

DUMAND—Deep Underwater Muon and Neutrino Detection

Steering Committee, 1980

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TO: DUMAND Group
FROM: John Learned
SUBJECT: OCEAN PMT TESTS & OPTICAL ATTENUATION MEASUREMENT

I've been thinking about what to do next in the ocean, as a first step with DUMAND-like PMT's. The following was developed in discussions with Brad & Ugo, though modified since they saw it last. I solicit your comments before proceeding with the design, ordering & construction.

Goals: It is not possible to do any useful muon measurements with one or two ordinary PMT's. For example, at 2 km depth a counter recognizing all μ 's through 1 m^2 would see $10^{-3}/\text{sec}$. Two such counters separated by 10 m see only 1.2/day (vertical flux). [See D'79, P. 340.] Muons could be observed at higher rates at lesser depths, but at least a 1 km depth is required to be below the sunlight (and the active biological region). My conclusion is then that muon observations don't make sense until one can field a much larger detector [e.g., the $10 \text{ m} \times 10 \text{ m} \times 10 \text{ m}$ instrument proposed by Kitamura and myself has 10^4 times the solid angle area of the above example].

What remains then is a study of potassium isotope (K^{40}) decay generated light (plus all other ocean radioactivity that results in electrons of more than 0.6 MeV). We could also sample possible biologically produced light. The latter is more difficult to design for since we don't expect much bioluminescence, and that to be episodic. I will thus focus on the use of K^{40} light as the basis of an initial experiment. In fact, as will be shown below, I believe that we can build a simple two-tube device that will yield measurements of:

- 1) The actual in-ocean phototube noise rate (R^0) (with the right temperature, spectral response, quantum efficiency, etc.);
- 2) The density of decays (ρ) which has some spatial and possibly temporal variability in the ocean (and which Brad believes is uncertain up to a factor of two);
- 3) And the effective absorption length (λ) (for photons from such decays as seen by the photocathodes through the glass pressure housings (blue cutoff).

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Technique: It is clear that in principle, we could use a PMT in an instrument that has two configurations, closed (seeing a restricted volume of water) and open (unobstructed view), to determine the decay density and the attenuation length for the decay light. However, phototube noise must be subtracted. A third configuration with the tube covered would provide the capability to measure this dark noise (which must be done on the spot because of temporal changes due to exposure, voltage, and temperature sensitivity). Alternatively, addition of a second tube allows for deduction of the noise with only two positions and provides a cross-check on the PMT stability. More tubes might be added but I'll stick to two for simplicity.

In the closed (see Fig. 1) configuration, we observe singles (R_a^C, R_b^C) and coincidence (R_{ab}^C) rates:

$$R_a^C = R_a^N + \rho \cdot V_c \cdot f_a, \quad (1)$$

$$R_b^C = R_b^N + \rho \cdot V_c \cdot f_b, \quad (2)$$

$$R_{ab}^C = \rho \cdot V_c f_a^1 f_b^1, \quad (3)$$

where f_a and f_b^1 are probabilities for observation of the decay. The container of volume, V_c , which has $\rho \cdot V_c$ decays/second within it, is assumed to be painted white inside, with the two phototubes as the greatest absorbers of photons. (It is of course also assumed to be free flooding so that it samples the local water effectively.) The decay observation probabilities, f_a & f_b^1 , are assumed thus near unity. With no absorption each decay would result in about 10 photoelectrons (P.E.) shared by the two tubes. With discriminators set at, say, the $\frac{1}{2}$ P.E. level, the f_a & f_b^1 will clearly be near unity. Simple statistics are not the whole story because decays nearer one PMT will have higher probabilities of illuminating that tube and non-isotropic photon emission, etc. In any case the small deviations from unity in f_a & f_b^1 can be calculated and, more importantly, calibrated in the lab by the addition of known amounts of potassium to the test tank. Thus we obtain from the two individual tube counting rates and their coincidence rate, the decay density, ρ , and the individual dark rates, R_a^N & R_b^N :

$$R_a^N \approx R_a^C - R_{ab}^C \quad (4)$$

$$R_b^N \approx R_b^C - R_{ab}^C \quad (5)$$

$$\rho \approx R_{ab}^C / V_c \quad (6)$$

It is known that the noise rate will be somewhat greater than in total darkness due to afterpulsing. This will result in a few percent (of R_{ab}^N) apparent increase in the dark noise, and is both small (if R_{ab}^N is not greatly different from R_{ab}^C) and correctable by laboratory calibration.

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The second set of observations are to be done in an open configuration (see Fig. 1 for one of several possible realizations), in which each PMT views the unobstructed ocean through a well-defined solid angle, and in which a common parcel of water is simultaneously viewed by both PMT's. The observed rates are:

$$R_a^O = R_a^N + n g_a \lambda \rho \quad (7)$$

$$R_b^O = R_b^N + n g_b \lambda \rho \quad (8)$$

$$R_{ab}^O = n^2 g_a g_b / V_o^{1/3} \quad (9)$$

where n is the equivalent number of photons per decay (about 40); g is a geometric factor with dimensions of area

$$g_a \equiv \frac{\eta A_a \Delta\Omega}{4\pi} \quad (10)$$

and λ the effective optical attenuation length, with η equal to the quantum times collection efficiency of the PMT, A its area, and $\Delta\Omega$ the solid angle through which it views the ocean.

Equations (7) & (8) are derived in the following way: the number of decays seen is given by the integral

$$R_a^O = R_a^N + \int_{r_{\min}}^{\infty} \eta \cdot n \cdot \frac{A_a}{4\pi r^2} \cdot e^{-r/\lambda} \cdot \frac{\Delta\Omega}{4\pi} \cdot 4\pi r^2 dr \quad (11)$$

$$= R_a^N + n \frac{\eta A_a \Delta\Omega}{4\pi} \lambda \rho e^{-r_{\min}/\lambda} \quad (12)$$

so that with $r_{\min} \ll \lambda$ & the definition of g (Eq. (10)) we can obtain Eq. (7), and similarly r_{\min} for Eq. (8). This calculation also assumes that at r_{\min} the probability of observation is not large ($ng/r_{\min}^2 \ll 1$). Depending on the actual geometry this will also result in a small, calculable, and measurable correction.

The coincidence rate is the product of the two simultaneous probabilities for observation, times the common volume observed (V_o):

$$R_{ab}^O = \frac{n \eta A_a}{4\pi L^2} \cdot \frac{n \eta A_b}{4\pi L^2} \cdot \rho V_o \quad (13)$$

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where L is the mean distance to the common volume from the PMT's (assumed symmetrically placed). [Again, I assume isotropic emission of photons from the decay, which though not true, is correctable.] Now, taking

$$\frac{\Delta\Omega}{4\pi} = \frac{V^{2/3}}{4\pi L^2}, \quad (14)$$

and substituting back into Eq. (13) with the definition of g (Eq. (10)), we obtain the advertised Eq. (9).

We can then substitute and solve for λ :

$$R_a \equiv R_a^O - R_a^N, \quad (15)$$

$$R_b \equiv R_b^O - R_b^N, \quad (16)$$

$$\frac{R_a R_b}{R_{ab}^O R_{ab}^C} = \frac{\lambda^2 V_o^{1/3}}{V_c}, \quad (17)$$

and

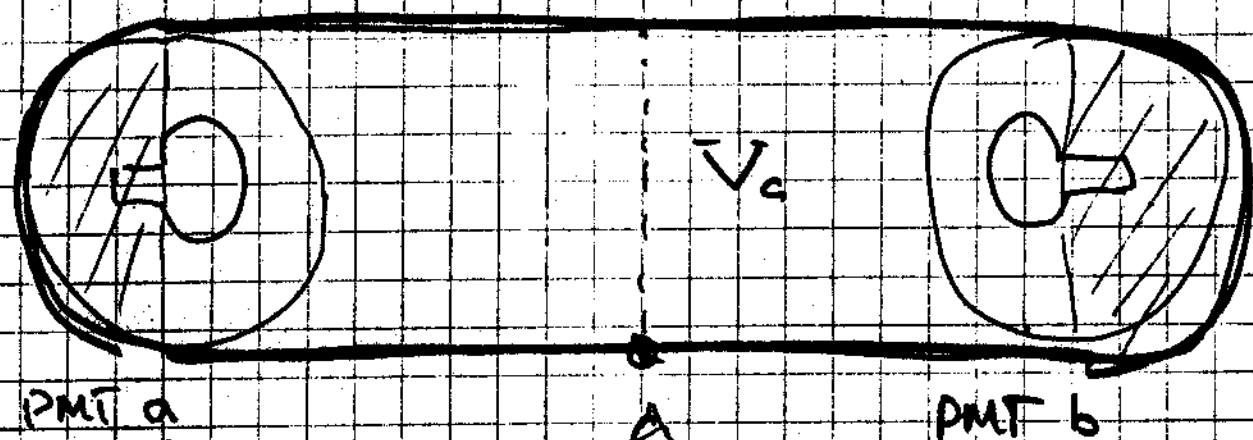
$$\lambda = \left(\frac{V_c}{V_o^{1/3}} \right)^{1/2} \left(\frac{R_a R_b}{R_{ab}^O R_{ab}^C} \right)^{1/2}. \quad (18)$$

The beauty of this approach is that most constants drop out of the ratio, and we are left with one term depending upon measured rates and one term upon geometrical factors related to the instrument. These geometric factors can be both calculated and calibrated in the laboratory. My first estimate is that all corrections are small and can be made with sufficient accuracy to yield an excellent measure of λ . I don't see why a $\delta\lambda/\lambda < 10\%$ is not possible. Notice that the λ derived is purely one of absorption and not scattering (as many photons are scattered in as out). Note also that one measures a single λ , whereas the color of the received light does depend upon distance. We might want to make runs with various filters and measure different λ 's.

There are several problems in the scheme illustrated in Fig. 1: The PMT's change orientation when the container opens and may be susceptible to magnetic field effects (but could be shielded), and the container should be white inside when closed and black when open. We need to work on the configuration, but I'm enthusiastic about the experiment. It may just be the best way to measure ρ & λ !

FIGURE 1

a) CLOSED POSITION



b) OPEN POSITION

