Draft DUMAND Note 80-23

Design of the Sea Urchin Module.

III. Experimental Measurement of Spine Efficiency, and Redesign for Improved Sensitivity.

by

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SUMMARY. With the measurement of the quantum efficiency of the fluor and the optical efficiency of single Sea Urchin spines, it is possible to calculate the sensitivity of the Sea Urchin module from observed quantities and compare it with predicted values. The sensitivity of the module is found to be about half the theoretical value. However, the theoretical prediction does not take into account absorption and re-emission of the fluorescent light in the spines. Reasons for attributing the discrepancy to this factor are given. The most readily improved parameter in the original Sea Urchin design is the opacity. That is significantly increased by a new design in which the original 8" PMT in a 17" sphere is replaced by a 13" tube in a 26" sphere. The design sensitivity of 6 stengers is readily reached with that design, and its other advantages are discussed.

The design and predicted sensitivity of the Sea Urchin module have been described in previous notes (1,2), referred to hereafter as I, II. In order to verify the predicted performance of the detector we have carried out measurements on the quantum yield of the fluor selected, and measurements of the optical efficiencies of single spines. The predictions of sensitivity in I and II were made on the basis of measured attenuation lengths and the computer program CYL6X which calculates spine efficiencies, assuming the quantum yield known.

1. Quantum Yield. The quantum yield of the two fluors found most effective (see II), Hostasol Yellow 8G and 3G, has now been measured. We used a spectrophotofluorimeter of special design (3), for whose use and for assistance in operation we are greatly indebted to Prof. R. H. Mackay, of the Department of Biochemistry and Biophysics. Measurements were taken with the fluor illuminated at the wavelength of the mercury line 436 nm. Quantum yields were measured, following the procedure described by Parker (4), by comparing the spectral yield with that of a standard solution, in our case fluorescein in 0.1N NaOH. A sketch of the apparatus is shown in Fig. 1.

The results for both Hostasol Yellow 8G and 3G indicate quantum yields well above 90%. We estimate an error of not over 10%.

2. Measurement of Spine Efficiency. The equivalent area for light collection of a spine was measured by the arrangement of Fig. 2. In (a), the spine is exposed to the source, which is filtered to yield a spectrum simulat-

ing that of Cerenkov light in the ocean (see Fig. 3 of II). It is coupled to the PMT by optical grease, and the signal measured. In (b), the PMT is exposed directly to the same illumination, with a mask M that exposes a known area of the PMT photocathode. Comparison of the two measurements yields the equivalent area of the spine; note that no corrections for spectral efficiency, etc., are necessary; the measurement includes all such corrections. The ratio of the equivalent area, thus determined, to the geometrical cross-section of the spine is the optical efficiency of the spine.

Observations were made with both Hostasol Yellow 8G and 3G, at several different concentrations, using PMT's with S11A, S1, and S20 cathodes. The observed maximum spine efficiencies fall below those calculated from the program CYL6X by a factor of about 2. We believe this to be due to the effect of fluorescence reabsorption and reemission, since the absorption and emission spectra of these fluors overlap. That effect is not taken into account in CYL6X. The effect is manifest in the spectra of Fig. 3.

3. Calculation of Sea Urchin Sensitivity. Our observations on a single 8-ft spine gave an equivalent area of 28 cm for the optimum fluor filling, which corrects to 34 cm^2 for a 3m-long spine, using the observed attenuation coefficient.

The total equivalent area of the Sea Urchin module is then given by

$$A = A_o \times OPF \times \varepsilon_o f \times C$$

where

A_o is the geometrical area, in m^2

OPF is the opacity factor, from I, Table 2; this is the fraction of the area actually occupied by spines,

ε_o is the observed efficiency of the spine, defined as the ratio of effective area of the spine to geometrical cross-section.

f is a calculated factor that converts the efficiency in air to the efficiency when immersed in water,

C is the fraction of the emergent light from the spine that reaches the PMT photocathode.

The value of OPF has a maximum of .785 ($\pi/4$).

4. Possible Sea Urchin Designs. We now consider two important design possibilities.

Case I. 17" sphere, 8" PMT, Spines 3m long.

Spine efficiency $\varepsilon_o = 34/762 = 0.0446$

$f = 0.48$

$A_o = 32.5\ m^2$

OPF = 0.39 (for packing fraction 0.7, Table 2 of I.)

$C = .80$ (from CYL6X)

Thus

$$A = 32.5\ m^2 \times .39 \times .0446 \times .48 \times .80$$
$$= .22\ m^2$$

The sensitivity in stengers is $S = 20A = 4.4$, which is only half the value predicted by CYL6X.

<u>Case II.</u> Proposed Improved Geometry. A considerable improvement can be obtained by going from a 17" sphere and an 8" PMT to a 26" sphere with a 13" PMT. The direct cost of the change is perhaps $250, but other costs and savings will occur which need to be evaluated in detail.

We can now decrease the spine length from 3m to 8 ft, a value at which 1" and 1.5" spines (without bottoming) are available from Sylvania Glass Co. at low prices, since they are used in fluorescent lamp manufacture.

The increased sphere area now allows, at a PF of .666, 900 1" spines. We now have:

$$A_o = 24.1\ m^2$$
$$OPF = .797$$
$$\varepsilon = .047$$

The other values remain the same. Thus,

$$A = 24.1 \times .797 \times .047 \times .48 \times .80$$
$$= .347$$
$$S = 6.9$$

The overall Sea Urchin diameter has been decreased from 6.43 to 5.54m.

The following table gives some possible choices for the 13" Sea Urchin.

Table 1. Spine properties (8-ft spines)

Diam.	No.of Spines	Wall mm	Spine Wt.,g	In-Water Wt.of glass	Toluene vol,l.	Toluene Buoyancy,g	Net In-Water Wt., g.	S
1"	900	.66	320	185.4	1.115	150.2	35.2	6.9
1.5"	600	.66	480	278.1	2.51	338	-60	6.1
		1.00	720	417	2.51	338	+82	6.1
2"	450	.66	640	371	4.45	601	-230	5.35
		1.00	960	556	4.35	587	-31	5.35

Sylvania quotes 8-ft (93") lengths of 1" tubing at $.29 each; for 1.5" tubing the price is only .19! They will quote on the cost of bottoming.

5. Buoyancy of the 13" PMT Sea Urchin Module. Caclulation of the total buoyancy of the module shows that in addition to the approximately 30 kg contributed by 600 1.5" spines, the 26" sphere contributes about 109 kg (assuming it is one inch thick.) Filling the top half of it with toluene costs about 45 kg, leaving 94 kg net, less the weight of the PMT and associated electronics and the external support structure of the spines. A net buoyancy of 50-60 kg per module seems a reasonable guess. At $4/kg of buoyancy, this just about makes up for the increased cost of the PMT and sphere. A string with ten modules would have a total buoyancy of 500-600 kg., less the weight of the cable.

REFERENCES.

1. DUMAND Note 80-13: The Sea Urchin Module. I. Survey of Design Problems, by D. McGibney and A. Roberts, Hawaii DUMAND Center, and U. Camerini, Univ of Wisconsin, Madison.

2. DUMAND Note 80-14: Design of the Sea Urchin Module. II. Spine Design, by D. McGibney and A. Roberts, Hawaii DUMAND Center

3. R. H. Mackay, Arch. Biochem. Biophys., 135, 218 (1969)

4. C. A. Parker, Photoluminescence of Solutions, Sec. 3L; Elsevier, London, 1968

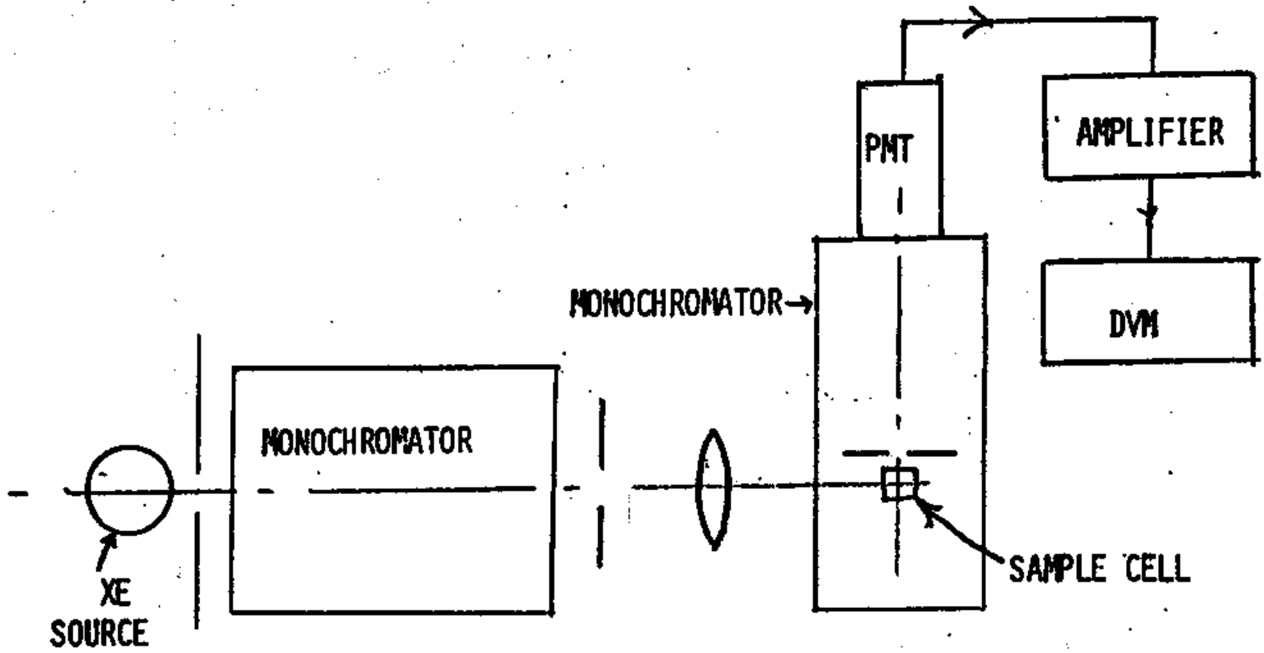

Fig. 1. Spectrophotofluorimeter arrangement for measuring quantum yield of fluors, by comparison with standard.

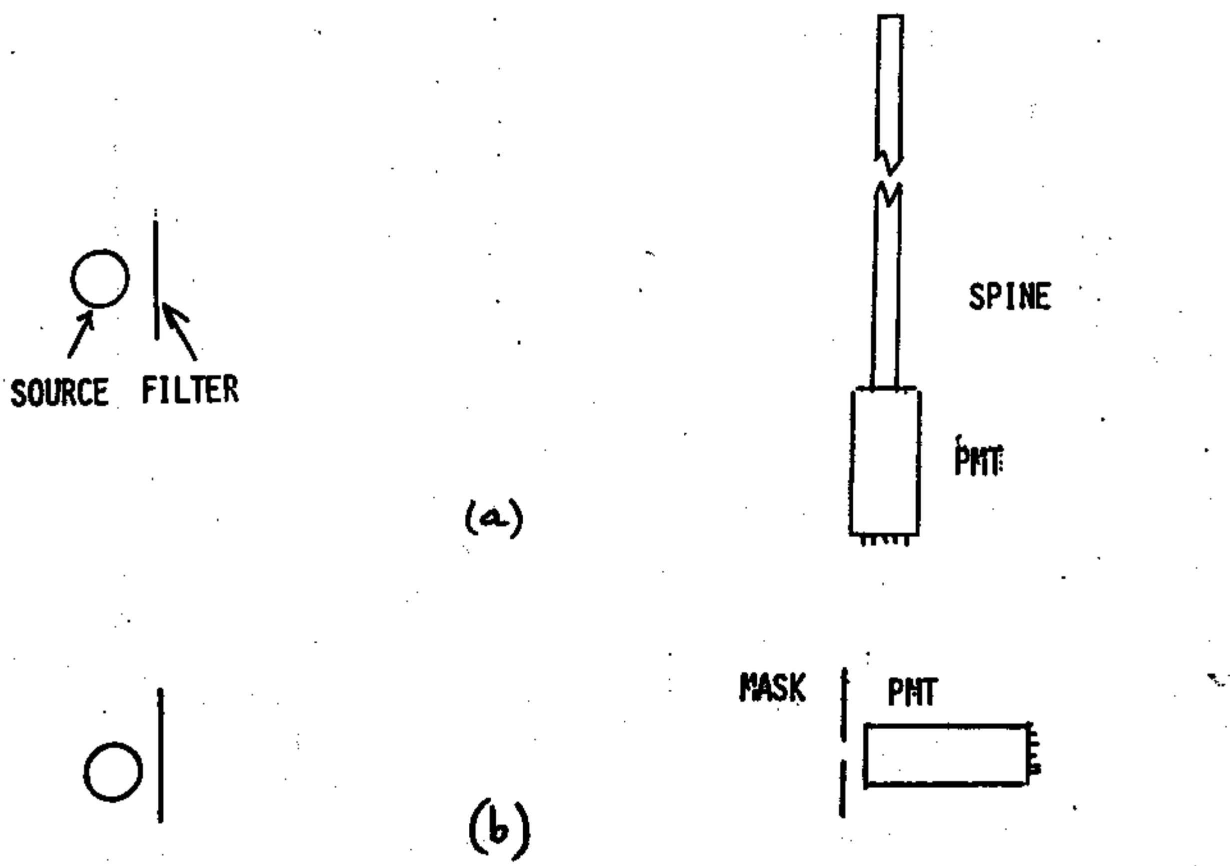

Fig. 2. Apparatus for measuring effective area of fluorescent spine. a) Arrangement for reading output of spine with PMT. b) Arrangement for observing PMT direct response. The mask defines the photocathode area.

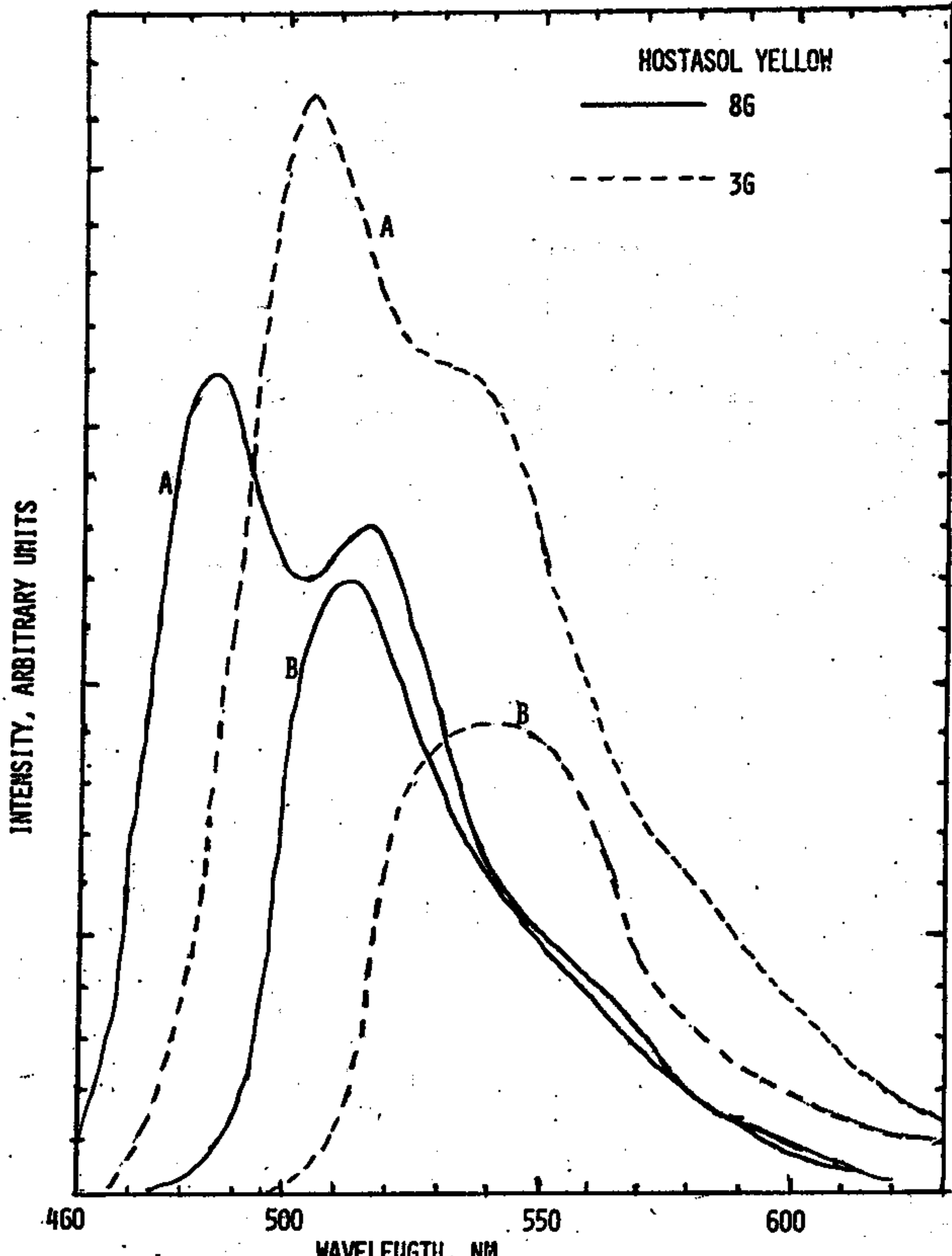

Fig. 3. Fluorescent spectra of Hostasol Yellow 8G and 3G, excited by the mercury line 436 nm. Spectra marked A are for extremely dilute solutions, in which reabsorption of fluorescent light is negligible; curves marked B are typical of spines using concentrations that yield maximum light output. The vertical scales are arbitrary and are not comparable for any two curves. The effect of reabsorption is to cut off the short wavelength end of the fluorescent spectra; the fraction lost is of the order one-half.