12 August 1938 NRL Report No.S-1466

NAVY DEPARTMENT

BUREAU OF ENGINEERING

Report on

Absorption Coefficients

NAVAL RESEARCH LABORATORY
ANACOSTIA STATION
WASHINGTON, D.C.

Number of Pages:	Text - 8 Plates - 36
Authorization:	NRL ltr. 31 January 1938, P16-4(9) Stephenson
Date of Test:	5 February to 24 March, 1938.

Reported by: ____________________
E. B. Stephenson, Sr. Physicist

Reviewed by: ____________________
H. C. Hayes, Pr. Physicist, Supt.Sound Division

Approved by: ____________________
H. M. Cooley, Captain, USN, Director

Distribution:
BuEng. (5)

bms

TABLE OF CONTENTS

APPENDICES

ABSTRACT

ABSORPTION COEFFICIENTS

During the period 5 February to 24 March 1938, the USS SEMMES and S-20 operated in the South Atlantic and Caribbean Sea. They made some 40 approach runs during which the intensity of the received signal was measured on 17.6, 23.6 and 30 kcs. for ranges between 500 yards and about 10,000 yards. After each run the temperature of the water was measured from the surface to 120 feet with an accuracy of 0.01° or better.

Thirty five plates of range-intensity and temperature-depth curves are included showing wide deviations from the theoretical formulae but a fairly definite correlation between the form of the range-intensity curves and the temperature gradients.

An adequate explanation is given for the "afternoon" effect phenomena.

The loss coefficient, α, which includes all the factors which reduce the intensity of the sound signal in water, may be simply expressed in decibels per yard for normal curves where the temperature gradient is small and uniform.

The average value of α for normal curves increases with the frequency according to the empirical formula

$$\alpha = .0040\ f^2 + .161\ f.$$

The major conclusion is that the path of the sound beam, determined largely by the temperature gradients but complicated by reflection, refraction and scattering, is the dominant factor in determining the intensity of the received signal.

ABSORPTION COEFFICIENTS

1. Theory

For sound waves propagated in an infinite, homogeneous medium, the relation between the intensity and the range is given by the formula -

$$\frac{I_r}{I_o} = \left(\frac{R_o}{R}\right)^n \quad 10^{-\alpha(R - R_o)} \qquad (1)$$

(Reference (1))

where I_o and I_r are the intensities at the ranges R_o and R respectively, α is the absorption coefficient, and n is an exponent determined by the type of propagation. For spherical waves, or for plane waves in a conical beam, n is equal to 2 from simple geometry. It is also possible to calculate α for a given medium from the numerical values of the velocity of sound, the coefficient of viscosity, the density and the frequency, (Reference (2)), but this value is about 0.1% of the experimental values.

If a series of measurements of the intensity at known ranges are made, it is possible to evaluate the constants of this equation. Intensities are commonly measured in decibels above a specified level. By definition

$$db = 10 \log \frac{I}{I_o},$$

therefore

$$db_1 - db_2 = 10 \log \frac{I_1}{I_2}.$$

By taking the logarithms of both sides of equation (1) and eliminating I_o and R_o from two simultaneous equations, we may write -

$$\frac{db_1 - db_2}{10(R_2 - R_1)} = n \frac{\log \frac{R_2}{R_1}}{R_2 - R_1} + \alpha \qquad (2)$$

- -

Reference (1) - NRL Report S-1204 of 16 October 1935.

Reference (2) - "A Textbook of Sound" by Wood, pp. 317-335.

This is the form of the simple linear equation y = ax + b for which a is the slope of the line and b the intercept on the y axis. By plotting decibel differences against the logarithms of the range ratio the values of n and α may be found (Reference (3)).

2. Practice

When measurements are made between two surface ships in open water, the assumption of an infinite homogeneous medium in which the above formulae are valid no longer meets the actual conditions.

(a) Reflection.

Due to the shallow submergence of the transmitting and receiving units, the upper portion of a conical beam soon suffers reflection at the air-water surface. This reflection is with change of phase. Similarly, the lower portion of the beam may be reflected from the bottom, or from any surface where there is a rapid change in the ρc product. This reflection is without change of phase. Multiple reflections are possible at the longer ranges or in shallow water.

(b) Refraction.

The temperature of the water is seldom uniform over any considerable range of depths, generally, though not always, being higher at the surface and decreasing with depth. Since the velocity of sound increases nearly 2 yards per second per degree Fahrenheit, the bending due to the temperature gradient may be considerable and even cause the sound beam to pass below the detector on the receiving ship.

The velocity of sound increases with the depth due to the increase in pressure and salinity, and this tends to bend the ray upward. The net refraction effect will be the algebraic sum of the temperature gradient and the depth and salinity effects, (Reference (4)).

(c) Scattering.

Neither the air-water surface, the water-earth surface, nor a thermocline boundary surface, is smooth or level for supersonic waves so the reflected beam will always be somewhat scattered. Also turbulence absorbs, reflects, and scatters sound as may be noted in the diffuse echo from the wake of a ship. Turbulence may also be caused by the wind as shown by Langmuir (Reference (5)). He shows

- -

Reference (3) - "Underwater Sound Investigations in Northern Waters," August 1937, BuEng. file S68 (1-28-W6). NRL file C-S68/S6 Propagation

Reference (4) - "Velocity of Sound in Sea Water," U.S. Coast & Geodetic Survey, Sp.Pub. No. 108.

Reference (5) - "Surface Motion of Water Induced by Wind," Science, Vol. 87, No. 2250, February 11, 1938.

"The effect of the wind is to produce a series of alternating right and left helical vortices in the water having horizontal axes parallel to the wind." The water descends under the wind streaks and rises between the streaks. While this motion is slow, it gives rise to a generally turbulent condition. "A windy day causes the temperature gradient to disappear down to a certain depth, but produces a very sharp temperature gradient at the lower limit of the isothermal layer." The depth of the stirring action is roughly proportional to the distance between wind streaks and there is a qualitative relation between the streak spacing and the wind velocity. It would appear that this type of turbulence would produce considerable scattering.

When subject to reflection, refraction and scattering, one should not expect the observed data to agree accurately with the theoretical formulae which did not consider any of these. The deviation of the experimental data from the theoretical values, however, may indicate the relative importance of the different factors in the equation or may permit discrimination between the disturbing effects.

Throughout this report the symbol α will be used to represent the loss or dissipation factor and includes not only the true absorption, the loss of energy which is transformed into heat by the viscosity of the water, but also all the other variable losses due reflection, refraction, diffraction, or scattering.

3. Experimental Procedure

Three independent transmitters operating continuously at 17.6, 23.6 and 30 kilocycles respectively, were used on the SEMMES as she steamed at constant speed towards the S-20 which was lying to. The S-20 listened for one minute on a given frequency and recorded the average value of the intensity against clock time, then tuned to the next frequency, thus making a reading on each frequency every third minute or about every 450 yards, since the ship's speed was usually about 150 yards per minute.

Initially and every tenth minute thereafter, a RAR test was made by simultaneously transmitting a radio and a sound signal from the SEMMES and measuring the time interval between them when they arrived at the S-20. This time interval multiplied by the velocity of sound at the measured temperature gives the range against clock time. The clocks of the SEMMES and S-20 were synchronized so that from the S-20's intensity vs. clock time curves and the SEMMES' range vs. clock time curves, range intensity curves for three different frequencies could be plotted. Ranges were also checked against navigational data when possible.

Zero levels were obtained with the S-20 tied alongside the SEMMES by adjusting the transmitting powers so as to give the same received signal intensities on the S-20's receiver at a definite sensitivity expressed as microvolts input for standard output. This sensitivity was maintained constant by frequent checks with a standard signal generator. However, absorption coefficients are based on the slopes of the curves and not the absolute values of the intensities so the results of this report are not dependent on the accuracy of the zero levels.

After each range run eleven temperature readings were made between the surface and 120 feet. A platinum resistance thermometer and a high grade bridge were used to measure temperatures in terms of resistance. The accuracy of the temperature readings was limited by the galvanometer. The low sensitivity galvanometer used prior to February 18 was good to ± 0.1° C. Afterwards a better galvanometer was used which was sensitive to 0.001° C., but the accuracy was usually limited to ± 0.005° C. due to the roll of the ship making the exact balance point uncertain. The thermometer was calibrated at the ice point and by comparison with three good Laboratory thermometers over the temperature range from 20 to 25° C. and over a period of days. The absolute values of the temperatures are considered good to ±0.1°C. and the variations with depth to ± 0.005° C.

Temperature Gradients.

Plate 34 shows a series of curves of temperatures vs. depths taken at approximately 2-hour intervals for some 36 hours. The previously observed "afternoon effect" is shown in curves 10 to 13 and is correlated with the wind, sea and sun conditions. The outstanding points are: On a calm day with a bright sun there is a rapid heating of the water at the surface and a gradual but less marked heating at greater depths reaching a maximum about 1700. During the early evening, with increasing wind, the surface layers cools and a small inverse gradient appears at 1700. Between 2000 and 0600 with winds up to 28 knots the temperature is uniform within .01° C. down to 120 feet and the lowest temperatures of the series are found. The next morning the cycle starts to repeat.

The explanation of this cycle is as follows: The sun light falling on the water is largely absorbed and transformed into heat. Ninety per cent of the visible light will be absorbed in the first 125 feet and ninety-nine per cent will be absorbed at a depth of 250 feet for a logarithmic absorption coefficient of 0.008 (Reference (6)) which is a probable value for this area. The infra-red light, containing about one-third of the total energy of the sunlight, will be completely absorbed in the first few inches. This explains the relatively high temperature of the shallow surface layer when the sea is calm as there is then little stirring action by the wind and convection or diffusion effects are small.

- -

Reference (6) - Stephenson JOSA, August 1934, Vol. 24, pp. 220-1.

If the weather continues calm, the warm layer will cool slowly at night due to radiation to the atmosphere at the surface and to a small convection to the colder water below. If a strong wind arises vertical currents are set up (Reference (5)) which thoroughly mix the water as shown by curves 5, 6 and 7, where the temperature is uniform, with 0.01° C. for 120 feet. The mixing evidently extended to depths greater than 120 feet since the minimum temperatures were obtained at 0800 at the end of the period of high wind indicating that the warm surface water was mixed with the colder water from considerably below 120 feet.

In Plate 35 the sea was not so calm in the afternoon nor was the wind so strong at night so the warm layer did not get so hot nor was the mixing so thorough at night.

The temperature vs. depth curves throughout this report are plotted to a large temperature scale, one small division equals 0.01°C., to show the differences actually measured. Without precise temperature measuring equipment, no gradient would have been found in a majority of cases in the Guantanamo area.

4. Experimental Results on Absorption Coefficients

Some 38 range-intensity runs were made altogether. The data are plotted in Plates 1 to 33 showing the effects of range, frequency, temperature gradients, wind, sea, and sunlight on the sound transmission.

The curves may be arranged in three general groups where there is a definite correlation between the type of transmission curve and the temperature gradient.

In Group I where the temperature gradient is zero or slightly negative, a single straight line comes the nearest going through all the points beyond 1000 yards, though there may be irregular but somewhat cyclical variations impressed on this line. The loss coefficient is given in db/yd. for each frequency. Obviously, for this type of curve the loss factor is numerically so much more important than the $\left(\frac{R_o}{R}\right)^n$ factor that n = 0 after the first 1000 yards. The general method was not designed for accurate measurements at ranges under 500 yards as the longer ranges were considered more important for practical service. The irregular variations from the straight line are due to minor reflection, refraction or scattering effects.

Group II shows three runs, Plates 1, 19 and 33, that have fairly definite breaks in the curves with high absorption in the first 3500 yards and half to a third this value at the longer ranges. This occurs where there is a small positive gradient in both upper and lower layers of water.

Group III, Plates 27 to 30, shows the effect of a large gradient in the first 20 feet and a smaller but considerable gradient down to 120 feet. The sea is always calm with little wind and the sun is bright. The Type III range-intensity curves are characterized by large positive values of α that are 10 times the normal for the first 1500 yards, then become zero and negative and finally positive again. There is definite evidence of reinforcement in the 4 to 6 kiloyard range as this point is 10 to 15 db higher than for a run with normal α.

There is a transition from Types I to II to III and a definite correlation with the temperature gradient.

The loss coefficients for all the runs where an average value was obtainable were averaged for each frequency and are shown in the following table. Comparable runs from February 1937 at 24.5 kilocycles are also shown.

Frequency kc	α in $\frac{\text{db}}{\text{kiloyard}}$	α/f	Average Deviation from Mean	Number of Runs
17.6	4.06	.231	± 20%	26
23.6	6.00	.255	± 20%	26
30.0	8.44	.281	± 10%	13
24.5	5.6	.229	Feb. 1937	7

If the quantity α/f is plotted against frequency, Plate 36, a straight line is obtained of the form $\alpha/f = mf + b$ where m and b are constants which may be evaluated from the data to give the empirical equation -

$$\alpha = .0040\ f^2 + .161\ f$$

where α is the decibel loss per 1000 yards and f is the frequency in kilocycles. This means that in addition to the classical absorption term based on the viscosity of the medium and proportional to the square of the frequency, there is another term proportional to the first power of the frequency. This first power term is 80% of the total loss at 10 kilocycles, 66% at 20 kilocycles and 57% at 30 kilocycles.

Calculating from the formula the α for 24.5 kilocycles used in February 1937, the value is 6.3 compared with 5.6 observed, a difference of 12% that is within the mean variation.

SUMMARY

Some 38 range-intensity runs at 17.6, 23.6 and 30 kilocycles were made in the South Atlantic and Carribean area during February and March 1938, and accurate temperature measurements from the surface to 120 feet depth were made after each run, a total of 48 thermal stations.

A brief theoretical discussion and a description of the experimental technique are given.

The data and derived results are presented in the form of curves on a total of 36 plates.

An Empirical formula is derived for the decibel loss per thousand yards as a function of frequency. An adequate explanation is given for the occurrence of the "afternoon effect" on a bright, calm afternoon and for its complete disappearance on a windy night.

The path of the sound beam, determined largely by temperature gradients, is shown to be the major factor in determining the intensity of the direct signal.

Definite conclusions are drawn on numerous phases of the problem on absorption coefficients.

CONCLUSIONS

(a) The theoretical formula, based on the assumption of an infinite homogeneous medium, does not adequately express the law for the propagation of the sound beam in water under normal service conditions because the beam is subject to refraction, reflection and scattering effects.

(b) Beyond the first thousand yards and when the temperature gradient is small, a straight line gives the best average fit for the points on a normal range-intensity curve. Therefore, the loss coefficient, α, which includes all the factors which reduce the signal intensity in the water, may be simply expressed in decibels per yard.

(c) The range-intensity data consistently and conclusively show that the decibel loss in intensity per yard in range increases with the frequency. For the conditions in the area studied the average values may be expressed by the empirical formula -

$$\alpha = .0040\, f^2 + .161 f$$

Single determinations of α under different conditions may vary $\pm$ 50% from the average value, and the mean deviation is $\pm$ 20%.

(d) The occurrence of the previously noted "afternoon effect" is confirmed. The excessive heating of a shallow surface layer is due to the total absorption of the infra-red light, about 1/3 of the total energy from the sun, in the first few inches of water. There is a definite correlation between the formation and disappearance of the shallow heated layer and the wind. The data confirm the vertical stirring action of the wind as suggested by Langmuir.

(e) The path of the sound beam, determined largely by the temperature gradients but complicated by reflection, refraction and scattering, is the major factor in determining the intensity of the direct signal as a function of range.

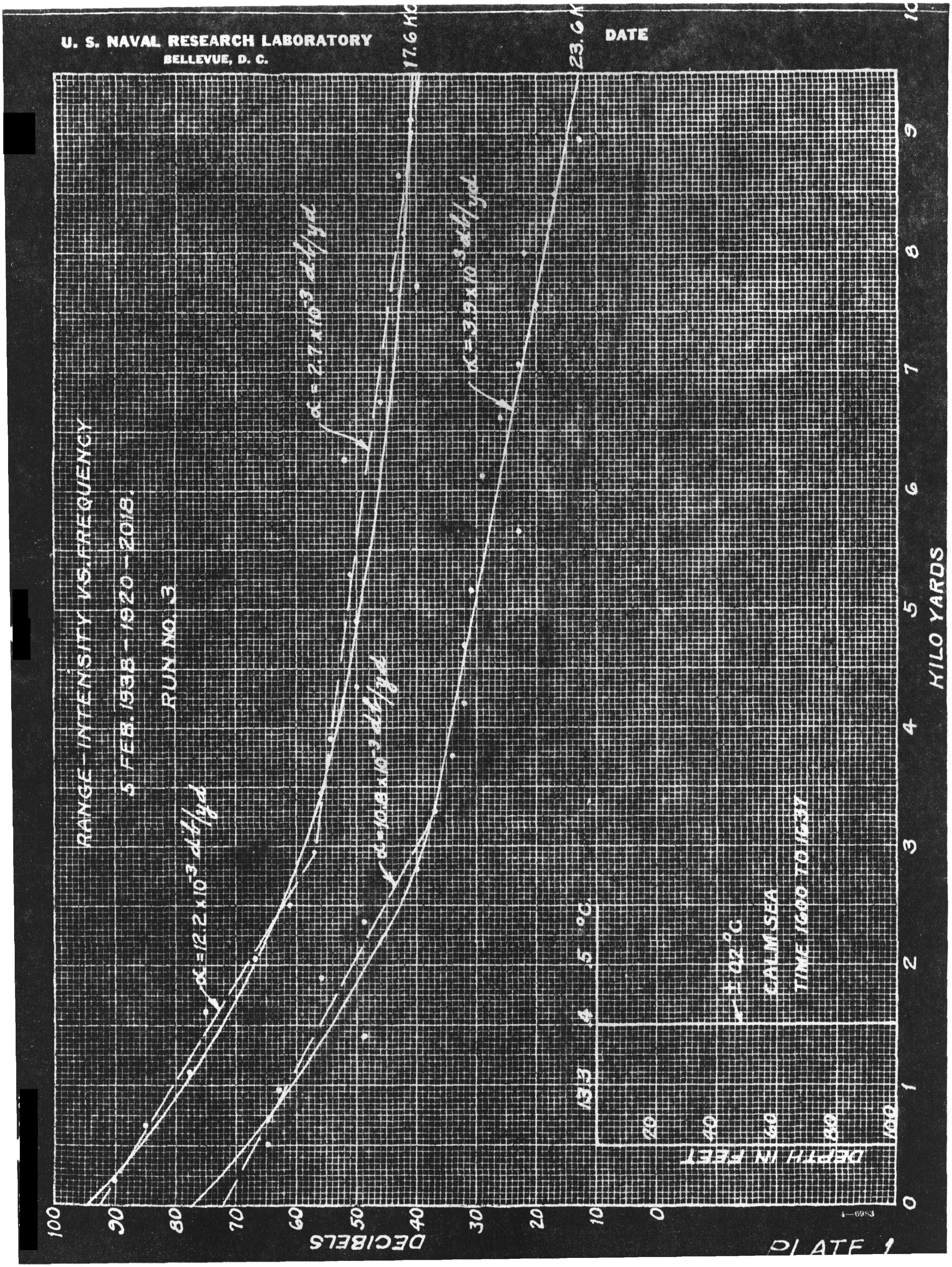

U. S. NAVAL RESEARCH LABORATORY
BELLEVUE, D. C.
DATE
RANGE-INTENSITY VS. FREQUENCY
5 FEB. 1938 - 1920 - 2018.
RUN NO. 3
17.6 KC
23.6 KC
α = 12.2 x 10^{-3} db/yd
α = 10.8 x 10^{-3} db/yd
α = 2.7 x 10^{-3} db/yd
α = 3.3 x 10^{-3} db/yd
13.3 4 5 °C
± 0.2 °C
CALM SEA
TIME 1600 TO 1637
DEPTH IN FEET
20 40 60 80 100
KILO YARDS
0 1 2 3 4 5 6 7 8 9 10
DECIBELS
100 90 80 70 60 50 40 30 20 10 0

PLATE 1

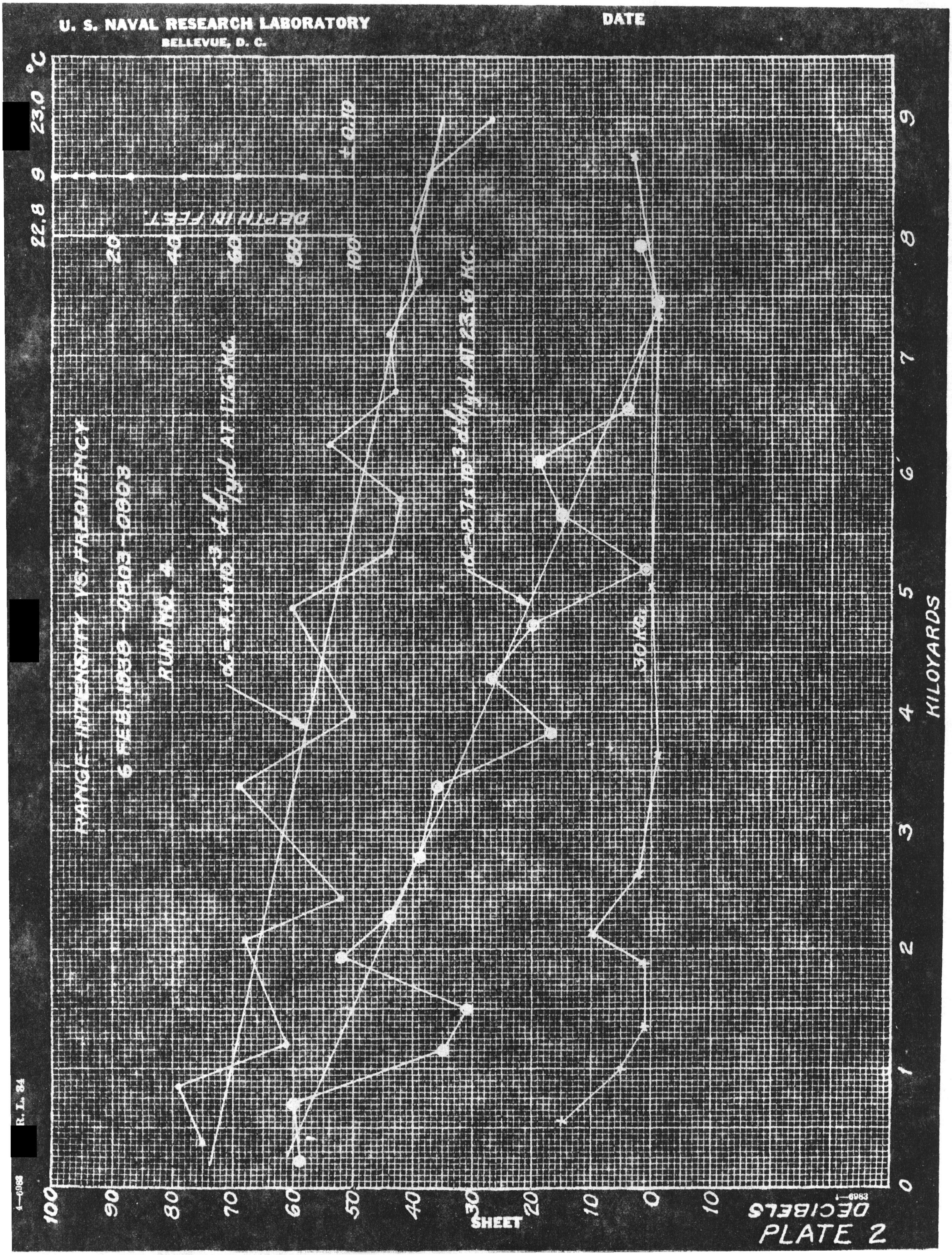

U. S. NAVAL RESEARCH LABORATORY
BELLEVUE, D. C.
DATE
RANGE-INTENSITY VS FREQUENCY
RUN NO. 4
30 KC.
DEPTH IN FEET
KILOYARDS
DECIBELS
SHEET
R. L. 34

PLATE 2

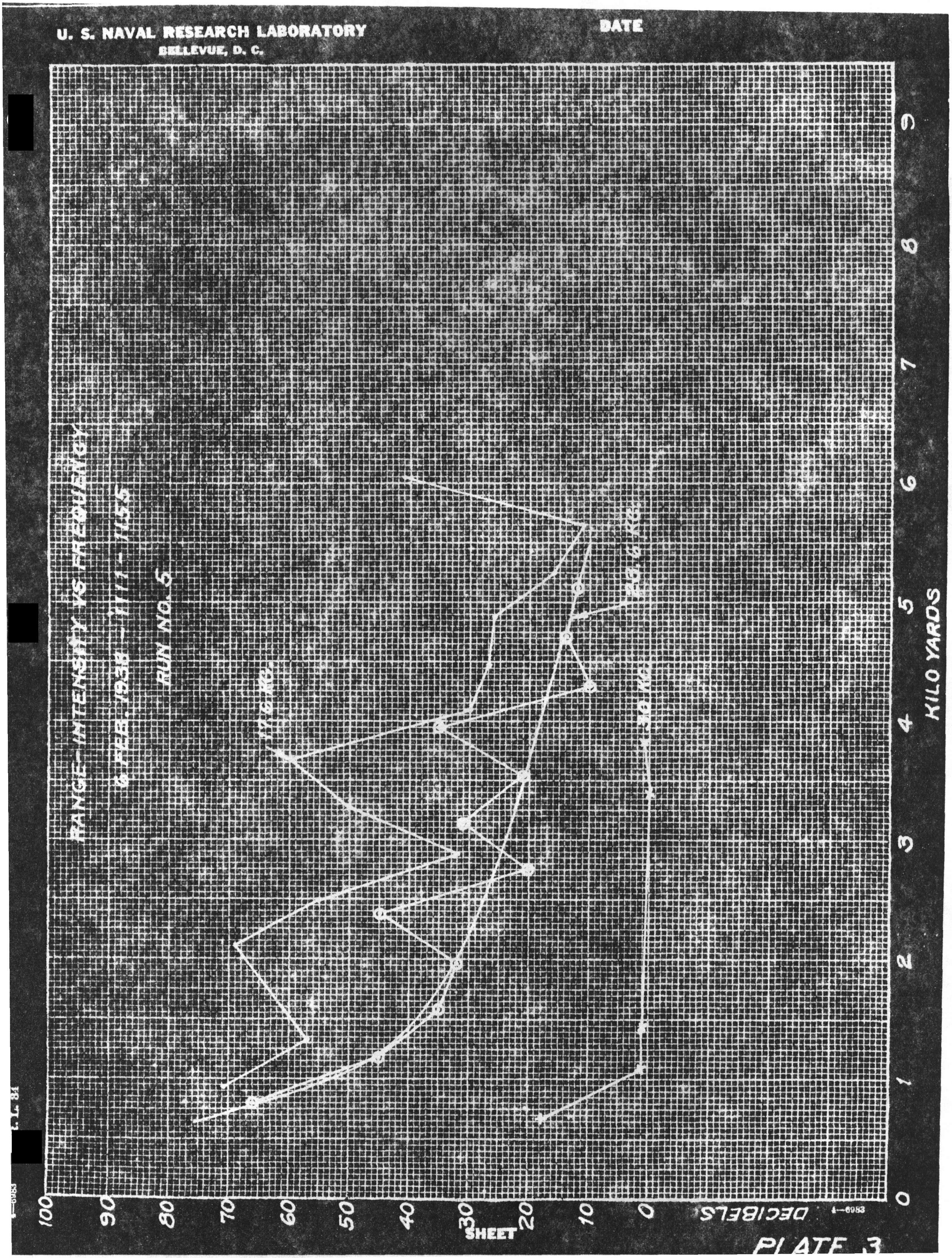
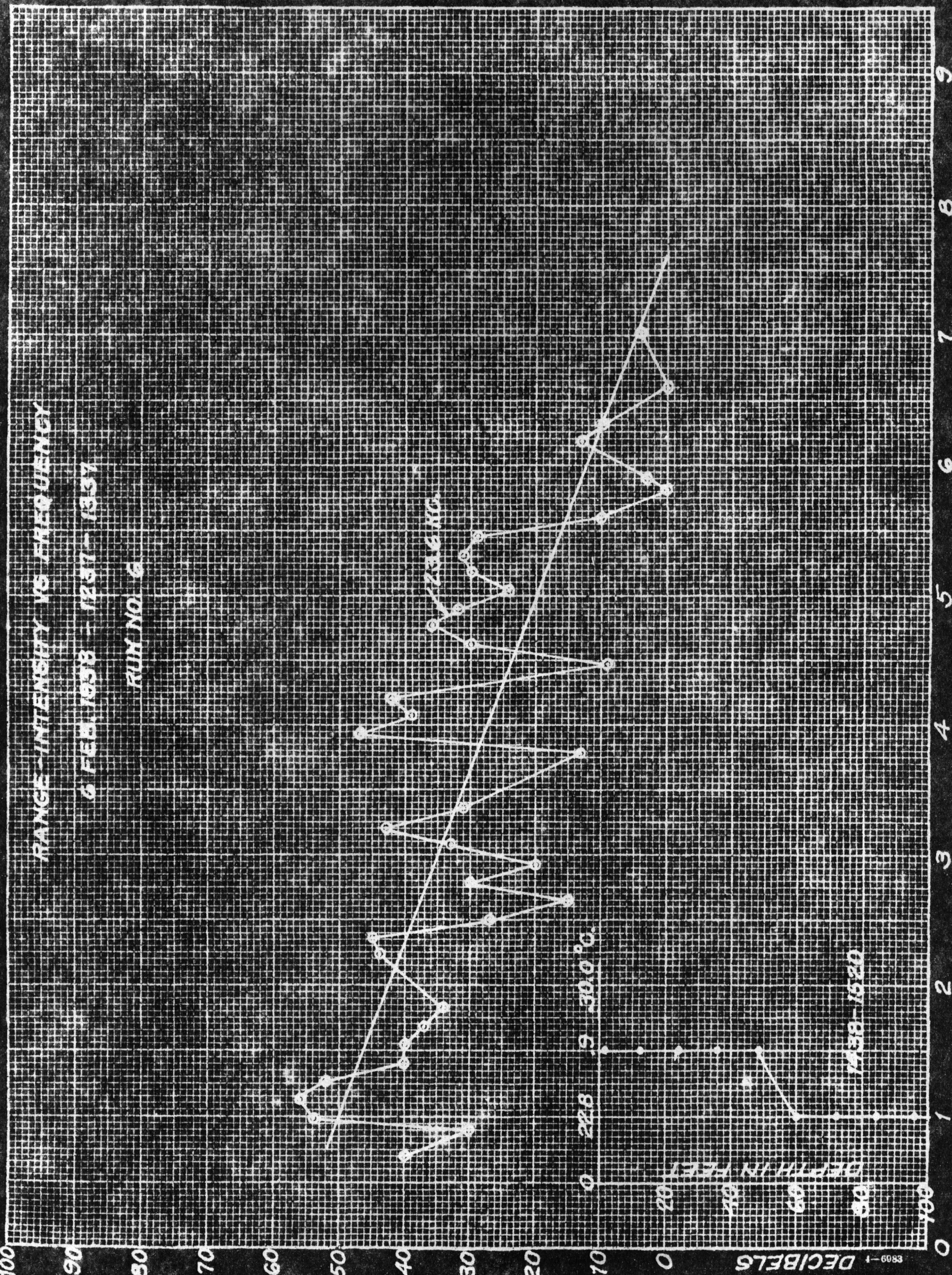

U. S. NAVAL RESEARCH LABORATORY
BELLEVUE, D. C.
DATE
RANGE-INTENSITY VS FREQUENCY
6 FEB. 1938 - 1111 - 1155
RUN NO. 5
17.6 KC.
26.6 KC.
30 KC.
KILO YARDS
DECIBELS
SHEET

PLATE 3

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

DATE



R. L. 34

4—6083

PLATE 4

4—6983 [redacted]R. L. 34 [redacted] [redacted]

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

DATE

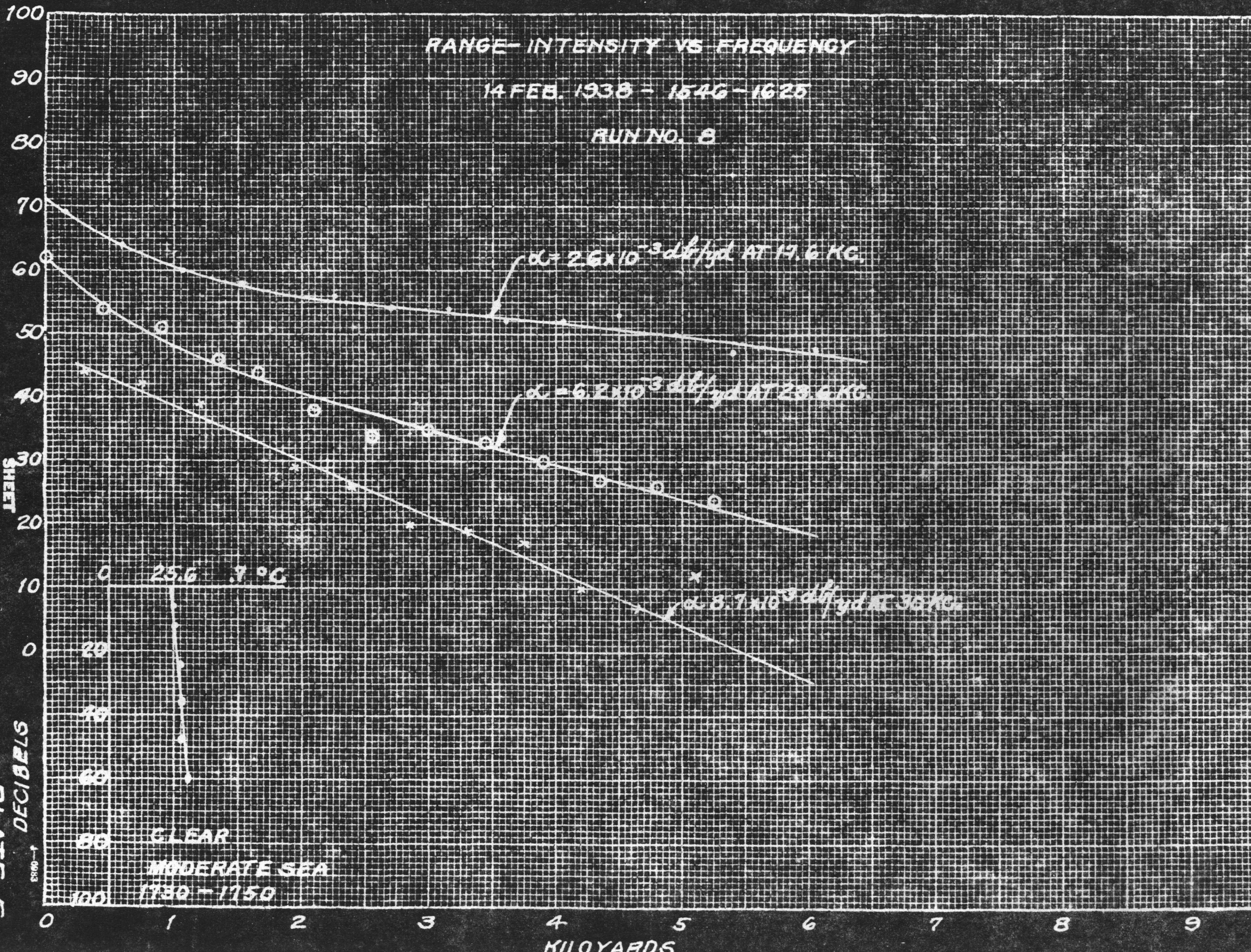
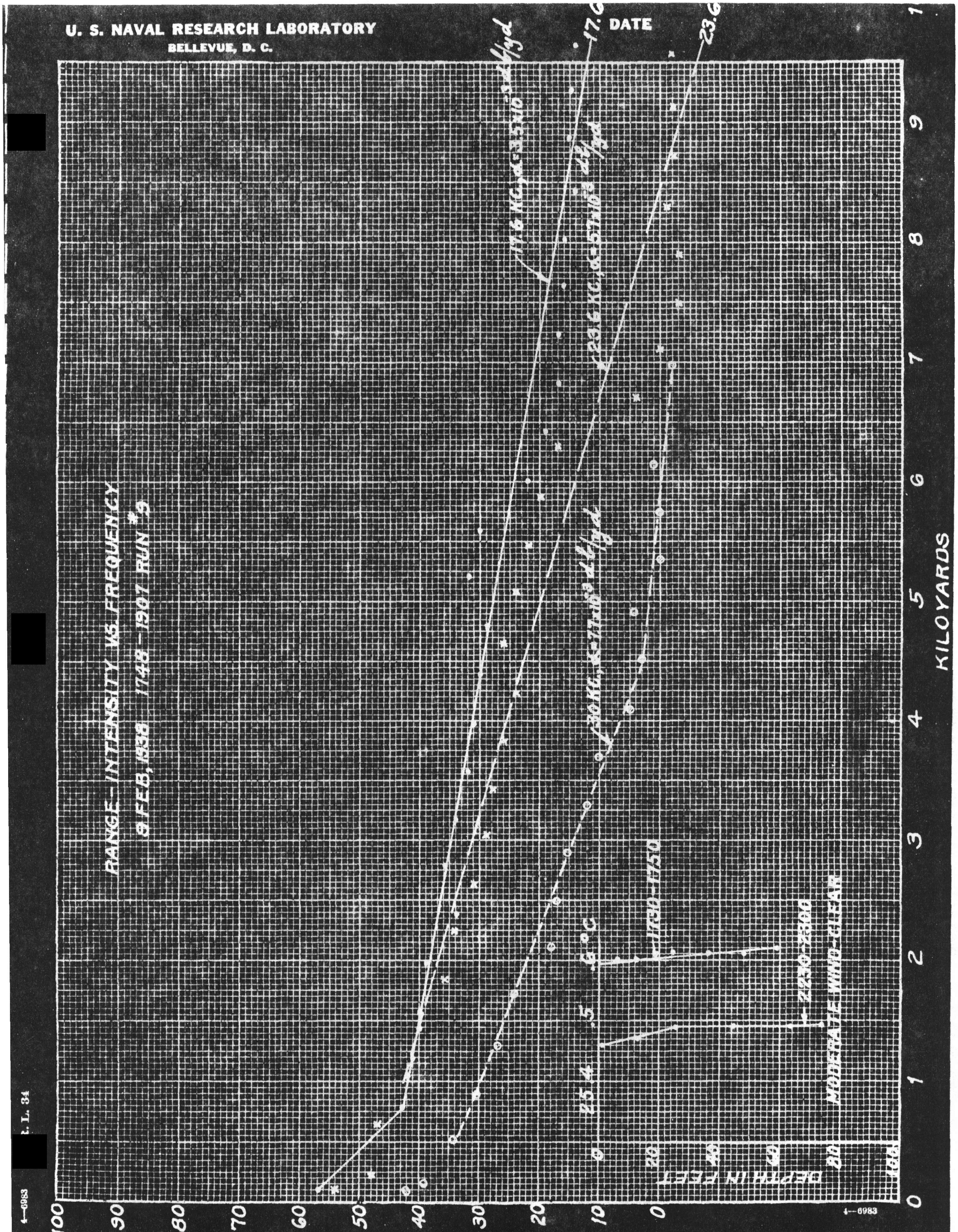


PLATE 5

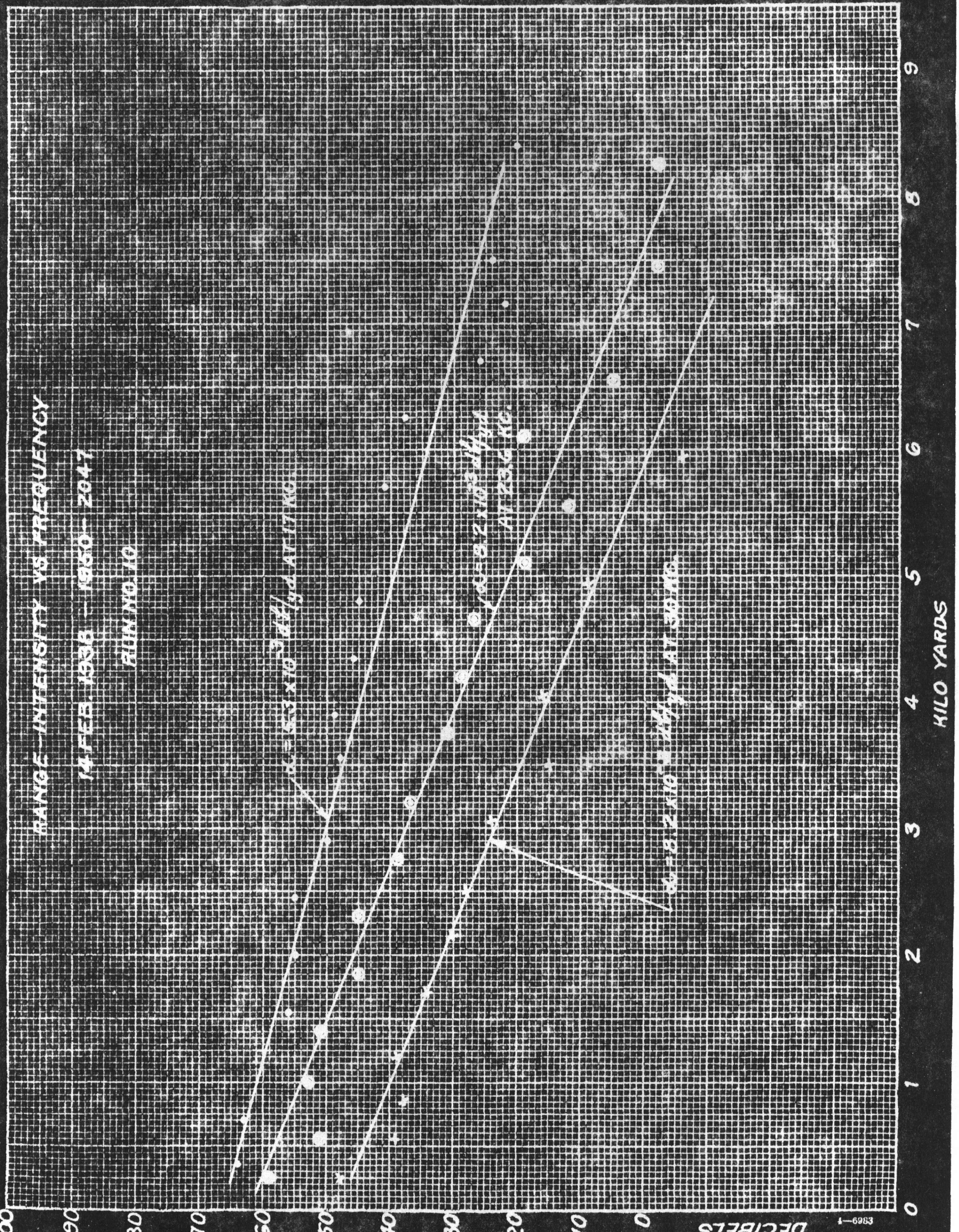


U. S. NAVAL RESEARCH LABORATORY
BELLEVUE, D. C.
DATE
RANGE-INTENSITY VS. FREQUENCY
9 FEB, 1938 1748-1907 RUN #3
KILOYARDS
DECIBELS
DEPTH IN FEET
MODERATE WIND-CLEAR
1730-1750
2230-2300
17.6
23.6
N. R. L. 34
4-6983

PLATE 6

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

DATE



SHEET

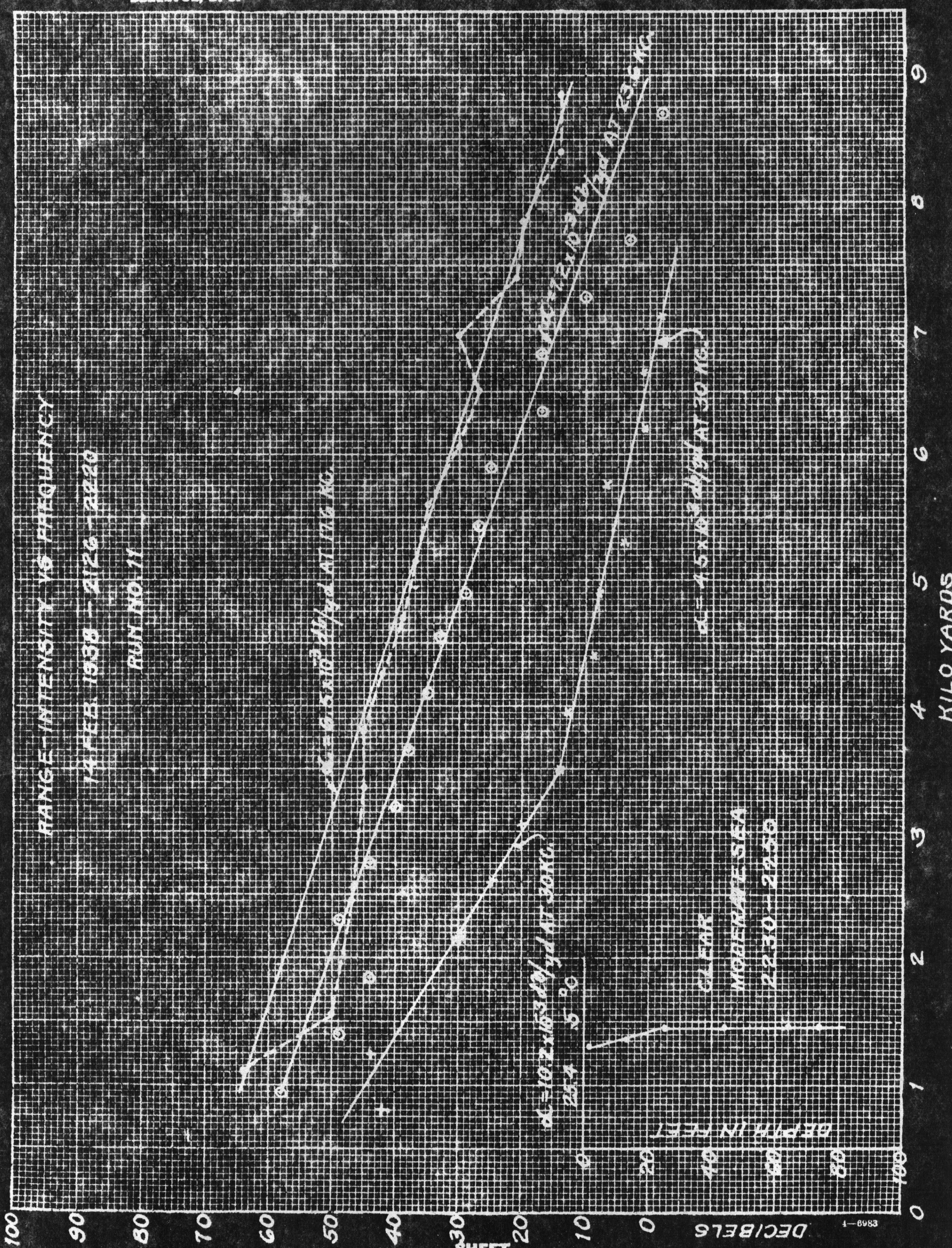
R. L. 34

PLATE 7

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

DATE

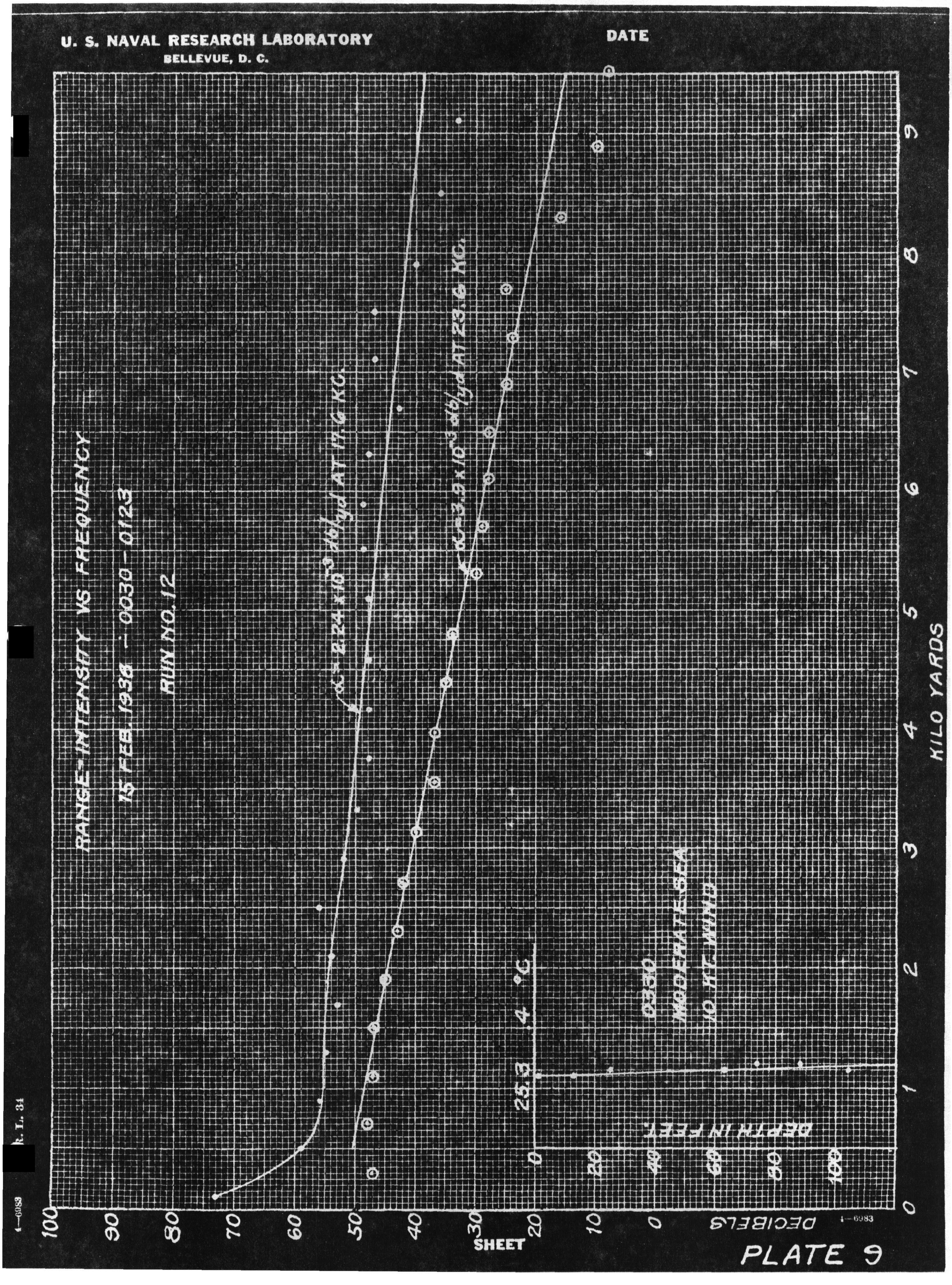
[redacted]



[redacted] R. L. 34

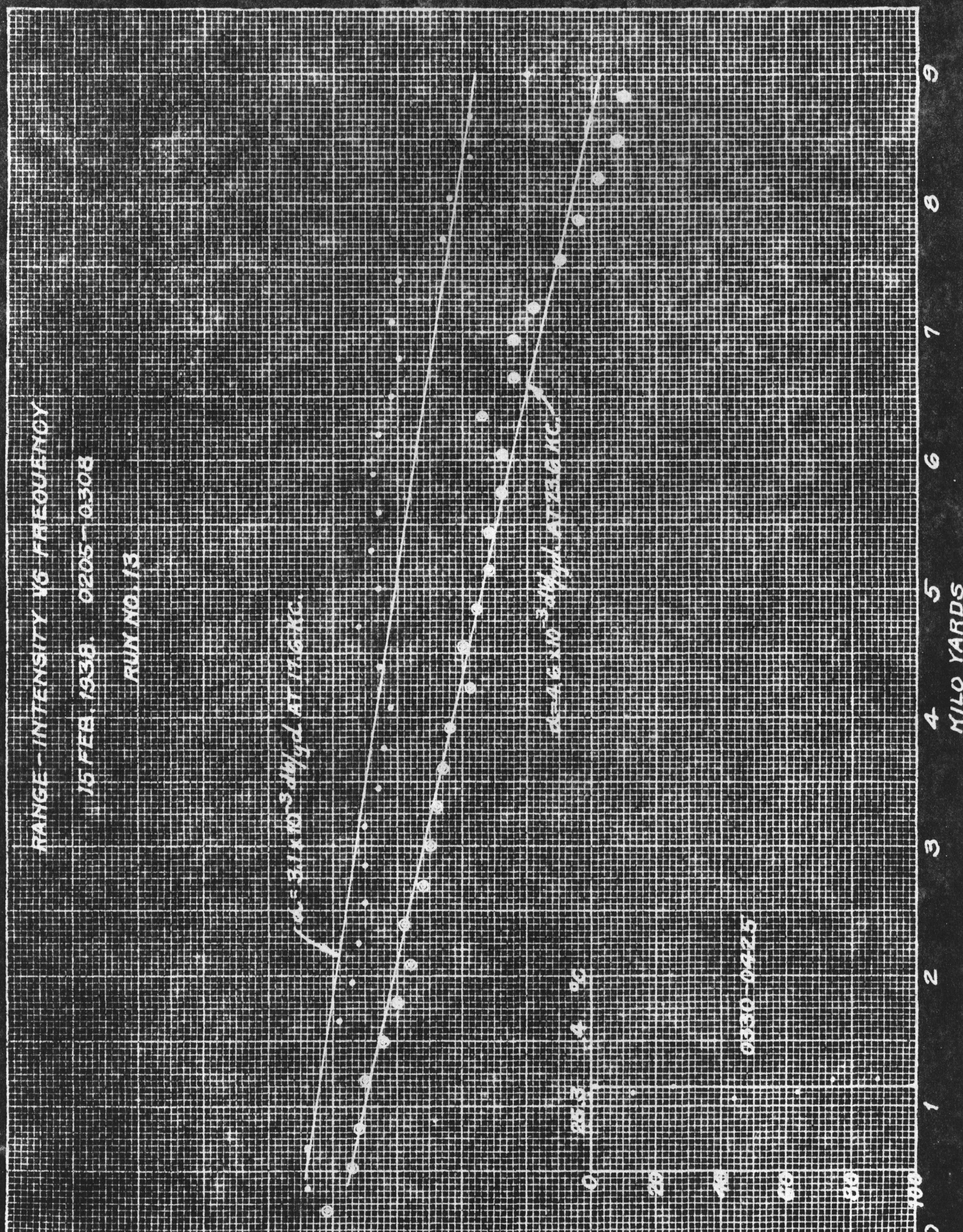
4-6983

PLATE 8


U. S. NAVAL RESEARCH LABORATORY
BELLEVUE, D. C.
DATE
RANGE-INTENSITY VS FREQUENCY
15 FEB. 1938 - 0030-0123
RUN NO. 12
α = 2.24 x 10⁻³ db/yd AT 17.6 KC.
α = 3.3 x 10⁻³ db/yd AT 23.6 KC.
25.3
.4
°C
0330
MODERATE SEA
10 KT. WIND
DEPTH IN FEET
KILO YARDS
DECIBELS
SHEET
N. R. L. 34
4—6983
PLATE 9

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

DATE



R. L. 34

4-6983

SHEET

PLATE 10

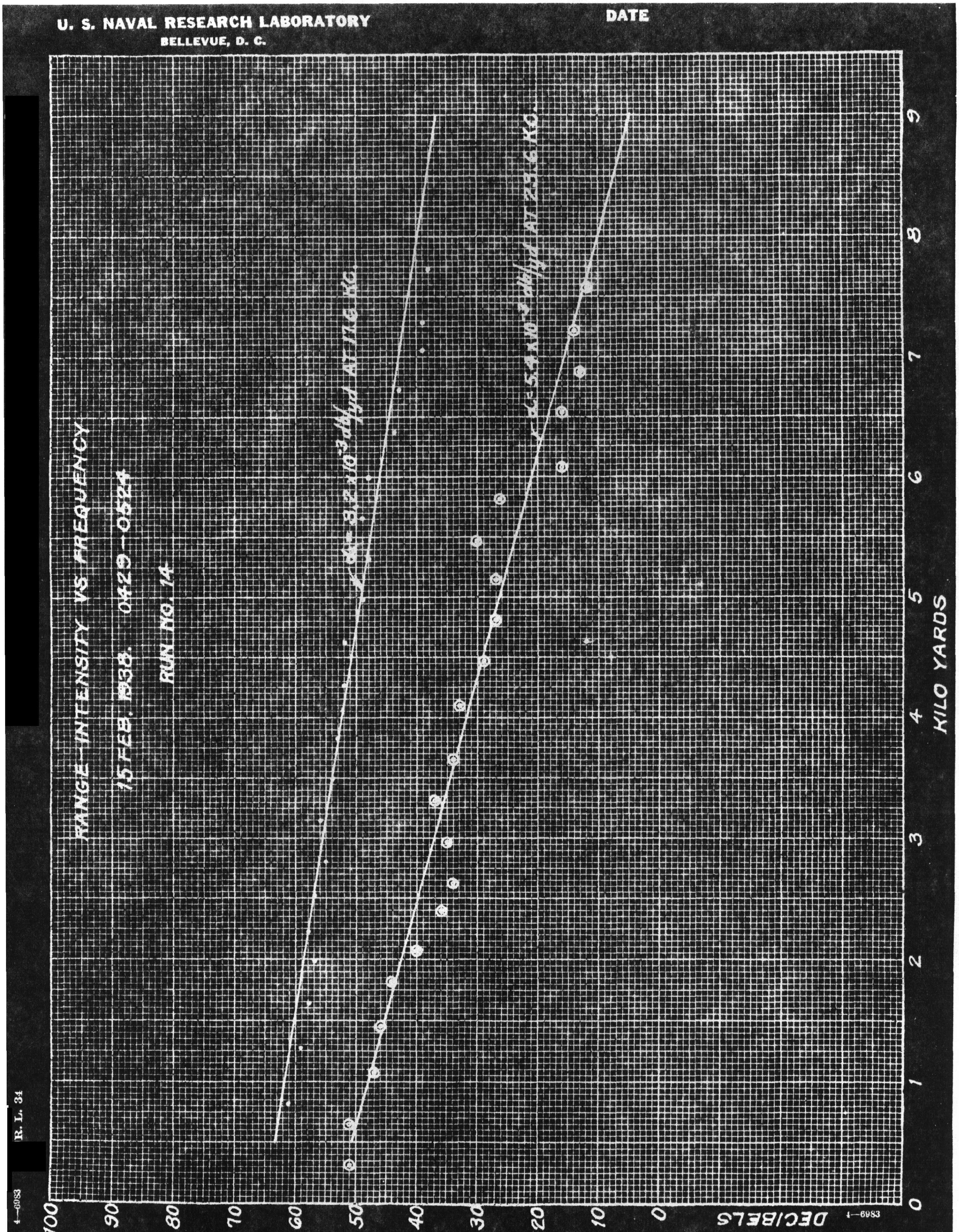

U. S. NAVAL RESEARCH LABORATORY
BELLEVUE, D. C.
DATE
RANGE-INTENSITY VS FREQUENCY
15 FEB. 1938. 0429-0524
RUN NO. 14
α = 3.2 x 10-3 db/yd AT 17.6 KC.
α = 5.4 x 10-3 db/yd AT 23.6 KC.
0 1 2 3 4 5 6 7 8 9
KILO YARDS
100 90 80 70 60 50 40 30 20 10 0
DECIBELS
SHEET
R. L. 34
4-6983

PLATE 11

U. S. NAVAL RESEARCH LABORATORY

BELLEVUE, D. C.

DATE

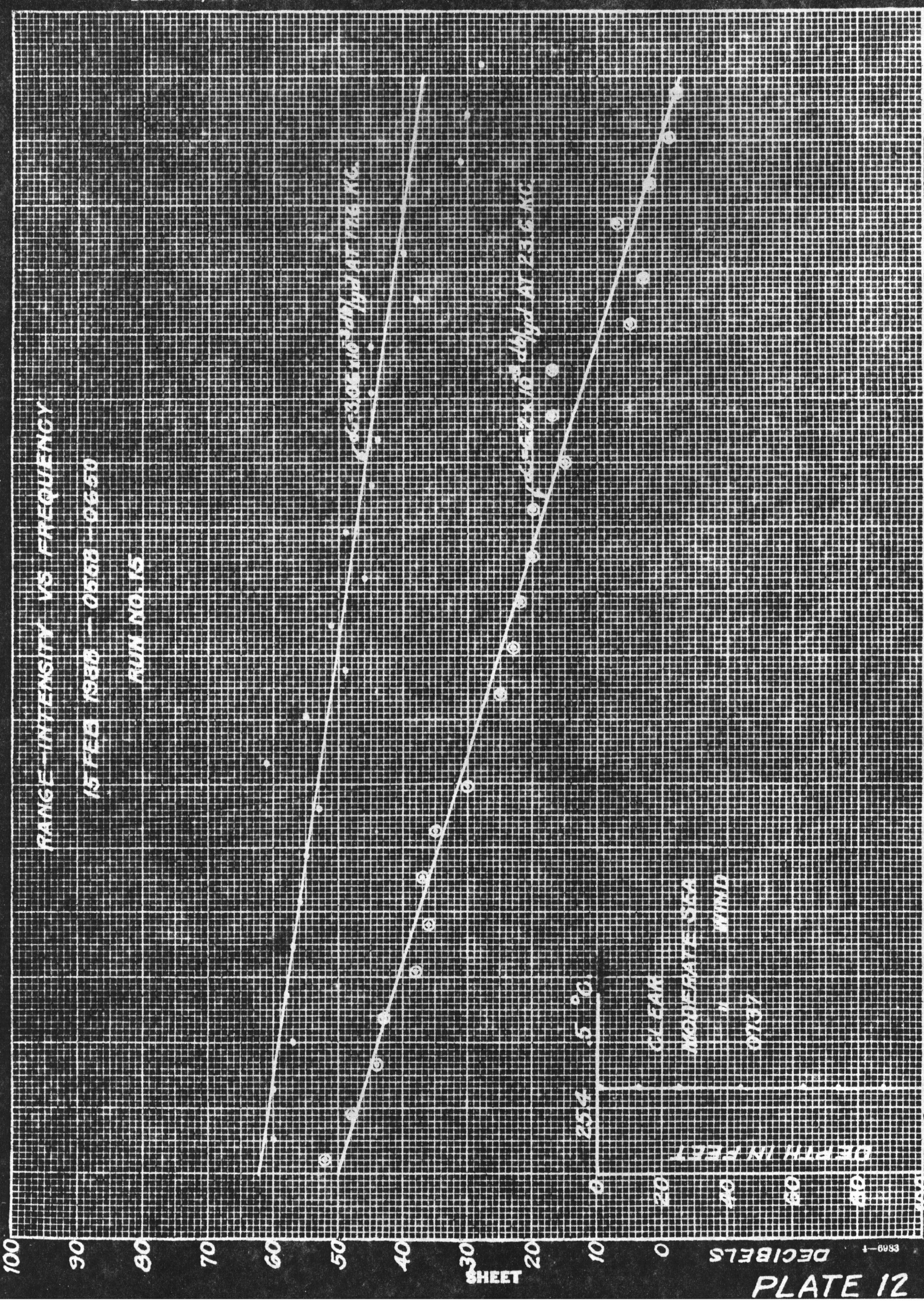


PLATE 12

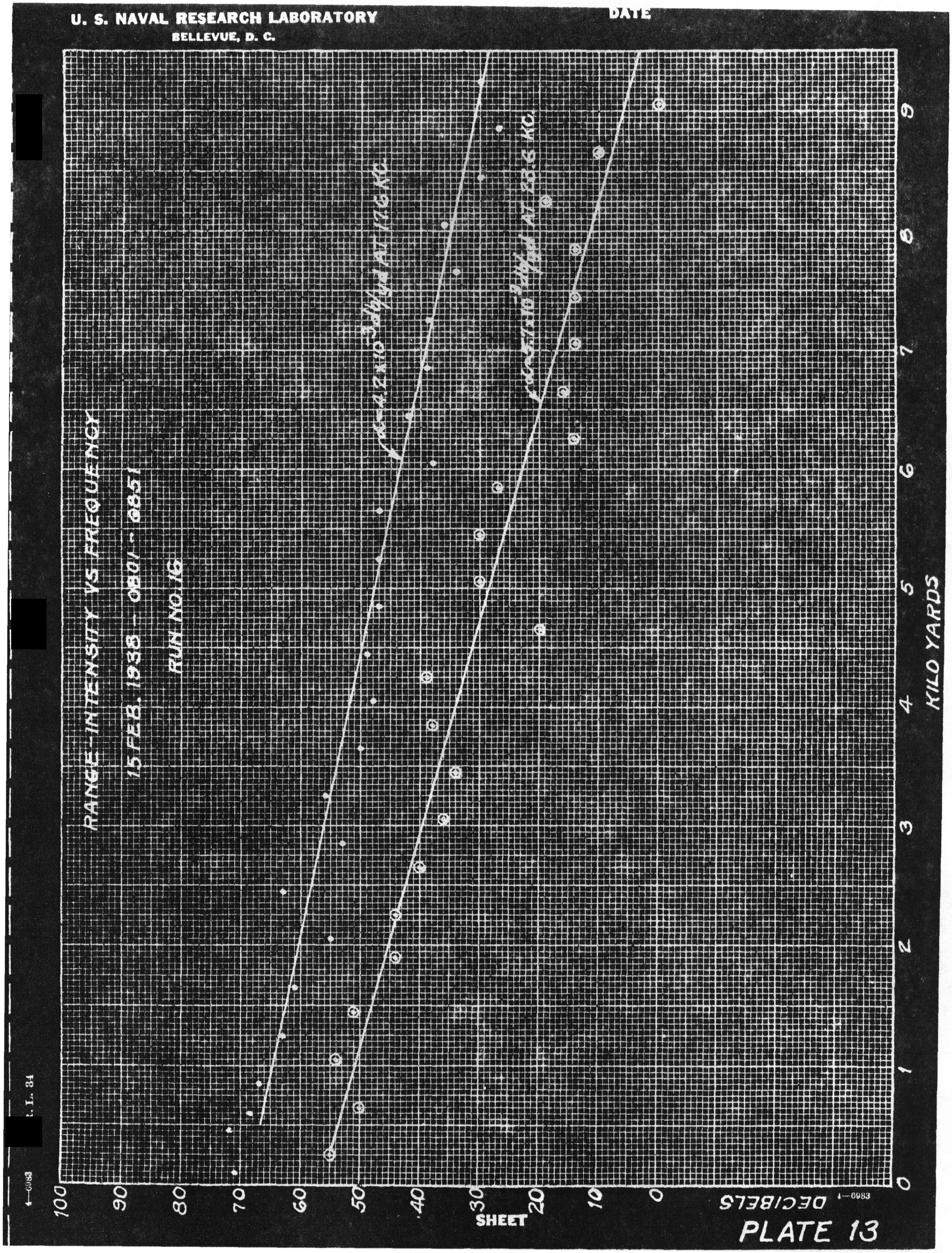
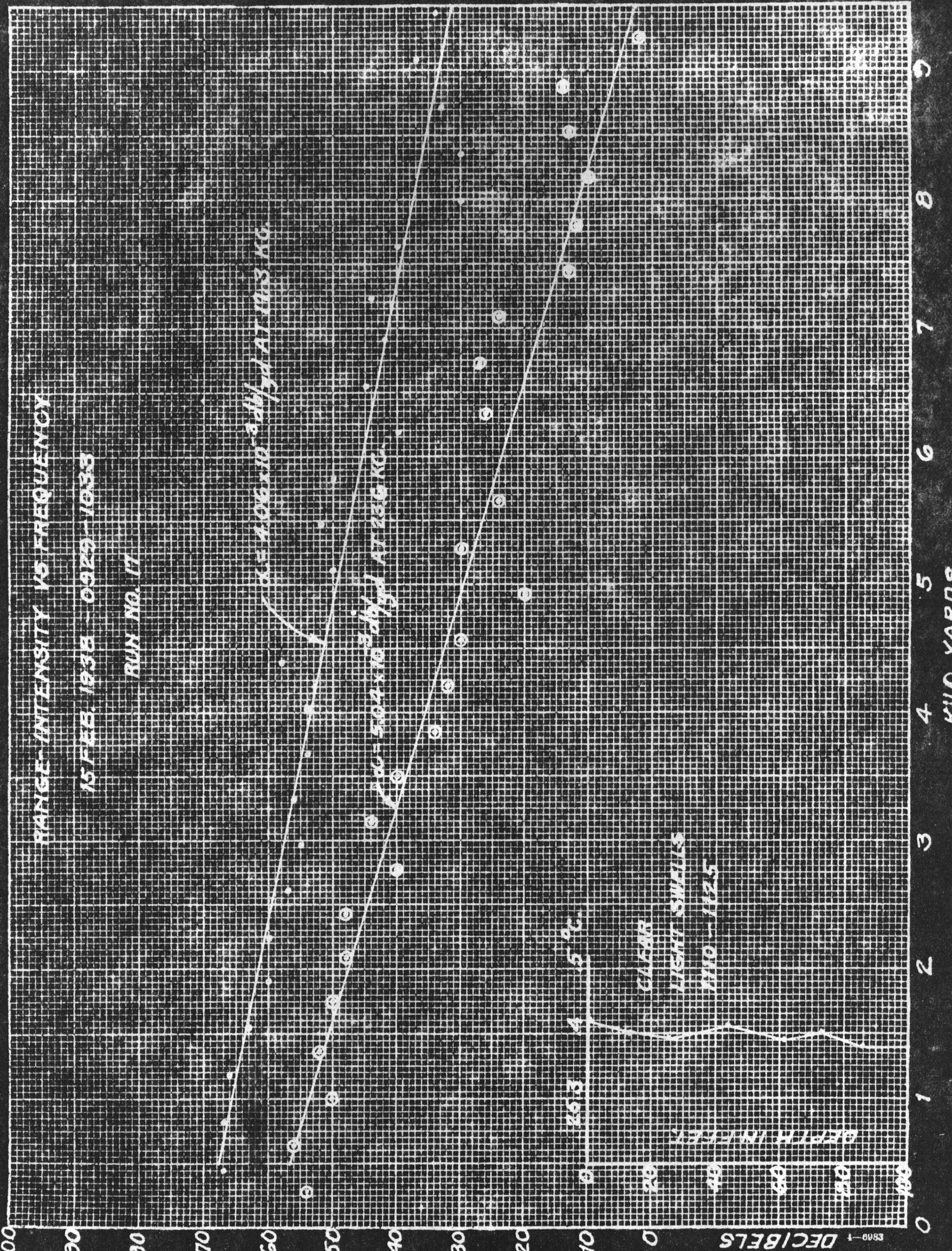

U. S. NAVAL RESEARCH LABORATORY
BELLEVUE, D. C.
DATE
RANGE-INTENSITY VS FREQUENCY
15 FEB. 1938 - 0801 - 0851
RUN NO. 16
α = 4.2 x 10-3 db/yd AT 17.6 KC.
α = 5.1 x 10-3 db/yd AT 23.6 KC.
0 1 2 3 4 5 6 7 8 9
KILO YARDS
100 90 80 70 60 50 40 30 20 10 0
DECIBELS
SHEET

PLATE 13

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

DATE



L. 34

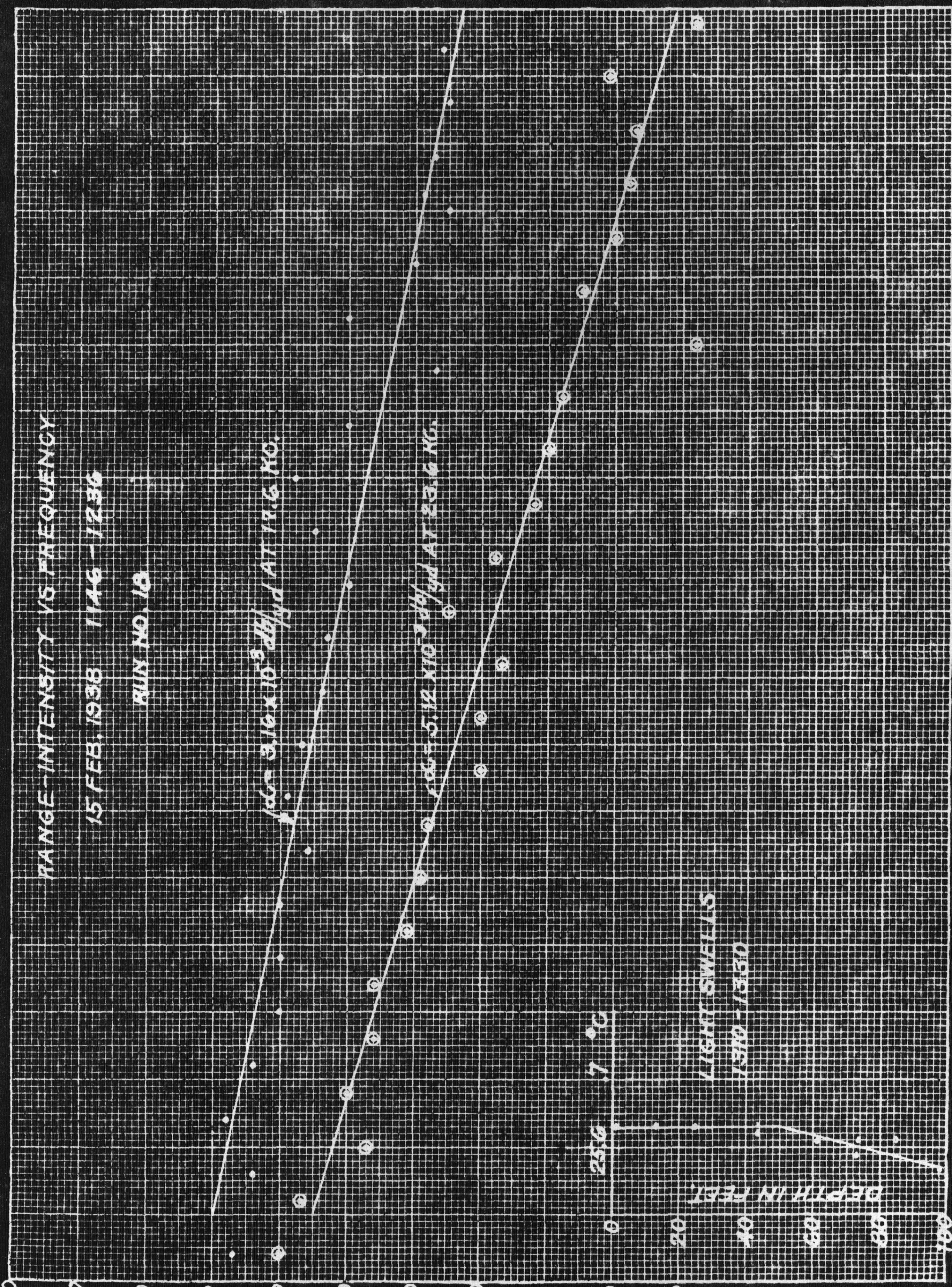
1—6983

SHEET

PLATE 14

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

DATE



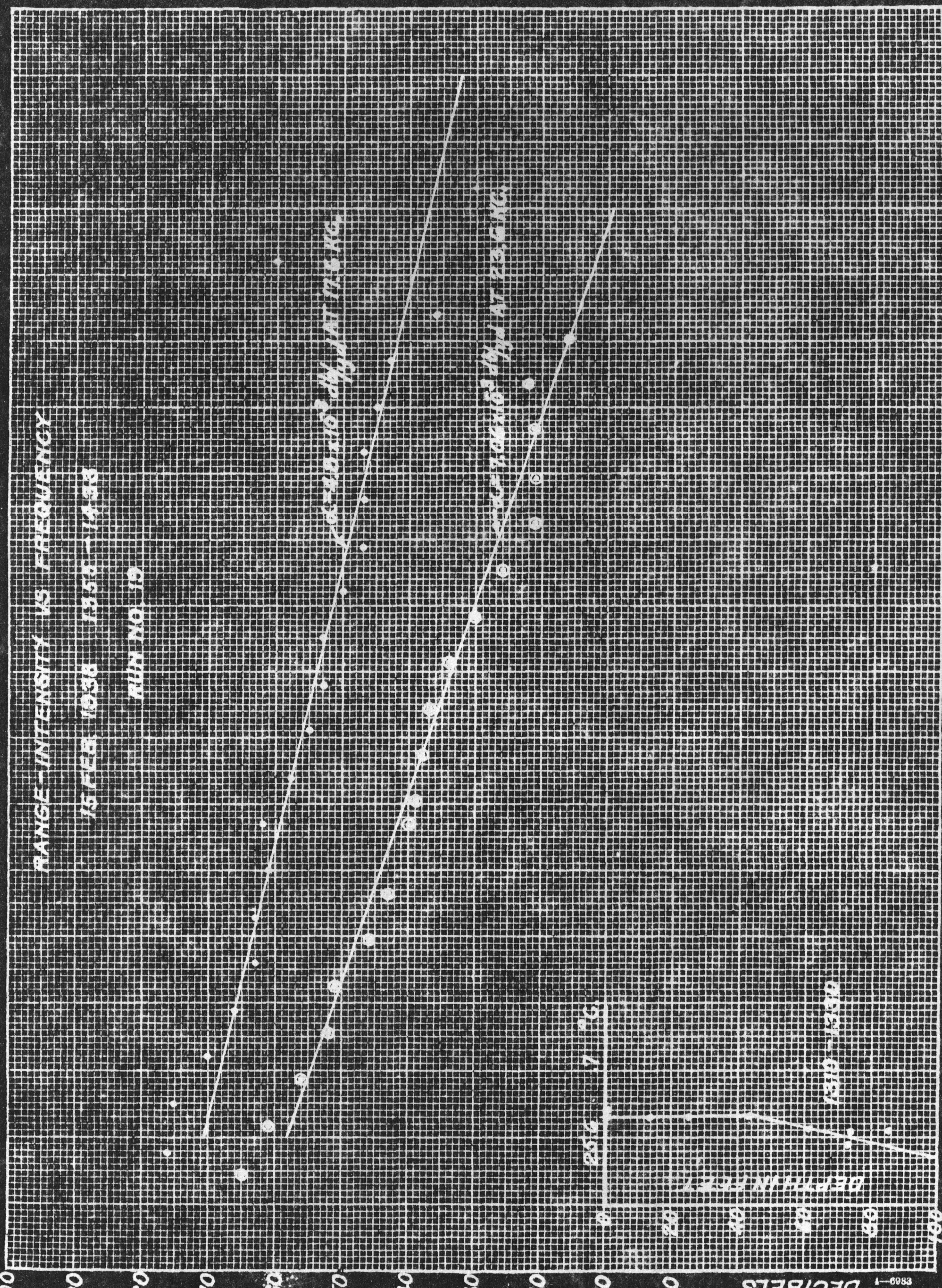
SHEET

4-6983

PLATE 15

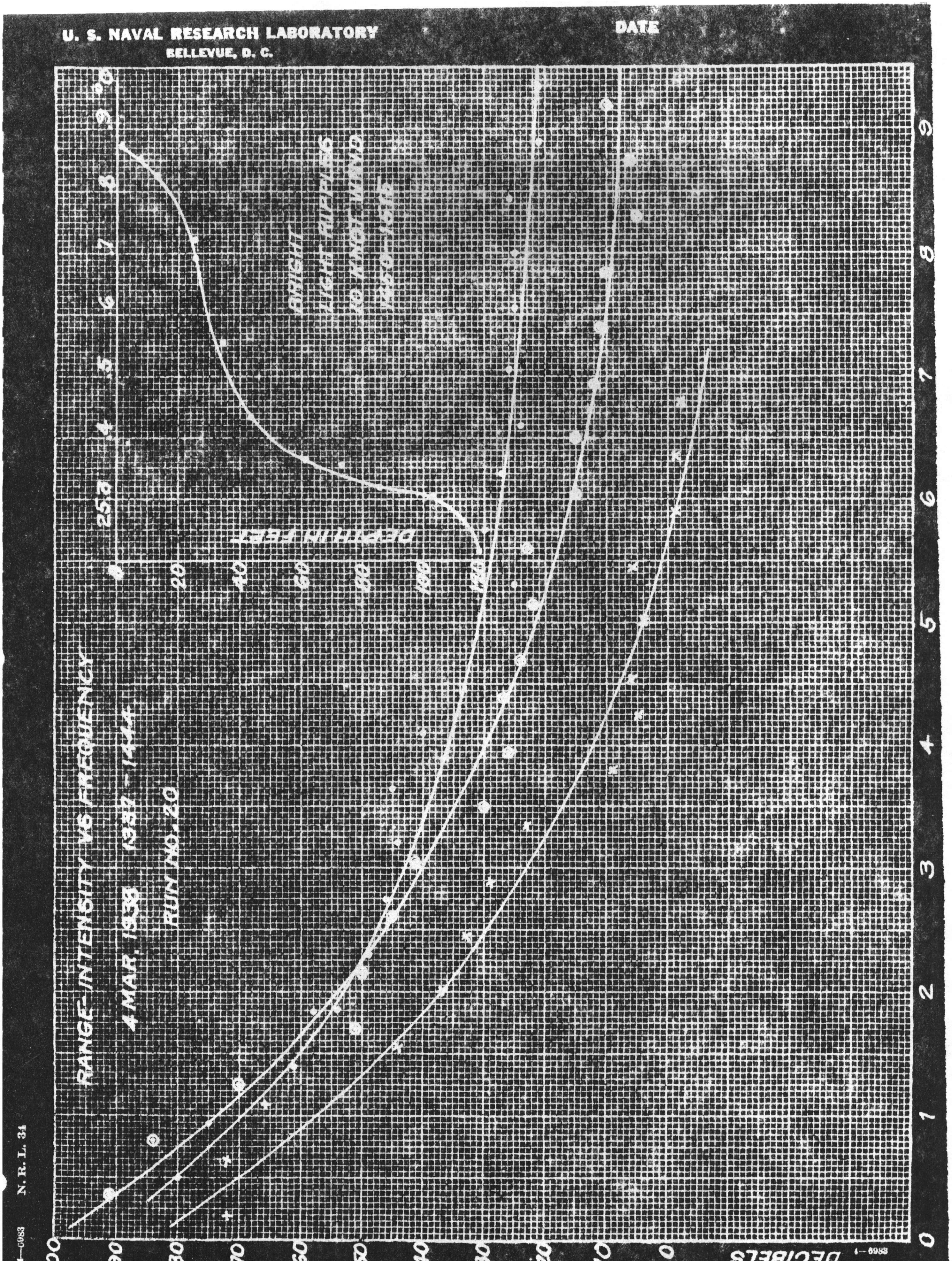
U. S. NAVAL RESEARCH LABORATORY
BELLEVUE, D. C.

DATE



SHEET

PLATE 16

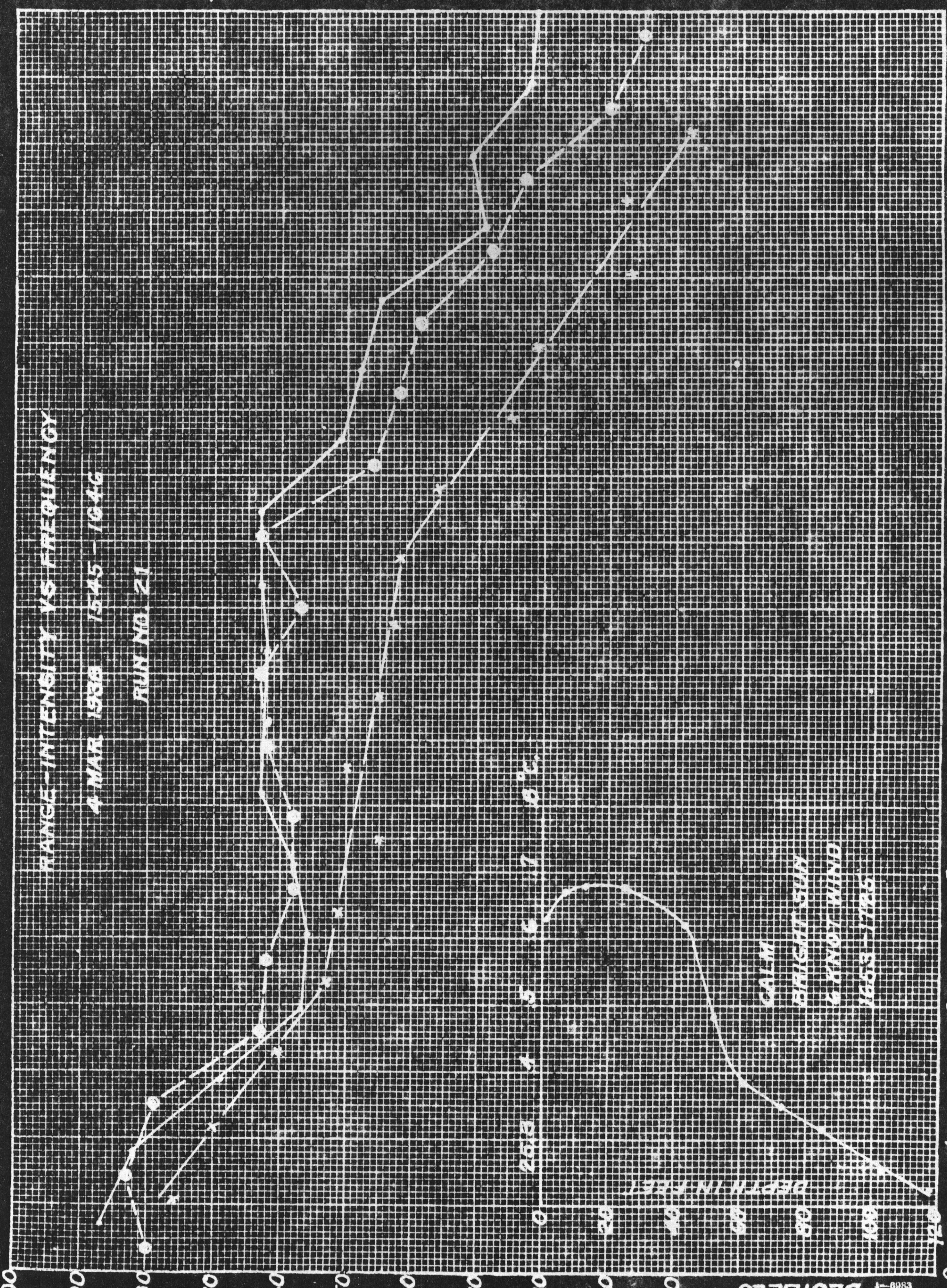


U. S. NAVAL RESEARCH LABORATORY
BELLEVUE, D. C.
DATE
RANGE-INTENSITY VS FREQUENCY
4 MAR, 1938 1337-1444
RUN NO. 20
BRIGHT
LIGHT RIPPLES
DEPTH IN FEET
DECIBELS
SHEET
N. R. L. 34

PLATE 17

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

DATE



t. L. 34

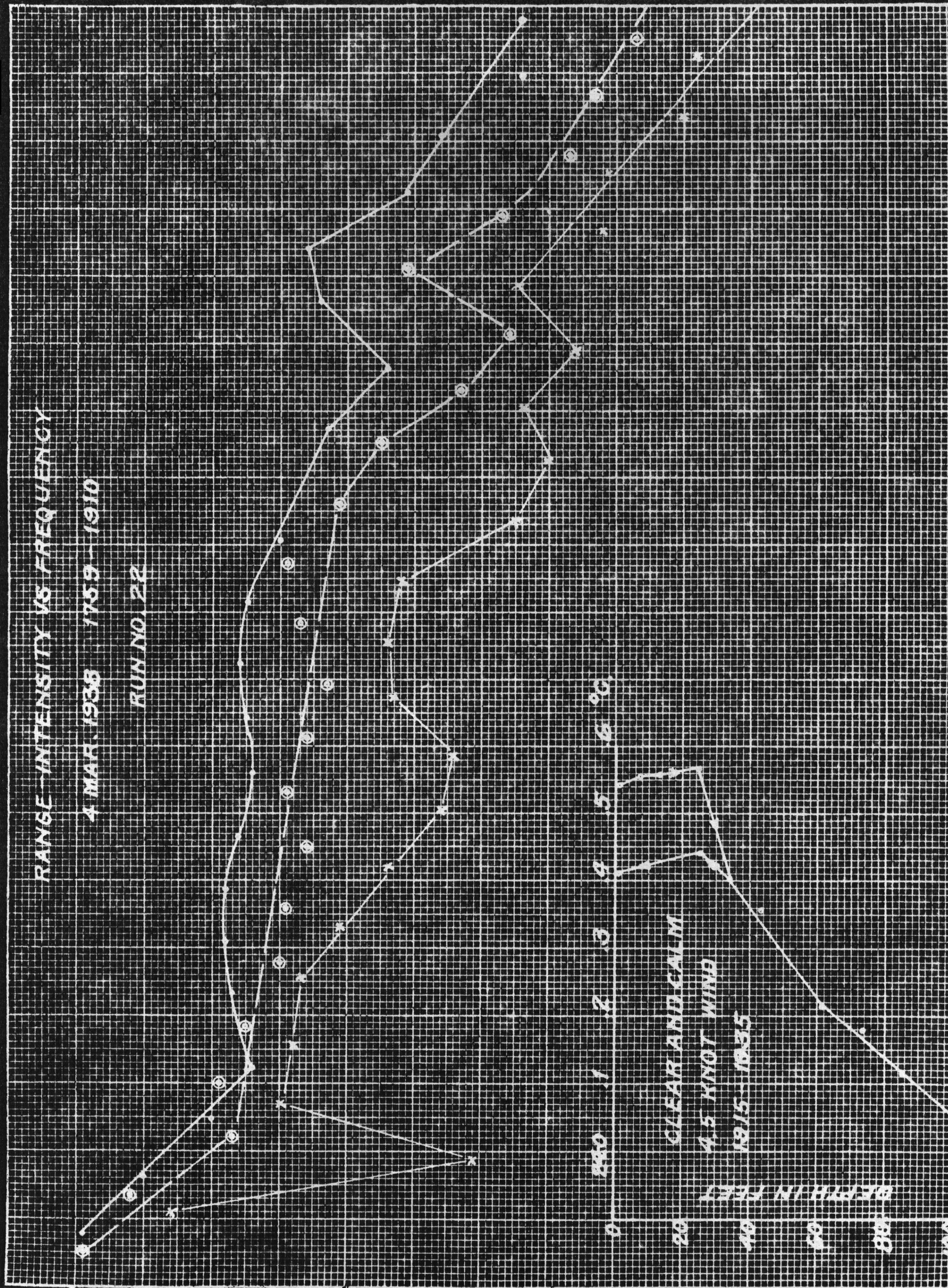
4-6983

SHEET

PLATE 18

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

DATE



R. L. 34

4—6983

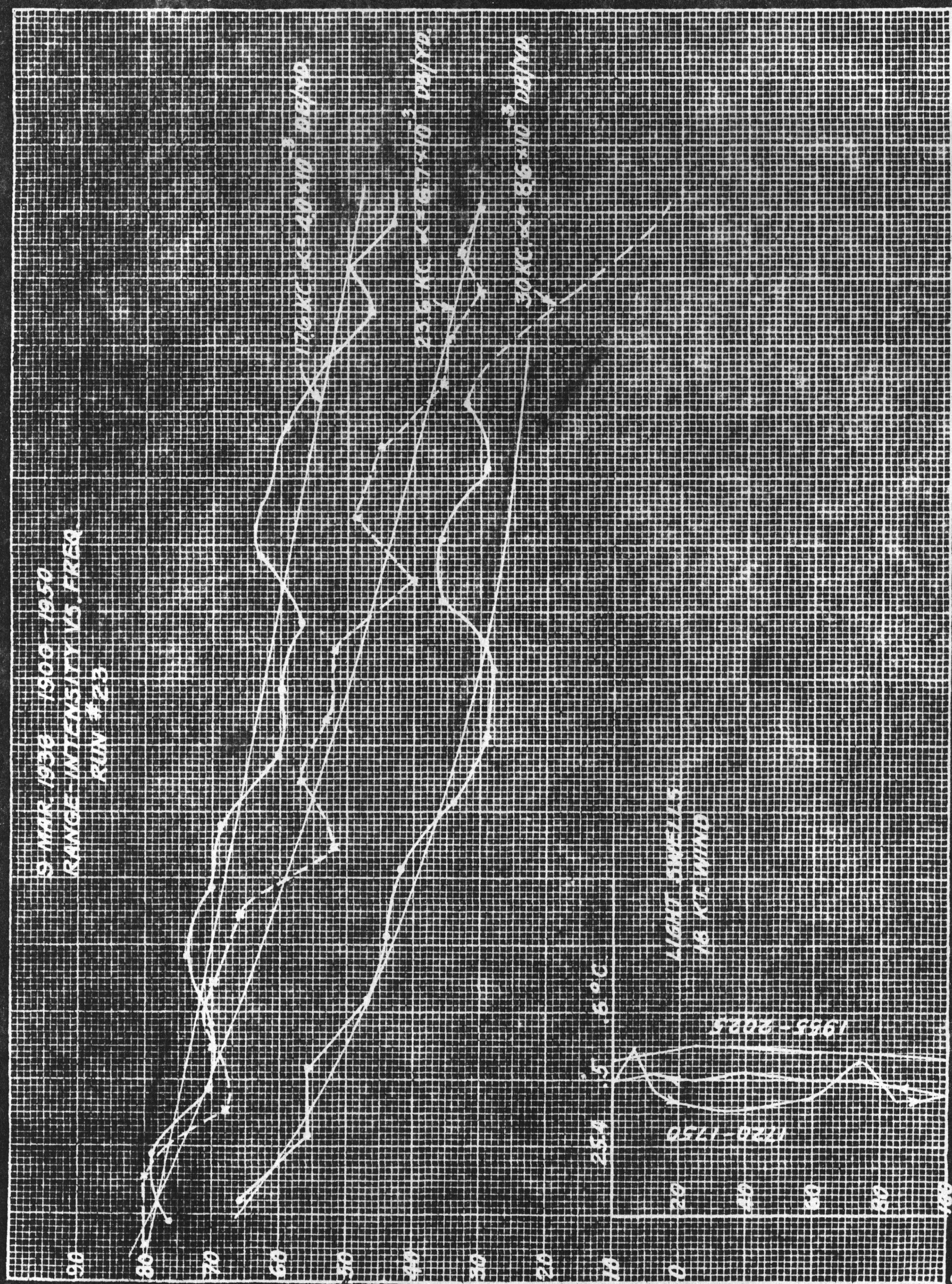
SHEET

PLATE 19

U. S. NAVAL RESEARCH LABORATORY

BELLEVUE, D. C.

DATE



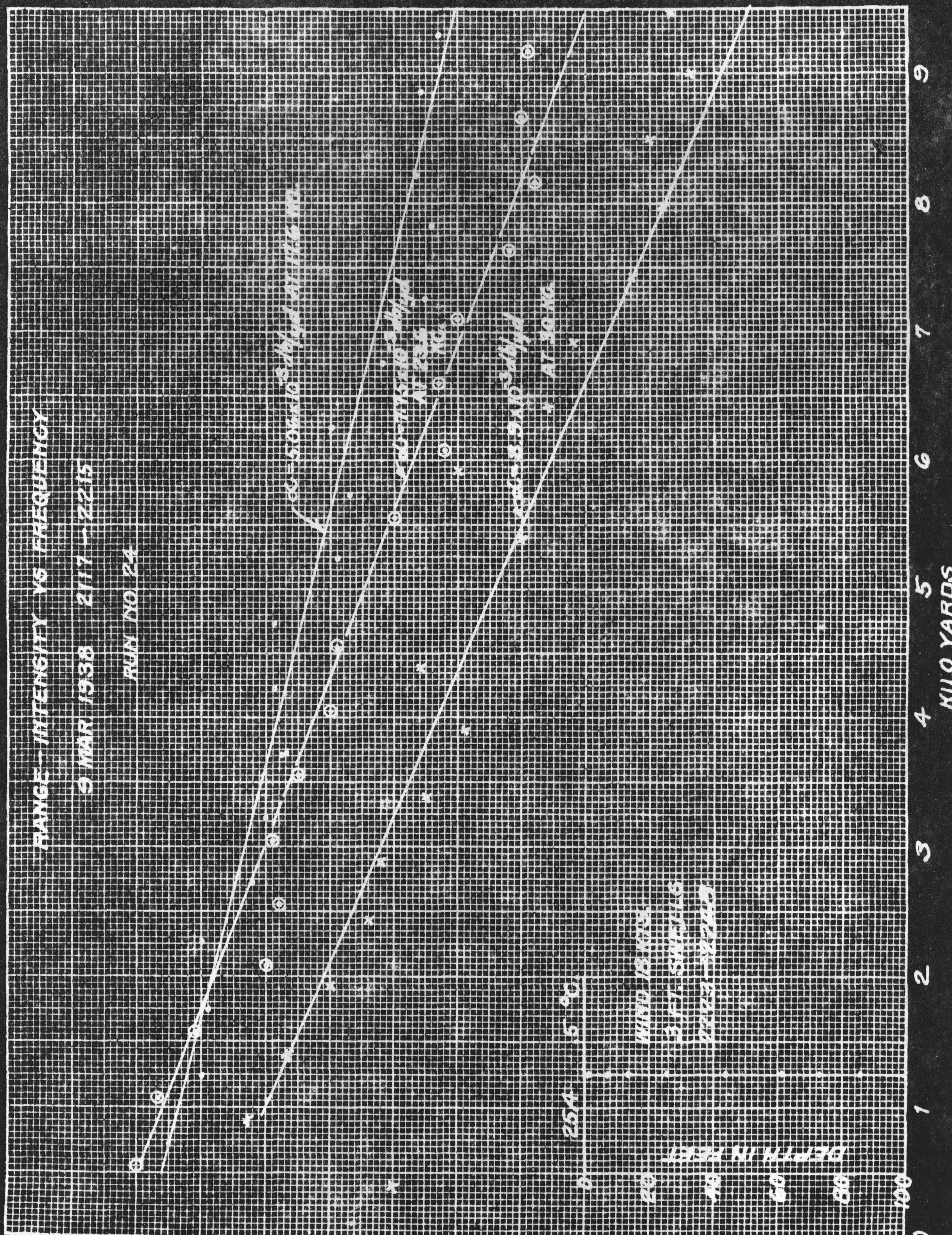
4—6983

SHEET

PLATE 20

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

DATE



SHEET

R. L. 34

PLATE 21

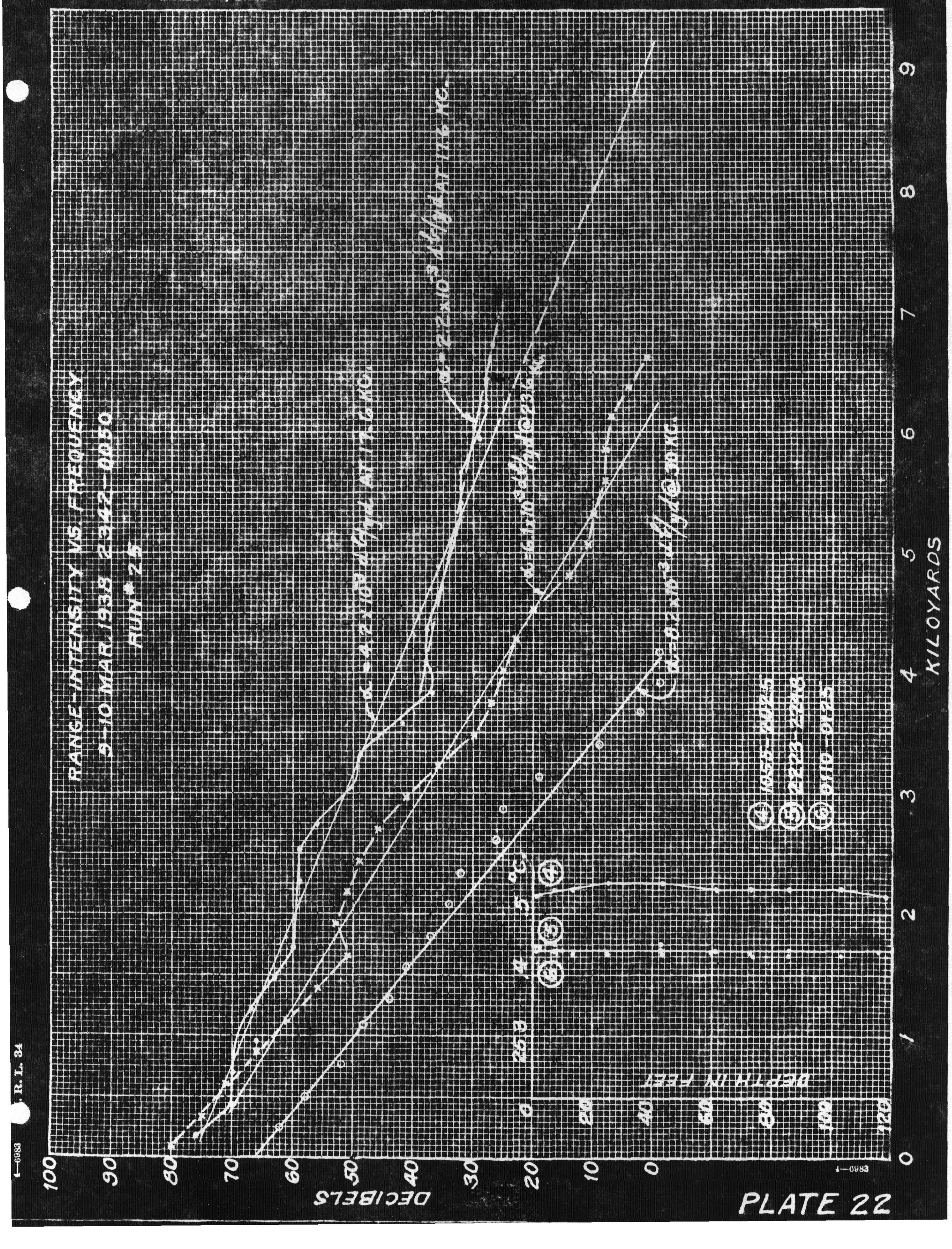
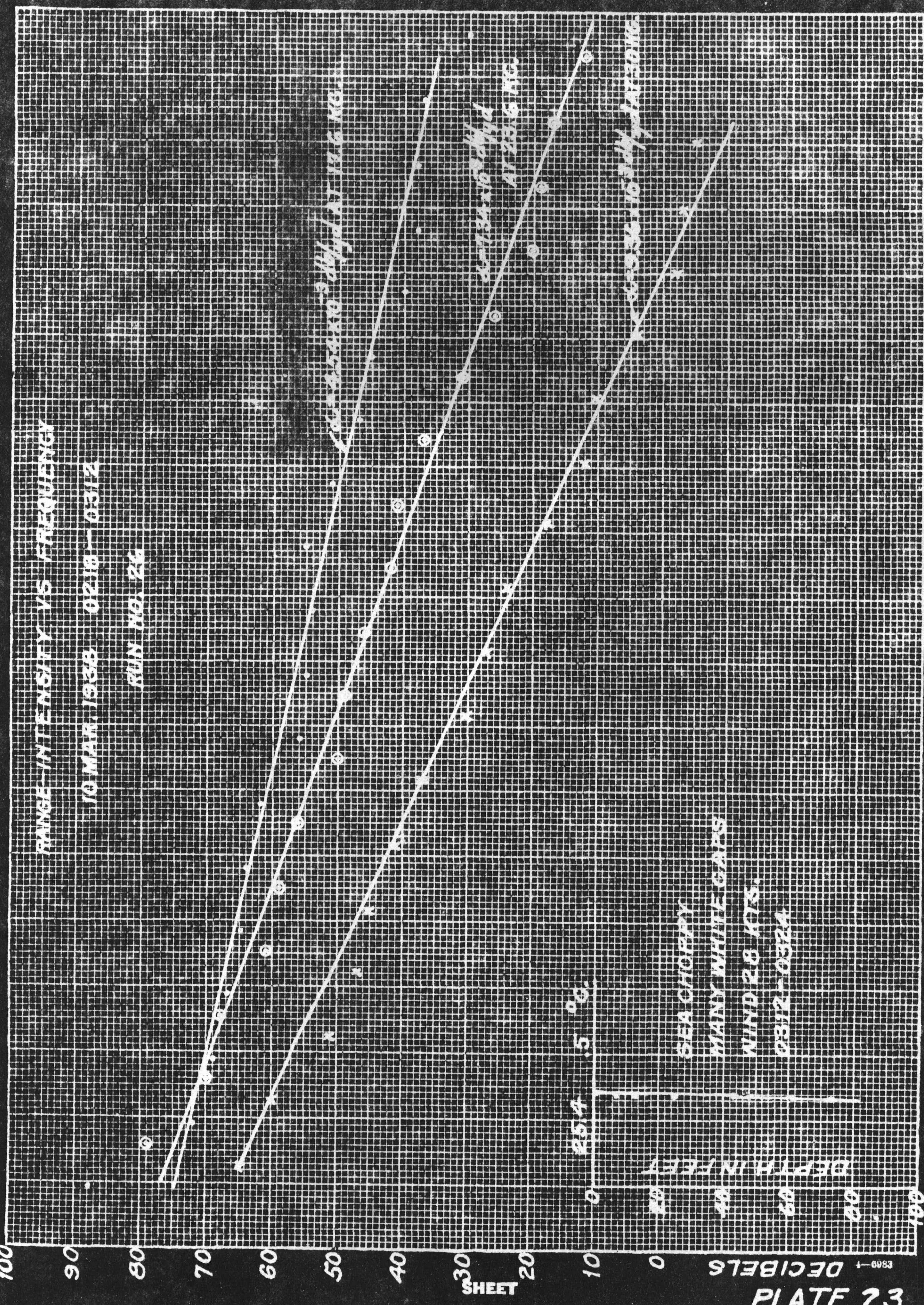

RANGE-INTENSITY VS. FREQUENCY
9-10 MAR. 1938 2342-0030
RUN # 25
KILOYARDS
DECIBELS
DEPTH IN FEET
°C

PLATE 22

U. S. NAVAL RESEARCH LABORATORY

BELLEVUE, D. C.

DATE



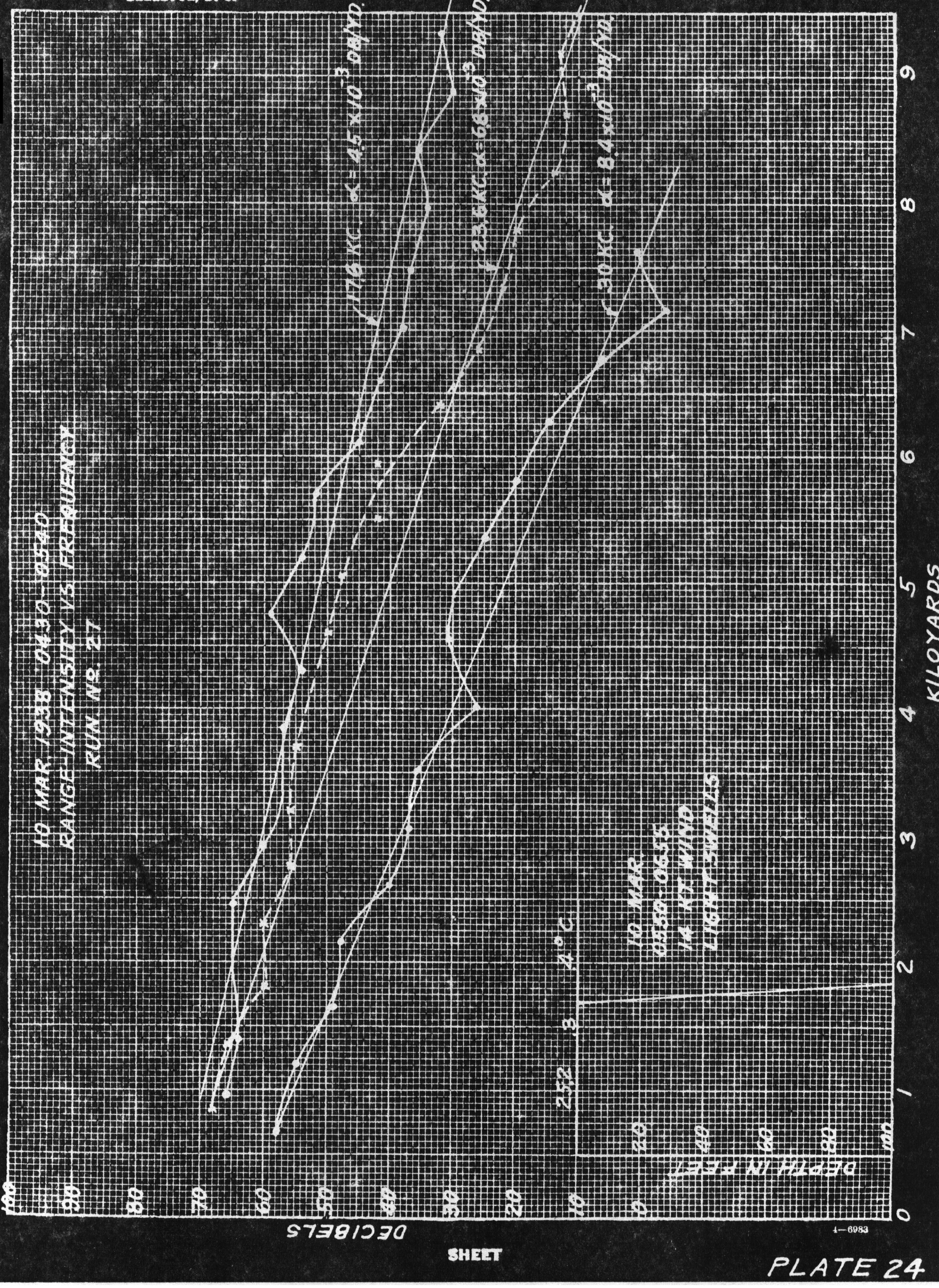
SHEET

PLATE 23

U. S. NAVAL RESEARCH LABORATORY

BELLEVUE, D. C.

DATE



SHEET

R. L. 34

4—6983

PLATE 24

U. S. NAVAL RESEARCH LABORATORY

BELLEVUE, D. C.

DATE

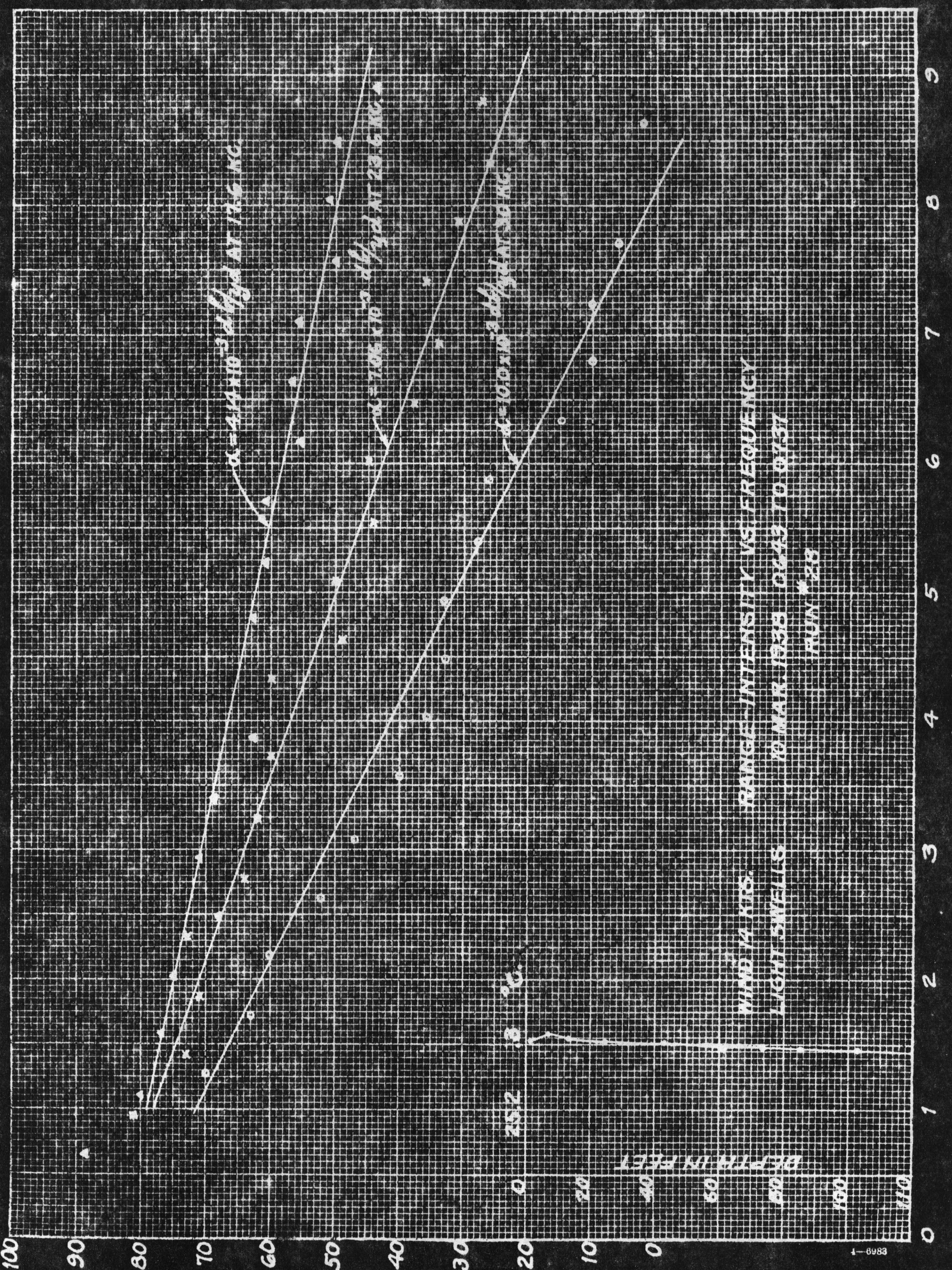


PLATE 25

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

DATE

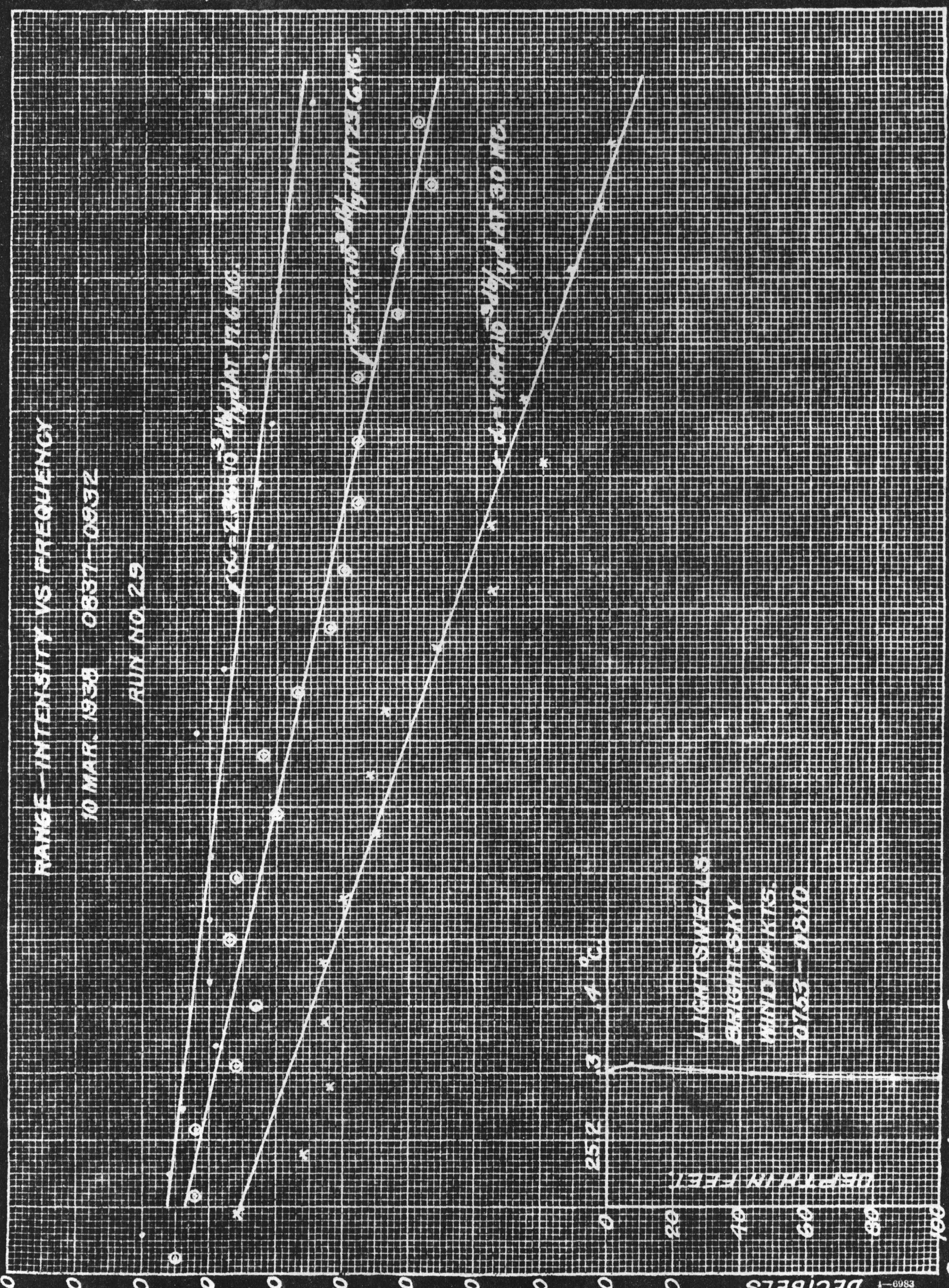
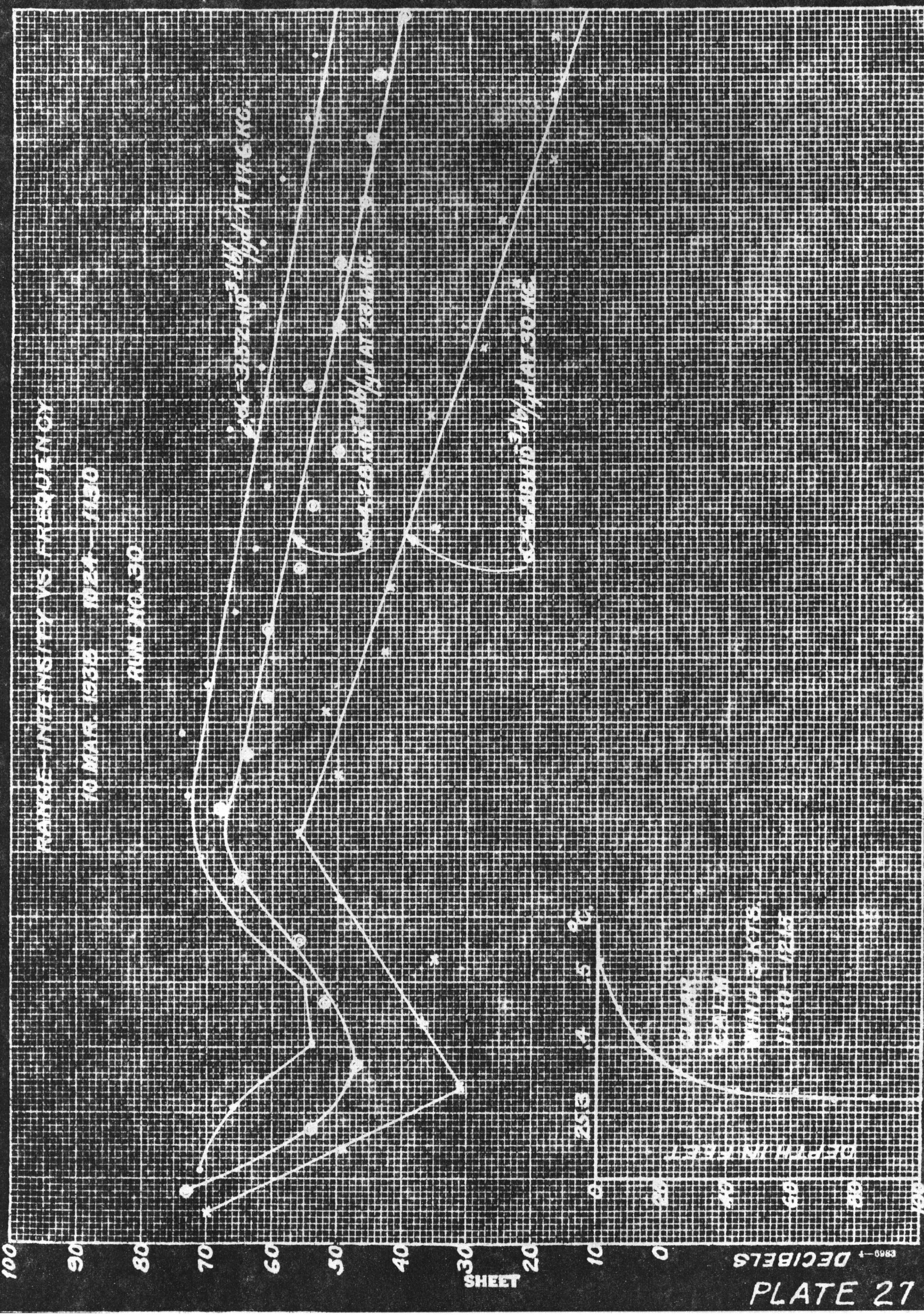


PLATE 26

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

DATE



SHEET

R. L. 34

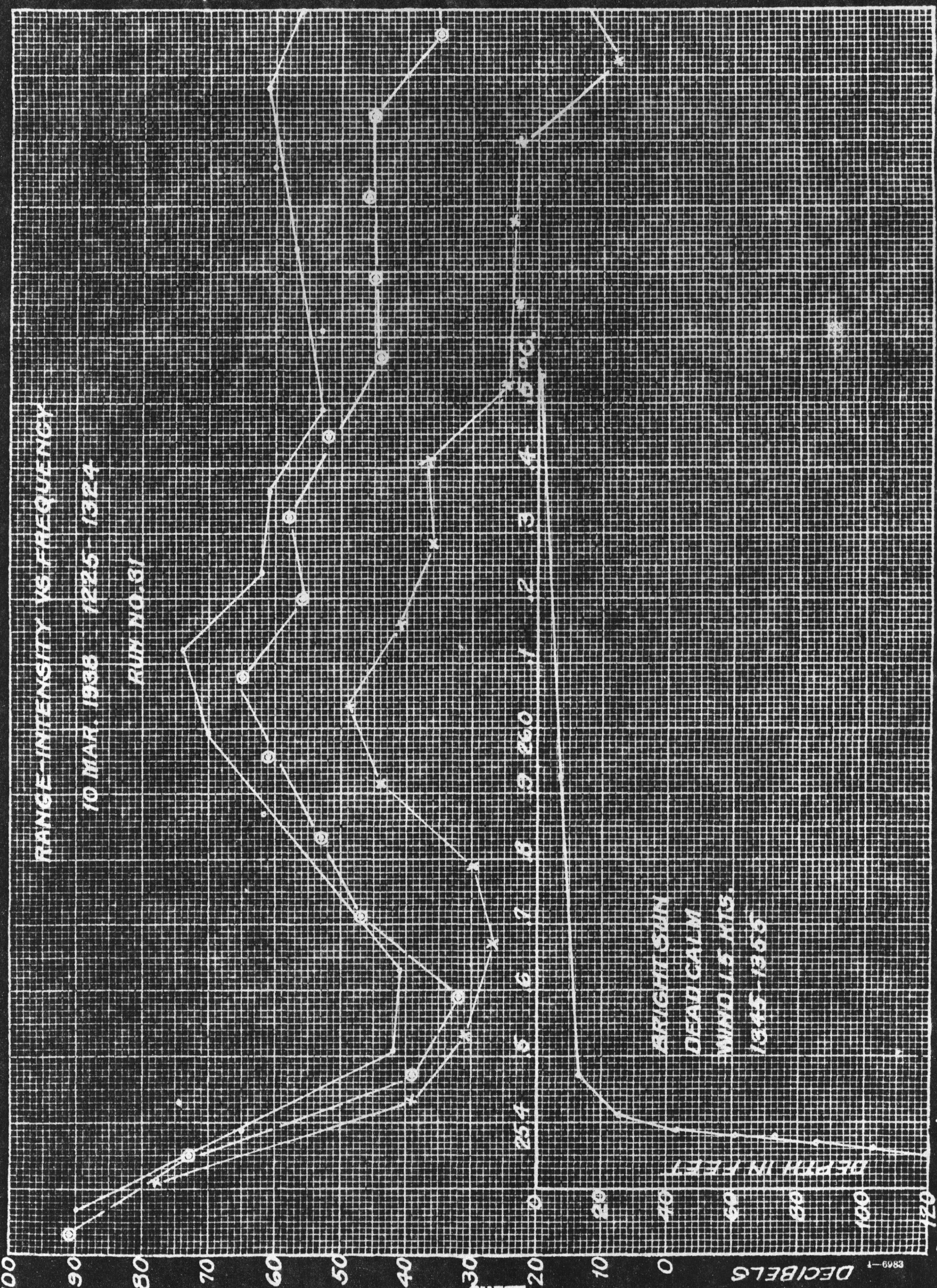
4—6983

PLATE 27

U. S. NAVAL RESEARCH LABORATORY

BELLEVUE, D. C.

DATE



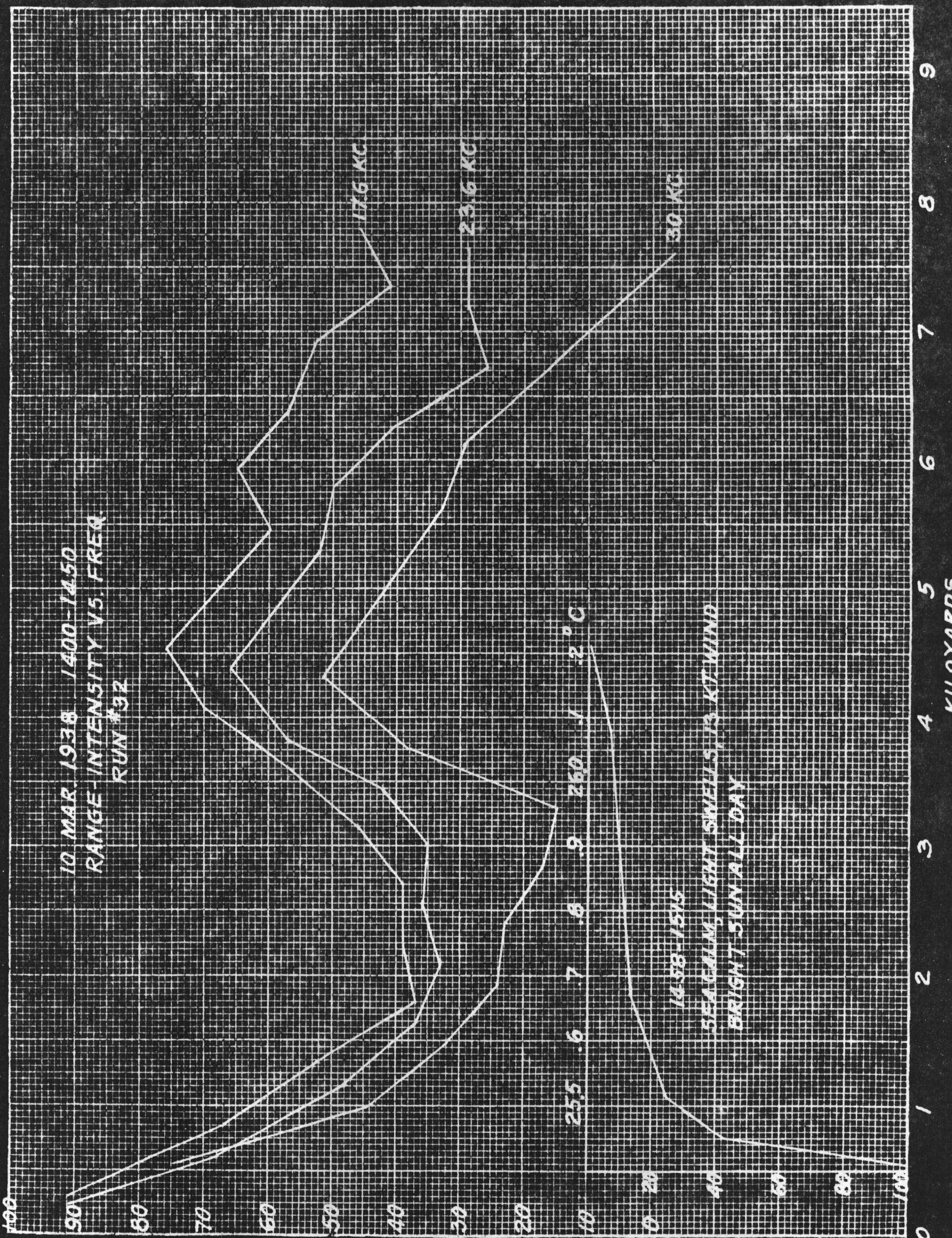
SHEET

4-6983

PLATE 28

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

DATE



SHEET

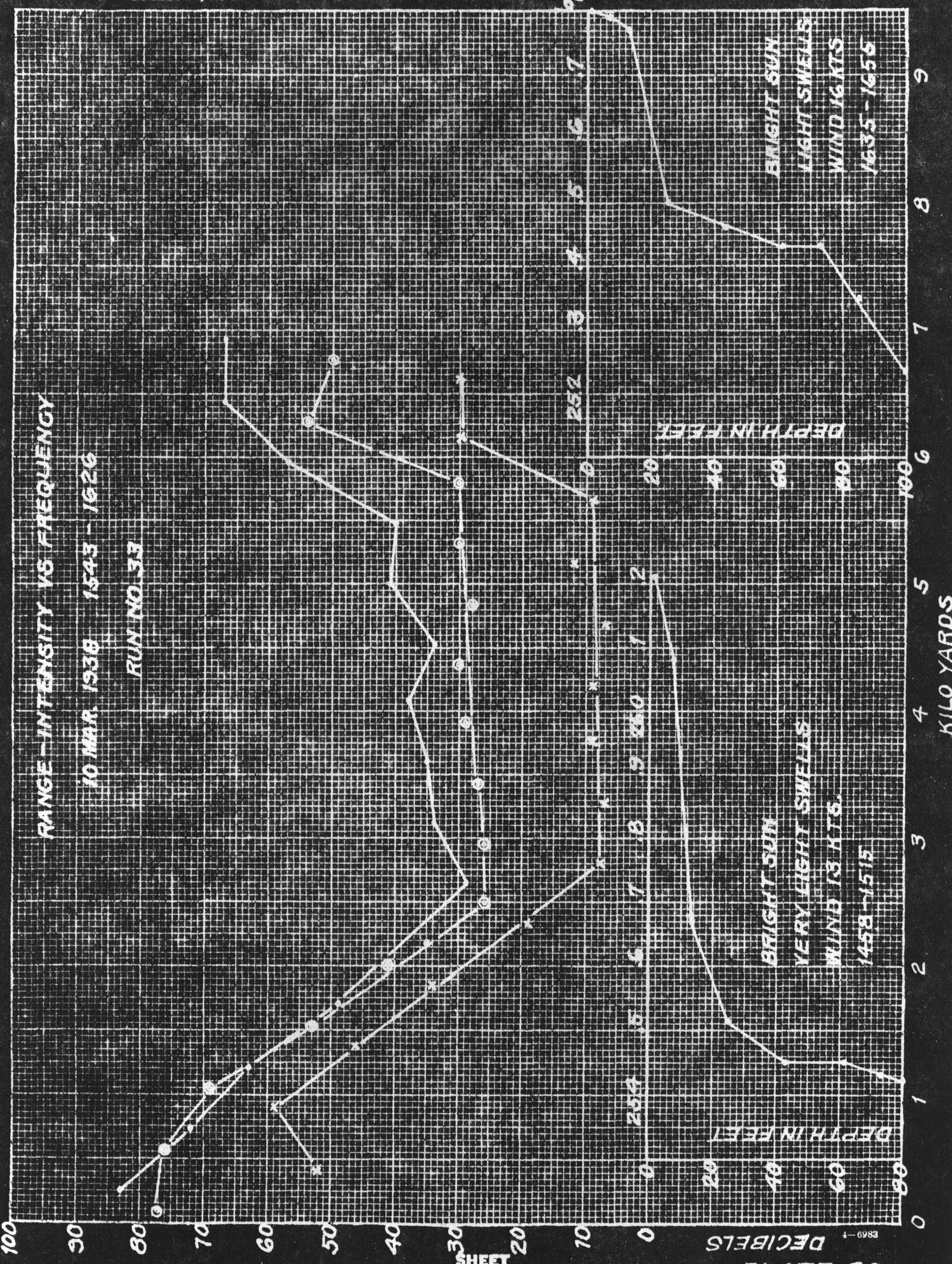
R. L. 34

4—6983

PLATE 29

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

DATE

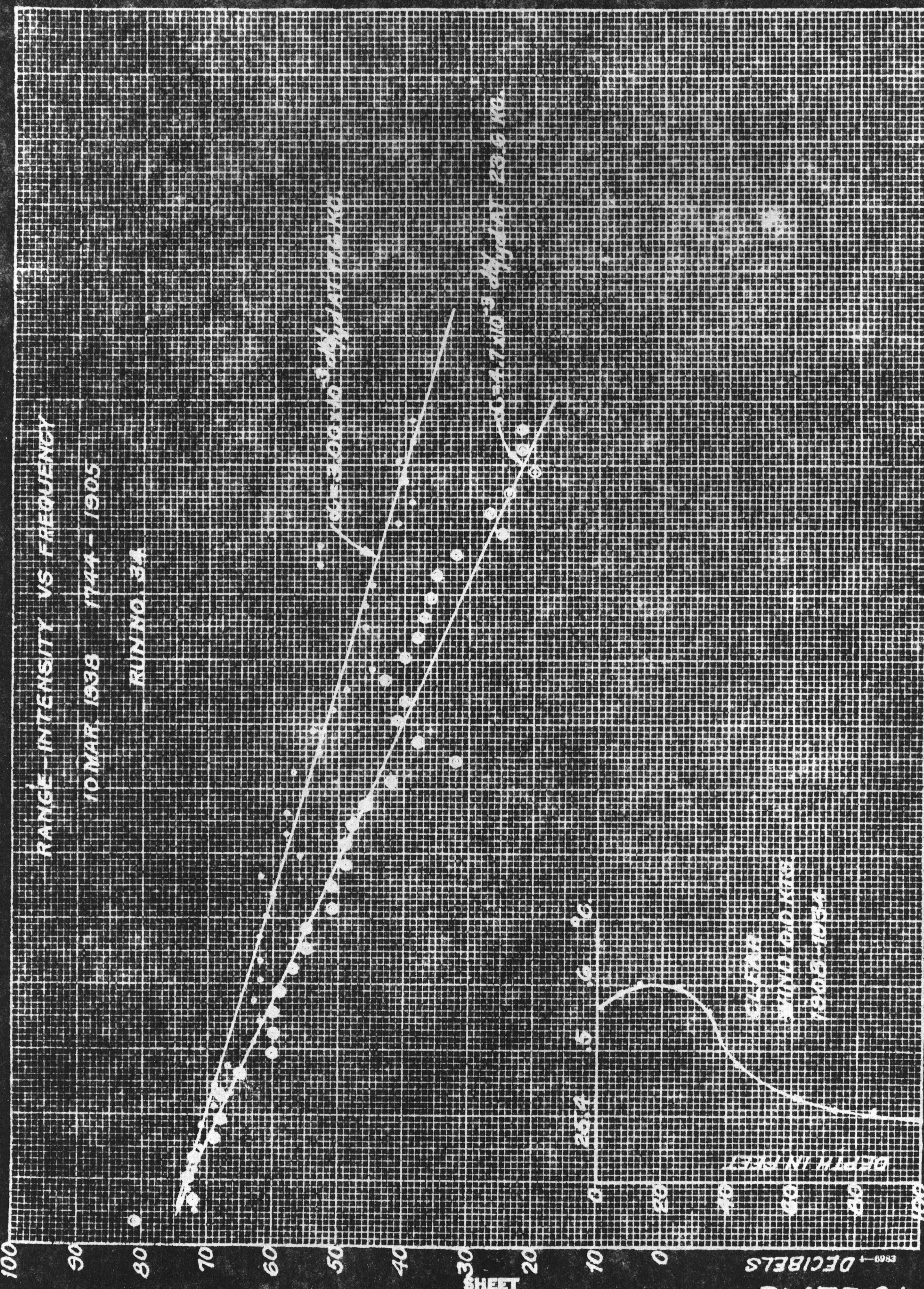


SHEET

PLATE 30

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

DATE



SHEET

R. L. 34

PLATE 31

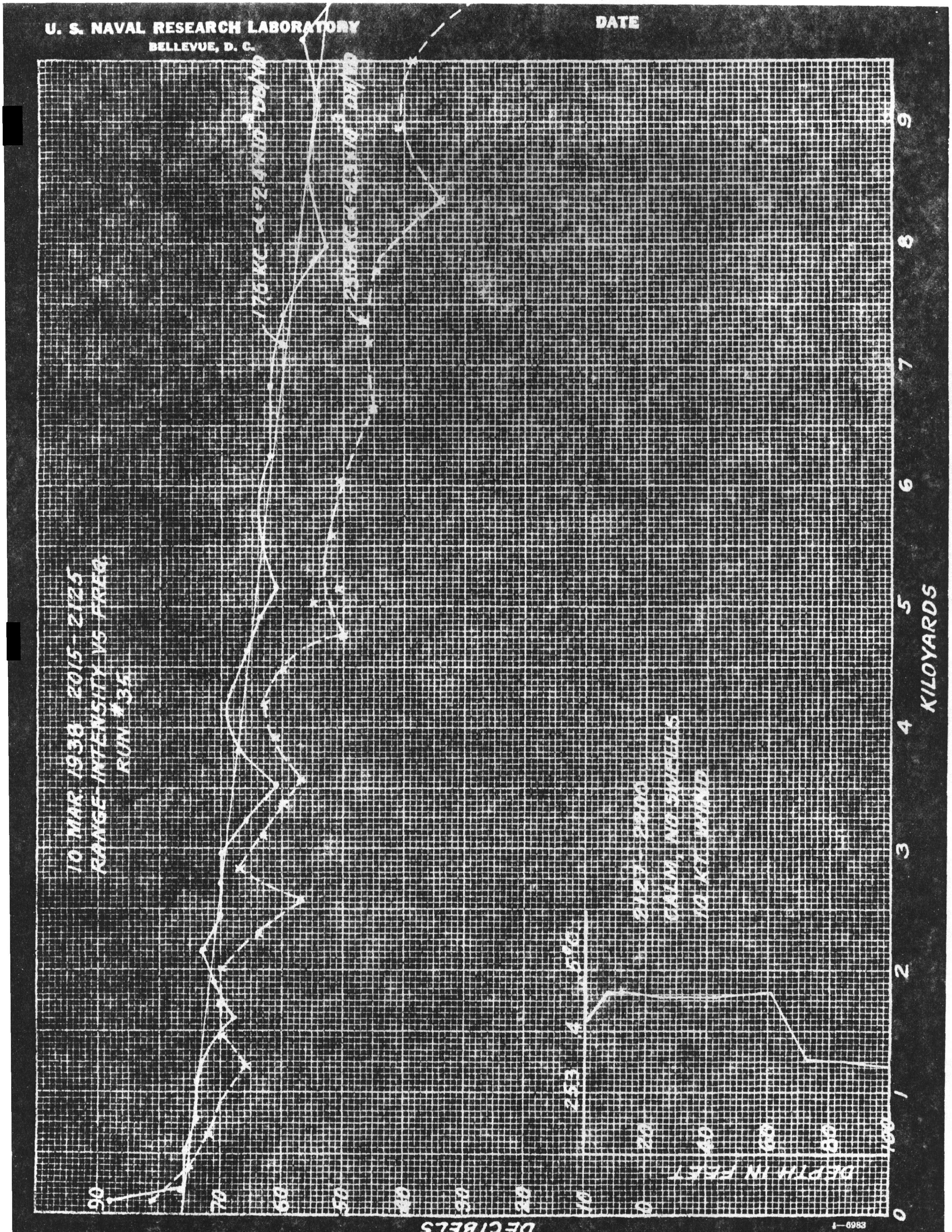

U. S. NAVAL RESEARCH LABORATORY
BELLEVUE, D. C.
DATE
10 MAR 1938 2015-2125
RANGE INTENSITY VS FREQ.
RUN #35
2127-2200
CALM, NO SWELLS
10 KT WIND
KILOYARDS
DECIBELS
DEPTH IN FEET
SHEET

PLATE 32

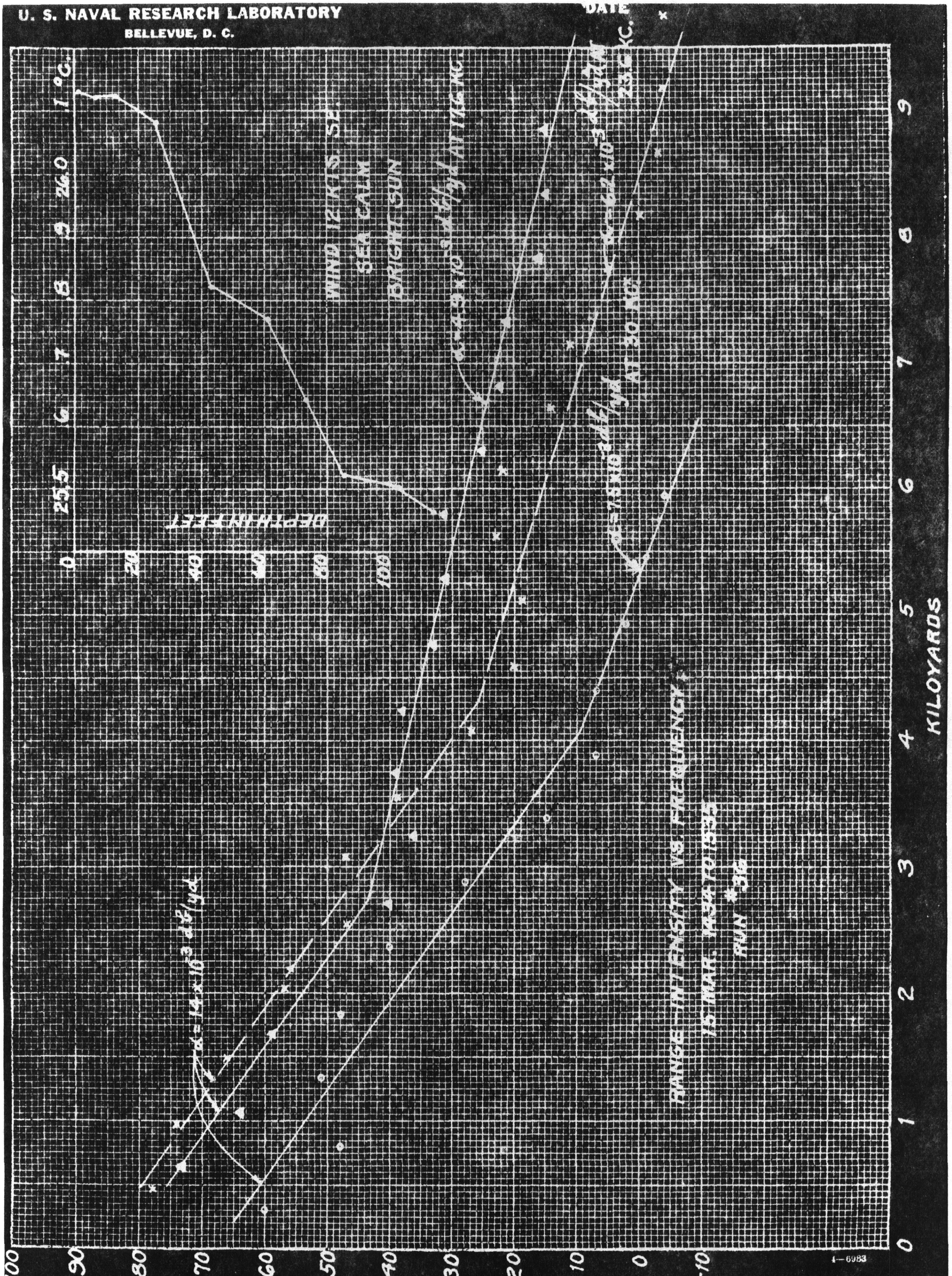
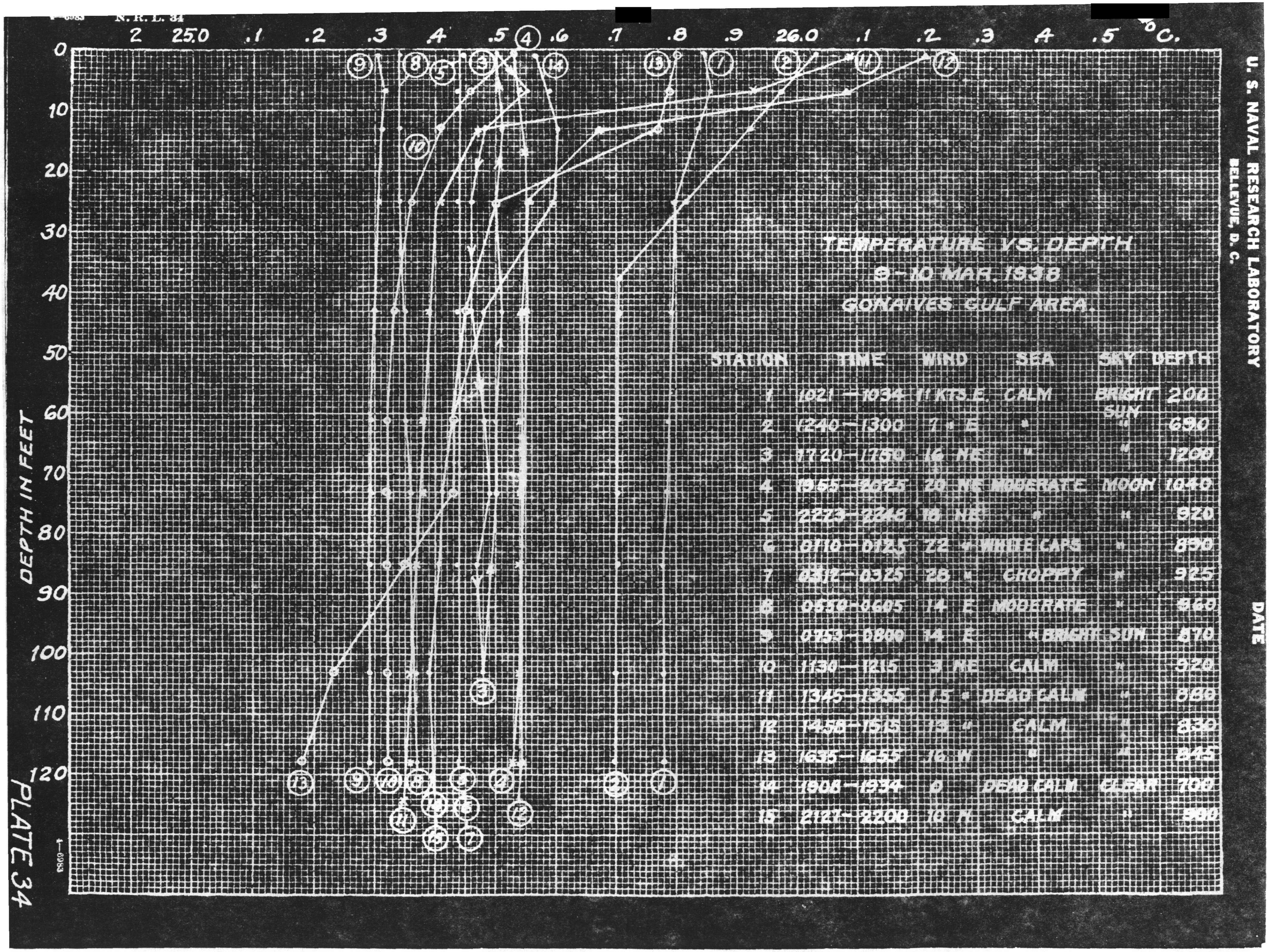
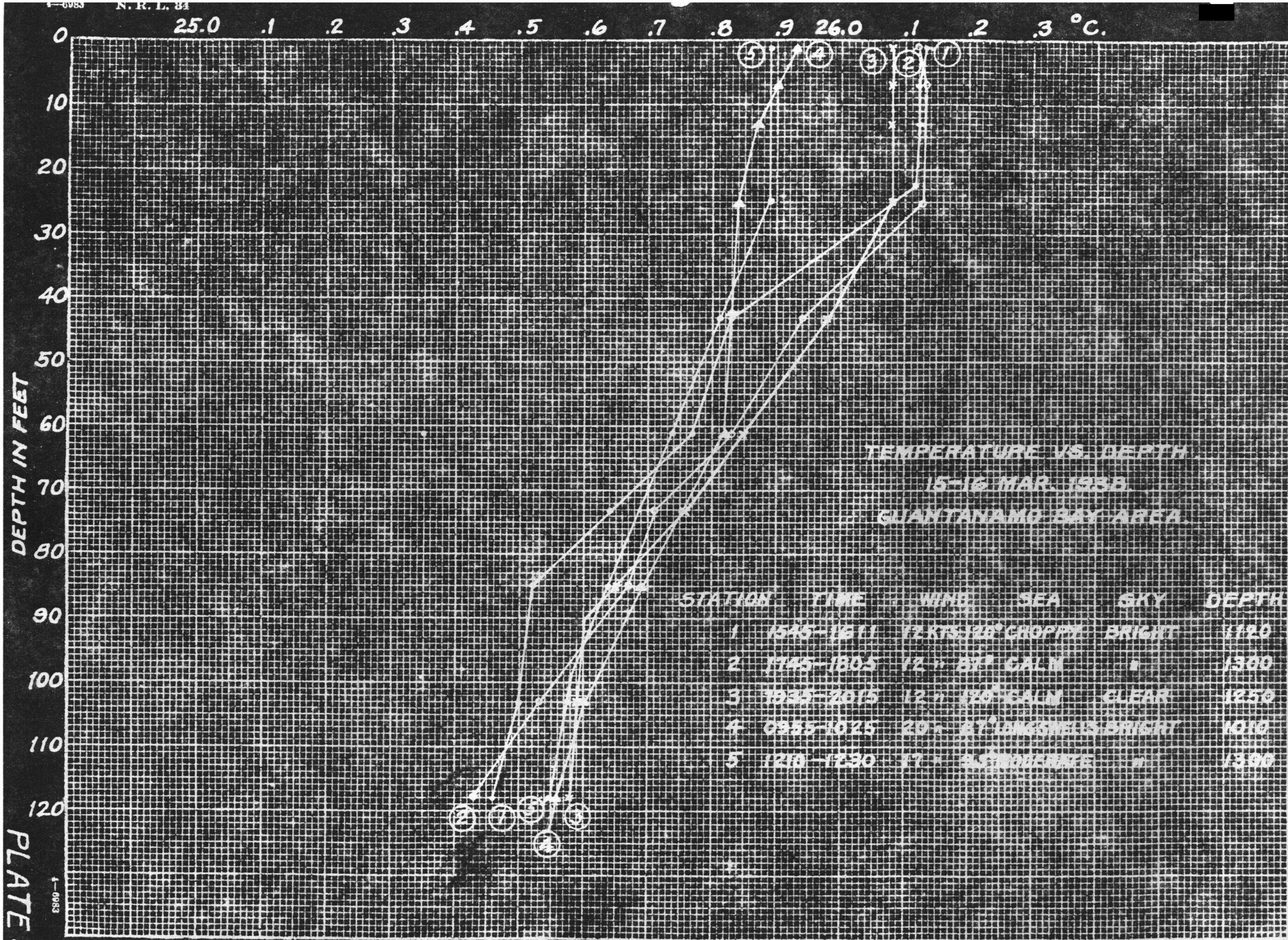

U. S. NAVAL RESEARCH LABORATORY
BELLEVUE, D. C.
DATE
WIND 12 KTS SE.
SEA CALM
BRIGHT SUN
DEPTH IN FEET
RANGE INTENSITY VS. FREQUENCY
15 MAR. 1434 TO 1535
RUN #36
AT 30 KC.
23.6 KC.
KILOYARDS
DECIBELS
4-6983

PLATE 33


U. S. NAVAL RESEARCH LABORATORY
BELLEVUE, D. C.
DATE
N. R. L. 34
TEMPERATURE VS. DEPTH
9-10 MAR. 1938
GONAIVES GULF AREA.
STATION TIME WIND SEA SKY DEPTH
1 1021—1034 11 KTS. E. CALM BRIGHT SUN 200
2 1240—1300 7 " E " " 690
3 1720—1750 16 NE " " 1200
4 1955—2025 20 NE MODERATE MOON 1040
5 2223—2248 18 NE " " 920
6 0110—0125 22 " WHITE CAPS " 890
7 0312—0325 28 " CHOPPY " 925
8 0550—0605 14 E MODERATE " 960
9 0753—0800 14 E " BRIGHT SUN 870
10 1130—1215 3 NE CALM " 920
11 1345—1355 1.5 " DEAD CALM " 880
12 1458—1515 13 " CALM " 830
13 1635—1655 16 W " " 845
14 1908—1934 0 DEAD CALM CLEAR 700
15 2127—2200 10 N CALM " 900
DEPTH IN FEET
°C.
4—6983
PLATE 34

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

DATE



N. R. L. 84

4-6983

PLATE 35

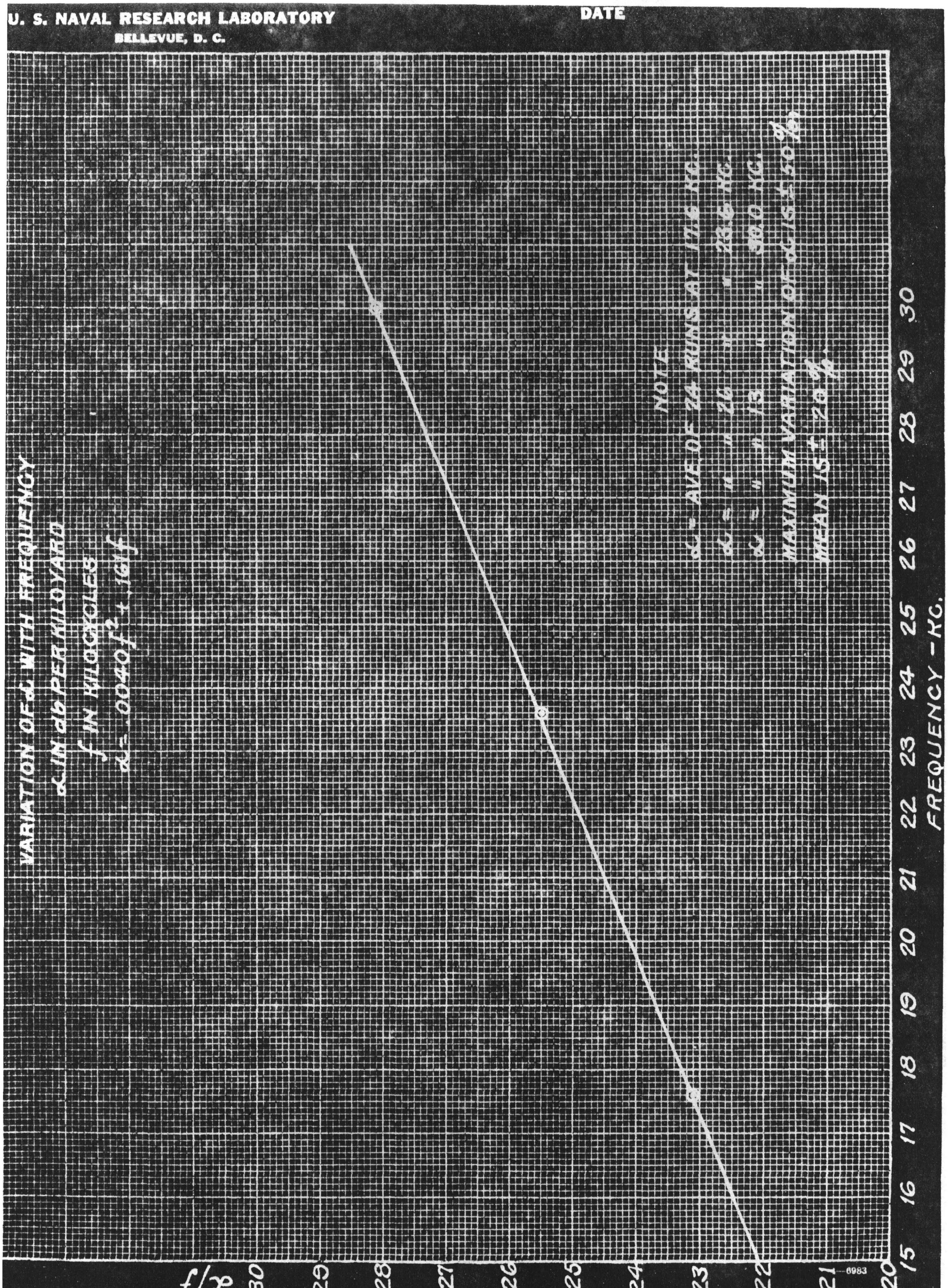

U. S. NAVAL RESEARCH LABORATORY
BELLEVUE, D. C.
DATE
SHEET
VARIATION OF α WITH FREQUENCY
α IN db PER KILOYARD
f IN KILOCYCLES
α = .0040f² + .161f
NOTE
α = AVE OF 24 RUNS AT 17.6 KC.
α = " " 26 " " 23.6 KC.
α = " " 13 " " 30.0 KC.
MAXIMUM VARIATION OF α IS ±50%
MEAN IS ±20%
FREQUENCY - KC.
15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30
.20 .21 .22 .23 .24 .25 .26 .27 .28 .29 .30
f/α
6983

PLATE 36