SPS EXPECTATIONS

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The DUMAND Monte Carlo program (DUMC) has been used to make up-to-date estimates and what we can expect for the SPS cruise. These are supplemented by analytical calculations of expected false triggers from backgrounds.

The main difference from preceding calculations is that we now have good PMT calibrations (Matsuno, DIR-1-86) and these have been incorporated into DUMC. Where previously the threshold was set at a certain number of p.e., we can now more realistically set at a certain pulse width. The measured 1 p.e. and 2 p.e. pulse width distributions are remarkably Gaussian. I have assumed this applies for higher p.e.'s and parameterized the mean and standard deviations by the formulas which fit the 1,2 p.e. data:

$$\langle PW \rangle = 36 + 117\,n \quad \text{(ns)}$$
$$\sigma_{PW} = 15.4 + 36.2\,n \quad \text{(ns)} \qquad (1)$$

where n = number of p.e. The program already produces a Poissonized distribution in p.e.; this is now converted to a Gaussianized PW using (1).

Assuming a Gaussian distribution, the following table gives the fraction of times a PMT will be triggered by light at the 1 and 2 p.e. levels:

Pulse Width (ns)	Fraction 1 p.e.	2 p.e.
108	0.848	0.972
153	0.561	0.921
198	0.235	0.816
213	0.155	0.767
258	0.029	0.586

That is, setting the threshold at 198 ns we would reject 1-0.235 = 0.765 of the 1 p.e. background while accepting 0.816 of the 2 p.e. signal.

Effective areas have been calculated with DUMC using a coincidence scheme which requires that all tubes in the coincidence be adjacent. This enables the time window to be minimized and is very effective in reducing false triggers. Further, two threshold levels are allowed: a higher primary level THRES which at least one PMT must exceed, and a lower secondary level THRES2 which the other PMT's in the coincidence must exceed. The results presented here are for (THRES,THRES2) = (108,108), (198,108) and (198,198) ns at coincidence levels N from 4 to 7.

Fig. 1 shows the effective areas for fully reconstructed muons expected at a depth of 4.5 km (the depth-dependence is insignificant). We see that 1000 m^2 is possible if we can operate at the 4-fold level. This is bigger than anything which has yet been done underground or undersea! If backgrounds are so high that we have to operate at the 7-fold level (pray that all modules work), then we have about 200 m^2, about half of IMB.

As everyone knows, it all depends on backgrounds. False trigger rates have been calculated using the formula

$$R_N = R_1 \sum_{j=N}^{7} j(7-j+1)P_j^{j-1}(1-P_j)^{7-j} \tag{2}$$

where N is the coincidence level, R_1 is the single PMT trigger rate at the primary threshold. The probabilities P_j are given by

$$P_j = 1 - \exp(-R_2\tau_j) \tag{3}$$

where R_2 is the single PMT trigger rate at the secondary threshold and τ_j = 1.35(j-1)D/c, where D = 5.18 m is the PMT spacing, c is the speed of light, and 1.35 is the index of refraction of water at 500 atm.

The rates R_1 and R_2 are obtained by taking the trigger rate R_0 which would be expected at zero threshold and multiplying this by the fractions in the middle column of the table above which correspond to the particular pulse width threshold. Two possibilities for the rate R_0 have been used:

K^{40}:	$R_0 = 10^5$ Hz	(4)
Stimulated Bioluminescence:	$R_0 = 2.26\times10^7 \exp(-h/1.015)$ Hz	

where the latter is from TTR3 data (Bradner et al., to be published in Deep Sea Research), assuming a 15" diameter PMT with 0.2 quantum efficiency and and a 0.45 cosα + 0.55 angular acceptance (α = entry angle, average loss = 0.55); h is the depth in km. Actually the median has been used rather than the average and no attempt has been made to simulate the actual biolight pulse distributions. Also, no correlations are assumed. So these may be regarded as the two possible extremes which we may anticipate, although I suppose it could be worse. If it is, we are really in trouble.

The muon event rates which are predicted are shown in Fig. 2 as a function of depth. For the two background assumptions in (4) I plot the maximum signal which can be obtained for the three threshold and four coincidence levels tried, subject to the requirement that S/N $>$ 1. The results may be summarized as follows:

- Suppose the combination of Kaimalino plus Ram Tensioner eliminates all the stimulated bioluminescence and the background is essentially K^{40}. Then we can operate a 4-fold adjacent trigger with both thresholds at 108 ns down to about 3 km. Beyond that we must raise the threshold or go to a higher coincidence level.

- Muon rates vary from 10 s^{-1} at 1 km to about 1 min^{-1} at 4.5 km.

- At K^{40} background levels we can operate a 5-fold (108,108)ns trigger at all depths down to 4.5 km. We would lose some signal but it would only be slightly below the 4-fold rates shown in Fig. 2 and this would give us the uniform sensitivity we would need to make reliable muon-depth comparisons.

- At the other extreme in which we are dominated by biolight producing a depth-dependent background, we cannot expect to get much of a signal above 3 km. Even a 7-fold (198,198)ns trigger is dominated by false triggers. At 3km we can get about 2 muons/min with a 7-fold trigger and both thresholds at 198 ns (compared to 1 s^{-1} if we have only K^{40}). At 4.5 km we can get somewhat less than 1 min^{-1} with a 5-fold trigger at the same thresholds. The same signal results at 3 and 4 km because the shallower depth has both a higher signal and a higher background and so a tighter trigger must be used.

- At background levels between the two extremes assumed we should still be able to get useful data by the right trigger combination.

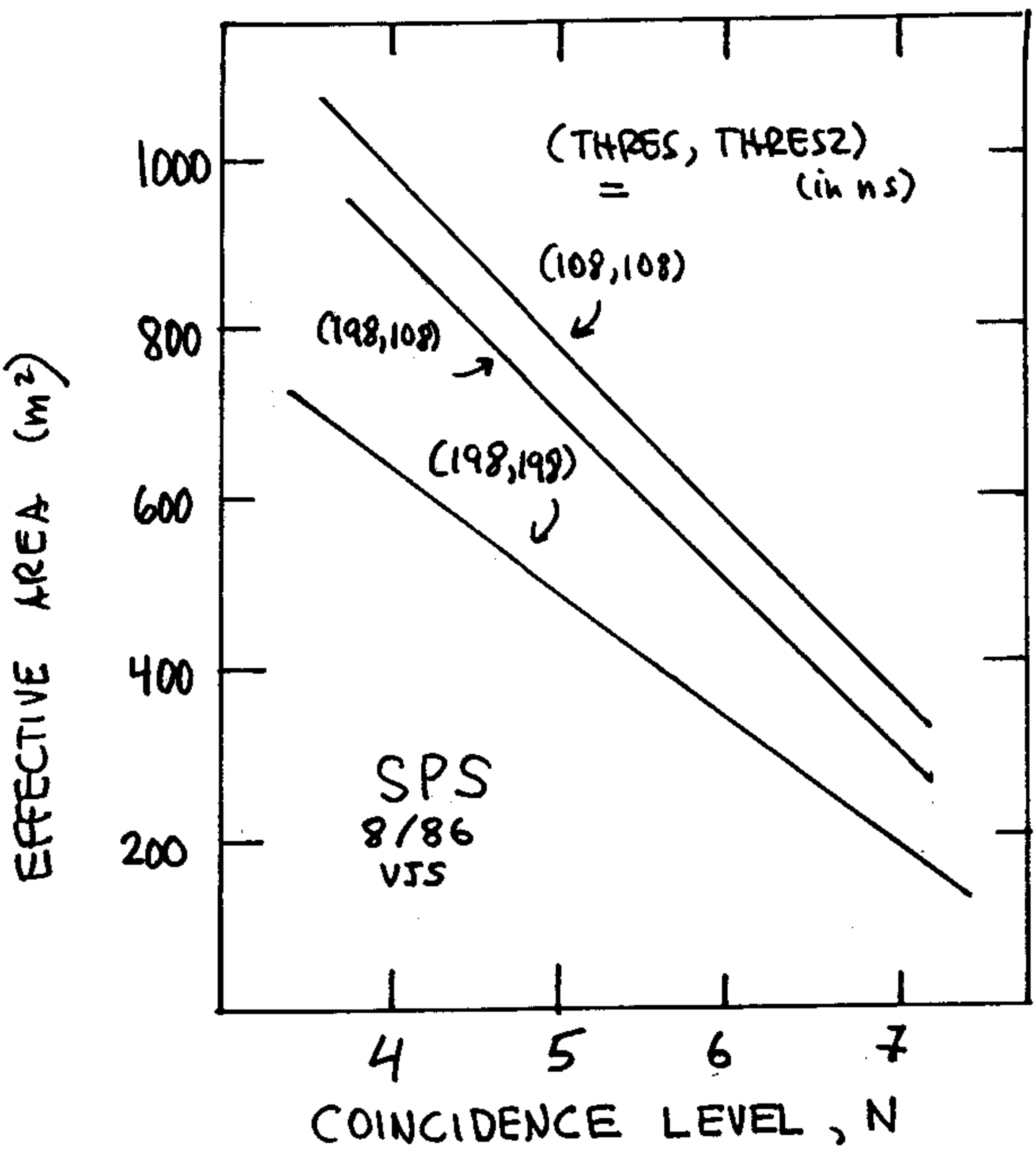
I have not made runs yet in which only 6 (or fewer) tubes are functional; however, from the above it should be clear that the capabilities are likely to be severely degraded with fewer than seven PMTs. I wish now we had designed for eight.

For completeness, the zenith angle resolution depends significantly on the coincidence level, as more tubes give a better fit. The average angular error varies from about 8^0 for 7-folds to 13^0 for 4-folds, at the (108,108) ns threshold level. These are 1^0-4^0 lower for higher thresholds. The medians are also a bit lower. Of course, there is no determination of azimuth or muon energy.

FIGURE CAPTIONS

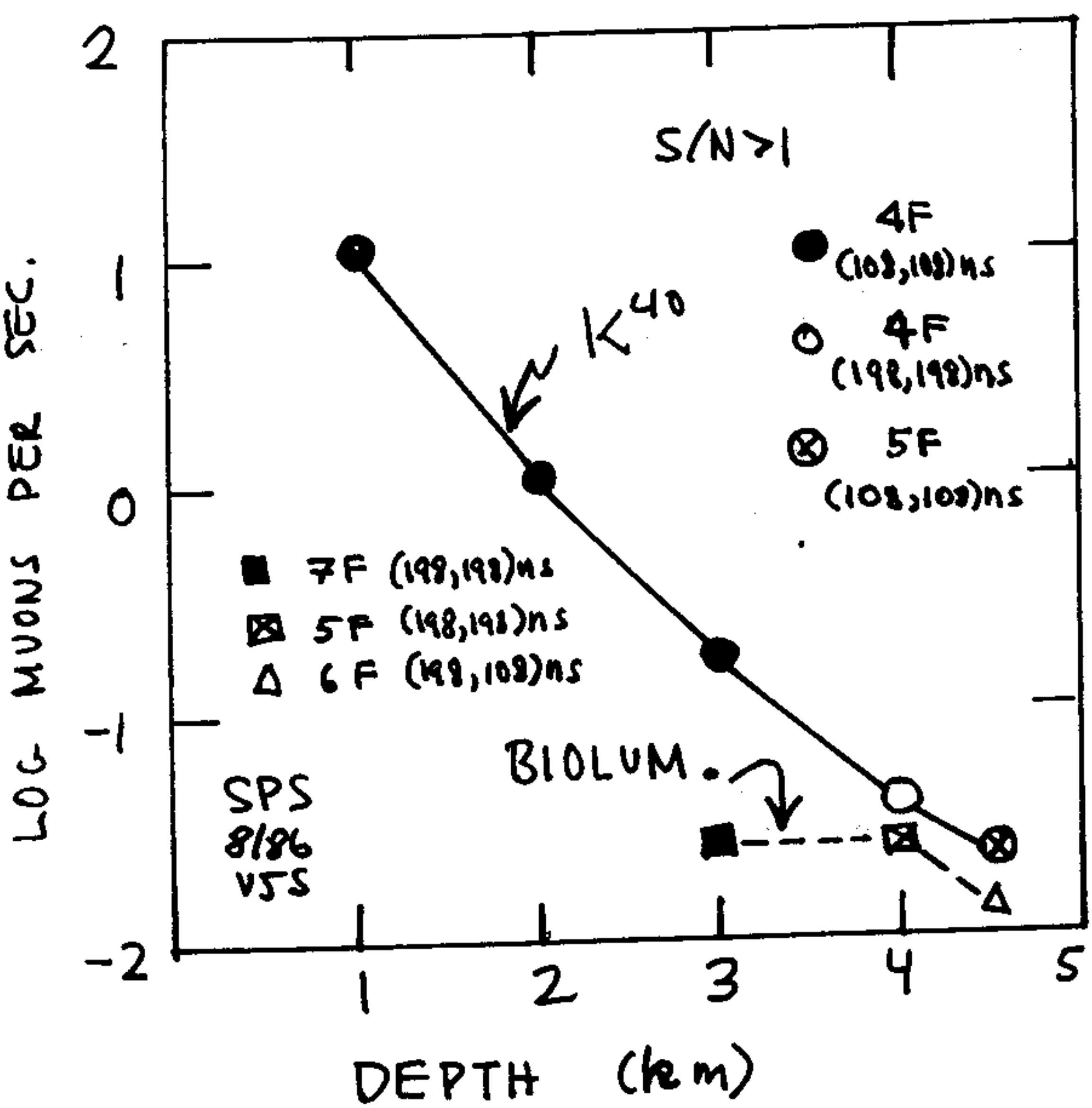
1. Effective area of the SPS as a function of coincidence level N for three sets of pulse width threshold settings. The coincident PMT's are assumed to be adjacent on the string and must have at least one pulse width greater than the primary thresholds, the others need only exceed the secondary level. The number of tubes in coincidence must be $\geq N$.

2. The expected downward muon signal in the SPS as a function of depth. The maximum signal, consistent with $S/N > 1$ is shown for two background assumptions: K^{40} and a depth-dependent stimulated bioluminescence comparable to that seen in TTR3. The different types of data points specify the trigger used.



(THRES, THRES2) = (in ns)
(108,108)
(198,108)
(198,198)
1000
800
600
400
200
EFFECTIVE AREA (m²)
SPS
8/86
VJS
4
5
6
7
COINCIDENCE LEVEL, N

Fig. 1



LOG MUONS PER SEC.
2
1
0
-1
-2
1
2
3
4
5
DEPTH (km)
S/N>1
4F (108,108)ns
4F (198,198)ns
5F (108,108)ns
K^{40}
7F (198,198)ns
5F (198,198)ns
6F (198,108)ns
SPS
8/86
VJS
BIOLUM.

Fig. 2