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NAVY DEPARTMENT

BUREAU OF ENGINEERING

Report

on

Absorption Coefficients of Supersonic Sound in Open Sea Water.

NAVAL RESEARCH LABORATORY
ANACOSTIA STATION
WASHINGTON, D.C.

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Date of Tests: 30 January to 9 March 1939.

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H. M. Cooley, Captain, USN, Director.

Distribution:
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INTRODUCTION

1. This expedition was in part a continuation of a program of surveying strategic areas to study the water conditions affecting underwater sound transmission and reception. Previous expeditions had covered the North and Central Atlantic and Guantanamo-Cuba areas. This expedition covered the areas adjacent to the Panama Canal. Three areas were selected on the Atlantic side and three on the Pacific side, all beyond the 100 fathom curves, and so distributed as to divide the approaches into three approximately equal areas. Each area was occupied for a period of 24 hours and an average of nine runs was made in each period.

2. The theoretical basis for this work and the experimental routine are given in detail in previous reports on absorption coefficients (Reference 1). Certain new items in technique may be noted here.

3. An automatic recorder was used on the S-20 which gave a continuous record of the intensity of the signal transmitted by the SEMMES as she steamed towards the S-20 from a maximum range of about 14,000 yards. The zero decibel level on the recorder was maintained constant on all runs at 0.1 microvolts delivered by the D-2 type pick-up on the S-20 to the input of the amplifier. By the use of an attenuation box in the input to the amplifier, and by taking the recorder lead from the amplifier detector grid, the signal strength was always kept within the linear range of the amplifier and recorder. The zero range level was also measured in February and March, but is not used in calculating α , which is based on the slope of the range-intensity curve.

4. A platinum resistance thermometer with 250 feet of cable was used to measure the temperatures. The bridge was calibrated to read directly in degrees Fahrenheit to 0.01 degree. At the conclusion of each run temperatures were measured at 0, 0.5, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 12, 14, 16, 18, 20, 25, 30 and 35 fathoms. There is some uncertainty about the depths below 20 fathoms due to the drift of the ship while lying to.

5. An attempt was made to use a newly developed bathythermograph to record automatically both pressure and temperature, but it did not prove satisfactory under the working conditions.

6. In calculating the ship's speed during the approach runs in a given area, all the RAR data for the same r.p.m. were averaged and used on all runs at that speed, instead of using the RAR values for each run singly. This materially reduced the labor of plotting the curves and improved the average accuracy of the absorption coefficients. The velocity of sound for the RAR calculations was taken as that for the average surface temperature during the period (Reference 2).

Ref. 1 NRL Report No. S-1204 of 16 October 1935.
NRL Report No. S-1466 of 12 August 1938.
Ref. 2 Underwater Sound in Northern Waters, NRL file C-S68/86.

RESULTS

7. The original data are plotted on Plates 1 to 58 as range-intensity curves and temperature-depth curves with notations as to the number of the run, the date, time, sea, sky and wind conditions and the calculated values of the loss coefficient, α , for each frequency. Each point on a range-intensity curve represents the average value of the sound intensity, as read from the recorder tape, for a period of one minute.

8. The loss coefficient, α , is taken as the slope in decibels per kiloyard of the "best" straight line between 1000 and 10,000 yards on the Atlantic side. The drawing of this particular line is somewhat arbitrary and involves considerable judgment in certain cases. An attempt was made to be consistent for comparative purposes and the 1000 to 10,000 yard interval gave the most consistent results.

9. On Plates 29 to 30 the temperature gradients at different depths and α are plotted against clock time to show the relation between gradient and α .

DISCUSSION OF RESULTS ON THE ATLANTIC SIDE

10. The data for the Atlantic side are generally comparable with those obtained in the Guantanamo area in 1938. It is usually possible to get an average value of α from 1 to 10 kiloyards, though nearly all curves show considerable fluctuations from the mean value. A summary of the loss coefficient data is given in Table 1.

TABLE 1

SUMMARY OF LOSS COEFFICIENT DATA
ATLANTIC SIDE

Area	Date	Median Time	Loss Coefficient α = db/kyd. 17.7 Kcs.	23.6 Kcs.	Ratio α 23.6/α 17.7
B	30 Jan.	1617	3.5		
		1819	4.6		
		2026	4.4		
		2224	6.2	7.8	1.26
	31 Jan.	0026	7.6	9.1	1.20
		0245	6.8	7.2	1.06
		0613	5.0	5.1	1.02
		0818	4.0		
		1020	5.0		
Area		Average -	5.23	7.30	
C	31 Jan.	1238	3.5	4.2	1.20
		1611	5.7		
		1845	4.0	5.4	1.35
		2247	3.5	6.2	1.77
	1 Feb.	0214	5.6	8.4	1.50
		0534	4.5	6.0	1.33
		0810	5.6	6.7	1.20
		1016	5.5	7.4	1.35
Area		Average -	4.74	6.33	
A	2 Feb.	1041	7.6		
		1324	6.0		
		1542	5.5	6.1	1.11
		1907	5.7	6.9	1.21
		2139	6.8	8.0	1.18
	3 Feb.	0012	5.3		
		0210	5.8		
		0406	6.6		
		0541	5.1		
		0920	5.3		
Average			5.97	7.00	1.27
Grand Average			5.33 ±0.60	6.74 ±0.50	1.27
Guantanamo Feb.-Mar. 1938			4.06	6.00	1.48
Ratio Panama to Guantanamo			1.31	1.17	.85

11. For comparison the results at Guantanamo in February - March 1938 and the ratios of the coefficients for 23.6 kilocycles to 17.6 kilocycles in the two areas are also given. The higher average loss coefficient in Panama may be explained as due to much larger temperature gradients and to larger swells and white-caps from the sweep of the wind across the open Caribbean. It is also probable that the water is more disturbed by surface and deep water currents in the Panama area. While the loss coefficient for 23.6 kilocycles is always greater than for 17.6 kilocycles on the same range-intensity run, the ratio is less at Panama than at Guantanamo. The difference would appear to be greater than the experimental error, but there is no obvious explanation.

12. A notable characteristic of nearly all the curves is the wide fluctuation in intensity from the mean value. The fluctuations are a complex combination of short time and long time effects. For example, a common case like Run 17 gives the following values of α for successive 1000 yard intervals.

TABLE 2

Kiloyard Interval	α = db/kyd.
1-2	+ 8
2-3	+10
3-4	-23
4-5	+32
5-6	-14
6-7	+29
7-8	- 2
8-9	-10
9-10	+11
1-10 mean	+ 5.6

where negative α means an increase in intensity with range. In an extreme case like Run #27 short range values for α may run as high as $\pm$100 db/kyd. On the original tape short time swings of 15 db/sec. are common corresponding to values for α of $\pm$5 db/yd. or 1000 times the average value.

13. These rapid fluctuations lead to the conclusion that the intensity at any point is the resultant of a combination of two or more rays or paths, a direct ray, a reflected ray, and a refracted ray, at times in phase producing reinforcement and at times more or less out of phase producing interference, but at all times suffering loss through

absorption, scattering, reflection, or refraction. These effects may be different for the different paths. This opinion is confirmed by a detailed study of the continuous record. For short periods, either the high values of intensity or the low values may be steady with only a few decibels fluctuation, but the intermediate values fluctuate rapidly and irregularly from second to second by as much as ±20 decibels. This is evident on the short sections of tape shown on Plate 59. Since the usual ship's speed was 3 to 4 yards per second and the wavelength of underwater sound at 17.6 kilocycles is 3.3 inches, it is obvious that rapid fluctuations are possible if there are two or more waves traveling by different paths. Two paths are always present - the direct path and the path of the ray reflected from the air-water surface. Due to the roughness of this surface from ripples, swells or white-caps, this sound is generally diffused or scattered, but for short periods of seconds or less may give specular reflection. There is also a 180° phase displacement for this type of reflection.

14. A third path may also be present if there is a temperature inversion as was common on the Atlantic side, e.g., runs 17 and 27. Since sound travels faster in warm water than in cold, the lower half of the beam which tends to spread downward even with no gradient will be refracted upward by this warm layer to reinforce or interfere with the direct signal and with the signal reflected from the air-water surface. Where there are large inversions as in runs 11, 17 and 27, the range-intensity curves are generally characterized by relatively high levels, maintained to long ranges and also by relatively large and roughly periodic swings in intensity. The wind velocity is relatively low - 10 kts. or less for these runs. Also the peaks and valleys of the 24.6 kilocycle curve follow quite closely those of the 17.6 kilocycle curve. In run 21 with less marked inversion, the two frequencies are quite different. For runs 24 to 28 inclusive, readings were taken on 17.7 kilocycles only to develop the curve more in detail from the continuous record, but there was no significant change in form.

15. An interesting point to be noted on the temperature versus depth curves is that from 1700 on 31 January to 1050 on 1 February the maximum temperature of the inversion point between 10 and 15 fathoms was always higher than the surface temperature at the given time, and that on run 26 the peak inversion temperature was higher than any temperature measured in the period 31 January - 3 February. Apparently the wind did not reach sufficient velocity effectively to stir the water down to the 15 fathom level. The maximum wind recorded was 14 - 15 kts. and it was generally less than 10 kts. For this warm layer between 10 and 15 fathoms to persist for nearly a week between two colder layers seems to require a compensating change in salinity, but no data are available on this point.

16. The general effect of a temperature inversion of 0.2°F or more is to keep the major portion of the sound energy in the upper layer of water above the inversion point. The instantaneous values may fluctuate rapidly due to reinforcement or interference, but the general level is high. The average intensity at 10,000 yards is 40 decibels for all runs at 17.7 kilocycles and in several cases it is up to 70 decibels.

17. The subject of reflection coefficients is being covered in a separate report, but it may be stated here that during the period 3-7 February echoes were consistently obtained at 3000 yards and occasionally at 4000 yards or more when the submarine was on the surface or at periscope depth. At 60 feet the maximum range was approximately 1500 yards and at 100 feet no echoes were obtained at all. The temperature depth curves on runs 27 and 28 show large temperature inversions on 3 February. The temperature-depth data taken on 6 and 7 February are given on Plate 31 and show large gradients at the 10 - 15 fathom level with an inversion near 5 fathoms when the best echoes were obtained on 6 February. These data therefore confirm the explanation given in the preceding paragraph and indicate the tactical importance of this type of information.

DISCUSSION OF RESULTS ON THE PACIFIC SIDE

18. Runs 29 to 54 were made in three areas on the Pacific side beyond the 100 fathom curve approximately on a line between Capa Mala and Pinas Bay during the period 28 February to 9 March 1939. The range-intensity curves are generally characterized by an initially low level, a rapid drop in the first 2000 or 3000 yards, and a very slow decrease beyond this point. In general separate values of α are shown for 1000 to 3000 yards and for 3000 to 10,000 yards. A summary of the loss coefficients α and also the decibel level at 1000 and 10,000 yards is given in Table III.

TABLE 3

SUMMARY OF AVERAGE, PACIFIC SIDE

		Loss Coefficients				Db Level for 17.6 kcs.		Wind Velocity in Knots
		1000 to 3000 yds.		3000 to 7000 yds.		Yards		
Area	Date	17.7 kcs.	23.6 kcs.	17.6 kcs.	23.6 kcs.	1000	10,000	
A	2-3 Mar.	13.6	16.0	6.1	6.3	93	21.6	12
B	28 Feb.-1 Mar.	20.0	24.0	2.0	2.9	80	24.0	17
C	8-9 Mar.	24.7	26.6	3.1	3.6	90	22.0	19
Average		19.4	22.2	3.7	4.3	88	22.5	16

19. The temperatures of the waters of Panama Bay are determined in a complicated way by the combination of solar radiation, ocean currents, wind, tides, bottom contours, salinities, animal or vegetable growth and doubtless other factors. The cold Humbolt current running north or northwest along the Pacific coast of south and central America maintained a fairly constant temperature of approximately 60°F. at 20 fathoms depth during the period 28 February - 9 March. The surface temperature followed a daily cycle from a minimum of 66°F. at about 0200 to a maximum of 72°F.

at about 1500 averaging about 68°F. for the period. This is approximately 10°F. colder than the average surface temperature measured on the Atlantic side during the period 28 January - 3 February. The outstanding feature, however, is the high temperature gradients frequently reaching values as high as 1.2°F. per fathom around the 5 fathom curve. It should be noted that the temperature scale on the temperature-depth curves for the Pacific side is five times the scale used on the Atlantic side. Occasionally a temperature inversion was found on one run, but it did not persist until the next one.

20. In spite of the obvious effect of the temperature gradients on sound transmission, there is no consistent simple correlation between the gradients and the loss coefficients as was found on the Atlantic side.

21. The wind velocity was generally high averaging 16 knots and reaching a maximum of 24 knots. The direction was consistently within 15 degrees of North. It was noted, however, that the swells were not so high as on the Atlantic side and that white-caps appeared generally at about 14 knots as compared with 10 knots on the Atlantic side. During runs 29 to 36 while the S-20 was lying to she drifted some 30 miles in 20 hours or at a rate of 1.5 knots in an average wind of 17 knots.

22. It is a matter of common knowledge in Coco Solo that submarines making deep dives in Panama Bay may have to take on 5000 to 10,000 pounds of ballast after they have a good trim at periscope depth before they can submerge to greater depths. This is contrary to the general rule or to experience on the Atlantic side at Coco Solo. Attempts to compute the effects of temperature and pressure on the water and the submarine do not give values corresponding to the experience stated above, so it seems reasonable to assume that the deeper, colder water of the Humbolt current has a higher salinity than the shallow warm layer near the surface. The effect would be enhanced by rainfall, or run off from the adjacent land, and the thermal gradient would delay the mixing. Also the stirring action of the north wind at this season was not as effective as in the open Caribbean, as may be seen by a comparison of the temperature-depth curves in the two areas.

23. The high initial value of α, averaging 19.4 decibels per kiloyard for 17.6 kilocycles for the 1000 to 3000 yard interval of the range-intensity curve, can be explained as due to the large temperature gradient at the boundary between the shallow warm layer and the colder water below, which effectively drains the sound energy out of the upper layer. The low value of α averaging 1.5 decibels per kiloyard for 17.6 kilocycles on runs 31 to 35 and 46 to 49 for the 3000 to 10,000 yard range, may be explained on the assumption of relatively high salinity in the deeper, colder water. Since the velocity of sound increases with salinity and depth (reference 2) a certain portion of the energy refracted downward from the upper layer will be refracted upward from the more dense region to reach the receiver on the surface ship at longer ranges. While the intensity level is relatively low at 20 to 30 decibels, it is also relatively uniform, indicating in general a single path rather than a combination of two or more as found on the Atlantic side with a temperature inversion.

24. In addition to the vertical temperature gradients there was considerable evidence of horizontal gradients although these were not specifically measured. The injection water temperature on the SEMMES frequently varied in short periods of time. Readings of the thermometer on raising seldom checked the temperatures found on lowering as the ship was drifting all the time. The S-20 reported great difficulty at times in maintaining an even keel when running submerged, although normally her trim was good. This effect is believed to be due to the strong cold current running over a ridge and being given an upthrust that carried it into the warmer layer. There would be both a thermal and a current effect on the submarine and a horizontal temperature gradient would be found.

25. Certain areas in Panama Bay are conspicuous for the "red" water. These areas are patches of varying sizes up to several square miles. Several range runs were made through such areas, but the loss coefficients were so high and variable throughout the day that it was impossible to determine the effect of the red water itself. It seems probable that the same conditions that produce poor sound conditions are also favorable for the growth of these microscopic plants and that they are an indication rather than a cause of poor transmission.

26. The two temperature-depth curves on Plate 58 were taken during experimental torpedo firing by the S-20 as points about 20 miles west of the Perlas Islands. Listening conditions were fair on 24 February and good on 25 February. On the latter day the torpedoes could be picked up where fired by the S-20 or approximately 4000 yards and followed to the SEMMES which was the target. Since the water was relatively shallow the long range sound may have been reflected from the bottom as the temperature-depth curves would indicate poor direct transmission in deep water. No echoes were obtained at 3000 to 4000 yards from the S-20 submerged at periscope depth.

SUMMARY OF EXPERIMENTAL DATA ON THE TRANSMISSION OF SOUND THROUGH WATER.

27. The mass of data collected during the past six years with continuously improving measuring equipment and technique and covering areas with widely different characteristics warrants certain statements concerning the transmission of sound through open sea water that are summarized here for convenience.

(a) Sea water cannot in general be considered the homogeneous medium which the simple laws of wave transmission assume.

(b) Temperatures and temperature gradients vary widely in amount and with time. The time variations are seasonal, diurnal, or irregular due to winds and currents.

(c) Salinities are known to vary with location, depth and time, but little quantitative salinity data have been taken to correlate simultaneously with the sound data.

(d) The wind is an important, though irregular, factor because of its stirring action on the water which may extend to a depth of 200 feet or more and profoundly modify the temperature gradients.

(e) Animal or vegetable growth, both microscopic and macroscopic, may affect sound transmission, but the effect has not been measured positively or quantitatively.

(f) Turbulence is common and may be fine grained or coarse grained. It may be caused by the wind or by ocean currents, particularly where there is a relative movement between the surface layer and the deeper water.

(g) The sound beam is subject to absorption, reflection, refraction and scattering, operating according to the common laws of physics, but combining in complicated ways to determine the instantaneous value of the intensity at a given point.

(h) The numerical values for the pure absorption coefficient of homogeneous sea water which may be calculated from its physical constants according to classical theory are 100 to 1000 times smaller than the loss coefficients determined experimentally. The other items given in (e) to (g) above are, therefore, important causes of loss.

(i) Range-intensity curves, where decibels (log intensity) are plotted against range between 500 and 10,000 yards or more, may be divided into three broad or general types for which equally broad or general explanations may be given.

(j) The first type shows a linear relation between decibels and range with a generally high level and with only small variations. It is obtained where the temperature gradient is small or zero down to 100 feet or more and the surface has a light chop or ripples. The temperature gradient causes little if any downward refraction of the beam and the ripples scatter the sound reflected from the air-water surface so that it does not interfere with the direct signal. Run 14, Plate 14, is a typical example.

(k) The second type may show an average linear relation between decibels and range, but the instantaneous value may vary widely from the average in a somewhat periodic way. The average level is not quite as high as for the first type, but the peaks may reach surprisingly high values at long ranges. This type of curve is usually found where there is a small ~~positive~~ negative temperature gradient (decrease of temperature with depth) near the surface and a ~~negative~~ positive temperature gradient, or inversion, at lower depths. The surface gradient bends the beam downward, but the inversion bends it upward again and since there may be many paths of different length, there are strong reinforcements and interferences as indicated by the fluctuations in the curve. Run 11, Plate 11, is a typical example.

(l) The third type of curve shows a very rapid drop at 5 to 100 times the normal rate to a low value in the first few thousand yards and usually a subnormally low decrease thereafter. The first effect is due to a large ~~positive~~ negative temperature gradient in the shallow surface layer that effectively drains the sound energy out of this layer, or bends the beam so that it passes under a receiving ship at shallow depths. If there is a considerable increase in salinity or density with depth the beam may be refracted upward and a low level signal will be maintained at the longer ranges. Run 32, Plate 35, is a typical example of this type.

(m) While three general types of range-intensity curves may be distinguished there are many graduations or combinations between them and no exact or consistent correlation of any type with season and place is possible unless additional data on sea, sky, wind, temperatures and salinities are also known and considered.

(n) Water conditions are and will be the dominant factors in determining the ranges attained by sound equipment. Increased sound output or increased receiving sensitivity give a proportional gain in range under ideal conditions, but under unfavorable conditions, such as the extreme temperature gradients found on the Pacific side in Panama, they are ineffective because the beam does not strike the target.

(o) For the installations on the SEMMES and S-20 during 1938 at Guantanamo and 1939 at Panama, broadside echoes were generally obtained by the SEMMES at 10 knots or less on the 17.6 kilocycle equipment from the S-20 on the surface or at periscope depth if the direct signal intensity at the S-20 was 60 $\pm$ 5 db. or more. Thus an estimate of the echo ranges may be obtained from the range-intensity curves. This experimental value of 60 $\pm$ 5 db. applies accurately only to these two ships under the conditions stated, but should be approximated by any QC equipment in good condition and under the same conditions. If, however, the speed of the searching ship is increased so that the background of noise is raised 10 decibels, then a 70 decibel level is necessary to hear echoes. If the submarine is below a temperature inversion the echo range is extremely short or zero. The target angle is also a big factor.

CONCLUSIONS

28. From the data presented above, it is concluded:

(a) Water conditions are a major factor in the transmission of sound through water.

(b) Water conditions vary widely and rapidly with time and place and accurate classifications are not possible.

(c) Experimental determination at the particular time and place by sound methods is the most practical means of obtaining sufficiently accurate data for planning a sound tactical program.

(d) In the absence of exact data at the particular time and place, a rough estimate of conditions to be anticipated may be obtained from this and previous reports.

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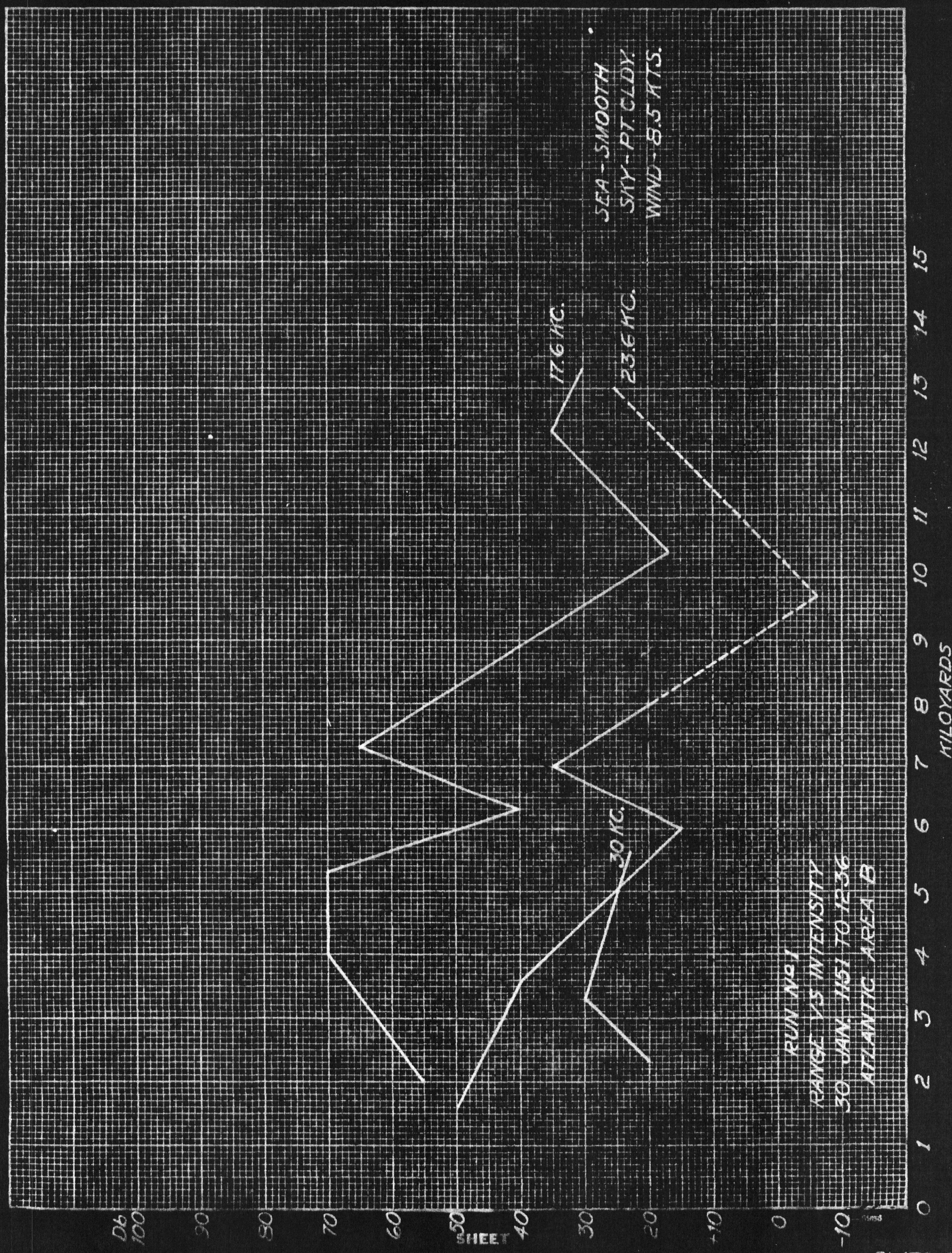

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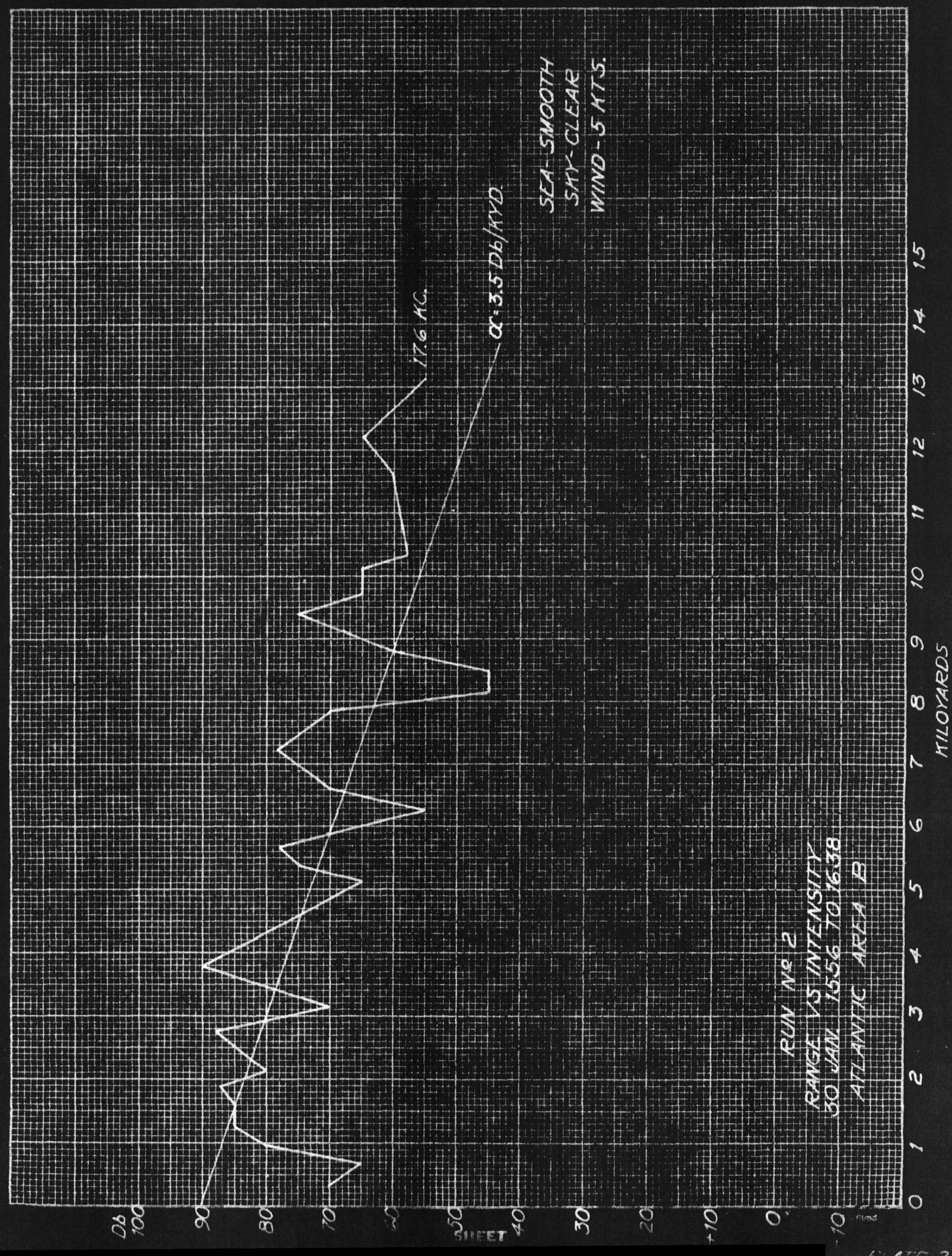

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PLATE 2

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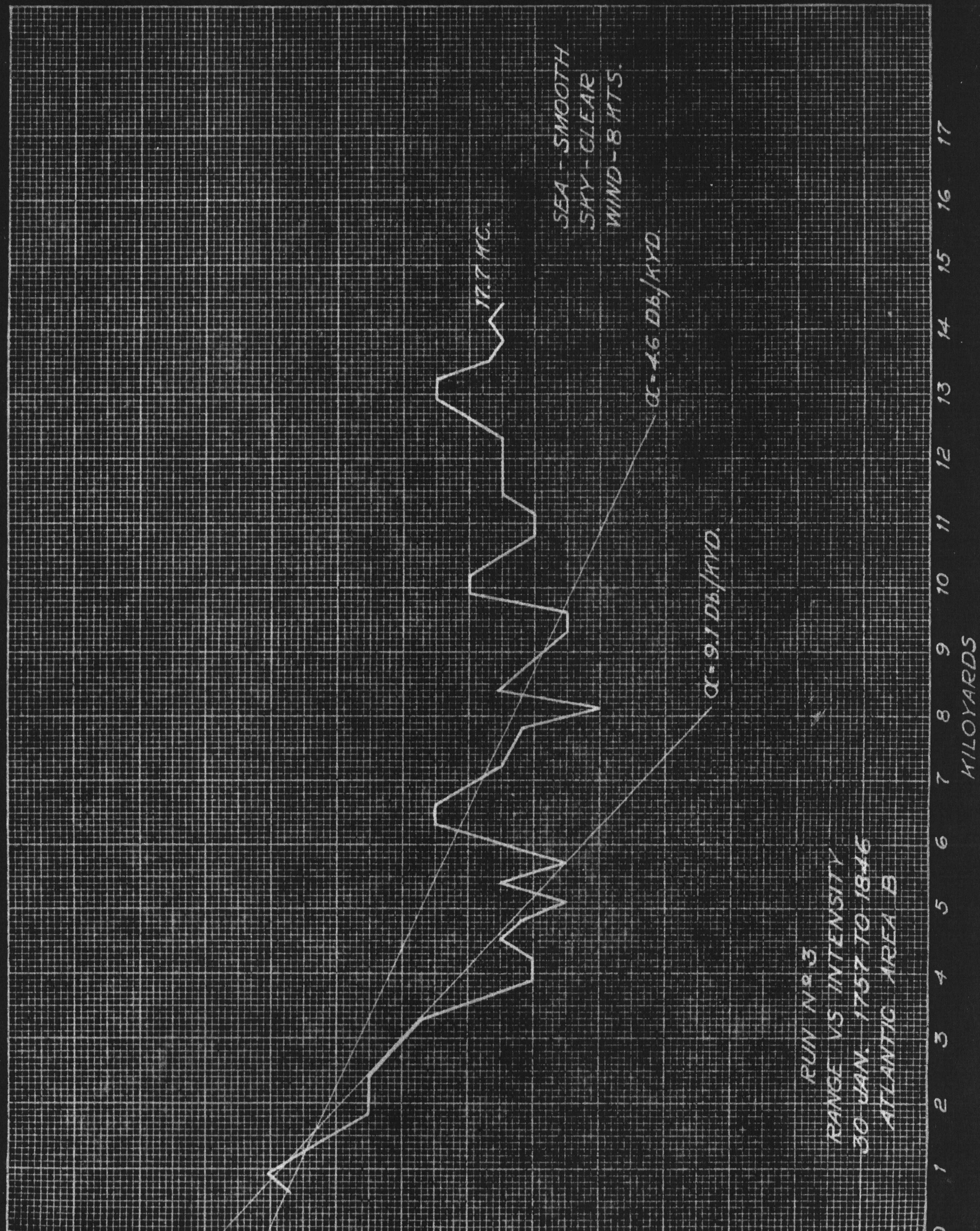

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PLATE 3

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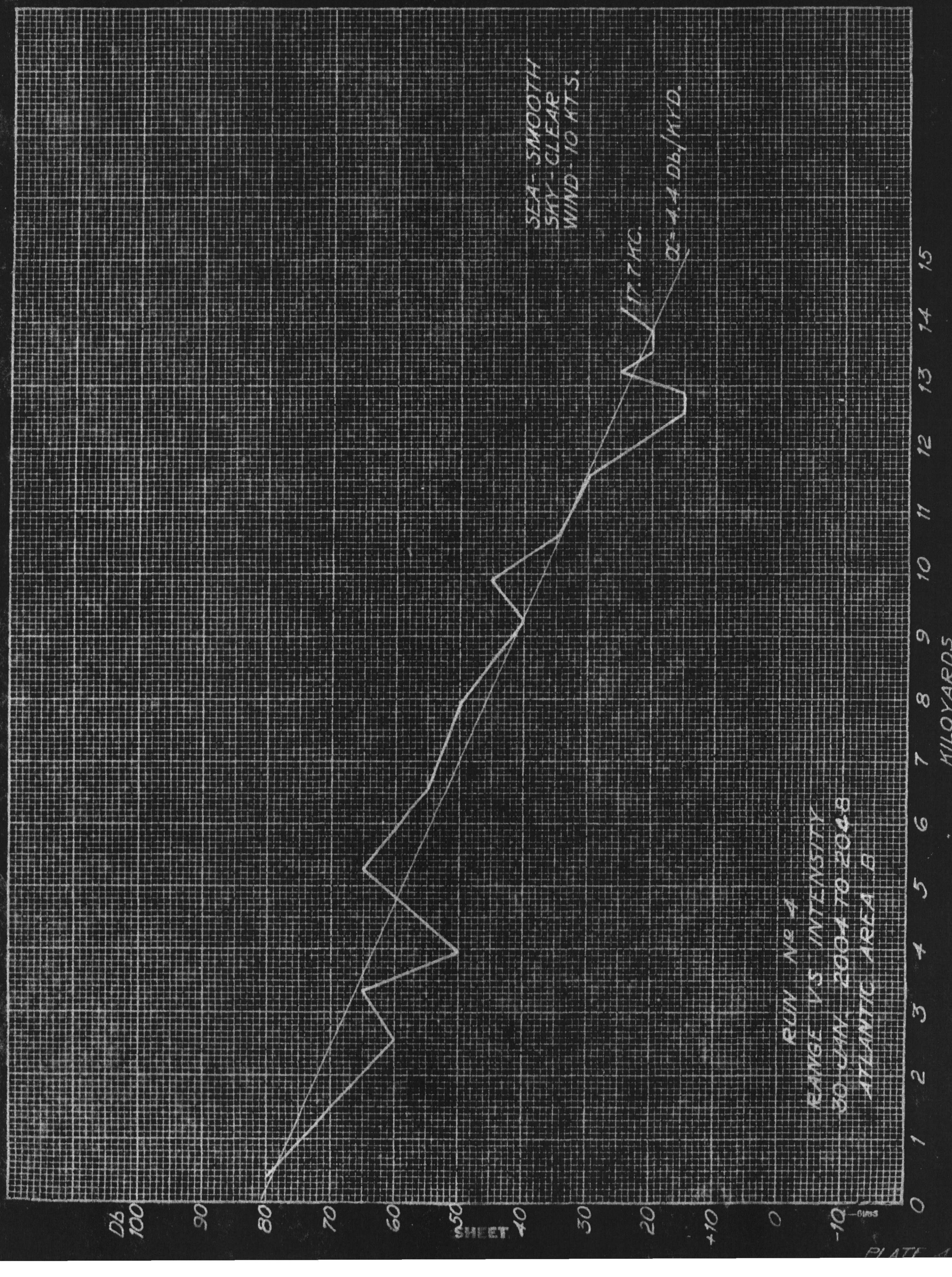

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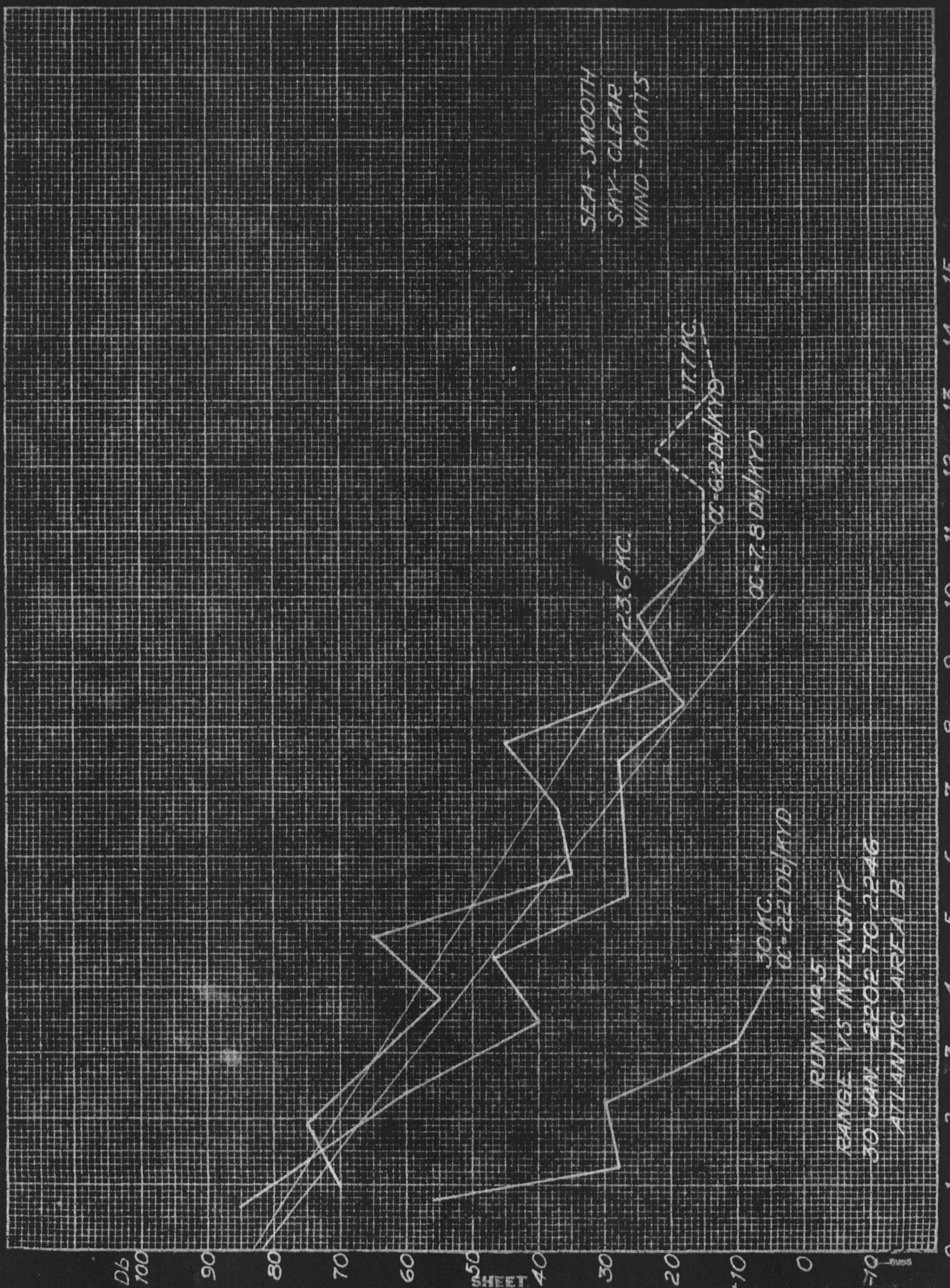

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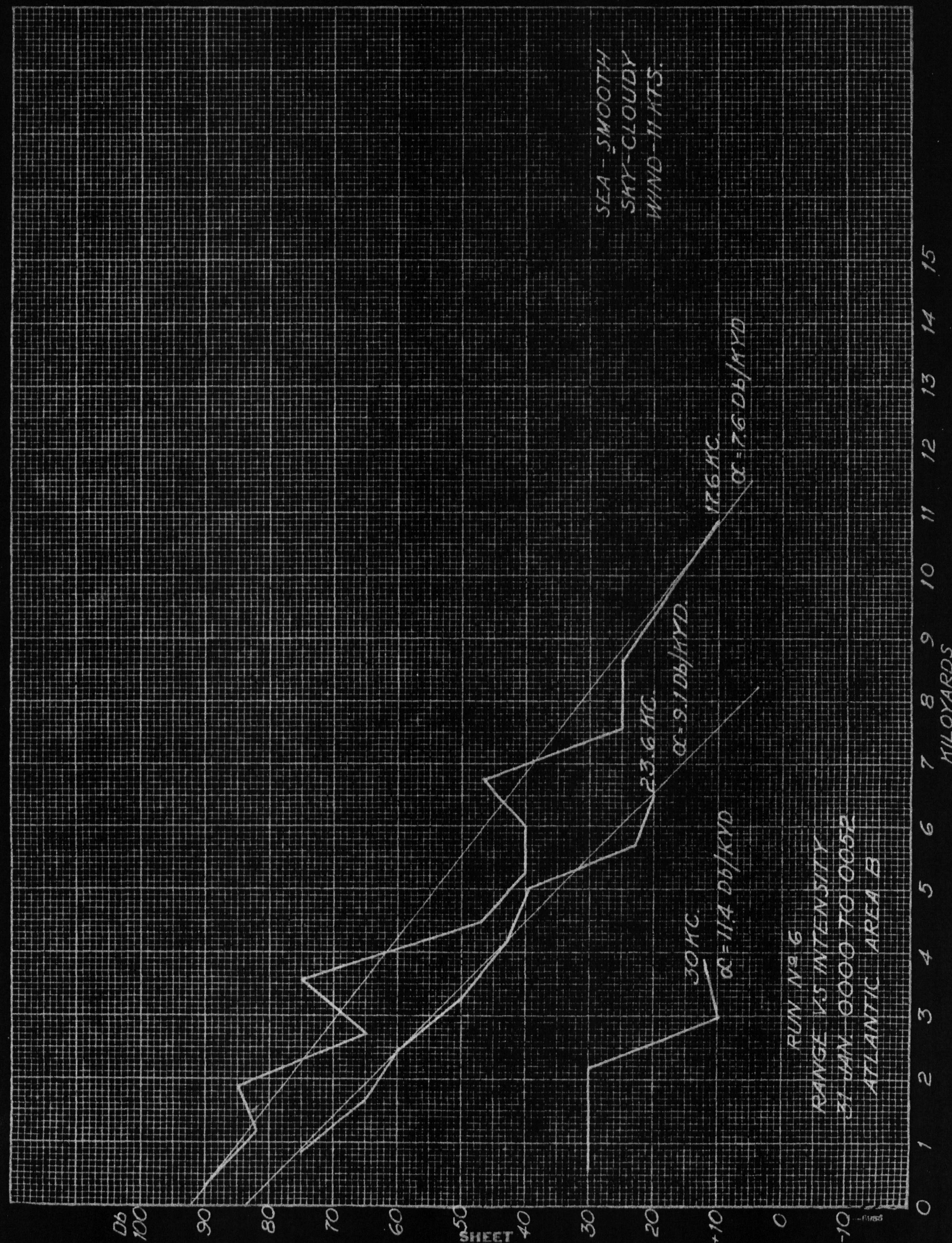

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PLATE 6

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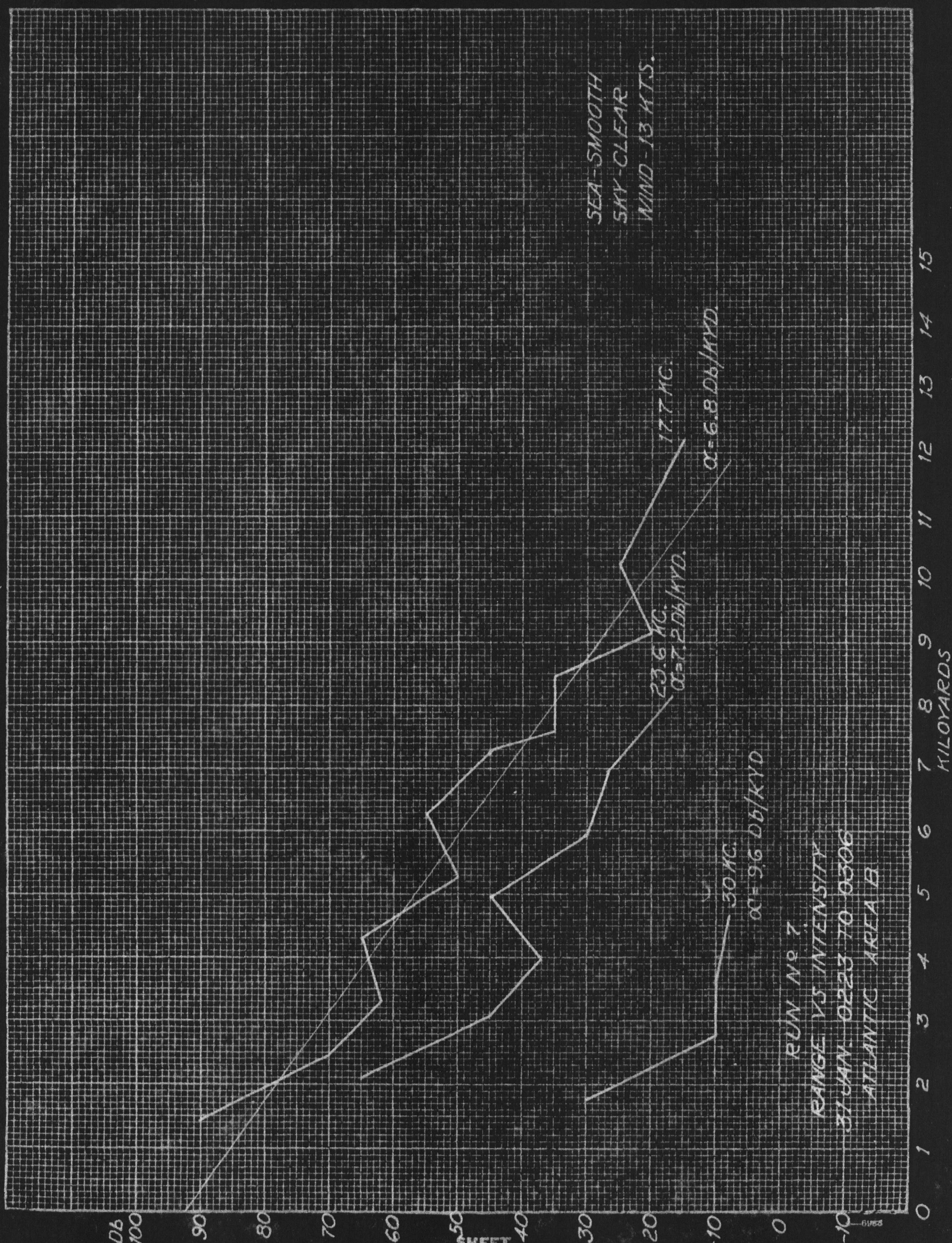

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PLATE 7

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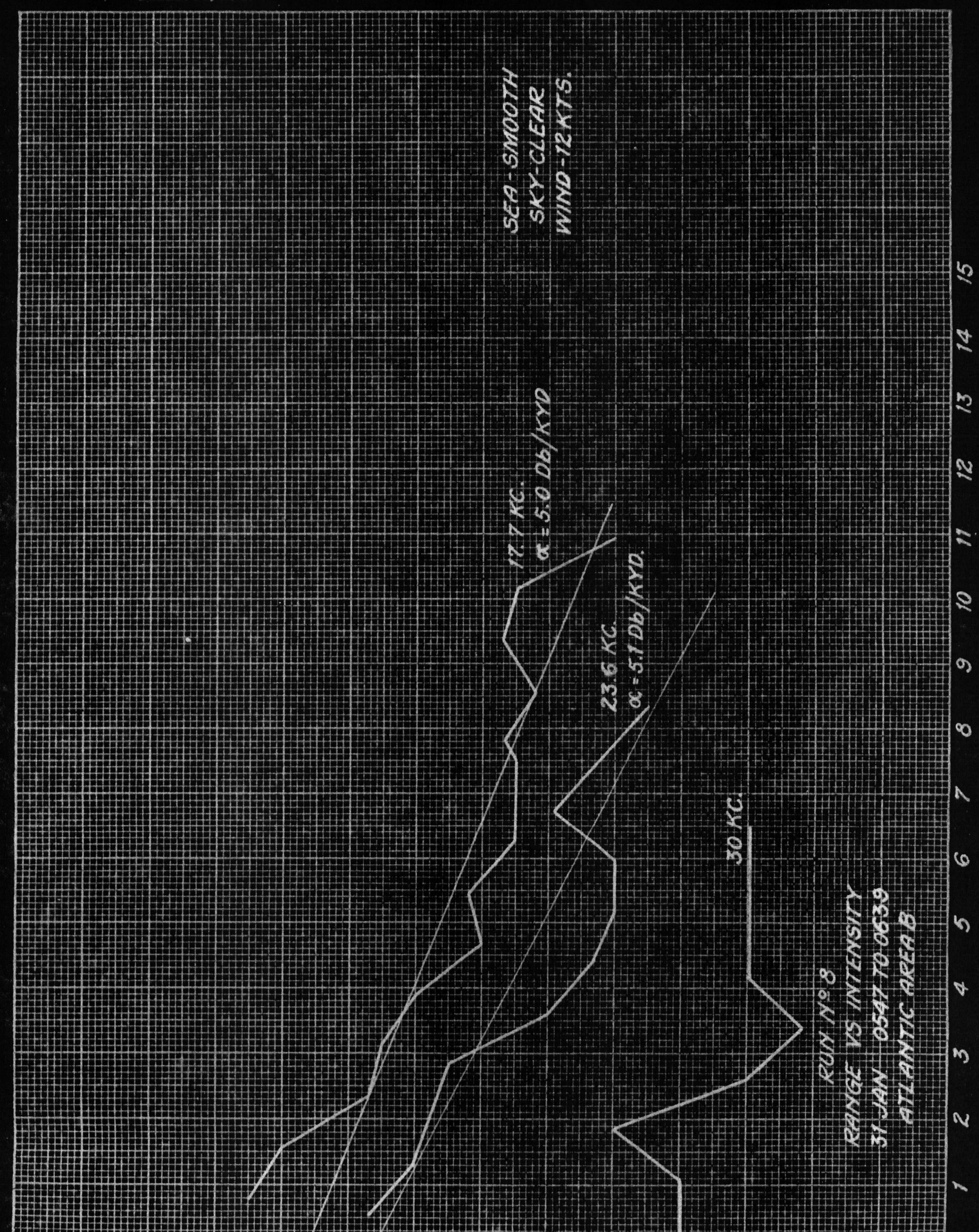

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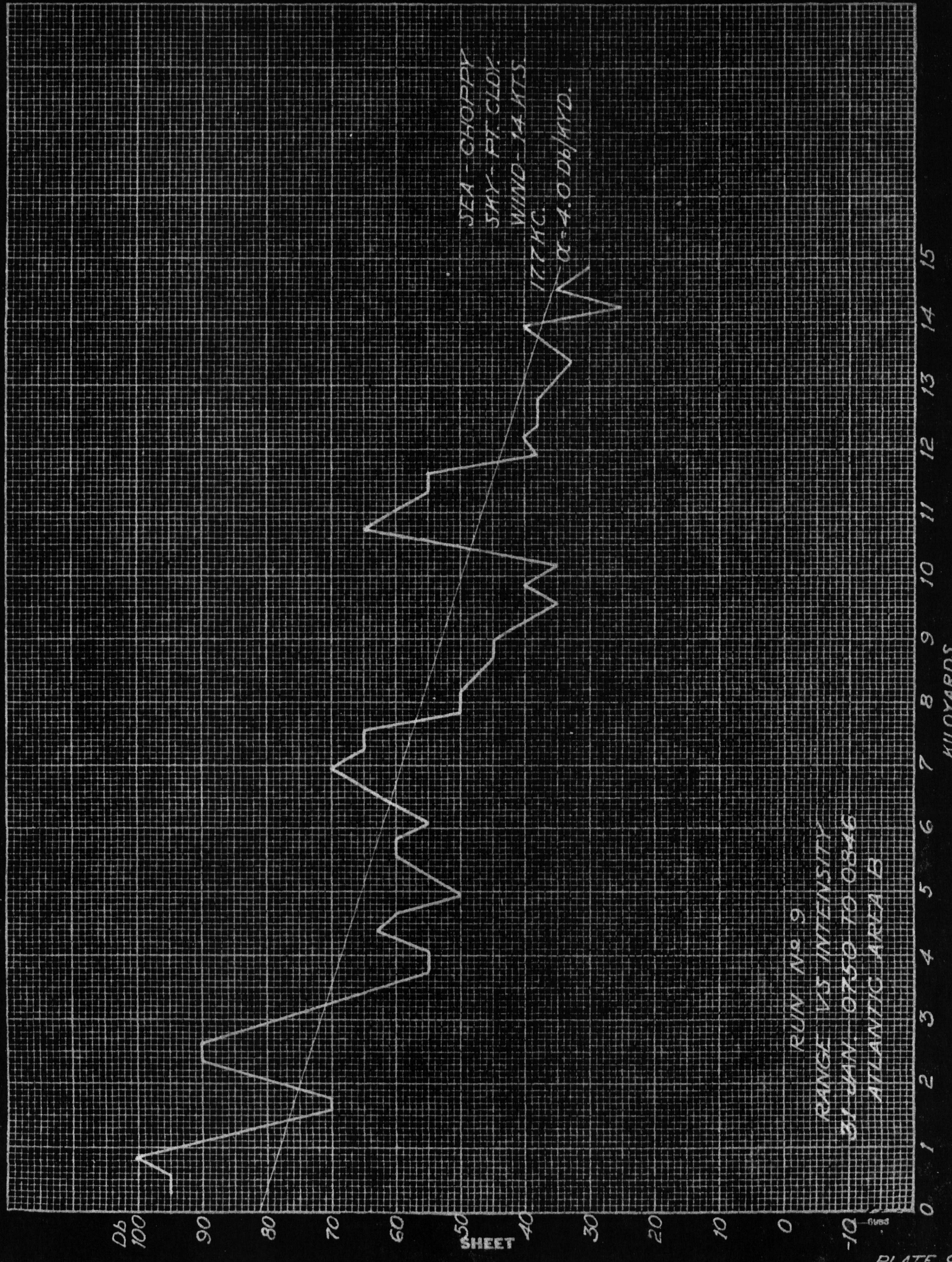
SEA - CHOPPY
SKY - PT. CLDY.
WIND - 14 KTS.
17.7 KC.
α = 4.0 Db/KYD.
RUN No 9
RANGE VS INTENSITY
31 JAN. 0750 TO 0846
ATLANTIC AREA B
KILOYARDS
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15
Db
100 90 80 70 60 50 40 30 20 10 0 -10
SHEET

PLATE 9

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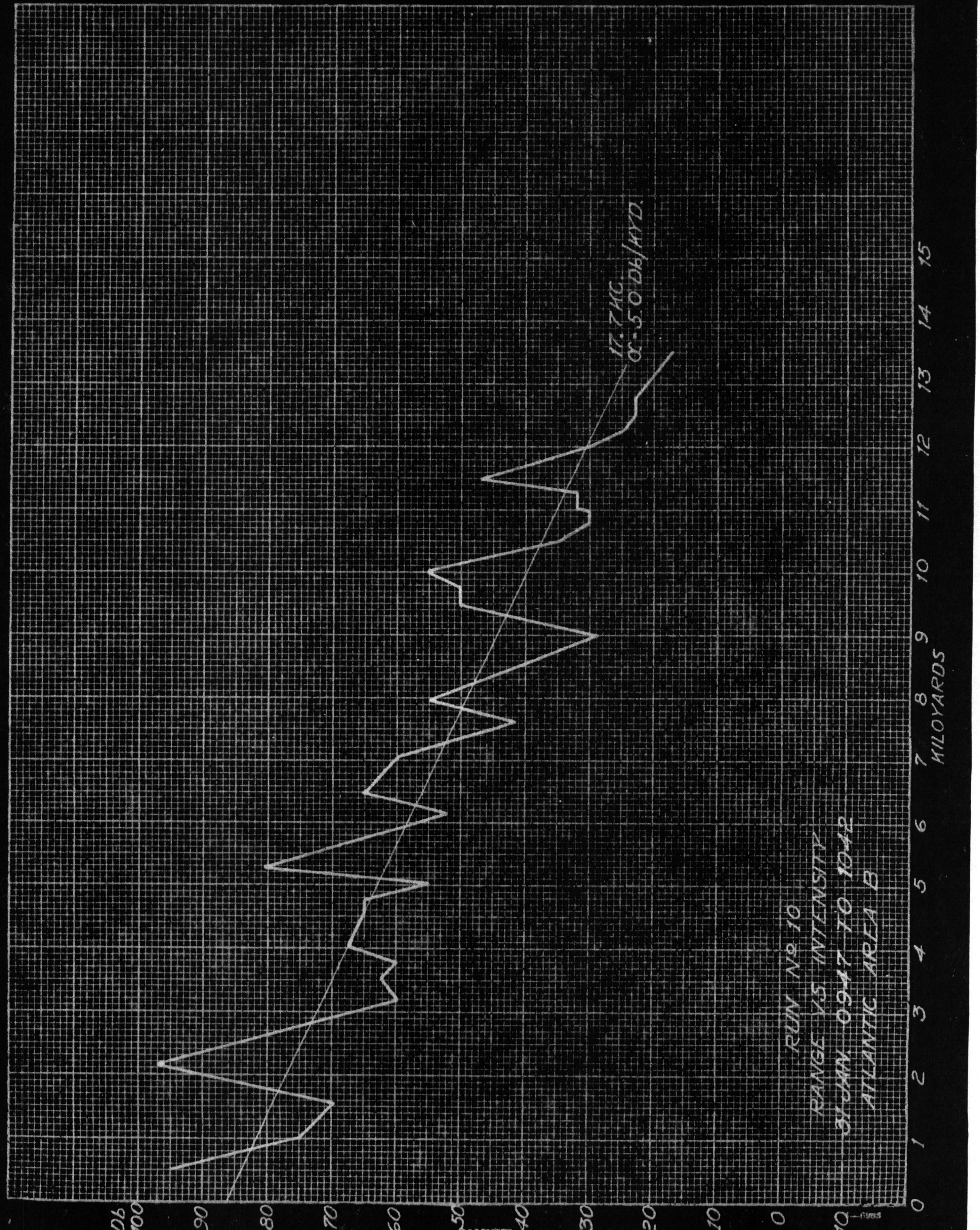

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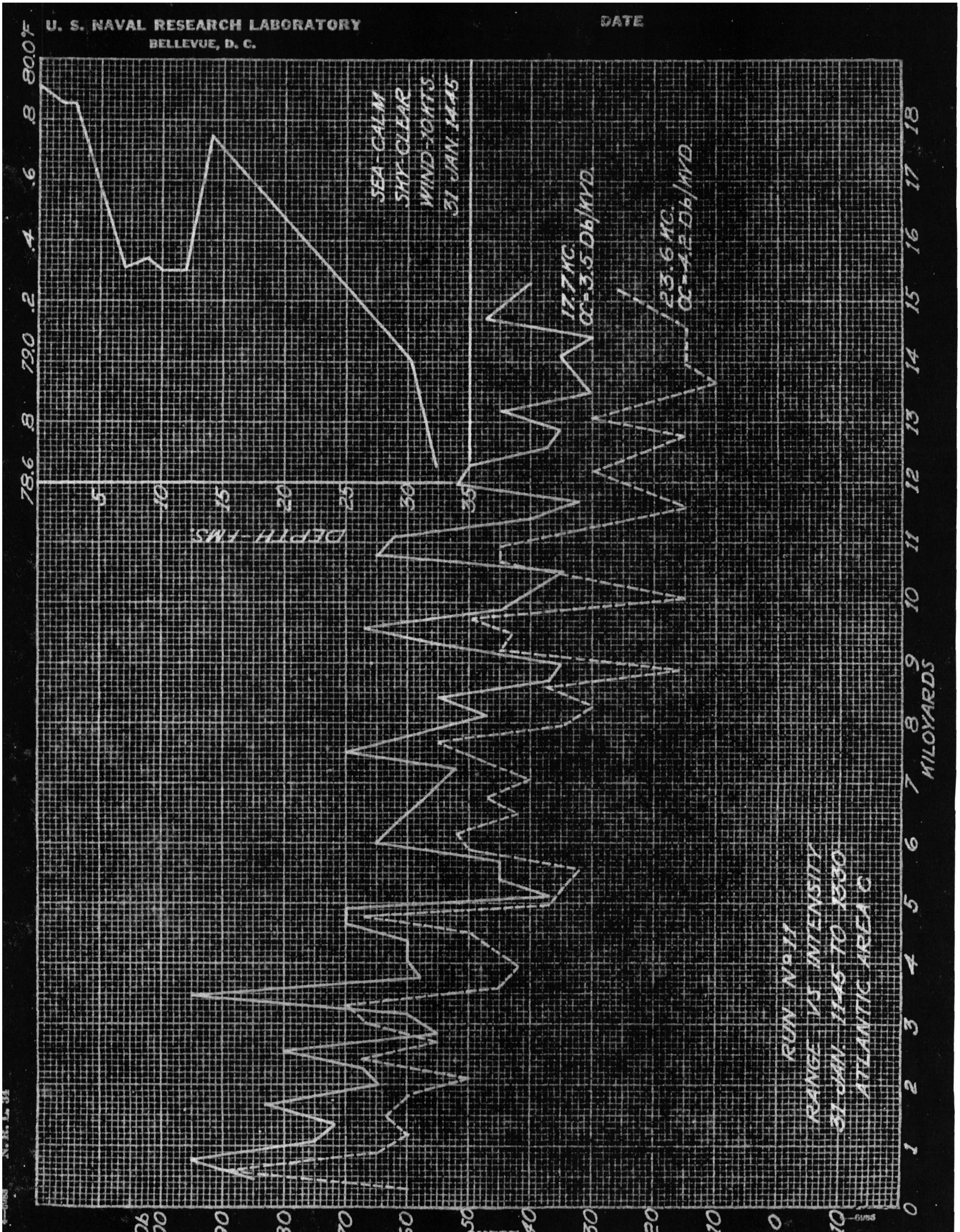
U. S. NAVAL RESEARCH LABORATORY
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DATE
SEA-CALM
SKY-CLEAR
WIND-10 KTS.
31 JAN. 1445
DEPTH-FMS
17.7 KC.
α=3.5 Db/KYD.
23.6 KC.
α=4.2 Db/KYD
KILOYARDS
Db
SHEET
RUN No 11
RANGE VS INTENSITY
31 JAN. 1145 TO 1530
ATLANTIC AREA C

PLATE 11

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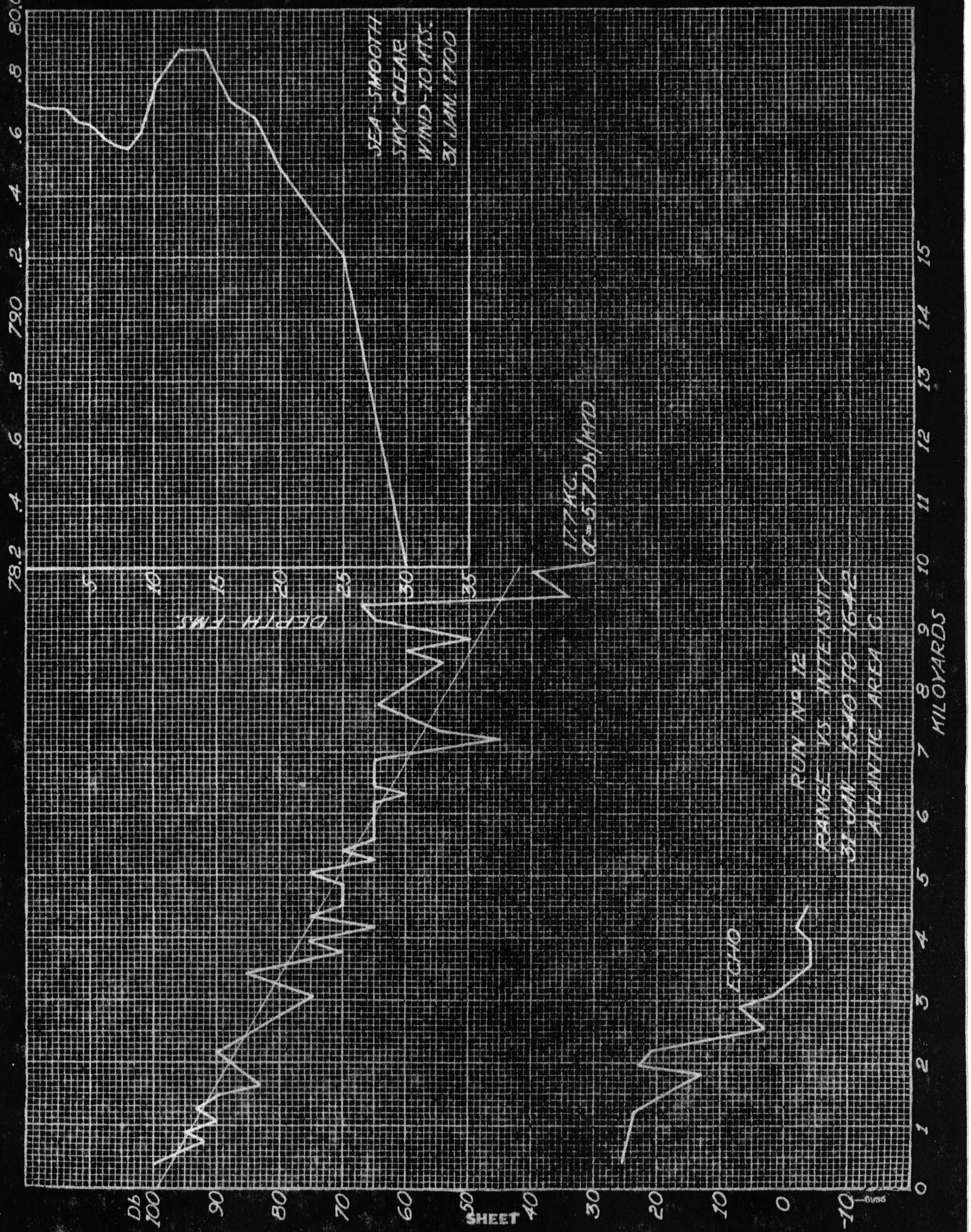

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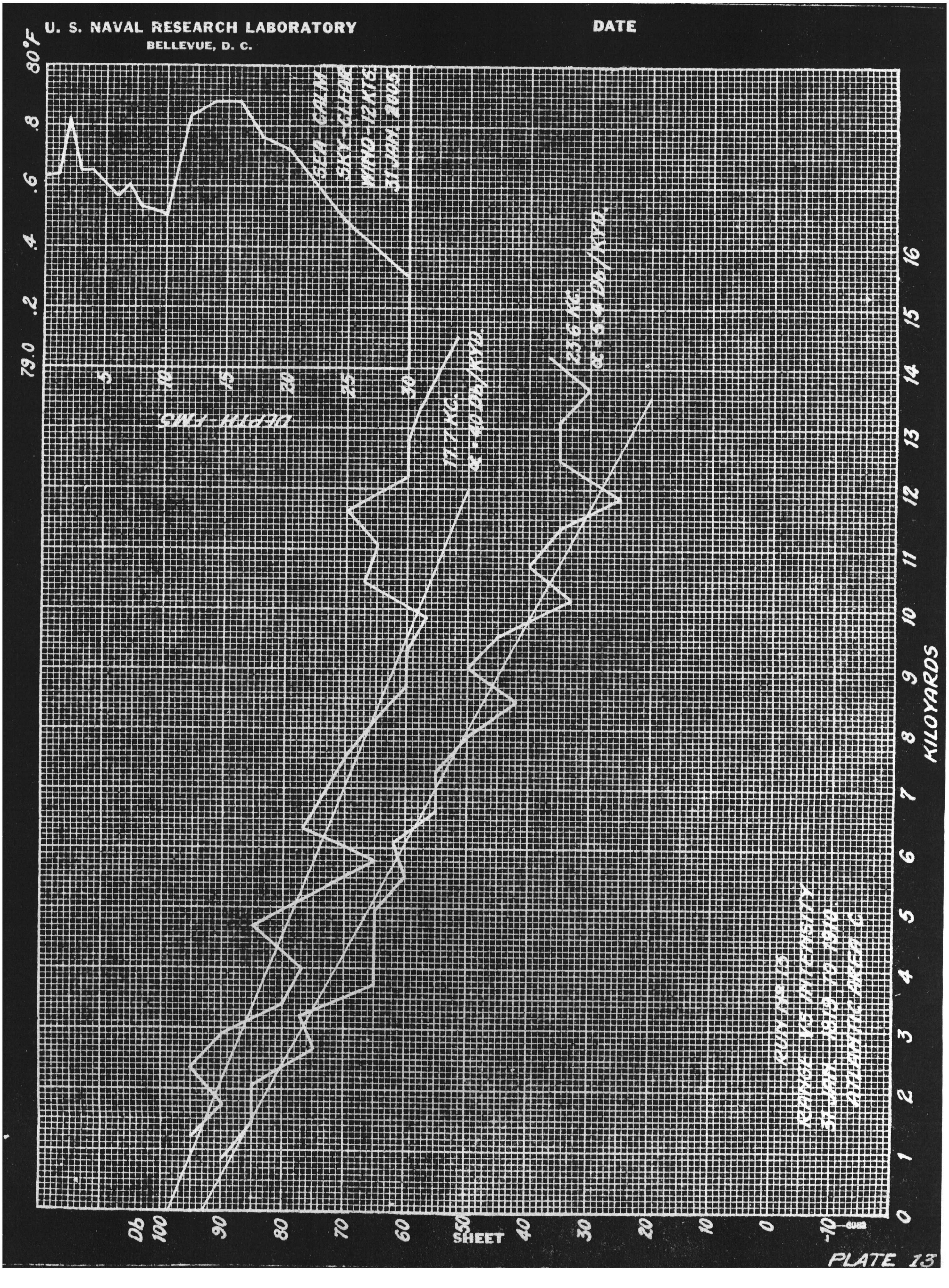
PLATE 12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DATE
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SKY-CLEAR
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31 JAN. 2005
DEPTH-FMS
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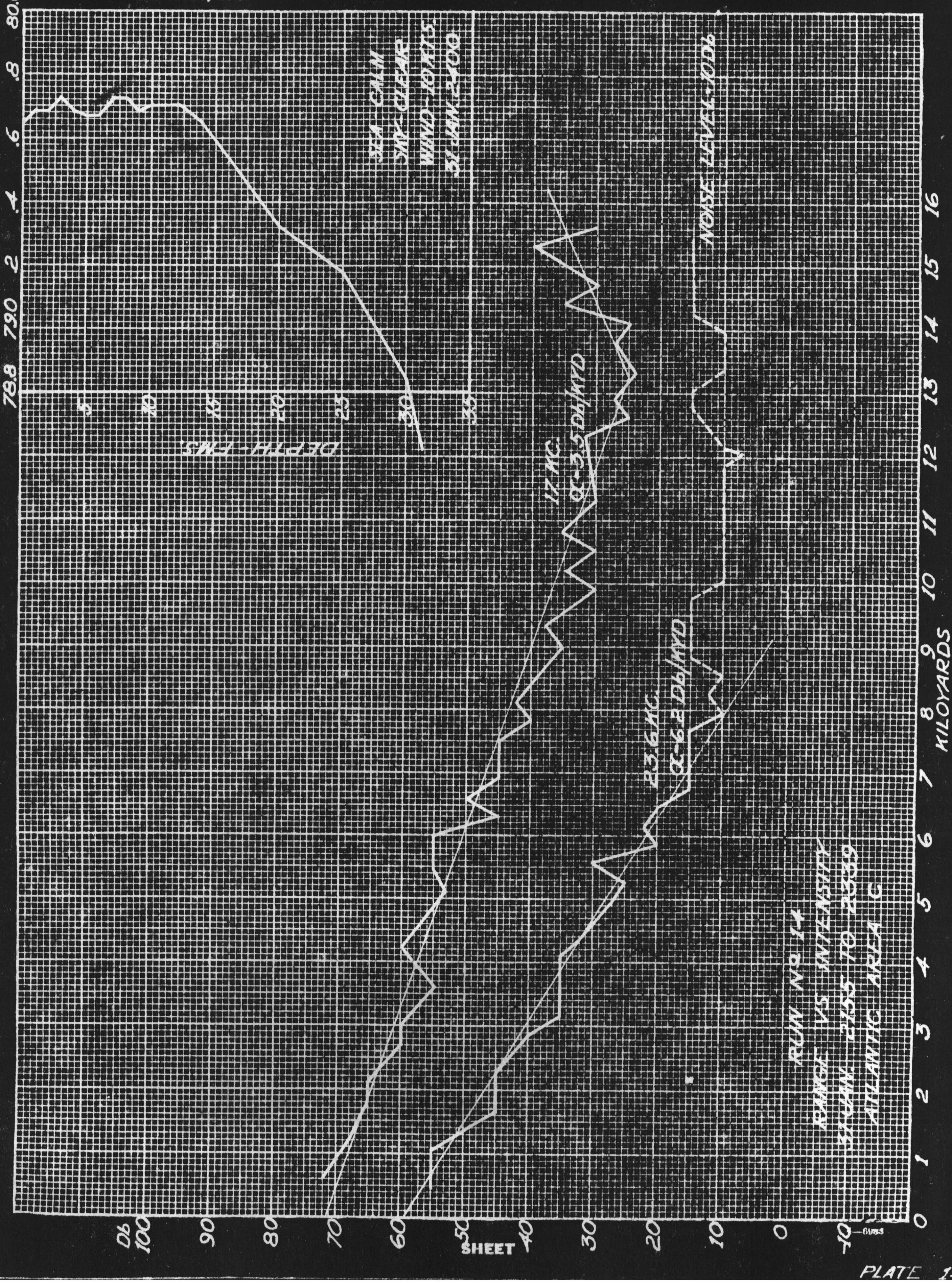
.2
.4
.6
.8
80°F
5
10
15
20
25
30
11.7 KC.
α=.40 Db/KYD.
23.6 KC.
α=5.4 Db/KYD.
RUN NO. 13
RANGE VS INTENSITY
31 JAN. 1819 TO 1910
ATLANTIC AREA C
KILOYARDS
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
Db
100
90
80
70
60
50
40
30
20
10
0
-10
SHEET

PLATE 13

U. S. NAVAL RESEARCH LABORATORY
BELLEVUE, D. C.

DATE



N. R. L. 34

SHEET

PLATE 14

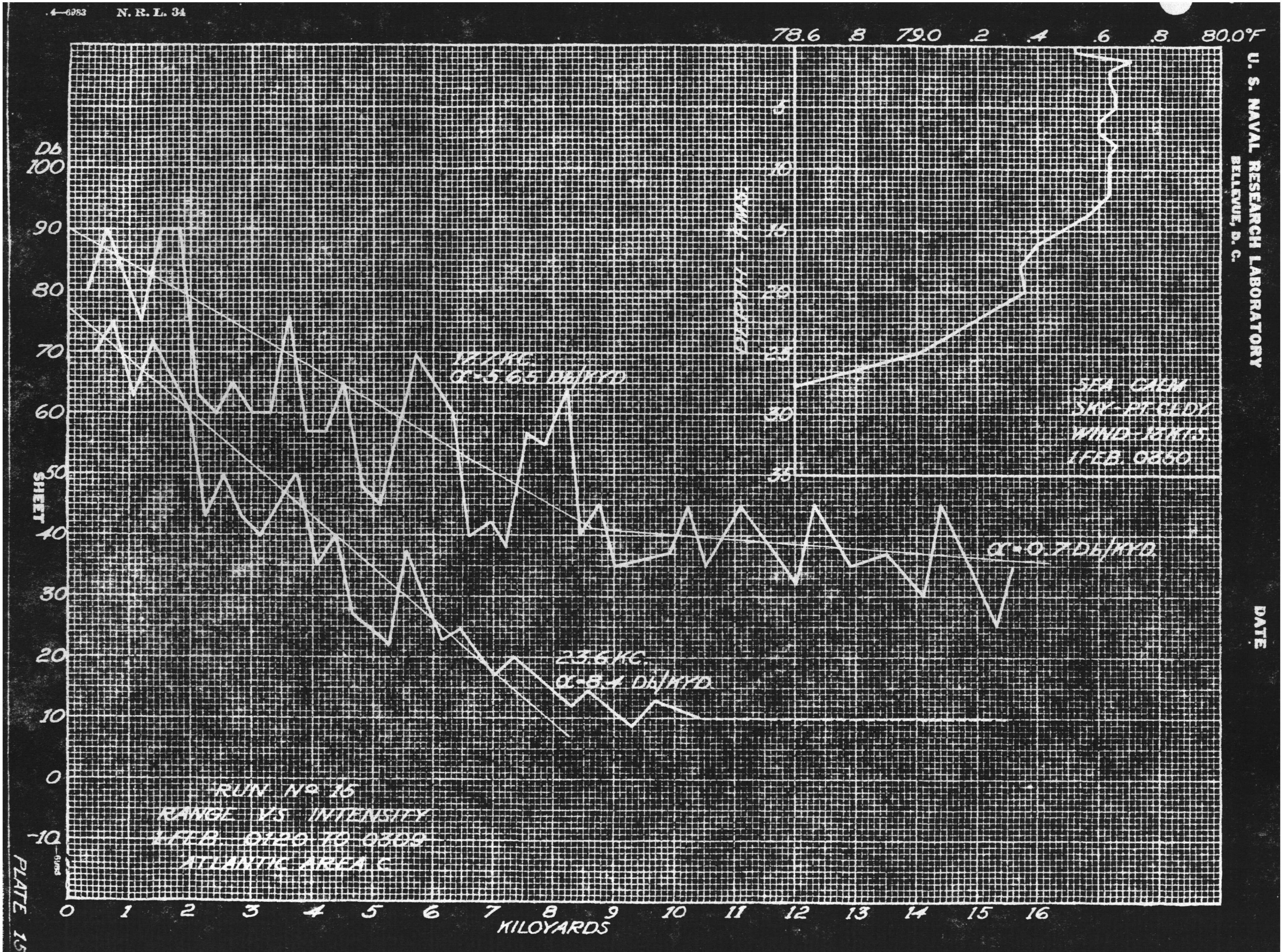
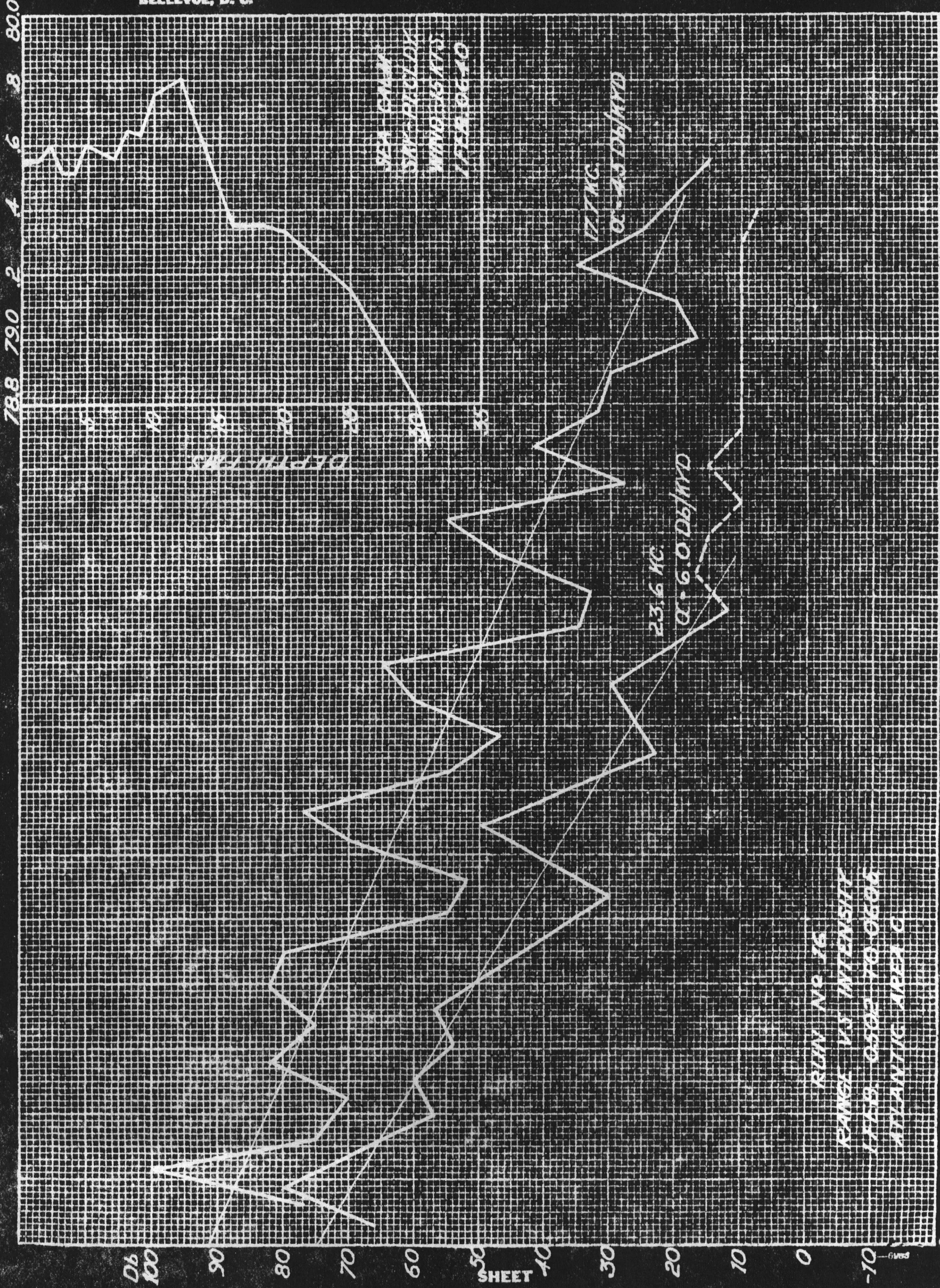

U. S. NAVAL RESEARCH LABORATORY
BELLEVUE, D. C.
DATE
SHEET
N. R. L. 34
78.6 .8 79.0 .2 .4 .6 .8 80.0°F
5 10 15 20 25 30 35
SEA CALM
SKY-PT. CLDY.
WIND-18 KTS.
1 FEB. 0350
Db
100 90 80 70 60 50 40 30 20 10 0 -10
17.7 KC.
α-5.65 Db/KYD.
α=0.7 Db/KYD.
23.6 KC.
α-8.4 Db/KYD.
RUN No 15
RANGE VS INTENSITY
1 FEB. 0120 TO 0309
ATLANTIC AREA C
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
KILOYARDS

PLATE 15

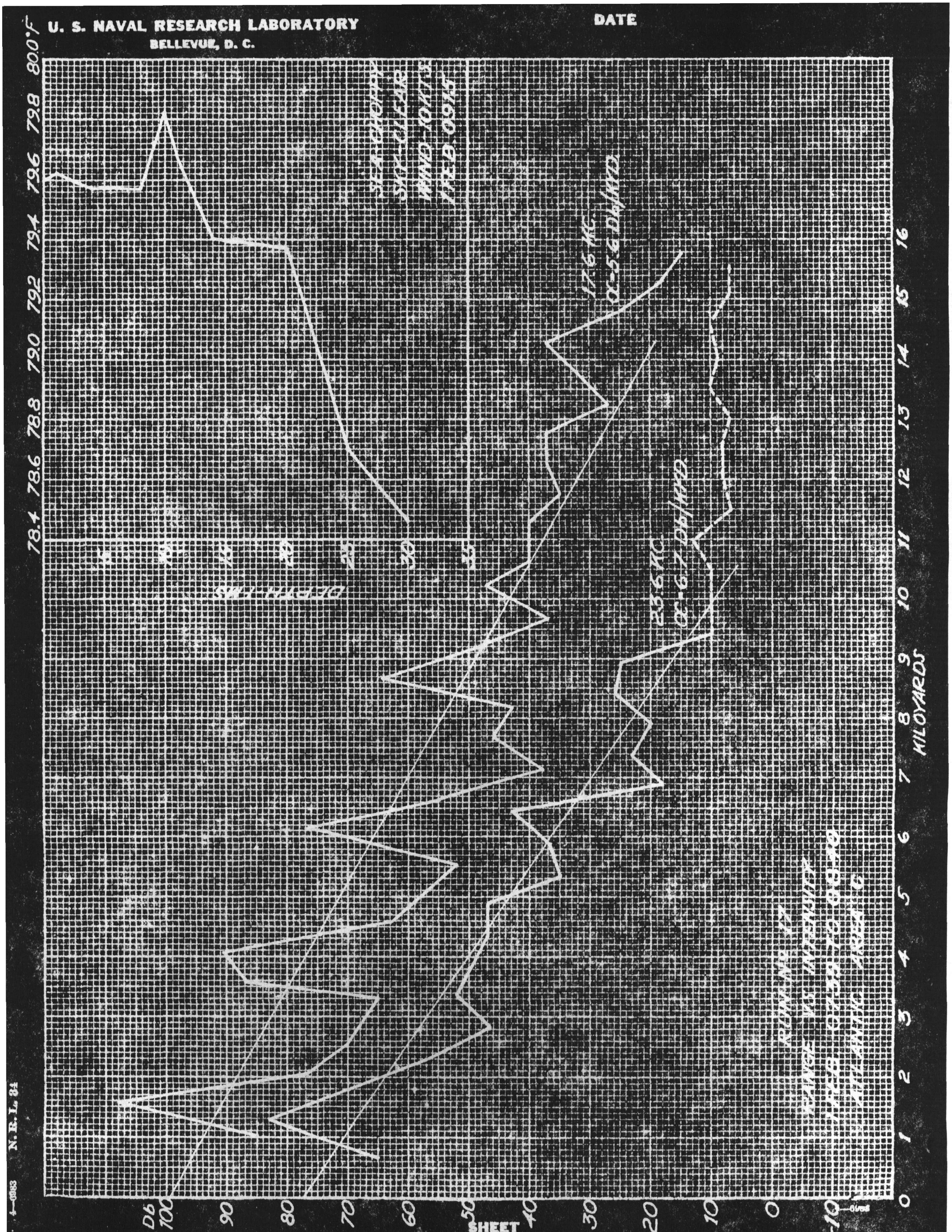
U. S. NAVAL RESEARCH LABORATORY
BELLEVUE, D. C.

DATE



SHEET

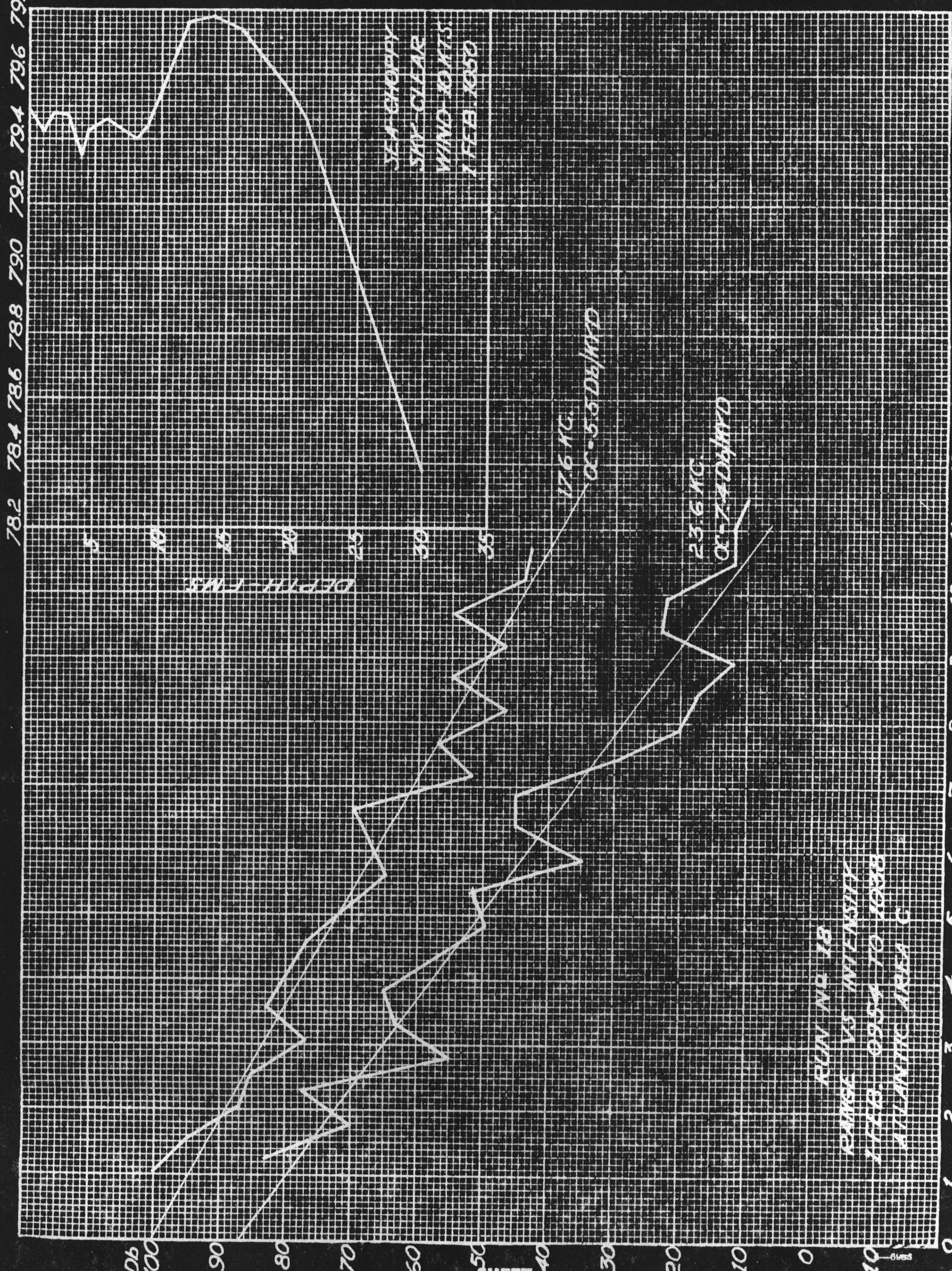
PLATE 16


U. S. NAVAL RESEARCH LABORATORY
BELLEVUE, D. C.
DATE
SEA-CHOPPY
SKY-CLEAR
WIND-10 KTS
17.6 KC
23.6 KC
DB
KILOYARDS
SHEET
N. R. L. 34
PLATE 17

U. S. NAVAL RESEARCH LABORATORY

BELLEVUE, D. C.

DATE

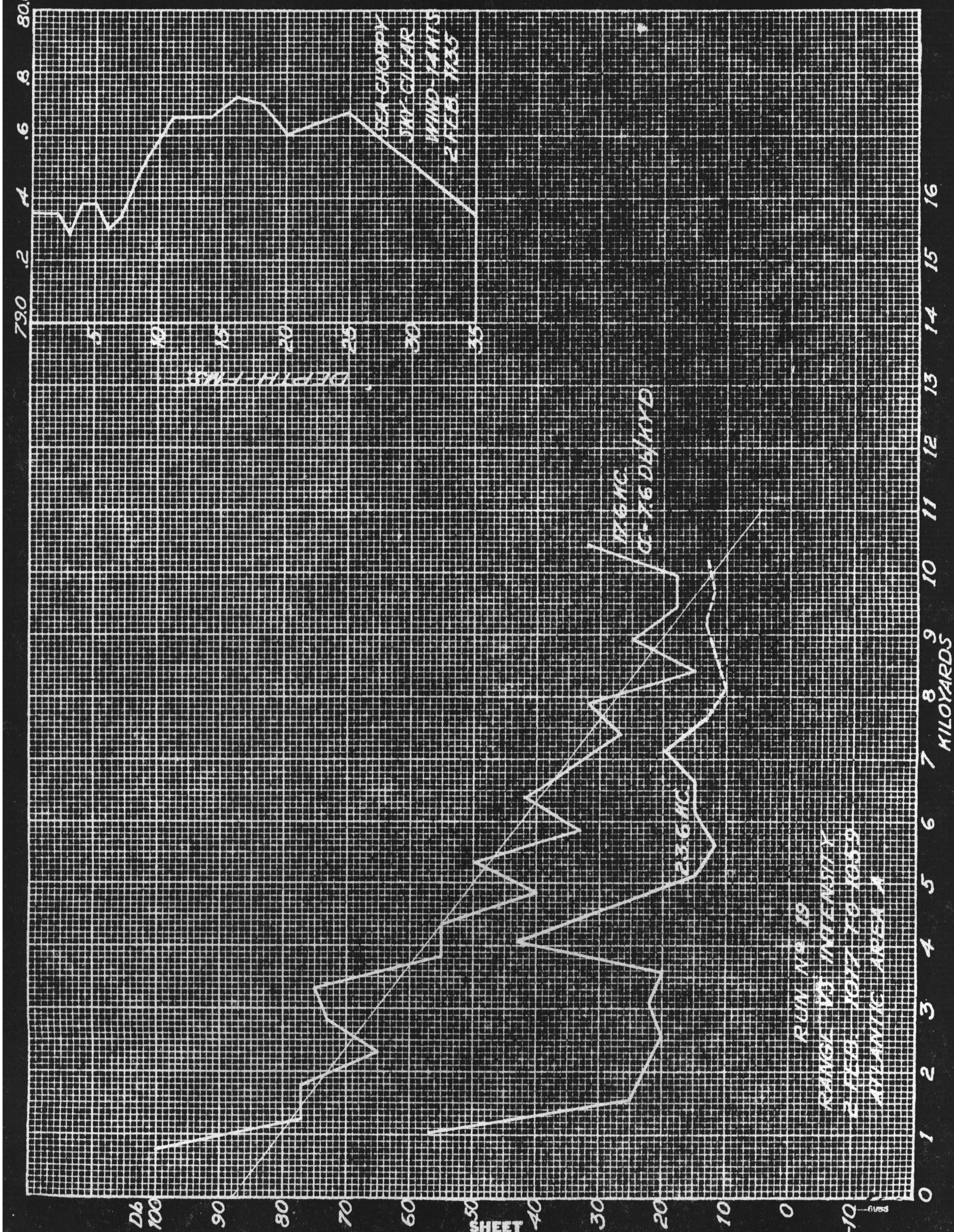


SHEET

PLATE 18

U. S. NAVAL RESEARCH LABORATORY
BELLEVUE, D. C.

DATE

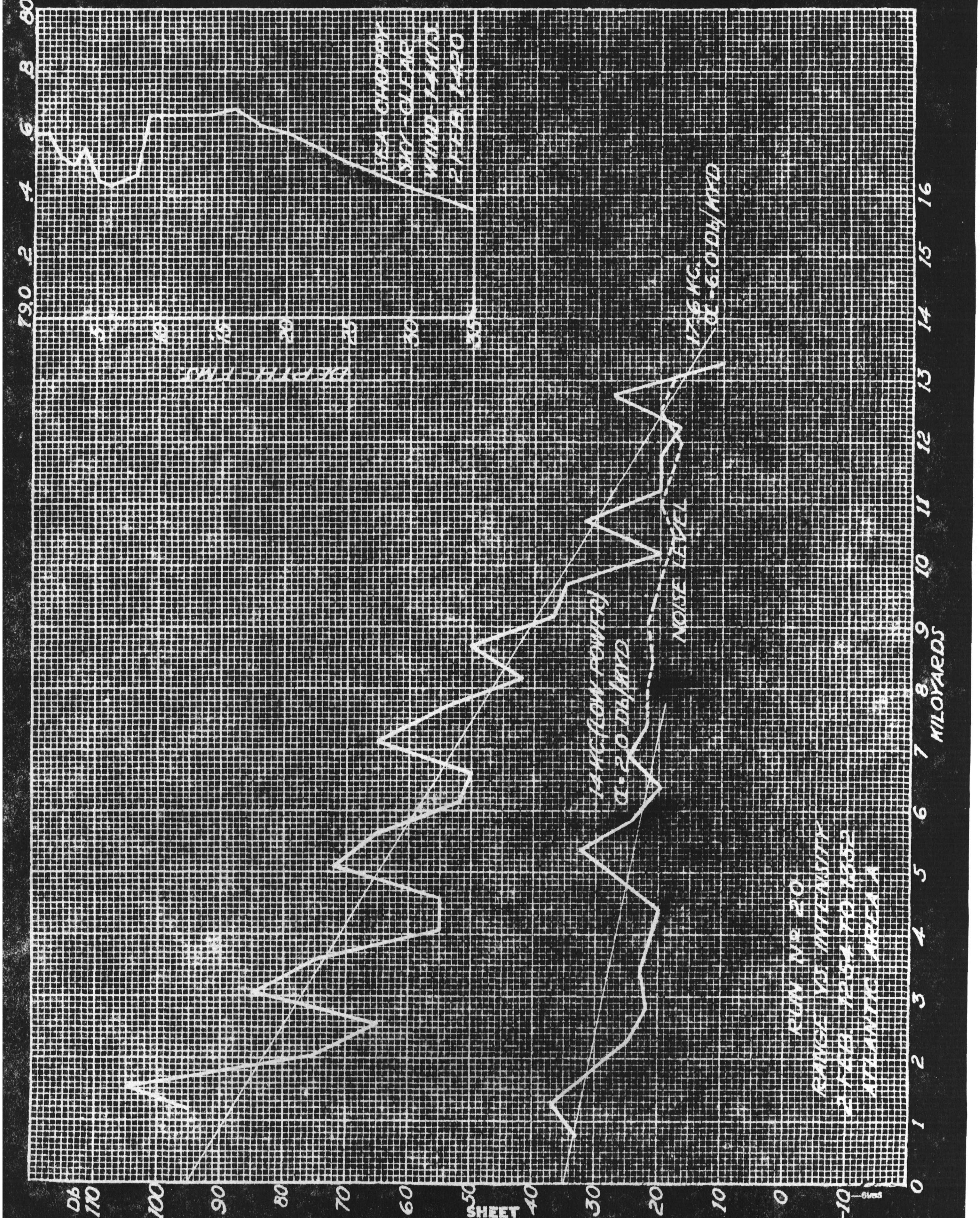


SHEET

PLATE 19

U. S. NAVAL RESEARCH LABORATORY
BELLEVUE, D. C.

DATE



SHEET

PLATE 20

U. S. NAVAL RESEARCH LABORATORY
BELLEVUE, D. C.

DATE

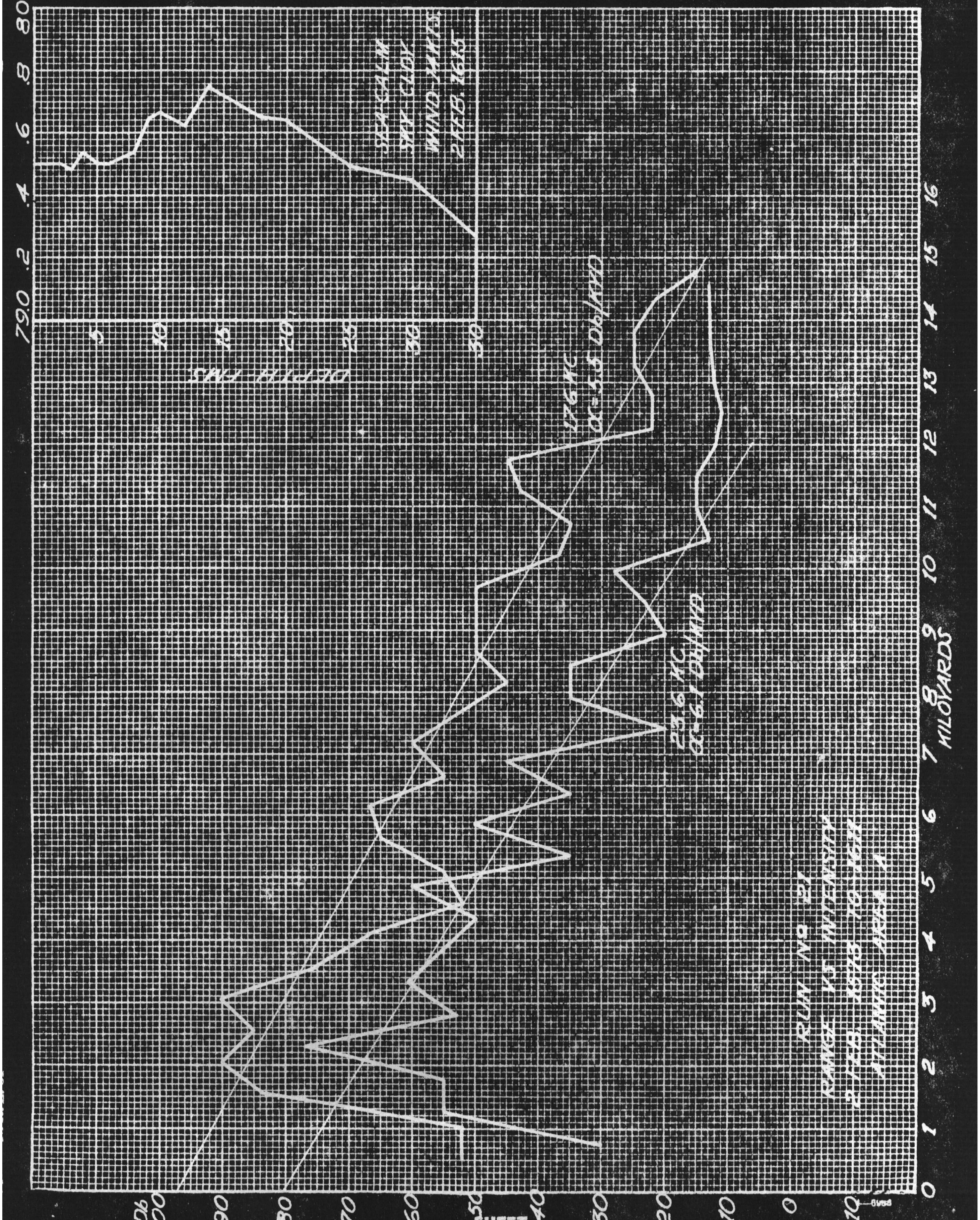
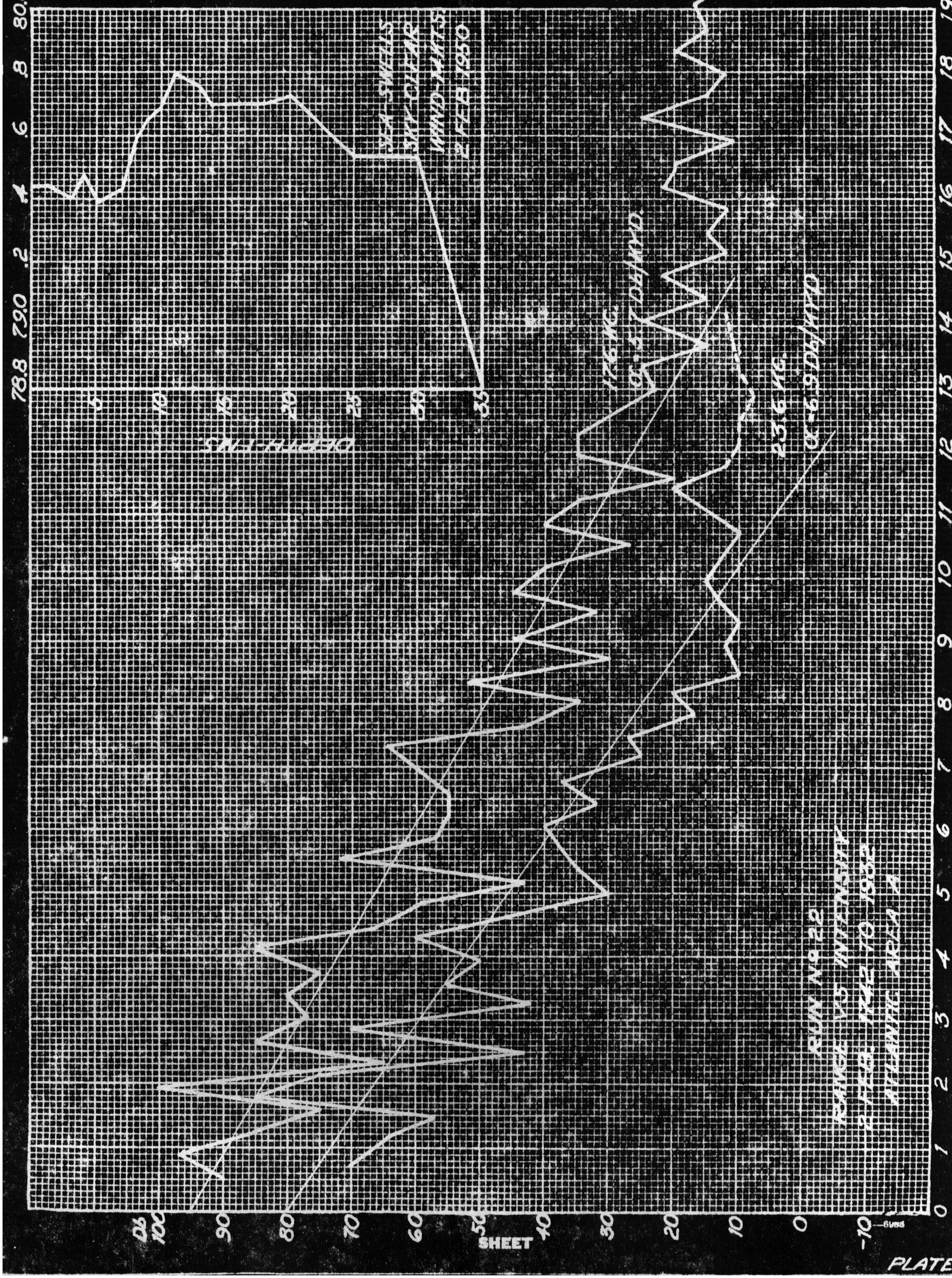


PLATE 21

U. S. NAVAL RESEARCH LABORATORY
BELLEVUE, D. C.

DATE



SHEET

PLATE 22

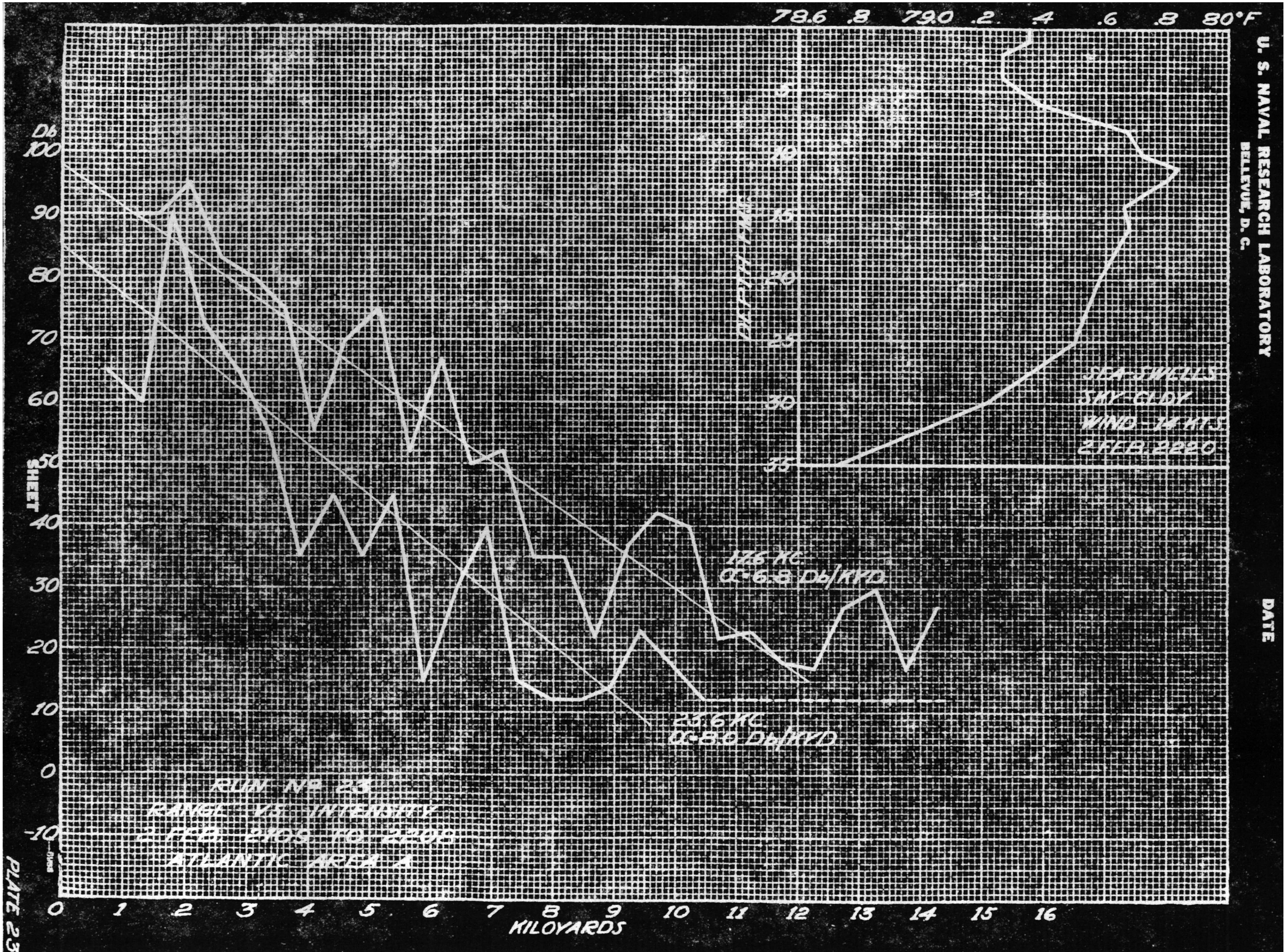

U. S. NAVAL RESEARCH LABORATORY
BELLEVUE, D. C.
DATE
SHEET
78.6 .8 79.0 .2 .4 .6 .8 80°F
DEPTH FEET
SEA-SWELLS
SKY-CLDY
WIND-14 KTS
2 FEB. 2220
176 KC.
α-6.8 Db/KYD
23.6 KC.
α-8.0 Db/KYD
RUN No 23
RANGE VS. INTENSITY
2 FEB. 2105 TO 2208
ATLANTIC AREA A
Db
KILOYARDS

PLATE 23

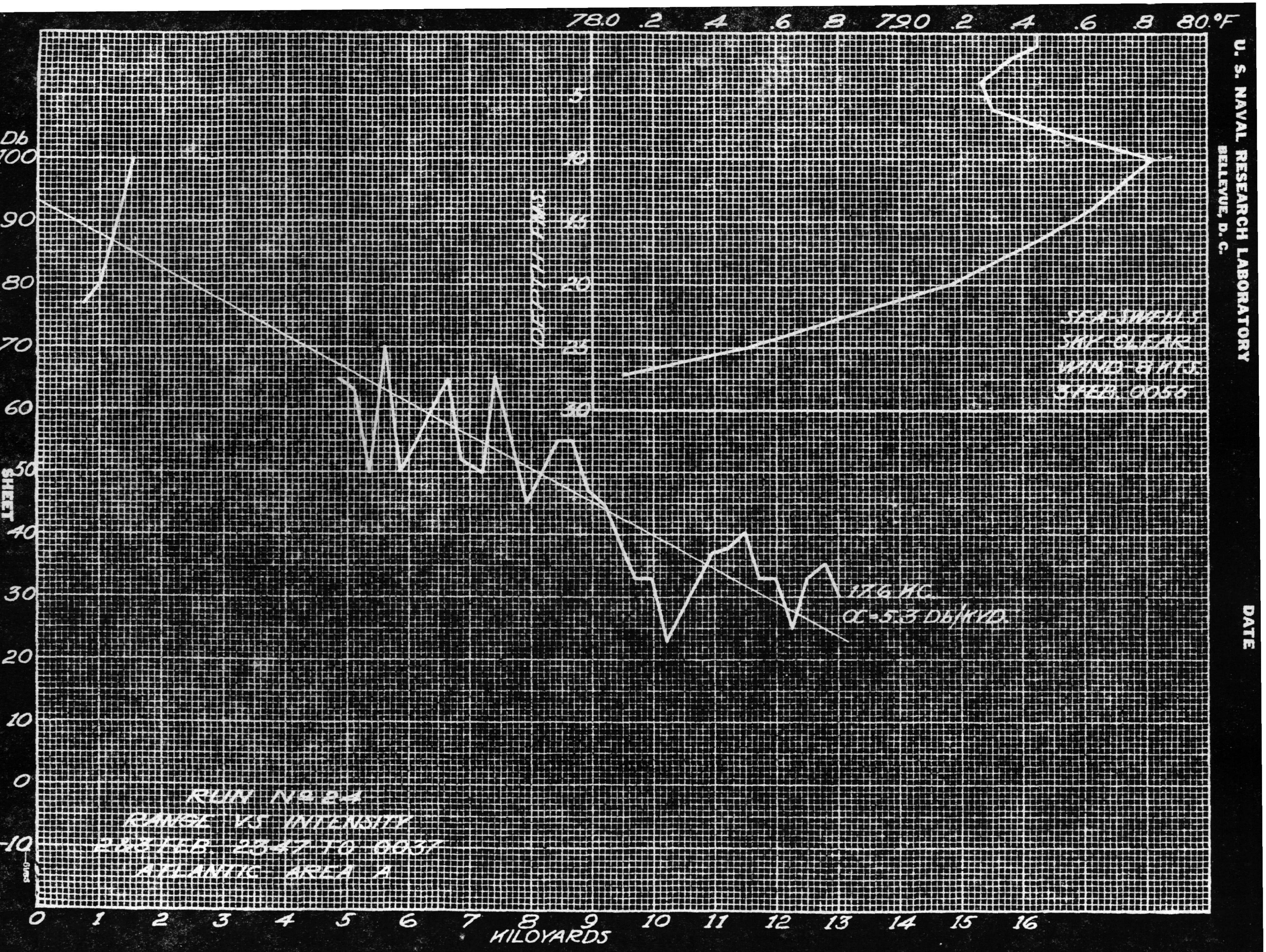

U. S. NAVAL RESEARCH LABORATORY
BELLEVUE, D. C.
DATE
SHEET
78.0 .2 .4 .6 .8 79.0 .2 .4 .6 .8 80.°F
5 10 15 20 25 30
SEA-SWELLS
SKY-CLEAR
WIND-8 KTS.
3 FEB. 0056
Db
100 90 80 70 60 50 40 30 20 10 0 -10
17.6 KC.
α=5.3 Db/KYD.
RUN Nº 24
RANGE VS INTENSITY
28 FEB. 2347 TO 0037
ATLANTIC AREA A
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
KILOYARDS

PLATE 24

U. S. NAVAL RESEARCH LABORATORY

BELLEVUE, D. C.

DATE

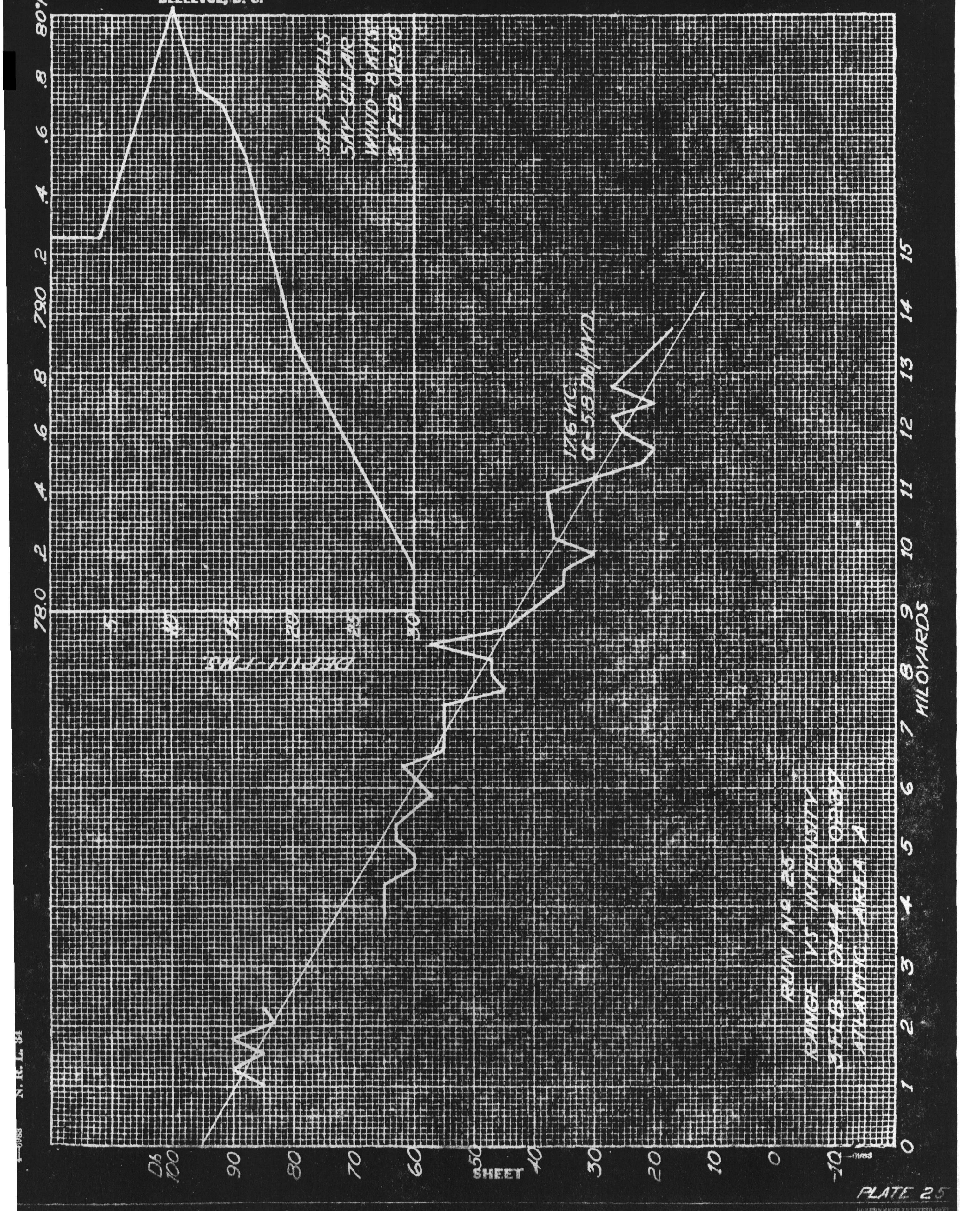


PLATE 25

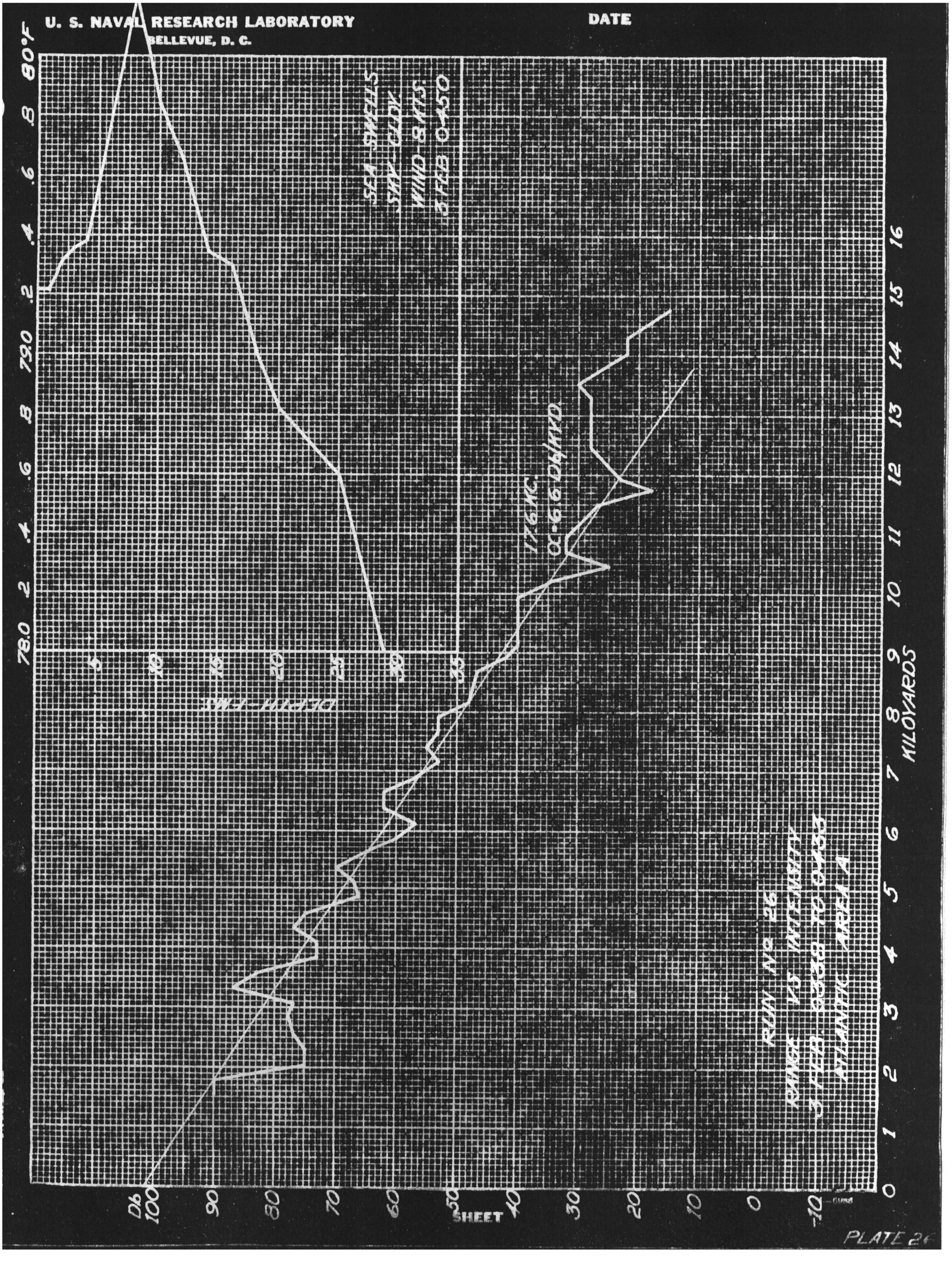
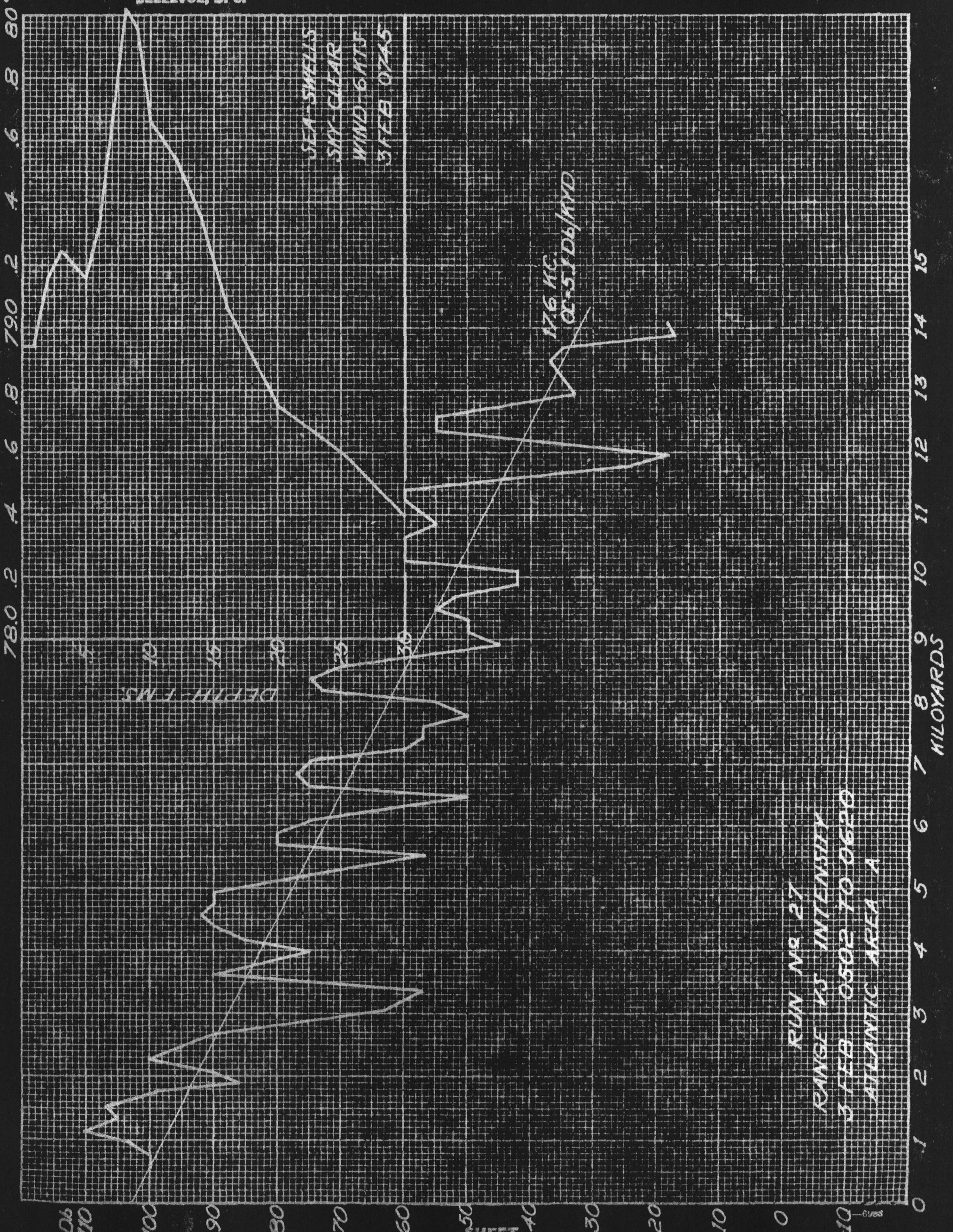

U. S. NAVAL RESEARCH LABORATORY
BELLEVUE, D. C.
DATE
SEA-SWELLS
SKY-CLDY.
WIND-8 KTS.
3 FEB 0450
17.6 KC
α=6.6 Db/KYD
RUN No 26
RANGE VS INTENSITY
3 FEB. 0338 TO 0453
ATLANTIC AREA A
KILOYARDS
80°F
Db
SHEET

PLATE 26

U. S. NAVAL RESEARCH LABORATORY
BELLEVUE, D. C.

DATE



SHEET

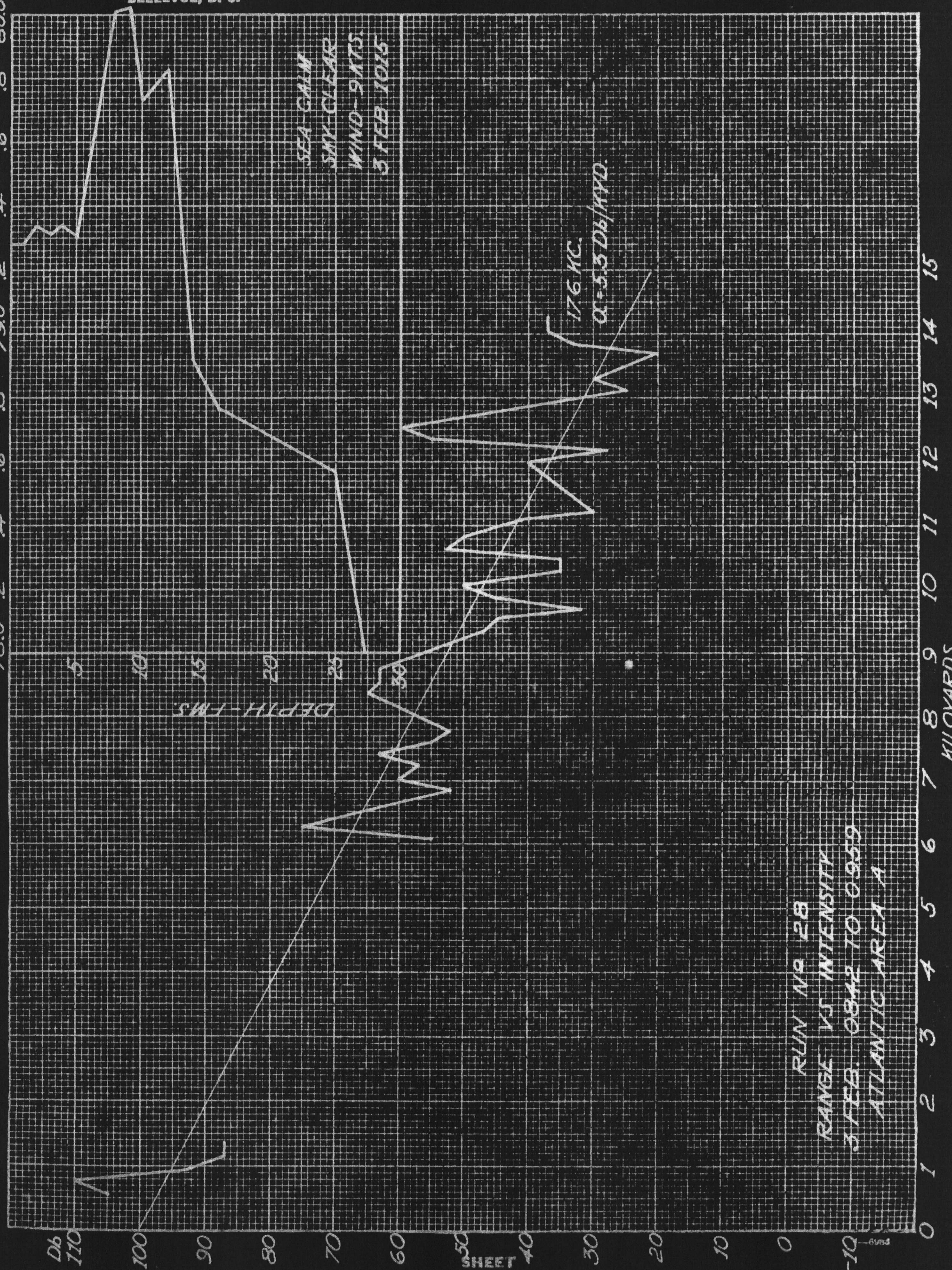
N. R. L. 31

PLATE 27

U. S. NAVAL RESEARCH LABORATORY

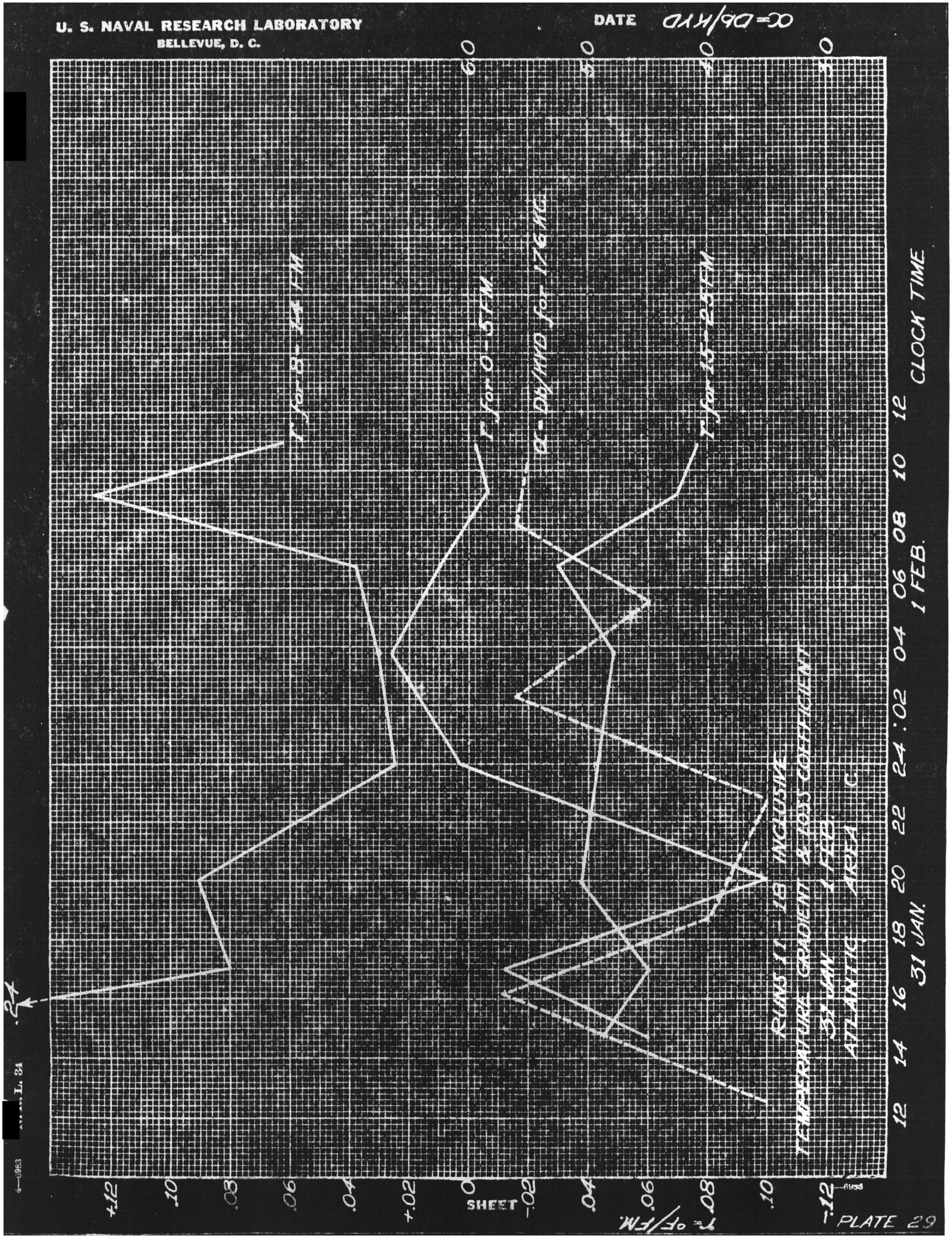
BELLEVUE, D. C.

DATE



SHEET

PLATE 28


U. S. NAVAL RESEARCH LABORATORY
BELLEVUE, D. C.
DATE
[redacted]
τ for 8-14 FM
τ for 0-5 FM
α-Db/KYD for 17.6 KC.
τ for 15-25 FM
CLOCK TIME
12 14 16 18 20 22 24 :02 04 06 08 10 12
31 JAN.
1 FEB.
RUNS 11 - 18 INCLUSIVE
TEMPERATURE GRADIENT & LOSS COEFFICIENT
31 JAN. 1 FEB.
ATLANTIC AREA C
6.0
5.0
4.0
3.0
+.12
.10
.08
.06
.04
+.02
0
-.02
.04
.06
.08
.10
-.12
.24
τ = °F/FM.
SHEET
[redacted]
L. 34
PLATE 29

U. S. NAVAL RESEARCH LABORATORY

BELLEVUE, D. C.

DATE

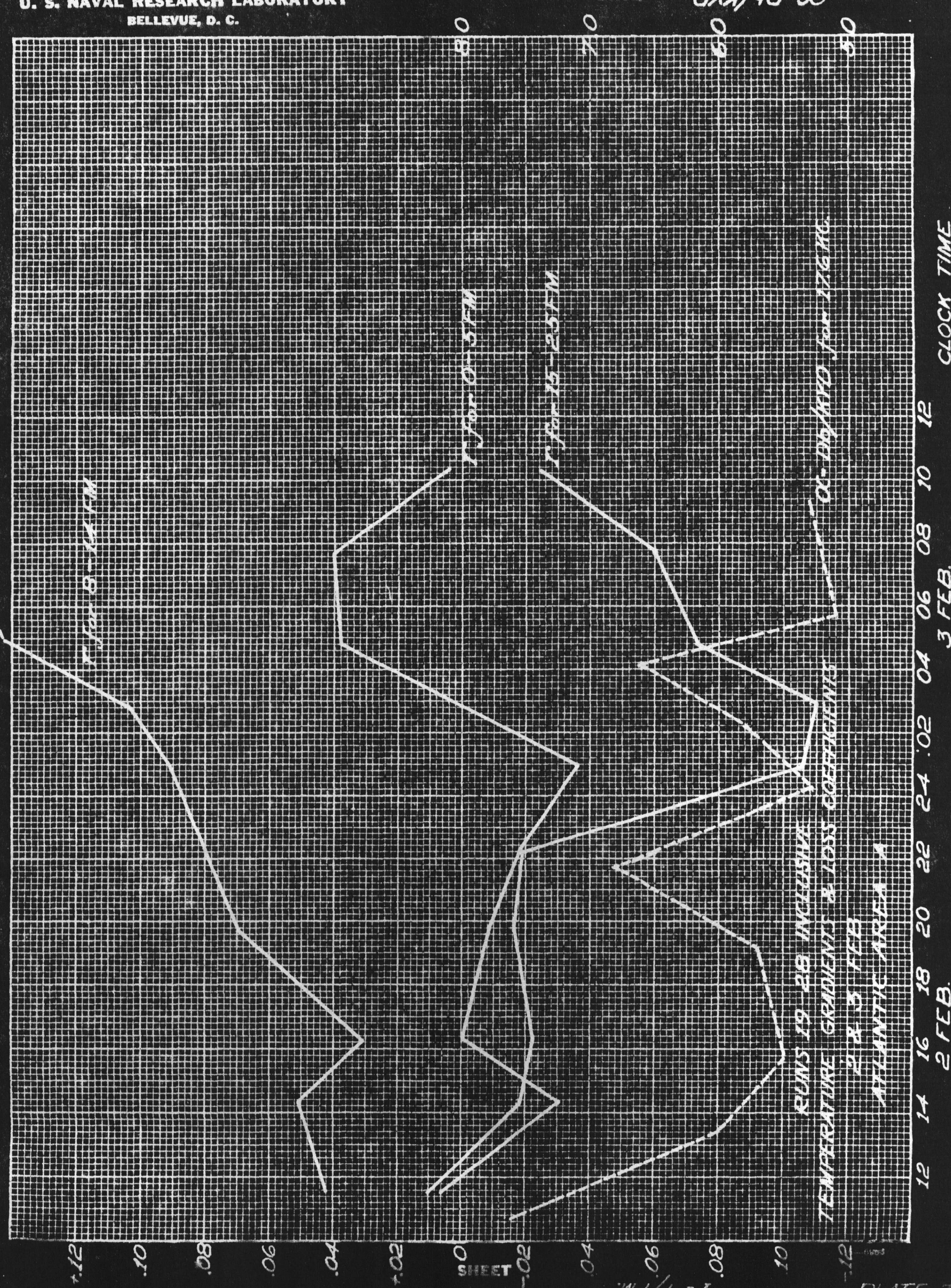


PLATE 30

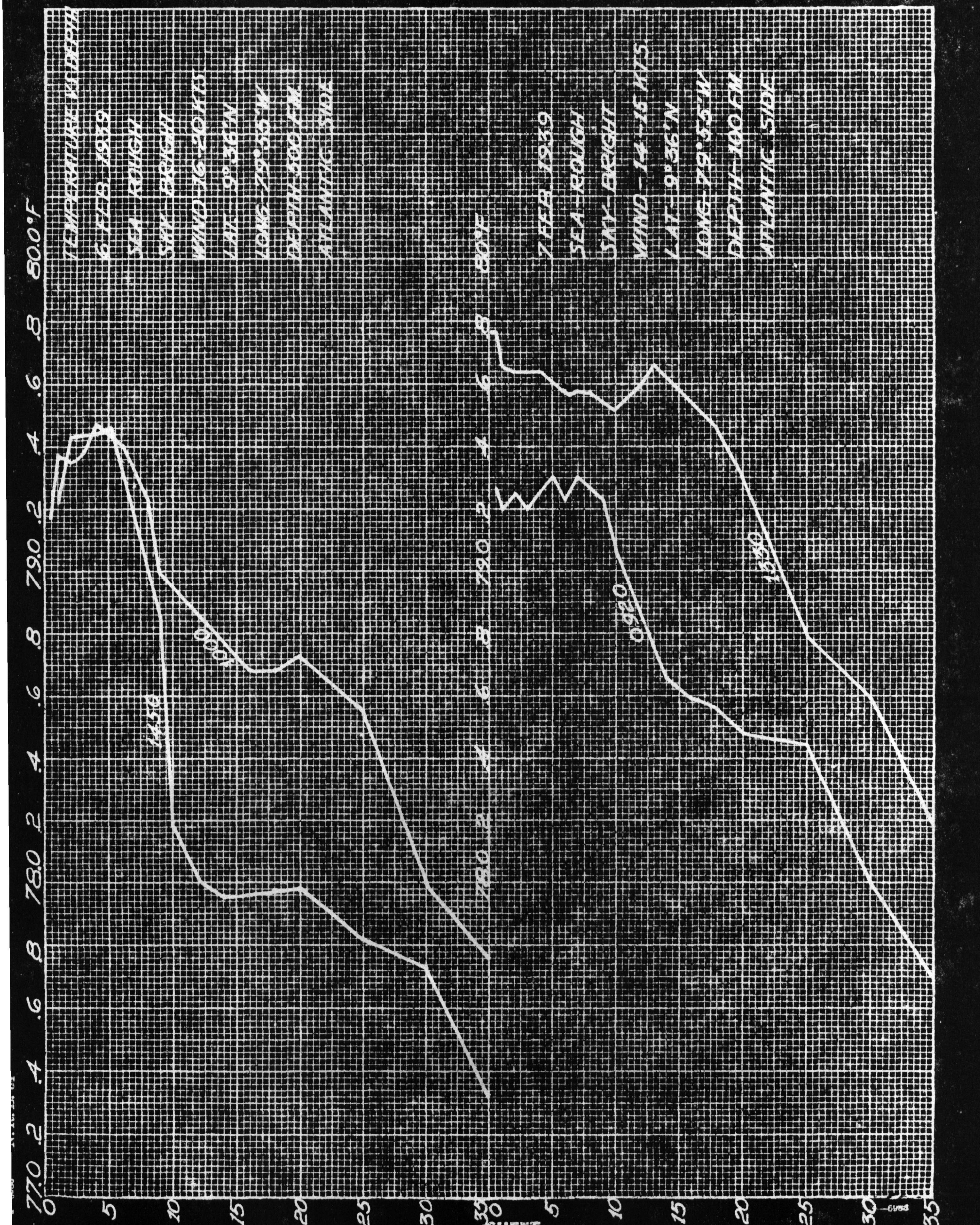
N. R. L. 34

4-6983

SHEET

U. S. NAVAL RESEARCH LABORATORY
BELLEVUE, D. C.

DATE



SHEET

PLATE 31

U. S. NAVAL RESEARCH LABORATORY

BELLEVUE, D. C.

DATE

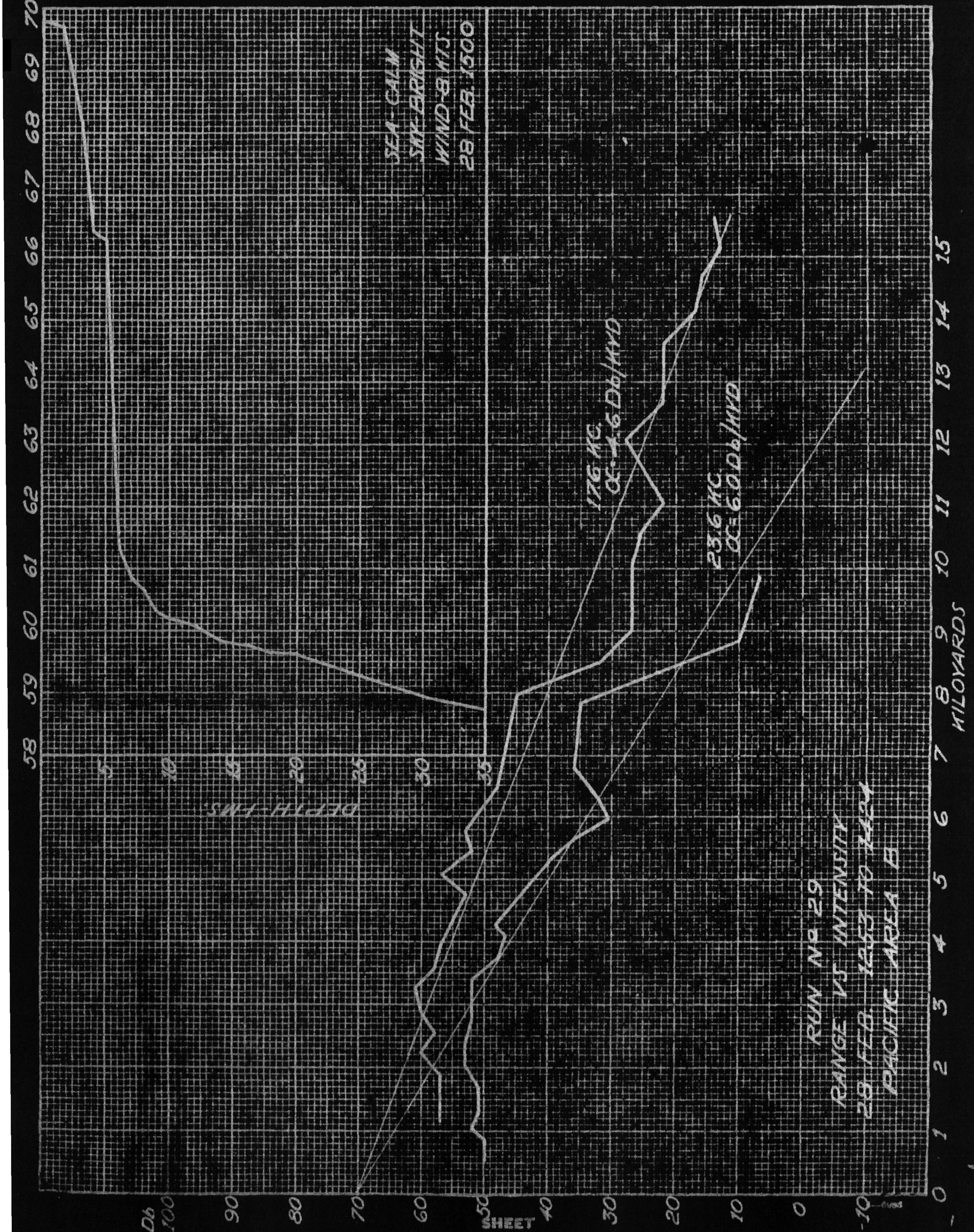


PLATE 32

U. S. NAVAL RESEARCH LABORATORY
BELLEVUE, D. C.

DATE

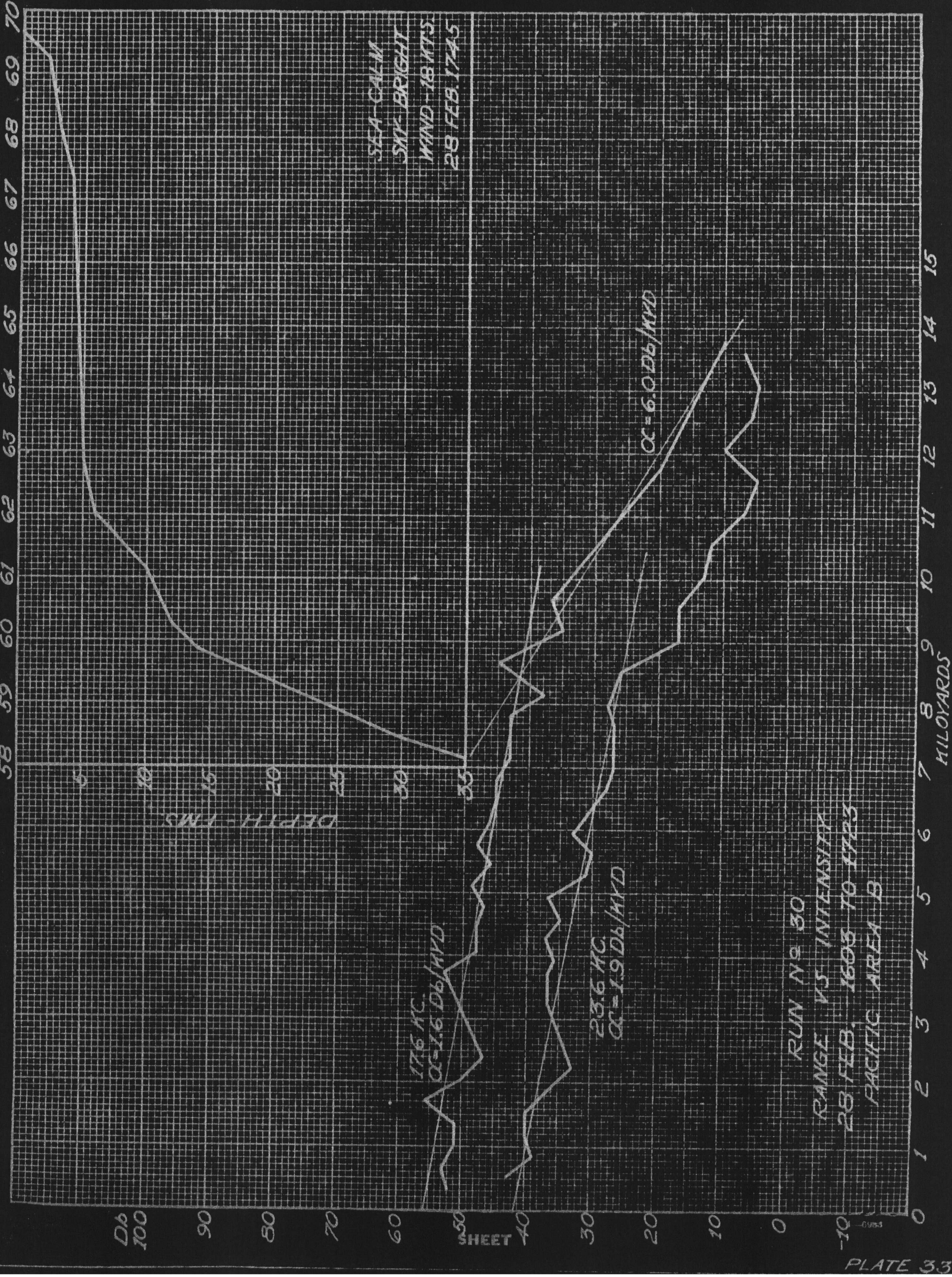


PLATE 3.3

U. S. NAVAL RESEARCH LABORATORY
BELLEVUE, D. C.

DATE

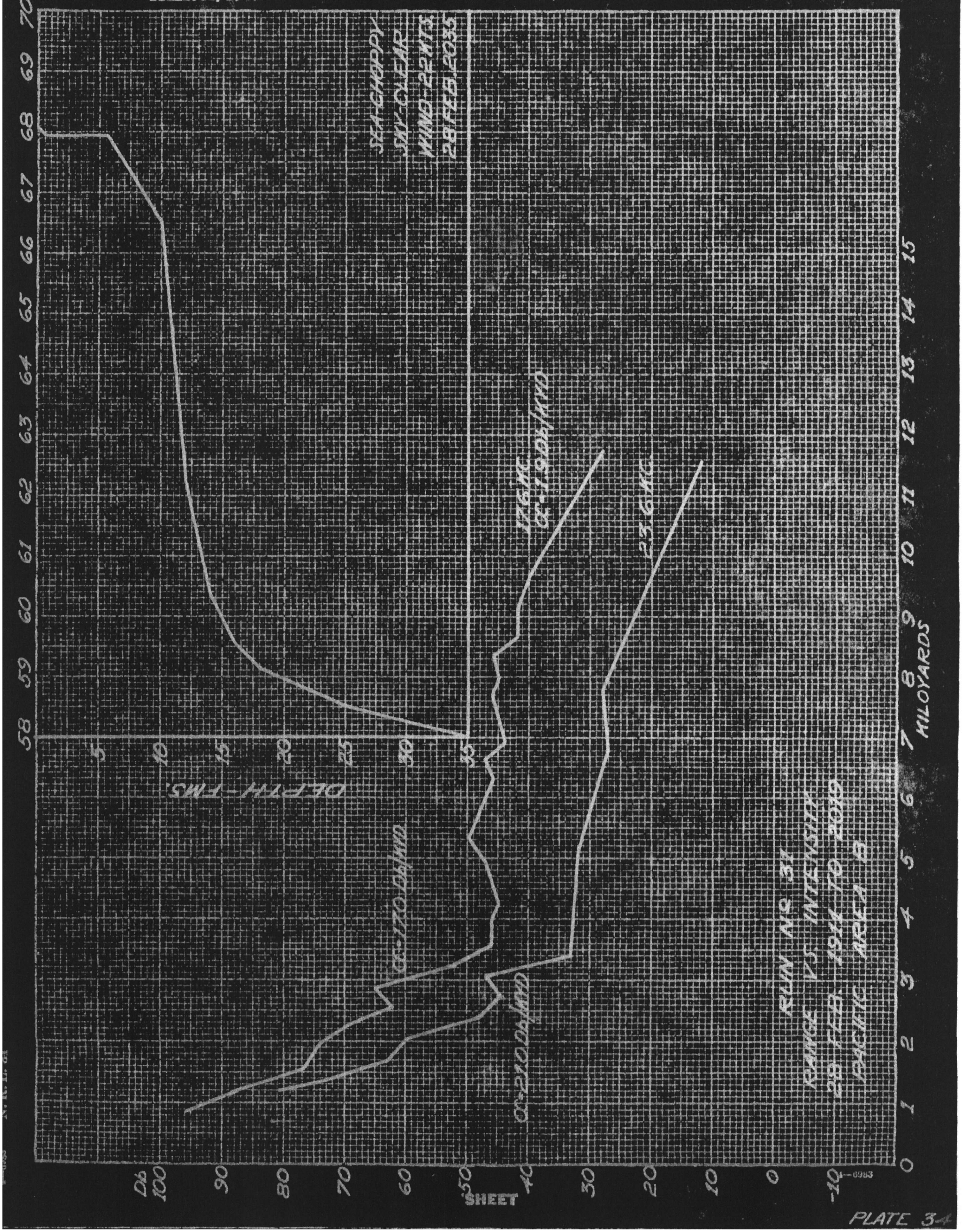
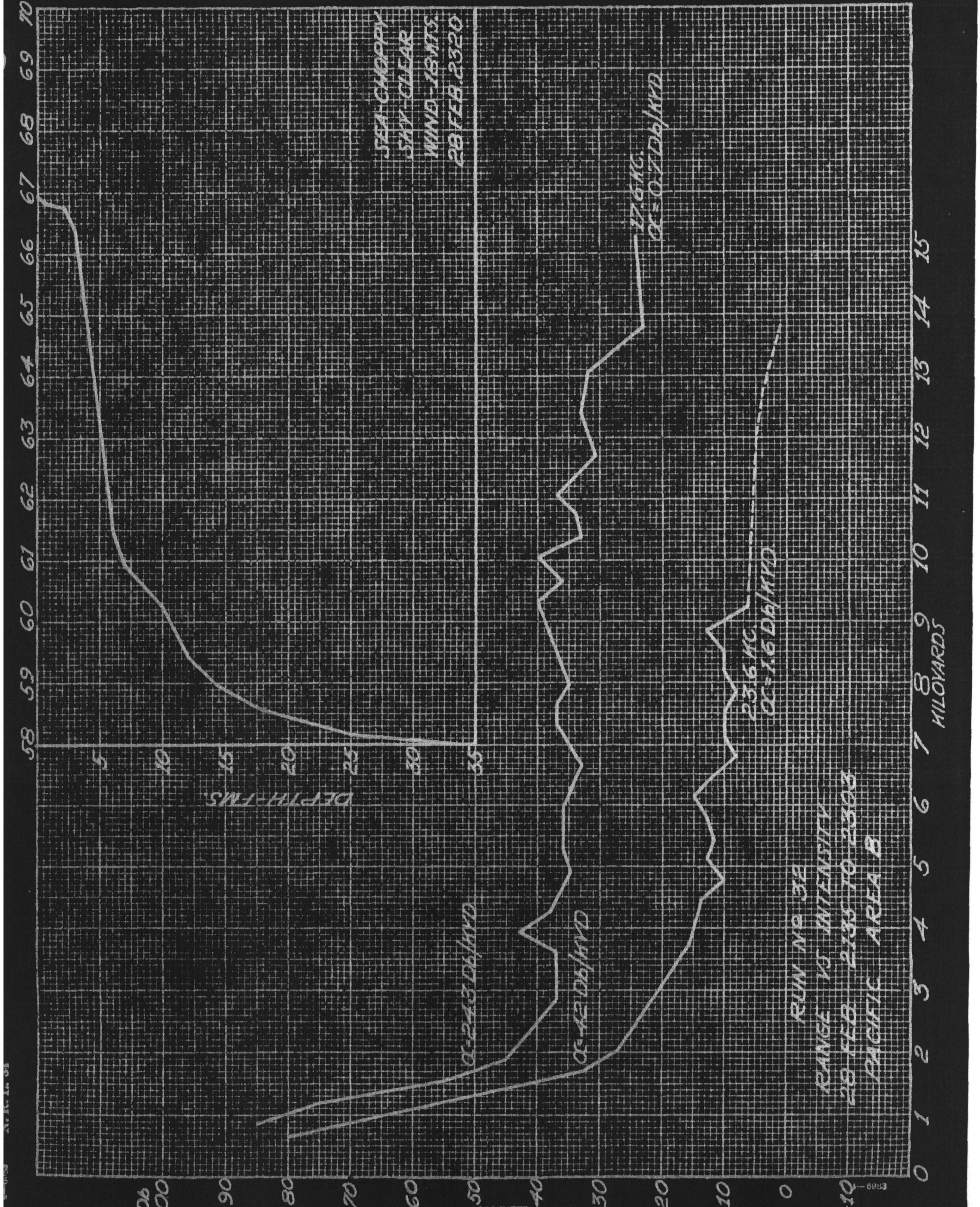


PLATE 3-4

U. S. NAVAL RESEARCH LABORATORY
BELLEVUE, D. C.

DATE



SHEET

PLATE 35

U. S. NAVAL RESEARCH LABORATORY
BELLEVUE, D. C.

DATE

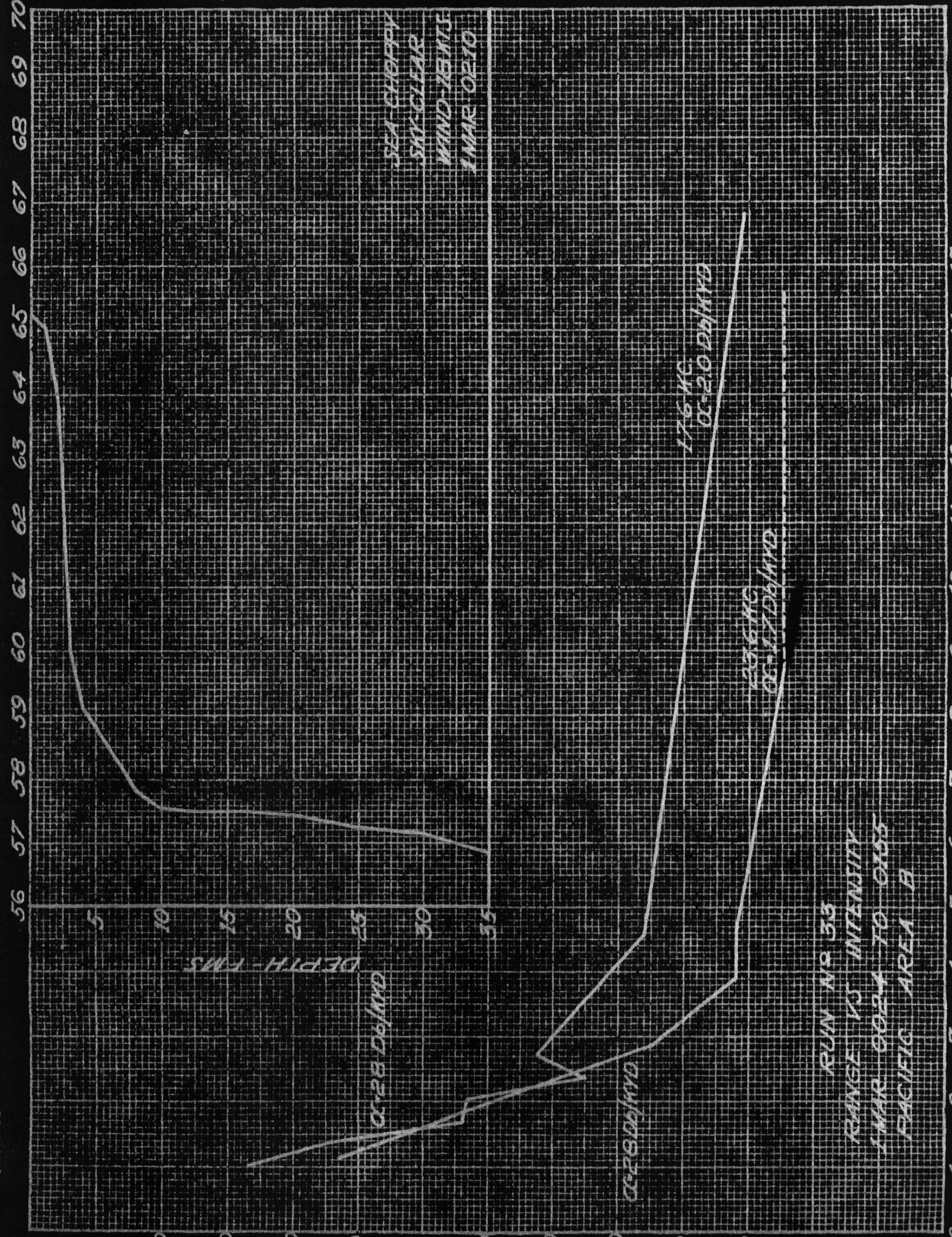
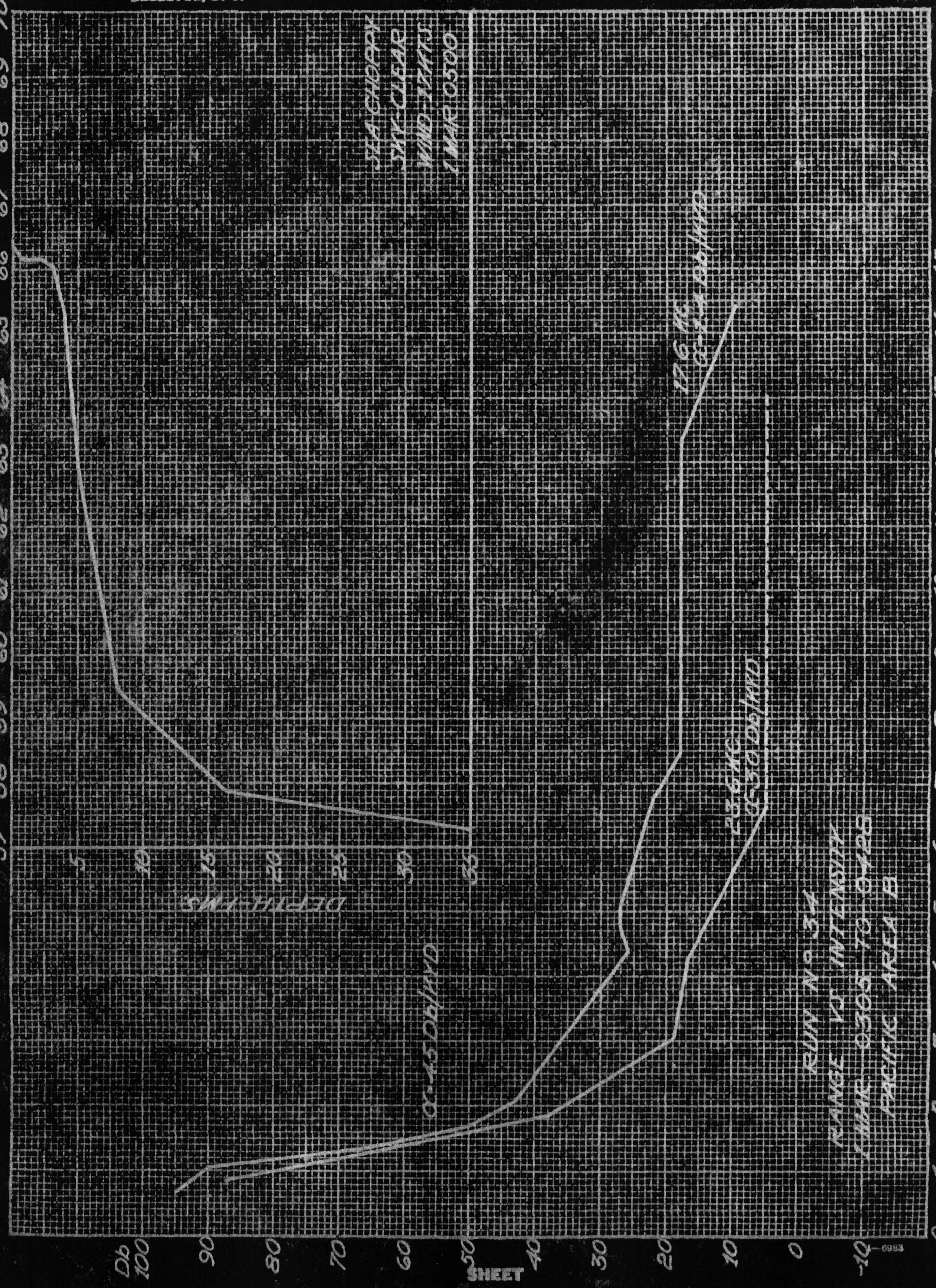


PLATE 36

U. S. NAVAL RESEARCH LABORATORY
BELLEVUE, D. C.

DATE



SHEET

PLATE 37

U. S. NAVAL RESEARCH LABORATORY

BELLEVUE, D. C.

DATE

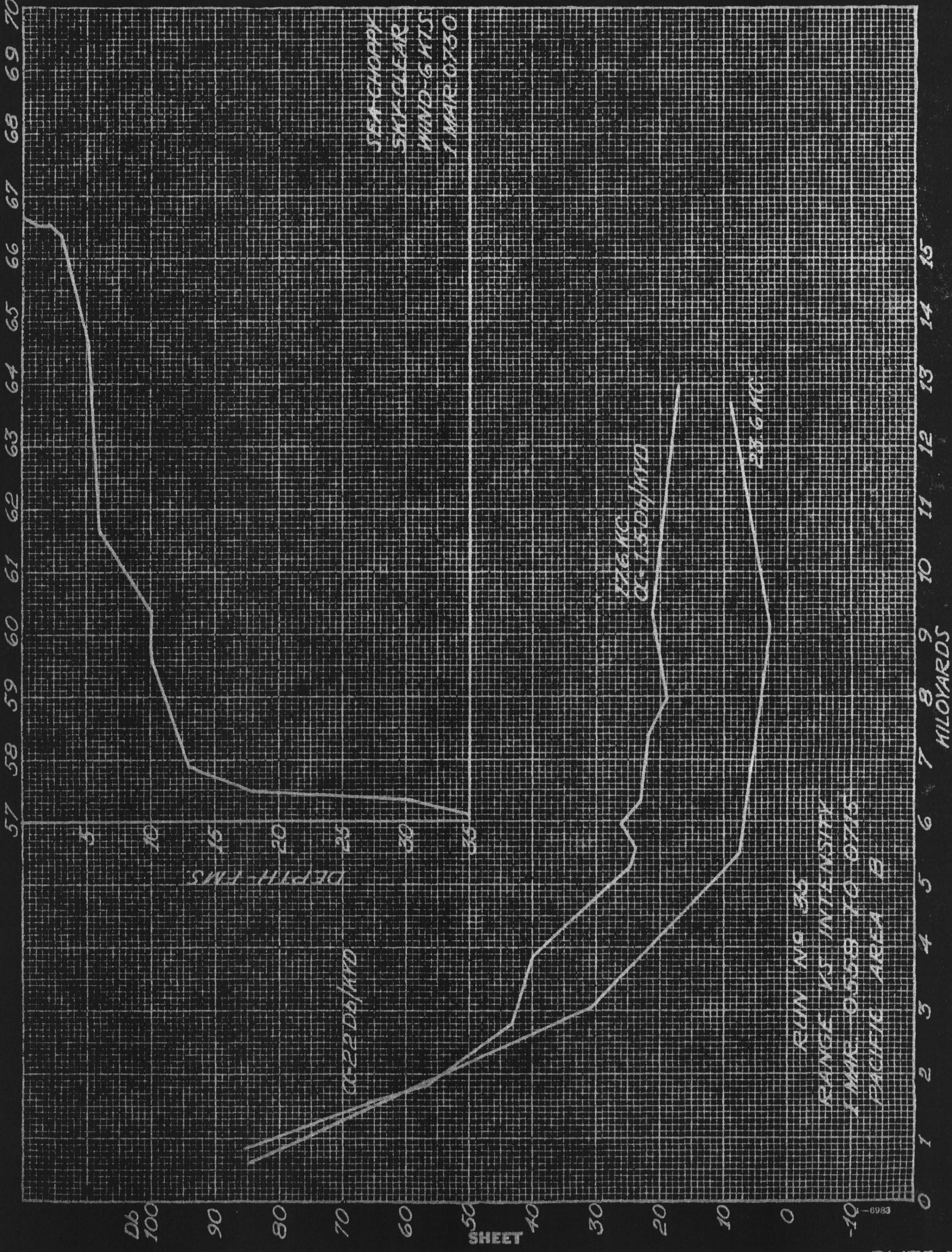


PLATE 38

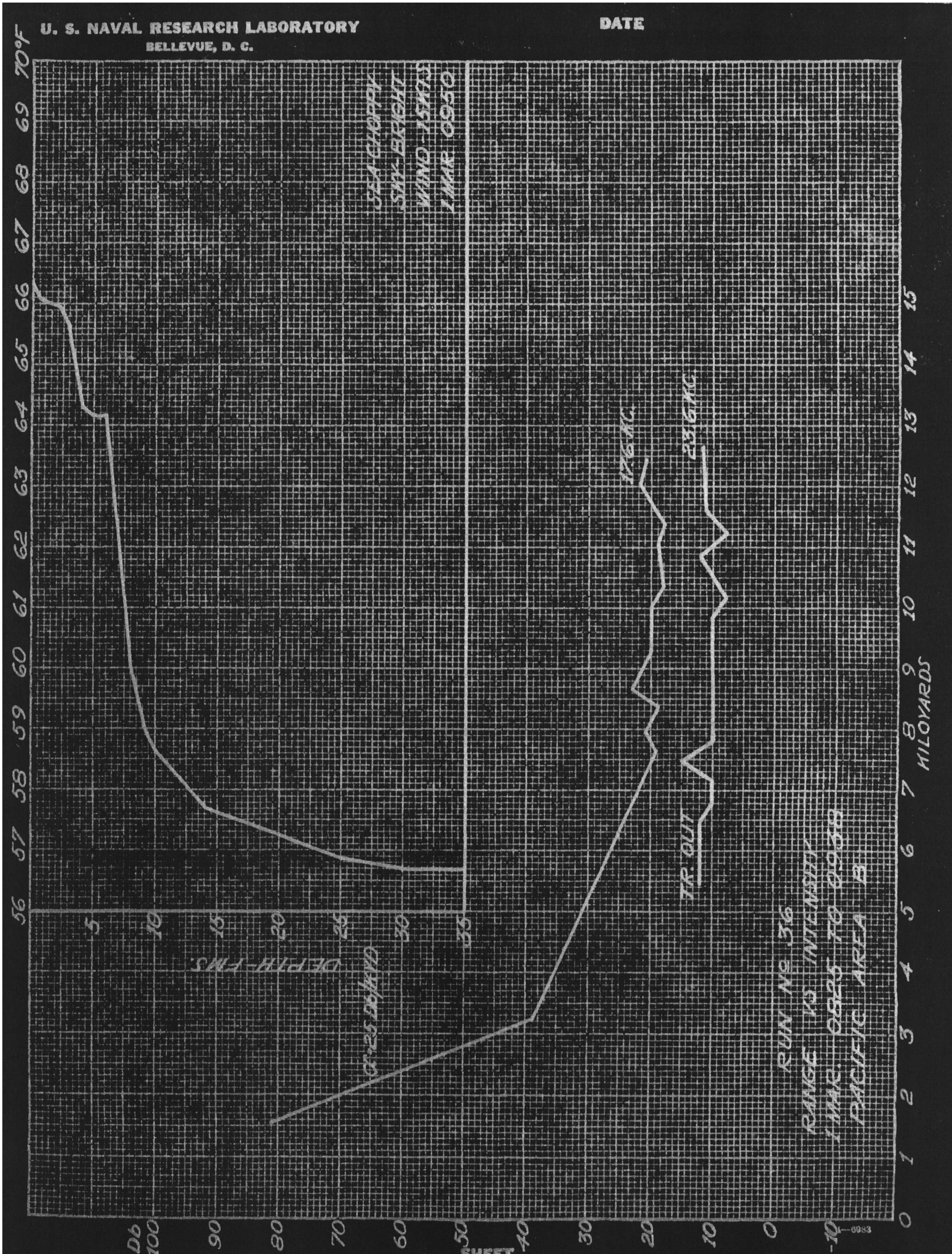
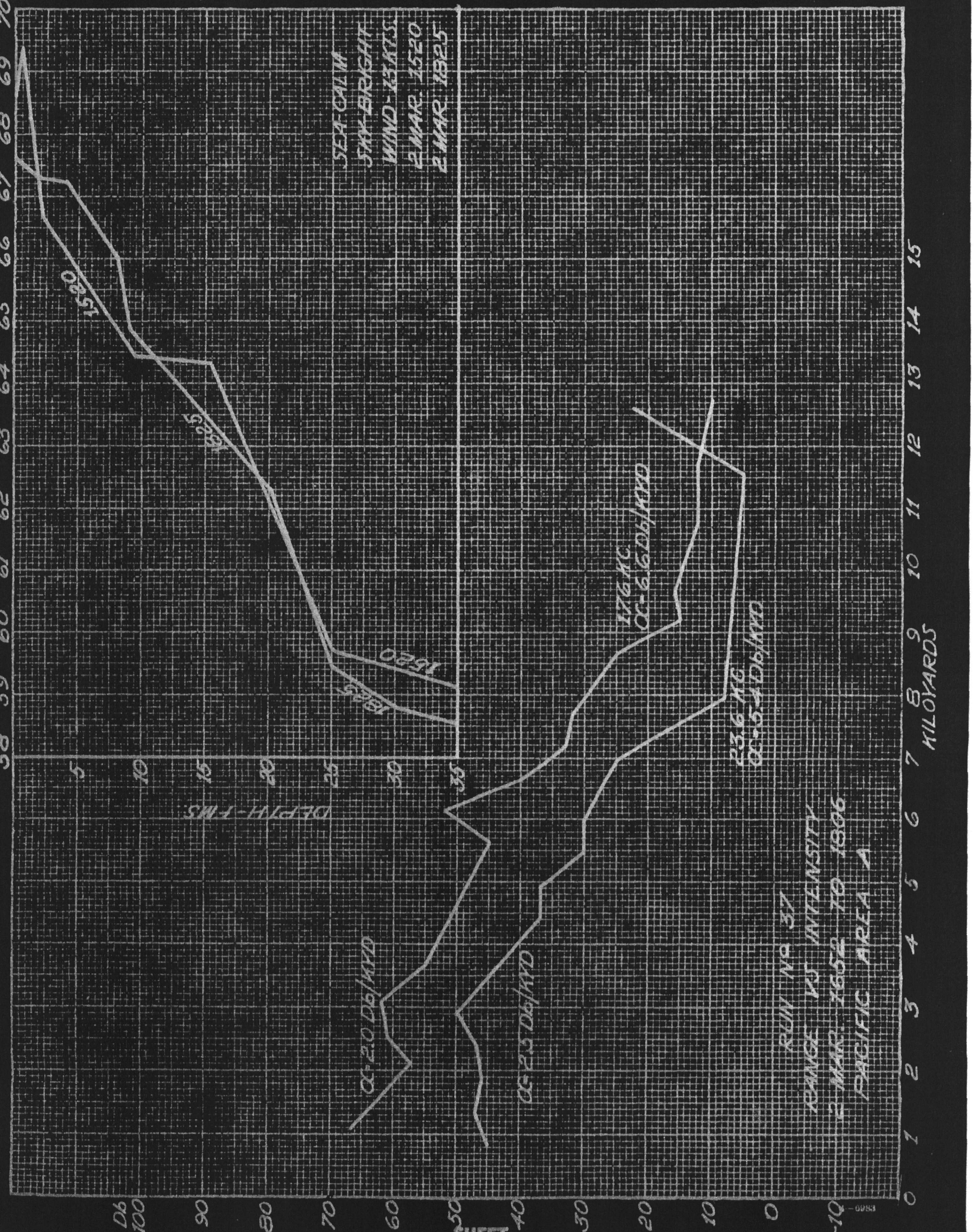

U. S. NAVAL RESEARCH LABORATORY
BELLEVUE, D. C.
DATE
SEA CHOPPY
SKY BRIGHT
WIND 15KTS
1 MAR 0950
DEPTH-FMS
17.6 KC.
23.6 KC.
TR. OUT
KILOYARDS
RUN No 36
RANGE VS INTENSITY
1 MAR. 0825 TO 0938
PACIFIC AREA B
Db
SHEET

PLATE 39

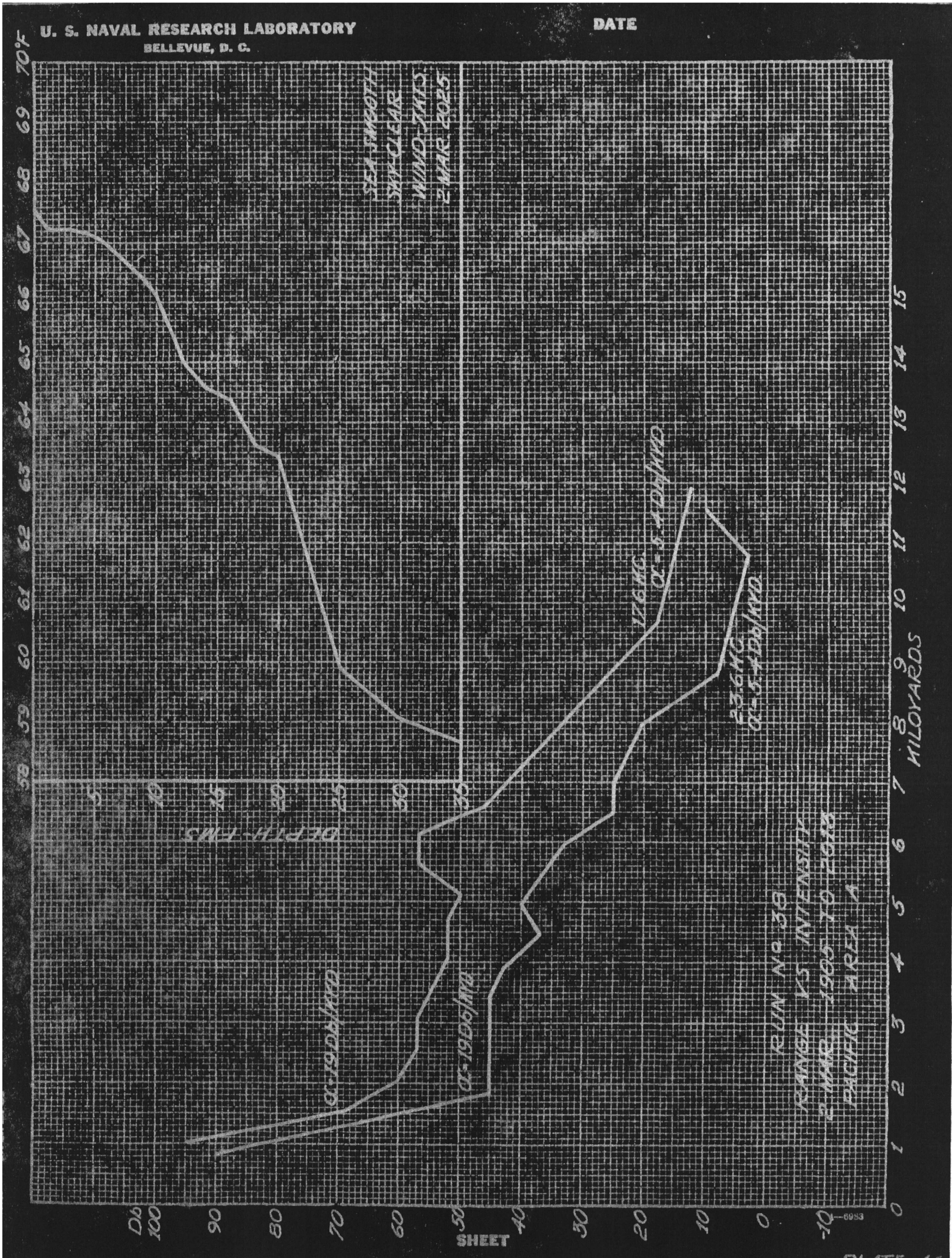
U. S. NAVAL RESEARCH LABORATORY
BELLEVUE, D. C.

DATE



SHEET

PLATE 40



U. S. NAVAL RESEARCH LABORATORY
BELLEVUE, D. C.
DATE
SHEET
SEA SMOOTH
SKY CLEAR
WIND 7 KTS.
2 MAR 2025
DEPTH-FMS
KILOYARDS
RUN No 38
RANGE VS INTENSITY
PACIFIC AREA A
17.6 KC
23.6 KC
70°F
Db

PLATE 41

U. S. NAVAL RESEARCH LABORATORY
BELLEVUE, D. C.

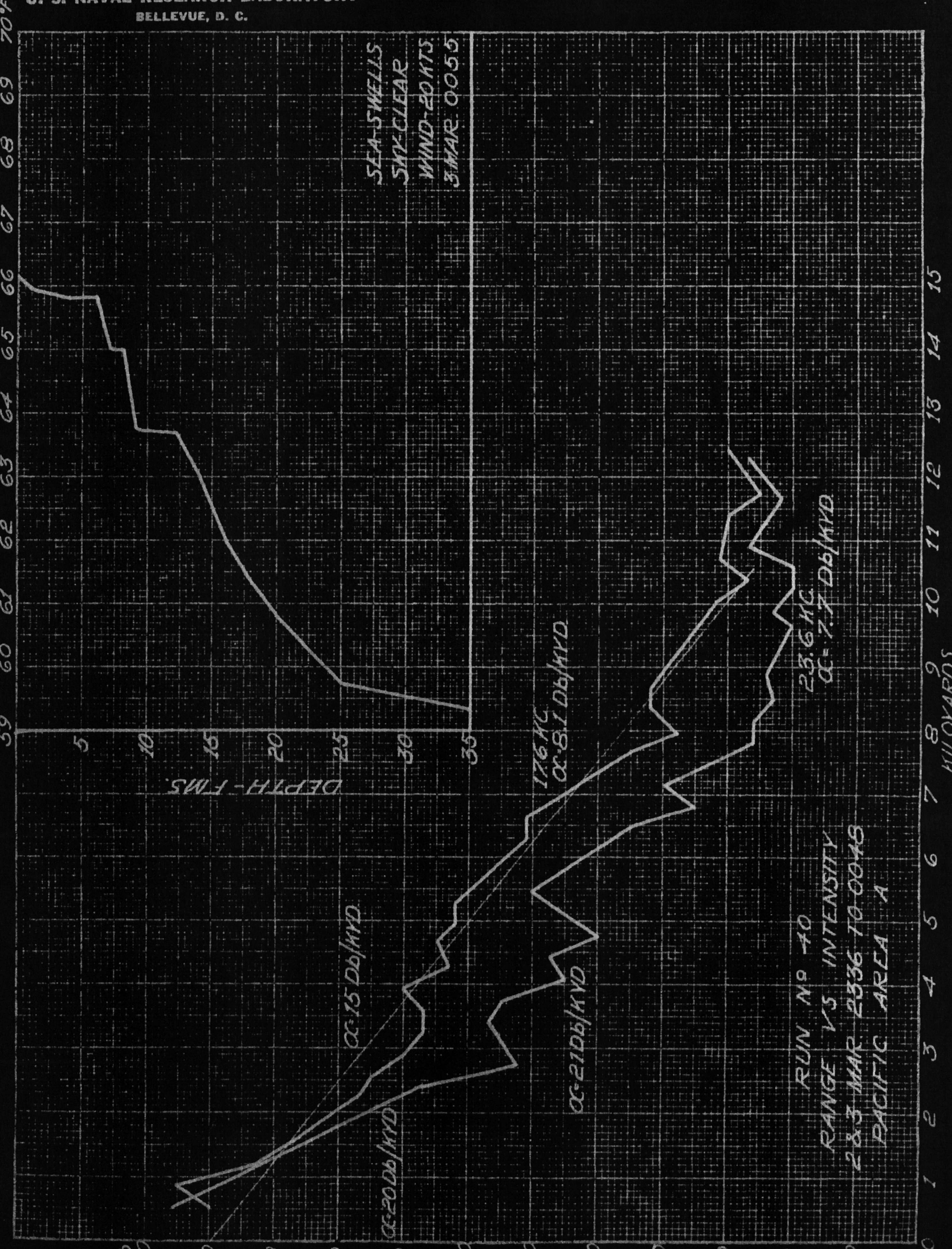
DATE

SHEET

PLATE 42

U. S. NAVAL RESEARCH LABORATORY
BELLEVUE, D. C.

DATE



SHEET

PLATE 43

U. S. NAVAL RESEARCH LABORATORY
BELLEVUE, D. C.

DATE

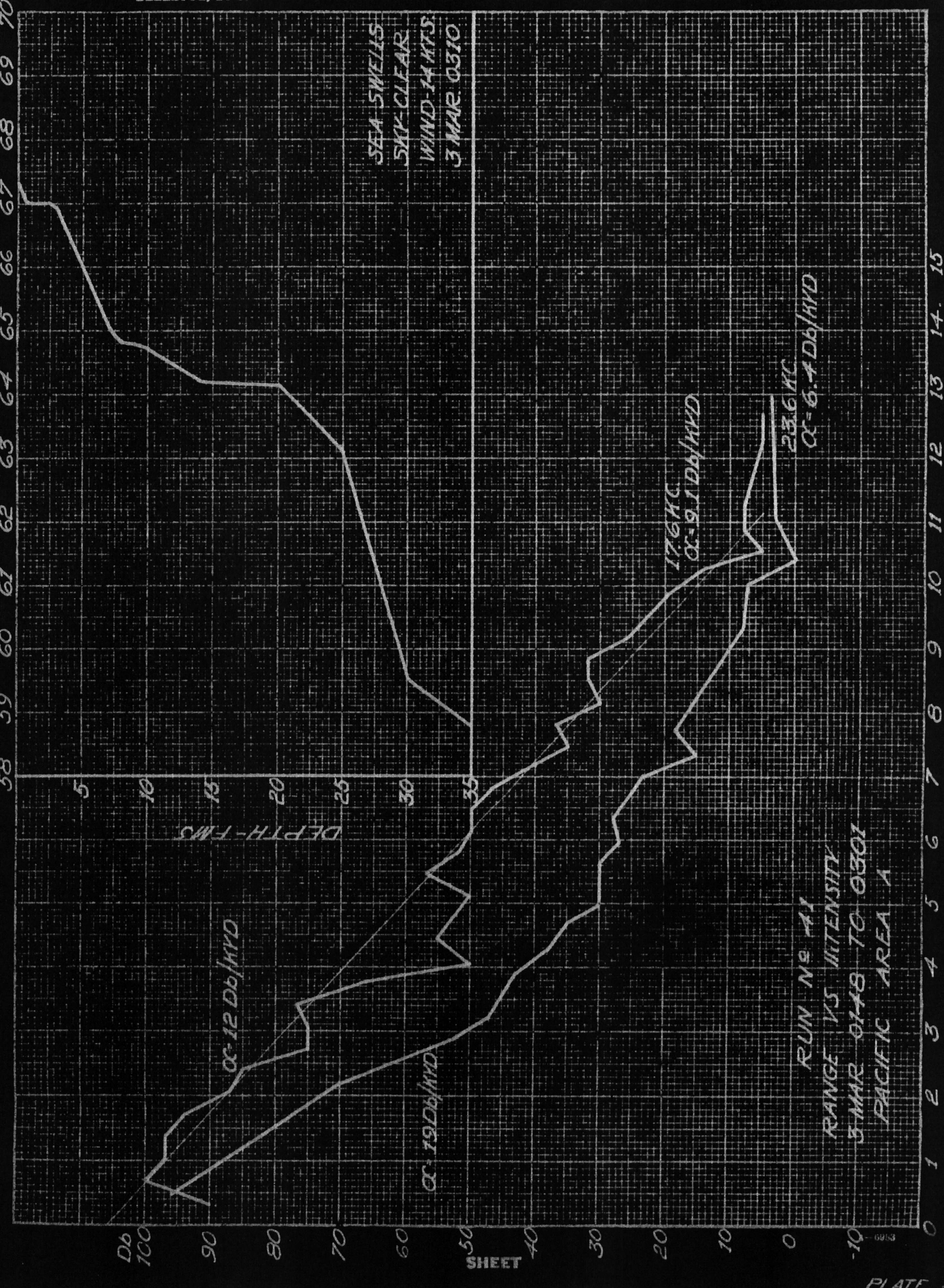


PLATE 4

U. S. NAVAL RESEARCH LABORATORY
BELLEVUE, D. C.

DATE

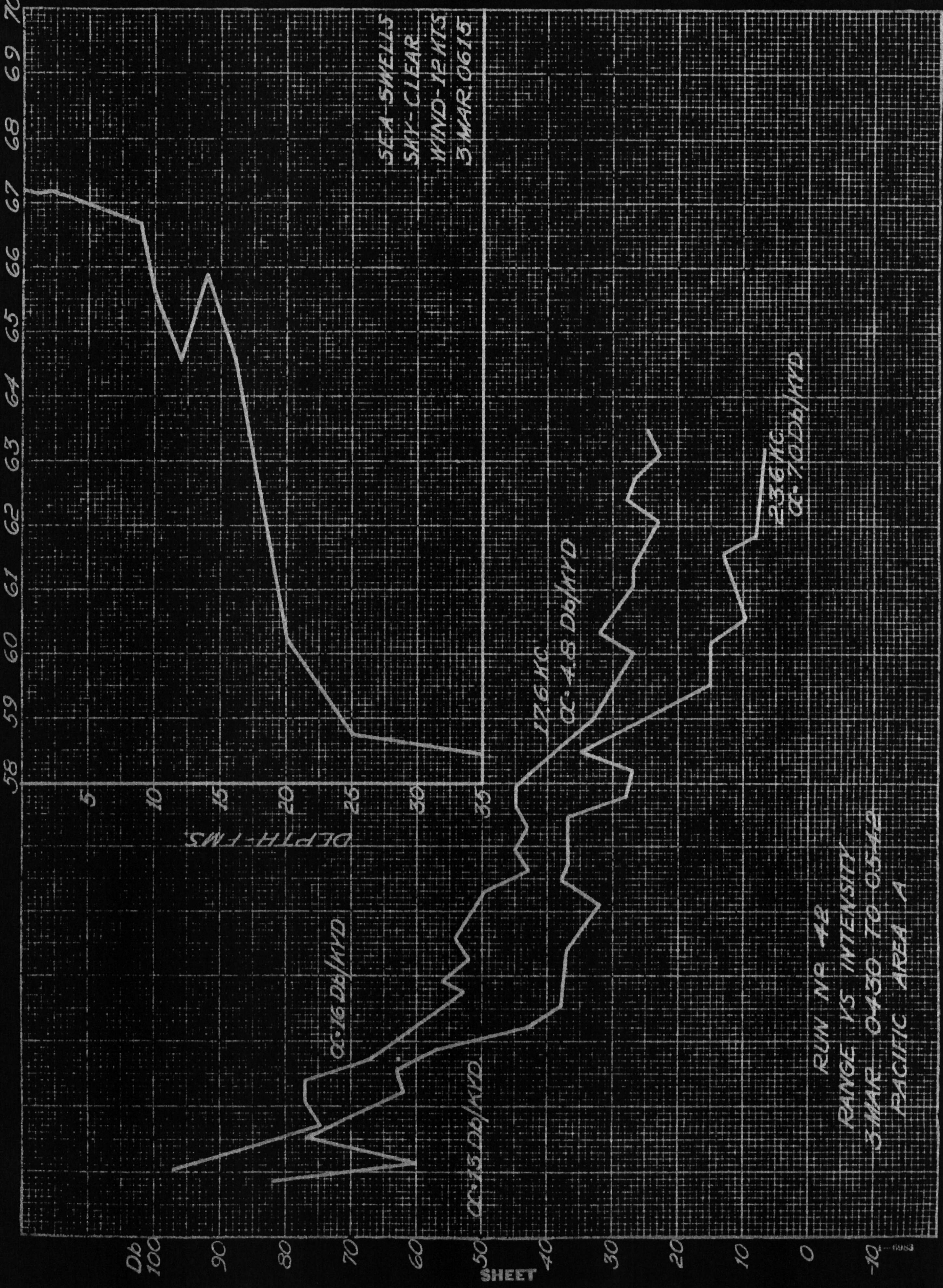
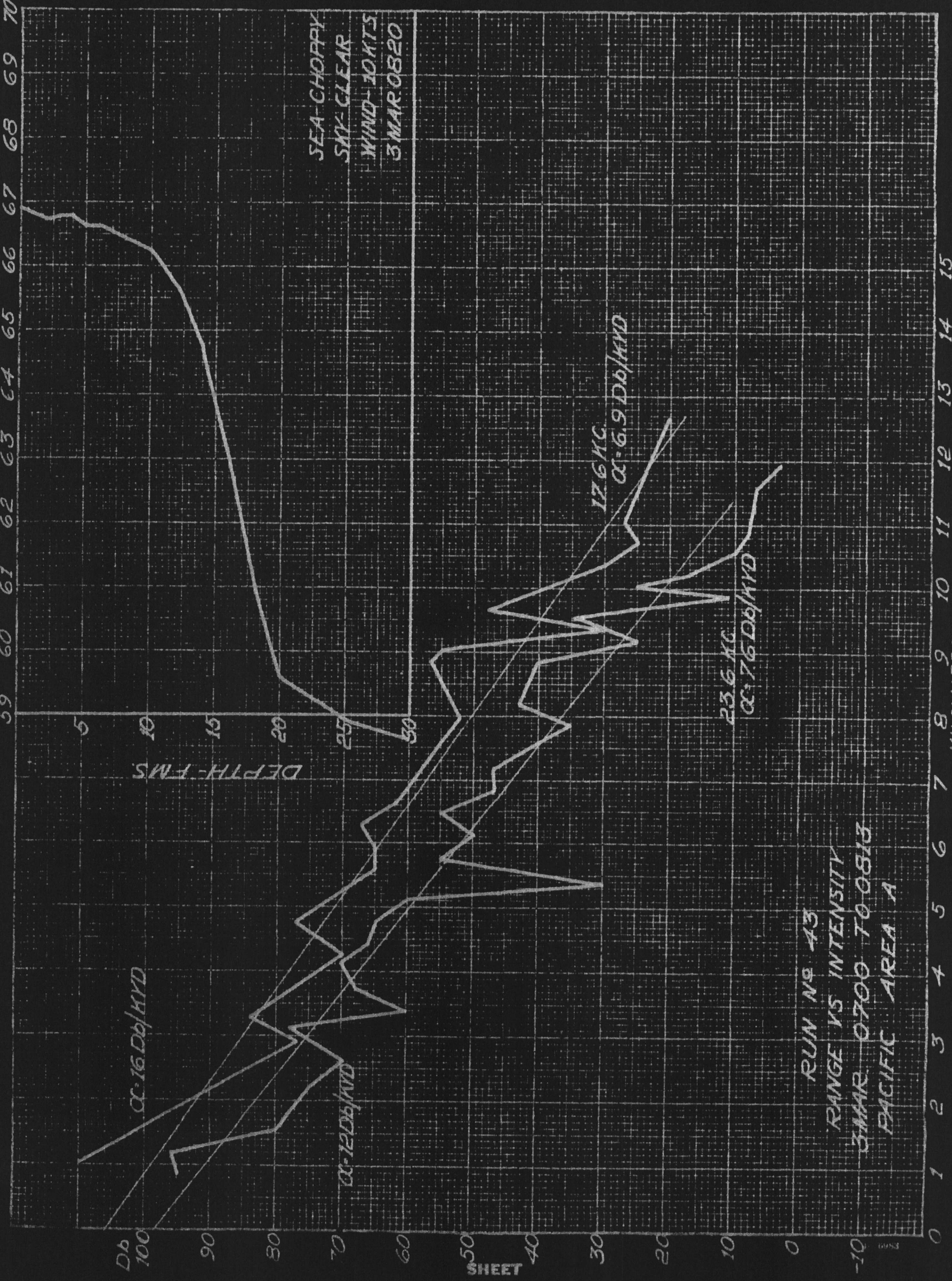


PLATE 45

U. S. NAVAL RESEARCH LABORATORY
BELLEVUE, D. C.

DATE

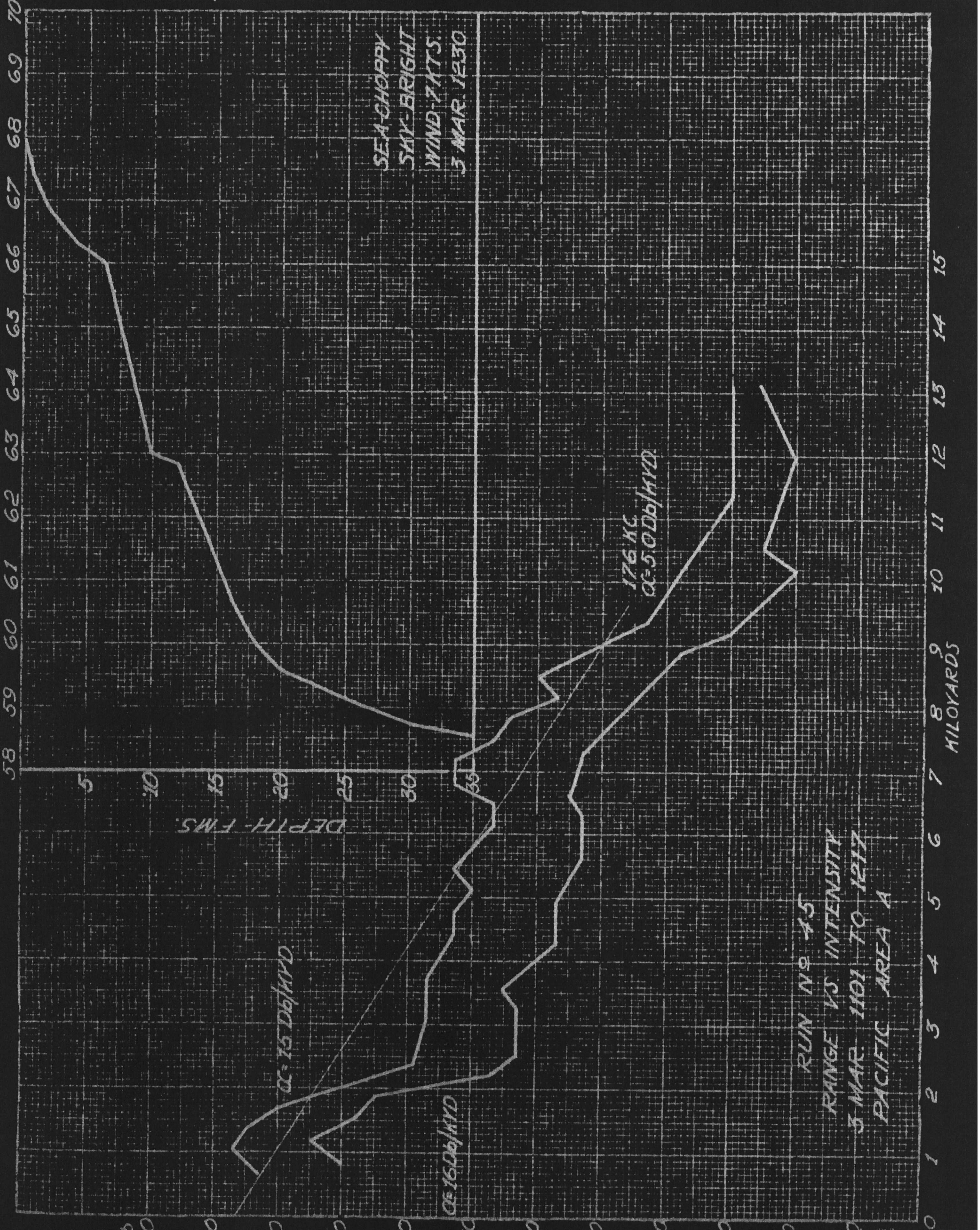


SHEET

PLATE 4

U. S. NAVAL RESEARCH LABORATORY
BELLEVUE, D. C.

DATE

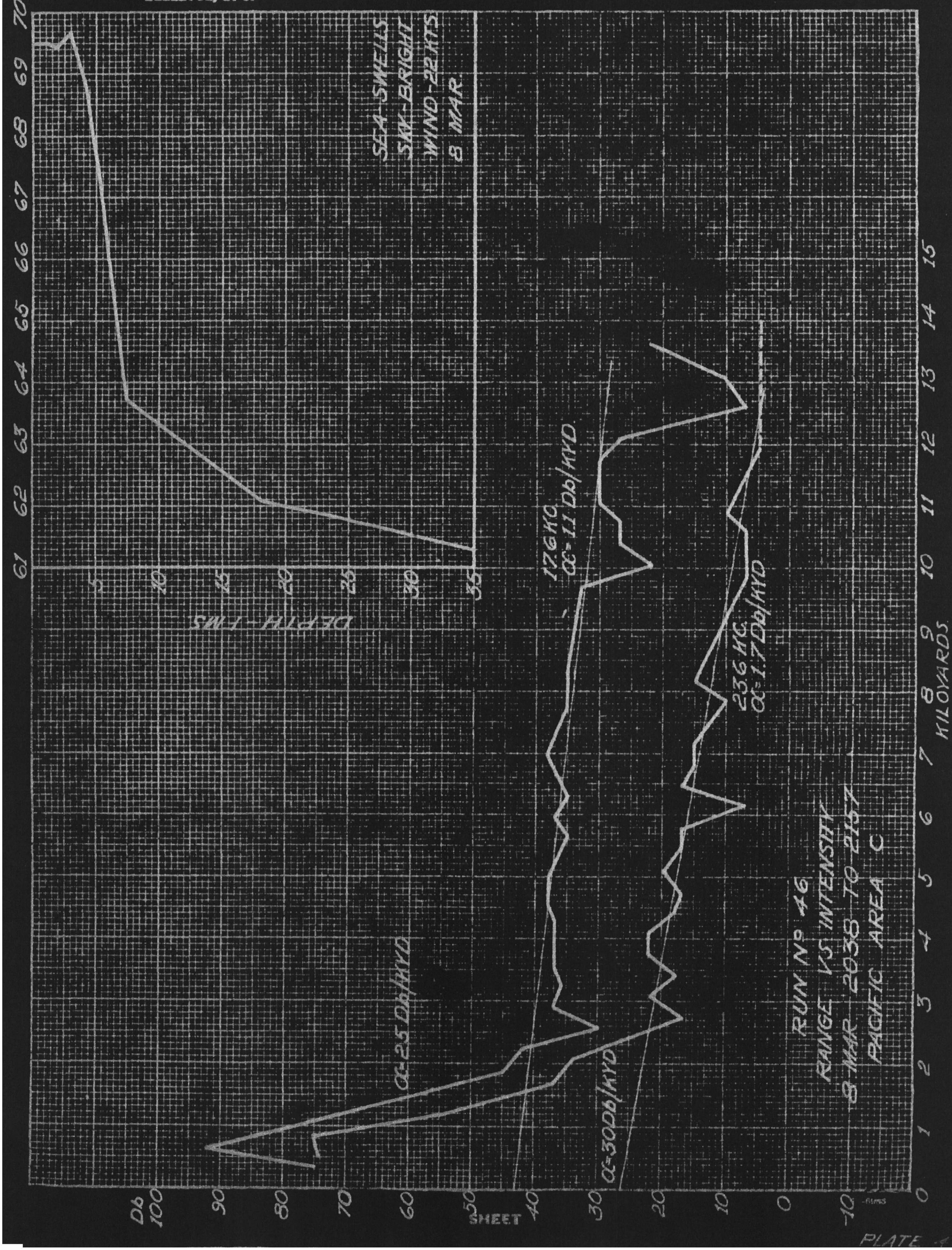


SHEET

PLATE 47

U. S. NAVAL RESEARCH LABORATORY
BELLEVUE, D. C.

DATE

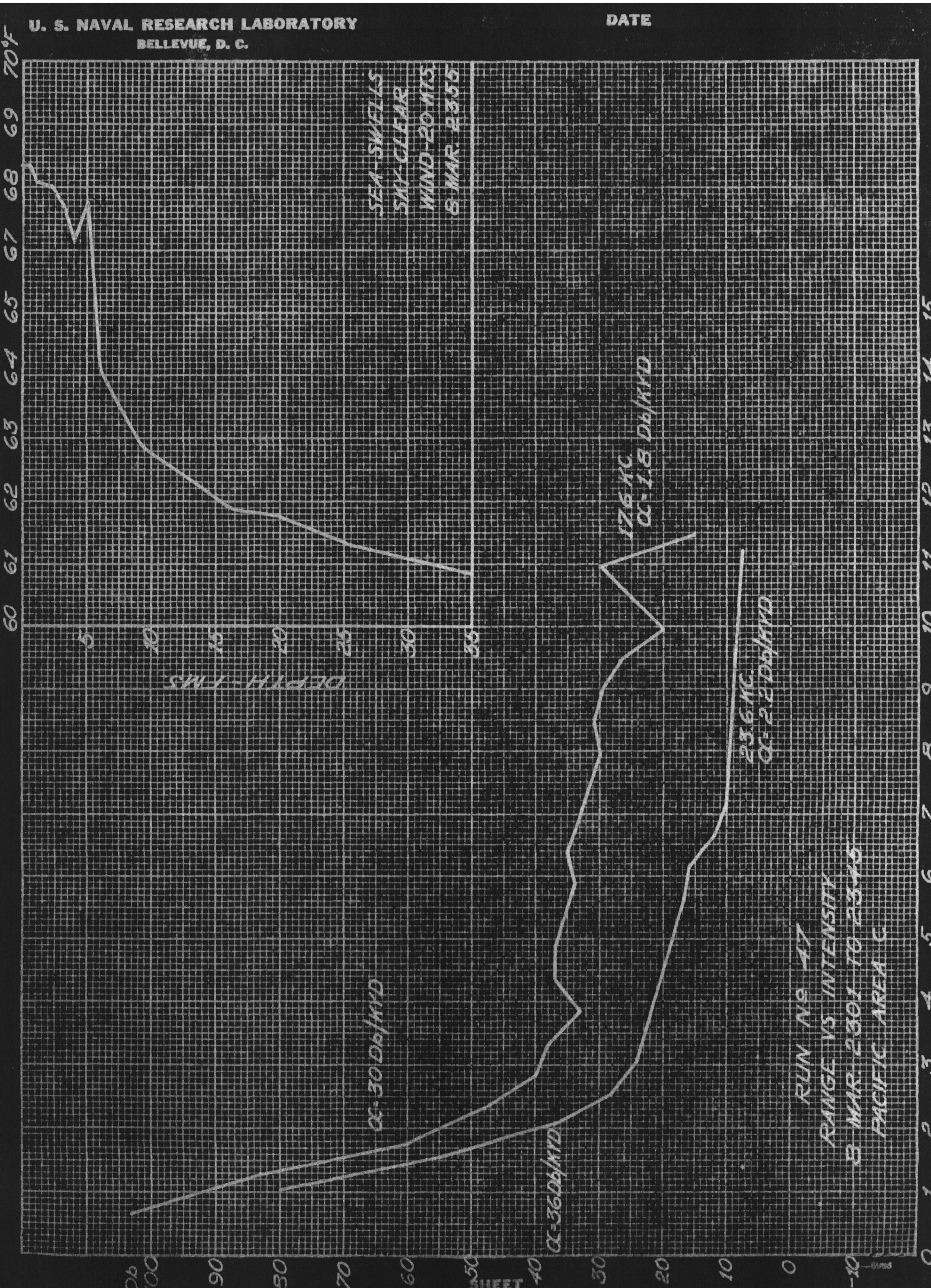


SHEET

PLATE 48

U. S. NAVAL RESEARCH LABORATORY
BELLEVUE, D. C.

DATE



N. R. L. 31

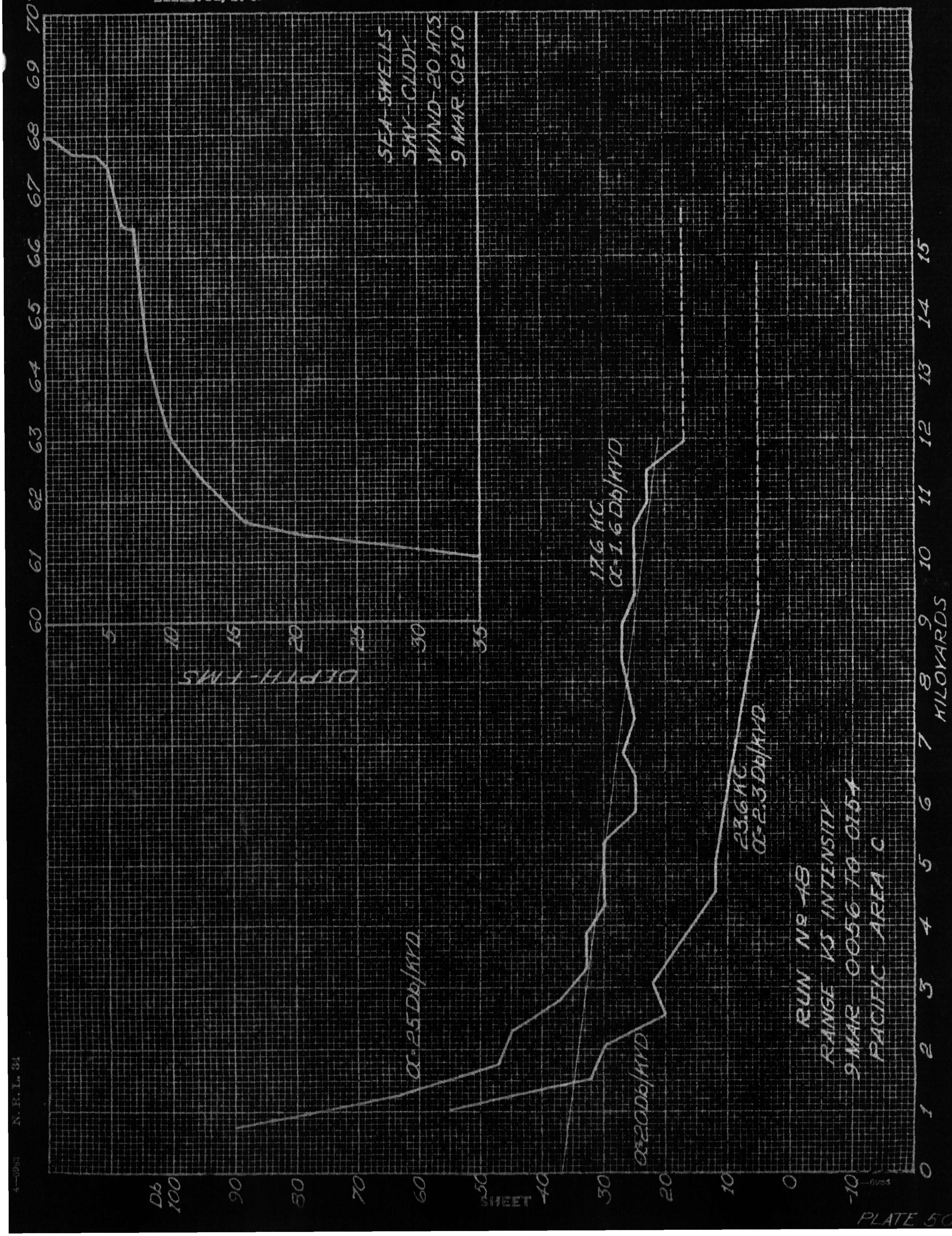
SHEET

PLATE 4S

GOVERNMENT PRINTING OFFICE

U. S. NAVAL RESEARCH LABORATORY
BELLEVUE, D. C.

DATE



N. R. L. 31

SHEET

PLATE 50

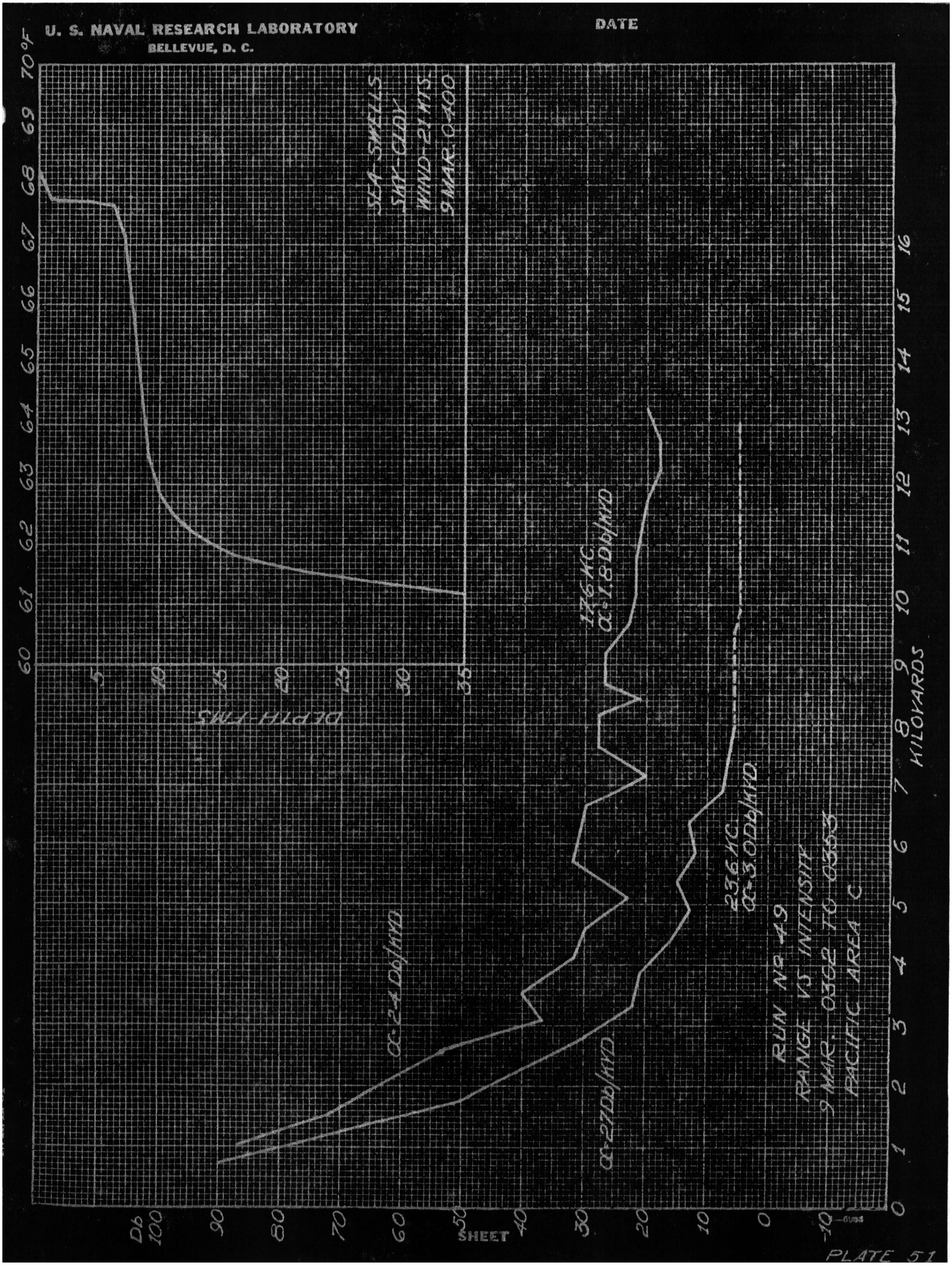
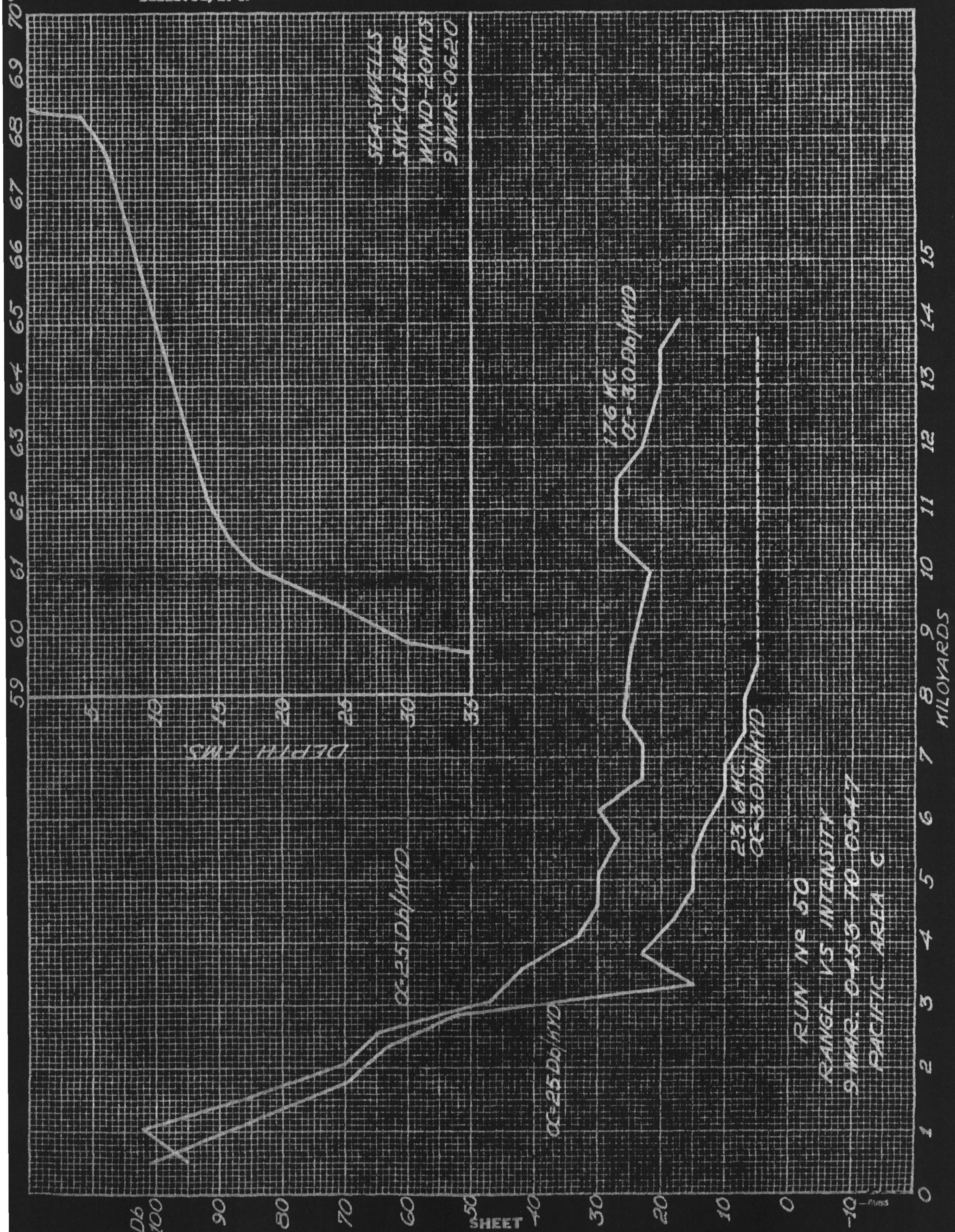

U. S. NAVAL RESEARCH LABORATORY
BELLEVUE, D. C.
DATE
SHEET
SEA-SWELLS
SKY-CLDY
WIND-21 KTS.
9 MAR. 0400
DEPTH-FMS
KILOYARDS
17.6 KC.
α=1.8 Db/KYD
23.6 KC.
α=3.0 Db/KYD
α=2.4 Db/KYD
α=2.7 Db/KYD
RUN No 49
RANGE VS INTENSITY
9 MAR. 0302 TO 0353
PACIFIC AREA C

PLATE 51

U. S. NAVAL RESEARCH LABORATORY
BELLEVUE, D. C.

DATE



SHEET

PLATE 52

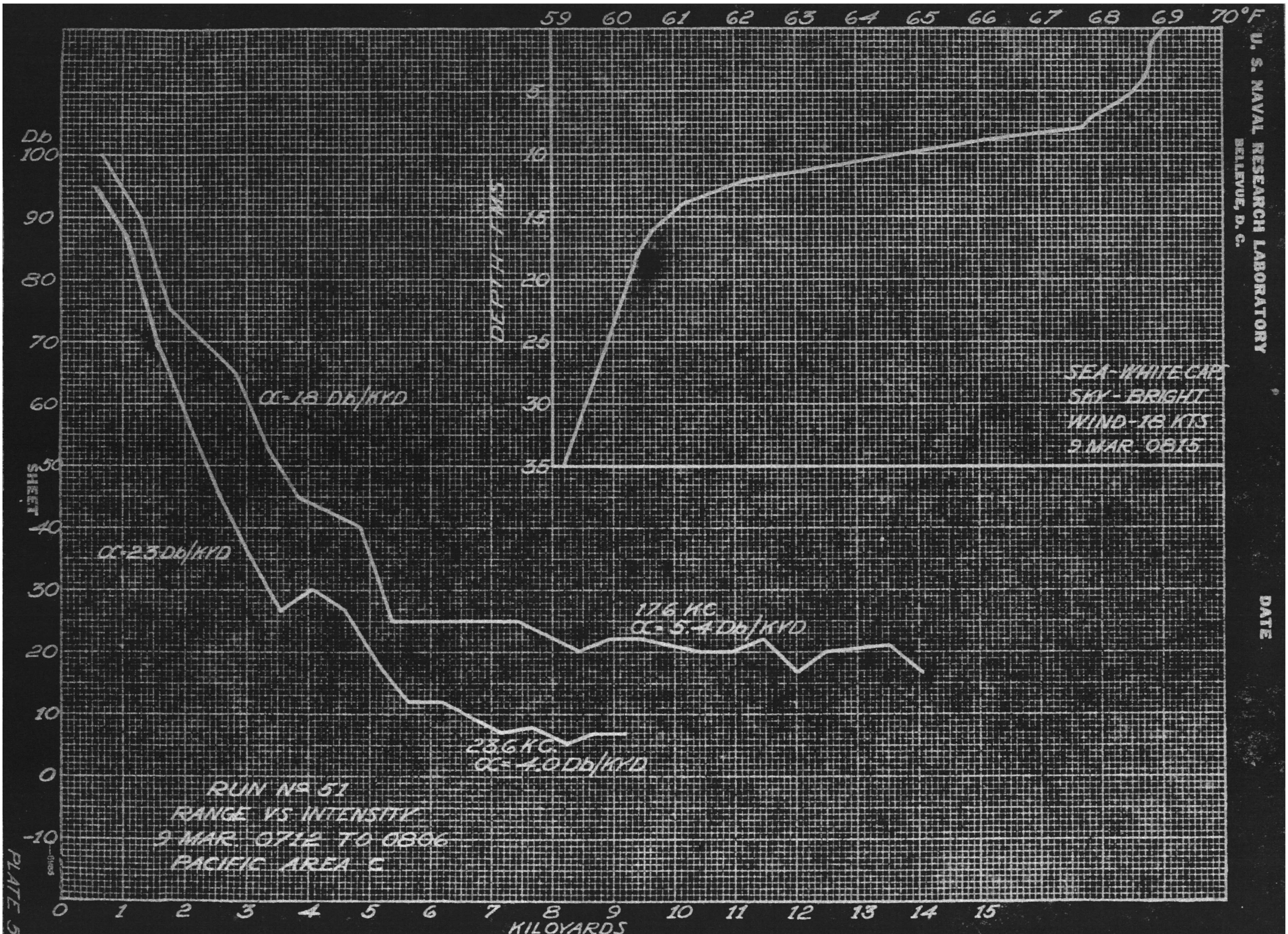

U. S. NAVAL RESEARCH LABORATORY
BELLEVUE, D. C.
DATE
SHEET
Db
KILOYARDS
70°F
DEPTH-FMS
SEA-WHITE CAPS
SKY-BRIGHT
WIND-18 KTS
9 MAR. 0815
α-18 Db/KYD
α-23 Db/KYD
17.6 KC
α=5.4 Db/KYD
23.6 KC
α=4.0 Db/KYD
RUN No 51
RANGE VS INTENSITY
9 MAR. 0712 TO 0806
PACIFIC AREA C

PLATE 53

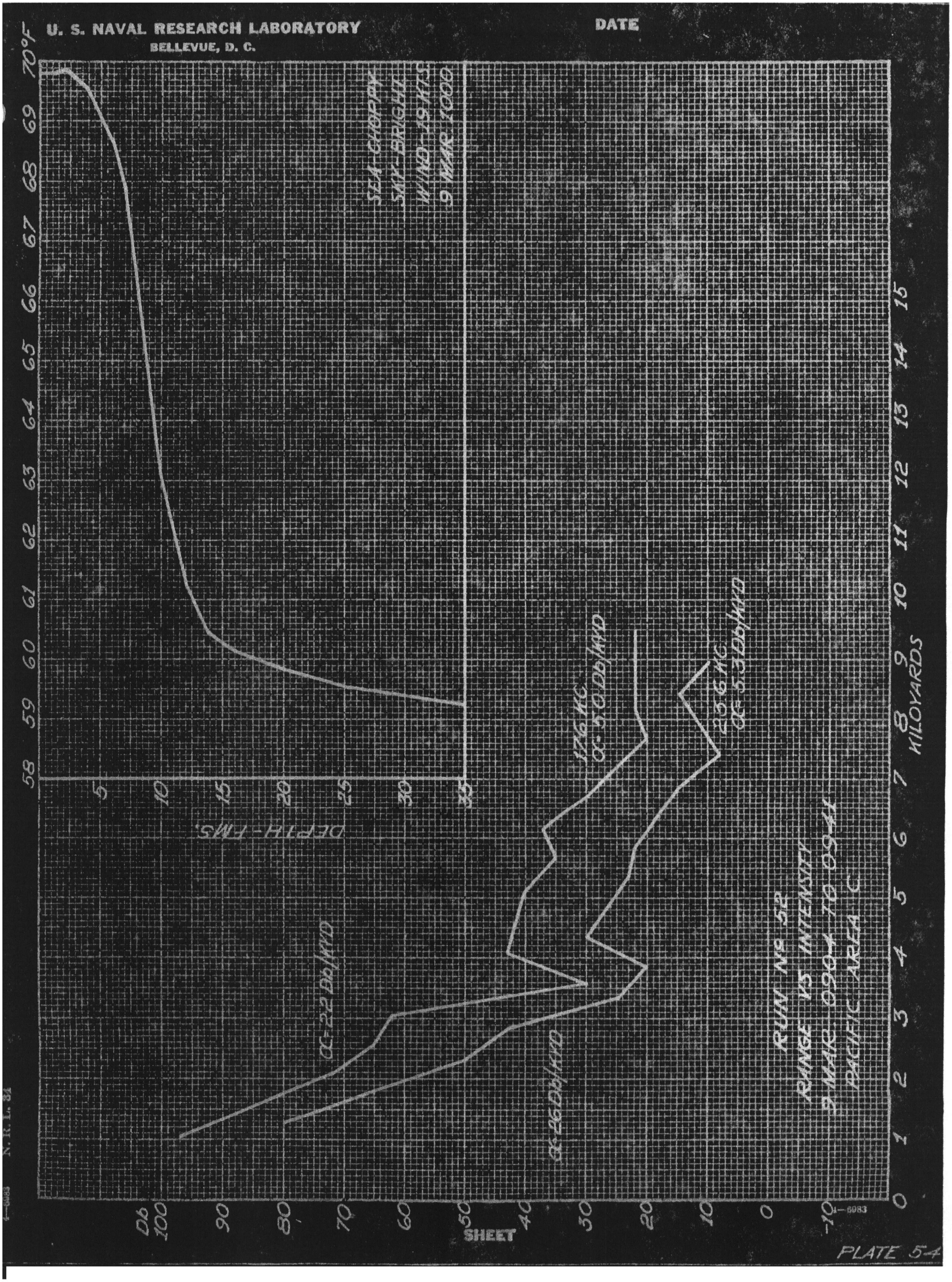
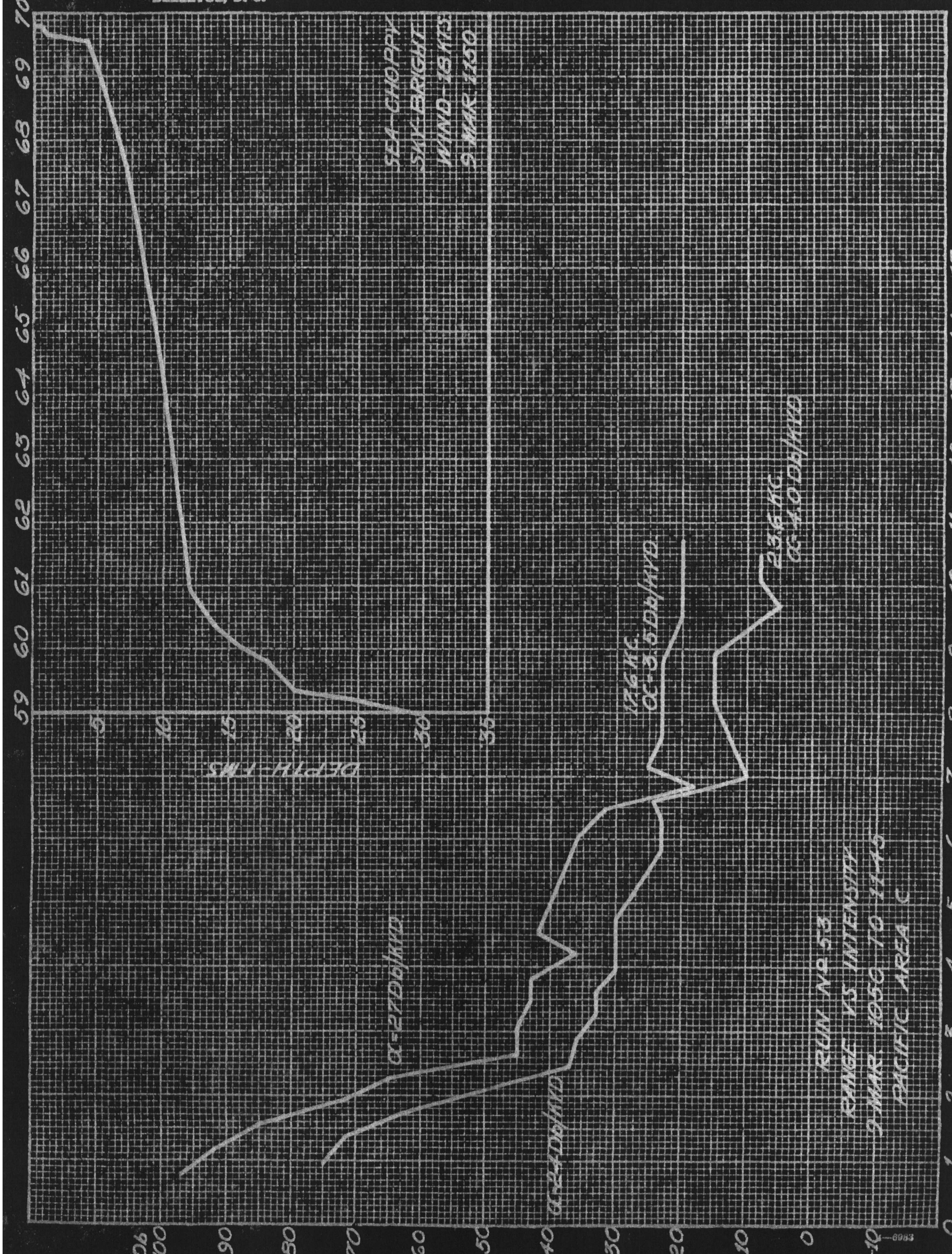

U. S. NAVAL RESEARCH LABORATORY
BELLEVUE, D. C.
DATE
SEA-CHOPPY
SKY-BRIGHT
WIND-19 KTS
9 MAR 1000
70°F
DEPTH-FMS.
17.6 KC
α=5.0 Db/KYD
25.6 KC
α=5.3 Db/KYD
α=2.2 Db/KYD
α=2.6 Db/KYD
RUN No 52
RANGE VS INTENSITY
9 MAR 0904 TO 0941
PACIFIC AREA C
KILOYARDS
Db
SHEET
N. R. L. 31

PLATE 54

U. S. NAVAL RESEARCH LABORATORY
BELLEVUE, D. C.

DATE



SHEET

PLATE 55

U. S. NAVAL RESEARCH LABORATORY
BELLEVUE, D. C.

DATE

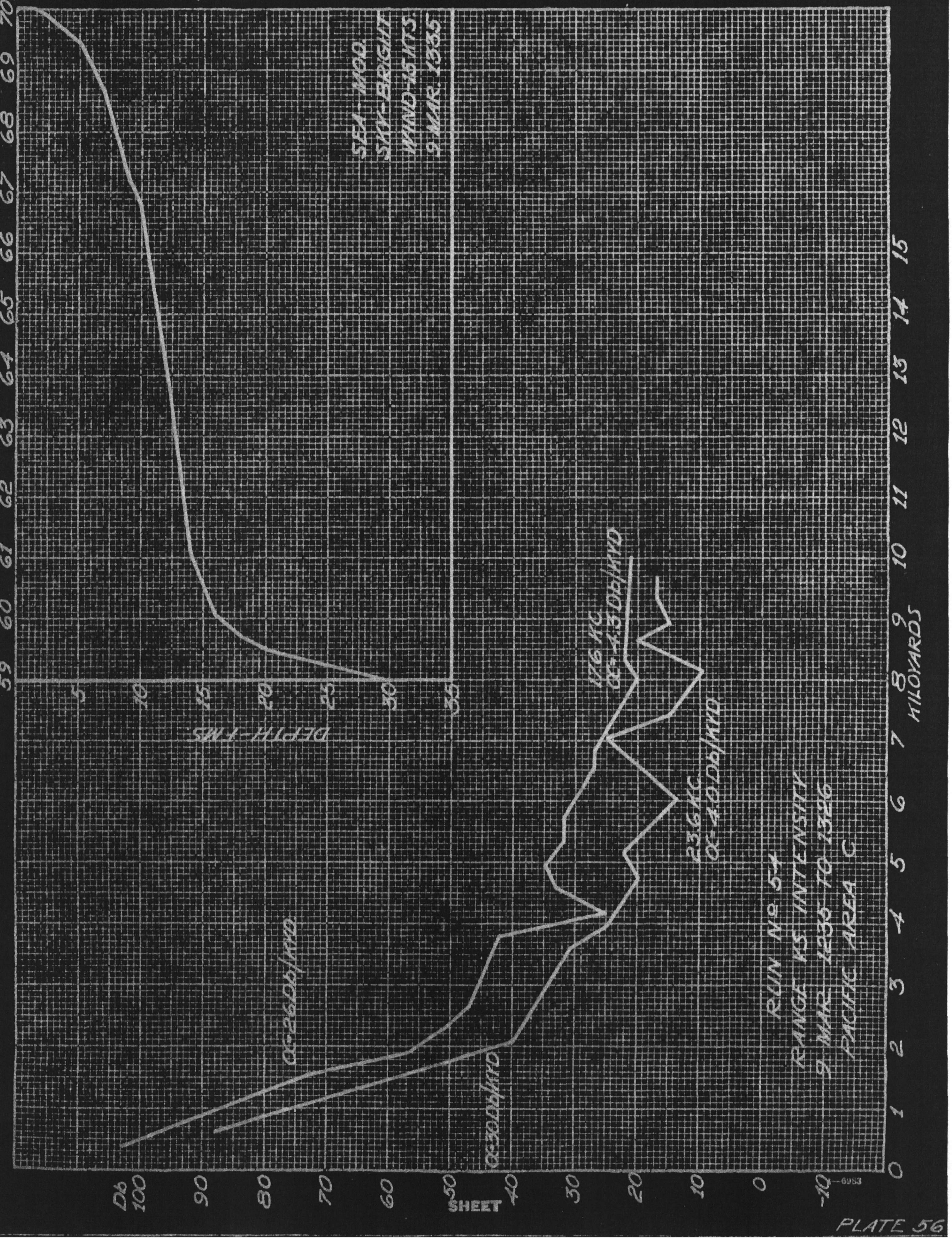
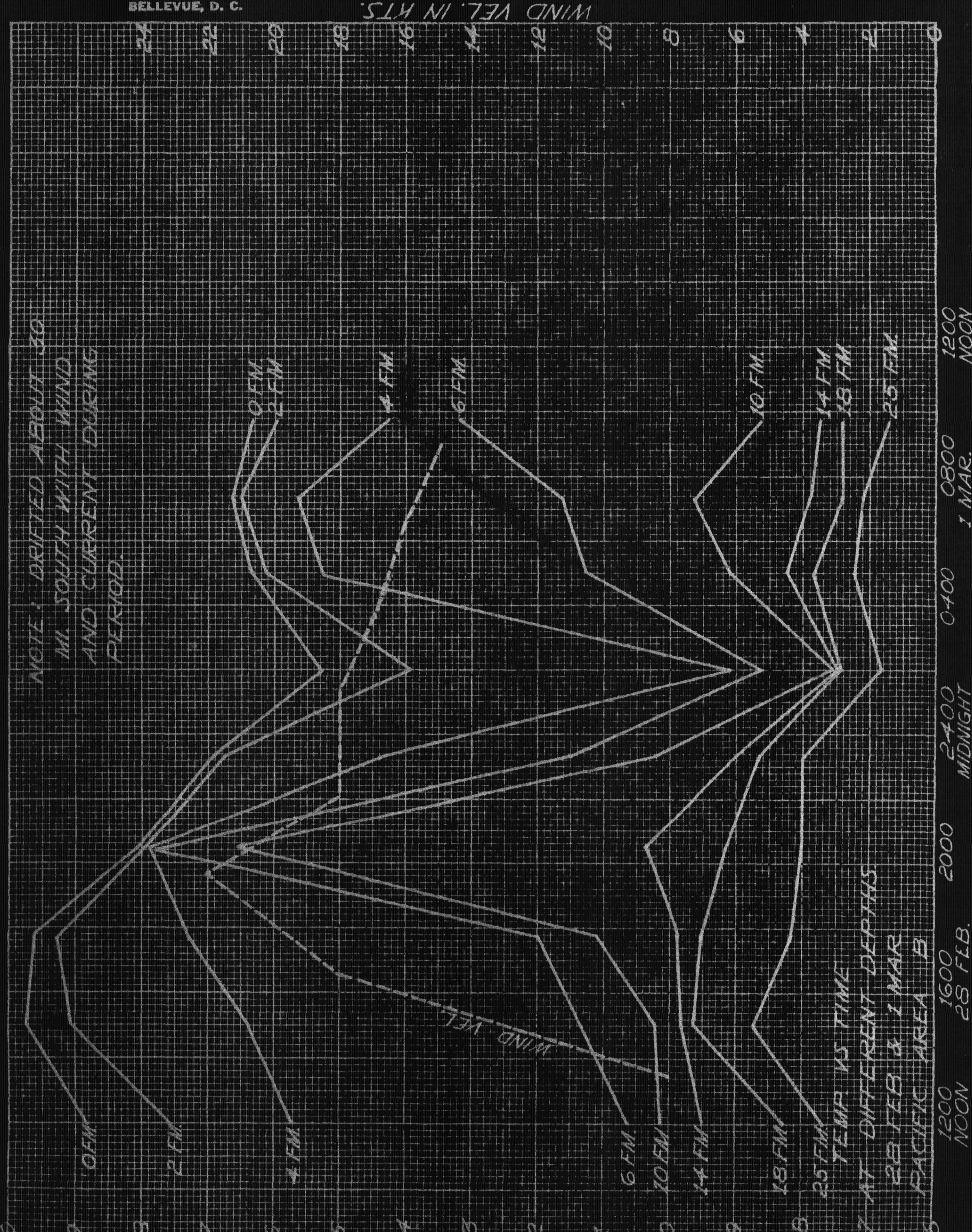


PLATE 56

U. S. NAVAL RESEARCH LABORATORY
BELLEVUE, D. C.

DATE



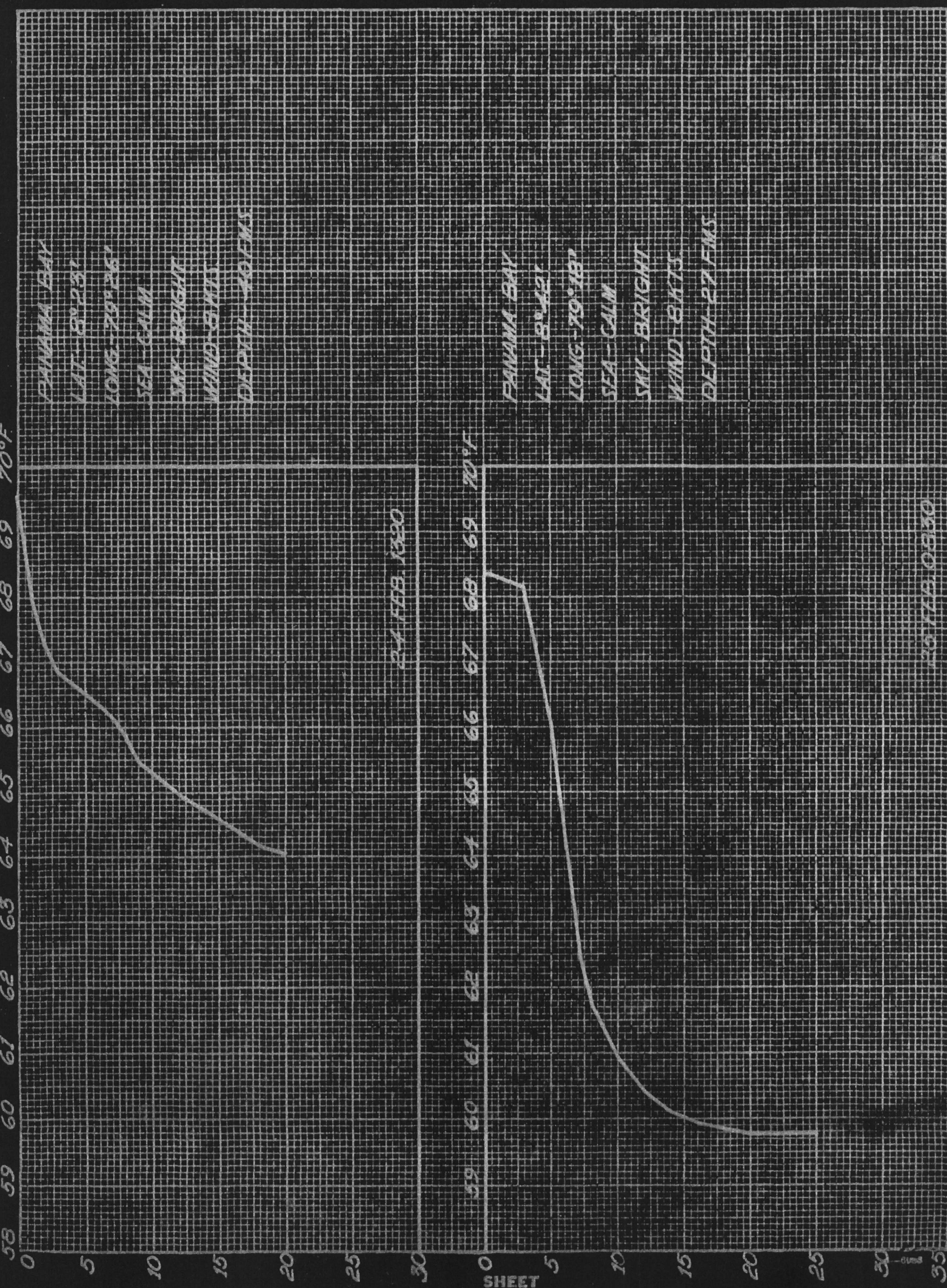
SHEET

4—6088

PLATE 57

U. S. NAVAL RESEARCH LABORATORY
BELLEVUE, D. C.

DATE



SHEET

PLATE 58

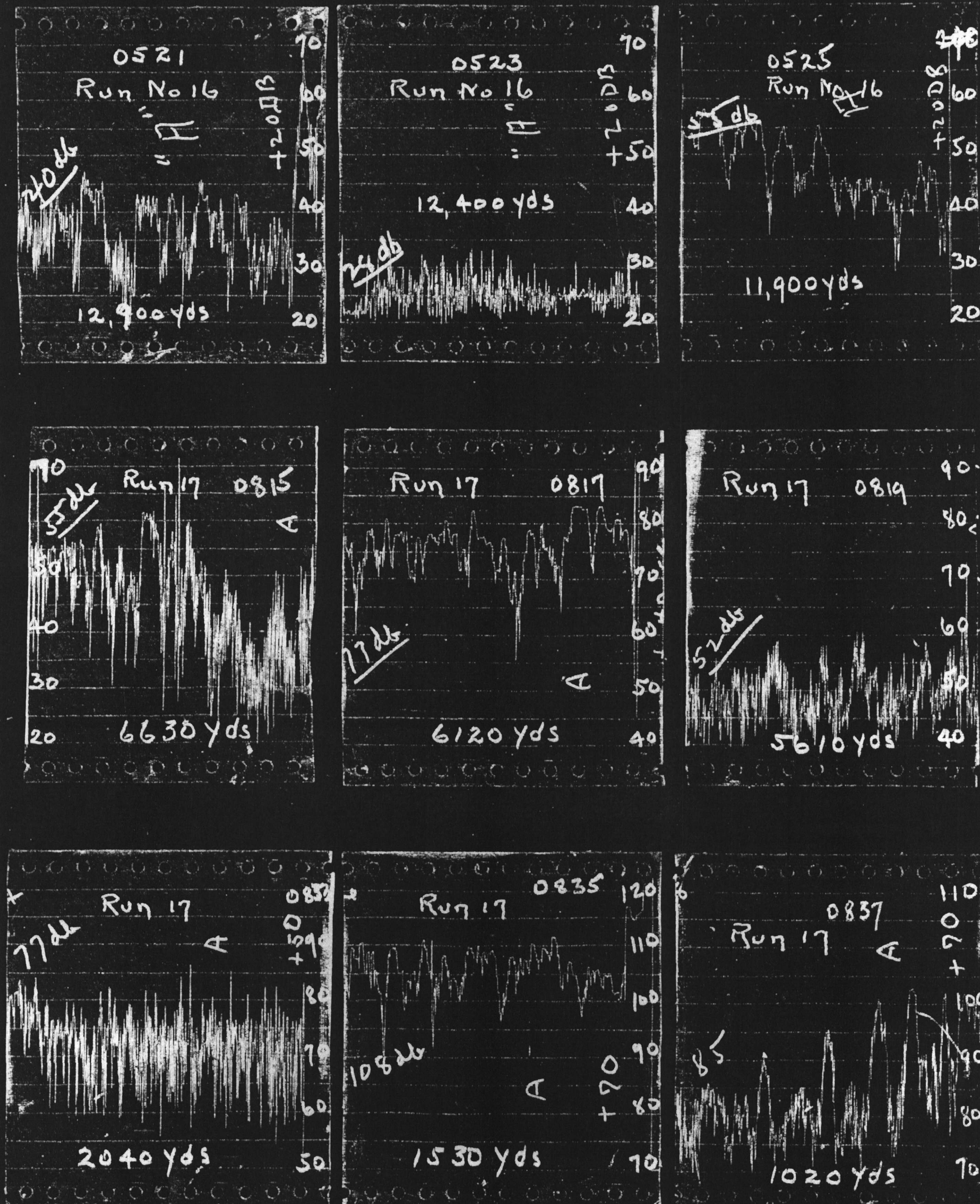

0521
Run No 16
12,900 yds
0523
Run No 16
12,400 yds
0525
Run No 16
11,900 yds
Run 17 0815
6630 yds
Run 17 0817
6120 yds
Run 17 0819
5610 yds
Run 17
2040 yds
Run 17 0835
1530 yds
Run 17 0837
1020 yds

PLATE 59