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NUWC SHALLOW WATER CURTAIN EFFECT WITH BIOT BOTTOM LOSS: SYSTEM IMPACT

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Abstract

(U) The Curtain Effect was originally conceived to compare the relative rates of loss of spreading and attenuation in deep water in order to estimate possible attainable acoustic detection ranges. It was later modified to compare spreading, attenuation, and bottom loss in shallow water for the same purpose (NUWC-NL Technical Document 4009, 2 March 1992). We now compare the Shallow Water Curtain under strongly downward refracting conditions for various source/receiver depths assuming an angular dependent Biot bottom loss. The result is a diagram which allows the visualization of the relative trade-off between source depth and frequency under these conditions.

1. (U) Introduction

(U) The initial application of the "Curtain Effect" (ref. 1, 2) allowed a simple estimation of the relative propagation range that can be obtained for various frequencies in a deep water sound channel where the principal loss mechanisms were spreading loss and attenuation. (Figure 1)

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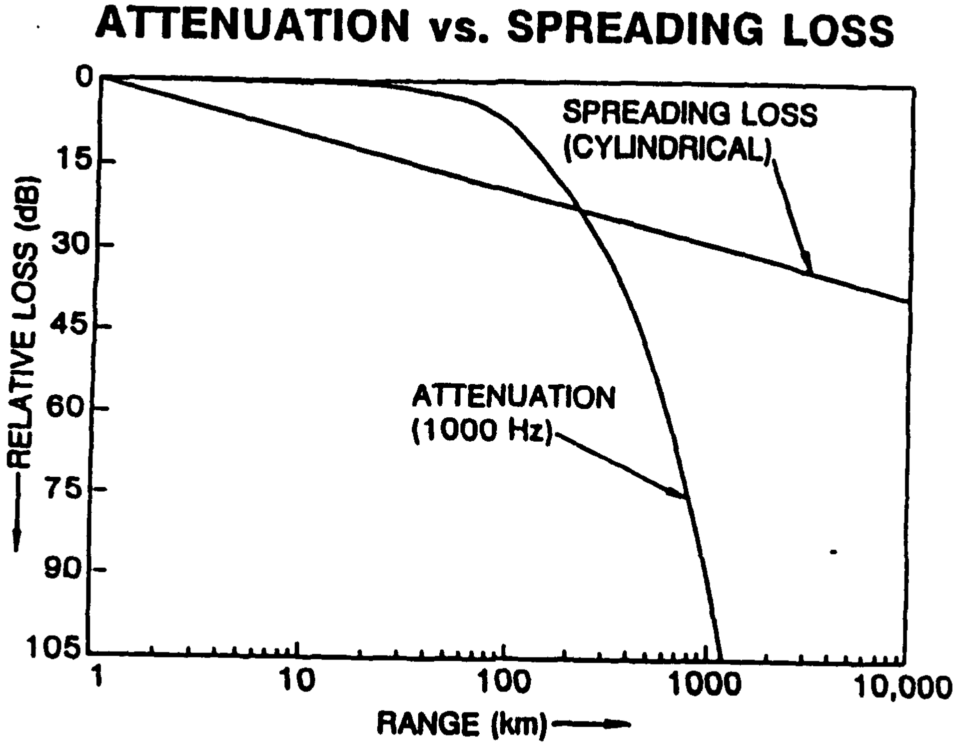

FIGURE 1. ATTENUATION AND SPREADING VS. RANGE

(U) The "Curtain Effect" is based on the concept (illustrated here at 1000 Hz) that spreading loss increases linearly with the logarithm of range, while attenuation increases linearly with range. Spreading loss is the principal loss mechanism at the shorter ranges. However, as the range increases, attenuation will become the dominant factor and its rapid increase creates a "curtain" which limits the range of propagation.

2. (U) Deep Water Curtain

(U) The concept of the Curtain Effect can be presented in various ways (ref. 1); each gives a different perspective on the limitations to propagation. We have found that a rate-of-loss vs. range plot as shown here (Figure 2) gives a valuable insight into the trends of the Curtain Effect.

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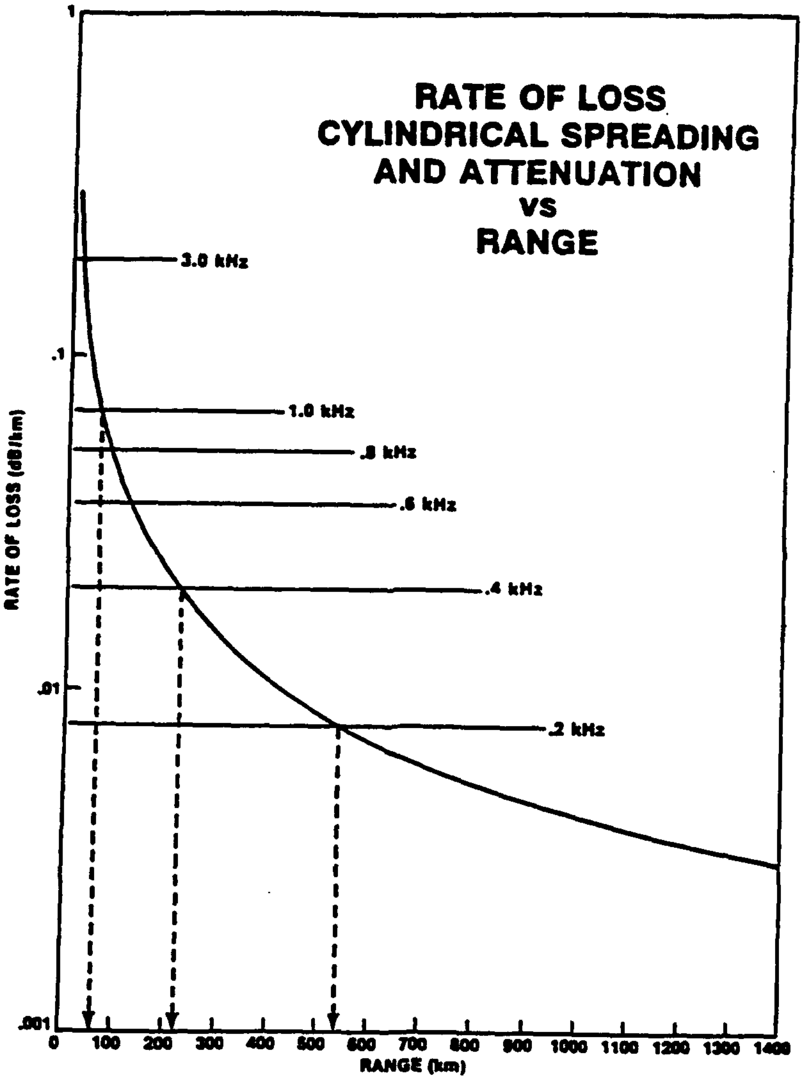

FIGURE 2. RATE OF SPREADING LOSS AND ATTENUATION VS. RANGE

(U) For example, below 200 Hz any lowering of the frequency results in a large increase in range, while at frequencies above 5 kHz the range change is small.

3. (U) Marsh-Schulkin Shallow Water Model

(U) To apply the concept to shallow water (ref. 3), specifically under downward refracting conditions where the bottom interaction can be the dominant loss mechanism, we chose to use the Marsh-Schulkin shallow water model (ref. 5) which, although developed in the early 1960's, is still in widespread use. (Figure 3)

(U) The principal limitation of this model is that it does not consider the placement of the source and receiver in the water column; predicted transmission loss is independent of source/receiver location.

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- **IN THE M-S MODEL, THE PROPAGATION LOSS IS REPRESENTED IN TERMS OF SEA STATE (WAVE HEIGHT), BOTTOM TYPE (OR BOTTOM LOSS, IF KNOWN), WATER DEPTH, FREQUENCY, AND THE DEPTH OF THE POSITIVE-GRADIENT LAYER. PROPAGATION LOSS IS INDEPENDENT OF SOURCE/RECEIVER DEPTH.**

- **FOR LONG RANGES, $R \geq 8H$,**

$$N = 10 \log R + \boxed{aR + a_t \left[\frac{R}{H} - 1 \right]} + 10 \log H + 64.5 - k_L \text{ dB}$$

FIGURE 3. MARSH-SCHULKIN SHALLOW WATER FORMULA (U)

(U) For "long ranges", all non-spreading losses - attenuation and boundary interaction losses - can be lumped together as shown by the dashed boxed-in area. This can be termed an "effective loss" and used in place of attenuation loss alone (as was the case for deep water).

4. (U) Shallow Water Curtain: Rate of Loss (Marsh-Schulkin Values) vs. Range

(U) The Marsh-Schulkin model can therefore be used to obtain effective loss values from shallow water propagation loss measurements. The range of effective loss values at 1000 Hz for various shallow water locations is shown by the cross-hatched region (ref. 3). These values range from just the normal volume attenuation value (indicating that boundary losses were very small) to over ten times that value (hence a domination by boundary losses). (Figure 4)

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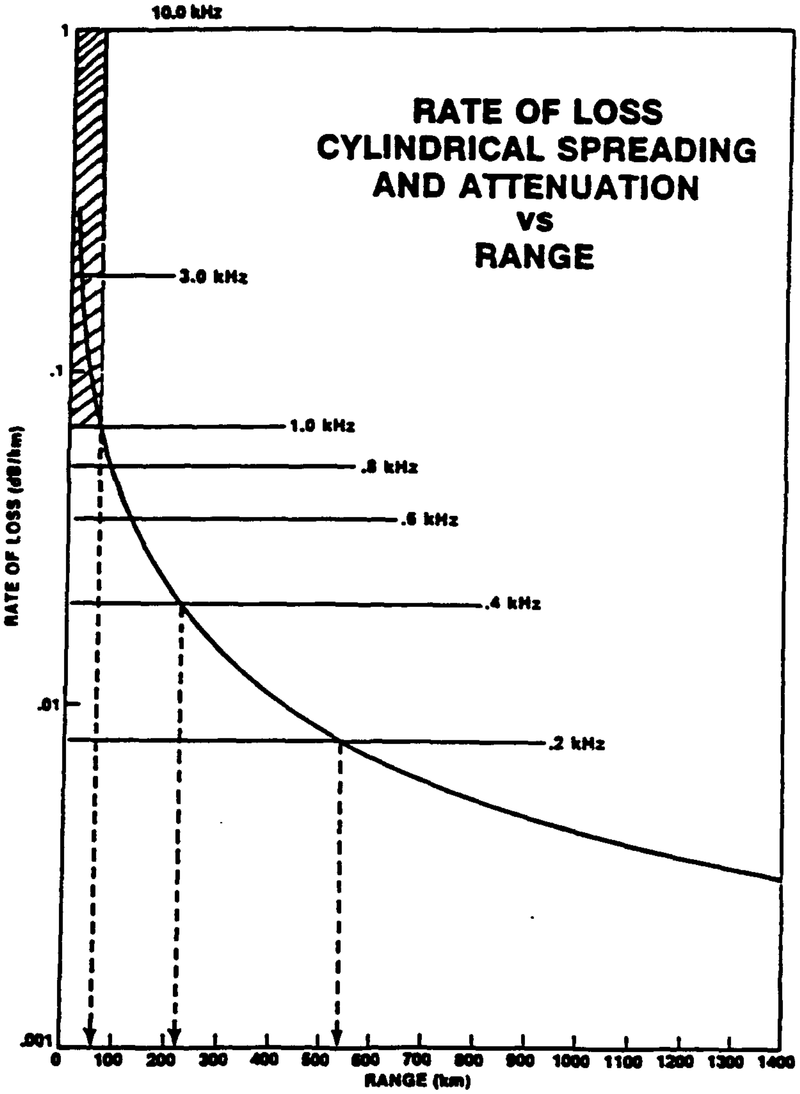

FIGURE 4. RANGE (HATCHED AREA) OF EFFECTIVE RATE OF LOSS AT 1000 HERTZ

(U) This suggests that, for example, in one shallow water location a 1000 Hz system may encounter the same propagation conditions in shallow water that it did in deep water. However, at another shallow water location its propagation range may be reduced, at best, to that of a 10,000 Hz system in deep water.

5. (U) Biot Bottom Loss

(U) Chizhik and Tattersall (ref. 6) have developed bottom loss curves, based on Biot theory, for area Foxtrot, a shallow water region located south of Long Island (ref. 7) on the New England Shelf. (Figure 5) These curves are characterized by relatively low values and a strong frequency dependence below the critical grazing angle (approximately 20 degrees), followed by a rapid increase in loss (but a lessened frequency dependence) above the critical angle.

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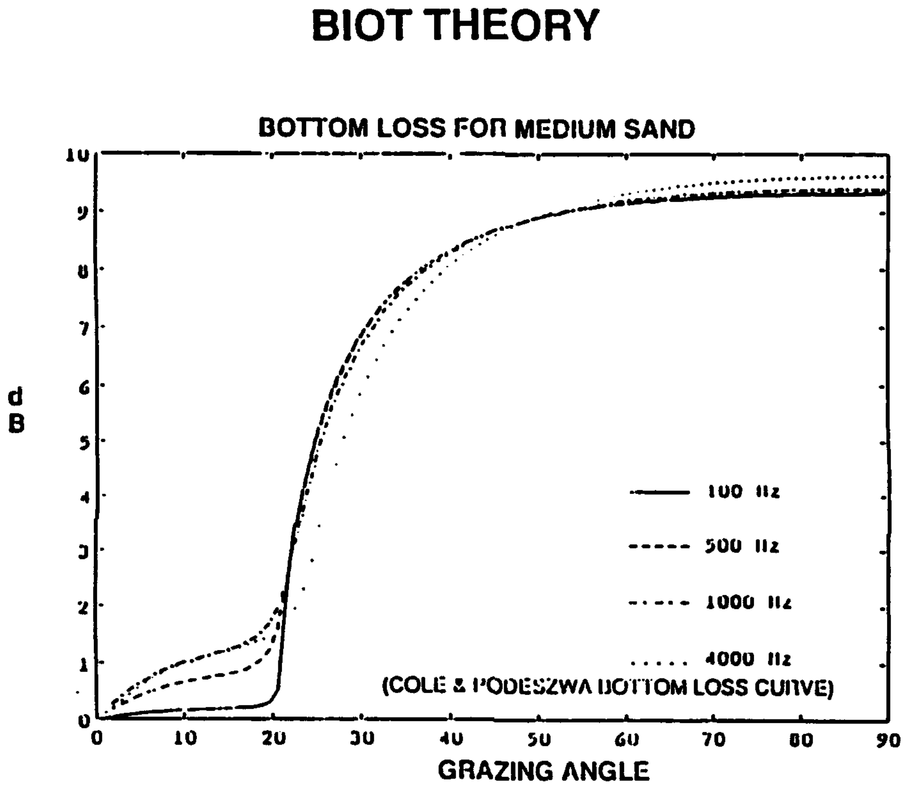

FIGURE 5. BIOT BOTTOM LOSS FOR MEDIUM SAND (REF. 6)

(U) These variations can have implications for source/receiver placement in the water column since the range of grazing angles that result from source/receiver depth changes in typical shallow water locations would correspond to a significant change in bottom loss for a bottom loss curve as shown here.

6. (U) Bottom Angle of Reflection Dependence on Source/Receiver Depth

(U) We examined the grazing angle dependence on source/receiver configuration for area Foxtrot under strongly downward refracting (summer) conditions. (Figure 6)

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THE MINIMUM OBTAINABLE BOTTOM GRAZING ANGLE IS A FUNCTION OF SOURCE DEPTH

$$\theta\ \text{min} = \text{COS}^{-1}\ \frac{C_{\text{SOURCE}}}{C_{\text{BOUNDARY}}}$$

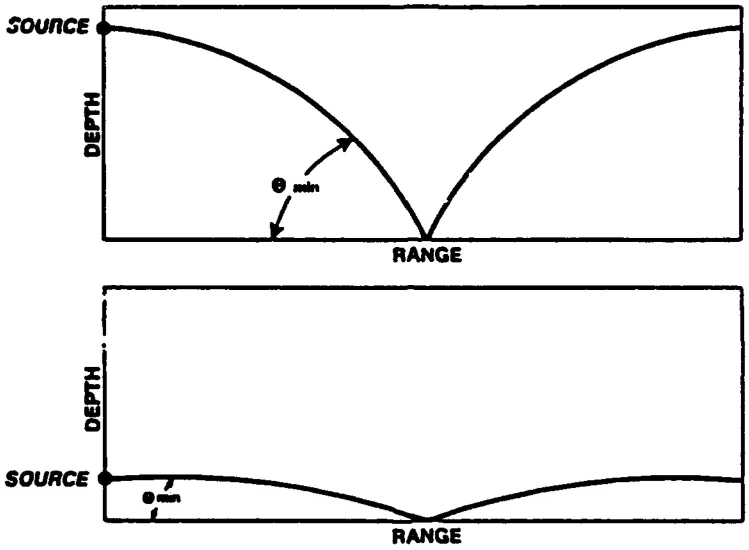

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FIGURE 6. MINIMUM GRAZING ANGLES UNDER SUMMER CONDITIONS

(U) For a shallow source/receiver configuration above the thermocline the resulting limiting grazing angle at the bottom would be approximately 15 degrees. For a deeper configuration in the middle of the water column and below the thermocline the angle is only 5 degrees.

(U) Although there can also be slightly different bounce rates (bounces/kilometer) for each s/r depth, we have found that the resulting change in transmission loss is small compared to the change in loss/bounce (ref. 8).

7. (U) Phenomenological Explanation of Depth Dependent Transmission Loss

(U) Herstein et al (ref. 8) have shown that if the sound speed profile (such as a strongly downward refracting summer profile) results in a grazing angle that is source/receiver depth dependent (diagram on left), and the bottom loss is also grazing angle dependent as was shown in the previous figure, we can then construct a curve of bottom loss vs. source/receiver depth (diagram on right). (Figure 7)

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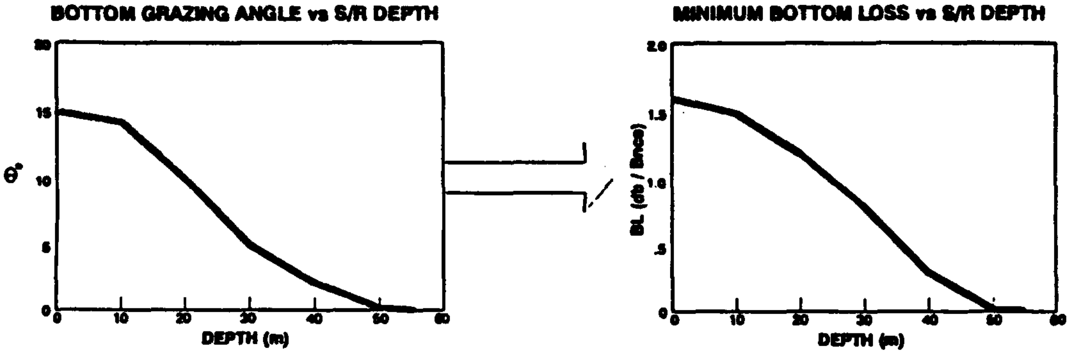
PHENOMENOLOGICAL EXPLANATION OF DEPTH DEPENDENT TRANSMISSION LOSS



S/R DEPTH = min [SOURCE DEPTH, RECEIVER DEPTH]

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FIGURE 7. EXPLANATION OF DEPTH DEPENDENT TRANSMISSION LOSS

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(U) This can be used to easily predict the optimum s/r depth for minimum transmission loss when bottom loss is the principle loss mechanism such as occurs many times in shallow water under downward refracting (summer) conditions.

8. (U) Curtain Effect for Two Source/Receiver Depths at Site Foxtrot under Strongly Downward Refracting Conditions

(U) Based on the number of bounces per unit range and the bottom loss per bounce, we can determine an effective rate of loss for the summer Foxtrot conditions. For the shallow source/receiver configuration (15 degree grazing angle) the effective loss rate increases up to approximately 1000 Hz and then flattens. It remains the dominant loss mechanism up to 10 kHz. For the deeper source/receiver (5 degrees) the rate of loss is lower but the frequency trend is the same. In this case the losses due to bottom loss and attenuation are equal at approximately 8 kHz. (Figure 8)

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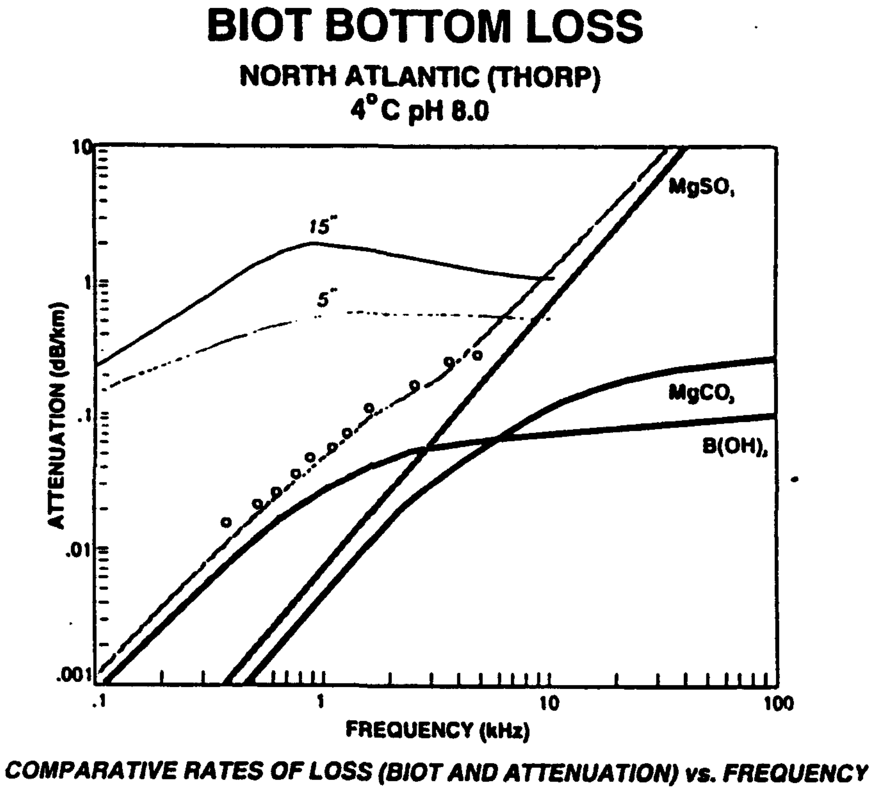

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FIGURE 8. COMPARISON OF BIOT RATE OF LOSS AT 5° AND 15° WITH ATTENUATION VS. FREQUENCY

(U) These results show the benefit of a deeper source/receiver configuration at all frequencies below 10 kHz. Above 10 kHz this would no longer hold because attenuation becomes dominant.

(U) These curves suggest the possibility of some interesting trade-offs. For example, the propagation loss for the deeper configuration at 8 kHz would be equivalent to a shallow configuration at 300 Hz. Another interesting implication is that under these conditions - where bottom loss is the dominant loss factor - the controlling propagation condition for a shallow configuration at 10 kHz is the same at 1 kHz.

9. (U) Curtain Comparison, Three Frequencies, Two Angles

(U) We now compare these results with the previous Marsh-Schulkin shallow water curtain (ref. 3) results at 1000 Hz (Figure 9). Three frequencies are shown, 100 Hz, 500 Hz, and 1000 Hz. The range of rates-of-loss between grazing angles of 5 and 15 degrees are shown for each frequency. The Biot results at 1000 Hz are in agreement with the higher end of the Marsh-Schulkin results, which would be expected since the lower end of the Marsh-Schulkin range corresponds to no bottom interaction at all.

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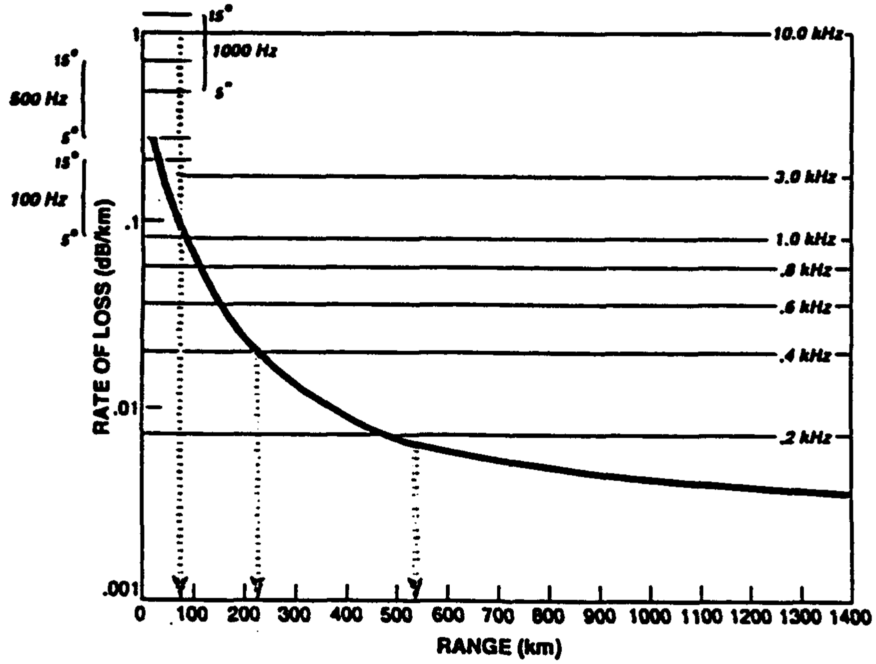

RATE OF LOSS CYLINDRICAL SPREADING, BIOT AND ATTENUATION vs. RANGE

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FIGURE 9. RANGE (HATCHED AREAS) OF BIOT RATE OF LOSS FOR GRAZING ANGLES BETWEEN 5° AND 15° FOR 100, 500, AND 1000 HERTZ

(U) There is some overlap of the ranges of Biot rate of loss for 500 and 1000 Hz. This suggests some of the system trade-offs that can be made under these conditions. For example, a 1000 Hz system operating below the thermocline (5 degree bottom grazing angle) may have less transmission loss than a 500 Hz hull mounted system (15 degree bottom grazing angle).

10. (U) Conclusions

(U) We can summarize our results as follows:

(U) For area Foxtrot under strongly downward refracting conditions the rate-of-loss was decreased by configuring the source/receiver below the thermocline and therefore reducing the grazing angle and resulting loss per bounce as compared to a shallow source/receiver configuration. This result is due to the strong grazing angle dependence of the Bottom Loss, which can be well represented by the Biot model.

(U) Shallow Water Curtain Effect diagrams provide visualization of the trade-offs possible between changes in frequency and source/receiver depth under these conditions.

11. (U) References

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