

**COINCIDENCE VS. HIGH-GAIN FIRST DYNODES - ONCE MORE, WITH FEELING**

It seems to follow with established logic that the best choice of first dynode would be a very slow one, like the S-20, which has a low noise level and a long time constant. **by** **A. Roberts, Hawaii DEMAND Center**  
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Probability Considerations.

Manufacturers of photomultiplier tubes have rather strong biases, based on long experience, in favor of certain design features, and against others. In particular, they prefer relatively simple photocathodes to complex ones; thus S-11 and bialkali cathodes are preferred to S-20 (trialkali), which, though more sensitive in the red, are more difficult and expensive to prepare. In searching for fibers for wavelength-shifting sensors like Sea Urchin, the designers have accordingly been guided by this preference (1-2), and have selected Hostasol SC, a fluor whose efficiency is as great when viewed by S-11 or bialkali photocathodes as by S-20.

The other preference of the manufacturers is to avoid high-gain first dynodes - e.g. gallium phosphide - which, although they markedly improve pulse-height resolution, add to the difficulties of manufacture. The fact that such high-gain first dynodes allow one to distinguish pulses originating from one photoelectron from those starting with two, makes it feasible simply to use a threshold discriminator to get rid of the very high K40 background. This is not possible without such a high-gain dynode, and in that case, other methods must be used. The most hallowed and obvious of these is the use of coincidences between two or more phototubes, and it appears that no matter how many times that idea is shown to be either less practical or more expensive, it keeps recurring. The present attempt to kill the almost invulnerable misconception is prompted by the paper of Wright (3).

First, we point out that in the case of large WLS detectors like Sea Urchin, there is no practical alternative to the high-gain first dynode; coincidences between several Sea Urchins per detector are a concept to make strong men blanch.

More reasonable is an alternative in which direct-view sensors of comparable sensitivity are placed in coincidence to decrease the background sufficiently. It is this case with which we now concern ourselves.

The point most often overlooked in these discussions is the requirement for a reasonable efficiency for the sensors. We illustrate the point with relevant examples.

Given an arbitrary value for detection efficiency, what is the incident flux necessary to reach this efficiency?

- a) for a single tube with high-gain first dynode, threshold 2 photoelectrons

b) for two tubes in coincidence, with conventional first dynodes and threshold one photoelectron.

In particular, we are interested in the case where the tubes in case b) are not identical with those in a) in photocathode area, but have only half the area. The comparison is then between a case of a single tube with high-gain first dynode, versus coincidence operation of two tubes with the same total area, operated in coincidence with a threshold of one photoelectron. We are not really interested in the problem for arbitrary thresholds; these are the only ones of practical concern.

The problem is easily solved, using the Poisson distribution. We ask, given an efficiency  $\epsilon$  for a single tube, what is the mean value of the distribution that yields the postulated value of efficiency for obtaining 2 or more photoelectrons?

Turning now to the coincidence arrangement, we note that if each tube has the same area as the single tube, we can readily plot a similar curve showing the probability of 1 or more for a given mean value, a curve obviously lying above the previous one. We note that to obtain the same detection efficiency in coincidence, each tube requires a higher individual efficiency, namely  $\sqrt{\epsilon}$ . If the coincidence tubes have each the same area as the single tube, it is easy to show that the intensity necessary to obtain the same efficiency is about one-fourth less than that required by the single tube. If we make the comparison for the same total photocathode area, we must double the values required above. Fig. 1 illustrates these remarks.

In Fig. 1 four curves are shown. Curve No. 2 is the efficiency of triggering with a threshold of 2 pe's, as a function of the mean number of photoelectrons  $M$ . Curve 1 is the same for a threshold of 1 pe. Curve 3 is an efficiency curve for two tubes in coincidence, each with the same photocathode area as the tubes of curves 1 and 2. Finally, curve 4 shows the coincidence efficiency for two tubes, each of half the original cathode area. Curves 4 and 2 thus compare the use of a coincidence pair with a high-gain dynode single tube, for the same total photocathode area.

To achieve the same efficiency for two coincidence tubes as the single tube, each of the two tubes should have an area of 0.77 of the single tube. However, we so far omitted all such considerations as the difficulty of orienting two coincident phototubes so as to achieve reasonably isotropic sensitivity; such difficulties probably require a safety margin in sensitivity in each tube.

The practical alternative to a single tube with high-gain first dynode is thus probably not a new tube with 25% less area; it is to compare modules with a single tube and a high-gain first dynode, with modules with two smaller phototubes in coincidence, but without the high-gain first dynode. To the physicist non-expert in PMT construction, the former solution appears preferable, unless the rigors of achieving high-gain first dynodes are indeed extremely severe; they would have to more than double the cost of the tube to make the latter alternative preferable. Perhaps the problem is indeed that difficult; but unless it is, the desirable solution, both for Sea Urchin and for direct-view tubes, appears to be the single tube with high-gain first dy-

node.

#### Background Considerations.

The above conclusions might be modified if it could be shown that background problems would be markedly more severe with the high-gain first dynode tube. This appears not to be the case.

In a two-fold coincidence arrangement, the background rate will go up as the square of the counting rate; with the single tube, only linearly. The single tube is thus advantageous at high counting rates.

At low rates, in small arrays, there are no difficulties. For 13" PMT's in water of 25m transparency, the two-fold coincidence rate due to K40, assuming a 20 ns resolving time, is only 150/sec. The single-tube background, assuming the large pulses to be 1% the total rate, is 600/sec. Both are small enough to offer no problems.

For a larger array, e.g. 500m on a side (4), more sensitive detectors are needed. With larger areas ( $0.4\text{m}^2$ ), the coincidence rate now becomes 3600/sec. The single-tube background is 3000/sec. Both these values are high enough to require additional treatment, e.g. the dissection procedure discussed by Roberts (5). In any case, there is no reason to select one or the other from the standpoint of background rate.

#### REFERENCES

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## EFFICIENCY

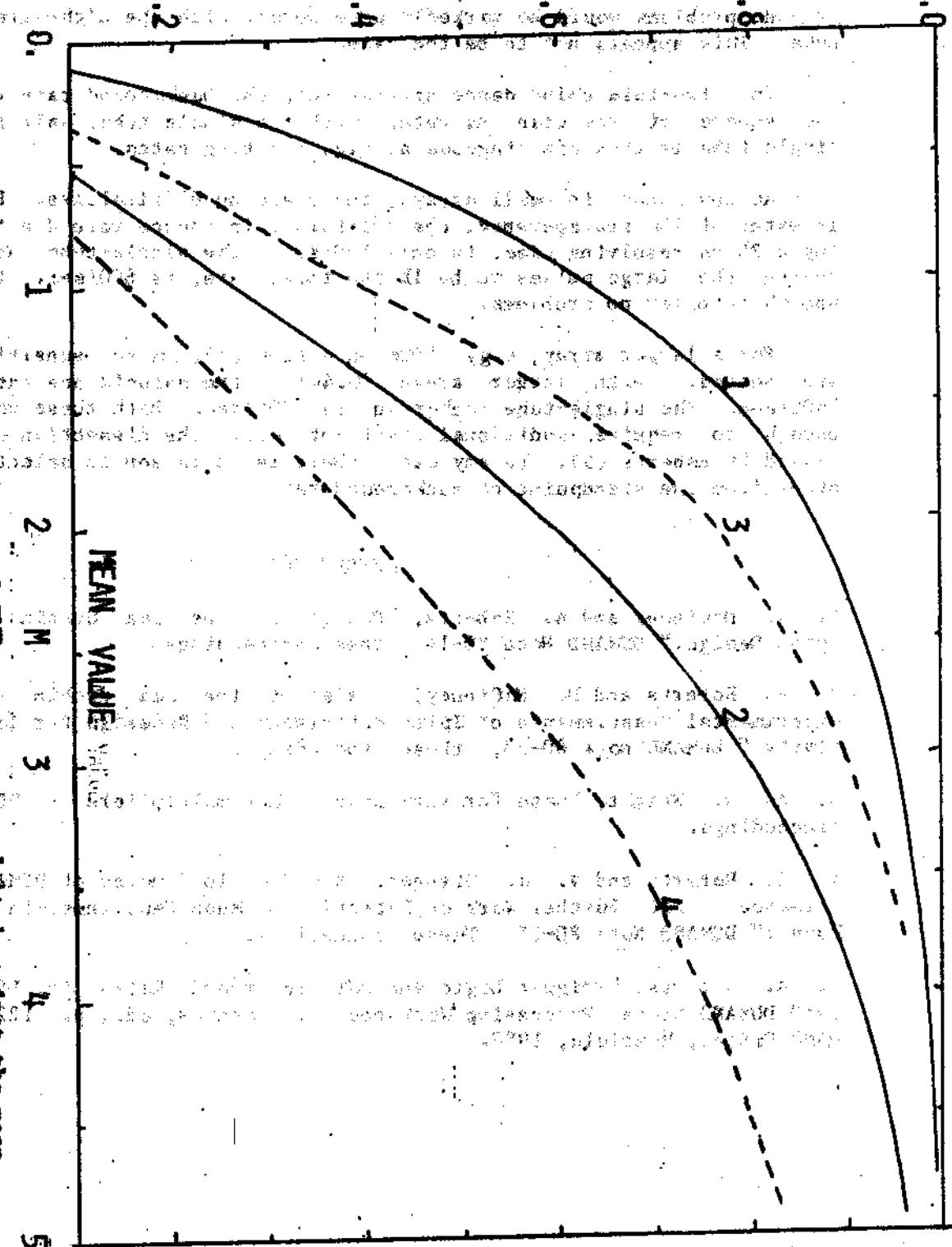


Fig. 1. The detection efficiency of several PR arrangements, plotted against the mean  $M$  of the number of photoelectrons produced. Curve 1 shows the probability for a single tube that the number of photoelectrons will be 1 or more; curve 2, a similar curve with a threshold of 2 or more. The latter curve describes a single-tube detector with high-gain first dynode; the former one of a pair of tubes in coincidence. Curve 3 shows the efficiency of a pair of tubes in coincidence, each with the same photocathode area as the single tubes, each with half the photocathode area of the original tubes.