

UNIVERSITY OF CALIFORNIA, SAN DIEGO  
SCRIPPS INSTITUTION OF OCEANOGRAPHY  
VISIBILITY LABORATORY  
SAN DIEGO, CALIFORNIA 92152

**INVESTIGATION OF ERRORS  
IN THE MEASUREMENT OF RADIANT ENERGY  
FOR CORRELATION WITH PRIMARY PRODUCTIVITY**

JOHN E. TYLER

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

REPRODUCTION IN WHOLE OR IN PART IS PERMITTED  
FOR ANY PURPOSE OF THE UNITED STATES GOVERNMENT

SIO Ref. 67-11

May 1967

Department of the Navy  
Office of Naval Research  
Contract N00014-67-A0109-002  
Project NR 104-923

## Table of Contents

	Page No.
Introduction . . . . .	1
Working Group 15 . . . . .	2
Calculations . . . . .	2
Source of Data . . . . .	3
Table I . . . . .	4
Application to Incubator . . . . .	6
Table II . . . . .	7
Table III . . . . .	7
Discussions of Tables IV and V . . . . .	9
Table IV . . . . .	9
Table V . . . . .	10

# INVESTIGATION OF ERRORS IN THE MEASUREMENT OF RADIANT ENERGY FOR CORRELATION WITH PRIMARY PRODUCTIVITY.

J. E. TYLER

## INTRODUCTION

Biologists who are interested in the primary productivity of the ocean are often unable to make productivity determinations by the "in situ" technique because of the demands of other groups on the ship's time. Under these conditions it has been the practice to use a substitute technique called the "deck incubator" technique, in which the sample of plankton-bearing ocean water is transferred to a deck incubator and allowed to propagate for an appropriate length of time before determining the  $^{14}\text{C}$  uptake.

From a radiometric point of view these two techniques differ to a considerable degree. In the "in situ" technique the plankton-bearing ocean water is returned to its original depth location where propagation takes place at normal radiant energy levels and with normal spectral and geometric distribution of the radiant energy. In the "deck incubator" technique the radiant energy level available is usually much too high and must be controlled, the spectral distribution and band width are abnormally different and the geometrical distribution of the radiant energy has no similarity whatsoever with the natural geometrical distribution underwater.

Experimental results for any individual case are still further confused by the fact that the measured radiant energy must be sensed by a detector, usually of the photovoltaic type, having spectral and directional sensitivity properties unrelated in any way to those of the phytoplankton which are being studied, and magnitude response which is often arbitrarily nonlinear.

These problems have been recognized to some extent by various workers engaged in primary productivity work and effective measures have generally been taken to control the magnitude of the radiant energy in deck incubator determinations. However, not enough has been done to control its spectral distribution, and very little, if anything, has been done to control the geometrical distribution of the radiant energy or to design a suitable photodetector or to design an appropriate deck incubator.

Perhaps the most curious effort, in connection with the control of the spectral sensitivity of the photocell-filter combination, has been the deliberate selection of photodetectors which measure "lumens", and the general adoption of "lumens" as a radiometric unit for productivity work. The "Lumen" is, of course, a unit which was specifically originated for radiant energy measurements relating only to human vision at the levels of photopic response. Its use in connection with photosynthesis is meaningless and is so recognized by many biologists who nevertheless continue to measure and publish in "lumen" units.

From the point of view of international cooperation, the communication of results is exceedingly difficult. Not only do we have measurements of radiant energy which are meaningless for correlation with productivity, but every laboratory seems to have a somewhat different type of meaningless measurement.

## WORKING GROUP 15

The problems outlined above have been recognized by International Oceanographic Organizations and in 1964 a working group was convened by UNESCO, SCOR, and IAPO, called Working Group 15 – *Photosynthetic Radiation in the Sea*, for the purpose of determining the correct radiometric measurement for correlation with primary productivity determinations.

Working Group 15 had its first meeting in 1964. At this meeting it was agreed that future radiant energy measurements should be in energy units, e.g. watts per unit area, (rather than in lumens-per unit area) and that the “total available energy” (or the “total available photons”) within the wavelength limits 350 to 700 nm should be measured.

One of the tasks assigned by the working group to individual members was the task of searching for instrument components that could be used both in air and in water to measure total energy between 350 and 700 nm and of calculating the errors to be expected from various combinations of components.

This work, together with its application to a deck incubator has been carried out under ONR contract number N00014-66-C0107-A02 and is reported herein.

## CALCULATIONS

Having adopted the more or less arbitrary position that “total available energy in the wavelength region 350 to 700” should be the measured quantity, W.G. 15 decided that an effort should be made to determine if a photodetector-filter combination existed for the purpose and what magnitude of errors could be expected from its use – that is, how much of the desired energy would the detector fail to measure and to what extent would the detector measure energy outside the desired wavelength region.

To obtain these results it is necessary to perform calculations of the type

$$\sum_{\lambda_1}^{\lambda_2} H(\lambda)\Delta\lambda = H_T \quad (1)$$

$$\sum_{\lambda_1}^{\lambda_2} S(\lambda)F(\lambda)H(\lambda)\Delta\lambda = R_T \quad (2)$$

$$S \sum_{\lambda_1}^{\lambda_2} F_O(\lambda)H(\lambda)\Delta\lambda = R_T \quad (3)$$

Equation (1) is used to calculate the total irradiance,  $H_T$  when the spectral distribution of the irradiance,  $H(\lambda)$  is known.

Equation (2) is used to calculate the relative response of a photodetector having spectral sensitivity  $S(\lambda)$ , to irradiance ( $H(\lambda)$ ) which has passed through a specific filter having spectral transmittance  $F(\lambda)$ .

Equation (3) is used to calculate the relative response of a photodetector whose spectral sensitivity  $S$  is invariant with wavelength to irradiance,  $H(\lambda)$ , which has passed through a filter having ideal spectral transmittance  $F_o(\lambda)$ . The wavelength limits ( $\lambda_1$  and  $\lambda_2$ ) for each computation are chosen with respect to the photosynthetically important radiation.

## SOURCE OF DATA

The computations illustrated by equations 1, 2, and 3 require the following data:

- $S(\lambda)$  The relative (or absolute) spectral sensitivity of selected photodetectors.
- $F(\lambda)$  The spectral transmittance of selected optical filters.
- $H(\lambda)$  The spectral irradiance of the radiant energy impinging on the irradiance-collecting element of the photometer or thermopile.

In all cases the data needs to cover a wavelength range greater than the photosynthetically active band in order to estimate the errors due to the inclusion of spurious flux.

Data for the spectral sensitivity of photodetectors was obtained from manufacturers specifications. In general these are average values and are well suited for this kind of calculation. However, the spectral range covered is usually limited. Manufacturer's specifications have therefore been extrapolated to  $10^{-5}$  and have been listed as "zero" at sensitivities below that level.

In the case of the thermopile, its relative sensitivity has been tabulated as 1 for all wavelengths.

Data for the spectral transmittance of optical filters has been obtained from manufacturer's specifications or has been measured experimentally. In spectral regions of strong absorption where accurate data were difficult to obtain the minimum measurable value has been assigned to the remaining wavelengths. Thus for the Schott BG 18 filter the transmission is assumed to be .0001 between .22 $\mu$  and .31 $\mu$ .

Data for spectral irradiance incident on the surface of the water has been assumed to be equal to the spectral irradiance of sunlight above the earth's atmosphere as given by Johnson's\* smoothed data.

No data for the spectral irradiance of the radiant energy under water was available, nor was there, at the outset, spectral data for the diffuse attenuation coefficient of natural water. Uncontaminated water was therefore represented by means of the equation

$$H_z = H_o e^{-\alpha z} \quad (4)$$

\* F. Johnson, *Jour. of Meteorology* Volume 11, p. 431 (1954).

in which Johnson's data were used for  $H_0$  and Hulburts\*  $a$  values were used in the exponent. This procedure leads to values of  $H_z$  which are low for the specified depth and probably somewhat distorted with respect to wavelength. However, there was no alternative and the unreality introduced should not distort the estimate of errors by a large factor.

Later in the program, experimental data on the spectral radiant energy available at a depth of 19 m in plankton-rich water was obtained from the Gulf of California and this was used directly for  $H_2$  in the calculation.

In tabulating the underwater irradiance data some extrapolation was necessary and H values less than  $10^{-5}$  times the peak H value were tabulated as zero.

The summation procedure in all cases was performed in the manner expressed by equation (5).

$$\sum_a^d xy\Delta\lambda = \left[ \frac{(xy)a}{2} + (xy)b + (xy)c + \frac{(xy)d}{2} \right] \quad (5)$$

The computations were carried out independently for four regions of the spectrum using a different value for  $\Delta\lambda$  for each region. In each region summations were made to determine the total radiant energy available, the radiant energy actually measured, and the energy desired to be measured, according to the W.G. 15 recommendation. Table I gives a summary of computations performed and indicates the symbol assigned to each summation.

**Table I**

Wavelength Limits	Energy Available	Energy Measured	Energy Measurement Desired	$\Delta\lambda$
.22 to .35 $\mu$	a	A	O	.005 $\mu$
.35 to .70 $\mu$	b	B	b	.01 $\mu$
.70 to 4.0 $\mu$	c	C	O	.1 $\mu$
4.0 to 7.0 $\mu$	d	D	O	1.0 $\mu$

Complete computations were made using the following variables:

For irradiance, H

$H_0$  = irradiance at the water surface

$H_1$  = 50 m deep in water specified by Hulburt's distilled water

$H_2$  = Gulf of California water

$H_{10}$  = 10 m deep in water specified by Hulburt's distilled water

For spectral Sensitivity of Photodetector, S

$S_1$  = Thermopile

$S_{10}$ ,  $S_{11}$ , and  $S_{17}$  = Photomultiplier tubes with the spectral sensitivities indicated by the subscript.

\* E.O. Hulburt J.O.S.A. 35, 698 (1945).

For optical Filters, F

$F_o$  = the ideal filter, transmitting 100% between .35 and .70 $\mu$ ; 0% elsewhere.

$F_1$  = Pittsburg Plate Glass Company 2043, heat absorbing glass

$F_2$  = Schott BG 18

The available radiant energy in each region of the spectrum is given by:

$$a = \int_{.22}^{.35} H\Delta\lambda \quad b = \int_{.35}^{.70} H\Delta\lambda \quad c = \int_{.70}^{4.0} H\Delta\lambda \quad d = \int_{4.0}^{7.0} H\Delta\lambda \quad (6)$$

Where H represents any of the above listed spectral irradiance distributions.

The experimentally measured radiant energy within these bands is given by:

$$A = \int_{.22}^{.35} SFH\Delta\lambda \quad B = \int_{.35}^{.70} SFH\Delta\lambda \quad C = \int_{.70}^{4.0} SFH\Delta\lambda \quad D = \int_{4.0}^{7.0} SFH\Delta\lambda \quad (7)$$

Where S and F represent combinations of these spectral functions (except  $F_o$ ) as previously listed.

The desired measurement of radiant energy is given by:

$$b = \int_{.35}^{.70} F_o H\Delta\lambda \quad (8)$$

In the other regions of the spectrum the desired measurement of radiant energy is zero, (by the arbitrary decision of W.G. 15).

In order to compensate for the different peak sensitivities of the various photodetectors as well as for the difference in filter factors for the optical filters used, the results have been normalized by setting the maximum value of SFH equal to  $H_o$ . There are fundamental differences between the action of a thermopile and that of a photoemissive detector which make it difficult to compare their relative outputs. A thermopile responds to total radiant energy, regardless of wavelength, whereas a photoemissive surface responds to quanta with an efficiency that is a function of wavelength. Furthermore, the output of photoemissive devices is generally given in amps/watt, whereas the output of thermopiles is generally given in volts/watt. Thus, direct comparison depends on circuitry. In these calculations, the spectral sensitivity of the thermopile ( $S_1$ ) has been taken as 1 at all wavelengths, consequently, results for the thermopile cannot be compared directly with those for the multiplier phototubes. However, the photomultiplier tubes can be compared with each other for relative sensitivity.

Tables II and III summarize the results. Calculations involving a thermopile are given in Table II. Column 1 gives the percent of the instrument's reading which is due to radiant flux outside the wavelength limits .35 to .70 $\mu$ . Column 2 gives the percent of the radiant flux within these limits which is measured.

Table III gives the same information for three photomultiplier tubes combined with two different filters, used in situ and above the surface.

The errors of omission and commission indicated in the tables are all manifestations of the mismatch between the realizable band width isolation and that specified as photosynthetically important. The large errors of commission exhibited by the thermopile when used out of water are due to insufficient filtering out of infrared and U. V. radiation. When a stronger filter is used, (the F<sub>2</sub> filter in this case) the error of commission is reduced (Column 1) but at the same time the error of omission is increased (Column 1 - Column 2).

The fact that photoemission is inherently restricted to the higher energy photons puts a natural band width restriction on the response of photomultiplier tubes which in large measure accounts for both the low error of commission and the high error of omission when these devices are used out of water.

The fact that water absorbs radiant flux in the red region of the spectrum and also in the blue beyond .35 $\mu$  means that at great depths errors of commission and omission are both reduced (possibly to zero) as depth increases, because the band width of the flux passed by the water itself becomes the limiting band width and lies wholly within the band width of the detector.

## APPLICATION TO INCUBATOR

In the deck incubator technique there are four situations to be considered:

- The response of the phytoplankton in situ
- The response of the phytoplankton on deck
- The response of the photodetector in situ
- The response of the photodetector on deck

Because photosynthesis is a nonlinear function of the available radiant energy it is the practice in the deck incubator technique to reduce the radiant energy in the deck incubator and simultaneously on the detector, by means of a screen or other non-wavelength selective filter (T) until,

$$\text{Photodetector response on deck} \times T = \text{Photodetector response in situ}$$

It is then desired or assumed that:

$$\frac{\text{Phytoplankton response in situ}}{G \times \text{Photodetector response in situ}} = \frac{\text{Phytoplankton response on deck} \times T}{G \times \text{Photodetector response on deck} \times T}$$

where G is a controllable circuit gain factor adjusted to a fixed setting for the experiment.

**Table II**

	(1) $\frac{A+C+D}{A+B+C+D}$ % of reading which is unwanted	(2) $\frac{B}{b}$ % of b which is measured
$S_1F_1H_0$	21.8	97.3
$S_1F_2H_0$	15.4	58.1
$S_1F_1H_1$	<1	99.6
$S_1F_2H_1$	<1	94.4
$S_1F_2H_{10}$	<1	81.7
$S_1F_1H_2$	<1	100.0
$S_1F_2H_2$	<1	81.2

**Table III**

	(1) $\frac{A+C+D}{A+B+C+D}$	(2) $\frac{B}{b}$
$S_{11}F_1H_0$	2.56	56.7
$S_{11}F_2H_0$	<1	47.3
$S_{17}F_1H_0$	6.57	62.7
$S_{17}F_2H_0$	<1	49.7
$S_{10}F_1H_0$	3.52	65.6
$S_{10}F_2H_0$	<1	50.3
$S_{11}F_1H_1$	<1	84.2
$S_{11}F_2H_1$	<1	83.8
$S_{17}F_1H_1$	<1	95.5
$S_{17}F_2H_1$	<1	90.0
$S_{10}F_1H_1$	<1	89.6
$S_{10}F_2H_1$	<1	88.6
$S_{11}F_2H_{10}$	<1	69.8
$S_{17}F_2H_{10}$	<1	74.5
$S_{10}F_2H_{10}$	<1	73.7
$S_{11}F_1H_2$	<1	82.9
$S_{11}F_2H_2$	<1	73.6
$S_{17}F_1H_2$	<1	83.5
$S_{17}F_2H_2$	<1	75.0
$S_{10}F_1H_2$	<1	88.2
$S_{10}F_2H_2$	<1	78.5

Thus, the essential condition for exact correlation between rate of photosynthesis and radiant flux is

$$\frac{\int RH_z d\lambda}{G \int SFH_z d\lambda} = \frac{T \int RH_o d\lambda}{GT \int SFH_o d\lambda} \quad (9)$$

- R = spectral response of phytoplankton
- S = spectral response of photodetector
- H<sub>z</sub> = spectral irradiance in situ
- H<sub>o</sub> = spectral irradiance on deck
- F = transmittance of optical filter

The factors G and T are invariant with wavelength and have been brought outside the integral sign where they cancel out of the equation leaving

$$\frac{\int RH_z d\lambda}{\int SFH_z d\lambda} = \frac{\int RH_o d\lambda}{\int SFH_o d\lambda} \quad (10)$$

The spectral response of the phytoplankton to radiant energy is unknown. For purposes of comparison in the tables it is assumed that the spectral response of the phytoplankton is unity between .350 and .700μ and zero at all other wavelengths. This assumption conforms with the basic assumption adopted by W.G. 15 that for a measure of the photosynthetically important radiant flux, all the available flux (or quanta) between .35 and .70μ should be measured.

Equation 10 can thus be written with integration limits as follows:

$$\frac{\int_{.35}^{.70} RH_z d\lambda}{\int_{.22}^{7.0} SFH_z d\lambda} = \frac{\int_{.35}^{.70} RH_o d\lambda}{\int_{.22}^{7.0} SFH_o d\lambda} \quad (11)$$

Tables IV and V compare these ratios for equality. Table IV is for an incubator with clear glass and neutral filters used to control the level of radiant energy. Table V is for an incubator with F<sub>2</sub> glass. Neutral filters are again used to control the energy level.

## DISCUSSION OF TABLES IV AND V

In interpreting the results shown in Tables IV and V it is important to remember that the spectral response of the phytoplankton has been assumed to be 1 between  $.35\mu$  and  $.70\mu$ , and zero at all other wavelengths. This assumption undoubtedly leads to incorrect ratios throughout the tables. Thus, the tables are more valuable to indicate trends than they are to indicate the absolute error.

Tables IV and V are, in essence, a tabulation of about 50 independent experiments in which the ratio of real productivity to photodetector response in situ, has been determined and then compared with this same ratio obtained in an incubator on deck.

In Table IV, section B last entry, ( $S_{10}F_2H_1$ ), the in situ ratio was determined to be 84.8 and the incubator ratio (Section A last entry) was 146.5. Thus, the incubator ratio is 72.8% too high(+).

In Table V, section B last entry, ( $S_{10}F_2H_1$ ) the same experiment has been performed, but incubation has taken place under an  $F_2$  glass filter. The incubator ratio is now found to be only 6.45% high.

Other pairs of ratios can be compared similarly and it can be seen that the use of an  $F_2$  filter over the incubator has had a profound effect, greatly improving the correlation. A more carefully selected filter could, of course, be expected to bring about an even greater improvement in correlation.

Table IV

Summation Limits	$\sum (\ ) \Delta \lambda$	Section A		Section B			Section C			Section D		
		1	2	1	2	3	1	2	3	1	2	3
		$H_o$	Ratio	$H_i$	Ratio	Error	$H_{1o}$	Ratio	Error	$H_2$	Ratio	Error
.35 - .70	H=RH	.0616		.0039		$\frac{\Delta}{\text{in situ}}$	.0258		$\frac{\Delta}{\text{in situ}}$	2.83		$\frac{\Delta}{\text{in situ}}$
.22 - 7.0	$S_1H$	.1396	.441	.0039	1.00	-55.9%	.0260	.992	-55.5%	2.83	1.0	-55.9%
.22 - 7.0	$S_1F_1H$	.0672	.917	.00342	1.14	-19.6				2.481	1.14	-19.6
.22 - 7.0	$S_1F_2H$	.0287	2.14	.00249	1.565	+36.7	.01438	1.79	+19.5	1.728	1.635	+30.9
.22 - 7.0	$S_{11}F_1H$	.00157	39.2	.000141	27.6	+42.0				.0869	32.5	+20.6
.22 - 7.0	$S_{11}F_2H$	.00092	66.2	.000102	38.2	+73.3	.000568	45.4	+45.8	.0627	41.2	+60.7
.22 - 7.0	$S_{17}F_1H$	.00300	20.5	.000268	14.55	+40.9				.1750	16.15	+26.9
.22 - 7.0	$S_{17}F_2H$	.00173	35.5	.000197	19.8	+79.3	.001079	23.9	+48.5	.1277	22.2	+60.0
.22 - 7.0	$S_{10}F_1H$	.000767	80.2	.000063	62.0	+29.2				.0411	69.0	+16.2
.22 - 7.0	$S_{10}F_2H$	.000420	146.5	.000046	84.8	+72.8	.000257	100.3	+46.0	.0293	96.5	+51.8
		On Deck			In Situ							

This table for incubator with clear glass and neutral filter. It is assumed that the plankton response is directly proportional to  $\sum_{.35}^{.70} H \Delta \lambda$

Column 2 Section A is the right side of equation 11; Columns 2 in Sections B, C, and D are the left side of equation 11.

$$\text{Error} = \frac{(\text{deck}) - (\text{in situ})}{\text{in situ}} \times 100$$

Another trend that can be seen in Table IV, section B, column 2, is that the ratio of in situ productivity to photodetector response has varied by a factor of 84.5 as a function of only the spectral sensitivity of the photodetector-filter combination. The change with water type (detector-filter combination remaining the same) has been only a factor of 1.2. This result emphasizes the importance of properly designing the photodetector-filter combination.

Table V

Summation Limits	$\sum (\ ) \Delta\lambda$	Section A		Section B			Section C			Section D		
		1	2	1	2	3	1	2	3	1	2	3
		H <sub>o</sub>	Ratio	H <sub>1</sub>	Ratio	Error	H <sub>1o</sub>	Ratio	Error	H <sub>2</sub>	Ratio	Error
.35 → .70	HF <sub>2</sub> =RHF <sub>2</sub>	.0242		.00249		$\frac{\Delta}{\text{in situ}}$	.01438		$\frac{\Delta}{\text{in situ}}$	1.728		$\frac{\Delta}{\text{in situ}}$
.22 → 7.0	S <sub>1</sub> F <sub>1</sub> H	.0672	.360	.00342	.728	-50.5%				2.481	.697	-48.3%
.22 → 7.0	S <sub>1</sub> F <sub>2</sub> H	.0287	.843	.00249	1.00	-15.7	.01438	1.00	-15.7%	1.728	1.00	-15.7
.22 → 7.0	S <sub>11</sub> F <sub>1</sub> H	.00157	15.4	.000141	17.65	-12.8				.0869	19.9	-22.6
.22 → 7.0	S <sub>11</sub> F <sub>2</sub> H	.00092	26.4	.000102	24.4	+ 7.57	.000568	25.4	+ 3.94	.0627	27.6	- 4.35
.22 → 7.0	S <sub>17</sub> F <sub>1</sub> H	.00300	8.6	.000268	9.30	- 7.53				.1750	9.87	-12.9
.22 → 7.0	S <sub>17</sub> F <sub>2</sub> H	.00173	14.0	.000197	12.65	+10.7	.001079	13.35	+ 4.87	.1277	13.55	+ 3.32
.22 → 7.0	S <sub>10</sub> F <sub>1</sub> H	.000767	31.6	.000063	39.6	-22.0				.0411	42.1	-24.9
.22 → 7.0	S <sub>10</sub> F <sub>2</sub> H	.000420	57.7	.000046	54.2	+ 6.45	.000257	56.0	+ 3.04	.0293	59.0	- 2.2
		← Deck			← In Situ							

This table is for incubator with F<sub>2</sub> glass + neutral filter.

Detector is not placed under F<sub>2</sub> glass in incubator, but has its own filter as shown + the incubator neutral filter.

It is assumed that the plankton response is directly proportional to  $\sum_{.35}^{.70} H\Delta\lambda$

Column 2 Section A is the right side of equation 11; Columns 2 in Sections B, C, and D are the left side of equation 11.

$$\text{Error} = \frac{(\text{deck}) - (\text{in situ})}{\text{in situ}} \times 100$$

DOCUMENT CONTROL DATA - R&D		
<i>(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)</i>		
1 ORIGINATING ACTIVITY (Corporate author) Visibility Laboratory University of California San Diego, California 92152		2a REPORT SECURITY CLASSIFICATION UNCLASSIFIED
		2b GROUP
3 REPORT TITLE INVESTIGATION OF ERRORS IN THE MEASUREMENT OF RADIANT ENERGY FOR CORRELATION WITH PRIMARY PRODUCTIVITY		
4 DESCRIPTIVE NOTES (Type of report and inclusive dates) Technical Report		
5 AUTHOR(S) (Last name, first name, initial) Tyler, John E.		
6 REPORT DATE May 1967	7a TOTAL NO. OF PAGES 10	7b. NO OF REFS 2
8a CONTRACT OR GRANT NO N00014-67-A0109-002	9a ORIGINATOR'S REPORT NUMBER(S) SIO Ref. 67-11	
b. PROJECT NO. NR 104-923	9b OTHER REPORT NO(S) (Any other numbers that may be assigned this report)	
c		
d		
10 AVAILABILITY/LIMITATION NOTICES DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED		
11. SUPPLEMENTARY NOTES	12 SPONSORING MILITARY ACTIVITY Office of Naval Research, Department of the Navy Oceanic Biology Branch, Code 408B Washington 25, D.C.	
13 ABSTRACT  A calculation has been made to determine the accuracy of the correlation between measurements of Radiant Energy and the <sup>14</sup> C Determination of Primary Productivity in the ocean as determined by the "deck incubator" technique.		

14	KEY WORDS	LINK A		LINK B		LINK C	
		ROLE	WT	ROLE	WT	ROLE	WT
Primary Productivity Radiant Energy Biological Oceanography							

**INSTRUCTIONS**

**1. ORIGINATING ACTIVITY** Enter the name and address of the contractor, subcontractor, grantee, Department of Defense activity or other organization (*corporate author*) issuing the report.

**2a REPORT SECURITY CLASSIFICATION** Enter the overall security classification of the report. Indicate whether "Restricted Data" is included. Marking is to be in accordance with appropriate security regulations.

**2b GROUP** Automatic downgrading is specified in DoD Directive 5200.10 and Armed Forces Industrial Manual. Enter the group number. Also, when applicable, show that optional markings have been used for Group 3 and Group 4 as authorized.

**3. REPORT TITLE** Enter the complete report title in all capital letters. Titles in all cases should be unclassified. If a meaningful title cannot be selected without classification, show title classification in all capitals in parenthesis immediately following the title.

**4. DESCRIPTIVE NOTES** If appropriate, enter the type of report, e.g., interim, progress, summary, annual, or final. Give the inclusive dates when a specific reporting period is covered.

**5. AUTHOR(S)** Enter the name(s) of author(s) as shown on or in the report. Enter last name, first name, middle initial. If military, show rank and branch of service. The name of the principal author is an absolute minimum requirement.

**6. REPORT DATE** Enter the date of the report as day, month, year, or month, year. If more than one date appears on the report, use date of publication.

**7a TOTAL NUMBER OF PAGES** The total page count should follow normal pagination procedures, i.e., enter the number of pages containing information.

**7b NUMBER OF REFERENCES.** Enter the total number of references cited in the report.

**8a CONTRACT OR GRANT NUMBER** If appropriate, enter the applicable number of the contract or grant under which the report was written.

**8b, 8c, & 8d PROJECT NUMBER** Enter the appropriate military department identification, such as project number, subproject number, system numbers, task number, etc.

**9a ORIGINATOR'S REPORT NUMBER(S)** Enter the official report number by which the document will be identified and controlled by the originating activity. This number must be unique to this report.

**9b OTHER REPORT NUMBER(S)** If the report has been assigned any other report numbers (*either by the originator or by the sponsor*), also enter this number(s).

**10. AVAILABILITY/LIMITATION NOTICES.** Enter any limitations on further dissemination of the report, other than those

imposed by security classification, using standard statements such as

- (1) "Qualified requesters may obtain copies of this report from DDC."
- (2) "Foreign announcement and dissemination of this report by DDC is not authorized."
- (3) "U S Government agencies may obtain copies of this report directly from DDC. Other qualified DDC users shall request through \_\_\_\_\_."
- (4) "U S military agencies may obtain copies of this report directly from DDC. Other qualified users shall request through \_\_\_\_\_."
- (5) "All distribution of this report is controlled. Qualified DDC users shall request through \_\_\_\_\_."

If the report has been furnished to the Office of Technical Services, Department of Commerce, for sale to the public, indicate this fact and enter the price, if known.

**11. SUPPLEMENTARY NOTES** Use for additional explanatory notes.

**12. SPONSORING MILITARY ACTIVITY** Enter the name of the departmental project office or laboratory sponsoring (*paying for*) the research and development. Include address.

**13 ABSTRACT** Enter an abstract giving a brief and factual summary of the document indicative of the report, even though it may also appear elsewhere in the body of the technical report. If additional space is required, a continuation sheet shall be attached.

It is highly desirable that the abstract of classified reports be unclassified. Each paragraph of the abstract shall end with an indication of the military security classification of the information in the paragraph, represented as (TS) (S) (C) or (U).

There is no limitation on the length of the abstract. However, the suggested length is from 150 to 225 words.

**14 KEY WORDS** Key words are technically meaningful terms or short phrases that characterize a report and may be used as index entries for cataloging the report. Key words must be selected so that no security classification is required. Identifiers, such as equipment model designation, trade name, military project code name, geographic location, may be used as key words but will be followed by an indication of technical context. The assignment of links, roles, and weights is optional.