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FIRE CONTROL DIVISION - RADAR RESEARCH SECTION

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LOCATION OF MORTARS BY SHIPBORNE
FIRE CONTROL RADAR EQUIPMENT

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By Lt. H. L. Gerwin, USNR

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- Report R-2651 -

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ABSTRACT

There has been shown to exist an urgent operational requirement for extending the use of shipborne fire control radars to the location of enemy mortar batteries. The purpose of the present problem is to determine the capabilities for this purpose of fire control radars now in the fleet. Tests to determine the performance capabilities of Radar Equipments Mark 8 Mod 2, Mark 12 Mod 1, Mark 13 Mod 0 and Mark 22 Mod 1 against 81 mm M43 HE mortar shells were conducted at the Chesapeake Bay Annex of the Naval Research Laboratory. Tests to further investigate the performance of the Radar Equipment Mark 22 were conducted aboard a destroyer.

During these tests, the Radar Equipment Mark 8 was unable to pick up any part of the mortar trajectory. Using the method of comparing radar performances described in the text of this report, a maximum reliable range of 1300 yards is what should be expected with this radar. The Radar Equipment Mark 12 obtained ranges of 6200 yards for the end-on view, and 3800 yards for the broadside view over water; but, because of strong land echoes, attempts with this equipment to observe the shells over or near land resulted in complete failure. The Radar Equipment Mark 13 obtained ranges of 4200 yards for the end-on view and 4400 yards for the broadside view over water. Because of land echoes, however, attempts to observe the shells over or near land were also difficult. The ranges obtained with the standard Radar Equipment Mark 22 Mod 0 were about 3600 yards for the broadside view and 3000 yards for the end-on view. These results could be obtained as well over land as over water. From observations made aboard the destroyer, it was noted that rain squalls seriously reduced the performance of the Radar Equipment Mark 22.

Tests were conducted to investigate more fully the reflection pattern of a mortar projectile. From these measurements it was concluded that the aspect of a mortar projectile will have a large effect on the maximum reliable range at X-band wavelengths, while at S-band wavelengths the effect of aspect is negligible.

The Radar Equipment Mark 8, either Mod 1 or Mod 2, offers no promise of being a useful mortar locator. Radar Equipments Mark 12 and Mark 13 are capable of sufficient range, and if means of separating land echoes from the shell echo can be devised, these radars may become practical mortar locators. The Radar Equipment Mark 22, though capable of separating the shell echo from the land echoes, does not have sufficient range ability to become a practical mortar locator.

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INTRODUCTION

1. During a landing operation, and before the firm establishment of a beachhead, there has been shown to exist an urgent operational requirement for extending the use of shipborne fire control radar equipments to the location of enemy mortar batteries. Reference (a) requested that this Laboratory determine the capabilities for this purpose of Fire Control Radar Equipments Mark 22, Mark 13, Mark 8, and Mark 12 and other fire control radar equipments in the fleet that may appear adaptable.

2. An investigation of the ability of shipborne radar equipments to locate enemy mortar sites resolves itself into two main problems:

(a) Does the radar equipment have the necessary power and resolution to detect such a small target at a useful range?

(b) If the radar equipment satisfies the above condition, what operating techniques and/or modifications are necessary to convert it to the mortar locating role?

3. Of the above two problems, it is immediately apparent that the first is the more important, so the following questions were studied:

(a) What is the maximum reliable pick-up range of 81 mm M43 HE mortar shells over water with the direction of the mortar fire at ninety degrees (broadside) to the direction of the radar?

(b) What is the maximum reliable pick-up range of 81 mm M43 HE mortar shells over water with the direction of the mortar fire at zero degrees (end-on) to the direction of the radar?

(c) What is the maximum reliable pick-up range of 81 mm M43 HE mortar shells over land with the direction of the mortar fire at ninety degrees (broadside) to the direction of the radar?

(d) What is the maximum reliable pick-up range of 81 mm HE mortar shells over land with the direction of the mortar fire at zero degree (end-on) to the direction of the radar?

INVESTIGATION AT THE CHESAPEAKE BAY ANNEX

4. It was considered probable that a method of backward extrapolation of the shell trajectory would be used to determine the position of the mortar; thus all studies were made of the shell in its ascending flight.

5. To conduct experiments to determine the maximum reliable range over water, the mortar battery was installed on a boat (LCM), and two types of runs were made. In the first run, the LCM proceeded on a course directly away from the radars under test, firing mortar shells over the bow to give the end-on view. In the second run, the LCM proceeded on a course directly toward the radars under test, firing mortar shells to port to give the broadside view,

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6. To conduct experiments to determine the maximum reliable range over or near land, the boat on which the mortar battery was installed was beached. The mortar was fired from the water's edge and in such a direction that the point of impact of the shell was within a given danger area. Because of the limited danger area, only the broadside view could be observed for this type of test.

7. The different radar sets were informed in advance of the position of the mortar and thus were able to turn their antennas toward the firing point. Each time the mortar was fired, a start signal was transmitted to each radar set to alert the operator.

8. The following radar equipments were tested (within the limits of time and availability) at the Chesapeake Bay Annex of this Laboratory:

(a) Radar Equipment Mark 8 Mod 2. This is an S-band main battery fire control radar designed for battleship and cruiser installation.

(b) Radar Equipment Mark 12 Mod 1. This is an L-band fire control radar used against aircraft and surface marine craft.

(c) Radar Equipment Mark 13 Mod 0. This is an X-band main battery fire control radar designed for battleship and cruiser installation.

(d) Radar Equipment Mark 22 Mod 1. This is an X-band radar designed as an auxiliary to Radar Equipments Mark 4 and Mark 12 to provide accurate elevation data at elevation angles near the horizon.

9. The performance data for the radar equipments against 81 mm M43 HE mortar shells have been tabulated on Plate 1, using a nomenclature of signal strength in which a "1-strength signal" represents a weak but reliable signal, a "2-strength signal" represents a strong signal, a "3-strength signal" represents a very strong signal, while a "0-strength signal" indicates no signal was observed for the mortar round fired.

10. No observations are tabulated for the Radar Equipment Mark 8, Mod 2 because at no time was this radar able to pick up the echo from the shell in any part of the trajectory. The minimum range that could be acquired for the test runs was 2000 yards. The radar was carefully checked by maintenance personnel to ensure that it was operating properly. The antenna was tried at several elevation angles from 0 degree to plus 6 degrees. The comparative evaluation of the expected performance of the radars, which is a part of this report, predicts that the expected ranges for the Radar Equipment Mark 8 would be lower than those of the Radar Equipments Mark 13 and Mark 22.

11. Referring to Plate 1, it can be seen that the maximum reliable range over water of the Radar Equipment Mark 12 is about 6200 yards for the end-on view and about 3800 yards for the broadside view. Attempts to observe the shells near land resulted in complete failure because the 10-degree beam width of the antenna prevented separation of the shell echo from the saturated land echoes. This condition is so serious that the radar in its present form is considered useless as a mortar locator.

12. The maximum reliable range over water of the Radar Equipment Mark 13 is about 4200 yards for the end-on and 4400 yards for the broadside view. Attempts to observe the shell near land were very disappointing. The difficulty in this case, as with the Radar Equipment Mark 12, was that the wide vertical beam width of the Radar Equipment Mark 13 results in saturated land echoes from which the shell echo could not be separated.

13. For this test, the maximum reliable range over water of the Radar Equipment Mark 22 was about 3600 yards for the end-on and 4400 yards for the broadside view. The maximum range of this radar is not affected when the shell is over or near land. This ability to observe the shell over land is attributed to the narrow beam width (1.2 degrees) of the antenna in the vertical plane.

INVESTIGATION ABOARD A DESTROYER

14. In view of the fact that the Radar Equipment Mark 22 Mod 1 could obtain good ranges on the mortar shell both over land and over water, it was decided to convert a destroyer installation of the Radar Equipment Mark 22 Mod 0 to Mark 22 Mod 1 and continue the investigation. The investigation aboard the destroyer was conducted by the Research and Development Center, COTCLant. The first test was conducted by having the destroyer anchor at various increasing ranges from the mortar battery site until the mortar shell could no longer be observed on the radar screen. No data were collected for this test, but it was deduced that the maximum range was between 2000 yards and 4000 yards.

15. From the observations noted in reference (b) and the data presented in Plate 1 of this report, it was considered probable that the signal strength depends somewhat on the shell aspect for X- and L-band wavelengths. A test was therefore conducted with the destroyer located at a range of 2400 yards from the mortar battery and with the mortar firing so that the line of fire was at various target angles, from 90 degrees (broadside) to 35 degrees. These data are tabulated on Plate 2. It is evident that the signal strength does vary with target angle. The best target angle seems to be about 80 degrees, where the signal strength is high as compared to that at 35 degrees. Target angles of less than 35 degrees were not obtainable because of the danger of hitting

the ship. The same tests were conducted with the mortar battery located at a range of 4000 yards. Because of poor results obtained, only two measurements were made; the first at a target angle of 90 degrees and the second at a target angle of 70 degrees. These data are tabulated on Plate 3.

16. It is immediately apparent that the ranges obtained with the Radar Equipment Mark 22 during the tests conducted aboard the destroyer were not as high as the ranges obtained when the tests were conducted at the Chesapeake Bay Annex. This effect is considered principally due to the fact that the magnetron used in the radar at the Chesapeake Bay Annex was a special experimental model which was known to give better performance than the magnetron which is normally installed with this equipment. On this basis it is probable that the maximum range of the standard Radar Equipment Mark 22 is only 75 percent to 80 percent of that recorded on Plate 1. The maximum reliable range of the Radar Equipment Mark 22 is then about 3500 yards for the broad-side view and 2900 yards for the end-on view.

17. To complete the data for the tests conducted aboard the destroyer, it was noted that rain squalls seriously affected the operation of the Radar Equipment Mark 22. Two effects were noted: the first was the reduced signal strength caused by attenuation when the radar pulse passed through falling rain; the second was the reflection from the falling rain which produced snow on the radar screen, obscuring the target. The two effects seriously reduce the performance of this radar during rain squalls.

INVESTIGATION OF MORTAR REFLECTION PATTERN

18. Although not required as a part of this problem, it was considered desirable to conduct measurements to investigate more fully the reflection pattern of a mortar projectile. The test was conducted by transmitting pulsed energy at a 4.2-inch M3 mortar projectile and measuring the reflected energy. The shell was mounted with its major axis horizontal and rotated through 360 degrees about a vertical axis.

19. Since the power density of the received echo from a one-foot corner reflector can be computed, it was used as a standard target for the measurements. The radar cross section (σ_{cr}) for a square corner reflector oriented to give triple reflection is given in reference (c) and is quoted below:

$$\sigma_{cr} = \frac{12\pi d^4}{\lambda^2} \quad (1)$$

where d is the length of a side of the square. Since power density received from a target is directly proportional to the radar cross section, the ratio of the signal received from the mortar projectile to the signal received from the standard target can be plotted as a ratio of the radar cross section of the mortar

projectile to the radar cross section of the standard target. The reflection pattern of the shell can then be plotted in decibels using any given radar cross section as a zero decibel reference. A convenient reference radar cross section is that determined when σ_{cr} was calculated at X-band wavelength for the one foot square corner reflector. This value is 3070 square feet. At S-band the radar cross section of the corner reflector is 349 square feet. This value was used as a reference in determining the radar cross section of the shell for all S-band measurements. Having determined the radar cross section, the value of 2070 square feet was used as a zero decibel reference for all plots so a direct comparison between any of the reflection patterns can be made. Plate 4 and Plate 5 are the reflection patterns for X-band wavelength for horizontal and vertical polarization, respectively. Plate 6 and Plate 7 are the reflection patterns for S-band wavelength for horizontal and vertical polarization, respectively.

20. Referring to the reflection patterns for X-band, Plates 4 and 5, it can be seen that the nose aspect presents a radar cross section which is about 21 decibels down from the reference radar cross section, whereas the radar cross section of the broadside aspect is only about 15 decibels down from the reference. Thus at X-band wavelength a difference of 6 decibels is noted between the two aspects. Referring to the reflection patterns for S-band, Plates 6 and 7, it can be seen that the nose aspect presents a radar cross section which is about 24.4 decibels down from the reference radar cross section and the broadside aspect presents a radar cross section which is about 25.4 decibels down from the reference. It is, then, evident that at S-band wavelengths, the aspect of the shell has little effect on the radar cross section of the shell. From these data it is apparent that the aspect of the 4.2-inch M3 mortar projectile will have a large effect on the maximum reliable range at X-band wavelengths, while at S-band wavelengths the effect of aspect is considerably less.

THEORY OF COMPARATIVE EVALUATION AND DISCUSSION

21. In observing the capability of a given radar to detect a mortar shell in the air, first interest is in the maximum reliable range at which the shell can be detected by the radar. Analyzing the problem on the assumptions that the shell or target is illuminated uniformly by the radar beam, that there is no effect corresponding to an interference pattern which results when both the direct and the reflected ray illuminate the target, that there is no anomalous propagation of the radar beam, and neglecting the absorption and scattering of the radio waves by the atmosphere, a suitable definition for the maximum reliable range at which a shell can be detected by a radar is:

$$R = \sqrt[4]{\frac{W_T k_S}{W_m} \left(\frac{G R T A_e}{4\pi} \right)^2} \quad (2)$$

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where

W_m = the pulsed power at the input to the receiver required to produce the "minimum detectable signal", assuming the radar antenna is trained directly on the target.

W_T = the peak power of the radar transmitter.

K_s = the scanning loss of the radar, which is a measure of the reduction in range sensitivity which results when the radar beam repeatedly passes over the target in searching or scanning.

G_{RT} = the power gain ratio of the transmitting-receiving antenna relative to a spherical radiator.

A_e = the effective area of the target.

R = the range to the target.

The above equation, except for the factor (k_s) is given in reference (d).

22. The magnitude of the minimum detectable signal (W_m) at the receiver of a radar system depends upon a number of parameters, namely:

- (a) The pulse repetition rate
- (b) The pulse length of the radar
- (c) The band width of the receiver.

23. An expression for the minimum detectable signal involving the above variables is given in reference (c) and is quoted below:

$$W_m = kT\Delta f \quad (NF) \quad \cdot \frac{1}{4} \left(1 + \frac{1}{t\Delta f} \right)^2 \left(\frac{1670}{r} \right)^{\frac{1}{3}} \quad (3)$$

where

$k = 1.37 \times 10^{-23}$ joules per °K (Boltzmann's constant)

T = absolute temperature, °K, assumed to be 300

NF = the noise factor of the receiver at the receiver terminals

Δf = the effective bandwidth of the receiver

t = the pulse length of the radar transmitter

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r = the repetition rate of the radar transmitter

$kT\Delta f$ = the noise energy generated by the antenna which is transmitted through the receiver, assuming the receiver, assuming the receiver input is matched.

24. All the factors in equation (2) can now be evaluated except A_e , the effective area of the target. This factor can be calculated by means of the following equation from reference (c):

$$A_e = \sqrt{\frac{\sigma \lambda^2}{4\pi}} \quad (4)$$

Values of A_e for the nose and the broadside aspects of the shell have been calculated at both X-band and S-band wavelengths. The values of the radar cross section used for these calculations were those referred to in paragraph 20 of this report.

25. By evaluating W_m , W_T , k_s , G_{RT} and A_e (in equation (2) as a ratio compared to the Radar Equipment Mark 22), a comparative evaluation of the expected performances of Radar Equipments Mark 22, Mark 13, AN/SO 12M, Mark 8 and SCR-584 A-B was made. These results are tabulated in Tables 1 and 2. The data reveal that for the broadside aspect, the maximum reliable range of the Radar Equipment Mark 13 should be 1.64 times higher than that obtained by the Radar Equipment Mark 22. By referring to Plates 1, 2, and 3 it can be seen that the ranges obtained with the Radar Equipment Mark 13 were higher than those obtained with the Radar Equipment Mark 22 in approximately the ratio quoted above.

26. The data reveal that for the broadside aspect the maximum reliable range performance of the Radar Equipment Mark 8 should be 0.37 times as high as that obtained by the Radar Equipment Mark 22. Using the value quoted in paragraph 16 of this report of 3500 yards for the maximum reliable range of the Radar Equipment Mark 22, a maximum reliable range of 1300 yards is what should be expected with the Radar Equipment Mark 8 Mod 2. This, then, explains why the Radar Equipment Mark 8 was not able to pick up any part of the mortar trajectory.

27. These data also reveal why the Radar Equipments SCR-584 and SO-12M outperform Radar Equipments Mark 22, Mark 13 and Mark 8 against this kind of target.

CONCLUSIONS

28. In conclusion, it is evident that neither the Radar Equipment Mark 8 Mod 1 nor the Radar Equipment Mark 8 Mod 2 offers promise of being a useful mortar locator. Radar Equipments Mark 12 and Mark 13 are capable of sufficient range, and if means of separating land echoes from the shell echo can be

devised, these radars may become practical mortar locators. The Radar Equipment Mark 22, though capable of separating the shell echo from the land signals, does not have sufficient range ability to become a practical mortar locator.

29. Of the radars considered, not one had both the necessary power and resolution to detect the mortar projectile at a useful range. No immediate modifications to improve this condition were known. In view of the fact that none of the radars had the ability to detect the mortar projectile at a useful range over land, an investigation of the operating techniques required to fit the radars for the role of mortar locators was not conducted.

RECOMMENDATIONS

30. It is recommended:

(a) That a more thorough study of the reflection pattern of mortar shells and other projectiles be made at wavelengths from K/4 to L-band.

(b) That a development program be assigned to investigate methods of separating land echoes from the mortar projectile echo.

(c) That the separating device be installed and operating techniques be developed which can be used with the radar to qualify it as an efficient mortar locator.

(d) That if this program is successful the development be continued to include artillery location and flying bomb location.

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REFERENCES

32. (a) BuOrd ltr S67(Re4f), Ser. 001413 to Director, NRL, "Request for Assignment of Problem 0-176R-S", dated 27 July 1945.
- (b) NRL secr ltr S-S67-7(399A), S-395-553/45, Serial No. 5403 to BuOrd, "Conference on Mortar Location held at Chesapeake Bay Annex on 3 August 1945", dated 12 September 1945.
- (c) NRL secr ltr S-S67-5(307) Serial No. 2645 dated 28 February 1944 forwarding report R-2232, "Radar Cross Section of Ship Targets, II", by W. S. Ament dated 18 February 1944.
- (d) Radiation Laboratory secr Report 433, "Optical Theory of the Corner Reflector", dated 2 March 1944.
- (e) NRL conf report RA 3A 208A, "Special Report on Minimum Detectable Radar Signal and its Dependence upon Parameters of Radar Systems", by A. V. Haeff, dated 23 February 1943.
- (f) NRL Logbook 4539.

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TABLE 1

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COMPARATIVE EVALUATION OF THE MAXIMUM RELIABLE RANGE

BROADSIDE VIEW OF 4.2-INCH MORTAR SHELL

	<u>Mark 22</u>	<u>Mark 13</u>	<u>SO 12M</u>	<u>Mark 8</u>	<u>SCR-584</u> <u>A-B</u>
W_T in Kilewatts	30	40	50	25	300
W_M in μ A-watts	2.73	0.508	0.20	0.754	0.164
K_S in db	* -4	-7	-2	-9	* -4
G_{RT} in db	36	37.5	40	28	33.3
A_e in square feet	0.308	0.308	0.308	0.274	0.274
Range Ratio Compared to Radar Mk 22	1.0	1.64	3.89	0.37	2.5

*Estimated

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TABLE 2

COMPARATIVE EVALUATION OF THE MAXIMUM RELIABLE RANGENOSE VIEW OF 4.2-INCH MORTAR SHELL

	<u>Mark 22</u>	<u>Mark 13</u>	<u>SO 12M</u>	<u>Mark 8</u>	<u>SCR-584</u> <u>A-B</u>
W_T in Kilowatts	30	40	50	25	300
W_M in $\mu\mu$ -watts	2.73	0.508	0.20	0.754	0.164
K_s in db	* -4	-7	-2	-9	* -4
G_{RT} in db	36	37.5	40	28	33.3
A_e in square feet	0.155	0.155	0.155	0.308	0.308
Range Ratio Compared to Radar Mark 22	1.0	1.64	3.89	0.55	3.7

*Estimated

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RADAR MARK 12 MOD. 1								RADAR MARK 13						
RANGE TO MORTAR (YDS.)	END - ON **				BROADSIDE *			END - ON						
	RUN 1	RUN 3	RUN 5	RUN 7	RUN 4	RUN 6	RUN 8	Ant. Elv. 1°24'	Ant. Elv. 2°40'	Ant. Elv. 5°	Ant. Elv. 5°24'	Ant. Elv. 1°24'	Ant. Elv. 2°40'	
2000						0								3
2200	1		1	0	0						3	2		2
2400		0				0	2			4		2		2
2600			1				2			4				
2800				2		2	3				0			2
3000	1	0	1		0	3			1					
3200				0		3	1				2	0		0
3400	1		1	3					0	2	1			
3600						0	1	0			2			
3800		1	1	2	<u>1</u>							0		2
4000	1			2	<u>0</u>	<u>2</u>		0	1	2	2			
4200				2							2			2
4400	2	2			0	0	1	0	<u>1</u>	<u>1</u>		0		<u>0</u>
4600			1				0				0			0
4800				2	0						0			
5000			1	0	1		0		0					0
5200		2												
5400	2			1			0	2	0		0	2		0
5600	1	1	1		0				0					
5800														1
6000		1	1/2		0									
6200	<u>1</u>	<u>1</u>	<u>1/2</u>		<u>1</u>									
6400														
6600														
6800														
7000		1												
7200														
7400		1												

** MORTAR FIRE AT 0° RELATIVE (END-ON) TO THE DIRECTION OF
 * MORTAR FIRE AT 90° RELATIVE (BROADSIDE) TO THE DIRECTION
 ===== MAXIMUM RELIABLE RANGE (ARBITRARY)

SIGNAL STRENGTH SHELLS FIRED OVER WATER FROM A BOAT

12/1/57

MOD. 0				RADAR MARK 22 MOD. 1												
BROADSIDE				END - ON						BROADSIDE						
Elv. 0'	Ant. Elv. 5°	Ant. Elv. 5°24'	Ant. Elv. 5°24'	RUN 1	RUN 3	RUN 5	RUN 7	RUN 9	RUN 11	RUN 13	RUN 2	RUN 4	RUN 6	RUN 8	RUN 10	RUN 12
4		2							4				2		3	2
						2	2	2	4		2	3			3	
2	2	3			3			3	4				2	2		1
		3				0					1	3		2	3	
		2	3				0		2				2	2		3
4				0	3	0		3	3	2	3	3			2	
		2	3				1/2		2	3			3	2		2
				2		0	0	2	0	1	2	2			1	
4	2	2					0		0				2	2		
2					2	0			1	2	2	1			1	2
2	2	2		2			0		0	2			2	1		
2							0		0	0	0	1			1	
		2	2	0	0		0	2					1/2	1		1
0		1				0	0	0		1	1	1		1		
							3									
2		1				0		0			0	0		0		
	0				0											
		0		2			1				0	0		0		
				0	0	2										
								2								
0																

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12/1/57

RADAR MK.22 MOD.1, RANGE

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TARGET ANGLE 90°							
ROUND	OBSERVED ELEVATION ANGLE						
	0	+1°	+2°	+3°	+4°	+5°	+6°
1	0	0	0	0	0	0	0
2	1	1	1	0	0	0	0
3	1	1	1	0	0	0	0
4	1	1	1	0	0	0	0
5	1	0	1	0	0	0	0
6	1	1	1	0	0	0	0
7	1	0	1	0	0	0	0
8	0	1	0	0	0	0	0
9	0	0	1	0	0	0	0
10	0	1	0	0	0	0	0
Avg.	0.6	0.6	0.7	0	0	0	0

TARGET ANGLE				
ROUND	OBSERVED ELE			
	0	+1°	+2°	+3°
1	1	1	2	0
2	1	2	2	2
3	1	1	2	2
4	1	1	2	2
5	0	1	2	2
6	1	2	2	2
7	1	2	2	3
8	1	2	2	3
9	0	0	1	1
10	0	2	2	2
Avg.	0.7	1.4	1.9	2.0

TARGET ANGLE 50°							
ROUND	OBSERVED ELEVATION ANGLE						
	0	+1°	+2°	+3°	+4°	+5°	+6°
1	0	1	1	1	1	1	2
2	0	0	0	1	0	0	1
3	NO OBSERVATIONS						
4	0	0	0	3/4	3/4	3/4	3/4
5	0	0	3/4	3/4	3/4	0	0
6	0	0	3/4	1	0	0	1
7	0	0	1	1	1	0	0
8	0	0	3/4	3/4	3/4	3/4	1
9	0	0	0	0	0	3/4	1
10	0	0	1	3/4	1	1	1
Avg.	0	0.1	0.6	0.8	0.6	0.4	0.9

TARGET AN				
ROUND	OBSERVED ELEV			
	0	+1°	+2°	+3°
1	0	0	3/4	0
2	0	0	0	0
3	0	0	0	0
4	0	3/4	3/4	0
5	0	0	0	0
6	0	0	0	0
7	0	0	0	3/4
8	0	0	0	0
9	0	0	0	0
10	0	0	0	0
Avg.	0	0.1	0.1	0.1

ASPECT INVESTIGATION ABOARD THE DESTROYER
INITIAL PART OF TRAJECTORY OVER LAND

RELATIVE SIGNAL STRENGTH
 RANGE TO MORTAR 4000 YDS.
 RADAR MK 22 Mod. 1. MORTAR 4.2 INCH

TARGET ANGLE 90°							
ROUND	OBSERVED ELEVATION ANGLE						
	0	+1°	+2°	+3°	+4°	+5°	+6°
1	0	0	0	0	0	0	0
2	1	1	0	0	0	0	0
3	0	0	0	0	0	0	0
4	0	0	3/4	3/4	0	0	0
5	1	0	1	3/4	0	0	0
6	0	0	0	0	0	0	0
7	0	3/4	0	0	0	0	0
8	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0
10	0	1	0	0	0	0	0
Avg.	0.2	0.3	0.2	0.1	0	0	0

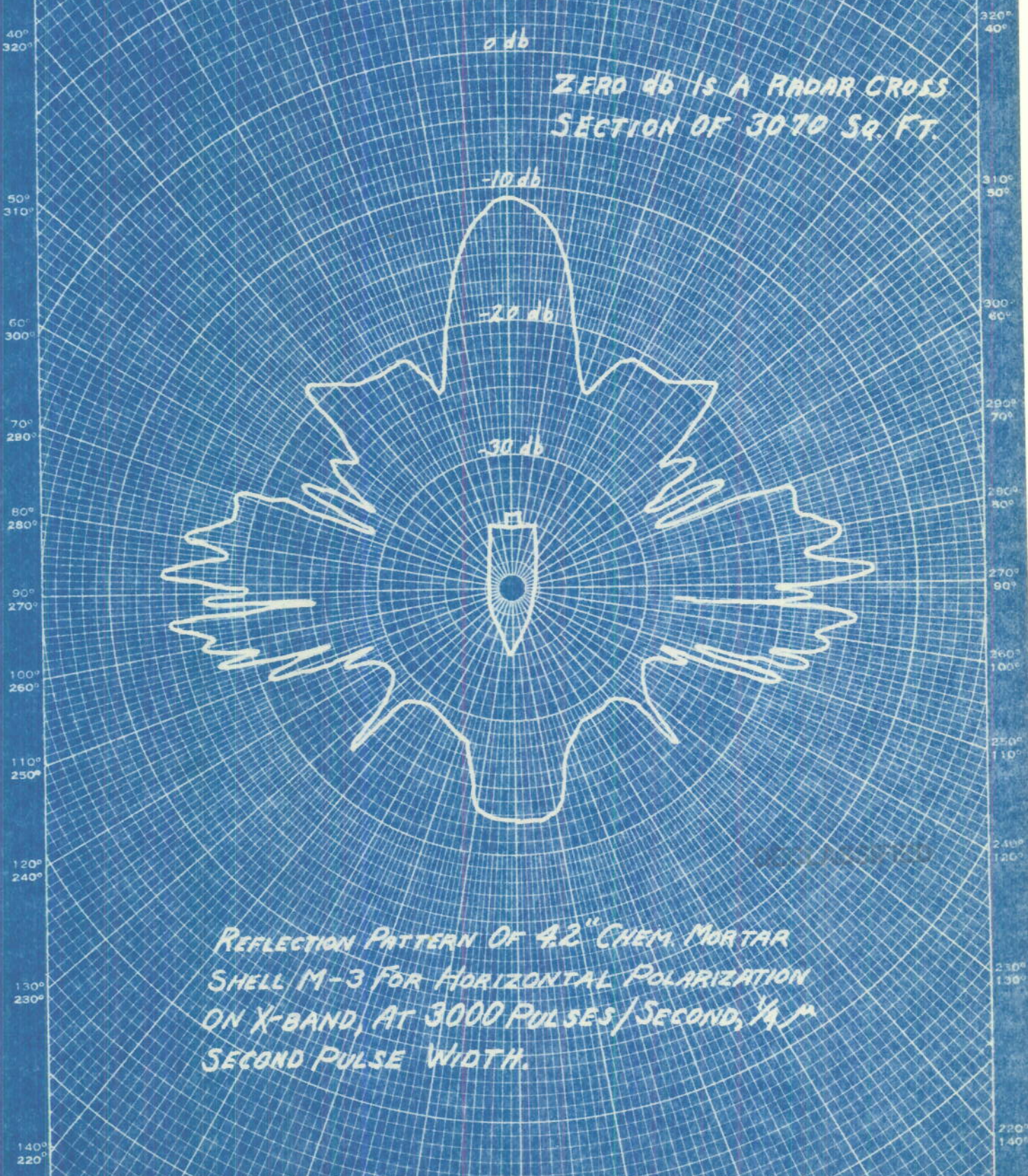
DECLASSIFIED

TARGET ANGLE 70°							
ROUND	OBSERVED ELEVATION ANGLE						
	0	+1°	+2°	+3°	+4°	+5°	+6°
1	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0
6	0	1	1	0	0	0	0
7	0	0	0	0	0	0	0
8	0	0	1	1	0	0	0
9	0	0	0	0	0	0	0
10	0	3/4	0	0	0	0	0
Avg.	0	0.1	0.2	0.1	0	0	0

DECLASSIFIED

ASPECT INVESTIGATION ABOARD THE DESTROYER
 INITIAL PART OF TRAJECTORY OVER LAND

30° 20° 10° 0° 350° 340° 330°
330° 340° 350° 10° 20° 30°



ZERO db IS A RADAR CROSS SECTION OF 3070 SQ. FT.

REFLECTION PATTERN OF 4.2" CHEM. MORTAR SHELL M-3 FOR HORIZONTAL POLARIZATION ON X-BAND, AT 3000 PULSES/SECOND, $\frac{1}{4}$ μ SECOND PULSE WIDTH.

150° 140° 130° 120° 110° 100° 90° 80° 70° 60° 50° 40°
210° 200° 190° 180° 170° 160° 150°

30°
330°

20°
340°

10°
350°



350°
10°

340°
20°

330°
30°

40°
320°

50°
310°

60°
300°

70°
290°

80°
280°

90°
270°

100°
260°

110°
250°

120°
240°

130°
230°

140°
220°

320°
40°

310°
50°

300°
60°

290°
70°

280°
80°

270°
90°

260°
100°

250°
110°

240°
120°

230°
130°

220°
140°

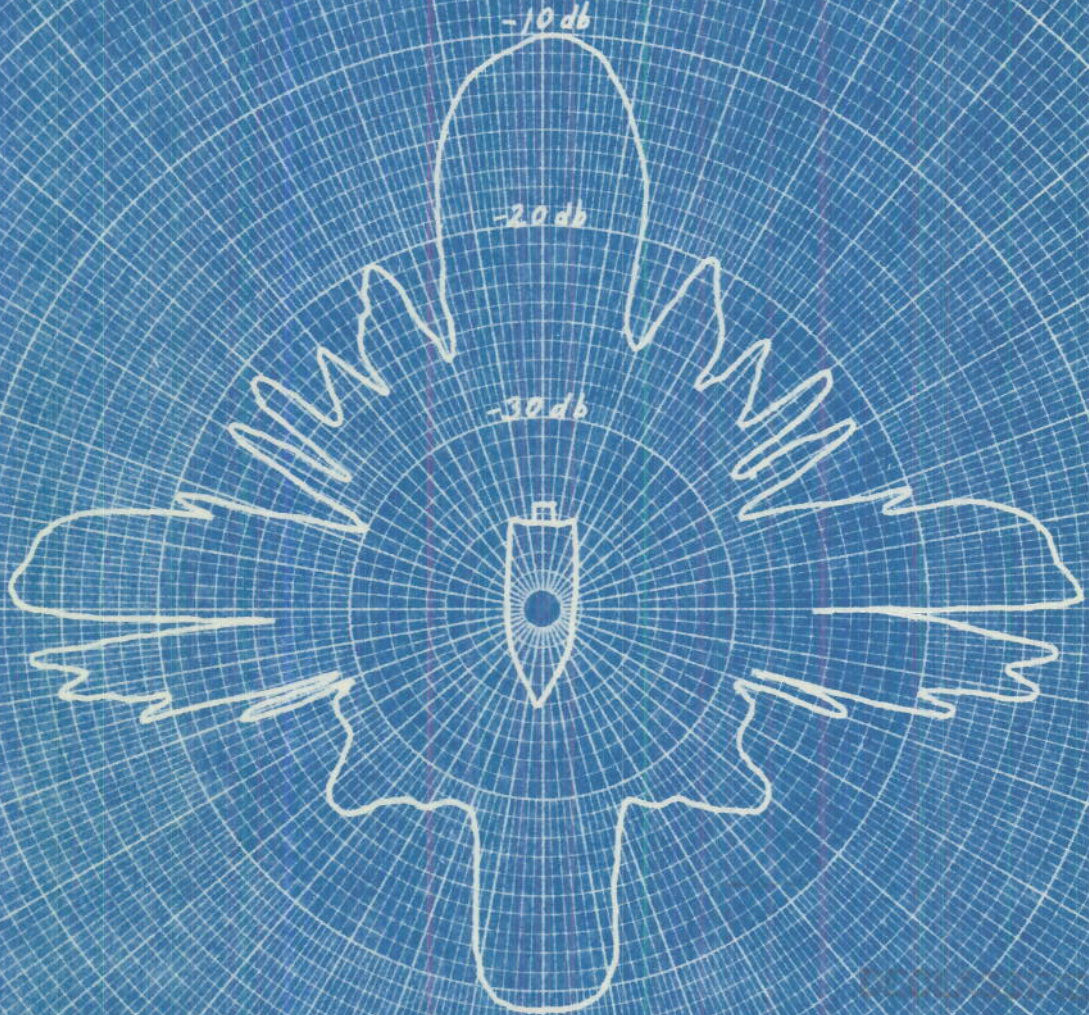
0 db

ZERO db IS A RADAR CROSS SECTION OF 3070 SQ. FT.

-10 db

-20 db

-30 db



REFLECTION PATTERN OF 4.2" CHEM. MORTAR SHELL M-3 FOR VERTICAL POLARIZATION ON X-BAND, AT 3000 PULSES PER SECOND, 1/4 μ SECOND PULSE WIDTH.

SECRET	NRL FIRE CONTROL DIVISION		PLATE 5
	12 SEPT. 45 R2651		

150°
210°

140°
200°

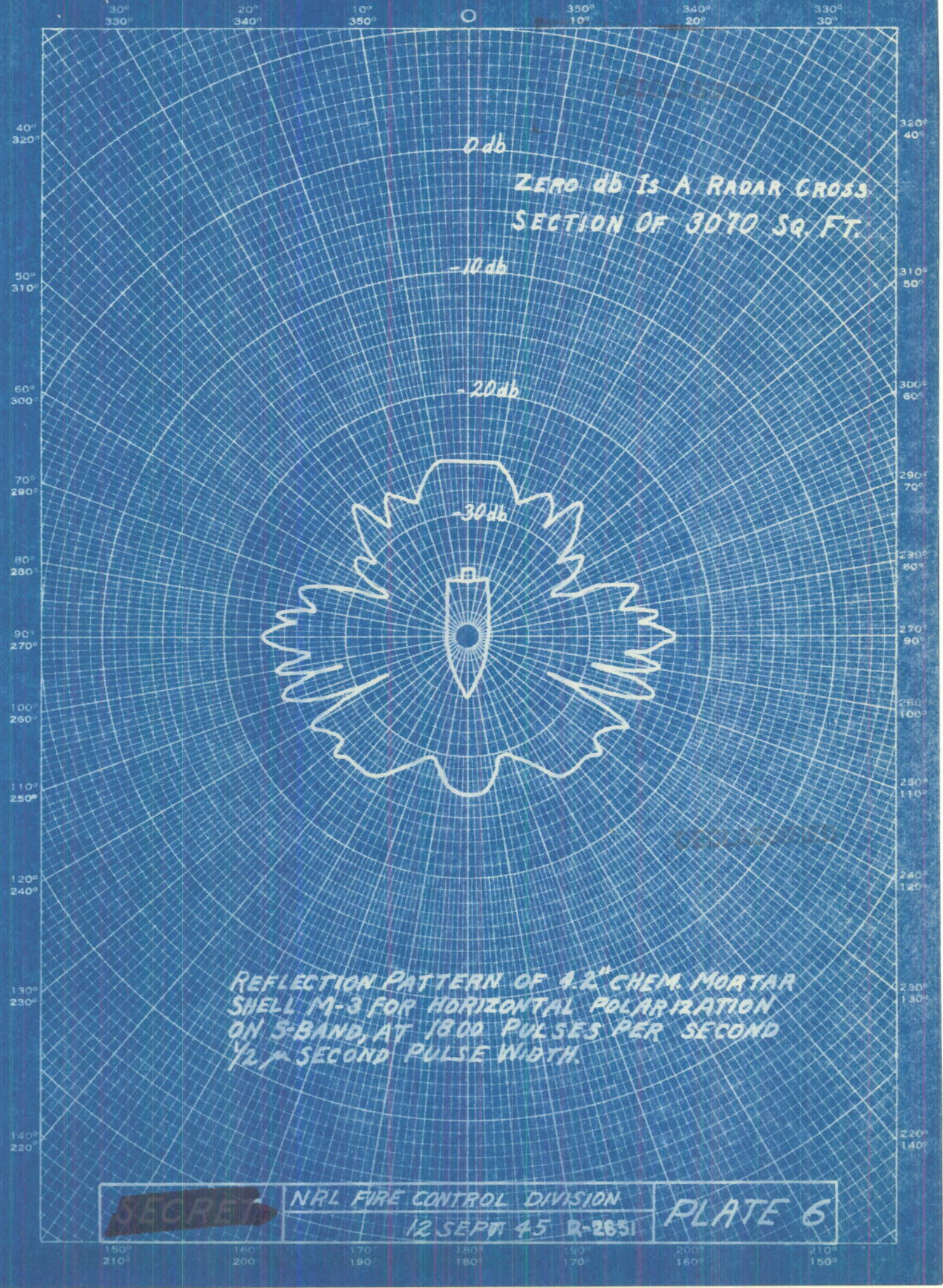
130°
190°

120°
180°

110°
170°

100°
160°

90°
150°



0db

ZERO db IS A RADAR CROSS SECTION OF 3070 SQ. FT.

-10db

-20db

-30db

REFLECTION PATTERN OF 4.2" CHEM. MORTAR SHELL M-3 FOR HORIZONTAL POLARIZATION ON S-BAND, AT 1800 PULSES PER SECOND $\frac{1}{2}$ SECOND PULSE WIDTH.

30°
330°

20°
340°

10°
350°



350°
10°

340°
20°

330°
30°

40°
320°
50°
310°
60°
300°
70°
290°
80°
280°
90°
270°
100°
260°
110°
250°
120°
240°
130°
230°
140°
220°

320°
40°
310°
50°
300°
60°
290°
70°
280°
80°
270°
90°
260°
100°
250°
110°
240°
120°
230°
220°
140°

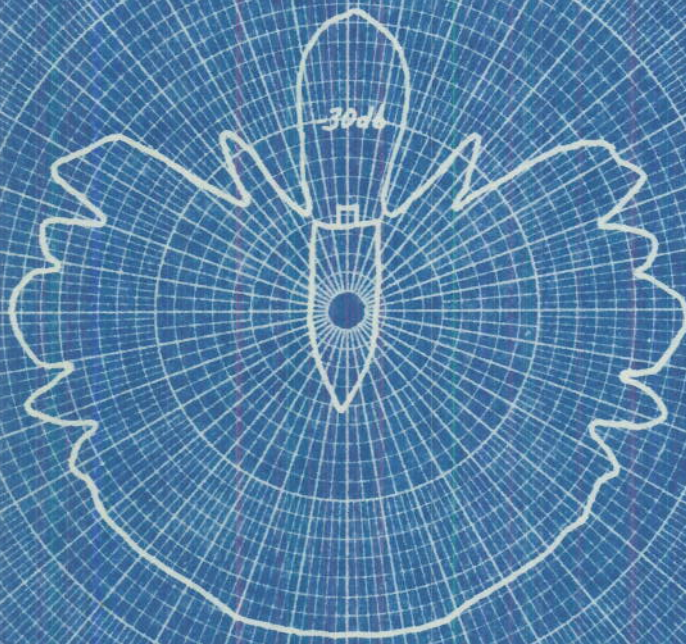
0 db

ZERO db IS A RADAR CROSS SECTION OF 3070 SQ. FT.

-10 db

-20 db

-30 db



REFLECTION PATTERN OF 4.2" CHEM. MORTAR SHELL M-3 FOR VERTICAL POLARIZATION ON S-BAND, AT 1800 PULSES PER SECOND, 1/2 μ SECOND PULSE WIDTH.

SECRET | NRL FIRE CONTROL DIVISION | 12 SEPT 45 R-2651 | PLATE 7

150° 210° | 160° 200° | 170° 190° | 180° 180° | 190° 170° | 200° 160° | 210° 150°