

To: DUMAND Group
From: John Leefeld
Subject: Attenuation of Cerenkov photons in the ocean.

- a) a new function
- b) incorporation of glass transparency and relative photo-cathode quantum efficiency
- c) analysis of existing data
- d) presentation of function coefficients for six different conditions

Abstract

A function has been found which will approximate the survival probability for Cerenkov photons versus distance in water. The attenuation of photons is not a simple exponential because of wavelength dependence of source, transmission and detection. Taking Cerenkov spectrum, glass transmissivity, relative quantum efficiency, and various approximations of water attenuation into account a function is calculated which predicts effective numbers of photons per unit source track length versus observation distance. This function multiplied by the appropriate detector geometrical factors (detector projected area, $1/r$ or $1/r^2$, and absolute quantum times collection efficiency) gives expected photoelectron yields. The DUMAND data from Keahole is reviewed in contrast to new data from Scripps (1) on the "clearest ocean waters" and it is found that a) Bradner (2) and Zaneveld's (3) data are consistent at 1.5 km depth, b) Zaneveld's (3) deep ocean data (4.1 km) is not as good as data reported in the new results, but c) conservatively, the new much combined with Zaneveld's results give confidence that the water transparency is in fact better than we have heretofore assumed. More observations are obviously in

order. Several (6) approximations to the attenuation have been made, ranging from the "old" conservative approximation⁽⁵⁾ to pure water, and the coefficients are presented herein. These have been incorporated in subroutines and inserted into the DUMAND Monte Carlo program.

I. Introduction

The attenuation coefficient in water for several conditions is shown in figure 1. In a recent paper Smith and Baker (ref. 1) have reviewed data of theirs and of others on the clearest natural waters. They have acquired new data in the range of 300-340 nm which was not reliably available previously. These workers are principally concerned with details of the optical properties of the water and they measure slightly different quantities than are most appropriate for DUMAND. Smith and Baker employ a "submersible UV spectroradiometer" to measure the diffuse attenuation coefficient, K , which is calculated from the logarithmic slope of the irradiance (E) with depth (z):

$$K(\lambda) = \frac{\ln[E(z_1)/E(z_2)]}{z_1 - z_2} \quad (1)$$

The total beam attenuation is defined as

$$c(\lambda) = a(\lambda) + b(\lambda) \quad (2)$$

where a is the absorption and b the total scattering coefficient. It is c that is often measured (ref. 2) or something close to c , because the optical oceanographers tend to use instruments with highly collimated beams. Nevertheless, just as with elementary particle crosssection measurements, the beam attenuation will contain some forward scattering. This does not of course concern us for DUMAND applications (and in fact we want just the opposite; namely we would like to include some scattering). The direct attenuation coefficient is approximately given by

$$K \approx a + b \quad (3)$$

where b_b is the backscattering part of b . The attenuation is now evidently trivial because our counters will receive some scattered energy, molecular and particle, particularly in the far blue. For DUMAND, K is probably "obscured" by the appropriate quantity. Also plotted in figure 1 are data from Zaneveld⁽²⁾ and one point from Bradner⁽³⁾. The Zaneveld points are taken from the graphs in his DUMAND '80 paper.⁽²⁾ It is noteworthy that Zaneveld's data at 9.5 m depth is consistent with Bradner's point, even though they were taken at "slightly" different locations and at different times. Also Bradner's observation should be close to K while Zaneveld's should be nearer to b . One notes that Zaneveld's data from all three depths plotted shows an attenuation coefficient rising rapidly in the blue, much more rapidly than the clearest ocean values of Smith and Baker. Assuming the data correct it appears that scattering is significant in the Keahole basin making the attenuation coefficient 2 to 3 times worse than optimal in the 400-450 nm range. We will see the importance of this difference later.

II An "effective photon" survival function

The diffuse attenuation coefficient (K) shown in figure 1 (ref. 1) is seen to exhibit several features. First the bumps on the red side apparently coincide with harmonics of the O-H stretch in water (6th at ~514 nm, 7th at ~604 nm, and 4th at 743 nm, ref. 4). The wavelength dependence of the coefficient can be looked at as a sequence of increases $\propto \lambda^m$ ($m=10$), approaching the resonance from the blue side, and $\propto \lambda^2$ thereafter. On the ultraviolet side it appears to be $\propto 1/\lambda^4$ (suspiciously like Rayleigh scattering). The red side behaviour makes sense as a high order resonance phenomena, but I don't understand the blue side. An analytical approach from first principles looks difficult, and probably not useful. We can get a clue to finding a function that will be

phenomenologically useful form. The following, however, suggests that we can represent such an emission (such as a power law function of wavelength) generally about some central value λ_0 : at x sufficiently far away and with x/λ sufficiently small, it follows that $a_0 + a_1(\lambda - \lambda_0) \approx a_0$ so that $e^{-[a_0 + a_1(\lambda - \lambda_0)]x} \approx e^{-a_0 x}$.

Then the number (dn) of Cherenkov photons per unit track length (dl) surviving to a distance x will be given by:

$$\frac{dn}{dl}(x) = g \int \frac{d\lambda}{\lambda^2} e^{-[a_0 + a_1(\lambda - \lambda_0)]x} \quad (5)$$

where g represents constants not depending on λ . (We will add the geometrical $1/x^2$ or $1/x^3$ factors later, as is appropriate for line or point radiation). If the region of integration is restricted to the neighborhood of λ_0 , then we see that this is in fact true and our unlabeled "exponential" function $e^{-a_0 x}$ is replaced by $e^{-a_1(\lambda - \lambda_0)x}$.

$$\frac{dn}{dl} \approx g \frac{e^{-a_1(\lambda - \lambda_0)x}}{\lambda^2} \int d\lambda' e^{-a_1(\lambda' - \lambda_0)x} \quad (6)$$

$$= \frac{-a_1 x}{\lambda_0^2} (a_1 x)^{\gamma} \int_{\text{maximum}}^{\lambda'' \text{ max}} d\lambda'' e^{-a_1(\lambda'' - \lambda_0)x} \quad (7)$$

$$= \frac{-a_1 x}{\lambda_0^2} (a_1 x)^{\gamma} s(x) \quad (8)$$

This approach works, as will be seen later, and gives a reasonable fit to the numerically integrated data. While s is expected to be a small number we shall have to do something to prevent a divergence at $x=0$. I've simply added a constant to s . The function to be tried is then:

$$F(x) = A(x + x_0)^{-\gamma} e^{-\beta x}$$

If we have the true function of s , we can determine the coefficients in equation 9, by considering four points:

$$F_0 = F(0) \quad \text{at } x = 0 \quad \text{and} \quad A \quad \text{the free parameter}$$

$$\begin{aligned}
 F_1 &= F(x_1) \\
 F_2 &= F(x_1) + F(x_1 + D) \\
 F_3 &= F(x_3) + F(x_1 + 2D)
 \end{aligned} \tag{10}$$

The solutions may be written

$$\begin{aligned}
 Y &= \frac{\ln(F_2^2/F_1 F_3)}{\ln(x_1 x_3/x_2^2)} \\
 S &= \frac{\ln(F_2/F_3) - Y \ln(x_3/x_2)}{x_1} \\
 A &= F_1 e^{Bx_1 x_3} \\
 x_0 &= (A/F_0)^{1/Y}.
 \end{aligned} \tag{11}$$

III Calculating the Appropriate Functions

A useful function can be calculated numerically as the product of the number of Cerenkov photons per unit track length (dn/dl) times the attenuation ($\exp(-a(\lambda)x)$) to some distance x , times the relative quantum efficiency ($Q(\lambda_i)/Q_{\max}$), times the phototube envelope transparency [raised to a power equal to the actual thickness divided by nominal thickness, (t/t_0)], over wavelength. I call this function the "effective number of photons per unit track length", as a function of distance:

$$\frac{dN_{eff}}{dl} = 2\pi a \left(1 - \frac{1}{n^2}\right) 10^7 \left\{ \frac{\Delta \lambda}{\lambda^2 - \Delta \lambda^2} \frac{[G(\lambda_i)]^{t/t_0} Q(\lambda_i)}{Q_{\max}} e^{-a(\lambda_i)x} \right\} \text{photons/cm}(12)$$

$a = 1/137$, $n = 1.35$ for sea water at depth, and the 10^7 converts wavelength λ_i in nm to cm.

To apply this source function in calculations we must convert it to either one of two cases, radiation from a line or from a point. For consistency with Stenger and Roberts (ref. 5) I take

$$\frac{dN(x)}{dx} = \frac{dN_{\text{eff}}}{dl} \cdot \frac{100}{2\pi(1 - 1/n^2)x}, \text{ photons/m}^2 \quad (13)$$

where the photons arrive at the Cerenkov angle at a perpendicular

distance (from a single highly relativistic track)

$$p = \sqrt{1 - 1/n^2} \cdot x. \quad (14)$$

The other case, which applies to localized bursts, is, for consistency, made a function of energy by dividing by the energy loss rate/cm, A, at minimum ionization:

$$A \approx 2.18 \times 10^{-3} \text{ GeV/cm.} \quad (15)$$

Then

$$\frac{dN}{dl} = \frac{dN_{\text{eff}}}{dl} \cdot \frac{1}{A \cdot 4\pi x^2}, \text{ photons/m}^2 \text{ GeV}^{-1} \quad (16)$$

We see that the function (dn/dl , equation 12) for effective photons/cm² versus distance (dl) is well behaved at small distances because we have the $1/p$ and $1/x^2$ terms in line and point radiation cause them to diverge. The approximation of calculating photon density and then multiplying by detector area to predict signal strength is not useful at distances of the order of a detector's radius, and so in a computer program one should cut off p or x at such small dimensions.

Note that dN/dA and dl/dE must be multiplied by the area and maximum quantum times collection efficiency of the phototube to get expectation numbers of photoelectrons. Further, in the present calculations the envelope is taken as 3 mm thick pyrex, as is appropriate to the EMI hemispherical phototubes (refs. 6 and 7). The relative quantum efficiency is taken to be the nominal distribution given by EMI (ref. 6) for this bialkali photocathode. The glass cuts the photons off below ~250 nm while the quantum efficiency cuts these off

above ~650 nm. The average number of photons visible near a ionizing track converges then to a value of 297/cm. (This is surprisingly very close to the nominal value given in the particle handbook⁸, which yields 215 photons/cm). One

In Figure 2 one sees plotted the various components used in calculating the effective Cerenkov source distribution. The data is also tabulated in Appendix I. One should observe that the effective distribution is peaked at about 340 nm while the attenuation is least in the range of 400-500 nm. This emphasizes the importance of the Keahole observations which imply several times the "ideal" attenuation coefficient in the 350-450 nm range. Six functions of attenuation have been parameterized as indicated in figure 2 by numbers 1 through 6. The first five employ the Smith and Baker data for the range of 500-800 nm, where almost all observations agree, and employ Smith and Baker data multiplied by a constant factor between 200-400 nm. The range of 400-500 nm is spanned by sketched in functions. The first corresponds to the old Stenger and Roberts approximation. The third is consistent with Zeeveld's 4.1 km data and the fifth is the Smith and Baker data. The sixth corresponds to Smith and Baker's "pure water" absorption coefficient. Given present data $m = 3$ seems the most reasonable and conservative choice.

Figure 3 and 4 show results of various calculations of the photon density from cascades and from maximum ionizing tracks and the data is tabulated in Appendix II. The new calculations and fitted function agree satisfactorily and they agree with the Stenger and Roberts function reported in by up to about 25 m. That function, which utilized a power series approximation, diverges at large and small distances. Also shown in figure 3 is the enhance-

ment in photon density over isotropic emission at the detector, which is shown by the following angular distribution for light from cascades as calculated in ref. 12. Finally in figure 5 we present curves showing photon density versus distance for the various models. Note that the range of visibility of a track to a detector of 1 ps/100 photons/m² (which we will do anyway) (e.g. about ~143 m) goes from ~10.5 to 13 to 19 to 23 to 28 m as we go from the old model to our observed data to best ocean conditions to pure water. At an $s = 6$ (e.g. Upsilon nine detector) the gain is even stronger going from 22 to 28 to 44 to 59 m. If one looks at this in terms of the cube of these numbers which will reflect the inverse of the required detector density, the possible gains are spectacular in operating in the clearest ocean waters (which are marginally clearer than pure water). These functions have been programmed and incorporated in the DARM Monte Carlo. (9)

Die Ergebnisse sind folgende: Bei den 1000 Versuchspersonen wurde eine durchschnittliche Anzahl von 1,25 Schlägen pro Tag festgestellt. Der Unterschied zwischen den beiden Gruppen ist nicht signifikant. Die Ergebnisse zeigen jedoch, dass die Gruppe mit der höheren Anzahl von Schlägen eine höhere Anzahl von Schlägen pro Tag hat als die Gruppe mit der niedrigeren Anzahl von Schlägen. Dies ist ein interessanter Befund, da es sich um eine prospektive Studie handelt.

References

- 1) Raymond C. Smith and Karen A. Baker, "Optical Properties of the Darkest and Clearest Natural Waters (200-900)", *Applied Optics*, 20, 177 (1981). This paper also contains an excellent review of previous data except that in refs. 2 and 3, below.
- 2) J.R.V. Zaneveld, "Optical Properties of the Keahole Point Site", in *Proceedings of the 1980 International DUMAND Symposium*, Aug 24-28, 1980, August 2, V.J. Stenger ed., I, 1 (1981). Hereafter referred to as D'80.
- 3) H. Bradner and G. Blackinton, "Long Baseline Measurements of Light Attenuation", D'80 I, 9 (1981).
- 4) C.K.N. Patel and A.C. Tan, *Nature* 280, 302 (1979).
- 5) V.J. Stenger and A. Roberts, "The Generation and Propagation of Cerenkov Light in the DUMAND Monte Carlo Program", D'80 I, 161 (1981).
- 6) See EMI Industrial Electronics Ltd, 1979 Catalogue.
- 7) AIP Handbook 3rd Edition, D.W. Gray, Ed., AIP, McGraw-Hill, NY (1972), 6 92.
- 8) Particle Properties Data Booklet, N. Barash-Schmidt et al., RMP 52 77 (1980).
- 9) The functions ATTEM1, [JGL]ATTEM1.FOR and [JGL]ATTEM2.FOR and [JGL]WHAT.FOR.

Figure Captions

- 1) Attenuation versus wavelength. The Smith and Baker data is for the clearest natural scatter observed by them and reproduced here. The ultraviolet data, extrapolated from Zaneveld's data, are seen to fit Bradner's data to be consistent with Bradner's at 1.7 km depth. Zaneveld's data is not as good as Smith and Baker's. Bradner's data is however for total attenuation coefficient. Bradner's observation should however be close to the "diffuse" attenuation coefficient for this location.
- 2) Components of the "effective photon spectrum" and various models for the attenuation coefficient. The glass transparency is taken as 3 mm thick pyrex with reflectance 30% and 92% transmission over the band from 300 to 800 nm (from refs. 6 and 7). The efficiency is taken to be that of the EMI bialkali photocathode (ref. 6). For the effective photon distribution it is normalized to unity quantum efficiency (0.27) at 370 nm. The Cerenkov spectrum (ref. 8) is proportional to $1/\lambda^2$. The effective Cerenkov source distribution, shown as the heavy curve, extends from ~ 300 to 450 nm with maximum value at 340 nm. The units are photons/10 nm with 1.45 photons/nm at the peak and integral of 237 photons/cm of relativistic track. Various models for the attenuation coefficient are also shown as indicated by index m : 1) corresponds to the old Stenger and Roberts' approximation (ref. 5); 2) is a more reasonable version of 1; 3) corresponds at least roughly to the Zaneveld 4.1 km Keahole data (ref. 2); 4) is an intermediate approximation; 5) is the diffuse attenuation coefficient for the clearest ocean waters from Smith and Baker (ref. 1); and 6) is the absorption coefficient for pure water (ref. 9). Also shown is the scattering cross section for a) for pure water (ref. 10) and b) for pure water (ref. 1).
- 3) Logarithm (base 10) of the photon density per GeV of source that radiates at minimum ionization versus distance from point source. The flux distance dependence is $1/r^2$ times photon attenuation. The old Stenger and Roberts (ref. 5) calculation and fit agree with the new calculation and fit satisfactorily in the range of 1 to 25 m. Their approximation being a power series diverges at large and small distances. The curve labeled as "fit with angular enhancement" has the same distance dependence as otherwise, but has about a 12 fold increase in photon density at the Cerenkov angle (over isotropic emission). The angular distribution function is taken from ref. 5.
- 4) Logarithm (base 10) of the photon density versus perpendicular distance from a relativistic track. Stenger and Roberts' calculation and fit (ref. 5) and new calculation and fit agree satisfactorily out to ~20 m. Note effect of glass transparency and relative quantum efficiency.
- 5) Photon density versus perpendicular distance for various models of attenuation as discussed in text. The old model (ref. 5) $m = 1$,

is overly pessimistic, while $m = 3$, fits the new Zarnstorff data (ref. 2) best, $m = 1$ corresponds to best ocean conditions (ref. 1), and $m = 5$ to for pure water (ref. 1). On the right hand curve, sensitivity is indicated in strengths (photocurrents/100 photons/cm²) with plausible values ranging up to $\sim s = 6$. Note "spectacular" gain in seeing distance between $m = 1$, 3 and $m = 5$, particularly at large s values.

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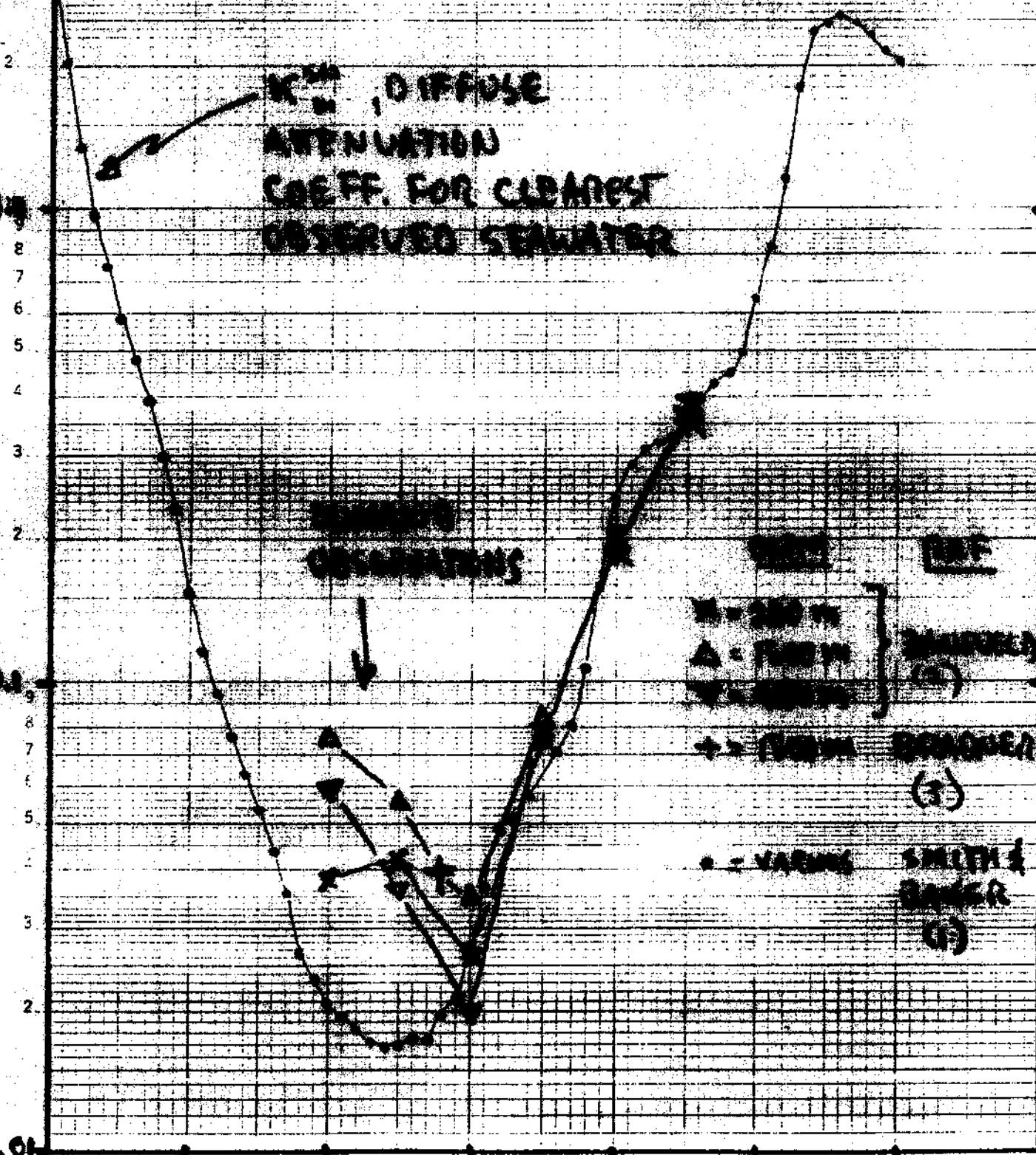
DEPT. OF PHYSICS

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LOGARITHMIC DIFFUSE
ATTENUATION
COEFF. FOR CIGARETTE
SMOKING SPECTRUM



W. VANDENBERG

2

SHADE &
HATCH
DIFFUSE
AREA

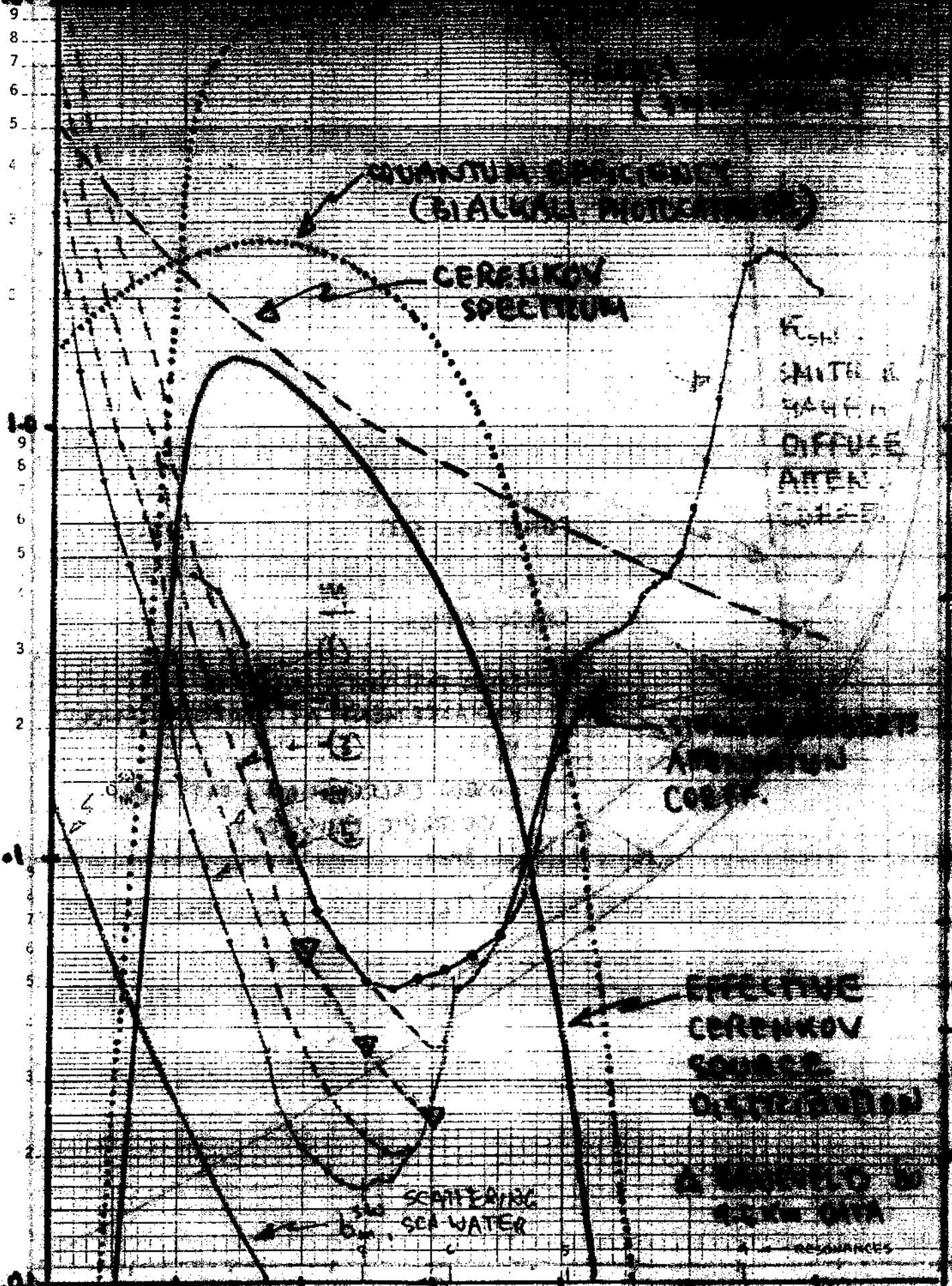
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SCATTERING
SEA WATER

REMARKS

CERAMIC
SPECIMEN

MONOCRYSTALLINE
CERAMIC



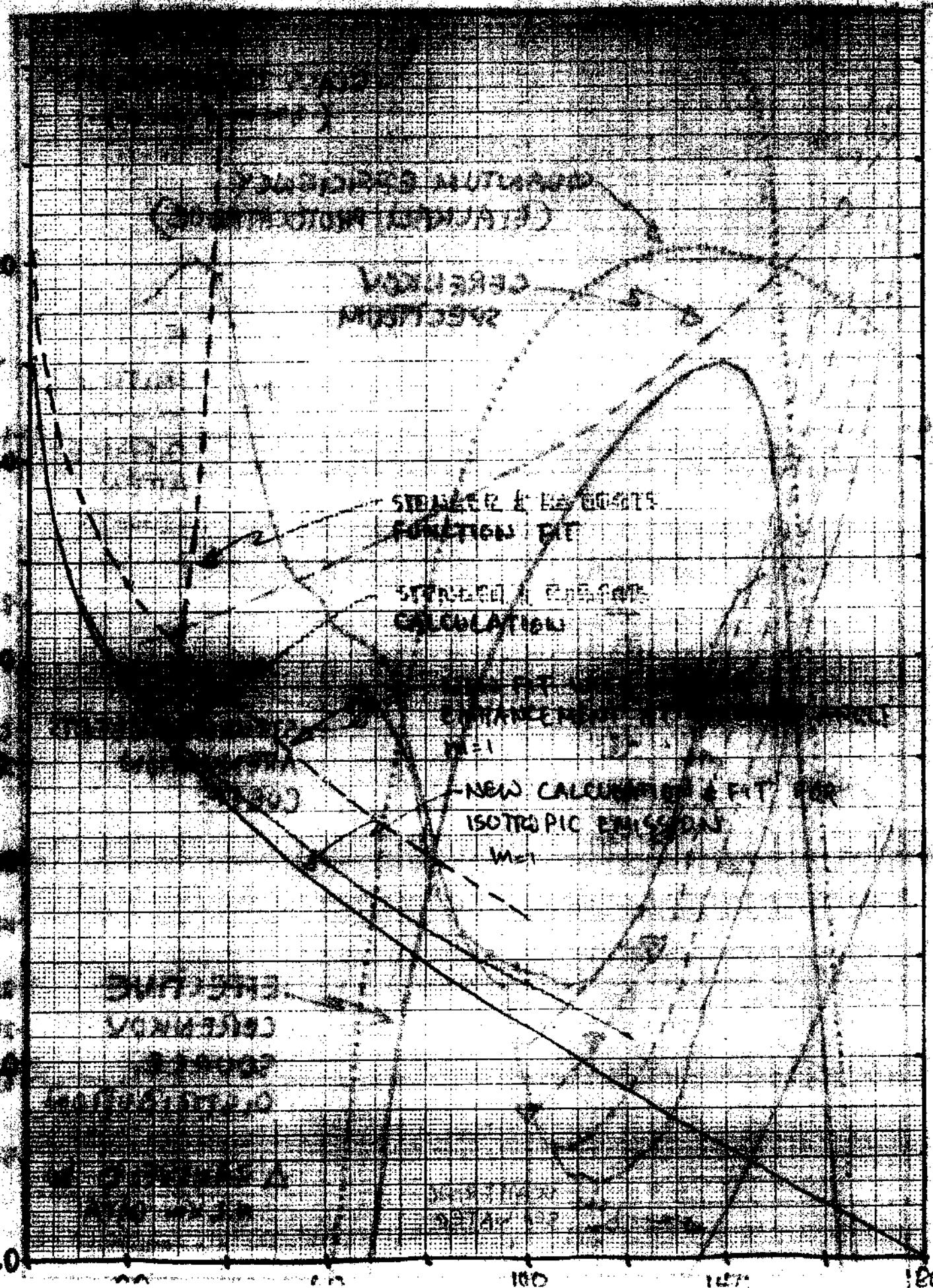
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SEMILOGARITHMIC DRAWING

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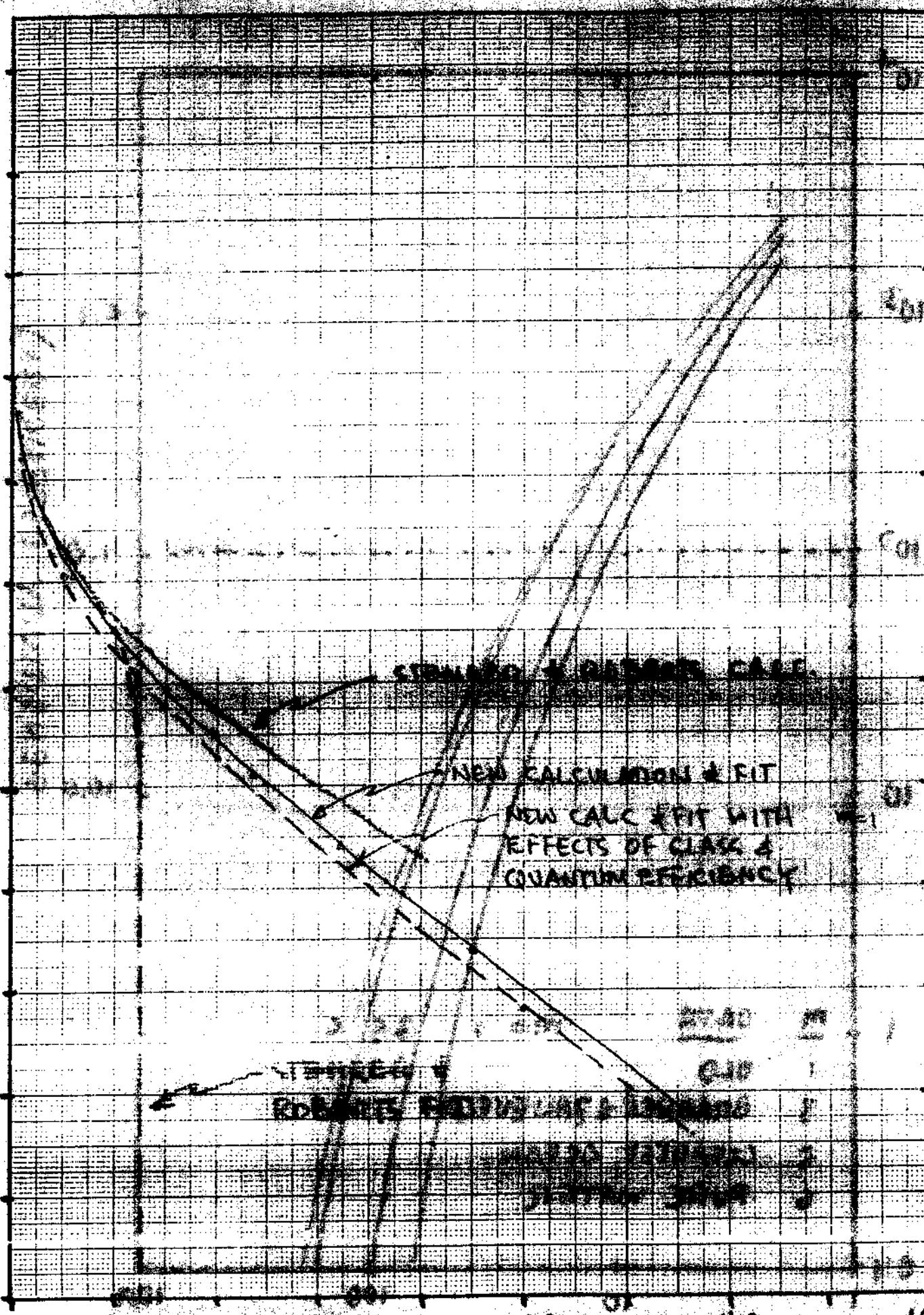


PHOTO DENSITY (arbitrary units/m²)

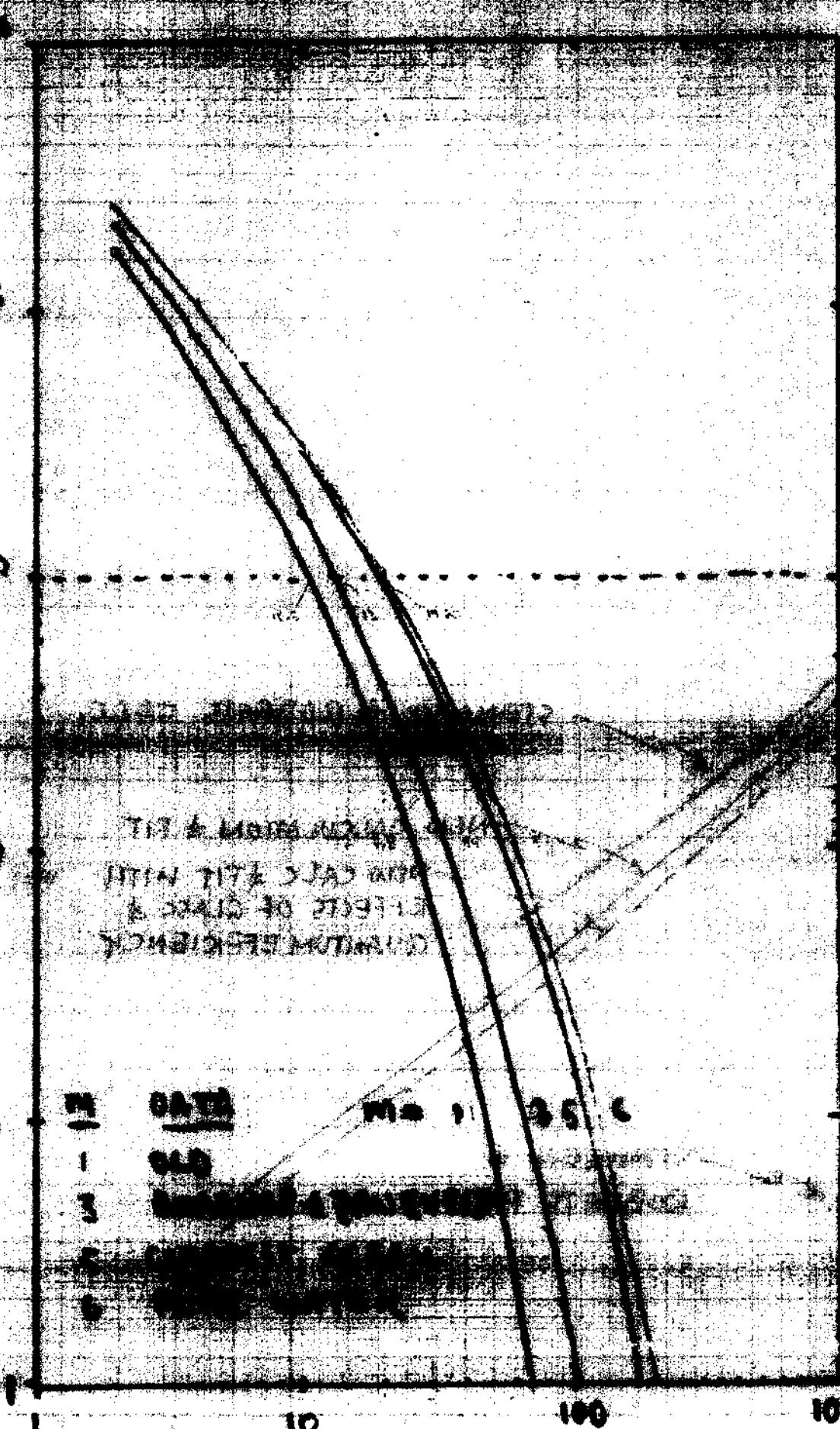
10³

10²

10¹

1

0.1



0.1

TIT + MoSi 42%
TIT + 2% Al₂O₃
C/Si/SiC/SiC/SiC

10 100 1000

FILE [JGL]ATTEN.FOR

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PROGRAM ATTEN
C PROGRAM FOR CALCULATING ATTENUATION OF CERENKOV
C LIGHT IN SEA WATER AS A FUNCTION OF THE WAVELENGTH
C ATTENUATION COEFFICIENT FROM THE DABER, REEDER
C AND BAKER, APPN, OPTICS, 201377, 1981.
C
C LAM IS WAVELENGTH IN NM
C DNDF IS NUMBER OF PHOTONS/CM TRACK AT SLANT DIST X
C X IS THE SLANT DIST TO TRACK IN METERS
C DNDE IS THE NUMBER OF PHOTONS/M2*GEV FROM ISOTROPIC SOURCE
C DNDA IS THE NUMBER OF PHOTONS/M2 AT SLANT DIST X
C RHO IS THE RADIAL DIST FROM A TRACK (AT SLANT DIST X)
COMMON /STUFF/ LAM(61), DAC(61), DNDF(100), DNDE(100),
+DNDA(100), RHO(100), OE(61), PWAC(61)
COMMON /PARAM/ AM, B, RINDEX, DX0
DIMENSION FACTOR(3), PATCH(10,3)
DATA NX/100/, DX/2.0/, XMIN/2.0/
DATA NL/61/, DL/10/, LMN/200/, SUR/0.1/, BUMP/0.1/
DATA THICK/0.1/, THNUM/0.3/, OLM/0.22/
DATA ALPHA/7.299E-3/, BDEL/1.35/, P1/3.44397, B2/2.18E-3/
C B IS ENERGY LOSS RATE IN GEV/CM
C RINDEX IS SEA WATER INDEX OF REFRACTION AT DEPTH
C DAC IS THE DIFFUSE ATTENUATION COEFFICIENT IN NM
DATA DAC/3.14*2.05136, 0.968, 0.754, 0.589, 0.461, 0.349,
+0.306, 0.230, 0.154, 0.116, 0.0944, 0.0765, 0.0617, 0.0499,
+0.0353, 0.0267, 0.0231, 0.0209, 0.0195, 0.0182, 0.0169, 0.0156,
+0.0168, 0.0176, 0.0175, 0.0194, 0.0212, 0.0230, 0.0248, 0.0265,
+0.0319, 0.0568, 0.0648, 0.0717, 0.0807, 0.10, 0.12, 0.14,
+0.29, 0.31, 0.32, 0.33, 0.34, 0.35, 0.36, 0.37,
+1.17, 1.8, 2.18, 2.4, 2.6, 2.8, 3.0, 3.2
C FACTOR SCALES THE ATTEN COEF IN THE FAR BLUE
C MM. DETERMINES THE TRANSMISSION COEF TO BE USED
C CORRESPONDS TO 75' DEPTH IN PURPLE WATER
C AND BAKER, APPN, GIVES PURE WATER ATTEN COEF ( ALSO SEE APPN 1)
DATA FACTOR/1.29, 0.86, 0.71, 0.53/
C PATCH SMOOTHES THE ATTEN COEF IN THE 410-900 NM REGION
DATA PATCH/0.75, 0.08, 0.01, 0.51, 0.50, 0.48, 0.44, 0.41, 0.35,
+.034, .05, .045, .04, .036, .032, .03, .028, .024,
+.032, .028, .026, .024, .022, .021, .02, .021, .018
C PWAC IS THE ABSORPTION COEF FOR PURE WATER
DATA PWAC/
+3.0700, 1.9900, 1.3100, 0.9270, 0.7200, 0.5590, 0.4570, 0.3700, 0.2980,
+0.2150, 0.1410, 0.1050, 0.0844, 0.0678, 0.0561, 0.0454, 0.0357, 0.0263, 0.0156,
+0.0220, 0.0191, 0.0171, 0.0162, 0.0153, 0.0144, 0.0135, 0.0126, 0.0117, 0.0038,
+0.0156, 0.0176, 0.0196, 0.0217, 0.0257, 0.0247, 0.0237, 0.0227, 0.0217, 0.0200,
+0.0708, 0.0799, 0.1080, 0.1270, 0.1460, 0.1650, 0.1840, 0.1930, 0.1990, 0.1990,
+0.3490, 0.4000, 0.4300, 0.4500, 0.4600, 0.4600, 0.4600, 0.4600, 0.4600, 0.4600,
+2.3800, 2.4700, 2.5500, 2.5100, 2.3600, 2.3000, 2.2500, 2.2000, 2.1500, 2.1000
C OE IS THE QUANTUM EFFICIENCY VERSUS WAVELENGTH FOR A STRECKER
C PHOTOCATHODE. DATA FROM EMI SPECIFICATIONS
DATA OE/0.15, 0.16, 0.172, 0.184, 0.196, 0.207, 0.216, 0.226,
+0.233, 0.241, 0.248, 0.253, 0.257, 0.261, 0.265, 0.268, 0.273,
+0.27, 0.269, 0.268, 0.263, 0.258, 0.25, 0.24, 0.23, 0.22, 0.21,
+0.198, 0.185, 0.175, 0.166, 0.156, 0.147, 0.138, 0.129, 0.120, 0.112,
+0.063, 0.05, 0.0375, 0.028, 0.02, 0.013, 0.0084, 0.005, 0.002,
+0.0014, 0.0015, 0.0/

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[JGL]ATTEN2.FOR IS FOR M=1 (OLD
STENGER & ROBERTS APPROXIMATION)

THE PEGASUS

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550 CONTINUE
  WRITE(6,609)
600 FORMAT('1 WAVELENGTH DEPENDANCE',
     +'/5X,'1 LAMDA, NM! 5X,'ATTEN COEF, 1/M!, 5X,
     +' QUANTUM LT/F 1/5X,'GLASS TRANS 5X
     +'NUMBER PHOTONS' 5X,'EFFECTIVE PHOTONS' //?
     WRITE(6,650)(LAM(JL),DRC(JL),OE(JL),GL(JL),DN(E(JL)),JL=1,NL)
650 FORMAT(100(1X,110,3(F10.4),10X,F10.1,10X,F10.3//))
  WRITE(6,700)
700 FORMAT('1 NUMBER OF PHOTONS/CM TRACK VERSUS DISTANCE' //,
     +' DIST, NM! BX,'PHOTONS/CM' ,7X,
     +' PHOT/M2*GEV' ,IX,'PHOT/M2' ,3X,'RADIAL DISTANCE'
     +5X,'FITTED FUNC' //)
     WRITE(6,800)(X(IX),DNDT(IX),DNDA(IX),DNDC(IX),
     +FOND(T(IX)),IX=1,NX)
800 FORMAT(100(1X,F10.0,5X,3(E10.3,5X),F10.1,5X,E10.3//))
  LAMIOT=LAM(NL)-LAM(1)
  BINVE=1/BETA
  WRITE(6,900) SUM,LAMTUT,SUMPE,XX1T,XX2T,XX3T,AA,GAM,XX0,BETA,BINV,
  +MM,KK
900 FORMAT(////' SUM=' ,F10.1,'PHOTONS/CM IN ',15,'NM'/
     +' EFFECTIVE TOTAL PHOTONS/CM=' ,F10.2//)
     +' XX1=' ,F10.2/
     +' XX2=' ,F10.2/
     +' XX3=' ,F10.2//
     +' AA=' ,F10.3/
     +' GAM=' ,E10.3/
     +' XX0=' ,F10.3/
     +' BETA=' ,F10.5/
     +' 1/BETA=' ,F10.2//)
     +' MM=' ,I5/
     +' KK=' ,I5//)
  STOP
END

```

FUNCTION FUT(XX)

C THIS PHENOMENOLOGICAL FUNCTION PRODUCES THE SURVIVING
C NUMBERS OF PHOTONS/CM TRACK THAT REACH A DISTANCE X.
C IT MUST HAVE GEOMETRIC FACTORS ADDED TO REPRESENT
C RADIATION FROM A LINE OR A POINT.

COMMON /PARAM/AA,GAM,BETA,XX0

FUT=0.0

IF(XX.LT.0.0)RETURN

FUT=AA*(XX+XX0)**(-GAM)*EXP(-BETA*XX)

RETURN

END

FUNCTION PHOTONS(XX)

C DOES THE INTEGRAL OVER WAVELENGTH FOR CERENKOV LIGHT
C SEEN FROM DISTANCE X. UNITS ARE PHOTONS/CM.

COMMON /STUFF/ LIM(61), DAC(61), ENDI(100), X(100), DNE(100),
 +DNDA(100), RHO(100), DN(61), NL, DL, LMIN, COEF, FOND(T(100)),
 +OE(61), GL(61), DNE(61)

PHOTONS=0.0

IF(XX.LT.0.0) RETURN

DP=0.0

DO 200 JL=1,NL

DP=DP+DNE(JL)*EXP(-XX*DAC(JL))

200 CONTINUE

PHOTONS=DP

RETURN

END

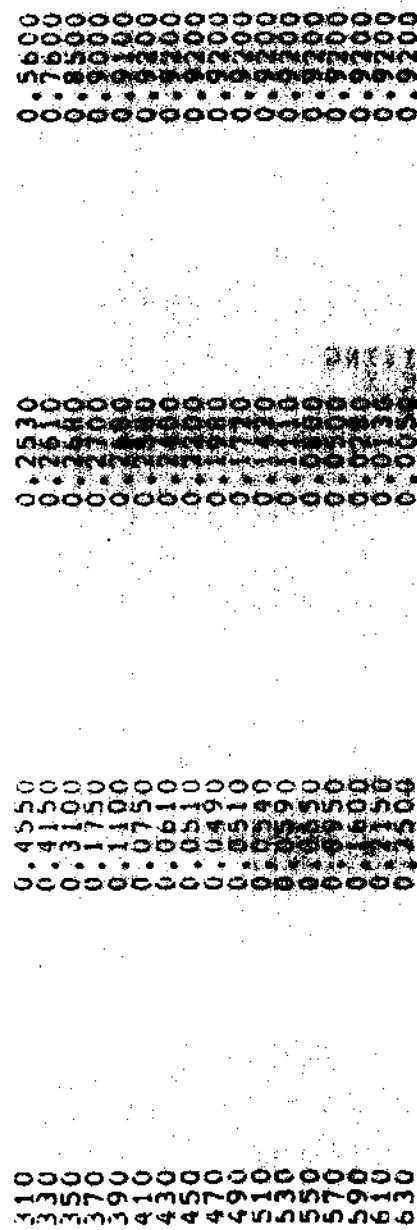
MAGNETIC DEPENDANCE 11

ATTEN COEF, 1/M QUANTUM EFFIC

ATTEN COFF, 1/M

GLASS TANKS

EFFECTIVE PHOTON NUMBER PHOTONS



GRH DEPENDANCE $M = 2$

SMA, NM ATTEN. COEF, 1/N

ATTEN-CUFF, 1 / 1

NUMBER PHOTONS EFFECTIVE PHOTON

GLASS TRANS

QUANTUM ELECTRIC

ATTEN. CU
BDA, NM

GTH DEPENDANCE $M \approx 3$

BDA, NH ATTEN. GUTT, 1/M

GLASS TRANS

NUMBER PHOTONS

EFFECTIVE PHOTONS

GRH DEPENDANCE

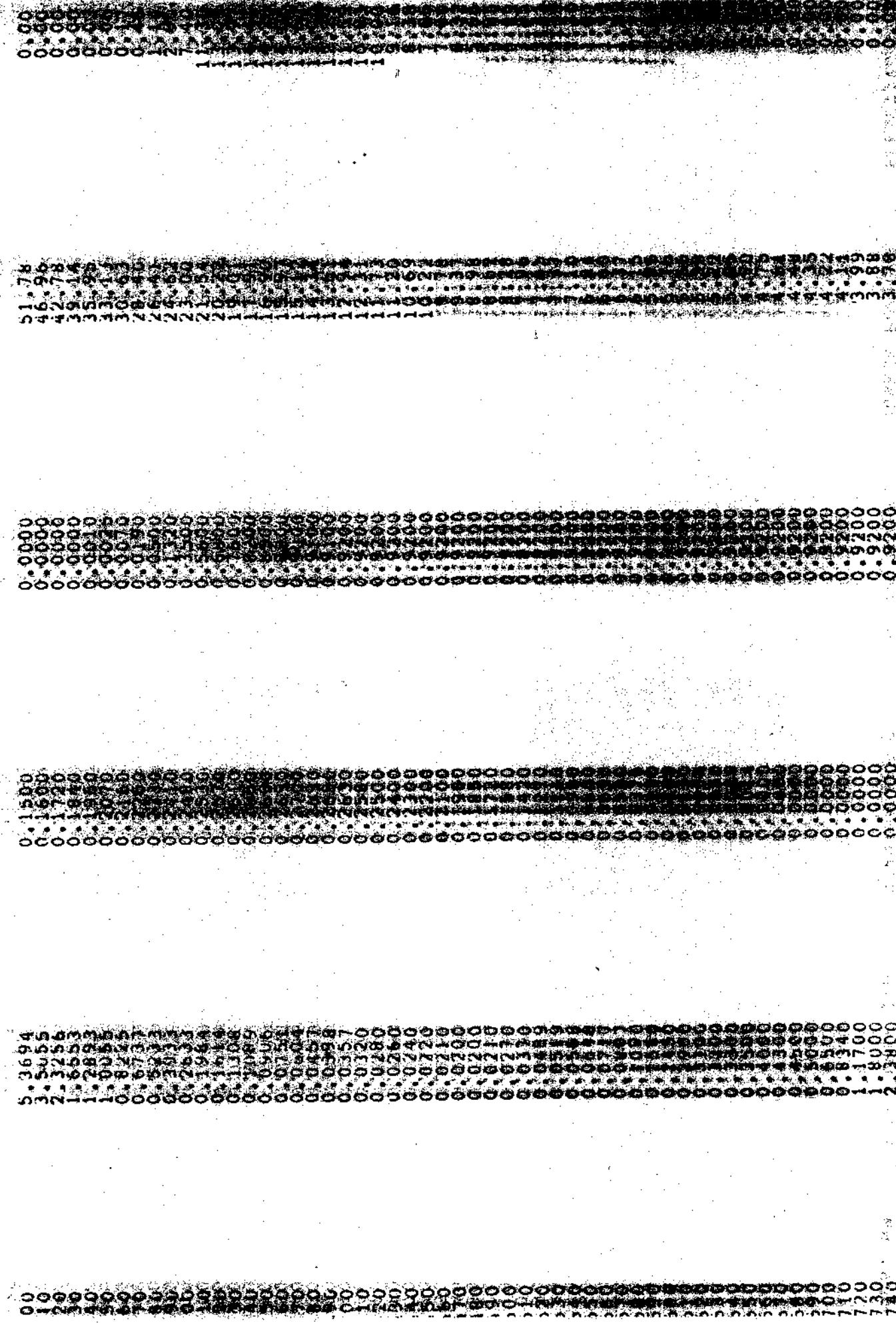
BDA, NM AUTEN CUEF, 1/M

QUANTUM EFFIC

GLASS TRANS

NUMBER PHOTONS

EFFECTIVE PHOTONS



51H DEPENDANCE $M = 5$

ATTEN GOFF, 1/14

QUANTUM ELECTRIC GLASS. THANKS

NUMBER PHONICS

EFFECTIVE TREATMENTS

PROGRAM TO TEST PHOTON DENSITY FUNCTIONS
(PHOCAS & PHOMIZE)

FILE [SIC!] WHERE, FOR

PROGRAM WHEREAS
C TEST ROUTINE FOR FILE WHAT FOR, THE CEREMONY FUNCTIONS
C DENSITY FUNCTIONS PHOMIZE AND PHOCAS.

```
DO 500 IM=1,6
RMIN=2.0
DELR=2.0
NR=100
E=1.0
FN=1.35
THC=ACUS(1/FN)
TH=THC
M=IM
WRITE(6,50)
50 FORMAT(1H1,5X,'DISTANCE,M',5X,'DNDA',10X'DNDE'///)
DO 200 IR=1, NR
R=RMIN+(IR-1)*DELR
DNDA=PHOMIZE(R,TH,THC,M,E)
DNDE=PHOCAS(R,TH,THC,M,E)
WRITE(6,100) R, DNDA, DNDE
100 FORMAT(6,100) R, DNDA, DNDE
200 CONTINUE
WRITE(6,300) TH, THC, M, E
300 FORMAT(//3F10.3,15F10.3)
500 CONTINUE
STOP
END
```

FILE [JGL] WHAT.FOR

24/08/1997 17:30:10 LOGGED IN BY SP2000

FUNCTION PHOCAS(R,TH,THC,M,E)

```

C--  

C--COMPUTES THE NUMBER OF PHOTONS/M**2 AT A DISTANCE R AND  

C--ANGLE TH FROM A CASCADE OF ENERGY E IN GEV.  

C--K = 1,2,3,4,5,6 CORRESPONDS TO ATTENUATION LENGTHS IN WATER  

C--OF NOMINALLY 10, 25, 40, 49, 50, 60. THE FIRST IS VERY PESSIMISTIC,  

C--THE THIRD CORRESPONDS TO BRADNER/ZANEVICH DATA AND THE SIXTH  

C--THE 'CLEAREST' NATURAL SEAWATERS! OBSERVED BY SMITH AND DAKER,  

C--AND THE SIXTH CORRESPONDS TO PURE WATER AND APPLIES TO PROTON  

C--DECAY EXPERIMENTS.  

C--DATA CLUM/0.7 PI/3.14159/ DEDX/2.18E-3/ RMIN/0.5/  

C--CLUM IS THE ANGULAR DISTRIBUTION FUNCTION OF BELYAEV ET AL.,  

C--WHERE X IS THE ANGLE IN RADIANS AND T= CERENKOV ANGLE.  

CLUM(X,Y)= ( (.556166-768.412*Y**2-1700)*Y**4+1.32864E08*Y**6 )  

+*EXP(-.5*(Y/.02515618**2)+(.602246+19.3602*Y**2-532.938*Y**4+  

+12180.9*Y**6-.00011866*Y**8+.00148023*Y**10)  

++ .0204746*X**5-.0111966*X**6+.00148023*X**7 )  

C--  

IF(CLUM.GT.0.)GO TO 200  

C--INITIALIZATION ON FIRST CALL  

C--COMPUTE ANG. DIST. NORMALIZATION FACTOR  

IST=2000  

DX=.1/FLOAT(IST)  

X=-1.  

YY=CLUM(PI,PI-THC)  

DO 100 I=1,IST  

X=X+DX  

T=ACOS(X)  

Y=CLUM(T,T-THC)  

CLUN=CLUM+(Y*YY)*DX/2.  

CCC TYPE 9000,X,YY,Y,CLUN  

YY=Y  

9000 FORMAT(1X,F6.3,3G12.5)  

100 CONTINUE  

C--THE ANGULAR DISTRIBUTION FUNCTION IS NORMALIZED TO 2.  

C--WHEN INTEGRATED OVER COS(THETA) FROM -1 TO 1.  

CLUN=CLUN/2.  

CCC PRINT 901,X,CLUN  

Y=CLUM(0,0)/CLUN  

900 FORMAT('ANGULAR DISTRIBUTION OF CERENKOV LIGHT',/  

+'0THC = ',F6.3,'RAD F(THC) = ',G10.3,/  

+'0 CTH TH F(TH)')  

DO 200 I=1,20  

X=-1+0.1*I  

T=ACOS(X)  

Y=CLUM(T,T-THC)/CLUN  

PRINT 902,X,T,Y  

FORMAT(1X,F6.3)  

150 CONTINUE  

C--  

200 CONTINUE  

C--TAKE R = RMIN AS MINIMUM  

R=RMIN  

IF(RR.LT.RMIN)RR=RMIN  

C--GET PHOTON INTENSITY FOR GIVEN ENERGY AND ANGLE  

C--DNDT/4PIRP**2 IS THE AVERAGE NUMBER OF PHOTONS/R**2 THROUGH A SPHERE  

C--OF RADIUS R METERS. CLUM/CLUN IS THE ANGULAR WEIGHTING FACTOR.  

CCC PHOCAS=DNDT(RR,M)*CLUM(TH,TH-THC)/(CONST*RR**2)  

92 TYPE 92 PHOCAS  

FORMAT(10PHOCAS = ',G10.3)  

RETURN  

END

```

[TGL] WHAT FOR CONT.

```

C CALL PHOCAS TO PRODUCE PHOTON DENSITY IN A
C RING OF RADIUS R, INDEX NINDEX, AND LENGTH L
C MAKE A FUNCTION OF R, NINDEX, L
C TO GET THE NUMBER OF PHOTONS THAT SURVIVE TO REACH
C OCCULTATION POINT FOR PURE WATER
C THIS SOURCE IS ASSUMED TO BE APPROPRIATE FOR A
C PER NINDEX AT A PERPENDICULAR DISTANCE RHO FROM A SINGLE
C CERENKOV RADIATING TRACK. THE INDEX OF REFRACTION IN
C THE MEDIUM IS RINDEX. REQUIRES THE FUNCTION DNBT TO
C CALCULATE THE NUMBER OF PHOTONS THAT SURVIVE TO REACH
C SLANT DISTANCE RHO FROM A RADIATING TRACK IN A
C UNIT AREA IN A RING OF RADIUS R, INDEX NINDEX
C CHECKS WHETHER RHO IS SMALLER THAN 100 TIMES THE
C RADIUS. IF IT IS, THE RATIO OF RHO TO RADIUS IS USED AS
C FUNCTION OF RHO/RADIUS. THIS IS USEFUL FOR PHOTON
C PHOTON DENSITY IN A RING OF RADIUS RHO, INDEX NINDEX
C RHO/INDEX, LENGTH L. RHO/INDEX IS THE RADIUS AT WHICH THE PHOTON
C DENSITY MAKES SENSE, THAT IS ABOUT ONE DETECTION
C RADIUS.
C
C      DATA RINDEX/1.35/, RHOMIN/0.5/, PI/3.14159/, KALL/0/
C INITIALIZE CONSTANT FACTORS
C      RHO=0.01, R=0.1, GO TO 100
C CONSTANT DIVISION BY UNITS OF PHOTON/CM OF SOURCE
C TRACK LENGTH L
C      L=1.0, GO TO 100
C      L=1.0/(INDEX*2.31)
C SINE OF RELATIVISTIC ANGLE
C      SIN=1.0/(INDEX*2.31)
C MINIMUM RHO/INDEX DISTANCE
C      XX=RHO/RHOMIN/STC
C      100 CONTINUE
C      RALL=RALL+1
C      CONVENT TO SLANT DISTANCE
C      XX=RHO/STC
C NO DIST TOO CLOSE
C      IF(XX.LT.RHOMIN) XX=RHOMIN
C NOW CALL PHOCAS
C      CALL PHOCAS, R, NINDEX, XX, RALL
C
C
C
C      FUNCTION DNBT CALLING PHOCAS TO PRODUCE PHOTON
C      DENSITY IN A RING OF RADIUS R, INDEX NINDEX, LENGTH L
C      PER NINDEX AT A PERPENDICULAR DISTANCE RHO FROM A
C      A DISTANCE RHO FROM A RADIATING TRACK THAT SURVIVES TO
C      A DISTANCE RHO FROM A RADIATING TRACK THAT SURVIVES TO
C      4/81 BY J. LEARNED FOR DETAILS.
C      THIS FUNCTION IS CALLED BY PHOCAS TO PRODUCE PHOTON
C      DENSITY FROM A SINGLE RELATIVISTIC TRACK, AND FROM
C      PHOCAS TO PRODUCE PHOTON DENSITIES FROM A CASCADE.
C      DIMENSION A(4,6)
C
C      DATA A/1.0, -0.175, 1.497, -0.04952,
C      /-0.175, 0.669, 0.104, -0.02722,
C      /0.104, -0.02722, 0.075, 0.01679,
C      /-0.02722, 0.01679, 0.04347/
C      DNBT=A(1,M)*(X+A(3,M))**(-A(2,M))*EXP(-X*A(4,M))
C      RETURN
C      END

```

上卷第2章
植物的呼吸作用

DNA PHOTONICS

• Cognitively challenging tasks can be used to increase motivation and engagement.

Consequently, the first step in the analysis of the data is to estimate the parameters of the model.

MONTEZUMA, CALIFORNIA, APRIL 1937. - A woman who had been working as a maid in a house in the city of San Francisco, California, was found dead in her room at the Hotel Monte

ప్రాణికి విషాదం కలిగిన విషాదానికి విషాదానికి విషాదానికి విషాదానికి

GENEalogical Tree of the *Leucosia* species