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THESIS

AN EXPENDABLE MEASURING DEVICE
FOR LIGHT ATTENUATION IN THE OCEAN

by

Glen Dean Snyder

June 1975

Thesis Advisor: Sydney H. Kalmbach

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An Expendable Measuring Device for Light Attenuation in the Ocean

by

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ABSTRACT

The feasibility of an inexpensive expendable device for determining the diffuse attenuation coefficient k for downwelling irradiance in ocean waters is investigated. A suggested instrument for such measurements is a modified standard US Navy Expendable Bathythermograph (XBT) probe used in conjunction with an unmodified launcher and recorder. Information gained from such a device would rapidly supplement existing inadequate data and could be utilized by tacticians in determining the capabilities of underwater optical systems to a higher degree of certainty than presently possible. In addition such a probe could be used by fisheries biologists to calculate euphotic depths and to improve standing phytoplankton crop estimates.

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ACKNOWLEDGEMENTS

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I. INTRODUCTION

A. GENERAL

The optical characteristics of water have long been of interest to man and perhaps started with his observation of reflections from smooth surfaces. His next problems may have been catching fish which were never in the positions where they appeared to be and viewing objects in turbid waters.

Light which penetrates below the surface of the ocean is the single source of energy for photosynthesis, and it allows fish and man alike to observe their surroundings. But how far can one detect an object in water? To predict that distance, one must know the illumination of the light source, which may be a lamp or sunlight, the object's reflectivity, its contrast with the background, the concentration and type of suspended scattering particles, and many other variables.

Measuring the transparency of water seems first to have been the idea of a certain Captain Bérard. He observed a dish caught in a net at a depth of 40 meters during operations off the Mulgrave Islands and Wallis Island. The head of the Papal Navy in 1865 was Commander Cialdi who was also interested in the ocean's transparency and the theory of wave movements in the sea. His approach was more scholarly than military, and he employed Professor P. A. Secchi to organize and supervise a scientific program of observations [Tyler, 1968]. In the report of this work Secchi examined the effect of several variables on disc visibility. Among these variables were disc size and whiteness, the sun's altitude, and the ship's shadow. He also observed the effect of the color of the water and of the disc, the clearness of the sky and the height of the observer above the water. The experimental procedure for obtaining water "transparency"[1] with the Secchi disc, as it is now called, was thereby established.

Much research has taken place since those early measurements but inconsistencies in Secchi disc data still occur [Tyler, 1968 and Williams, 1970]. Many ocean areas of naval interest lack sufficient Secchi disc data to make possible reasonable predictions of water transparency. At best these data are semi-quantitative, and in some large ocean areas, notably the central South Pacific Ocean, are extremely scarce [Frederick, 1970].

The characterization of natural waters is becoming more important as food needs of the world increase. To represent these waters in terms of energy available for photosynthesis requires knowledge of the photosynthetic response spectrum of the phytoplankton in the water. Pickett and Myers (1966)

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[1]Transparency, sometimes called visibility, as measured by a Secchi disc is the average of the depths in meters at which the disc disappears and reappears.

show that this photosynthetic response spectrum changes with irradiation levels the response spectrum is not dependent on wavelength. R. C. Smith (1968) felt that the best method to characterize water with respect to energy available for photosynthesis is in terms of the total energy between 350-700 mμ. Williams (1970) also made reference to a "weighted average" vertical extinction coefficient.

We know, however, for different areas, time of year and time of day, certain wavelengths are attenuated more than others. This is quite important militarily. A submarine commander must consider water transparency when selecting operating depths to avoid visual detection by patrol aircraft or surface-craft. New optical communication and detection systems such as SAOCS (Submarine/Aircraft Optical Communications System), ORICS (Optical Ranging Identification and Communications System), and ORADS (Optical Ranging and Detection System) all depend on such "windows" (regions in the visible spectrum in which attenuation is low) for optimum performance. In a report on ORADS the Naval Undersea Center, San Diego (1973), refers to water transparency as the dominant factor in determining operational depth limits and average power requirements. For SAOCS and ORICS the submarine commander must know the reliability of his communications link as a function of depth just as the aircraft commander must know the detection capability of his ASW equipment, both of which depend on the diffuse attenuation coefficient k[1]. To determine these windows k must be known on a seasonal basis for each ocean operating area.

A great deal of data has been gathered on the values of k during different times of the year in different ocean areas, but to date this information is still inadequate. Ocean areas have been categorized by Jerlov (1968) and a value of k associated with each area, but again this is a gross approximation and varies considerably throughout the year, and it is not sufficient to make accurate predictions of underwater optical system capabilities.

Poole and Atkins (1929) developed a widely used empirical formula relating Secchi disc depth (Z_s) and the irradiance coefficient k:

$$k \doteq 1.7/Z_s \qquad (1\text{-}1)$$

where Z_s is the measured depth in meters. This indicates that the illumination at the Secchi depth is about 16%. Gall (1949) confirmed these figures but with ranges from 16% to 25%. Holmes (1970) studied turbid coastal waters and proposed that the 1.7 of the Poole-Atkins relation be reduced to 1.44 in such cases. Based on Holmes' observations, determination of k from Secchi depth data might be off by 22% and still not be the coefficient associated with the wavelength of interest.

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[1]See Appendix A for the definition of k and other terminology used later in the text.

B. THE PROBLEM

The problem is that seasonal diffuse attenuation coefficient data is not available in ocean areas of operational interest in such quantity as to allow prediction of underwater optical system performance. To gather such data currently requires an expensive operation utilizing a vessel totally devoted to oceanographic tasks, and such vessels are few in number.

C. PURPOSE

The purpose of this investigation is to determine the feasibility of producing a low cost device for adequately measuring the diffuse attenuation coefficient which can be easily adapted to current naval vessels and which can be operated by naval personnel with minimal or no training in its operation.

II. NATURE OF THE PROBLEM

A. DETERMINATION OF k

1. Why Determine k

If one considers a communication or detection system utilizing the passage of energy through any medium there is attenuation. For a beam of light in water this consists of absorption of energy by the medium and scattering of energy out of the beam path by particles suspended in the medium and by the water itself as well as material dissolved in it. The relationship observed for light in water is exponential:

$$E_z = E_o \, (\exp) \, -k\Delta z \qquad (2\text{-}1)$$

where

E_o = irradiance at the surface or some reference point

E_z = irradiance at a depth z (in meters)

Δz = change in depth from the reference point

k = diffuse attenuation coefficient (or vertical extinction coefficient) which is a combination of absorption and scattering (m^{-1}).

For a given set of system parameters including power output and receiver sensitivity k must be known to determine the maximum range of the system.

2. <u>Determining k</u>

Since the early 1930's, electro-optic means have been available for determining k quite accurately and such means are employed by practically all hydro-optical expeditions [Timofeeva and Gorobets, 1967]. From Eq. (2-1) it is seen that

$$k = \frac{\ln (E_o/E_z)}{\Delta z} \qquad (2\text{-}2)$$

In practice the measurement of k involves lowering a photometer to various depths while light levels are recorded and the ship is dead in the water, or nearly so. Much time and money could be saved if a lightweight expendable sensor could be used by a ship underway at moderate speeds.

B. REQUIREMENTS

The requirements of such a system are as follows:

1. It must be capable of providing large quantities of data in a relatively short time.
2. These data must be as accurate or more accurate than those now provided.
3. The system must be of low cost and easy to operate.
4. Data provided must be from ocean areas of operational importance.

Additional criteria could be set forth, but this set is a minimum for a viable system.

III. POSSIBLE SOLUTION

A. USE OF EXISTING EQUIPMENT

The Expendable Bathythermograph (XBT) System, a device which measures water temperature as a function of depth and records this on graph paper, is currently in use on virtually every sonar equipped vessel. If an expendable light sensor could be designed to utilize the existing recording and launching systems of the XBT, then k could be determined with no more time or expense than obtaining an XBT measurement. Such a sensor is herein proposed, whose cost is comparable to the XBT (about $20.00) and which is easy to operate. The probe could easily be adapted to whatever wavelength is of interest, perhaps using the water types described by Jerlov as a guide. The number of data-gathering vessels and the ocean areas probed would be sufficient to provide the quantity of data required.

IV. EXPERIMENTAL PROCEDURE

A. MODIFICATIONS

1. Basic Operation of the XBT

The basic operation of the Sippican XBT system is that of a bridge circuit error signal being sent to a servo system as a positioning signal for a stylus. The result is a graphic record of temperature versus depth. The functional block diagram is shown in Figure 4-1. Timing and mode control are automatic. Upon insertion of a canister with its probe into the launcher, the chart drive operates about 2 seconds to align the stylus with the zero depth marker of the chart paper. Upon entering the water the probe completes the bridge circuit to ground starting the chart drive motor and timer. After 88 seconds (for 1500 ft drop) the chart drive stops and the system is ready for another XBT to be inserted. During the 88 seconds the stylus has traced out the temperature as sensed by the thermistor mounted in the probe during its constant rate descent. The return signal terminates as the wire breaks when the probe reaches a depth exceeding the available wire length.

2. The Probe

Figure 4-2 is an exploded representation of the probe, canister, and their associated items. The XBT probes can be obtained for maximum depth drops of 660, 1500, 2,500, and 6000 feet. Launch vessel maximum speed

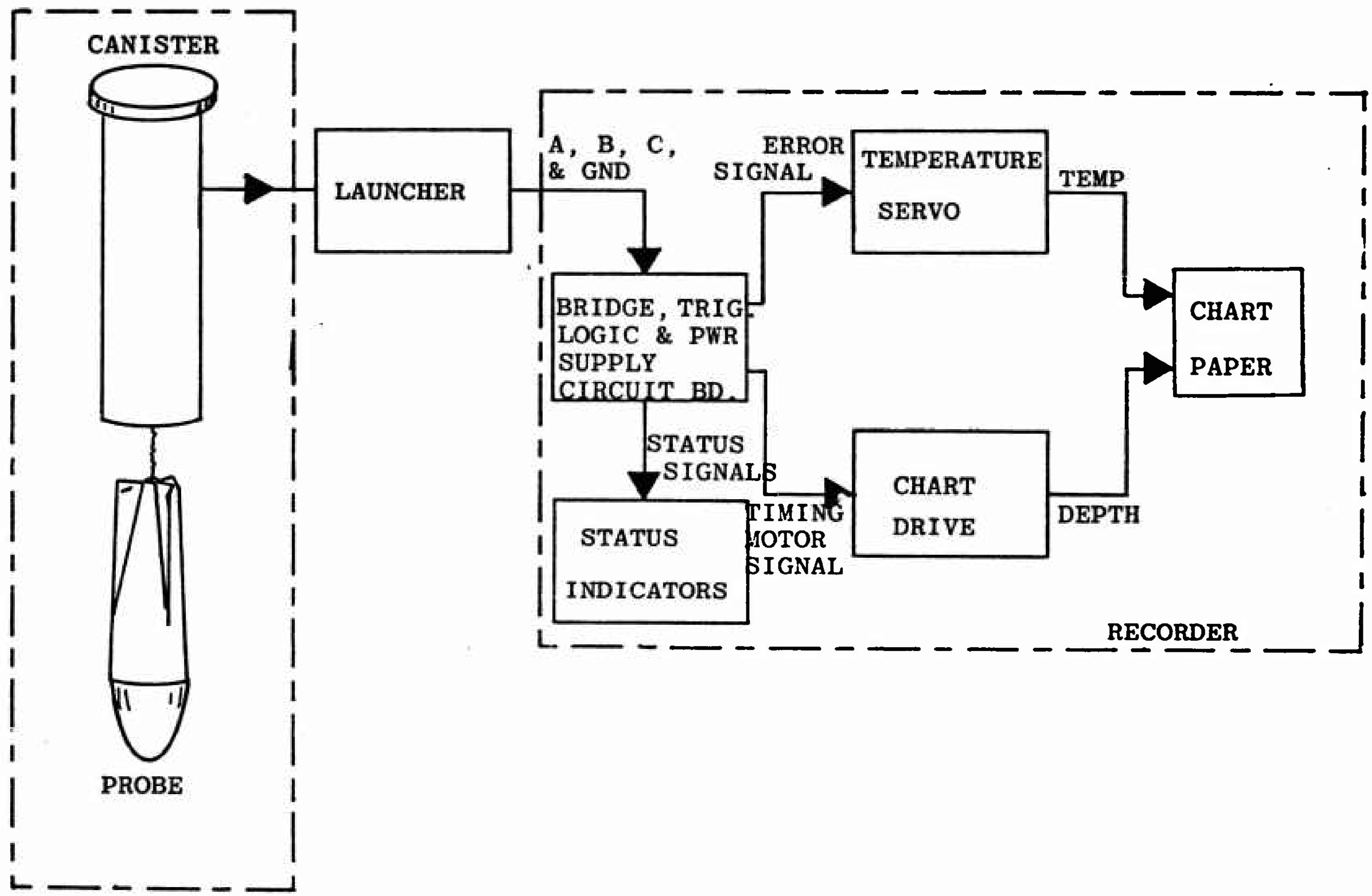


Figure (4-1). OVERALL FUNCTIONAL BLOCK DIAGRAM OF XBT SYSTEM

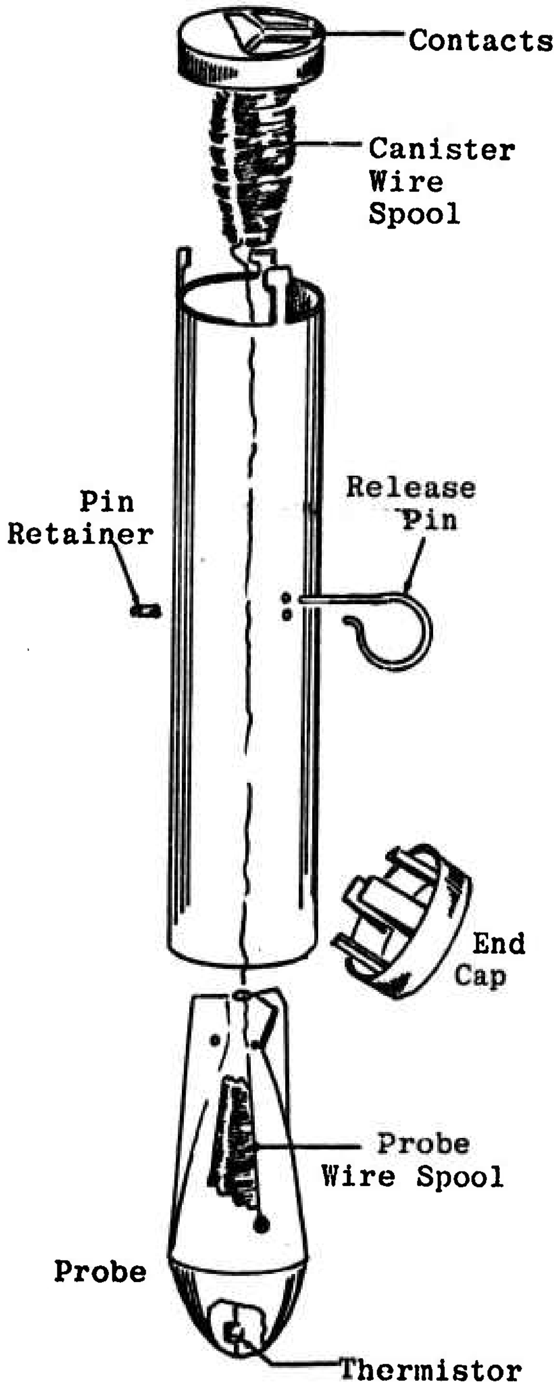


Figure (4-2). XBT PROBE EXPLODED VIEW

requirements vary from 10 knots to 30 knots, depending on the model probe used. The probe wire unwinds from its spool as the probe is dropped and the canister wire spool allows for ship maneuvers during the drop so that excessive strain is not applied to the fragile wire. Figure 4-3 shows the probe with a photocell mounted.

3. <u>Circuitry</u>

The circuitry to be considered is shown in Figure 4-4a where

R_T = Resistance of the thermistor

R_L = Resistance of the drop wire (approx. 5000 ohms).

A photoconductor was considered the simplest replacement for the thermistor, so a photocell whose resistive parameters most nearly corresponding to those of the thermistor was sought.

Two probes were tested to determine their resistance versus temperature characteristics. The results are shown in Figure 4-5. A slope α was determined from this plot:

$$\ln R_1 - \ln R_2 = \alpha(T_1 - T_2) \tag{4-1}$$

which gives:

$$\alpha = \frac{\ln (R_1/R_2)}{T_1 - T_2} \tag{4-2}$$

In the circuitry of the recorder exist three calibration resistances corresponding to -1.1°, 16.7°, and 34.4°C. Using the values of these resistances and their corresponding

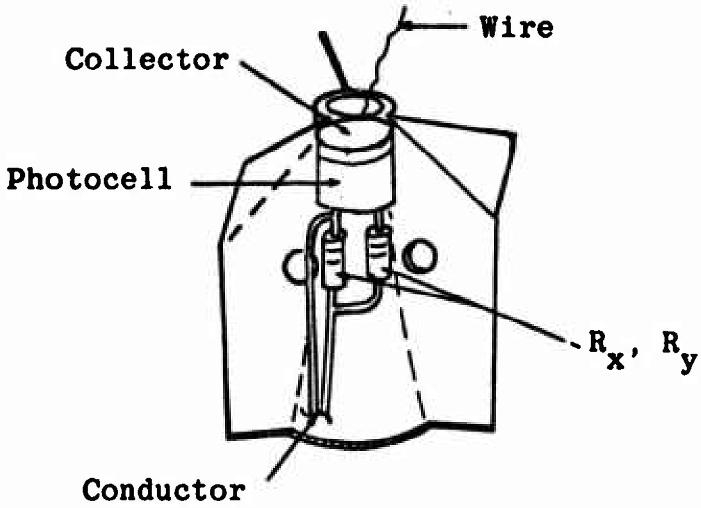
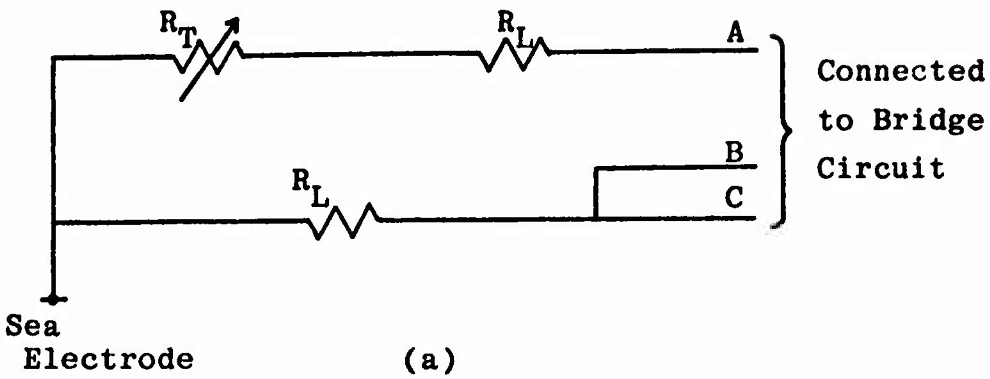


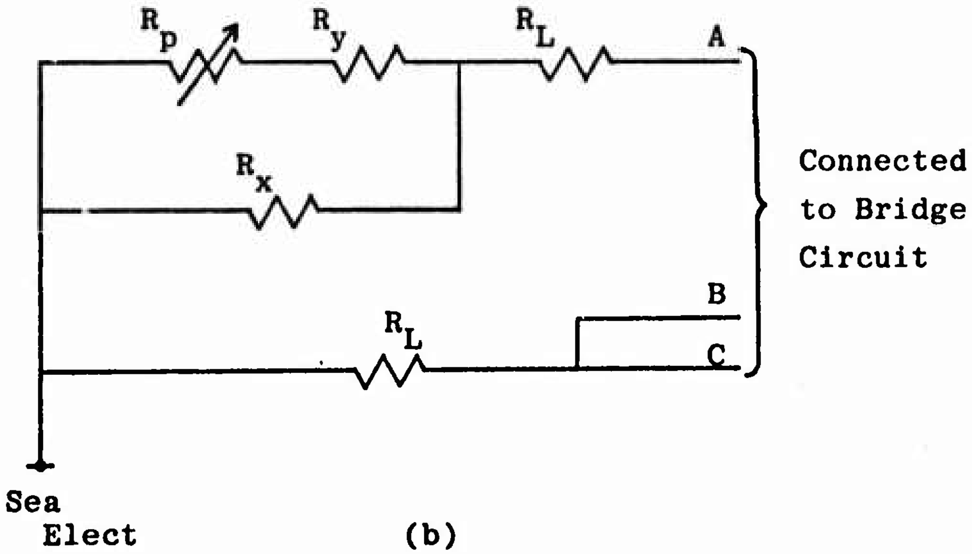
Figure (4-3). MODIFIED XBT PROBE, LIGHT SENSOR INSTALLED.

UNMODIFIED XBT PROBE CIRCUIT



(a)

MODIFIED LIGHT-SENSING CIRCUITRY



(b)

Figure (4-4). PROBE CIRCUITRY

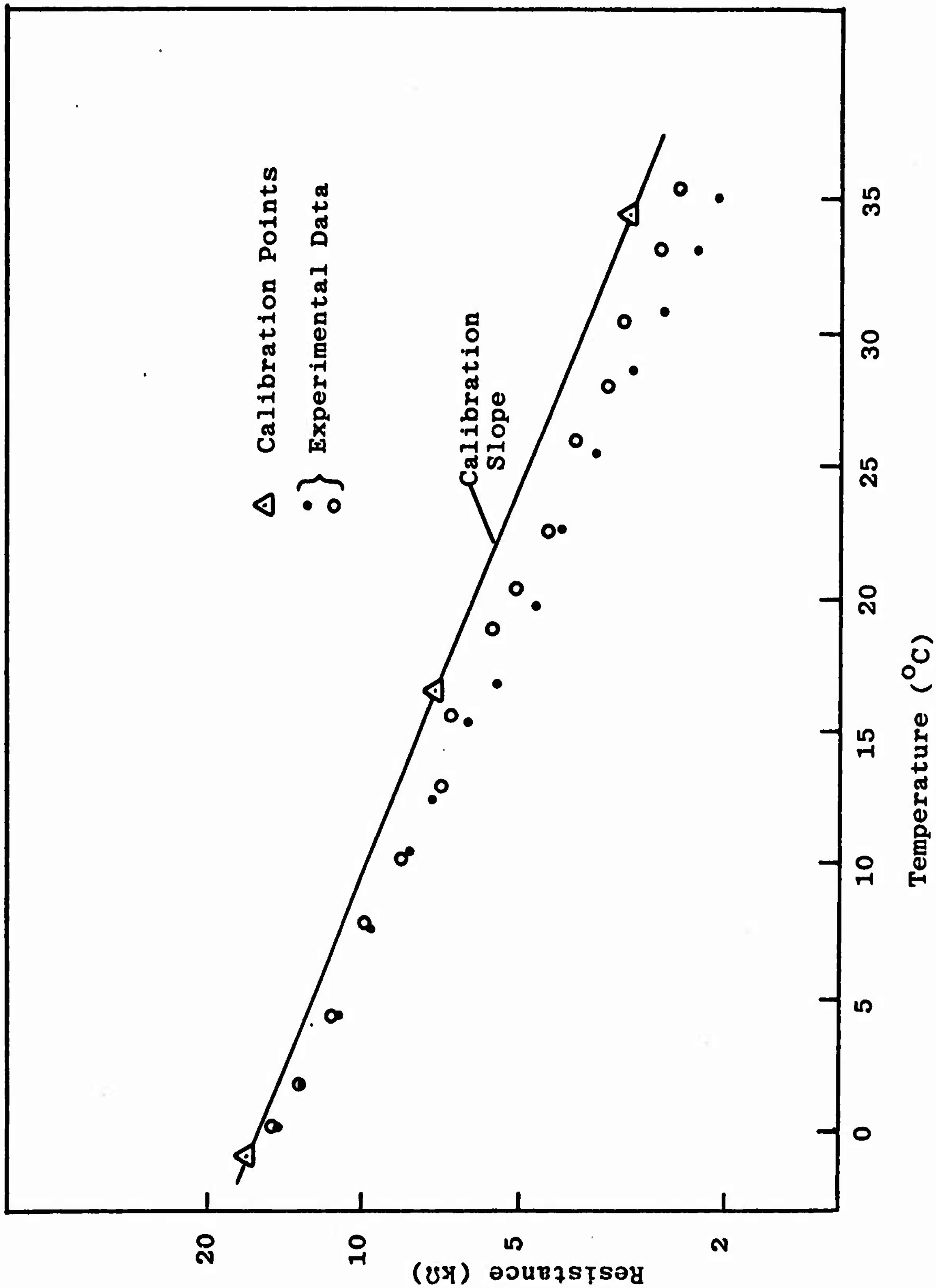


Figure (4-5). THERMISTOR TEMPERATURE RESPONSE, Resistance vs Temperature (Semi-log).

temperatures in Eq. 4-2 gave a slope of -0.0483 $^{o}C^{-1}$. These points constitute the straight line above the experimental data.

From the XBT recorder technical manual it was determined that the maximum and minimum values of thermistor resistance were about 17 kΩ and 3050Ω respectively. These values compared favorably with those of Figure 4-5. No photocell resistance range of such limited scope could be found so an adaptive modification was attempted.

Leg A of the circuit in Figure 4-4a had a maximum resistance of about twenty-two Kohms (R_L + R_T) and a minimum value of 8050 ohms for the thermistor; this leg must also have these values for the photocell circuit to conform to limiting stylus positioning signals. The simple circuit of Figure 4-4b was adopted and the following equations solved for R_x and R_y:

$$(R_{PM} + R_y)R_x/(R_{PM} + R_y + R_x) + R_L = 22 \text{ k}\Omega \qquad (4\text{-}3)$$

$$(R_{pm} + R_y)R_x/(R_{pm} + R_y + R_x) + R_L = 8050\Omega \qquad (4\text{-}4)$$

R_{PM} = maximum resistance of the photocell, 55 kΩ @ 0.25 fc

R_{pm} = minimum resistance of the photocell, 670 Ω @ 100 fc.

From these values the unknowns were

R_y = 2822 Ω

R_x = 24.08 kΩ

It must be pointed out that the photocell maximum and minimum values are arbitrary. These values were determined after selecting photocell CL-505 from Clairex Corporation of New York, testing the cells using a Weston Illumination Meter and comparing the results with published data (see Figure 4-6). Selection of the CL-505 was also based on temperature stability, wavelength sensitivity (nearest to the human eye) and size. A few of the cells were pressure tested to the equivalent depth of 350 feet with no apparent physical damage or change in conductive characteristics.

The circuit of Figure 4-4b was assembled and tested on deck with satisfactory results, including time response, which was limited by recorder stylus travel time rather than by photocell response time. The recorder gave full scale deflection in 1.5 seconds, which corresponds to 31 ft of probe travel for the XBT. The modified probe will travel slightly slower.

4. Cosine Collector

Since the k to be determined is for downwelling light, it was important to know the response of the sensor to light at angles relative to the normal to its surface. To accomplish this, a cosine collector [Tyler and Smith (1970)] was constructed of type W-2447 white plexiglass manufactured by Rohm and Haas. The collector consisted of a wafer of thickness 0.125 inches and attached as shown in Figure 4-7.

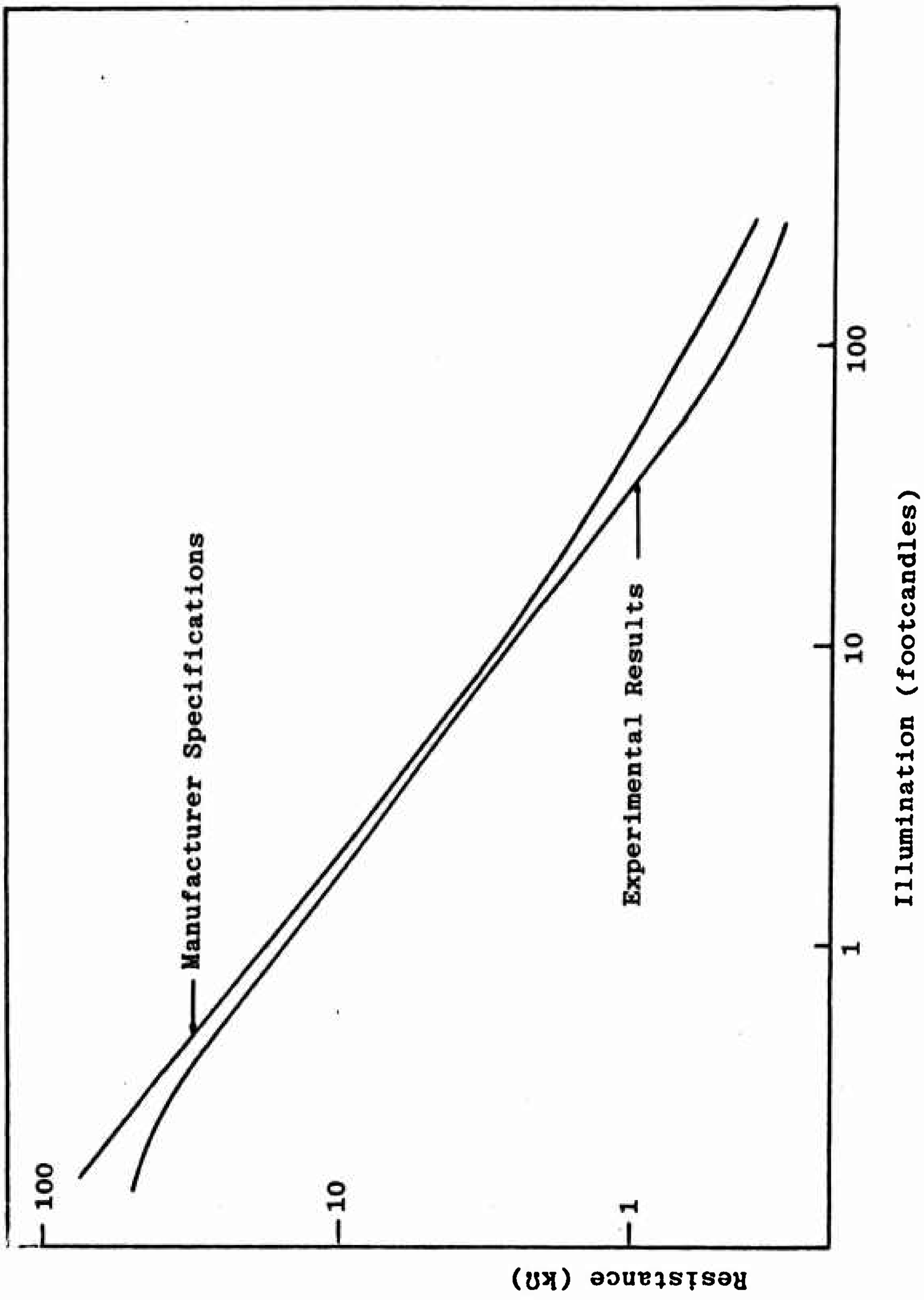


Figure (4-6). PHOTOCELL (CL-505) RESPONSE, Resistance vs Illumination (Log-log).

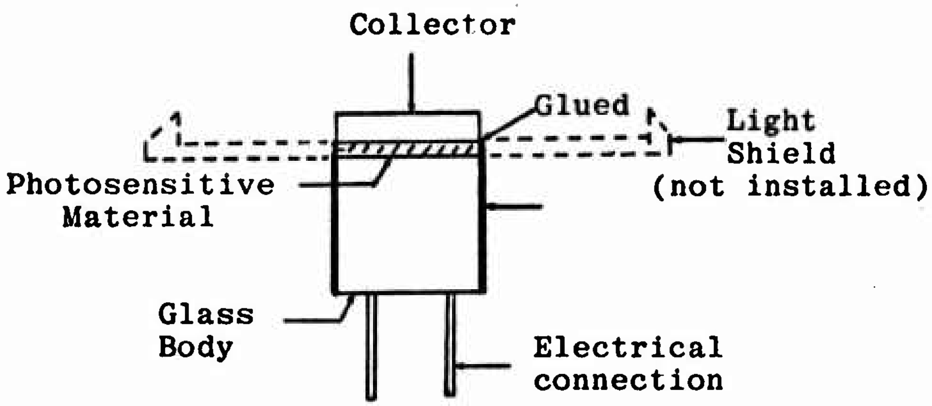


Figure (4-7). PHOTOCELL AND COSINE COLLECTOR

Due to space limitations a light shield at the base of the collector was not installed.

A photocell and collector unit was tested by submerging it in tapwater in the downwelling beam of a mercury lamp and inclining the unit within the beam to obtain cell response. Care was taken to assure the cell remained at the same depth below the surface and at the same position within the light field. As can be seen in Figure 4-8, even with a hand fashioned collector and experimental inaccuracies, the response is very nearly cosine. Certainly with a slight change of design to include a light shield, careful machining and quality control processes, the errors can be made negligible. Tyler and Smith point out that error introduced by the irradiance collector will have little effect on the calculated values of the diffuse attenuation coefficient since k values depend only on the ratio of two downwelling values of irradiance.

A collector/CL-505 photocell unit was attached alongside the sensor of a Submarine Photometer Model No. 15MO2 made by G. M. Manufacturing & Instrument Company of New York (which also uses a Weston Photronic cell Model 856, Type YR). The CL-505 photocell and G. M. photometer were lowered simultaneously through the water, while a third sensor monitored skylight irradiance for changes. The results are plotted in Figure 4-9. As can readily be seen, the CL-505 photocell compares favorably with the G. M. photometer in measuring k under these conditions, if the experimentally

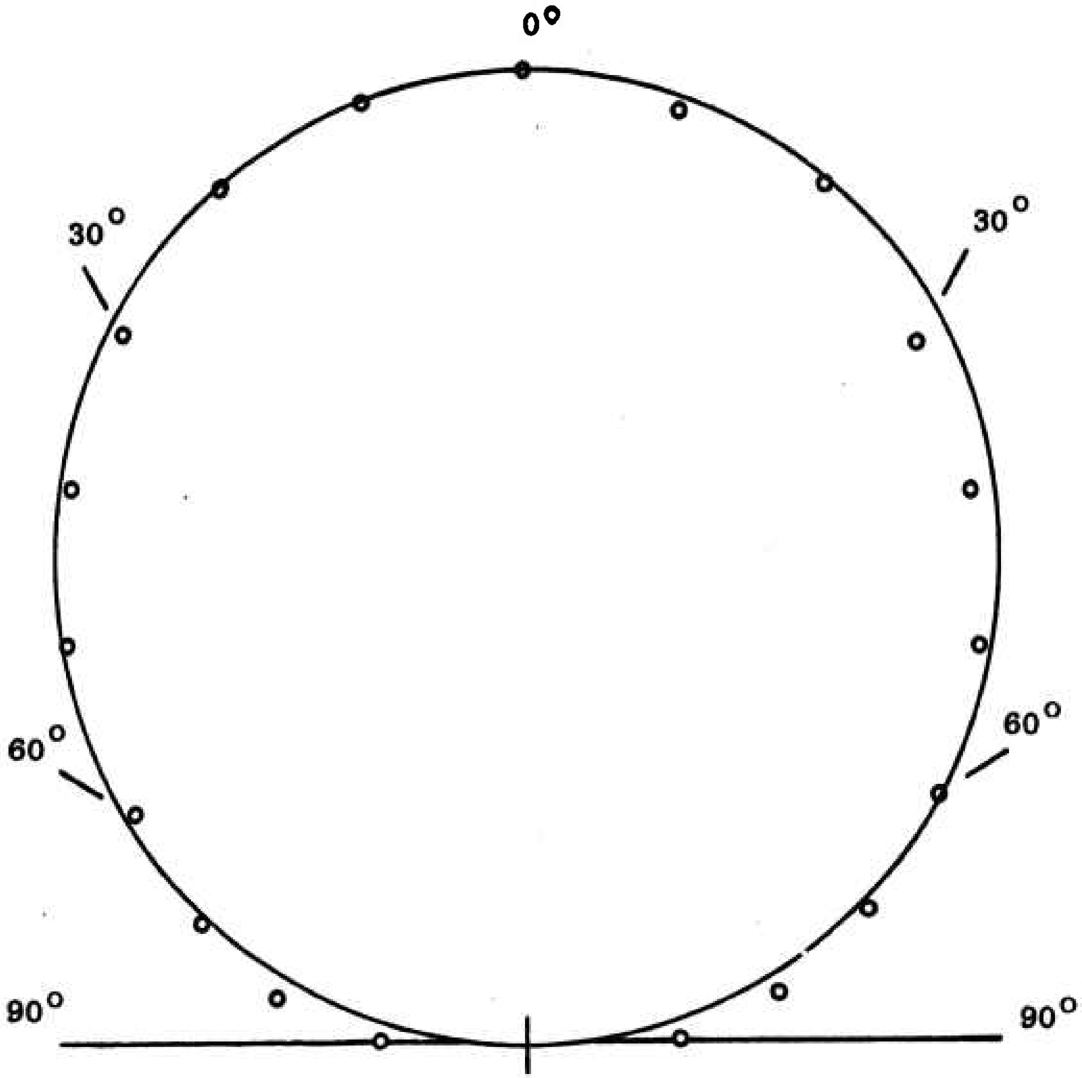


Figure (4-8). COSINE COLLECTOR RESPONSE

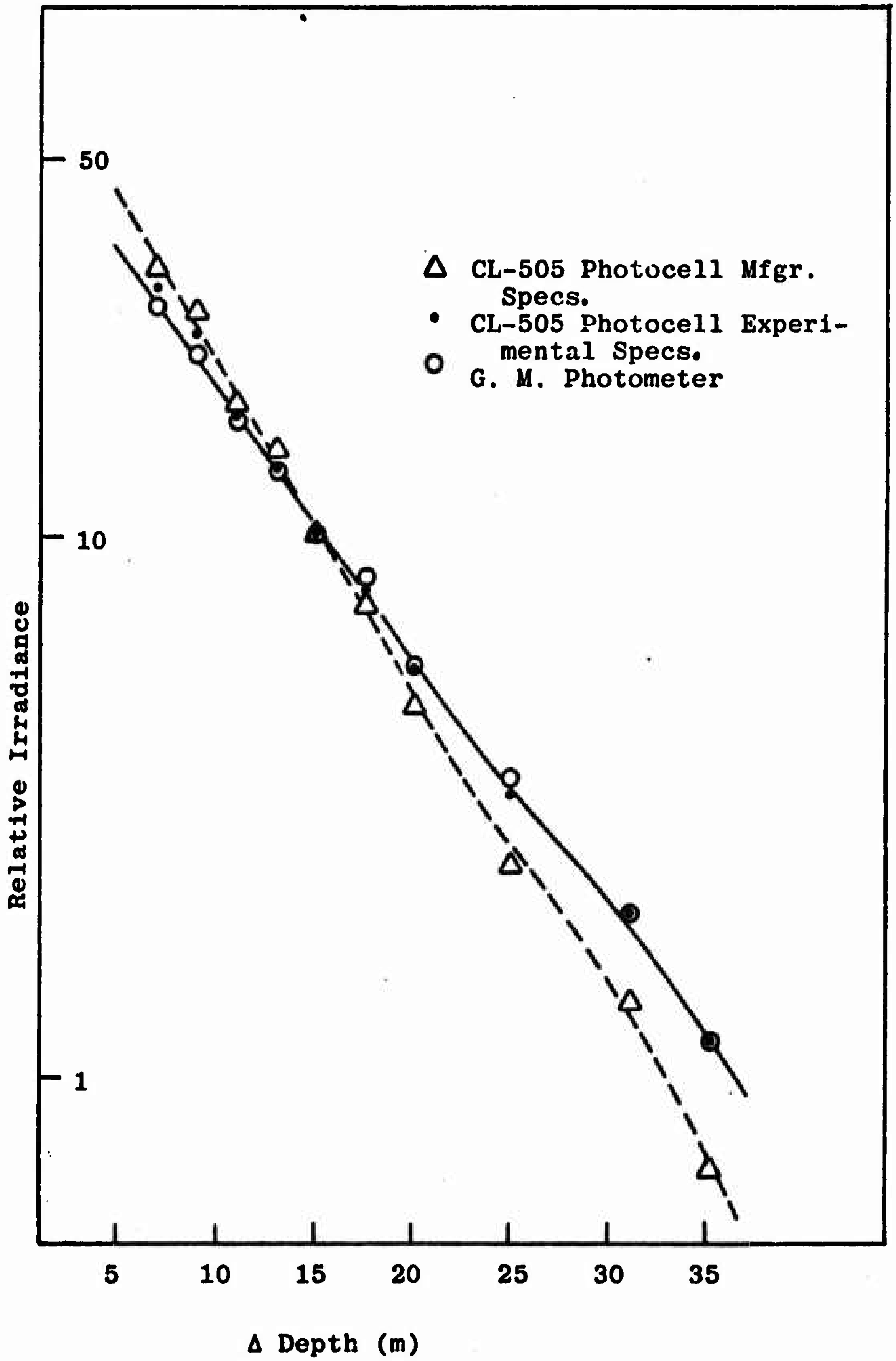


Figure (4-9). COMPARISON OF CL-505 PHOTOCELL AND G. M PHOTOMETER RESPONSES UNDERWATER, Irradiance vs. Depth (Semi-log).

determined CL-505 photocell characteristics are used. When using the manufacturer's characteristics for irradiance versus resistance for the CL-505, a marked difference in k is noted, confirming the difference in spectral responses between the Weston Photronic cell and the CL-505 photocell (see Figure 4-10).

A Wratten No. 58 optical filter was then attached to both the CL-505 photocell and the photometer, and the resultant spectral responses are shown on Figure 4-12. The previous experiment was repeated with filters in place, and excellent results were obtained (Figure 4-13).

5. <u>System Testing</u>

Figure 4-14 shows a plot of E versus Temperature for the circuit values assumed in Section 4.3. From these data k can be determined by obtaining the slope of ln E versus Depth.

A probe was lowered from the Research Vessel ACANIA in turbid harbor water while recording sensor response utilizing the XBT system. These values, read on the temperature chart, were picked off the chart and applied to Figure 4-14 to obtain E and were then plotted versus depth (semi-log) for comparison with photometer values (Figure 4-15). The radius of the photometer data circles in this figure indicate an assumed data error of ±5%. The plot of probe data shows recorder (E) variation during the measurement ±7.5% uncertainty to be discussed later. The readings plus errors

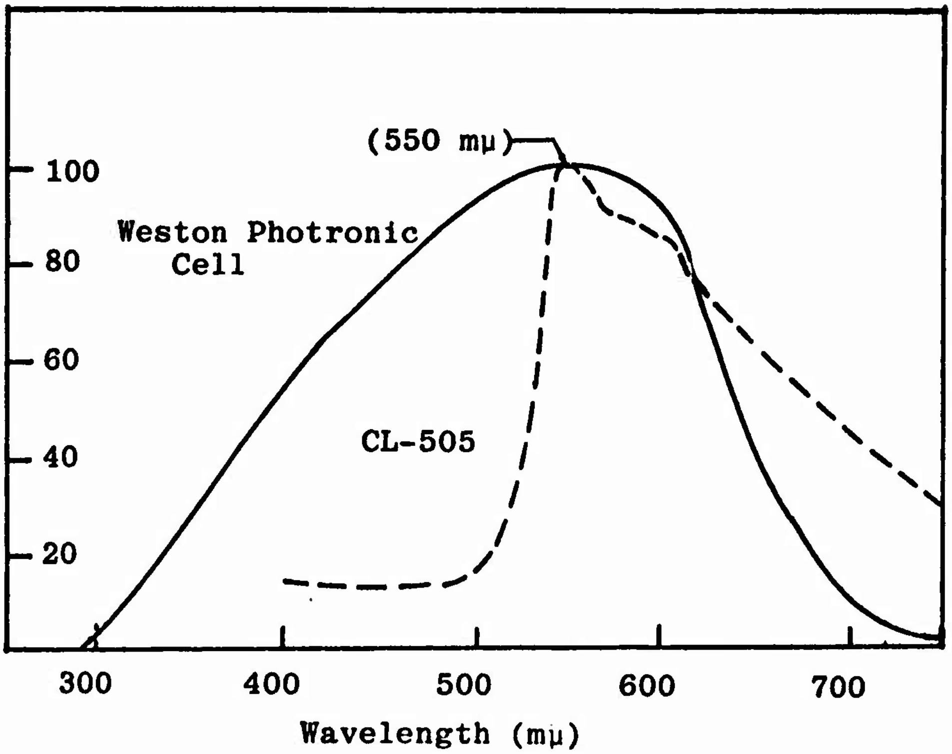


Figure (4-10). SPECTRAL RESPONSE COMPARISON OF WESTON PHOTRONIC CELL AND CL-505 PHOTOCELL

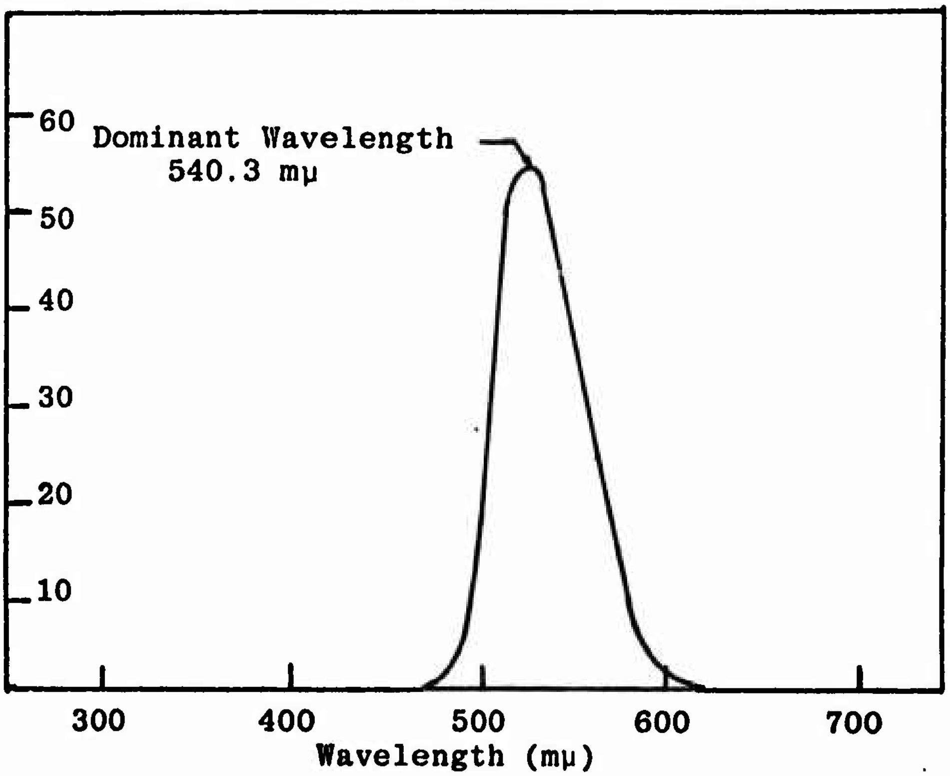


Figure (4-11). SPECTRAL TRANSMITTANCE OF WRATTEN FILTER NO. 58.

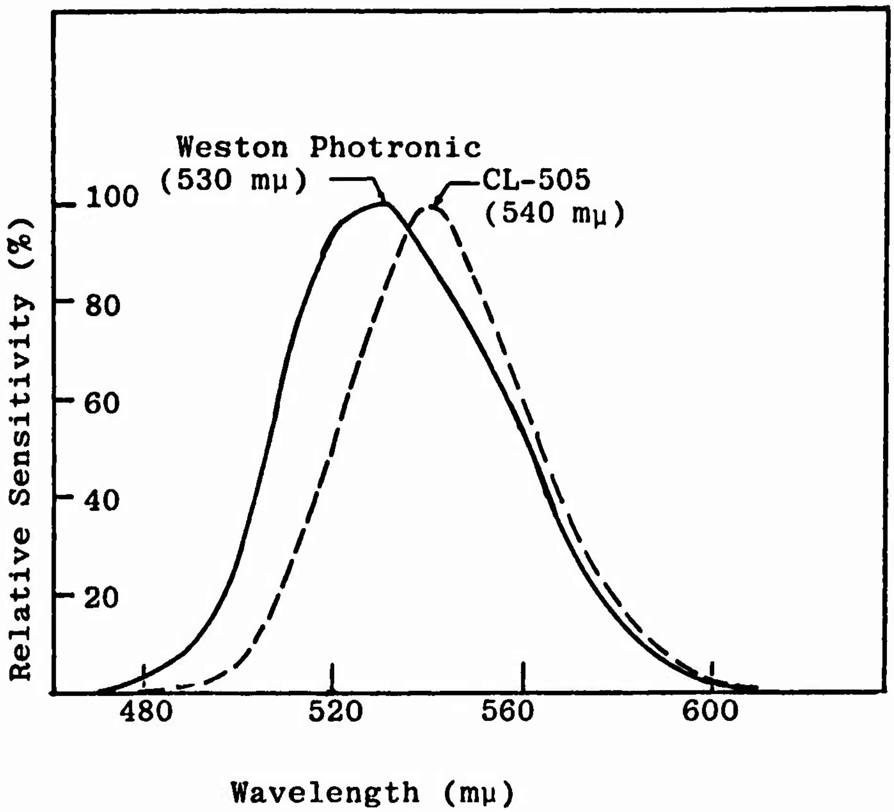


Figure (4-12). SPECTRAL RESPONSE OF WESTON PHOTRONIC CELL AND CL-505 PHOTOCELL WITH WRATTEN NO. 58 FILTER.

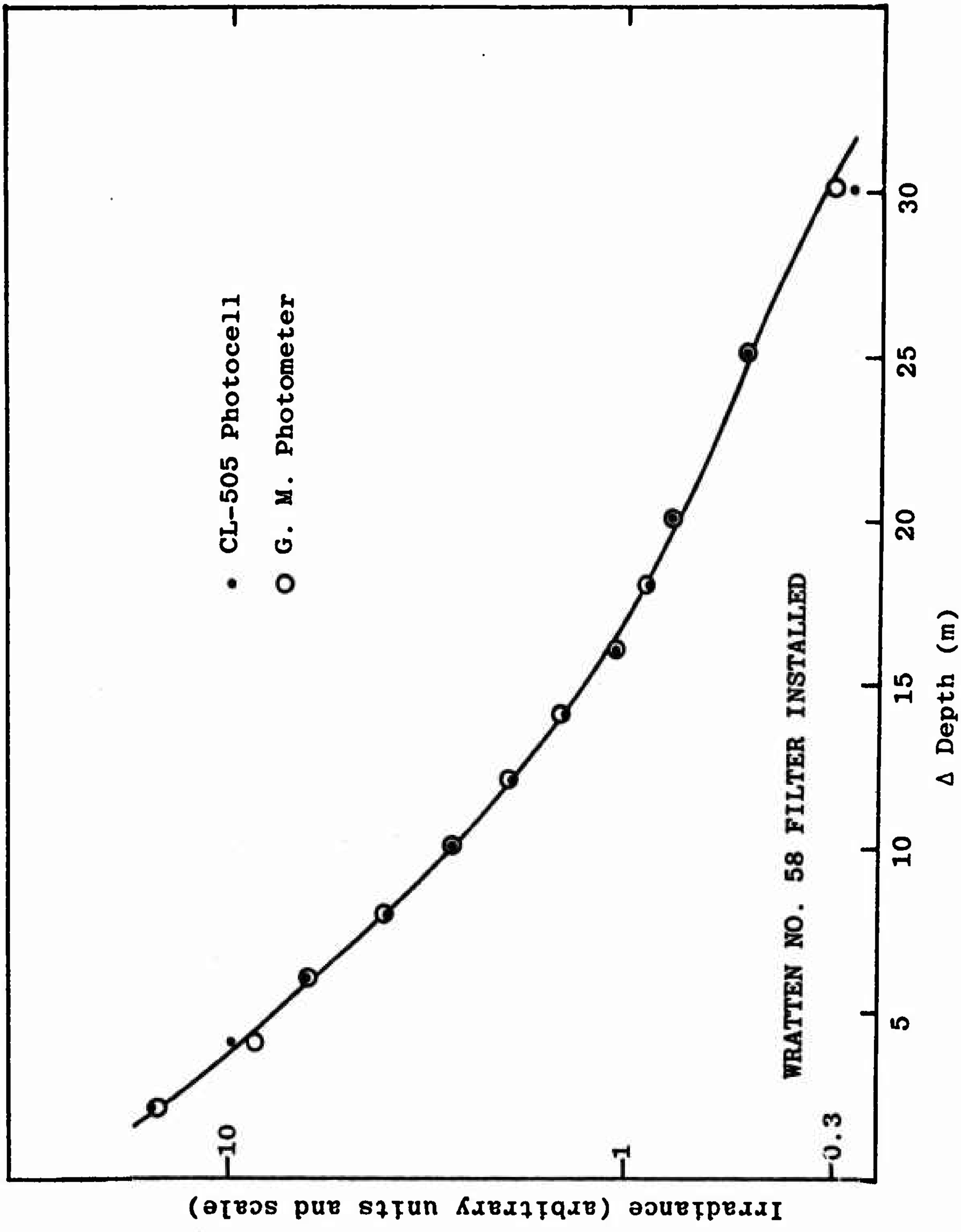


Figure (4-13). CL-505 PHOTOCELL AND PHOTOMETER COMPARISON WITH FILTER, Irradiance vs. Depth (Semi-log).

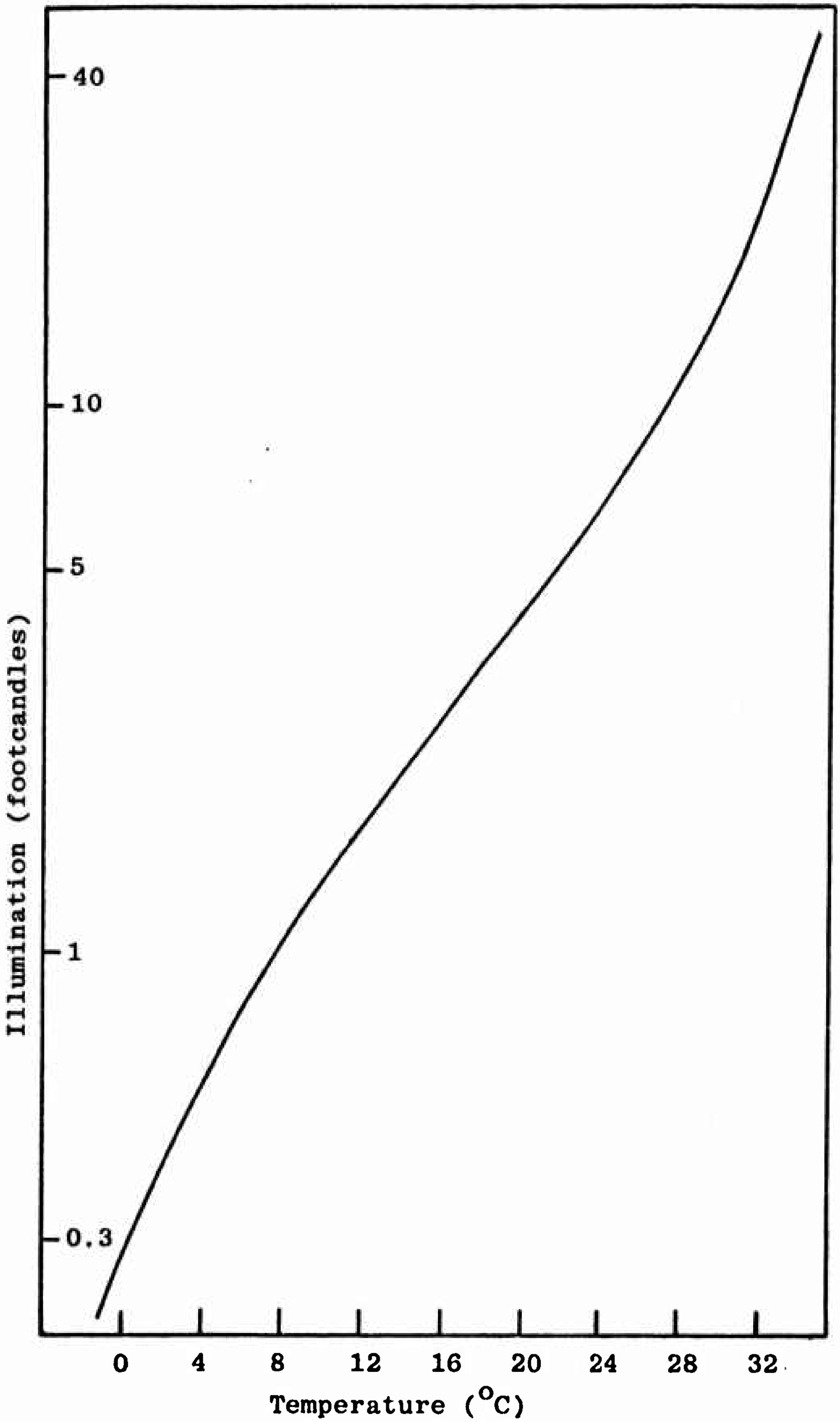


Figure (4-14). CALIBRATION CURVE CONVERTING T to E, vs. Temperature (Semi-log) Illumination.

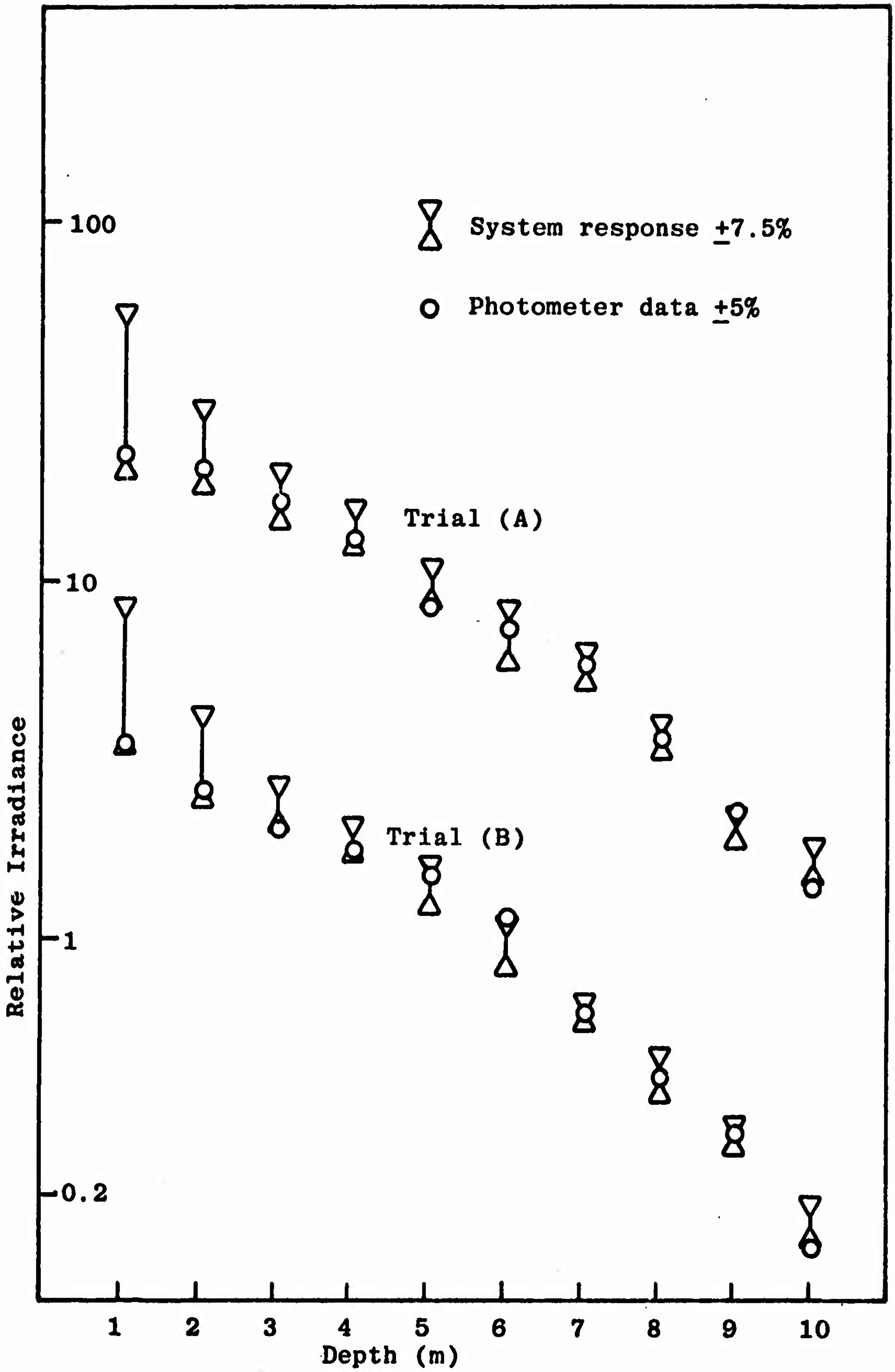
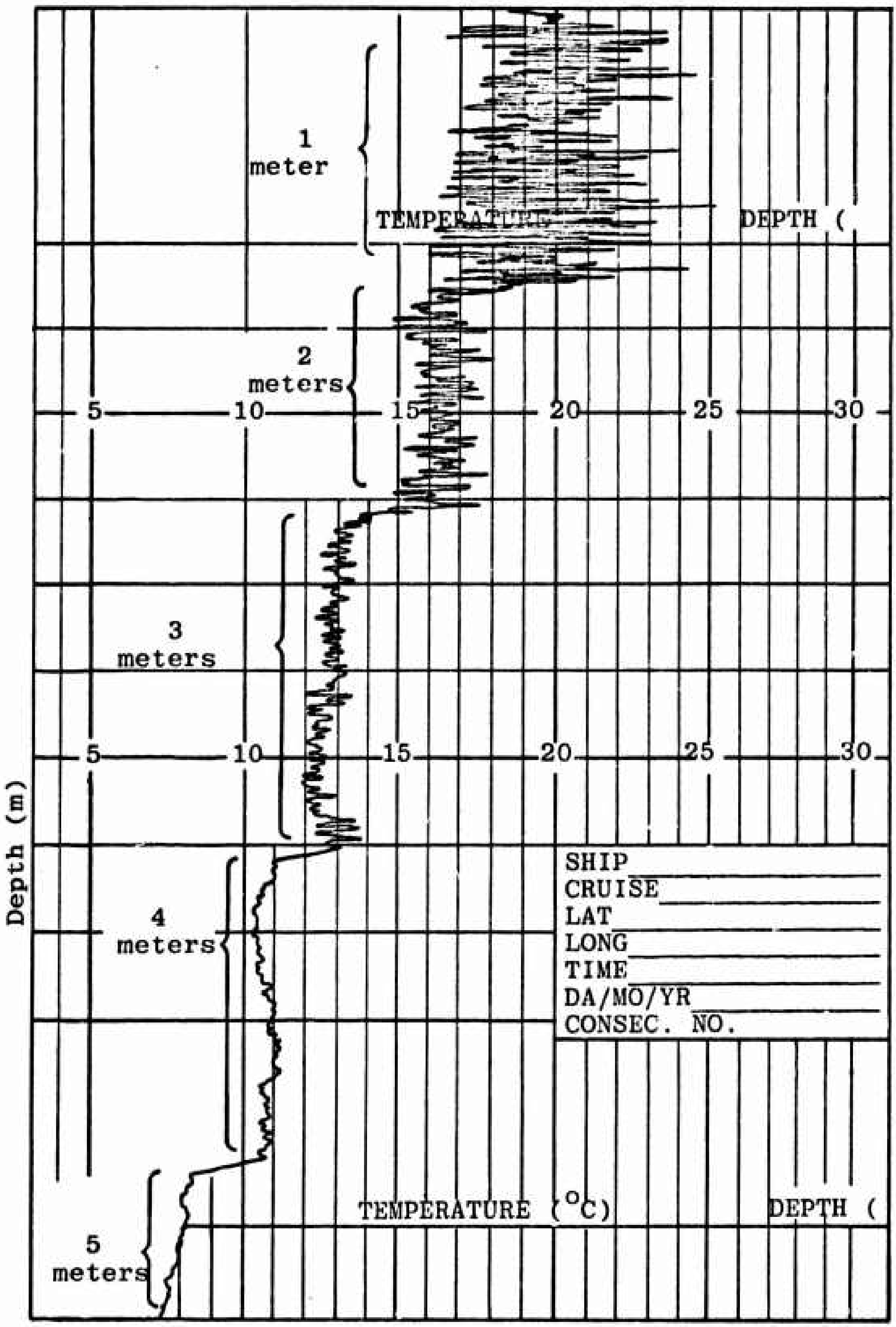


Figure (4-15). SYSTEM COMPARISON TO PHOTOMETER, Irradiance vs. Depth (Semi-log).

overlap at each data point showing good correspondence between photometer measurements and system output.

A sample of the data obtained is shown in Figure 4-16. Note the rapid and fairly large amplitude fluctuations of E near the surface due to ripples and less pronounced fluctuations at greater depths. These fluctuations were not apparent on the photometer as its meter movement was highly damped.



XBT System Output

Figure (4-16). SYSTEM RESPONSE AS A FUNCTION OF DEPTH, SAMPLE CHART.

V. DISCUSSION OF RESULTS

A. ERRORS

1. Photocell Errors

Photocell deviation was investigated through use of the Weston Illumination meter using skylight as the source, and five randomly selected CL-505 photocells were tested. With the data of Table (5-1) the deviation was found to be ±7.5%. Since the Weston Photronic cell does not conform to the sensitivity of the CL-505 photocell, considerable departure from the manufacturer's characteristic curve was noted at both high and low light levels (Figure 4-6). For this reason the manufacturer's specifications were used throughout the following calculations, even though the accuracy was said to be ±33.3% at 2 footcandles. Figure 5-1 shows the photocell characteristic curve with the ±7.5% deviation envelope.

Using Figure 5-1 and assuming a 30-meter depth change with a k of 0.15 m^{-1} corresponding to clear coastal water, a worst case situation was plotted using the envelope values for E. In this case the error involved from photocell deviation alone in calculating k is less than ±3.4%.

2. Depth Accuracy

In that the calculations for k involve a change in depth vice actual depth of the probe, it is assumed that depth error will be limited to the ±2% accuracy. Applying

TABLE (5-1)

CL-505 Photocell Resistance (Ω) as a Function Illuminance (fc) for Five Randomly Selected Photocells

E	R_1	R_2	R_3	R_4	R_5	R_{ave}
250	350	280	275	290	290	299
150	400	340	350	370	380	377
75	540	490	500	550	600	556
35	800	940	950	850	980	947
25	1.1K	1.3K	1.28K	1.1K	1.28K	1.26K
12	1.8K	2.3K	2.25K	1.7K	2K	2.14K
6	2.8K	3.8K	3.8K	3.3K	3.4K	3.69K
5	3.9K	4.4K	4.3K	3.8K	3.9K	4.37K
2.5	6.8K	7.8K	7.3K	6.3K	6.5K	7.4K
1.5	9.5K	12.2K	10.6K	9.1K	9.3K	11.1K
1.0	13K	15K	14K	12.5K	12.9K	14.9K
.75	15.5K	19K	18K	15.5K	15.6K	18.6K
.5	22K	27K	24K	22K	22K	25.7K
.25	38K	42K	38K	34K	33K	40.5K
.15	50K	58K	54K	49K	49K	56.6K

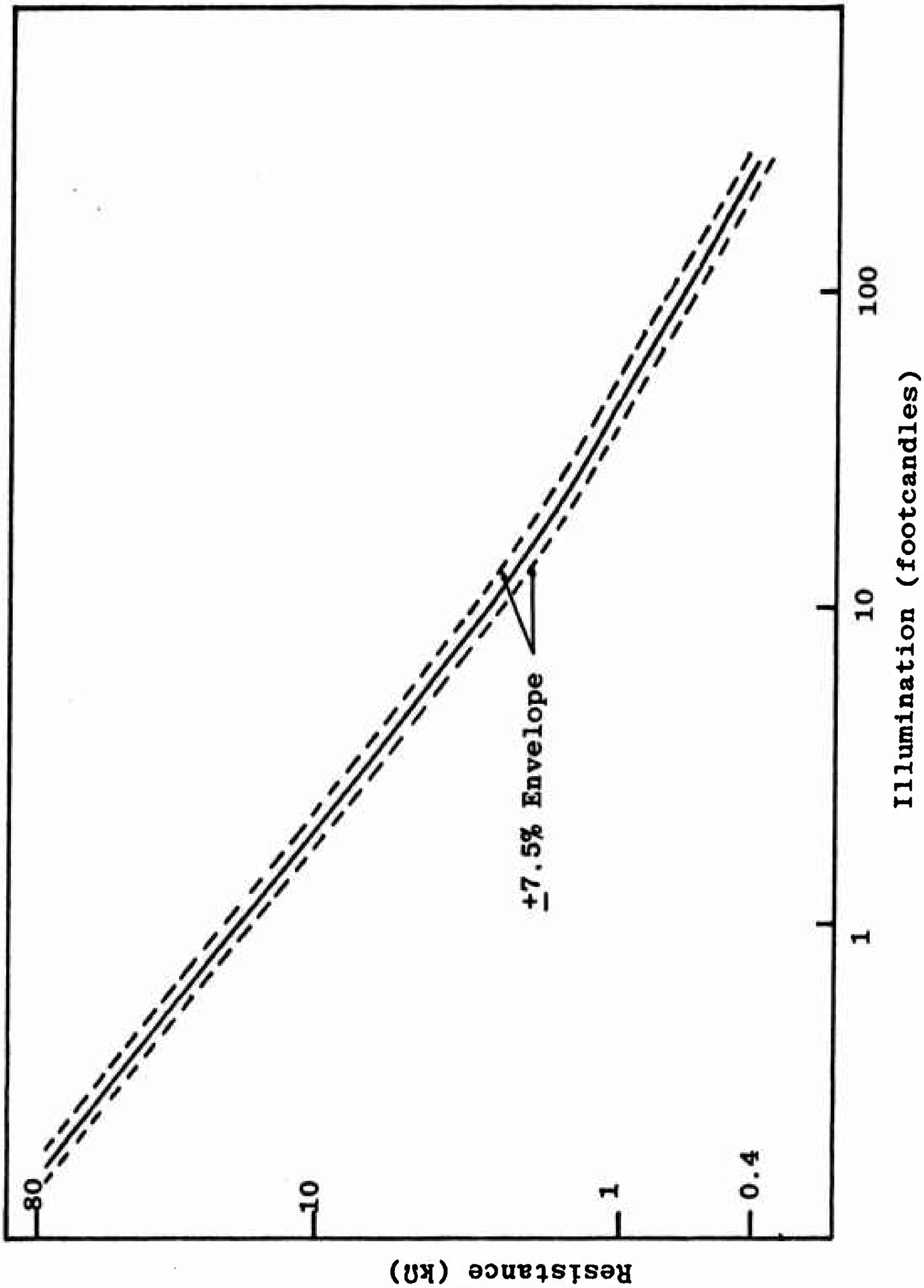


Figure (5-1). PHOTOCELL RESPONSE AND DEVIATION ENVELOPE, Resistance vs. Illumination (Log-log).

this depth error to the above case increases the possible uncertainty in k to about ±5.4%.

3. Recorder Accuracy

The recorder accuracy is ±0.2°C and introduces an error of ±6.5% at the upper end of the scale and ±5.2% at the lower end of the scale when converting temperature to E using Figure 4-13. Applying these bounds to the same case increases the uncertainty to about ±8%.

4. Other Sources

The other system source of error is that associated with picking off the CL-505 response values (recorded as though temperature by the XBT system) and converting them to irradiance. Admittedly interpolation is necessary and errors exist, the magnitude of which depend on the keen eye and interest of the processor. These will not be considered here in that if a system of this type is developed, it would ideally include circuitry to obtain ln E directly from the graph and the chart paper would be graduated and marked accordingly. For the purpose of this investigation and for lack of better information, photometer readings were assumed accurate to ±5%.

It is well to observe here that with the case assumed and the errors involved, this prototype system provides data which is a factor of two and a half more accurate than Secchi depth data and can be associated with the specific wavelength of interest.

VI. ALTERNATE SOLUTIONS AND REFINEMENTS

A. MODIFICATIONS TO THE XBT SYSTEM

Numerous modifications to the probe and to the XBT system present themselves.

1. Better Matching Circuit

The most significant modification would be to add a circuit which would use photocell resistance as input and output resistances compatible with producing a straight line corresponding to lnE directly on the graph paper. In this manner k could be read directly from the chart using a template instead of hand processing. Hand processing is time consuming and introduces another step for error to enter the calcualations.

2. Wavelength Filters

Optical filters, such as the Wratten type, could be introduced to assure that the k being measured was in fact for the desired wavelength or to determine the best wavelength to use for a particular purpose in given waters. Assurance was received from a photocell manufacturer that such filters could be encased with the photosensitive material to prevent exposure to seawater.

3. Slow the Probe

Since only the first hundred meters or so of ocean is of interest, a slower descent is advisable to elongate the recording to allow a more accurate determination of k. This is also advisable due to possible cavitation around the sensor disturbing the light field at higher speeds. Either reduction of ballast or producing a completely different hydrodynamic profile will accomplish this. The XBT system currently has an accuracy of ± 2 percent or 15 feet, whichever is greater. Prototype XBT probes are now in existance with a descent rate of 6 feet per second. It would seem reasonable to assume that probes with photosensitive elements attached could be manufactured with a comparable descent rate and depth accuracy.

4. Different Light Sensor

A different light sensor might be used to improve sensitivity at low light levels and obtain wider wavelength response. By selecting a cell which has a broader and flatter wavelength response, the introduction of filters would be more practicable. The shape of the light sensor could be modified to conform more nearly to the shape of the probe as shown in Figure (6-1). Such a configuration would allow for a larger sensing area and aid in probe stability. Thermally insulating the sensor would allow selection of a photocell with poor thermal characteristics in that drop time is of short duration.

5. Second Light Sensor

A second light sensor pointing downward to measure upwelling light would make possible the simultaneous measurement of E_u and E_d, upwelling and downwelling irradiance whose ratio is reflectance R,

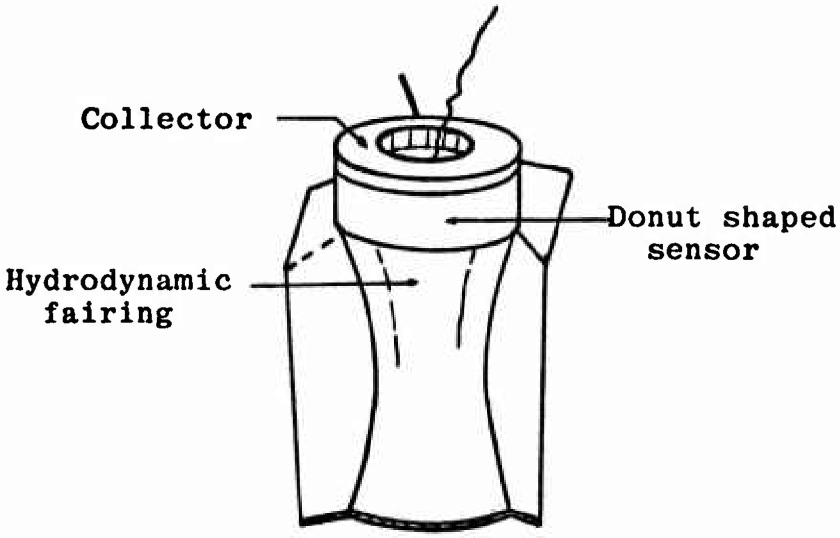


Figure (6-1). POSSIBLE LIGHT SENSOR SHAPE AND CONFIGURATION.

$$R = E_u/E_d.$$

This installation would require a major modification to the recorder to accept the signal from the second sensor and a 3-wire vice 2-wire conductor. The 3-wire conductor is already available commercially and is used in the airborne version of the XBT system.

6. Temperature and Light Sensor

The addition of a light sensor to the existing XBT system would also necessitate a major modification to the recorder and the use of a 3-wire conductor. This dual sensor configuration would allow the gathering of data simultaneously on temperature and k thus providing correlation information.

VII. CONCLUSIONS

A. SYSTEM FEASIBILTIY

1. Limitations

a. The primary limitation for the system presented herein is in the area of data processing. The determination of k is a hand process requiring the conversion of the XBT graphical output to E then plotting ln E versus Depth. The procedure is time consuming and is another source of error.

b. Determining k in turbid waters will be particularly difficult since the present probe's descent rate is quite rapid.

c. The selection of a simple series-parallel circuit imposes a limit on both the high and low irradiance measuring capabilities of the system and allows measurements only in "mid-depth" ranges.

d. The photocell selected has peak sensitivity at about 550 mμ with a sharp decrease in sensitivity below that point. This characteristic does not lend itself to the introduction of optical filters centered much below that peak.

2. Practicability

The criteria set forth previously for a viable system can be met at least in part.

a. Large quantities of data can be provided rapidly to supplement existing records in that any vessel, military or civilian, which has the XBT system onboard can collect such data.

b. Data accuracy of the system discussed is at least a factor of two better than Secchi disc determination of k. The scope of this investigation did not cover accuracy of other data gathering methods; thus, no comparison can be made.

c. System operation is no more complex or inconvenient than the current XBT system. Data processing would be accomplished at a central point for later distribution.

d. The cost would be comparable to current XBT probe models. The least expensive of these is $10.90 for the 600-ft/10 knot probe. A light sensor, a collector and the circuitry needed to match recorder parameters, can probably be produced for about $10.00. This brings the total cost to about $21, which is very comparable in cost to the next model probe ($19.80).

e. Ocean areas of current naval operations and interest could be monitored extensively by naval vessels on station. These data could be further supplemented if aircraft were also to employ the system.

The system is practicable and, in view of underwater optical system development, is of importance today in gathering data for future use.

VIII. RECOMMENDATION

It is recommended that a device be developed which meets the criteria set forth above, so that it will be possible to collect adequate data for predicting underwater optical system performance as such systems become operational in the fleet.

APPENDIX A

A. STANDARD TERMINOLOGY (similar to that of Jerlov 1968)

Wavelength. The distance between two successive points of a periodic wave in the direction of propogation, for which the oscillation has the same phase.

Note: The wavelength of monochromatic radiant energy depends on the refractive index of the medium. Unless otherwise stated, values of wavelength are those in air.

Symbol: λ

Unit: m 1 nm = 1 mμ = 10^{-9}m

Radiant Flux. The time rate of flow of radiant energy.

Symbol: F

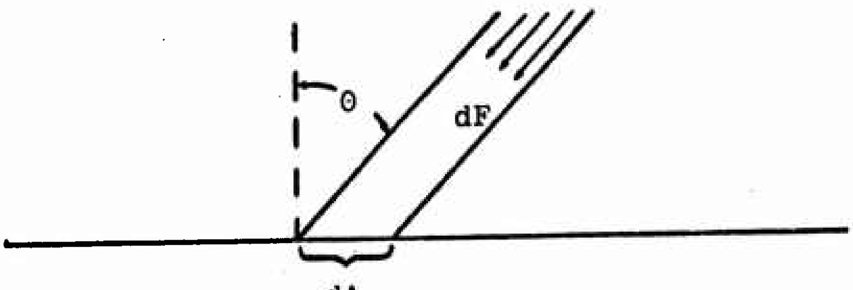
Unit: watt, W

Radiance. Radiant flux per unit solid angle per unit projected area of a surface.

Symbol: L

Unit: watt per square meter and per steradian, W/m^2 sr

Relation: $L = d^2F/dA\cos{-}dw$



Radiance

Irradiance (at a point on a surface). The radiant flux incident on an infinitesimal element of surface containing the point under consideration divided by the area of the element.

Symbol: E

Unit: watt per square meter, W/m^2

Relation: $E = dF/dA$

Downward Irradiance. The radiant flux on an infinitesimal element of the upper face ($0-180^{\circ}$) of a horizontal surface containing the point being considered, divided by the area of the element.

Symbol: E_d

Unit: watt per square meter, W/m^2

Relation: $E_d = dF/dA$

Upward Irradiance. The radiant flux on an infinitesimal element of the lower face ($180-360^{\circ}$) of a horizontal surface containing the point being considered, divided by the area of the element.

Symbol: E_u

Unit: watt per square meter, W/m^2

Relation: $E_u = dF/dA$

Transmittance. The ratio of the transmitted radiant flux to the incident radiant flux (in either irradiance or radiance form).

Symbol: T

Relation: $T = F_t/F_o$

Absorptance. The ratio of the radiant flux lost from a beam by means of absorption, to the incident flux.

Symbol: A

Relation: $A = F_a/F_o$

Scatterance. The ratio of the radiant flux scattered from a beam, to the incident flux.

Symbol: B

Relation: $B = F_b/F_o$

Attenuance. The ratio of the radiant flux lost from a beam by means of absorption and scattering, to the incident flux.

Symbol: C

Relation: $C = F_c/F_o$

Absorption Coefficient. The internal absorptance of an infinitesimally thin layer of the medium normal to the beam, divided by the thickness (Δr) of the layer.

Symbol: a

Unit: m^{-1}

Relation: $a = -\Delta A/\Delta r = -\Delta F_a/F\Delta r$

for homogeneous medium: $ar = -\ln(1-A)$

Scattering Coefficient (total). The internal scatterance of an infinitesimally thin layer of the medium normal to the beam, divided by the thickness (Δr) of the layer.

Symbol: b

Unit: m^{-1}

Relation: $b = -\Delta B/\Delta r = -\Delta F_b/F\Delta r = a + b$

For homogeneous medium; $br = -\ln(1-B)$

Attenuation Coefficient (total). The internal attenuance of an infinitesimally thin layer of the medium normal to the beam, divided by the thickness (Δr) of the layer.

Symbol: c

Unit: m^{-1}

Relation: $c = -\Delta C/\Delta r = -\Delta F_c/F\Delta r = a + b$

For homogeneous medium; $cr = -\ln(1-C)$

Beam Transmittance. The transmittance for a beam the diameter of which is small compared to its length.

Relation for homogeneous medium; $\ln T = -cr$

Diffuse Attenuation Coefficient (at a depth z). The ratio of the change of downwelling irradiance, divided by the irradiance at that depth, per unit change of depth (Δz) where z is positive in the downward direction.

Symbol: k

Unit: m^{-1}

Relation: $k = -\Delta E/E/\Delta z$

B. PHOTOMETRIC UNITS

Luminous Flux. The time rate of flow of light.

Symbol: F

Unit: lumen: the flux capable of producing the same visual sensation on a standard observer as that through a unit solid angle (steradian) from a uniform point source of one candela; also equal to the flux on a unit surface, all points of which are at a unit distance from a uniform point source of one candela.

Illumination. Area density of the luminous flux on a surface, that is, the flux divided by the area when the latter is uniformly illuminated.

Symbol: E

Unit: Footcandle-the illumination on a surface one square foot in area on which there is a uniformly distributed flux of one lumen.

Relation: $E = dF/dA$

Candela. The magnitude of the candela (cd) is such that the luminance of the total radiator, at the temperature of solidification of platinum, is 60 candelas per square centimeter (Comite International des Poids et Mesures 1964).

C. INSTRUMENTS

Cosine Collector. A collector which accepts radiant flux in accordance with the cosine law.

Optical Filter. A device which changes, by absorption or interference, the magnitude or spectral distribution of the radiant energy passing through it.

Photoconductive Cell. A photocell whose electrical conductance changes under irradiation. A voltage supply is required in the cell circuit.

Photovoltaic Cell. A photocell which sets up a potential difference between its terminals when exposed to radiant energy. It is a self-contained current and voltage generator.

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