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TECHNICAL REPORT No. 96
**Diffusion of a Vertical Sheet in
the Open Ocean (u)**

**H. A. Miranda, Jr.
P. S. Rooney
and
H. Schimmel**

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CU-120-62-ONR-266-Phys.

Columbia University
Hudson Laboratories
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Robert A. Frosch
Director

Technical Report No. 96

DIFFUSION OF A VERTICAL SHEET IN THE OPEN OCEAN (U)

by

H. A. Miranda, Jr.

P. S. Rooney

and

H. Schimmel

May 24, 1962

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ABSTRACT (C)

In a previous experiment mass transport in the wake of a submerged submarine was studied. Results indicated that after the initial few minutes local turbulence induced by the ship's screws was of relatively minor importance in the spreading. Ordinary oceanic turbulence appeared to be the dominant mechanism.

An experiment was designed to test this hypothesis: A thin, vertical sheet of radiotracer was dispensed from a towed line source. The marked waters were probed, as in the prior experiment, by a towed, vertical array of scintillation counters. The similarity of the diffusion patterns from the two experiments strongly supports the above hypothesis.

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INTRODUCTION

Submarine wake detection schemes involving the search for some scalar quantity deposited by the passing vehicle require, among other things, a knowledge of the turbulent mixing of ocean waters on a scale larger than 30 ft or so. This was shown to be the case in a previous report¹ which presented the results of some experimental work carried out with the submarine USS Albacore in the open ocean as well as in the Gulf of Maine.

In this work a radiotracer was dispensed from the keel while traveling at 6 knots and submerged at keel depths between 100 and 250 ft. The horizontal spreading of these marked waters was determined by probing with a specially designed, very low level set of scintillation counting detectors.¹ Surprisingly little vertical spreading was observed, even in waters which were virtually isothermal (1°C drop in the first 500 ft). The marked waters had spread to a width of about 500 ft in 3 hours. Little indication of vertical mixing was evident beyond the first 15 minutes or so. Moreover, the evidence pointed to the fact that wake turbulence plays a negligible role in the mixing process beyond this time.

¹ H. A. Miranda, Jr., H. Schimmel, and P. S. Rooney, Mass Transport in the Wake of a Submerged Submarine (Columbia University, Hudson Laboratories Technical Report No. 87, April 6, 1961). CONFIDENTIAL

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Accordingly, the hypothesis was formulated that ordinary oceanic turbulence is the dominant mechanism causing the spread of marked waters in the wake of a moving submarine for times greater than 15 minutes after passage. An experimental test of this hypothesis was subsequently attempted. This report discusses the experimental procedure and presents the results.

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APPARATUS AND PROCEDURE

The experimental apparatus employed is discussed fully in the report cited and will not be described here. Two modifications were made, however, which must be mentioned:

1) In all the earlier work, the radiotracer was dispensed from the USS Albacore. A hose was wrapped bellyband fashion about the submarine, and a suitable dispensing nozzle was placed at the end of the hose, which was located at the keel of the submarine. In this experiment, the dispensation was done without the use of a submarine. The dispensing apparatus was essentially the same as that previously used. Water was taken from the desired dispensing depth, pumped aboard the USS Gibbs, and returned to the same depth through a second hose. This hose was provided with a series of tiny holes periodically located over a 30-ft length to allow the dispensation of a vertical sheet of marked waters. The pressure drop in the line due to the presence of these holes was negligible compared to the pressure head developed by the pump, to assure equal water flow from each of the holes.

The pumping speed was approximately 10 gal/min. The radiotracer was injected into this flow at a rate of about $250 \text{ cm}^3/\text{min}$. Due to the possibility of heat absorption in the water's circuit to the ship and back, a heat exchanger was employed in a servo loop, whose temperature sensing elements consisted of one thermistor at the intake and a second thermistor at the outflow. Temperature compensation was easily achieved by nulling

the loop.

The dispensing apparatus, which consisted of two 1-in. hoses supported by a $\frac{1}{4}$ -in. strain cable, was weighted with a 1000-lb "fish" identical in shape to that used on the detecting rig. Because the drag per unit length of the dispensing cable was practically the same as that of the detection rig, the dispensing depth could be computed with considerable confidence.

The dispensing rig was suspended from the starboard side of the ship, by an A-frame device which protruded about 5 ft from the side and was located about 80 ft forward of the screws. The detection rig was placed in the water prior to the operation, so that upon completion of dispensation and removal of the dispensing rig, the experiment could proceed without further delay.

Dispensing was executed at a ship's speed of about 6 knots, along a straight line. Sea-anchored buoys were launched at 300-ft intervals so as to locate the surface above the marked waters. The resulting marked waters consisted of a vertical sheet 30 ft high, a few feet wide at most, and approximately 1000 ft long at the initiation of the experiment. From this point on, the procedure was identical with that of previous work, consisting of criss-crossing of the marked waters between the buoys with the detection rig under tow.

2) An automatic readout was designed and constructed which provided greater flexibility of operation, especially regarding the raising or lowering of the detection rig. The output of each of the eight scintillation counters was fed to a separate channel of this device, which yielded a trace

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whose darkness was proportional to the average counting rate of the respective counter. These outputs were displayed adjacent to one another on special recording paper, forming a graphical picture of the isocentration contours. This readout, used in conjunction with the normal recording of the counter outputs, proved very helpful during the operation and also in the subsequent interpretation of the data.

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OCEAN CONDITIONS

Because the previous work with the Albacore was carried out in isothermal waters, it was desired to perform this study under similar conditions. Unfortunately, the work was scheduled for August, when isotherms rarely exceed 200 ft over most of the Atlantic. In fact, great difficulty was experienced in finding a location with isothermal waters greater than 120 ft or so.

During the search for relatively deep isothermal waters, a large number of BT's were obtained. Many of these were taken at a fixed location. Strong evidence soon began to accumulate which suggested the existence of internal waves having periods of somewhat less than a day and amplitudes of the order of 60 ft.

Three dispensations were attempted. The first dispensation was made on August 19, 1961, at Lat. $35^{\circ} 14' N$, Long. $63^{\circ} 35' W$. The radiotracer sheet was injected so that its center was at the interface between the isothermal waters and the thermocline. This interface was located at a depth of approximately 100 ft. A second run was made on August 20, 1961, at Lat. $36^{\circ} 03' N$ and Long. $63^{\circ} 15' W$. The depth of the isotherm was again recorded as 100 ft, and the vertical sheet of marked waters was dispensed at a mid-depth of 70 ft. A third experiment was attempted on August 27, 1961, at Lat. $33^{\circ} 24' N$ and Long. $65^{\circ} 15' W$. The isotherm depth in this case was approximately 110 ft.

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RESULTS

Run No. 1 was accomplished with both the dispensing apparatus and detecting rig functioning properly, yet no contact was established with the marked waters, though the search continued for more than 4 hours. Some minor delays of an operational nature were experienced which accounted for perhaps 10 minutes or so of elapsed time in addition to that allotted for securing the dispensing rig.

A normal elapsed time of approximately $\frac{1}{2}$ hour is expected between the cessation of dispensation and the arrival at the first crossing site. This is an unavoidable time delay, comprised of the following three time intervals:

1) The ship must first slow down to about 1 knot so that drag on the dispensing line is low enough to allow retrieval by the bow winch. This takes about 5 minutes. This length of time cannot be shortened by reversing thrust due to the presence of the detection rig aft of the ship.

2) An additional 3 minutes are required to free the dispensing rig from the water completely.

3) Approximately 20 minutes are required to regain ship's speed, stabilize same at 3.5 knots, and return to the last buoy by making a 270-degree turn.

Some difficulty was experienced with solenoid valves in the dispensing rig during run No. 2. This caused the flow rate of concentrated radiotracer to vary sporadically throughout the dispensation. As a result,

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the vertical sheet of marked waters did not have a uniform concentration of radiotracer at the initiation of the experiment. Quantitative information on horizontal spreading rates was therefore unattainable. However, the primary objective of the experiment was achieved, namely, to test the hypothesis stated in the Introduction. Contact with the marked waters was established on six crossings, the last occurring $3\frac{1}{2}$ hours after dispensation.

Run No. 3 failed completely. During the time between runs Nos. 2 and 3 the condition of the solenoid valves apparently became aggravated, with the result that the dispensation started some few minutes earlier than intended. Marker buoys were therefore lacking, and the entire sample was missed.

DISCUSSION

Isoconcentration curves are shown in Fig. 1 for run No. 2. The ordinate is the depth in feet measured from the sea surface, while the abscissa is the distance in feet along a horizontal line perpendicular to the line of buoys (which marked the original dispensation sheet). The depth of the scintillation counters is indicated by the scale markings on the right for each crossing.

The detection rig could be lowered or raised with little difficulty. Advantage was taken of this capability between crossings, when required. For example, it was evident that on the first crossing the rig had to be lowered somewhat. The automatic readout was very helpful to this end.

It will be noted that crossings No. 3 and No. 4 are absent. These crossings were both made at locations along the dispensing line where radioactive fluid flow rates were greatly reduced due to the difficulties with solenoid valves stated above. Crossing No. 7, on the other hand, shows concentrations much higher than either crossing No. 6 or crossing No. 8. This crossing was made at a location along the dispensing line where the radioactive fluid flow rate happened to be unusually high.

Only on crossing No. 7 was the detection rig positioned at the correct depth so as to embrace the entire vertical breadth of marked waters. This crossing shows that the sheet of marked waters, which was originally 30 ft high, spread to about 60 ft some 3 hours after dispensation. Prior crossings indicate that this amount of vertical spreading may have

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been achieved much earlier.

A vertical subsidence of marked waters, of about 25 ft, is also evident at this crossing, though prior crossings indicate that this may also have occurred much earlier.

In Fig. 2 are shown the isoconcentration curves reprinted from Mass Transport in the Wake of a Submerged Submarine.¹ It will be recalled that this experiment was carried out by dispensing radiotracer material from the keel of a submarine. The striking similarity between the curves in Figs. 1 and 2 bears out the contention that oceanic turbulence may well be the dominant mechanism in the spread of marked waters associated with the passage of a submerged submarine.

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INTERFACE EXPERIMENT

The failure to identify positively the marked waters in run No. 1 suggested that exceedingly rapid dispersion may have occurred during the first $\frac{1}{2}$ hour after dispensation. Inasmuch as this run was executed at the interface between the isotherm and thermocline and evidence was building up which suggested the existence of long-period internal waves, an explanation for the disconcerting results came to mind. It was reasoned that, if internal waves were indeed present, the likelihood of velocity shear at and near the interface was high. Accordingly, a hastily conceived and somewhat crude experiment was devised to test this possibility.

A series of hourly BT's was taken over a period of 32 hours. Throughout this period, every attempt was made to maintain the ship in a fixed position. It is estimated that uncertainties in ship's longitude were about 1 mile, while uncertainties in latitude were much less than this. A plot of the observed isotherm depth vs time is shown in Fig. 3.

At the end of the first full day's observations, six sea-anchored buoys were prepared, three so that the anchors would be located at a depth of 120 ft and three, at a depth of 80 ft. These were launched on a straight-line course approximately 600 ft apart, at 0630 hours on August 25, 1961, a short time after the isotherm depth had reached 100 ft. The launching time is indicated by the vertical arrow in Fig. 3. It may also be seen there that the isotherm depth increased steadily for $2\frac{1}{2}$ hours prior to the launching time after achieving a minimum value of 60 ft. The isotherm

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depth continued to increase for about $\frac{1}{2}$ hour following the launching time.

Thus, buoys Nos. 1, 3, and 5 were anchored in the thermocline, and buoys Nos. 2, 4, and 6 were anchored in the isotherm. Their relative positions were observed from the bridge of the Gibbs by triangulation for $3\frac{1}{4}$ hours. Although the technique is admittedly inaccurate, the results are unmistakable. From the moment of launching to the end of the observation period, buoys Nos. 1, 3, and 5 continued to separate from buoys Nos. 2, 4, and 6, although there was considerable variation in direction and speed of movement. The general direction of movement was judged to make an angle of about 45 degrees with the original placement line.

The rms pair separation (S_{rms}) is plotted against time in Fig. 4. The rms pair separation velocity average during the first hour, shown in Fig. 4, was 20 ft/min. The decrease in pair separation velocity observed after the first hour is consistent with the fact that the isotherm depth ceased dropping shortly after the buoys were launched. In view of the observed velocity shear at the interface, it is not unreasonable to ascribe the failure of run No. 1 to this effect.

CONCLUSIONS

From the results of these experiments, one may conclude that

1) Wake turbulence from a submerged submarine in isothermal waters (approximately 0.5°C per 100 ft) is a relatively unimportant mechanism for mass transport beyond the first 15 minutes or so after passage. This situation is not far different from the dispersion of vapor trails from high-flying jet aircraft, and

2) The detection of wake material may possibly be avoided by cruising at the interface between the isotherm and thermocline.

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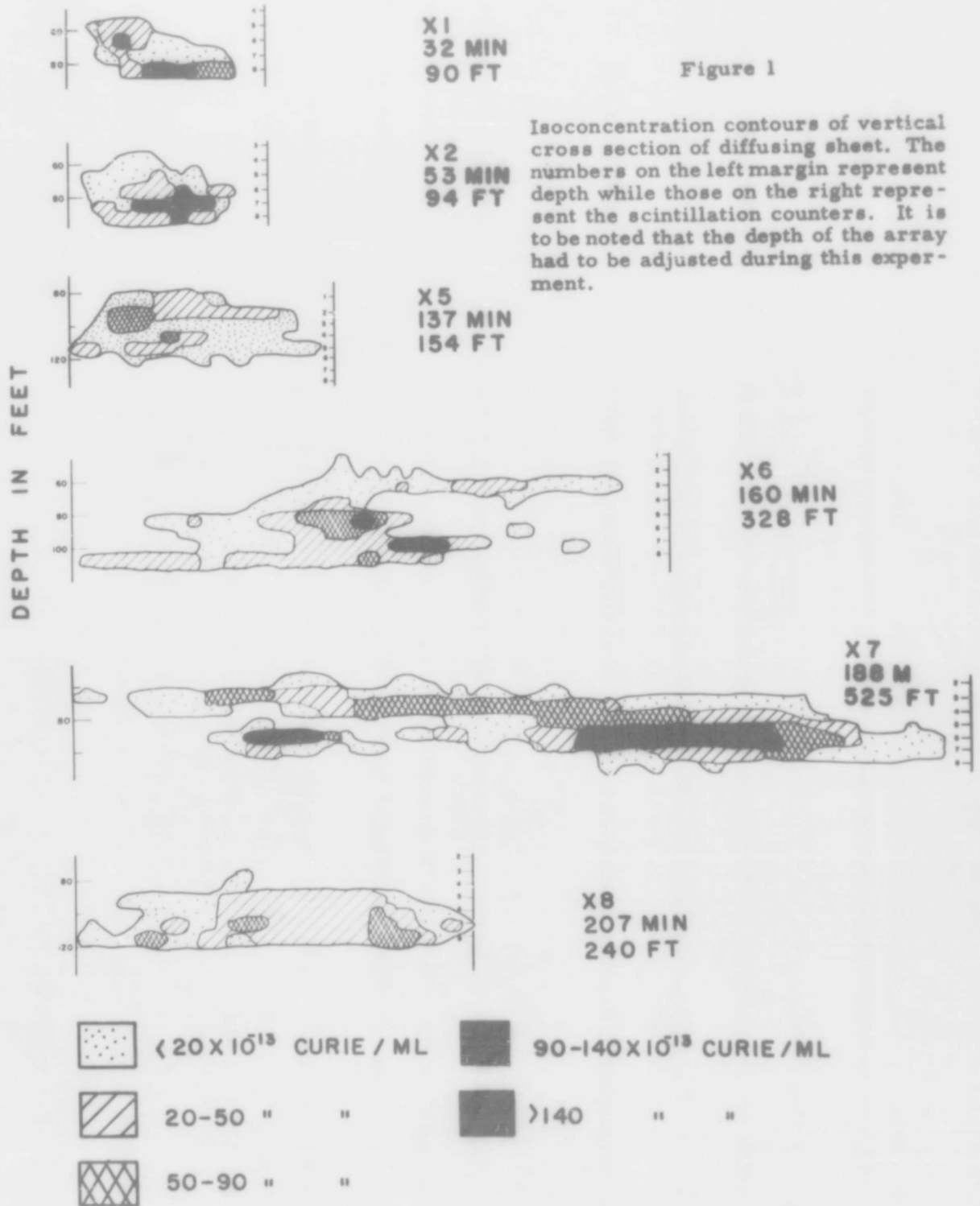
ACKNOWLEDGEMENTS

Special thanks are due to Mr. Robert Zuraw, who designed much of the electronic equipment and whose efforts during the experiment were largely indispensable. We are grateful for the help of Mr. Eugene Imbimbo in the preparation of the scintillation counting detectors and in the analysis of the data. We also wish to thank Mr. Seymour Adler for his help in designing and operating the dispensing rig.

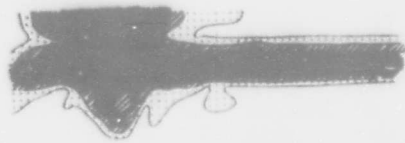
The cooperation of Mr. Philip Lorio, Health Physics Officer of Columbia University, is deeply appreciated.

Finally, we should like to express our thanks to Captain Salmon of the Gibbs, who performed the intricate ship maneuvers with great skill on very short notice.

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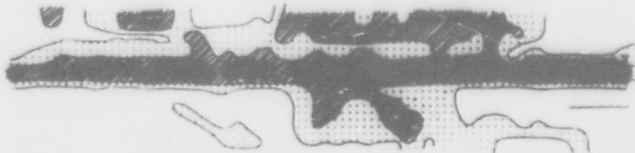
X1
36 MIN
220 FT

Figure 2

Isoconcentration contours of vertical cross section of a submerged submarine wake. This run was made at a keel depth of 100 ft and the depth of the array was the same for all crossings.



X2
44 MIN
175 FT



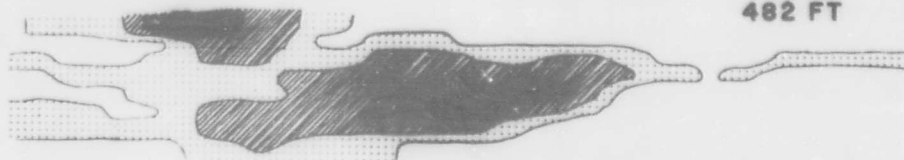
X3
69 MIN
350 FT



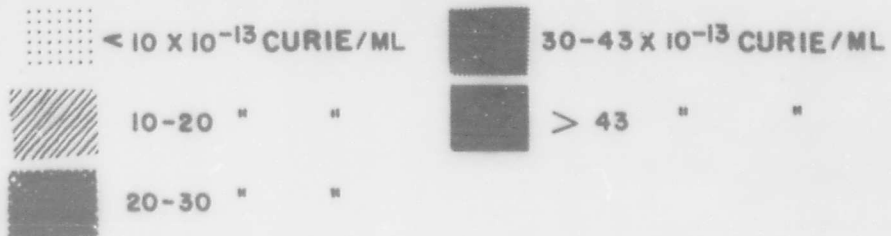
X4
79 MIN
222 FT



X5
90 MIN
341 FT



X6
108 MIN
482 FT



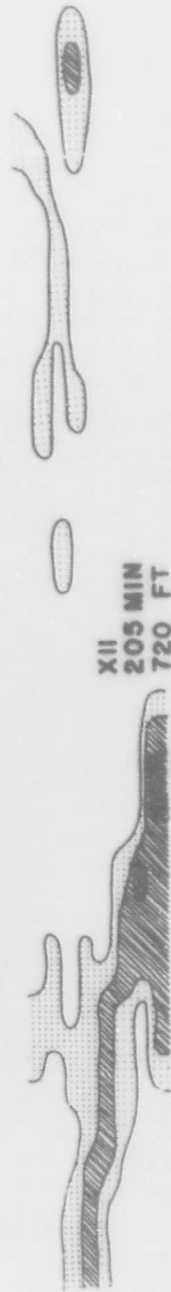
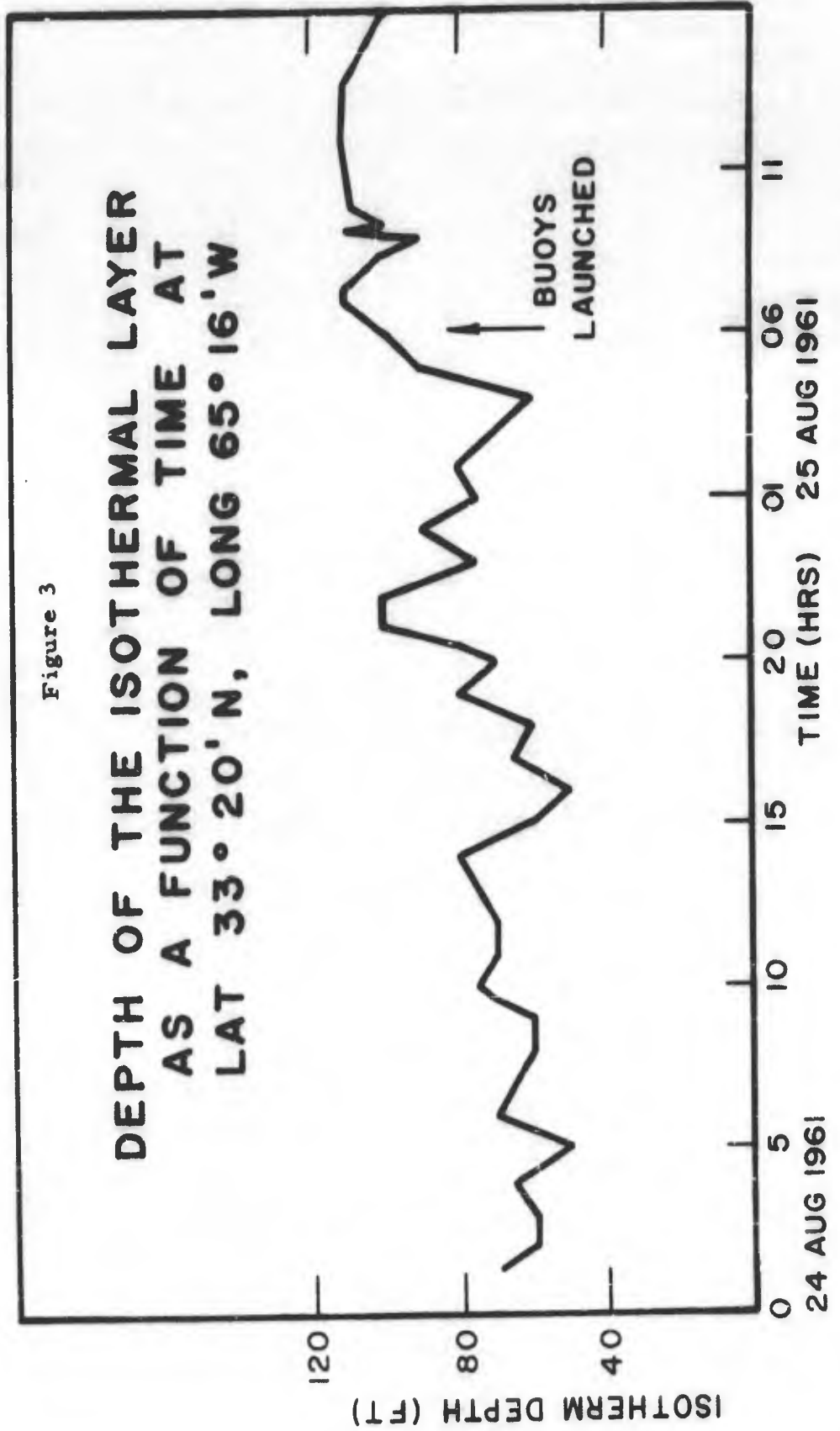
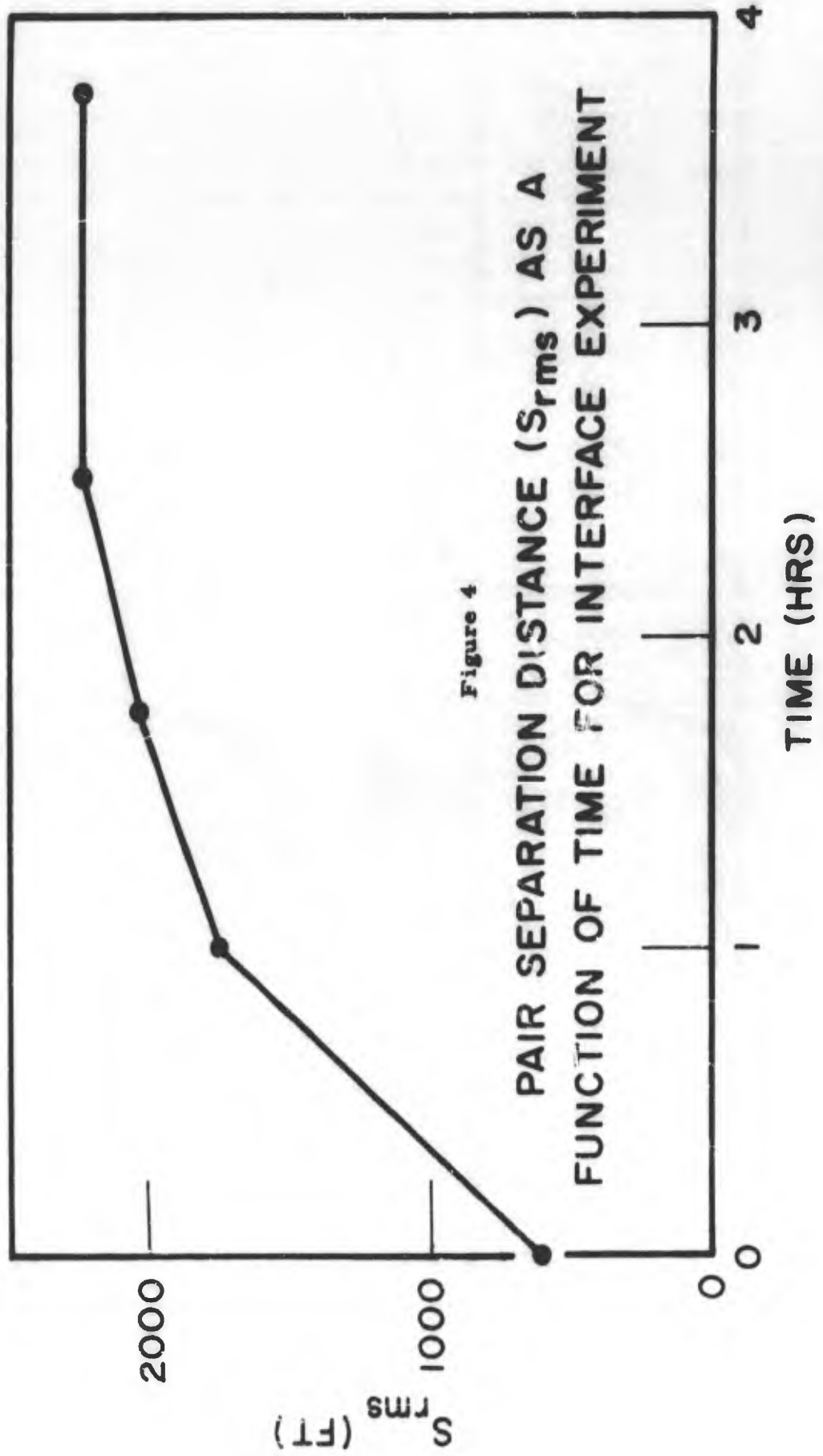


Figure 2 (continued)





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In a previous experiment mass transport in the wake of a submerged submarine was studied. Results indicated that after the initial few minutes local turbulence induced by the ship's screws was of relatively minor importance in the spreading. Ordinary oceanic turbulence appeared to be the dominant mechanism.

An experiment was designed to test this hypothesis: A thin, vertical sheet of radiotracer was dispensed from a towed line source. The marked waters were probed, as in the prior experiment, by a towed, vertical array of scintillation counters. The similarity of the diffusion patterns from the two experiments strongly supports the above hypothesis.

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- III. Schimmel, H.
- IV. Contract Nonr-266(84)

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