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COMPARISON OF THE PASSIVE PERFORMANCE OF THE AN/SQS-23 AND THE --ETC(U)
JUL 66 J K BEARD, B M BROWN

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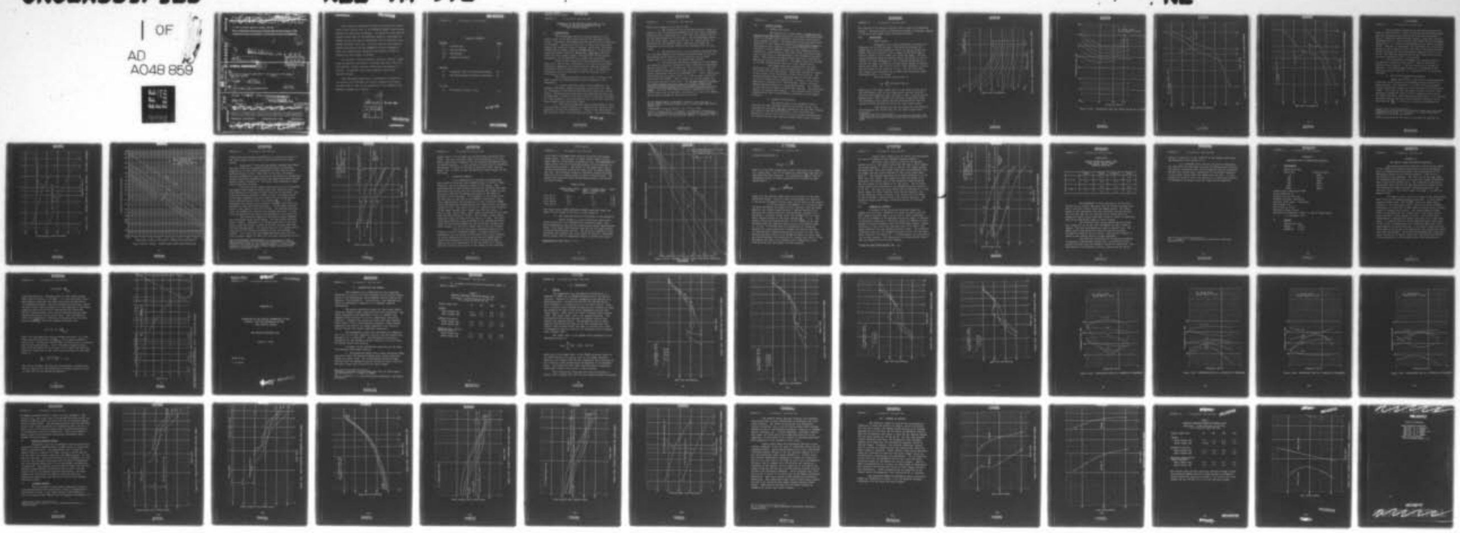

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(9) Technical memo.

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(6) COMPARISON OF THE PASSIVE PERFORMANCE OF THE AN/SQS-23 AND THE AN/SQQ-23 (PAIR) SONAR SYSTEMS.

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This technical memorandum describes the detection performance of the passive mode of the AN/SQQ-23 (PAIR) sonar system obtained by simulation techniques. It should be noted that the passive search mode of the AN/SQQ-23 (PAIR) is equivalent to PADLOC and for the sake of convenience will be referred to as PADLOC throughout this text. Sea test data for the original PADLOC installed on the USS GLENNON and typical AN/SQS-23 sonar are compared with simulation performance in order to demonstrate the validity of method.

The analysis, which utilized Dr. Wilbur H. Watson's (NEL) sonar propagation loss model, is divided into four (4) parts: Introduction, Passive Systems, Performance and Summary of Results. An appendix lists the parameters used in the simulation model.

This Memorandum should not be construed as a report for its purpose is to document the passive analysis work which has been done to date on the comparison of the AN/SQS-23 and AN/SQQ-23 (PAIR) sonar systems.

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COMPARISON OF THE PASSIVE PERFORMANCE OF THE AN/SQS-23 AND THE PERFORMANCE OF THE PAIR PASSIVE SYSTEM

I. INTRODUCTION

This memorandum describes the performance of the passive mode of the PAIR system obtained by simulation techniques. Throughout this memorandum this system will be referred to as PADLOC. Dectection ranges for in-layer and below-layer targets are predicted using a standard, snorkeling, cavitating, 10 knot Diesel target signature ~~(Target A)~~ and a 15 knot non-cavitating target signature ~~(Target B)~~. (The spectrum level plots for these targets appear in Figure IIIe.) The passive performance of the AN/SQS-23 is included for comparison.

These results reported in this memorandum deal with a deep water, 100 ft layer environment for a particular gradient structure. Operation in a shallow water, negative gradient environment will be reported at a later time. The predicted propagation loss was determined using the programs of Dr. W. H. Watson at NEL.

The following statements can be made relative to the model studies in summarizing the results reported in this memorandum:

1. Passive detection ranges using PADLOC for the standard cavitating, Diesel submarine, in and below the layer are comparable to the PAIR active detection ranges for a 20 dB target. Alerted passive detections are predicted for this type of submarine to 20 kyd in the layer and to 9 kyd below the layer. If 3 dB degradation is postulated for the non-alerted situation these ranges become 18 kyd and 8 kyd.

2. The passive detection ranges using PADLOC for the non-cavitating, quiet submarine are approximately one-half those predicted for the noisy submarine, 9 kyd in the layer and 6 kyd below the layer in the alerted operation. The corresponding

non-alerted ranges are 6.5 and 4.7 kyd.

3. The predicted ratio of maximum detection range for PADLOC to that of the passive AN/SQS-23 for the water conditions assumed in this comparison are 1.5 for the noisy target and 2.1 for the quiet target in the in-layer. The corresponding ratios for the below layer target are 2.9 and 4.9. These ratios are predicted for the specific water conditions and under the assumption that the noise field at the transducer face is isotropic.

4. The predicted ratio of the maximum detection range of a two-dome PADLOC to the maximum detection range of the one-dome PADLOC (split array) is 1.2 or more for the in-layer targets and 2.5 or more for the below-layer targets.

5. The predicted performance comparison of the PADLOC and AN/SQS-23 does not confirm the almost identical performances observed by Vachon* and Krieger for the two systems. The predicted PADLOC performances are quite similar to the in-layer target performance observed by DESDEVGRU II**. These observations show detections for noisy targets in a 200 ft layer between 20 and 30 kyd with PADLOC. Quiet targets were detected with the same system between 2 and 20 kyd. In the July tests*** of 1964 the median PADLOC detection range for in-layer targets was observed to be 20% greater than the AN/SQS-23 passive detection ranges. In tests with PADLOC and passive AN/SQS-23 while the active system was in operation, detections were made with PADLOC and no passive AN/SQS-23 detections were made.

*R. J. Vachon and C. J. Krieger, "PADLOC I Sonar Receiver AN/SQR-13(XN-1) Technical Evaluation", 28 June 1965, NEL Report Number 1297.

**DESDEVGRU 2 Progress Report, Jan. to Feb. 1965.

***H. E. Fridge and E. J. Cloutier, "An Analysis of Detection Trial Data Obtained During Technical Evaluation of the AN/SQR-13 (XN-1) Equipment in the USS Glennon (DD840), 15 September 1964.

II. PASSIVE SYSTEMS

A. PADLOC Description

The PAIR passive search system, PADLOC (PAssive Detection and LOCation) consists of two widely separated transducers, a clipped cross-correlator (coincidence correlator), and a graphic recorder. The pass band of the operational mode discussed in this report is nominally 1.0 kc/s to 2.5 kc/s. This band is wide compared to the center frequency so that variation of input spectral densities with frequency must be considered. Prewhitening of the input noise and signal amounting to 5 dB/octave is accomplished at the hydrophone preamplifiers. This produces an approximately flat noise spectrum at the output of the preamplifiers. The PADLOC system is intended to be used simultaneously with the active search system.

The target spectrum, attenuated by the path attenuation and modified by the prewhitening is embedded in flat noise from the environment. Each beam waveform is clipped at the output of the beamformer in both receive arrays. The clipped waveforms from corresponding beams in the two arrays are cross correlated and averaged for 1 second. Cross correlations are performed with 400 different delays, each providing optimum response on a particular bearing. All together the 400 correlator outputs provide 360° coverage. The correlator outputs are scanned each second. A five minute history of the sampled output after thresholding is displayed on the graphic recorder.

B. AN/SQS-23 Description

The passive mode on the AN/SQS-23 system utilizes the same receiver system as the active system; the bandwidth is nominally 370 c/s. Headphones and the video display are used for the operator interface. It is therefore not possible to operate the active and passive modes simultaneously. The passive system video display recycles about every 6 seconds.

The storage on the display persists only as long as the phosphor permits. Processing gain is obtained by display of multiple samples of the noise and signal field and operator memory.

III. PERFORMANCE

A. System Inputs

Propagation loss curves plotted as a function of frequency for the 100 ft layer, deep water environment for ranges from 2 to 20 kiloyards are shown in Figures III(a) and III(b); the first figure is for a target at periscope depth and the second is for a target just below the layer. The frequency dependence shown in Figures III(a) and III(b) is characteristic of layer propagation. Path attenuation plotted as a function of range is shown for the two target depths in Figures III(c) and III(d); the first is at the lower bandlimit (1 kc/s) and the second is the curve for 2 kc/s. The data for these four figures were obtained from the NEL Sonar Prediction Model developed by Dr. W. N. Watson.

The total input signal power is

$$S_{in} = \int_{f_L}^{f_H} S(f) \cdot H(f) \cdot W(f)\, dt$$

where S_{in} is the input signal power in the band, f_L and f_H are the band limits, S(f) is the signal power spectral density, H(f) is the propagation loss, and W(f) is the + 5 dB per octave prewhitening. This integral was evaluated numerically using the numerical values rather than dB representations from the curves for H(f) and S(f) to obtain the input signal power.

Path attenuation and other data for the AN/SQS-23 are drawn from the active study for the 100 ft layer water condition*.

* Revised Task 21, "Performance and Operations Analysis", NEL Letter Report to Bureau of Ships, Code 2140, Revised March 31, 1966.

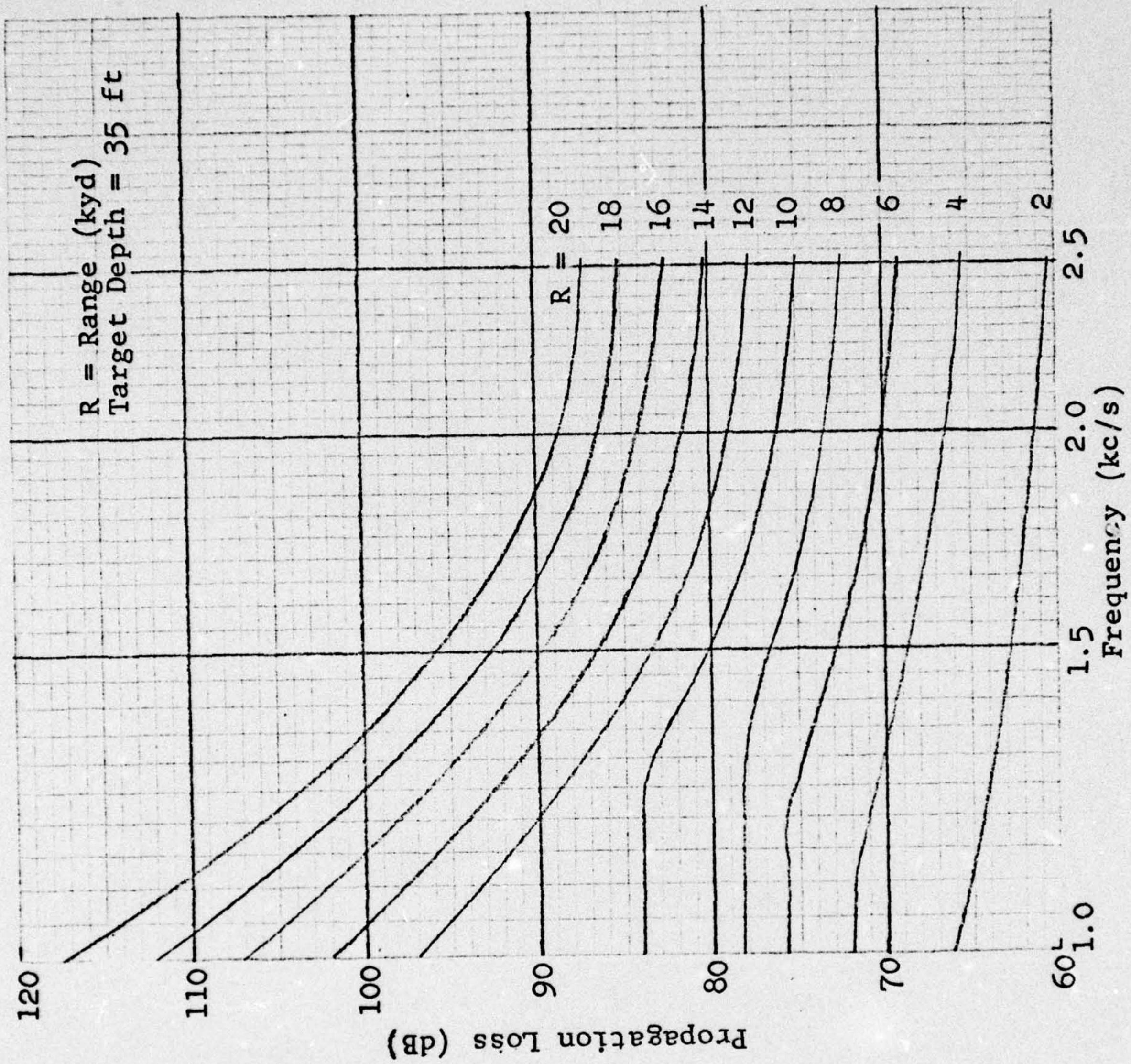

Figure III(a) PROPAGATION LOSS FOR TARGET IN 100 ft LAYER

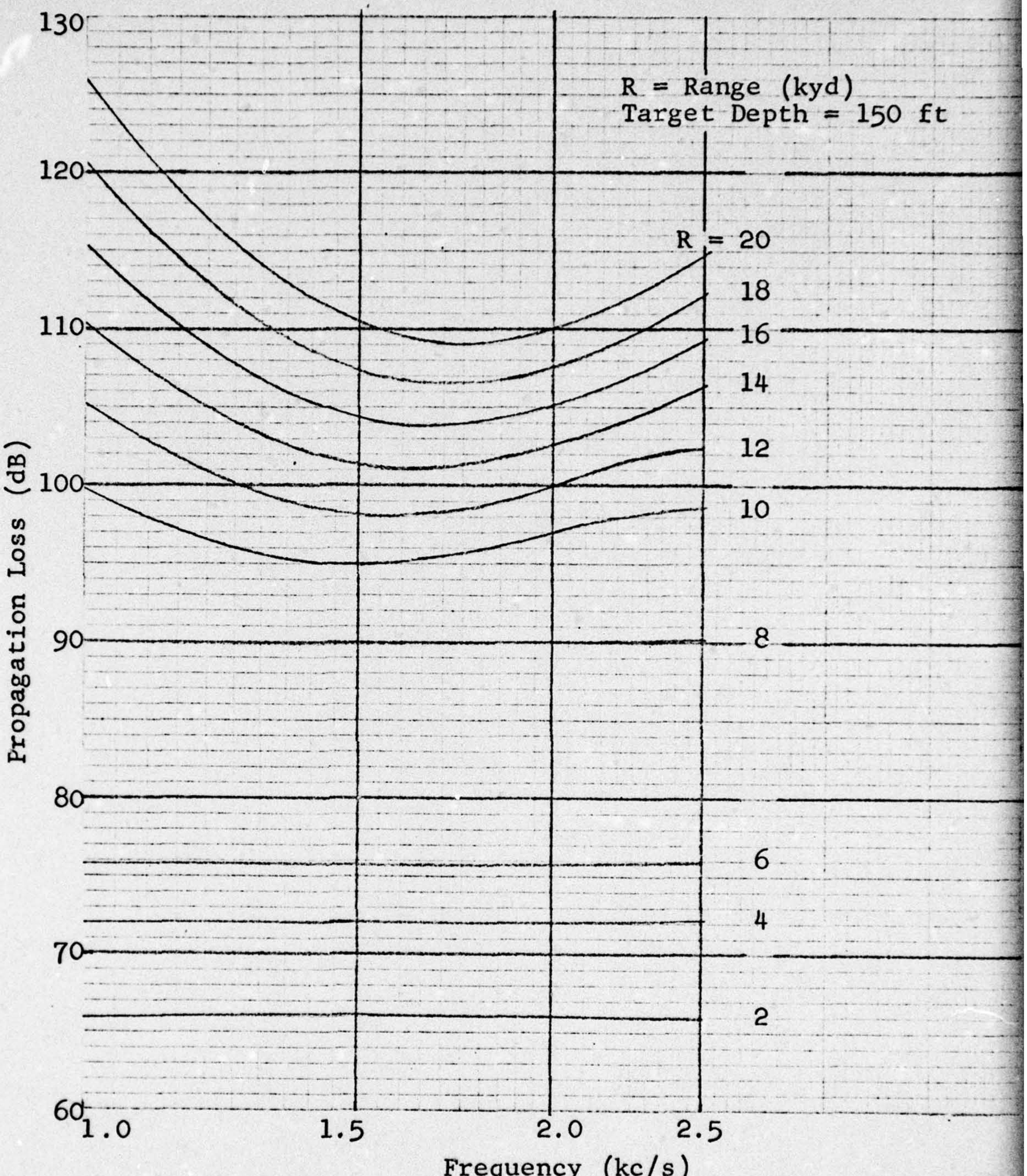

Figure III(b) PROPAGATION LOSS FOR TARGET BELOW 100 ft LAYER

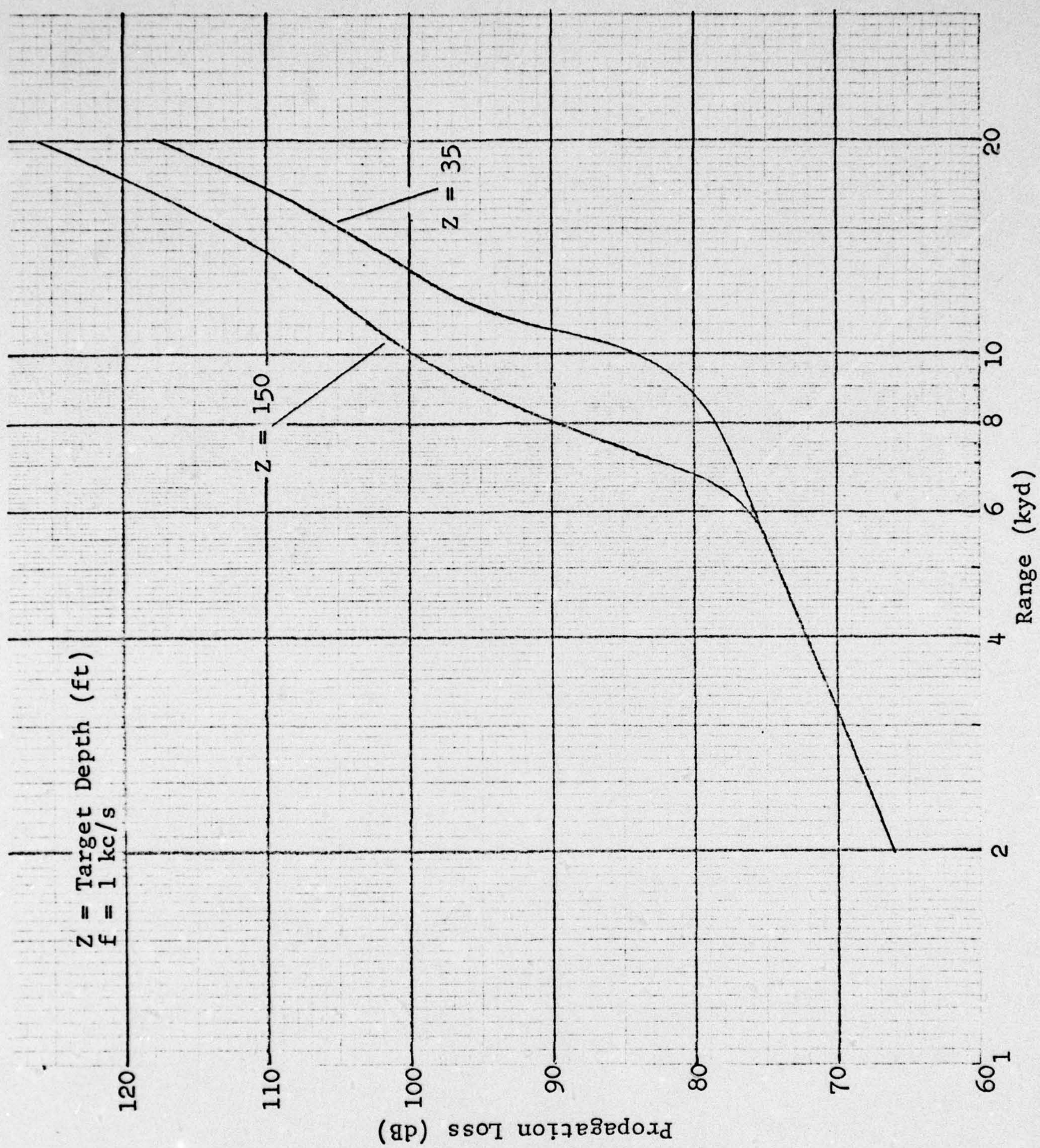

Figure III(c) PROPAGATION LOSS FOR 100 ft LAYER ENVIRONMENT

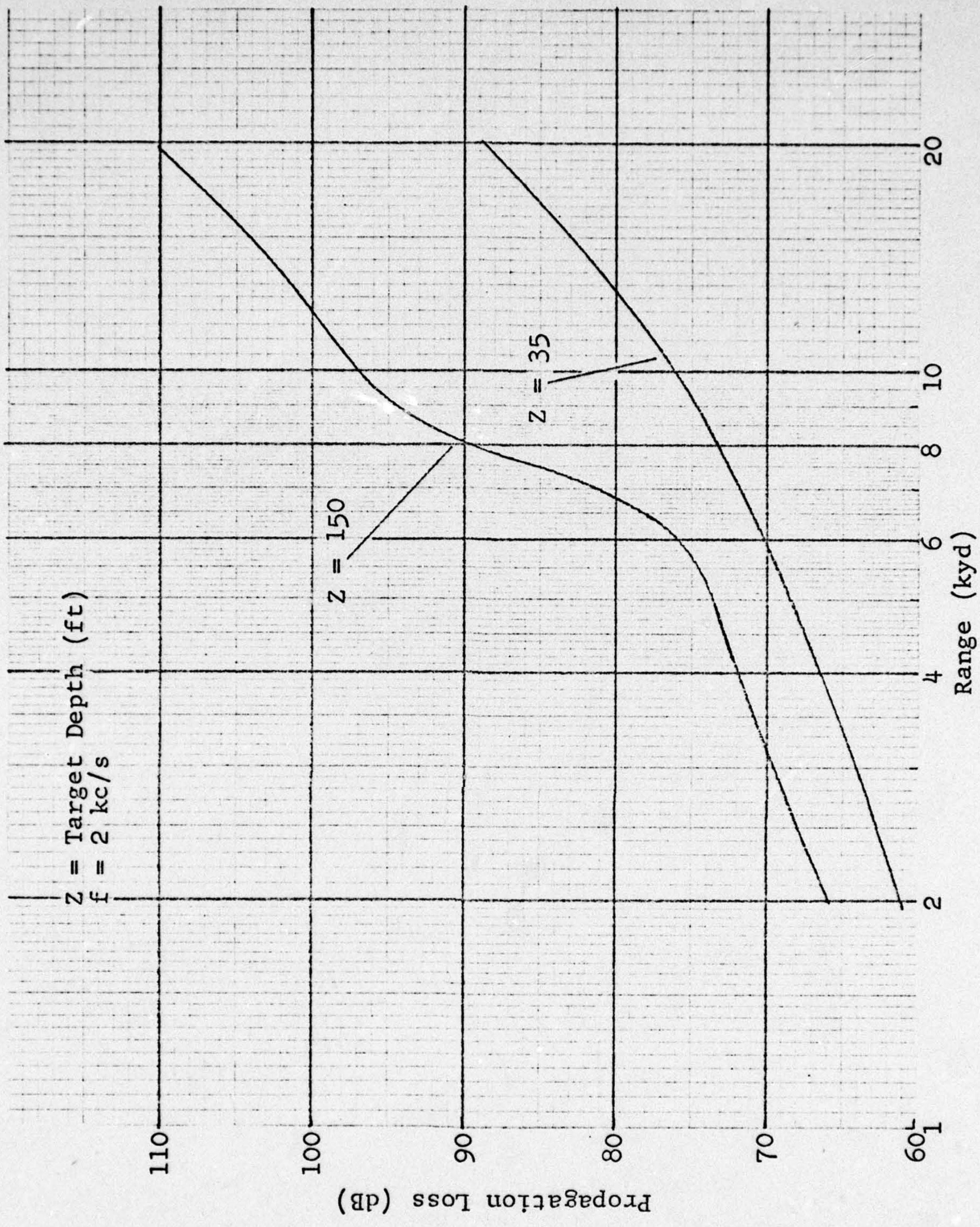

Figure III(d) PROPAGATION LOSS FOR 100 ft LAYER ENVIRONMENT

The continuous component of each target spectrum is shown in Figure III(e). Figure III(e) and the following signal spectrum information were abstracted from the Final Report, Phase I, Submarine Improved Sonar System, 1 June 1965, Volume I (Confidential), pp. 4-37, written under NObsr 93135 by Raytheon, Portsmouth, R. I. Discrete frequencies are not shown in Figure III(e). However, in any given 1 kc band there are, in general, between 5 and 10 spectral lines with about 5 c/s width at power levels exceeding the continuous target spectral level by 5 to 25 dB. The discrete spectrum adds no more than about 3 dB to the power contained in the 1.5 kc/s band.

The background is assumed to be sea noise given in the Knudsen curves plus ship noise**, both of which have a spectral level slope of - 5 dB per octave in the region of interest. The prewhitening results in a flattening of the continuous target spectrum to a variation of $\pm$ 1.0 dB across the band.

B. The Predicted PADLOC Performance

Figure III(f)*** is a plot of the signal-plus-noise statistics at the output of the PADLOC processor plotted on a Gaussian grid. The threshold is in units of noise standard deviation expressed relative to the noise mean at the processor output. This form of plot was chosen because the plots corresponding to different values of input signal-to-noise ratios are almost parallel, approximately straight lines. At a selected threshold setting the noise alone marking probability can be read from the $\left(\frac{S}{N}\right)_{in} = -\infty$ curve; at this same threshold the

**Ship noise is estimated from relations taken from a personal communication from Dr. W. H. Watson, U. S. Navy Electronics Laboratory, San Diego, California.

***The preparation of this plot is described in Appendix II.

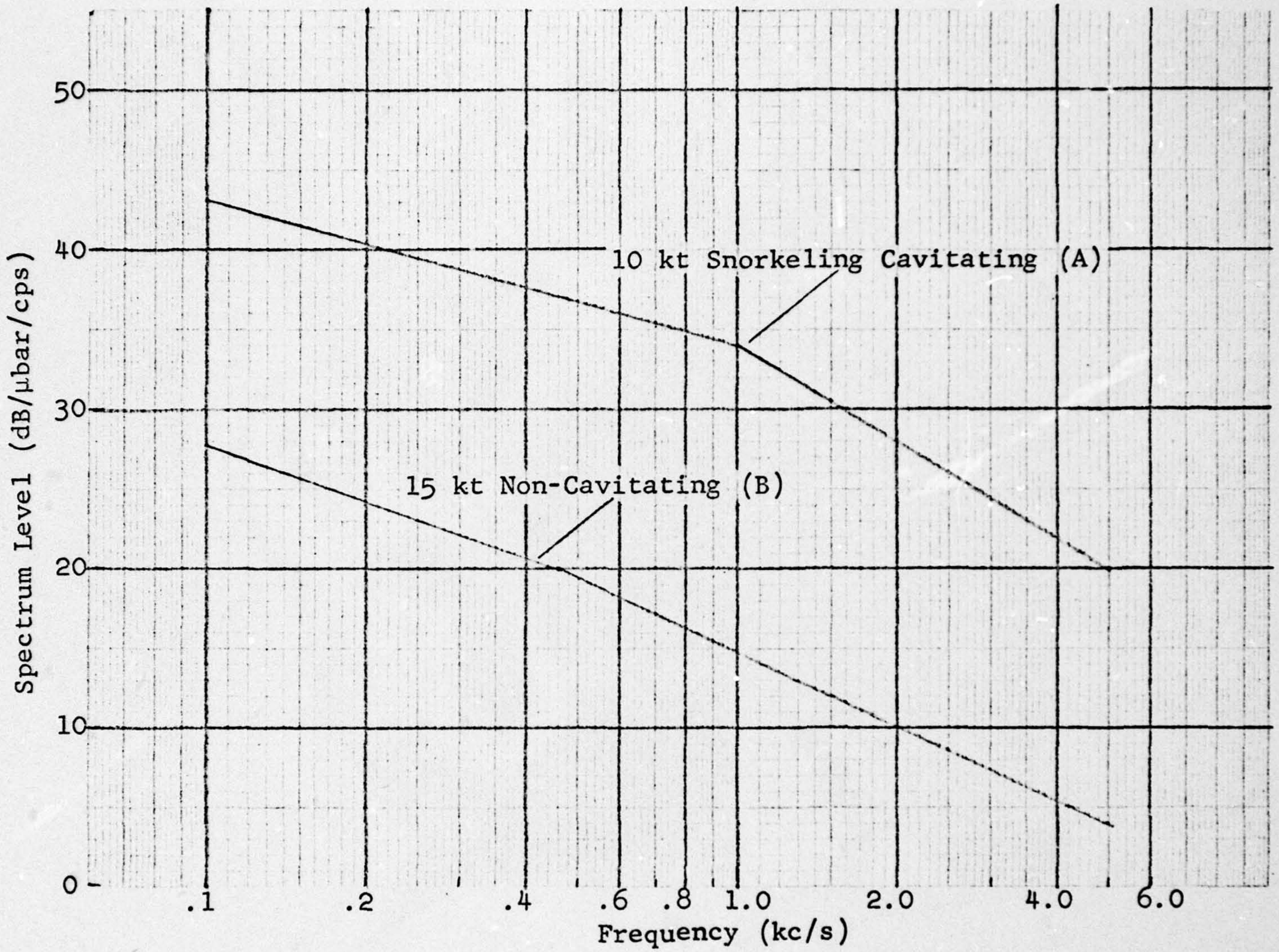

Figure III(e) SPECTRAL DENSITY OF TARGET SPECTRUM: CONTINUOUS COMPONENT

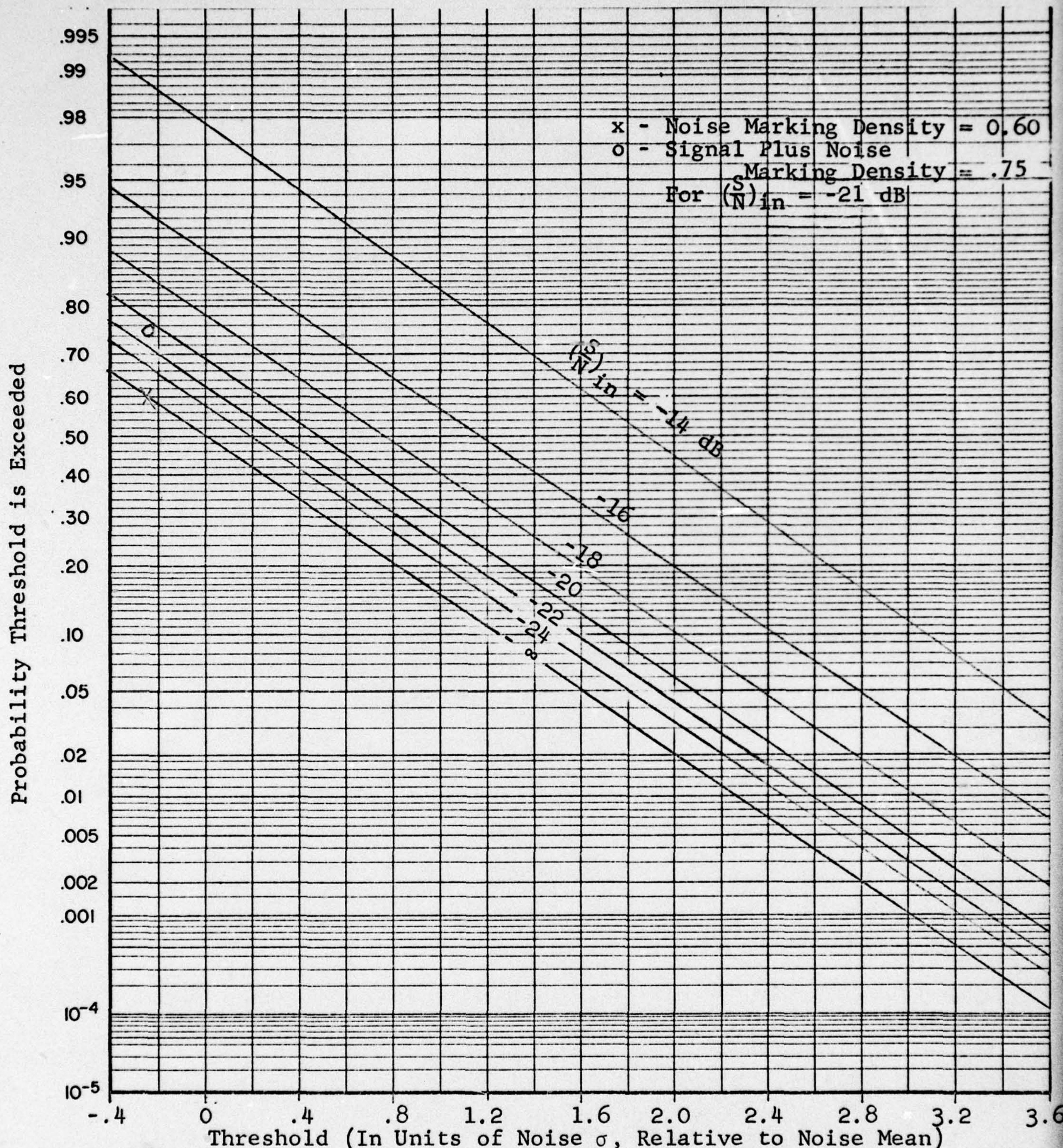

Figure III(f) PADLOC: OUTPUT SIGNAL PLUS NOISE STATISTICS signal-plus-noise marking probability as a function of each of the input signal-to-noise ratios can be read from the other curves.

Experiments* involving the graphic recorder have shown that best detection performance (maximum ratio of detection probability to false alarm probability) occurs when the noise marking density is 0.60. When this is the case, the signal detection probability rises from almost zero detection probability to unity detection probability when the signal-plus-noise marking density passes through 0.75. The false alarm probability under these conditions is <0.02.

With this result Figure III(f) can be used to determine the PADLOC input signal-to-noise ratio (per array) at which 0.50 probability of noting a target track can be attained. The 0.60 noise marking density is shown by the x in Figure III(f). At the same threshold value the 0 shows the 0.75 signal-plus-noise marking density on the curve marked $(\frac{S}{N})_{in} = - 21$ dB. Presumably the operator can recognize a target track with 0.50 probability when each array provides a - 21 dB signal-to-noise ratio at the output of one of its beams. The minimum detection level for PADLOC will therefore be assigned the value - 21 dB. It is attained with the false track probability less than 0.02.

The detection ranges for the passive system (PADLOC) were determined using Figure III(g). In these plots the noise level is shown. Overlaid is the target band level at the processor input for targets A and B at 35 feet average depth and 150 feet average depth. The dashed lines are the signals levels required for 0.50 detection probability for the multiping history. It is seen that the PADLOC detection range for the noisy in-layer target is about 19.5 kyd (the intersection of the

*B. H. Deatherage, "Conclusions and Recommendations from a Psychophysical Study of the Relative Detectability of Target Tracks in Simulated Passive Sonar Displays." A summary report prepared under Contract NObsr 89265, TRACOR Document Number 63-231-U, 6 September 1963.

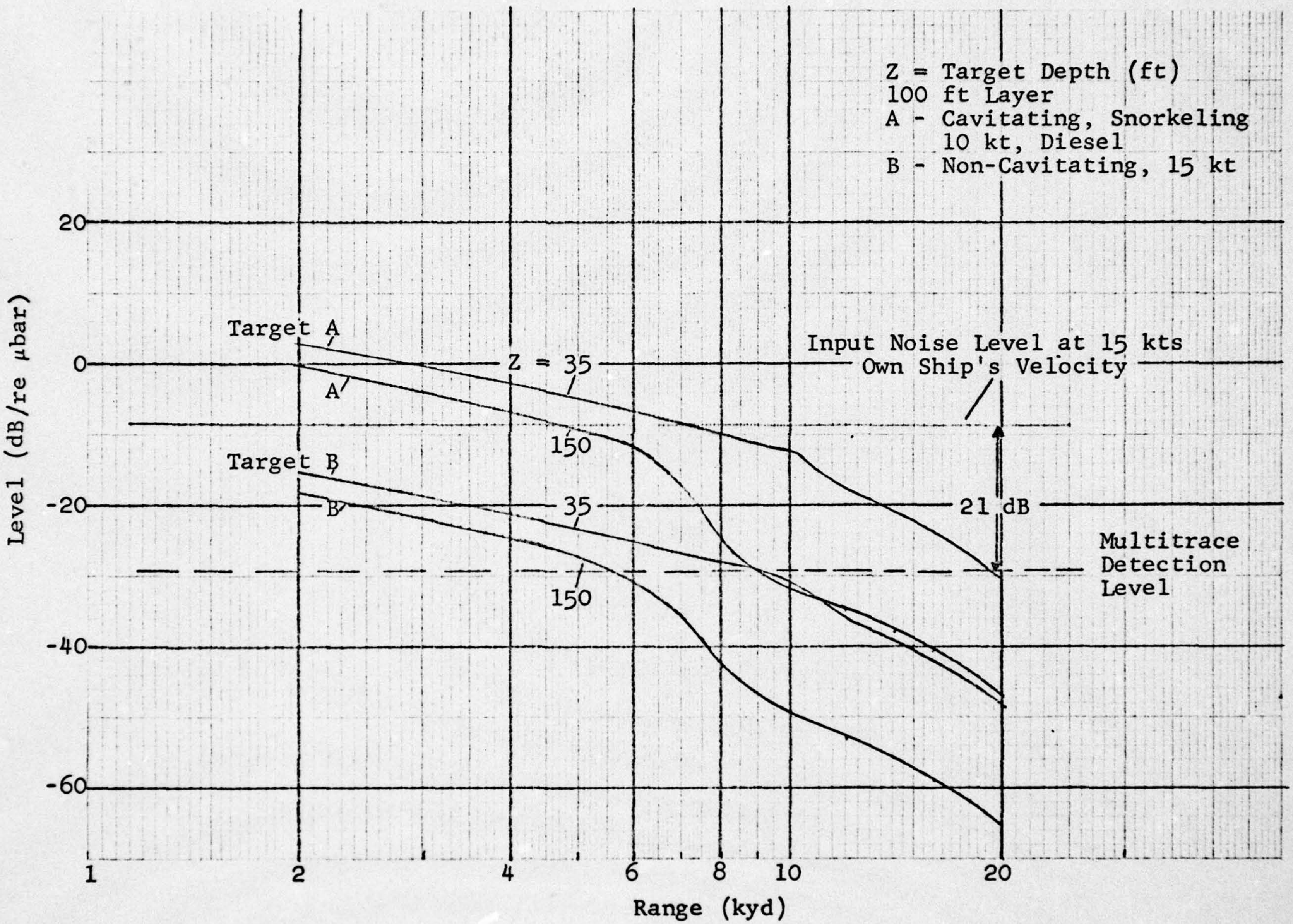

Figure III(g) PADLOC EXPECTED PERFORMANCE target level at 35 ft depth and the multitrace detection level line). The quiet in-layer target can be detected to 9.3 kyd. These ranges would correspond to the predicted performance with an alerted operator. If the operator is unalerted the estimated performance is found by raising the detection level line by about 3 dB. If this is done the detection ranges become 18 kyd and 8 kyd.

C. A Modified PADLOC

It is interesting to consider the performance which would be expected from a PADLOC system in which a single receiving array is employed instead of two arrays. One implementation of this system would involve splitting the transducer into two halves and cross correlating the outputs of the two halves with all the delays equivalent to the delay of arrivals from 24 bearings. The remainder of the system would be identical to that used in the PADLOC of Section B. To a first approximation the performance of this "modified" PADLOC can be determined by decreasing all the signal levels in Figure III(g) by 3 dB. This shift in level is caused by the splitting of the signal energy from a single dome into two parts. If this is done, the in-layer, noisy target alerted detection range will drop from 20 kyd to 18 kyd. The in-layer, quiet target detection range will drop from 9.3 kyd to 7.3 kyd. The ratio of maximum detection range of PADLOC to the maximum detection range of the modified PADLOC for the below-layer targets are quite similar, 1.1 for the A target and 1.2 for the B target.

This is the very best performance which can be expected from the "modified" PADLOC. Further reduction in performance will be caused if the noise field is not isotropic or if the separation of array halves does not significantly exceed the wavelength at the low end of the passive band. Because this last requirement is not satisfied it is likely that the relative noise level at the output of the correlator

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is at least 3 dB higher than would be found with the double array system. The decrease in signal excess caused by both these effects is therefore estimated at 6 dB. The DESDEVGRU II* report gives 8 dB as an observed estimate of this decrease in signal-to-noise ratio. The effect of the higher noise level can be determined by raising the noise level in Figure III(g) by 3 dB. The estimated changes in detection ranges resulting from the use of a single array are given in Table III(a). The ratios were computed using corresponding values in the second and third column.

TABLE III(a)

	PADLOC Range (kyd) (Two Dome)	Modified PADLOC Range (kyd) (Single Dome, Split Array)	Ratio
A at 35 ft	19.5	16	1.22
B at 35 ft	9.3	5	1.87
A at 150 ft	9.2	7.7	1.19
B at 150 ft	6.3	3.7	1.77

The range ratios (PADLOC/Modified PADLOC detection range) are about 1.2 for Target A and about 1.8 for Target B.

D. The Predicted Passive Performance of the AN/SQS-23

Figure III(h) is a plot showing the signal-plus-noise statistics of the AN/SQS-23 in the passive mode. To a good approximation the passive system passes narrow band Gaussian noise. The signal which emerges from the 370 c/s input filters is narrow band Gaussian as well. The beams are sampled in turn, rectified and averaged over a few cycles of carrier. The probability $P(0,\zeta)$ that an independent sample of noise will exceed

*DESDEVGRU II, loc. cit.

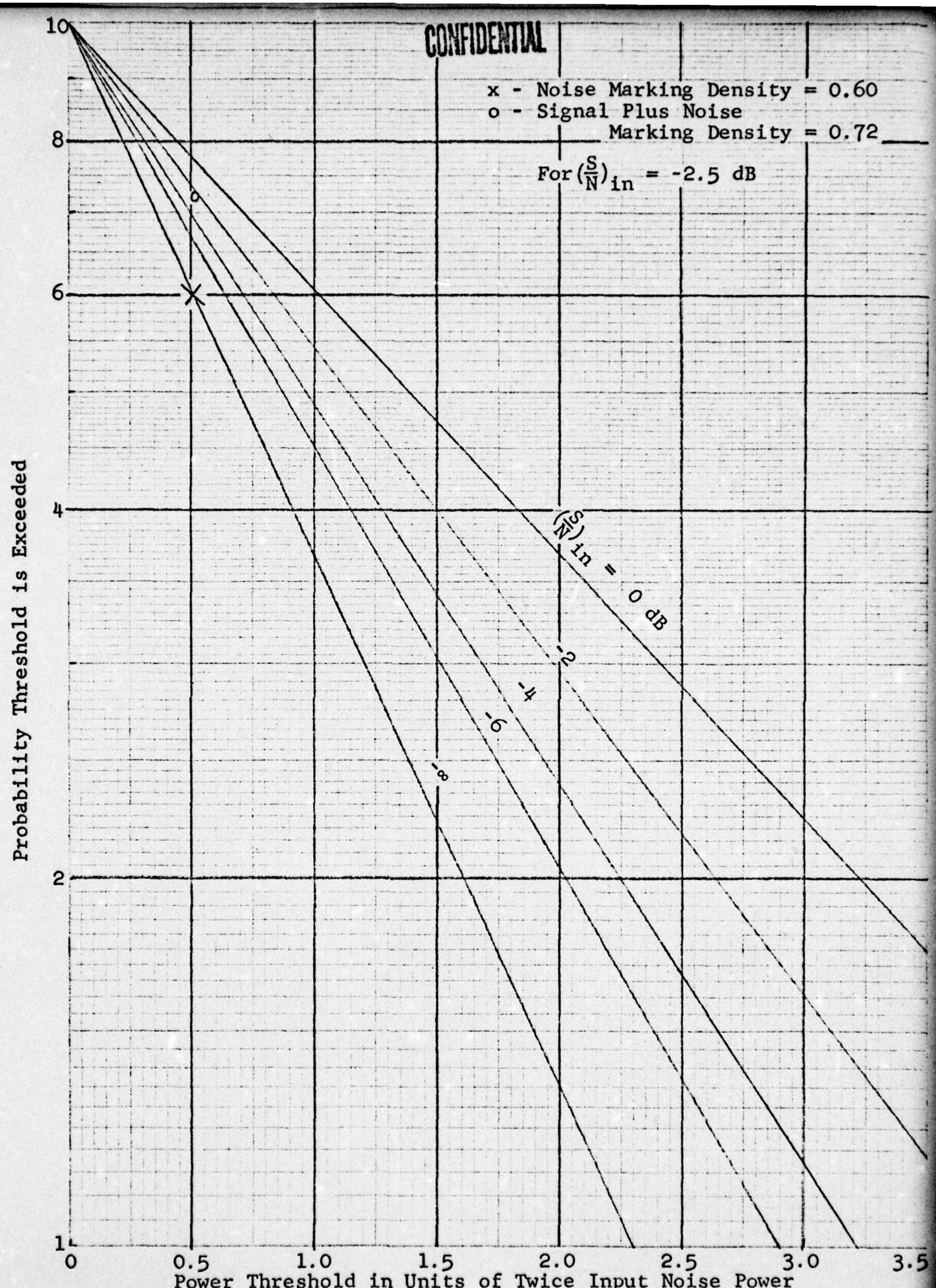

Figure III(h) SCANNER: OUTPUT SIGNAL PLUS NOISE STATISTICS a preset threshold ζ is

$$P(0,\zeta) = e^{-\frac{\zeta^2}{2N}},$$

where N is the time average noise power observed at the output of a single beam. All of the beams not containing signal may be described with this function. The probability $P(\frac{S}{N},\zeta)$ that an independent sample of signal-plus-noise will exceed the same threshold ζ is

$$P(\frac{S}{N},\zeta) = e^{-\frac{\zeta^2}{2N(1+S/N)}},$$

where S is the average signal power at the output of the beam containing signal. Plots of these distributions are shown for a few values of signal-to-noise ratio at the input to the display.

As in the example with PADLOC, it is expected that the beam containing the signal is most obserable when the beams which do not contain signal provide a marking density of 0.6 and when the signal-plus-noise marking density exceeds 0.72. The point x in Figure III(h) shows the threshold for 0.6 noise alone marking density on the curve labeled $(\frac{S}{N})_{in} = -\infty$. The signal -plus-noise marking density of 0.72 occurs at the same threshold when the signal-to-noise ratio at the display input is -2.5 dB. It follows that the probability of noting the presence of a beam containing a target will exceed 0.50 when the display input signal-to-noise ratio exceeds -2.5 dB. The minimum detection level of the AN/SQS-23 passive receiver with an alerted operator will therefore be assigned the value -2.5 dB. Presumably the false track probability is comparable to the 0.02 observed with the graphic recorder display.

Figure III(i) shows a set of curves for determining the detection ranges for the AN/SQS-23 passive system.

The input noise level is shown for the passive system as well as the signal levels for both the A and B targets at average depths Z = 35 ft and Z = 150 ft. The target source strengths were taken from Figure II(e) and the propagation loss was taken from the values obtained in the active study under Task 21*. The minimum detection level (shown dashed) is 2.5 dB below the noise level. The ranges at which the target level intersects the dashed line are the detection ranges expected for the targets at the depths 35 ft and 150 ft. The in-layer, noisy target can be detected by the AN/SQS-23 passive receiver to 14 kyd. The quiet in-layer target can be detected to 4.4 kyd. These ranges are those expected in an alerted operator test. If the detection level is raised 3 dB, results will be nearer to the performance observed with a non-alerted operator. The detection ranges under these conditions become 11.5 kyd and 3.1 kyd.

IV. SUMMARY OF RESULTS

A summary of the predicted detection ranges for PADLOC and the passive AN/SQS-23 are shown in Table IV(a) for both targets and both depths in the 100 ft layer environment. The ratio of PADLOC to the AN/SQS-23 detection range is included to facilitate comparison. Detection ranges for PADLOC are comparable to those obtainable with the active PAIR system. Signal excesses of 5 dB or more are available over 60 to 80% of the range interval less than maximum detection range. The predicted detection ranges for the AN/SQS-23 passive system are less than those found for the PADLOC but both performances are satisfactory for in-layer targets. The comparison is distinctly more favorable for PADLOC for below-layer targets.

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* Task 21, NEL Letter Report, loc. cit.

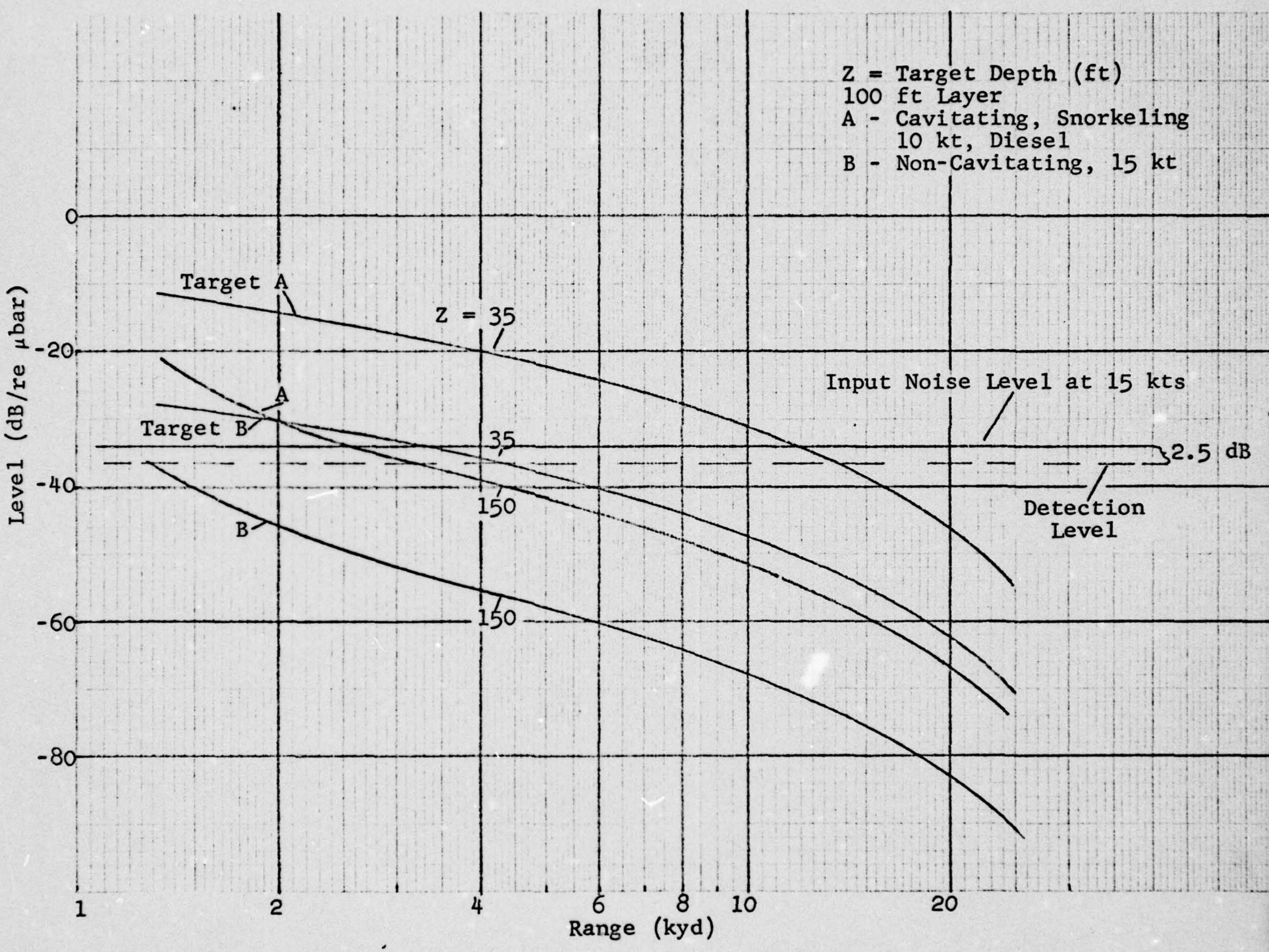


Figure III(i) AN/SQS-23 PASSIVE PERFORMANCE

TABLE IV(a)

PASSIVE DETECTION RANGES (KYD)
DEEP WATER, 100 FT LAYER
(ALERTED OPERATOR)

	TARGET	PADLOC	AN/SQS-23	RATIO
Z = 35 ft	A	19.5	13	1.5
	B	9.3	4.3	2.1
Z = 150 ft	A	9.2	3.2	2.9
	B	6.3	1.3	4.9

The DESDEVGRU II tests referred to in the introduction are in overall agreement with the predicted ranges for noisy, in-layer targets using the PADLOC system. The layer depths in the simulation and those available during the tests were not the same but the observed 20 to 30 kyd detection ranges for noisy targets with 200 to 300 ft layers is consistent with 20 kyd detection ranges in 100 ft layers.

The observed quiet target detections were found in a range of 2 to 20 kyd with the PADLOC for 200 to 300 ft layers. The predicted detection range is around 9 kyd. The model used in the prediction does not provide the great variability found in the sea trials. Only partial comfort is found in the average value (~ 9 kyd) agreement.

The observed performance of the passive AN/SQS-23 is generally significantly better than is predicted by the prediction model when the AN/SQS-23 system is turned off. The performance of the AN/SQS-23 passive system when the active system is turned on is very inferior to the PADLOC system when the AN/SQS-23 active system is on.

R. D. Vachon* points out that the present comparison was made with the continuous spectrum of radiated noise and that the shorter integration time in the AN/SQS-23 passive system may provide this system with a capability for detecting transients in the target signal which the PADLOC does not have. If this capability serves to alert the operator to a particular bearing, the AN/SQS-23 performance would be significantly upgraded.

*R. J. Vachon, U. S. Navy Electronics Laboratory (Personal Communication).

APPENDIX I

PARAMETERS USED IN PREDICTION MODELING

A. ENVIRONMENT

Velocity Profile

Depth (ft)	Velocity (fps)
0	4978
100	4979.8
400	4889
920	4897.5
1200	4915
8400	4992.5

Surface water temperature 60°F

Layer depth 100 ft

Surface velocity 4978 fps

Gradient in layer .018 fps/ft

Gradient below layer -.333 fps/ft

Wave height 3 ft

Wind velocity 10 kts

Own ship's speed 15 kts

Attenuation coefficient $.0012\ f + .006\ f^2$ dB/kyd where

f = frequency kc/s

B. SYSTEM

Directivity Index

PADLOC	14 dB
AN/SQS-23	23 dB

APPENDIX II

THE PADLOC SIGNAL-PLUS-NOISE STATISTICS

The signal-plus-noise statistics curves of the output of the PADLOC were prepared using Figure 11 from information given in TRACOR Document 66-220-C "The Determination of the Performance Curves for the PAIR Processor." This curve is reproduced in this appendix. The left side of the page shows the threshold (TH) necessary to provide the clutter probability shown along the horizontal axis. The threshold is plotted in logarithmic units (20 log TH) and represents the number of dB the threshold is above the noise standard deviation at the processor output. This entire curve is the $\frac{S}{N} = -\infty$ curve in Figure III(f).

In Figure 11 the curve at the right is the "processing gain" curve of the PADLOC temporal processor. It shows output signal-to-noise ratio (20 log $\frac{p-\mu}{\sigma}$, there p is peak signal output, μ is the mean noise output, and σ is the noise standard deviation) as a function of input signal-to-noise ratio (average signal to average noise ratio). The output signal-to-noise ratio is determined by the average size of the output signal peaks measured in many samples of noise. Since the output distribution is Gaussian the median and mean occur at the same value. It follows that the output signal-to-noise ratio equal to 20 log TH, corresponding to the threshold (TH) used in the determination of display marking, is the output signal-to-noise ratio which will provide 0.50 probability that signal-plus-noise will mark the display. The curves representing the signal-plus-noise statistics in Figure III(f) must therefore pass through 0.50 probability at the threshold value (TH) determined by

$$20 \log TH = (\frac{S}{N})_{out}$$

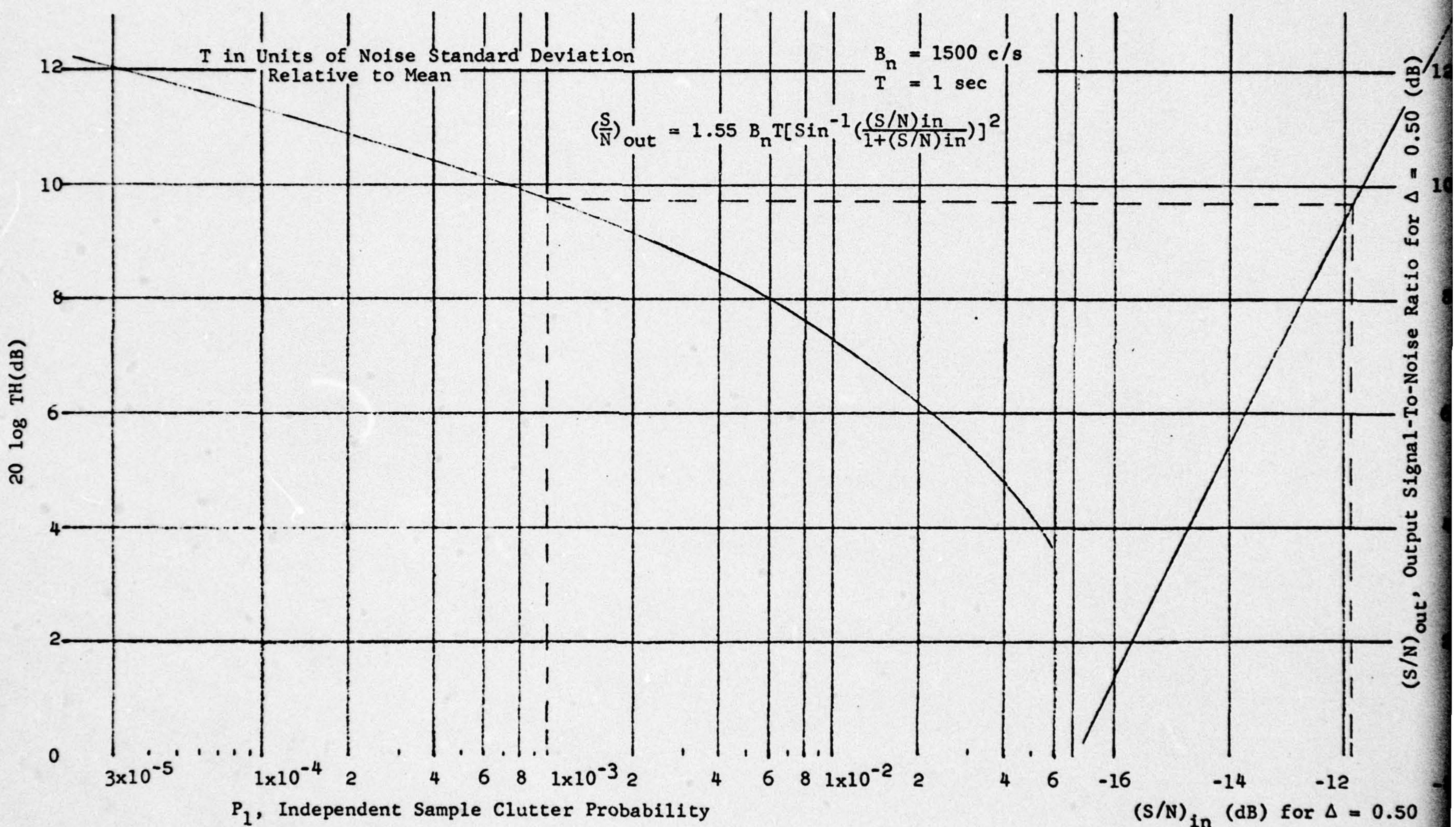
read from Figure 11. Straight lines are then drawn through these points parallel to the $(\frac{S}{N}) = -\infty$ curve and these curves approximately represent the signal-plus-noise probabilities of exceeding threshold. They are labeled with the input signal-to-noise ratios read from Figure 11, corresponding to the output signal-to-noise ratios used in determining the thresholds. Strictly speaking these curves are not parallel because their standard deviations are not quite equal. The intersections with 0.50 probability of marking are separated from the noise mean by $\sigma_o \sqrt{[S/N]_{out}}$ while the standard deviations are

$$\sigma^2 = \sigma_o^2 \left(1 + \left[\frac{S}{N}\right]_{out}\right),$$

where σ is the signal-plus-noise standard deviation, σ_o is the noise standard deviation, and $\left[\frac{S}{N}\right]_{out}$ is the output signal-to-noise ratio. The bracket denotes that the power ratio is required not the dB representation. For -7 dB output signal-to-noise ratio (-20 dB input) the noise mean is $\sim$0.5 units from the mean while the slope ratio of the -20 dB curve relative to the noise curve is

$$\frac{\sigma}{\sigma_o} = \sqrt{1 + [.20]} = 1.09.$$

The curves as drawn, omitting the slope change, introduce less than 0.5 dB error in the estimation of minimum detection level or 0.02 error in the marking probability.



TRACOR Document 66-220-C "The Determination of the Performance Curves for the PAIR Processor" Figure 11 PADLOC DETECTION NOMOGRAPH

Document Number
TRACOR 66-421-C

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ADDENDUM TO

COMPARISON OF THE PASSIVE PERFORMANCE OF THE AN/SQS-23 AND THE PERFORMANCE OF THE PAIR PASSIVE SYSTEM

THE NEGATIVE GRADIENT CASE

August 2, 1966

Prepared by:

J. K. Beard

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I. INTRODUCTION AND SUMMARY

This addendum is a continuation of the comparison (referred to as Part I in this document) of the passive performance of the PAIR passive system (PADLOC) and the passive performance of the AN/SQS-23. In particular, this addendum provides the performance comparison in a negative gradient environment*.

The passive detection ranges for four target depths using two standard target signatures have been determined. The target signatures were described in Part I: Target A has radiated levels typical of a 10 kt, snorkeling, cavitating submarine. Target B has radiation levels like that expected from a quiet, 15 kt, non-cavitating submarine. These target signatures are used at all depths employed in the study as typical "noisy" and "quiet" submarine signatures.

The propagation losses were determined for PADLOC in the 1 kc/s to 2.5 kc/s frequency interval with the normal mode program of M. A. Pedersen**. The propagation losses were determined for the AN/SQS-23 passive system at 4.5 kc/s using the TRACOR normal mode program.

A summary of the performance comparison in the negative gradient environment follows.

1. The predicted PADLOC noisy target detection ranges are about 6 kyd; the predicted PADLOC quiet target detection ranges are about 3 kyd. The corresponding detection ranges obtained with the AN/SQS-23 passive system are about 3 kyd for the noisy target and 1.6 kyd for the quiet target.

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*Valuable assistance in obtaining input data for this report was provided by A. L. Rhiner of USNEL.

**M. A. Pedersen, U. S. Navy Electronics Laboratory, San Diego, California.

TRACOR, INC. 1701 Guadalupe St. Austin, Texas 78701

2. A summary of the predicted detection ranges is given in Table I.

TABLE I
NEGATIVE GRADIENT DETECTION RANGES (kyd)
(Gradient: -0.015 ft/sec/ft to 120 ft; -0.1 ft/sec/ft below 120 ft)

Target Depth (ft)	35	60	100	150
PADLOC:				
Noisy Target (A)	5.2	5.7	6.2	6.4
Quiet Target (B)	<2 kyd	2.4	2.8	3.1
AN/SQS-23 Passive:				
Noisy Target (A)	2.1	2.4	2.9	3.2
Quiet Target (B)	1.3	1.6	1.7	2.2
Detection Range Ratio: PADLOC/AN/SQS-23				
Noisy Target (A)	2.5	2.4	2.1	2.0
Quiet Target (B)	<1.5	1.5	1.6	1.4

II. PERFORMANCE

A. PADLOC

The propagation loss information provided by M. A. Pedersen of USNEL for the PADLOC passband was in the form of contours: Contours of constant propagation loss plotted on a depth-range grid. Contours for 80, 90, 95, 100 and 110 dB were provided at the frequencies 1.2, 1.7 and 2.3 kc/s. From these contours a plot showing attenuation as a function of range was prepared for each of the three frequencies and for four target depths. These plots are shown in Figures II(a) through II(d). The points shown lie on the computed contours. The intermediate points were obtained by drawing smooth curves through the computed points. The propagation loss at given range was determined for each of the three frequencies from Figures II(a) through II(d), and used to construct the curves of propagation loss as a function of frequency given in Figures II(e) through II(h).

The signal power in the PADLOC system bandwidth at the beamformer output is

$$S_{in} = \int_{f_L}^{f_H} S(f) \cdot H(f) \cdot W(f)\, df$$

where S_{in} is the signal power at the PADLOC processor input in the band limited by f_L and f_H, S(f) is the signal spectral density at the target, H(f) is the propagation loss, and W(f) is the +5 dB per octave prewhitening accomplished in the preamplifiers. The quantities S(f), H(f), and W(f) must be expressed numerically, rather than in dB, in this integral.

This integral was evaluated with the curves shown in Figures II(e) through II(h) for the two standard targets described

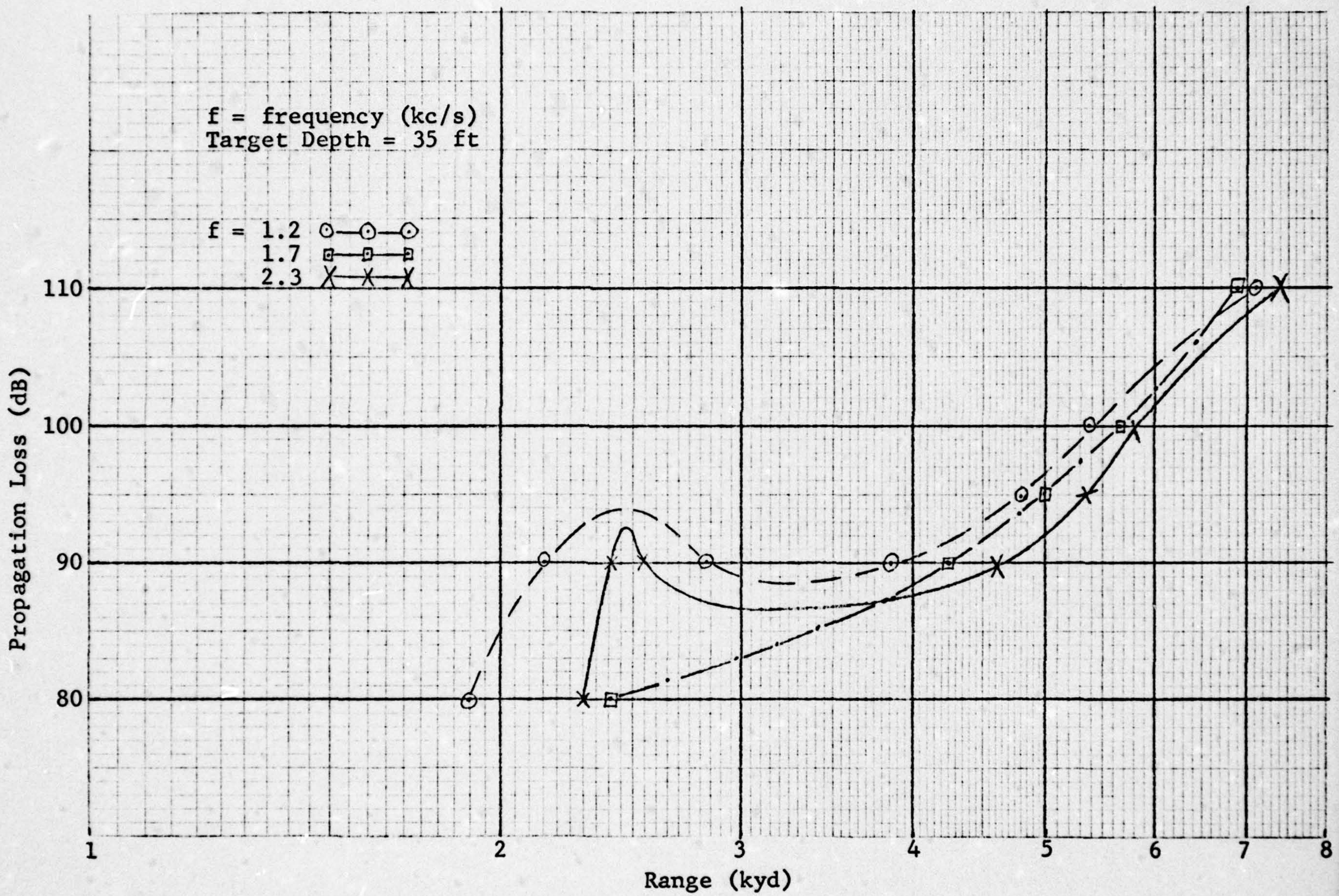

Figure II(a) PROPAGATION LOSS AS A FUNCTION OF RANGE

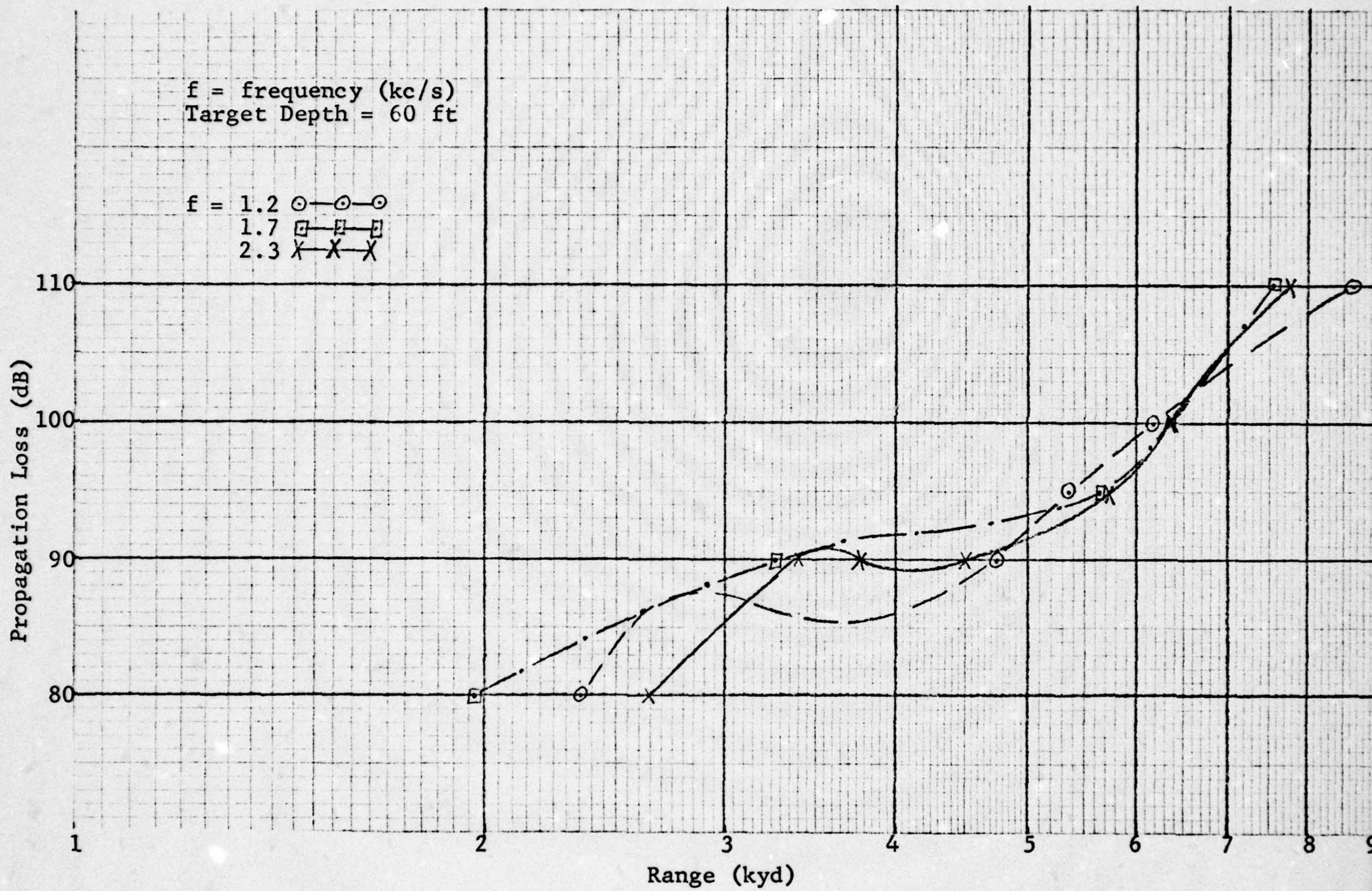

Figure II(b) PROPAGATION LOSS AS A FUNCTION OF RANGE

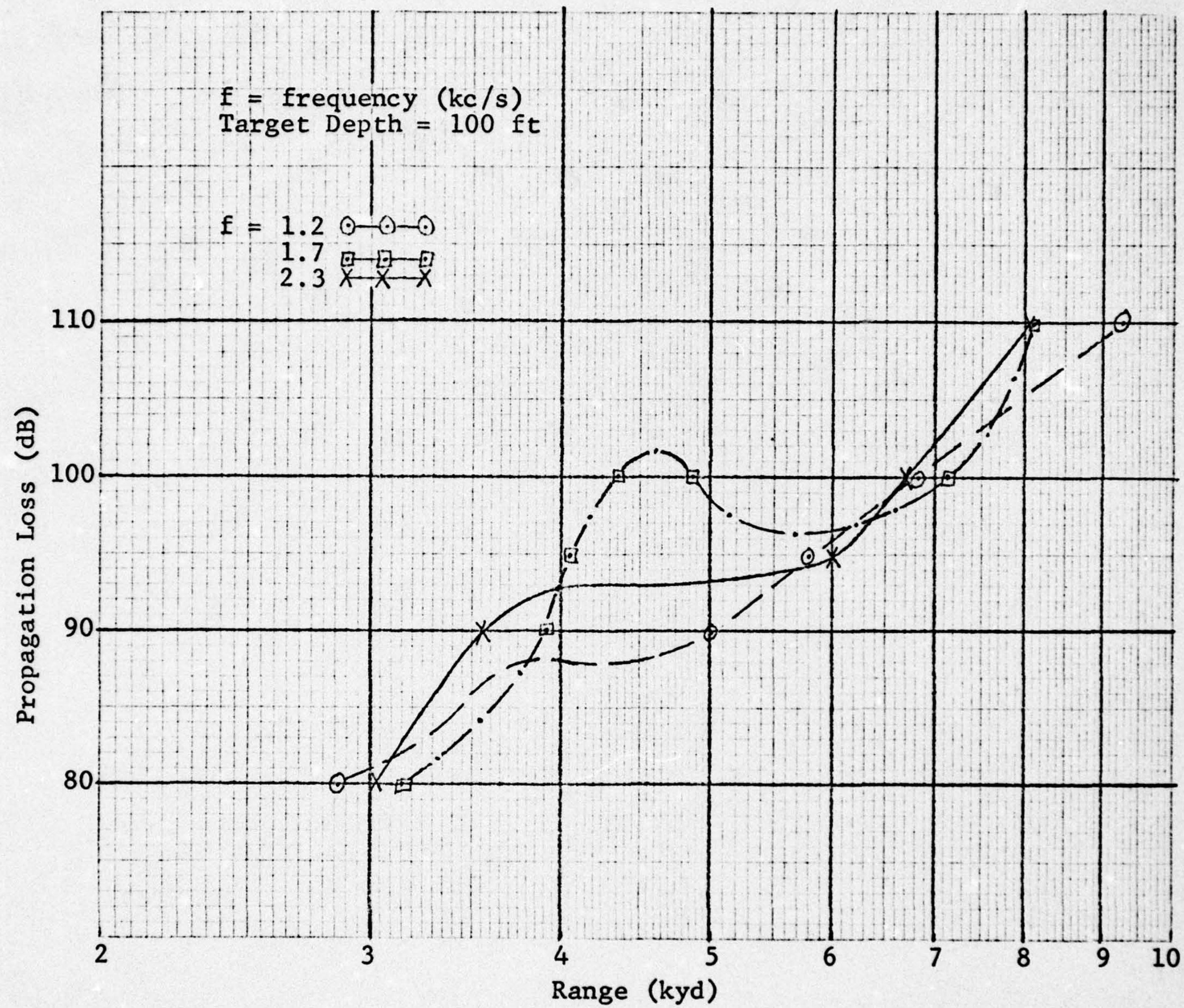

Figure II(c) PROPAGATION LOSS AS A FUNCTION OF RANGE

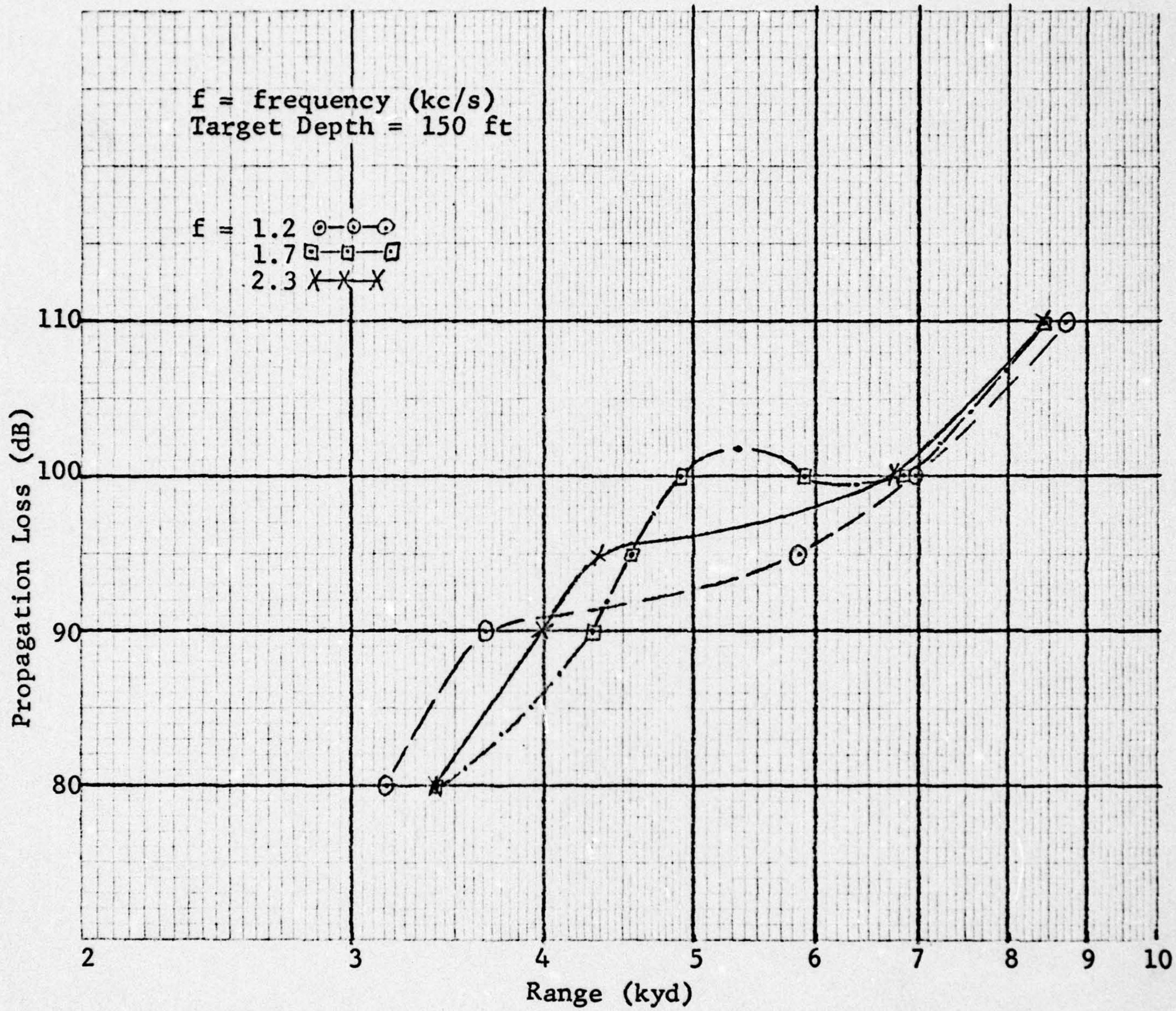

Figure II(d) PROPAGATION LOSS AS A FUNCTION OF RANGE

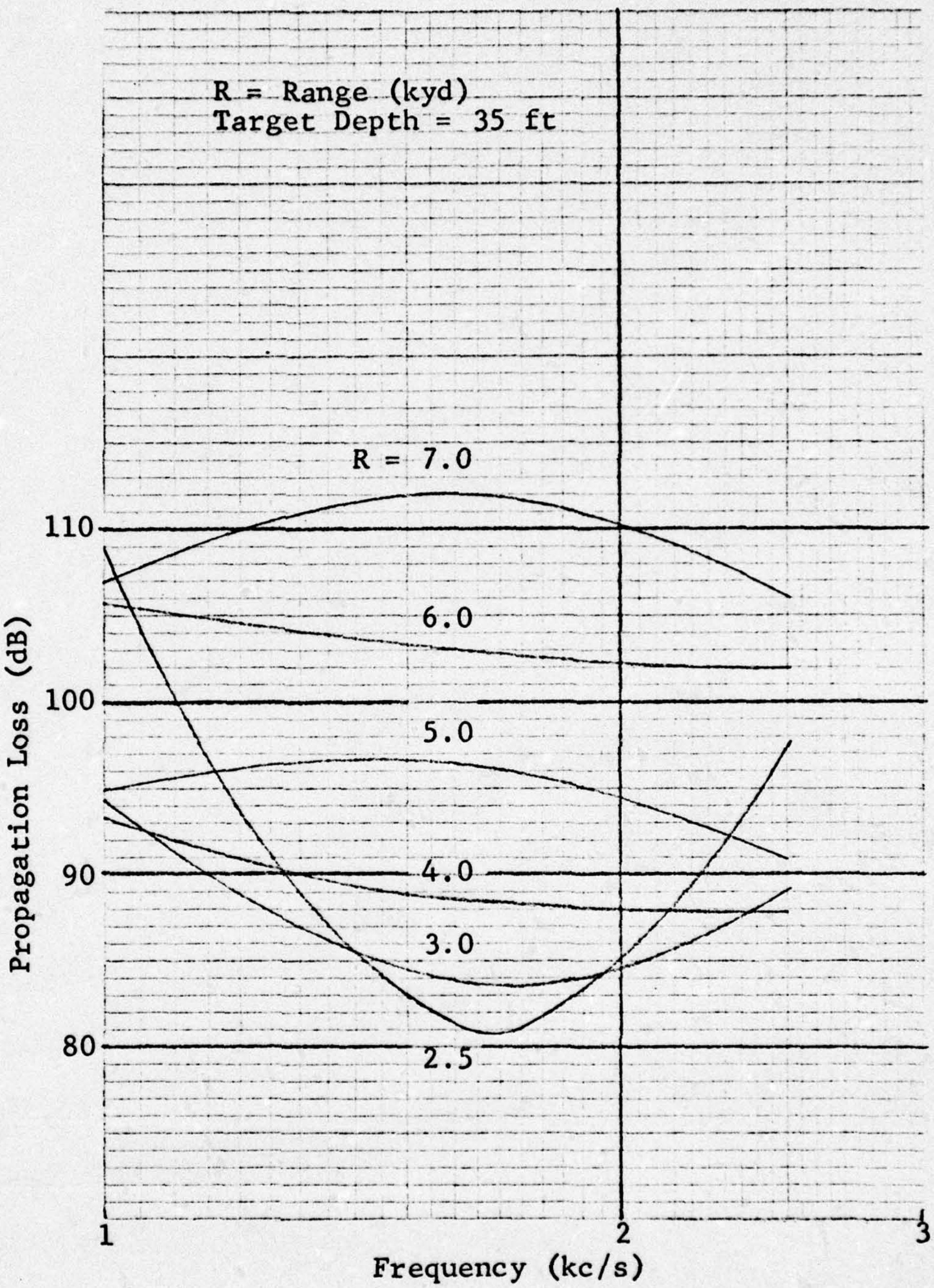

Figure II(e) PROPAGATION LOSS AS A FUNCTION OF FREQUENCY

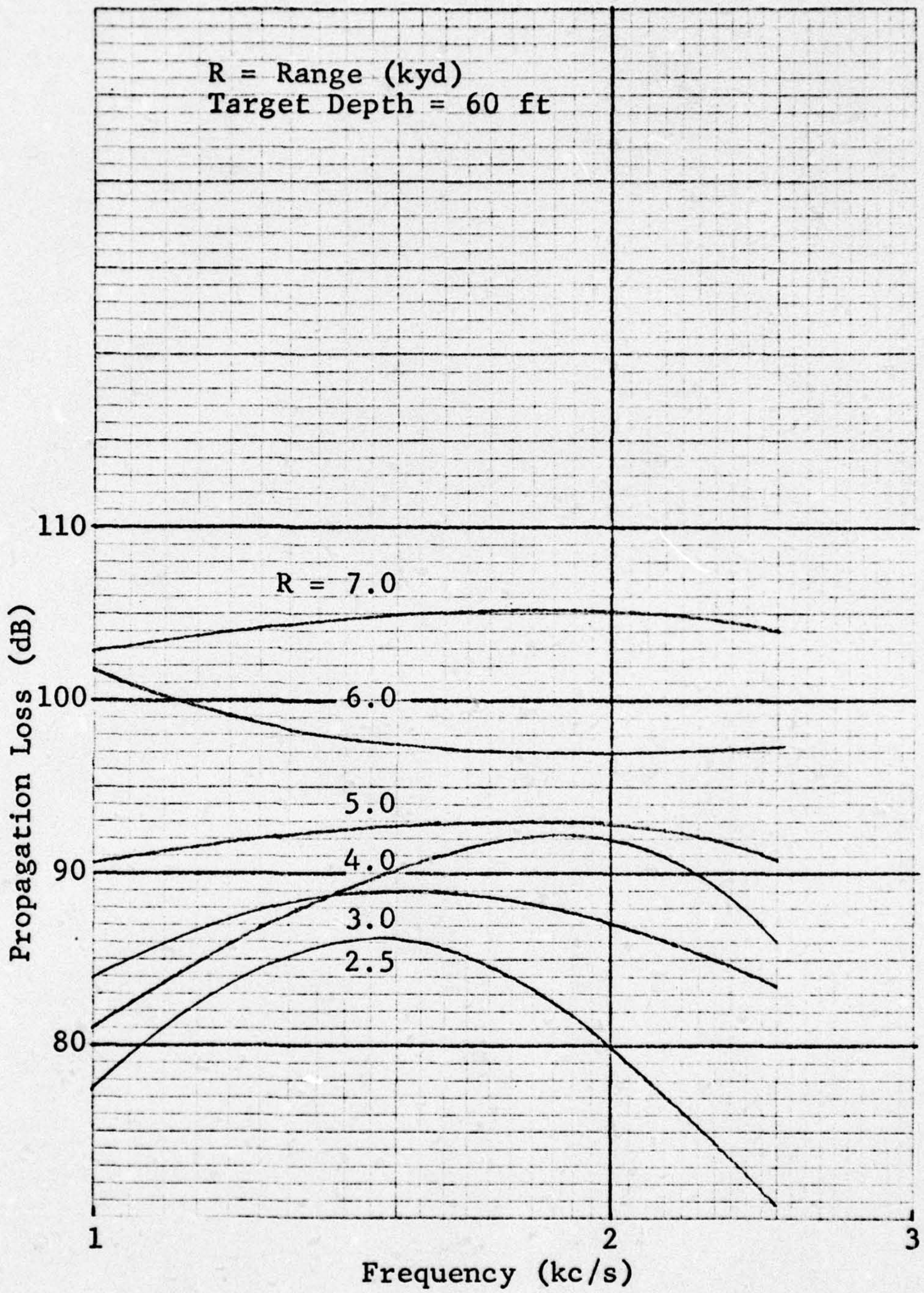

Figure II(f) PROPAGATION LOSS AS A FUNCTION OF FREQUENCY

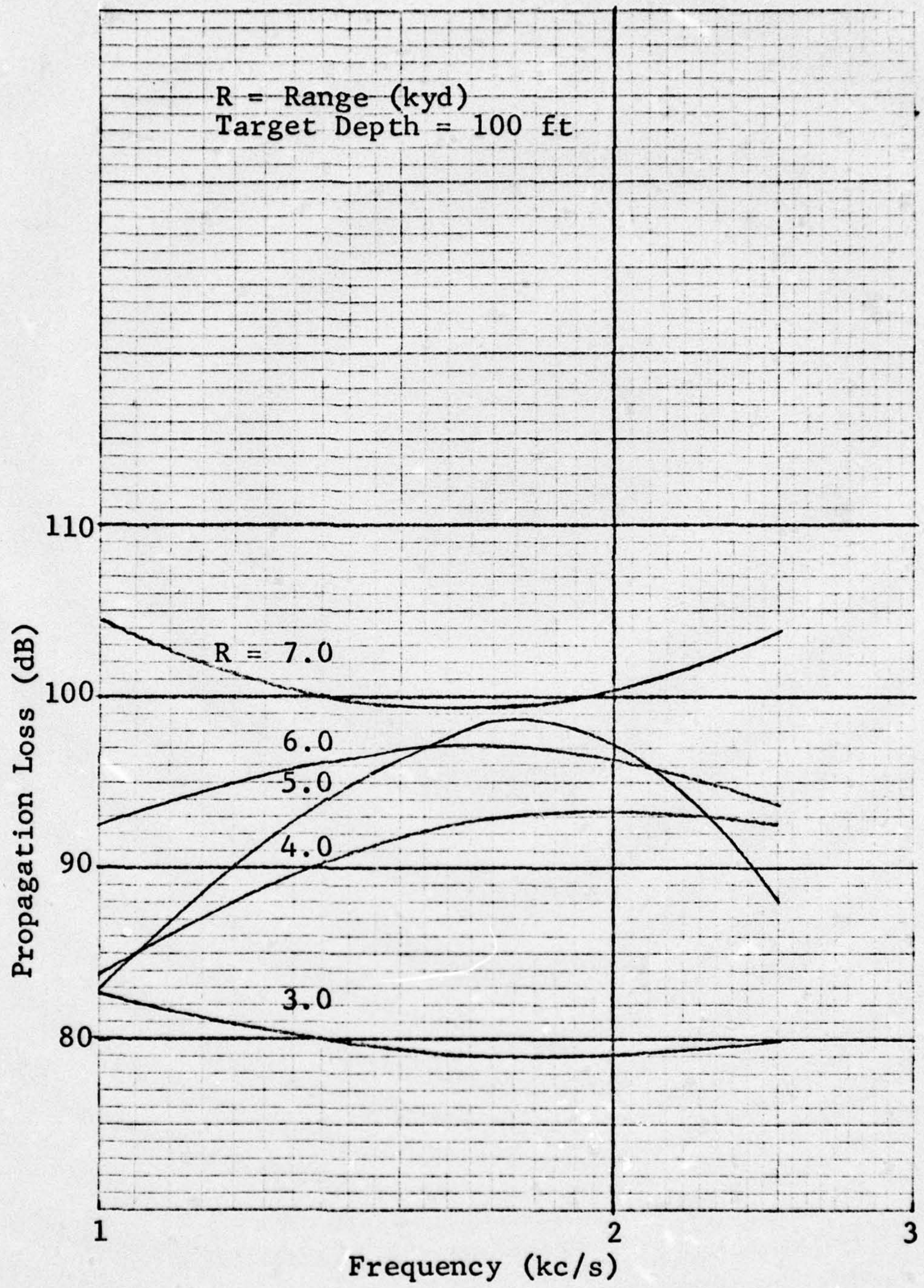

Figure II(g) PROPAGATION LOSS AS A FUNCTION OF FREQUENCY

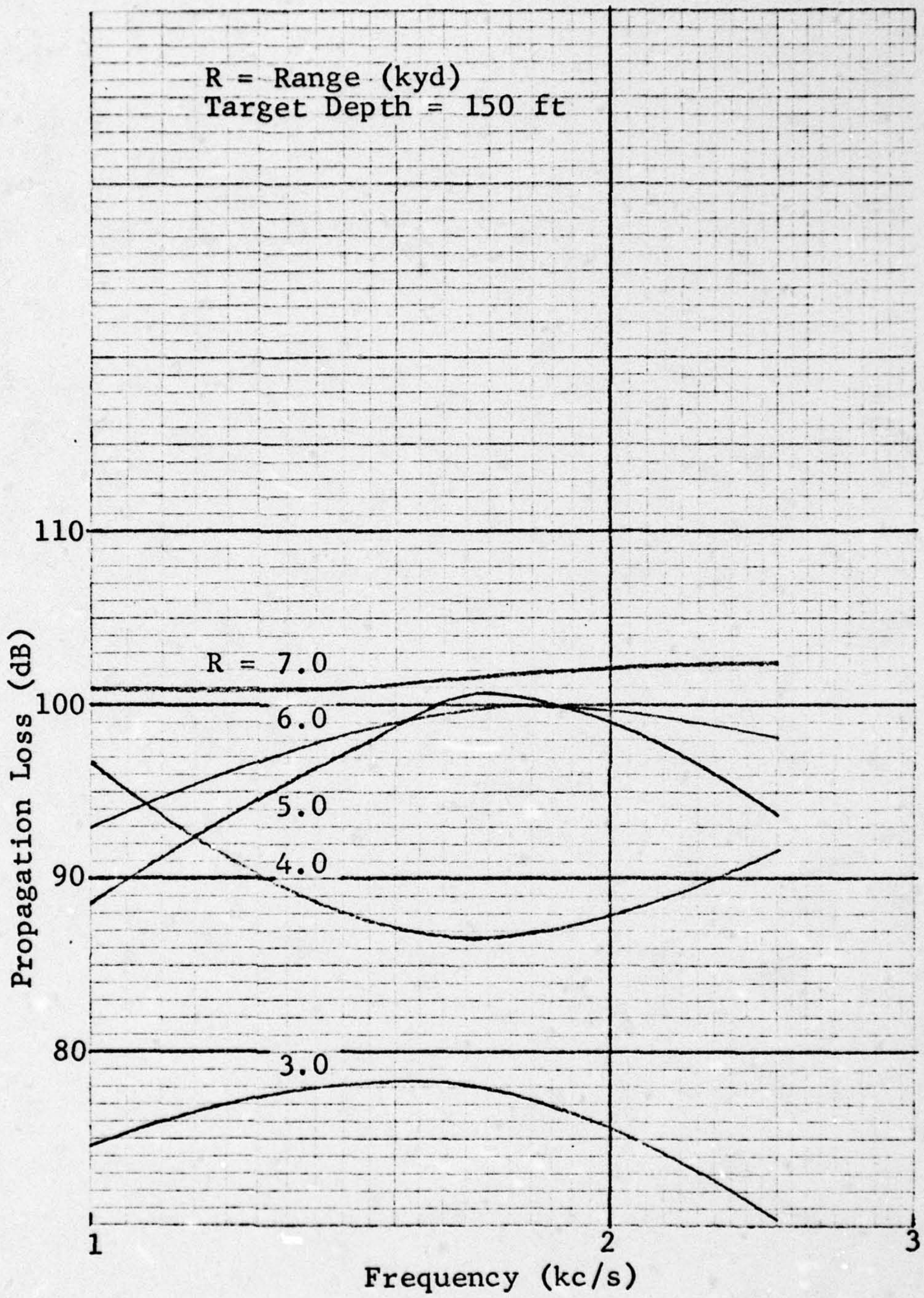

Figure II(h) PROPAGATION LOSS AS A FUNCTION OF FREQUENCY in TRACOR document 66-315-C, "Part I of this document." The values of S_{in}, the noise level, and minimum detection levels are plotted in Figures II(i) and II(j) for the two standard targets at four target depths. The minimum detection level (21 dB below noise in the system passband) was obtained in Part I of this study; this is the minimum signal level at which detection can be accomplished, with 0.50 probability. This result depends upon a study of the detection performance obtainable with a graphic recorder display.

B. AN/SQS-23 PASSIVE SYSTEM

Propagation loss for the AN/SQS-23 passive system was calculated using a TRACOR computer program based on normal mode theory, using 40 modes. The propagation loss is shown in Figure II(k) as a function of range, between 1 and 20 kyd and for the same four depths studied for the PADLOC system: 35, 60, 100, and 150 feet. Since the band pass of the AN/SQS-23 is only 370 c/s, the frequency dependence over the band of propagation loss and emitted target power is not significant and therefore is neglected. The radiated noise levels are taken from the two standard targets [Figure II(n)] described in Part I and the signal level at the display input was calculated. The input signal level was plotted in Figures II(l) and II(m) as a function of range along with the noise level and the minimum detection level*.

C. STANDARD TARGETS

The two standard target spectra described in Part I were abstracted from the Final Report, Phase I, Submarine Improved Sonar System, 1 June 1965, Volume I (Confidential), pp 4-37, prepared under NObsr-93135 at Raytheon, Portsmouth, R.I.

*Minimum detection level -2.5 dB is obtained from Part I, Figure III(h).

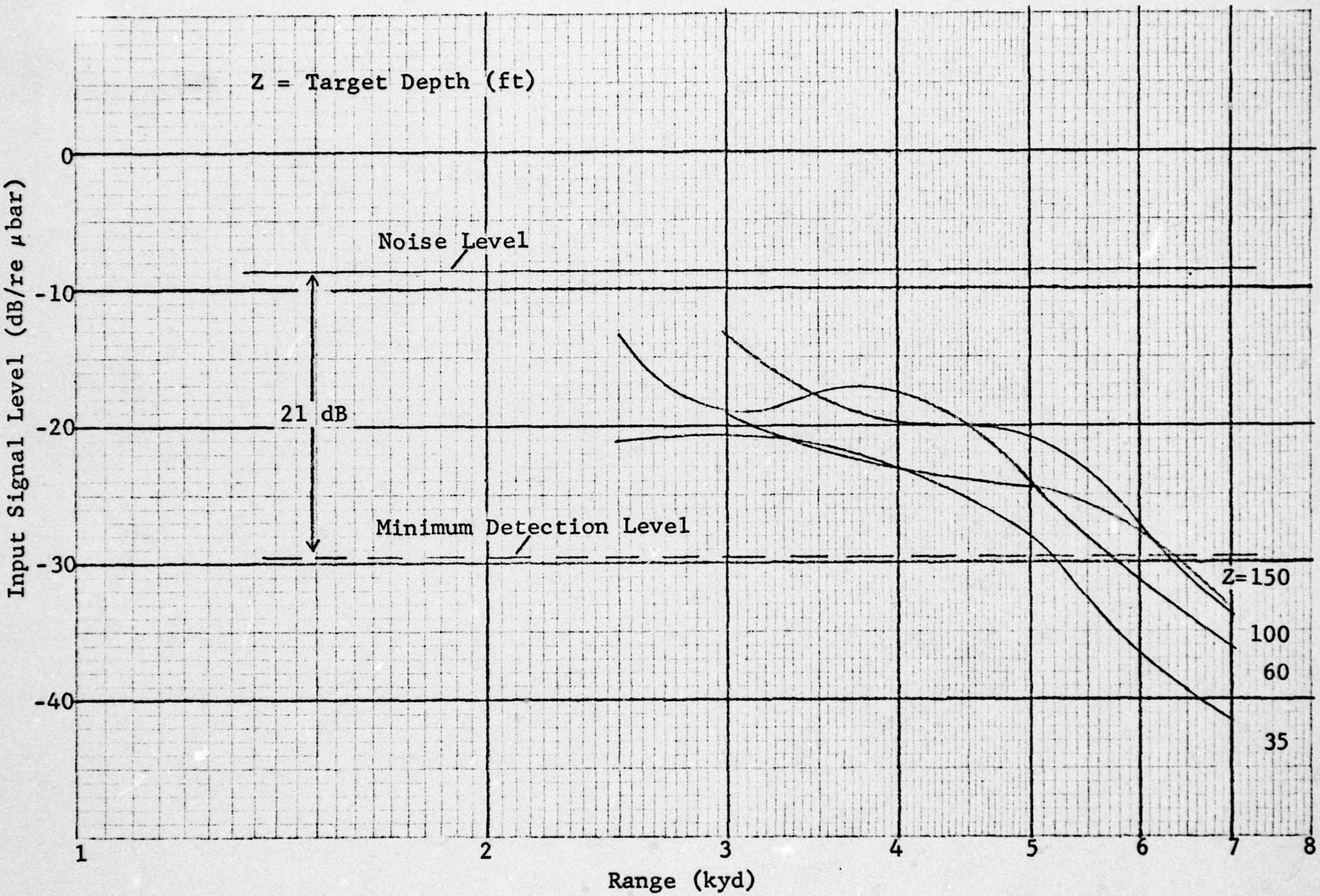

Figure II(i) PADLOC DETECTION PERFORMANCE FOR NOISY TARGET

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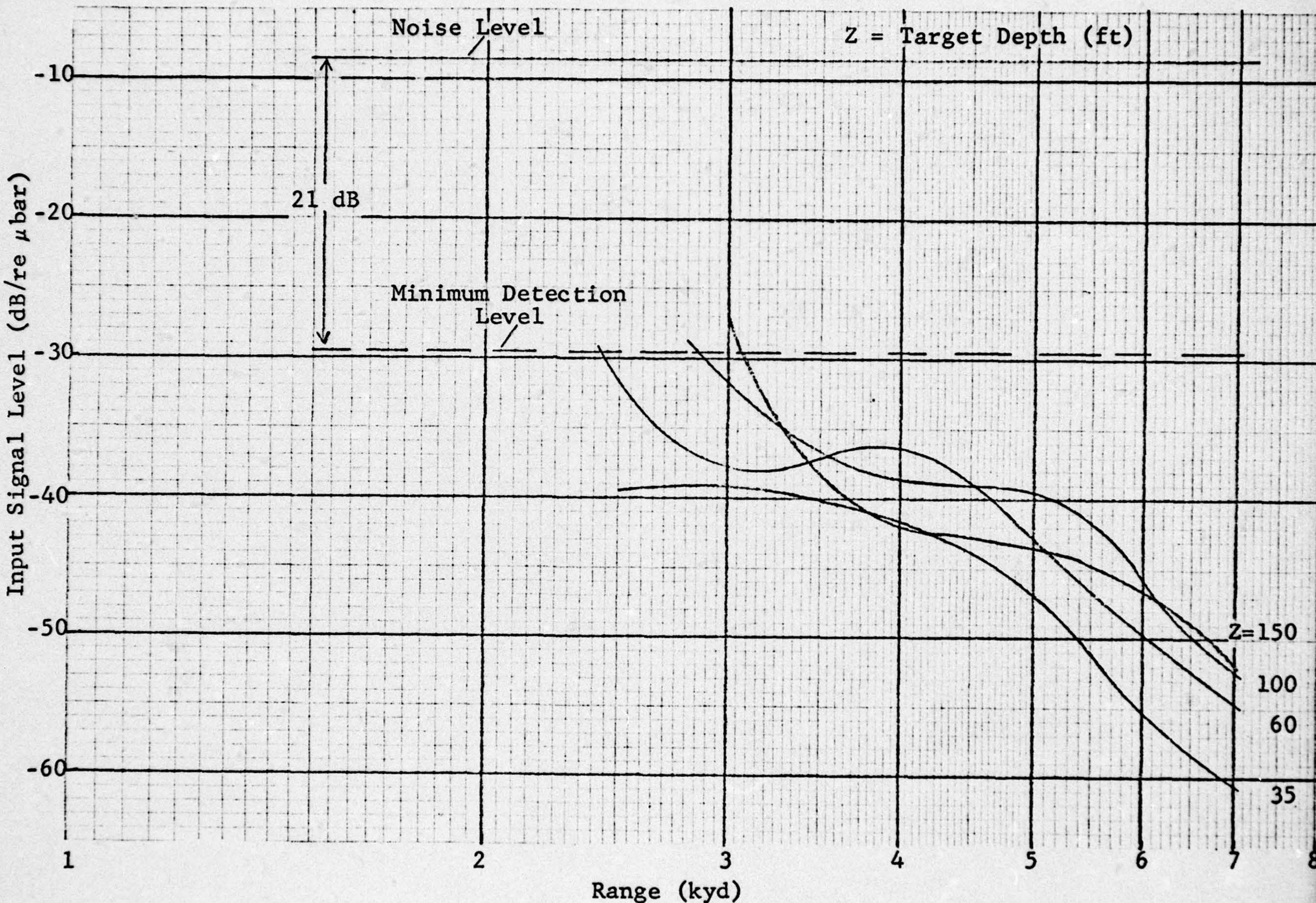

Figure II(j) PADLOC DETECTION PERFORMANCE FOR QUIET TARGET

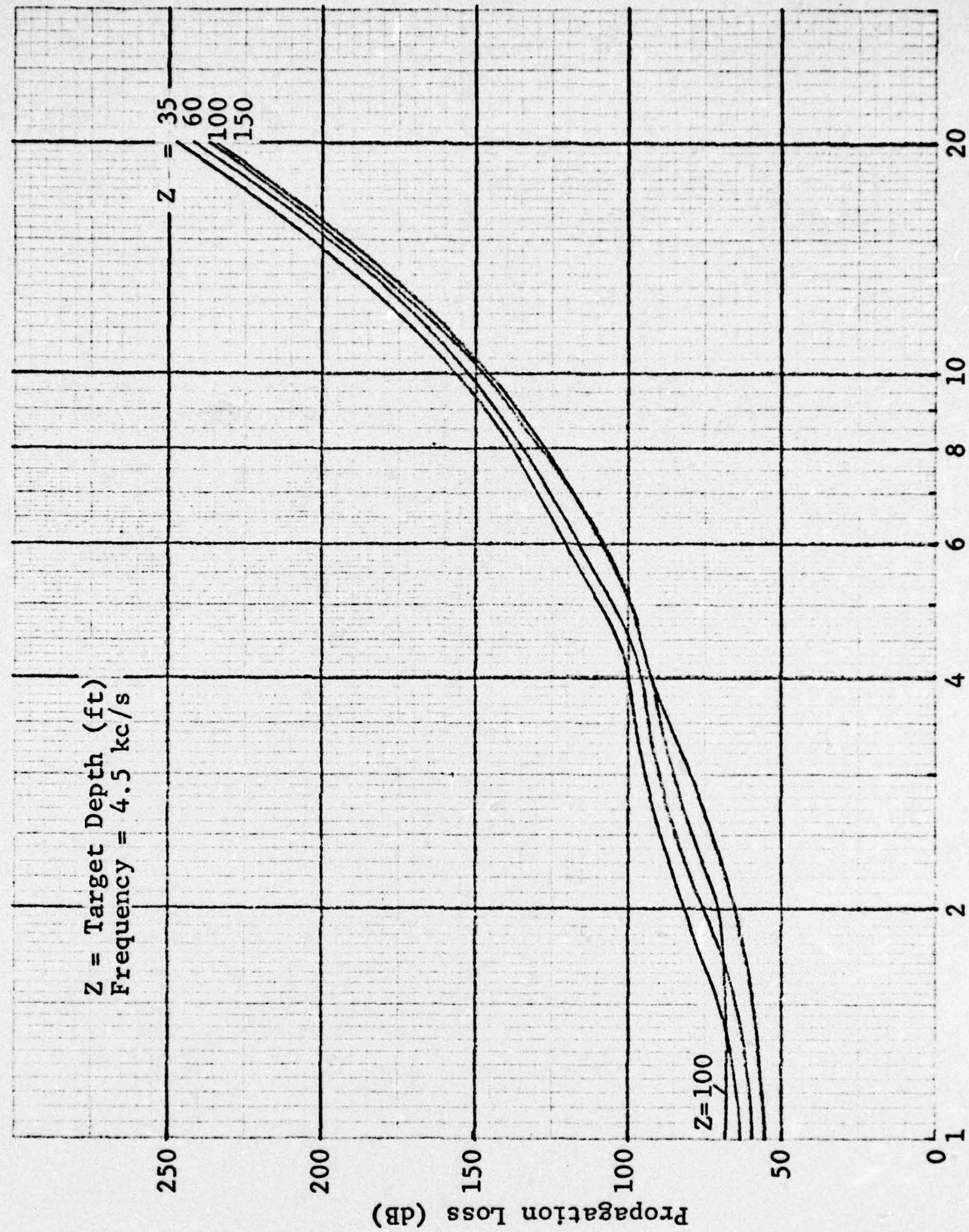

Figure II(k) AN/SQS-23 PROPAGATION LOSS

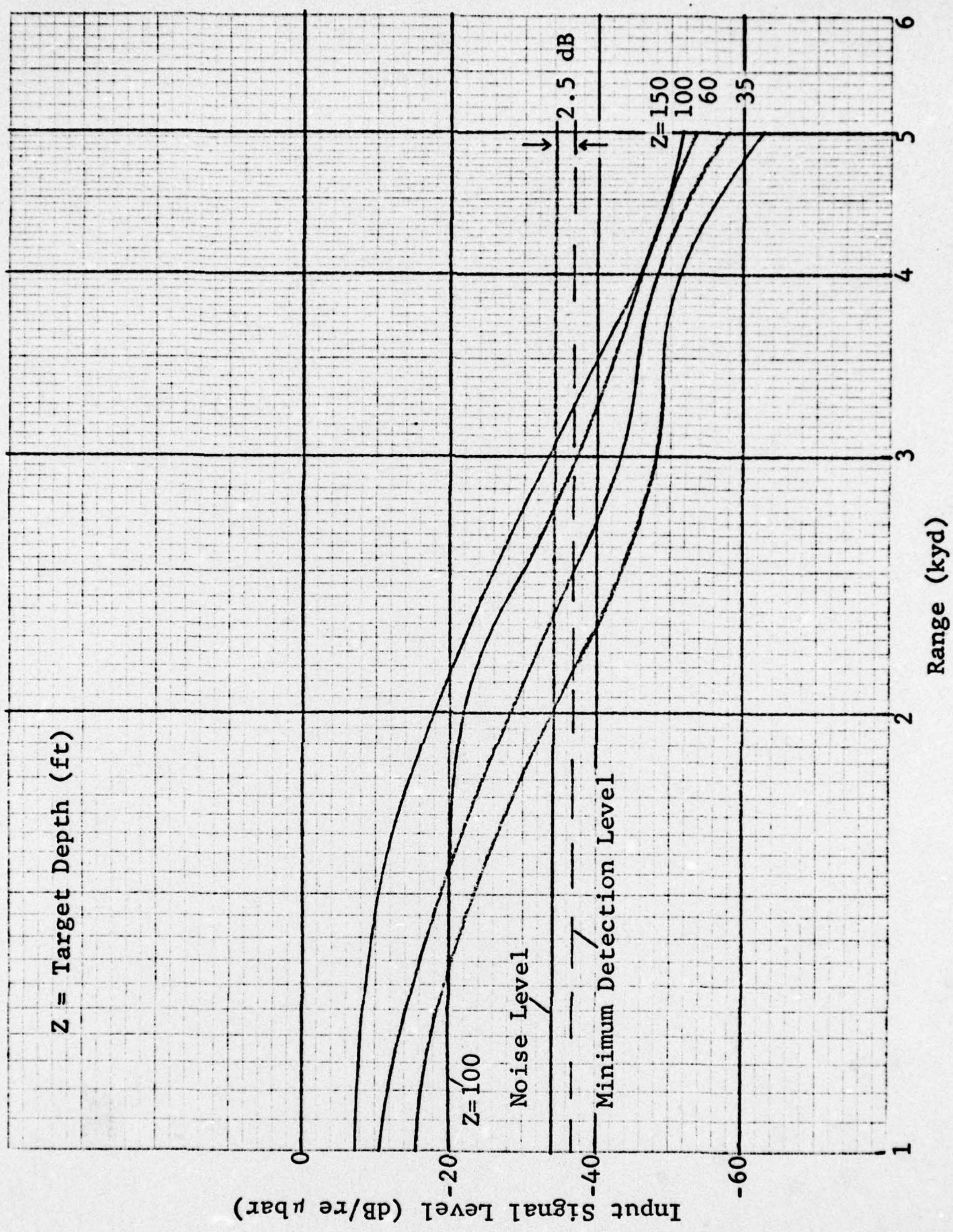

Figure II(1) AN/SQS-23 PERFORMANCE FOR NOISY TARGET

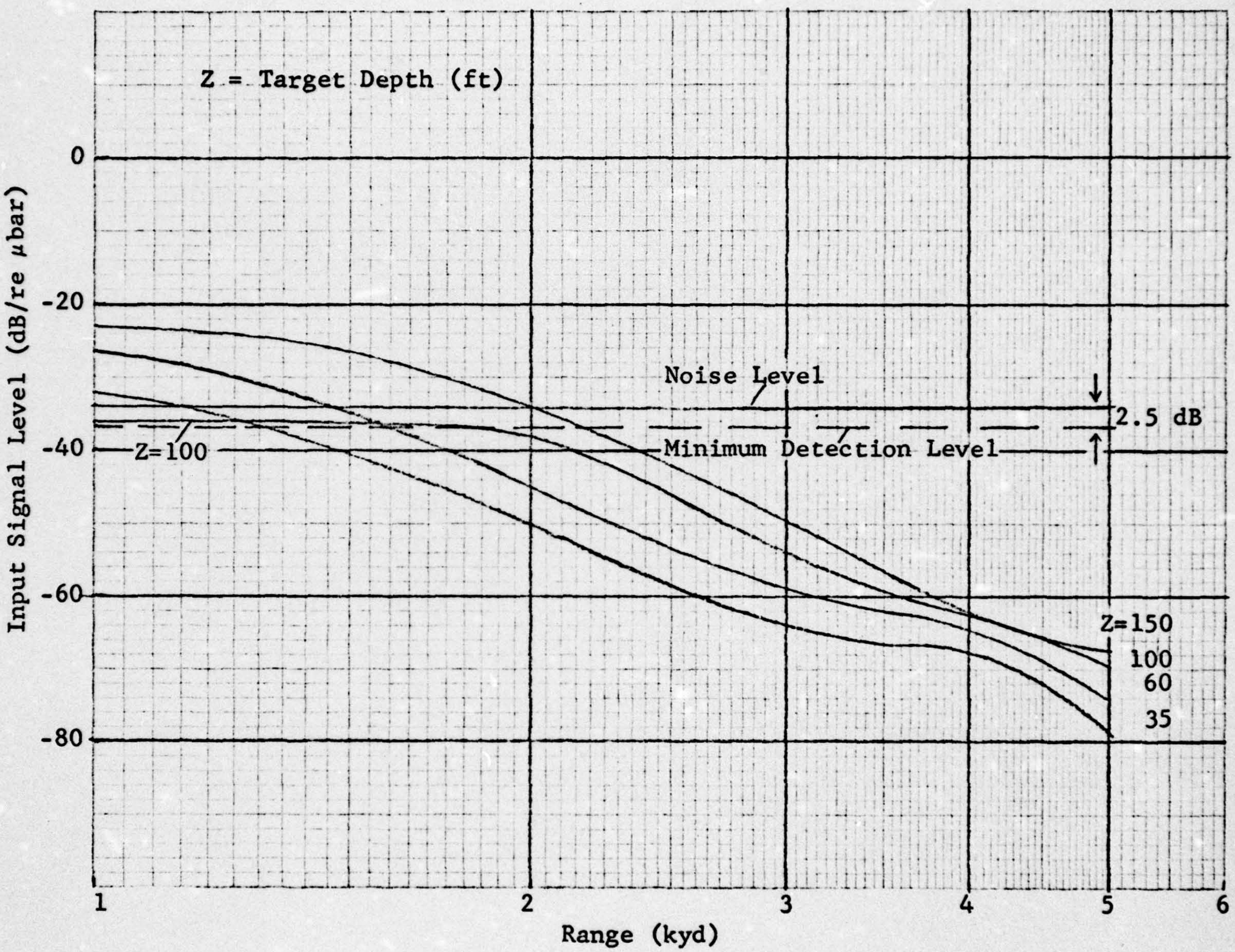

Figure II(m) AN/SQS-23 PERFORMANCE FOR QUIET TARGET

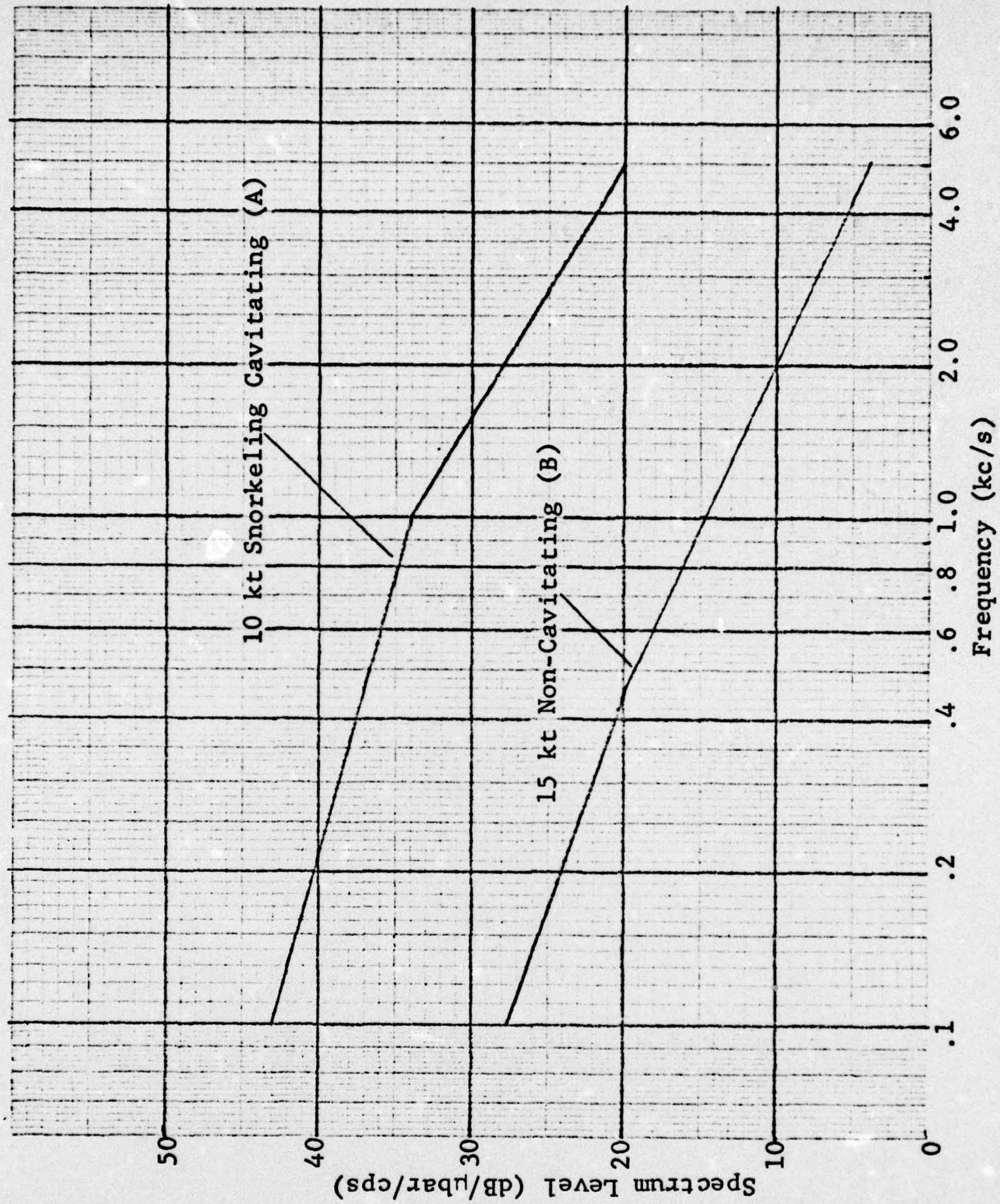

Figure II(n) SPECTRAL DENSITY OF TARGET SPECTRUM: CONTINUOUS COMPONENT

The emitted target spectrum consists of a component distributed more or less continuously in frequency and a discrete spectrum. The former is caused by flow turbulence, screws, cavitation, etc., and the latter arises from rotating machinery such as refrigeration equipment, eccentric or damaged screws, bearings, etc. A third component, transients emitted when tanks are blown and by non-repetitive activity on the submarine, is also known to be a factor in alerting detection*. This component is not included in this study.

Figure II(n) shows the distributed spectrum or continuous component of the two types of submarines chosen for the standard targets: the spectrum typical of a 10 kt, snorkeling, cavitating target (Target A) and the spectrum typical of a 15 kt, non-cavitating, quiet target (Target B). In both cases, the discrete frequencies component is assumed to consist of five to ten lines with 5 c/s width in each 1 kc/s of bandwidth. Of these, one is assumed to be 25 dB above the continuous component of the signal, one is assumed to be 5 dB above the signal component and the rest are distributed between 5 and 20 dB above the continuous component. Seven spectral lines were used in the 1.0 kc/s to 2.5 kc/s band in the PADLOC performance prediction. None were assumed in the AN/SQS-23 performance prediction. The snorkeling target implies small target depths, and the 15 kt non-cavitating target implies greater target depths. Both spectra are used for all depths studied as examples of "noisy" and "quiet" targets.

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*R. J. Vachon, U. S. Navy Electronics Laboratory (Personal Communication).

III. SUMMARY OF RESULTS

The detection ranges of each of the two systems as functions of depth are plotted in Figures III(a) and III(b). For the noisy target, the PADLOC system detects at an average propagation loss of about 100 dB, while the AN/SQS-23 detects when the propagation loss drops to about 80 dB; similar figures for the quiet target are 80 and 60 dB. For the weak negative surface gradient used here, the propagation loss increases rapidly with range near the limiting ray and more slowly at greater ranges. Therefore, the relative difference between the two systems is minimized near the limiting ray, where the quiet target is detected. Figure III(b), which shows detection range as a function of depth for the quiet target, shows two irregularities illustrating this phenomenon: (1) an inflection in the curve for the AN/SQS-23 and (2) the relatively short detection ranges of the PADLOC for shallow targets. Both of these irregularities are a result of sharp peaks in propagation loss predicted by normal mode theory at short ranges and near the limiting ray. These irregularities are apparent on the contour plots of propagation loss supplied by M. A. Pedersen.

The predicted PADLOC and AN/SQS-23 passive detection ranges are summarized in Table I for the negative gradient environment for the noisy and quiet targets.

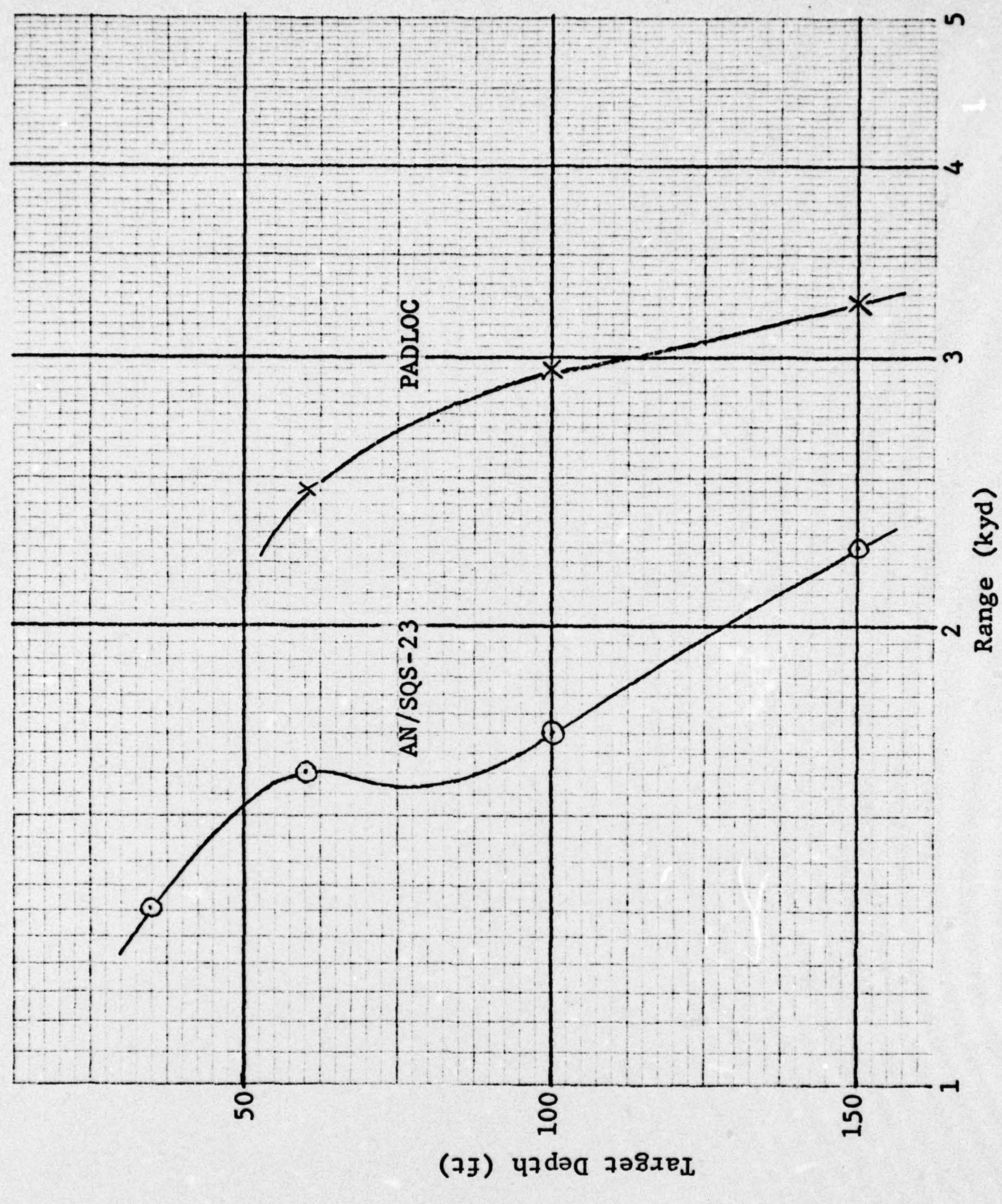

Figure III(a) DETECTION RANGES FOR QUIET TARGET

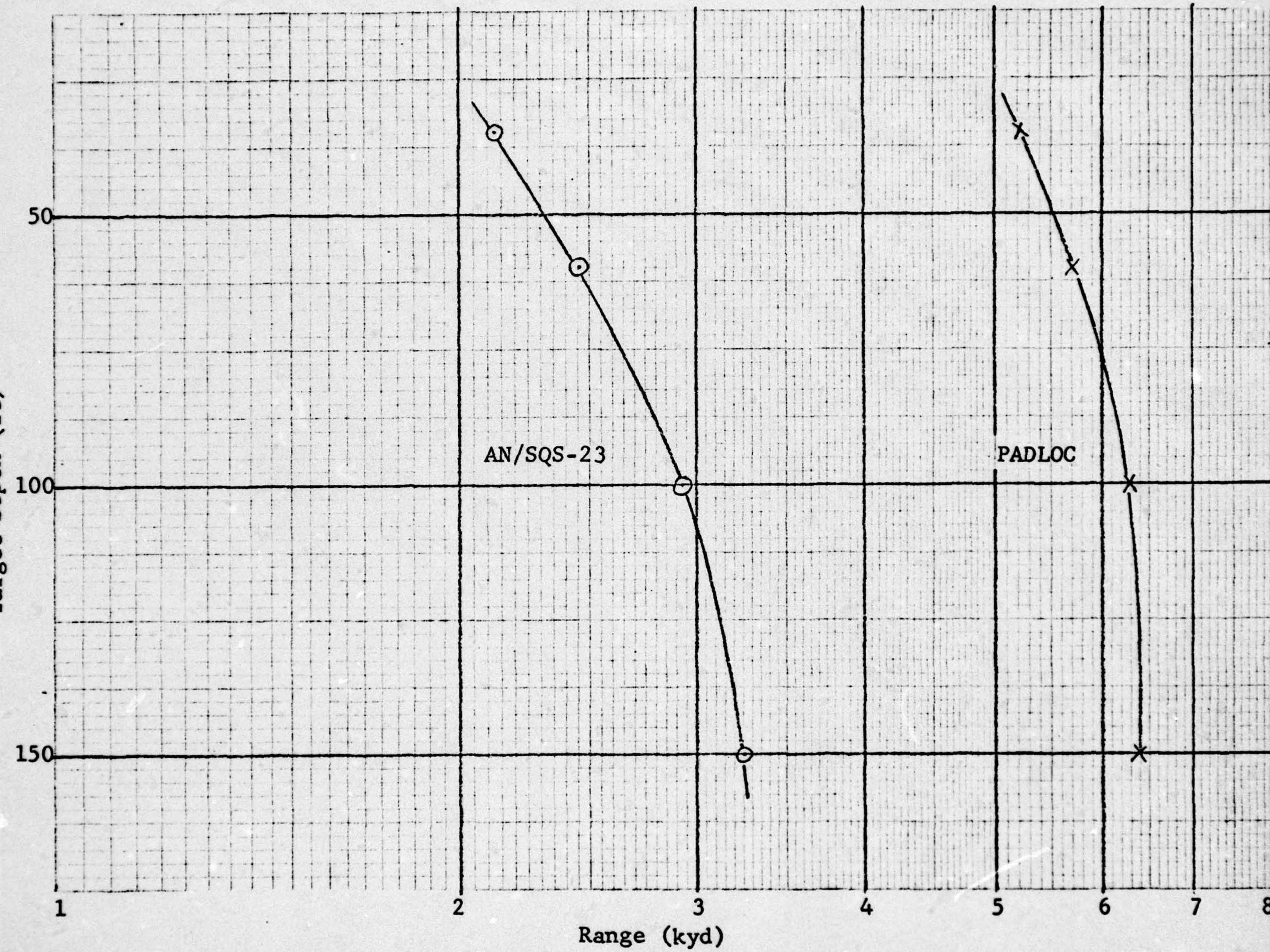

Figure III(b) DETECTION RANGES FOR NOISY TARGET

TABLE I

NEGATIVE GRADIENT DETECTION RANGES (kyd)
(Gradient: -0.015 ft/sec/ft to 120 ft;
-0.1 ft/sec/ft below 120 ft)

Target Depth (ft)	35	60	100	150
PADLOC:				
Noisy Target (A)	5.2	5.7	6.2	6.4
Quiet Target (B)	2 kyd	2.4	2.8	3.1
AN/SQS-23 Passive:				
Noisy Target (A)	2.1	2.4	2.9	3.2
Quiet Target (B)	1.3	1.6	1.7	2.2
Detection Range Ratio: PADLOC/AN/SQS-23				
Noisy Target (A)	2.5	2.4	2.1	2.0
Quiet Target (B)	1.5	1.5	1.6	1.4

The results shown in this table are plotted in Figure III(c). The predicted PADLOC detection range exceeds the AN/SQS-23 passive detection range by a factor 1.4 to 1.6 for the quiet target and by a factor 2.0 to 2.5 for the noisy target.

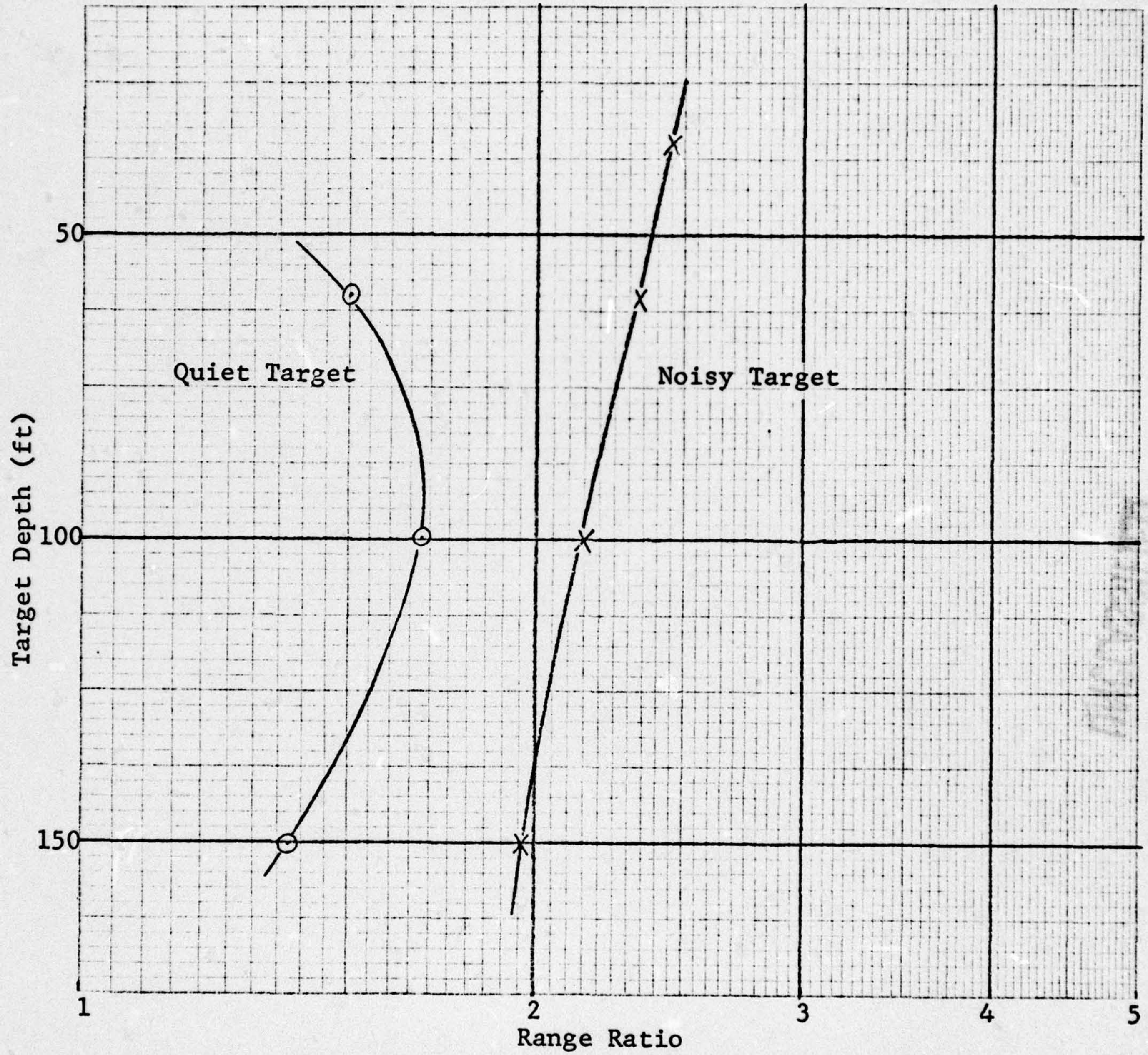

Figure III(c) RATIOS OF DETECTION RANGES: PADLOC/AN/SQS-23

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