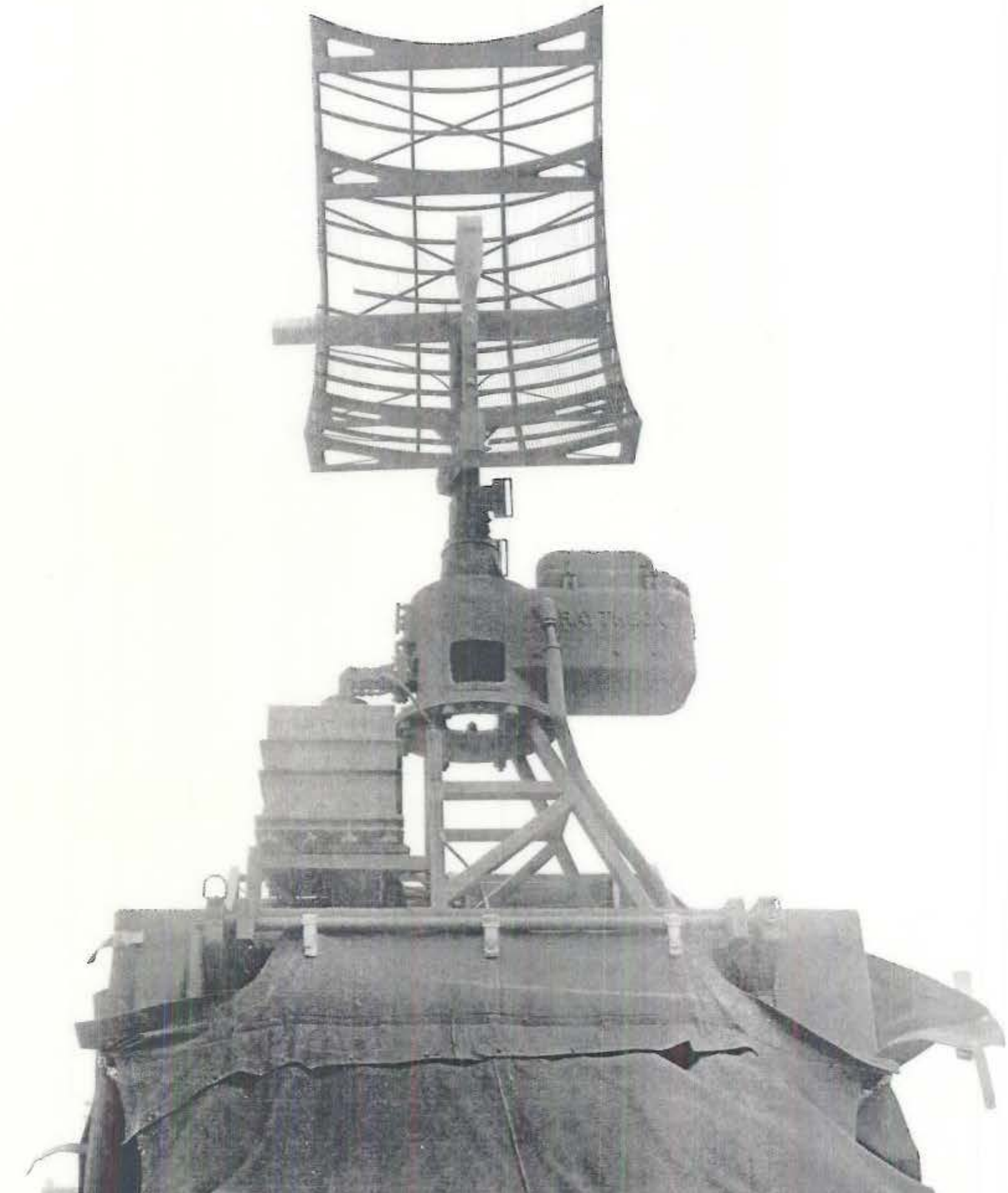
[redacted]

FOLIAGE THROUGH WHICH THE SO-7M AND SO-12M OPERATED

PLATE 22

[redacted]

SO-12M ANTENNA VERTICAL SHOWING MODIFICATION.



DECLASSIFIED

SO-7M ANTENNA VERTICAL SHOWING MODIFICATION.

DECLASSIFIED

DECLASSIFIED

LEFT TO RIGHT
81 mm M56 MORTAR SHELL
81 mm M43 MORTAR SHELL
60 mm MORTAR SHELL

PLATE 25

RECOMMENDATIONS

1. Recommendations regarding carbon-rayon fabrics must include the factors of protective value and wearability which have not been discussed in this report. Separate reports being written on chamber tests and wearing trials of carbon-rayon clothing will bear recommendations which will take into consideration the data presented in this report.

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ACKNOWLEDGMENT

The authors are indebted to Drs. W. H. Taylor and H. W. Carhart, and M. J. Curry who actively participated in conducting many of the tests; to Lt. B. N. Stolp, USNR, for physiological records and clinical tests; to Lt. (jg.) J. C. Conner, USNR, for management of volunteer personnel used in the physiological tests; to R. E. Cunningham and G. McCoy for chamber operation and contamination of cloth samples; and to L. Jussila and A. Thomson for analysis of H content of contaminated suits and samples.

[redacted]

APPENDIX

Table XVIII

Description of Carbon-Rayon Fabrics Received for Evaluation at NRL

A - WOVEN SAMPLES

Cloth No. 110.

Filling - Rayon containing 30% CWS-N44 micronized carbon, 340 denier, 200 filament, plied 60/1 cotton dyed green.
Warp - Unfinished 60/2 cotton dyed green, 100 sley.
Construction - double 2 x 1 twill, 104 picks.
Carbon content - 4.3 mg/cm.^{2}
Tensile strength of Fabric - Warp 110 lbs. dry and wet.
Filling 110 lbs. dry, 52 lbs. wet.
Dry strength Carbon-Rayon yarn - 0.75 g/denier
Extensibility - 18%.

Cloth No. 124.

Filling - Rayon containing 45 % CWS-N44 micronized carbon, 350 denier, 200 filament, plied with 60/1 cotton dyed green.
Warp - Unfinished 60/2 cotton dyed green.
Construction - double 2 x 1 twill, 104 picks.
Carbon Content - 6.4 mg/cm.^{2}

Cloth No. 127.

Filling - Rayon containing 30% CWS-N44 micronized carbon, 340 denier, 200 filament, plied 60/1 cotton dyed green.
Warp - Unfinished 60/2 cotton dyed green, 100 sley.
Construction - double 2 x 1 twill, 118 picks.
Carbon Content - 4.9 mg/cm.^{2}
Tensile Strength of Fabric - Warp,-110 lbs. dry and wet.
Filling 110 lbs. dry, approximately 60 lbs. wet.

Cloth No. 131.

Filling - Rayon containing 30% CWS-N44 micronized carbon, 350 denier, 200 filament, plied with 60/1 cotton dyed OD-7.
Warp - Unfinished 60/2 cotton dyed green, 92 sley.
Construction - double 2 x 1 twill, 124 picks.
Carbon Content - 5.2 mg/cm.^{2}

[redacted]

Table XVIII (Continued).

Description of Carbon-Rayon Fabrics Received for Evaluation at NRL.

Cloth No. 133.

Filling - Rayon containing 30% CWS-N44 micronized carbon, 350 denier, 200 filament, plied with 70/23 nylon (finish left on).
Warp - Unfinished 60/2 cotton dyed OD-7.
Construction - Double 2 x 1 twill. 124 picks.
Carbon Content - 5.2 mg/cm.^{2}

Cloth No. 133W.

Same as #133 except washed in Nacconol NR.

Cloth No. 136.

Filling - Rayon containing 30% CWS-N44 micronized carbon, 350 denier, 200 filament, plied with 70/23 nylon (scoured and dyed OD-7).
Warp - Unfinished 60/2 cotton dyed OD-7.
Construction - Double 2 x 1 twill, 124 picks.
Carbon Content - 5.2 mg/cm.^{2}

Cloth No. 137

Filling - Rayon containing 36% CWS-N44 micronized carbon, 350 denier, 200 filament, plied with 70/23 nylon (scoured and dyed OD-7).
Warp - Unfinished 60/2 cotton dyed OD-7.
Construction - Double 2 x 1 twill, 124 picks.
Carbon Content - 5.2 mg/cm.^{2}
Tensile Strength of Fabric - Warp 111 lbs. dry, 103 lbs. wet; filling 174 lbs. dry, 153 lbs. wet.

Cloth No. 138.

Filling - Rayon containing 36% CWS-N44 micronized carbon, 350 denier, 200 filament, plied with 60/1 cotton dyed OD-7.
Warp - Unfinished 60/2 cotton dyed OD-7.
Construction - Double 2 x 1 twill, 124 picks.
Carbon Content - 5.2 mg/cm.^{2}
Tensile Strength of Fabric - Warp - 109 lbs. dry and wet, filling 111 lbs. dry, 70 lbs. wet.

[redacted]

Table XVIII (continued).

Description of Carbon-Rayon Fabrics
Received for Evaluation at NRL

Cloth No. 139.

Filling - Rayon containing 36% CWS-N44 micronized carbon, 350/200, plied with 70/23 nylon (scoured and dyed OD-7).
Warp - Unfinished 60/2 cotton dyed OD-7.
Construction - Double 2 x 1 twill, 116 picks.
Carbon Content - 6.7 mg/cm.^{2}

Cloth No. 140

Filling - Rayon containing 36% CWS-N44 micronized carbon, 350/200, plied with 60/1 cotton dyed OD-7.
Warp - Unfinished 60/2 cotton dyed OD-7.
Construction - Double 2 x 1 twill - 116 picks.

Cloth No. 148.

Filling - Rayon containing 32% CWS-N182 micronized carbon, 350/200, undesulfurized, plied with 70/23 nylon (scoured and dyed OD-7) S twist.
Warp - Unfinished 60/2 cotton dyed OD-7.
Construction - Double 2 x 1 twill, 116 picks.
Carbon Content - 5.7 mg/cm.^{2}

Cloth No. 148a.

Filling - Rayon containing 32% CWS-N182 micronized carbon, 350/200, plied with 105/34 nylon (scoured and dyed OD-7).
Warp - Unfinished 60/2 cotton dyed OD-7.
Construction - Double 2 x 1 twill - 108 picks.

Cloth No. 166.

Filling - Rayon containing 22% CWS-N182 micronized carbon, 300/200, plied with 105/34 nylon.
Warp - Unfinished 60/2 cotton Dyed OD-7.
Construction - Double 2 x 1 twill 100 x 116 picks.

[redacted]

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Table XVIII (Continued).

Description of Carbon-Rayon Fabrics
Received for Evaluation at NRL

Cloth No. 167.

Filling - Rayon containing 27% CWS-N182 micronized carbon, 330/200, plied with 105/34 regular nylon.
Warp - Unfinished 60/2 cotton dyed OD-7.
Construction - Double 2 x 1 twill - 100 x 116 picks.

Cloth No. 168.

Filling - Rayon containing 37% CWS-N182 micronized carbon, 380/200, plied with 105/34 regular nylon.
Warp - Unfinished 60/2 cotton dyed OD-7.
Construction - Double 2 x 1 twill - 100 x 116 picks.

Cloth No. 169.

Filling - Rayon containing 32% CWS-N182 micronized carbon, 350/200 plied with 58/1 cotton.
Warp - Unfinished 60/2 cotton dyed OD-7.
Construction - Double 2 x 1 twill, 100 x 116 picks.

Cloth No. 173.

Filling - Rayon containing 32% CWS-N182 micronized carbon, 350/200, plied with 70/23 nylon.
Warp - Unfinished 70/23 nylon.
Construction - Double 2 x 1 twill, 150 x 118 picks.

Cloth No. 174.

Filling - Rayon containing 32% CWS-N182 micronized carbon, 350/200, plied with 30/10 nylon 5 turns S, then plied with 58/1 cotton (dyed OD-7) 5 turns S.
Warp - Unfinished 60/2 cotton.
Construction - Double 2 x 1 twill - 100 x 108 picks.

Cloth No. 175.

Filling - Rayon containing 32% CWS-N182 micronized carbon, 350/200, double wrapped with 100/1 cotton.
Warp - Unfinished 60/2 cotton.
Construction - Double 2 x 1 twill - 100 x 116 picks.

[redacted]

Table XVIII (Continued).

Description of Carbon-Rayon Fabrics Received for Evaluation at NRL.

Cloth No. 176.

Filling - Rayon containing 32% CWS-N182 micronized carbon, 350/200, plied with 30/10 nylon (undyed) 5 turns Z, then plied with 105/34 nylon (dyed OD-7) 5 turns Z.
Warp - Unfinished 60/2 cotton dyed OD-7.
Construction - Double 2 x 1 twill - 100 x 108 picks.

Cloth No. 177.

Filling - Rayon containing 32% CWS-N182 micronized carbon, 350/200, plied with 70/23 nylon (dyed OD-7) 5 turns Z, then plied with 70/23 nylon (dyed OD-7), 5 turns Z, then plied with 70/23 nylon (dyed OD-7) 5 turns Z.
Warp - Unfinished 60/2 cotton dyed OD-7.
Construction - Double 2 x 1 twill - 100 x 116 picks.

Cloth No. 190.

Filling - Rayon containing 34% PCI carbon, 350/120, double plied with 70/.23 nylon.
Warp - Unfinished 60/2 cotton dyed OD-7.
Construction - Double 2 x 1 twill - 100 x 108 picks.

Cloth No. 191.

Filling - Rayon containing 34% PCI carbon, 350/200, double plied with 70/23 nylon.
Warp - Unfinished 60/2 cotton dyed OD-7.
Construction - Double 2 x 1 twill - 100 x 108 picks.

Cloth No. 192.

Filling - Rayon containing 28% CWS-N182 carbon, 350/200, single plied with 70/23 nylon.
Warp - Unfinished 60/2 cotton dyed OD-7.
Construction - Double 2 x 1 twill, 100 x 108 picks.

Cloth No. 193.

Filling - Rayon containing 28% CWS-N182 carbon, 350/200, double plied with 70/23 nylon.
Warp - Unfinished 60/2 cotton dyed OD-7.
Construction - Double 2 x 1 twill - 100 x 108 picks.

[redacted]

Table XVIII (Continued).

Description of Carbon-Rayon Fabrics Received for Evaluation at NRL

Cloth No. 194.

Filling - Rayon containing 32% CWS-N182 micronized carbon, 350/200, plied with 70/23 nylon.
Warp - Unfinished 60/2 cotton dyed OD-7.
Construction - Double 2 x 1 twill - 100 x 54 picks.

Cloth Nol 195.

Filling - Rayon containing 32% CWS-N182 micronized carbon, 350/200, plied with 70/23 nylon alternated with 14/1 cotton (2 picks each).
Warp - Unfinished 60/2 cotton dyed OD-7.
Construction - Double 2 x 1 twill - 100 x 108 picks.

Cloth No. 196.

Filling - Rayon containing 32% CWS-N182 micronized carbon, 350/200 double plied with 70/23 nylon.
Warp - Unfinished 60/2 cotton dyed OD-7.
Construction - Double 2 x 1 twill - 100 x 108 picks.

Cloth No. 197.

Filling - Rayon containing 32% CWS-N182 micronized carbon, 350/200, double plied with 70/23 nylon.
Warp - Unfinished 60/2 cotton dyed OD-7.
Construction - Double 2 x 1 twill - 100 x 100 picks.

Cloth No. 198.

Filling - Rayon containing 32% CWS-N182 micronized carbon, 350/200, double plied with 70/23 nylon.
Warp - Unfinished 60/2 cotton dyed OD-7.
Construction - Double 2 x 1 twill - 100 x 92 picks.

Cloth No. 199.

Filling - Rayon containing 32% CWS-N182 micronized carbon, 350/200, double plied with 70/23 nylon.
Warp - Unfinished 60/2 cotton dyed OD-7.
Construction - Double 2 x 1 twill - 100 x 84 picks.

[redacted]

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Table XVIII (Continued)

Description of Carbon-Rayon Fabrics
Received for Evaluation at NRL.

Cloth No. 200.

Filling - Rayon containing 32% CWS-N182 micronized carbon, 350/200, double plied with 70/23 nylon.
Warp - Unfinished 60/2 cotton dyed OD-7.
Construction - Double 2 x 1 twill - 100 x 76 picks.

Cloth No. 201.

Filling - Rayon containing 32% CWS-N182 micronized carbon, 350/200, double plied with 70/23 nylon.
Warp - Unfinished 60/2 cotton dyed OD-7.
Construction - Double 2 x 1 twill - 100 x 54 picks.

B - KNIT SAMPLES

Cloth No. 128.

Rayon containing 30% CWS-N44 carbon, 150/100, plied with 120/2 cotton and knit on a tricot machine without finish.
4.8 mg/cm.^{2}

Cloth No. 170.

Rayon yarn containing 30% CWS-N182 carbon plied with 70/23 nylon.
1 end 350 denier carbon-rayon yarn plus 24 singles.
2 ends 14 single in back.
Knit on a Tomkins knitting machine.

Cloth No. 171.

Rayon yarn containing 30% CW-N44 carbon.
1 end 350 denier carbon-rayon yarn, plus 2 ends 24's in front.
1 end 350 denier carbon-rayon yarn plus 2 ends 24's in back.
Knit on a Tomkins knitting machine.

Cloth No. 172.

Rayon yarn containing 30% CWS-N182 carbon plied with 70/23 nylon.
2 ends of 350 denier carbon-rayon yarn plied with 70 denier nylon plus 1 end 24's.
Back of 2 ends, 24's cotton.
21 oz./sq. yard before washing; 15 oz./sq.yard after washing
Knit on a Tomkins knitting machine.

[redacted]

Table XVIII (Continued)

Description of Carbon-Rayon Fabrics Received for Evaluation at NRL.

Cloth No. 178.

Rayon yarn containing 30% CWS-N182 carbon, 200/120, is plied with 60/1 cotton and knit on a Tomkins machine with 2 ends of 30/1 cotton. It has a weight of 10.1 oz./yd.^{2} unwashed and 12.9 oz./yd^2 washed.

Cloth No. 180.

Rayon yarn containing 30% CWS-N182 carbon, 350/200, is plied with 60/1 cotton and knit on a Tomkins machine with 2 ends of 24/1 cotton. It has weight of 15.3 oz./yd^2 unwashed and 17.6 oz./yd^2 washed.

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[redacted]

APPENDIX

Table XIX

Vesicant-Resistance Properties of Carbon-Rayon Cloths

Cloth No.	H Penetration Capacity Time (Mins.) NRL	MIT	% Leakage
110	124		0
124			
127	252	235	
131	310		
133	266		
133W	194		
136			
137	358		
138	37		
139		441	
140		426	
148	395	480	
148a	441	545	0
166		191	
167		205	
168		660	
169		563	
173		618	
174		562	
175			
176			
177			
190			
191			
192			
193			
194			0
195			0
196			0
197			0
198			0
199			0
200			0
201			0
--			
--			
128	54		
170			
171			
172			
178	372		0
180	436		0

[redacted]