REPORT ON PROBABILITY OF DETECTING PHOTON
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April 20, 1992

SNO-STR-92-028

The norite wall contains about 4ppm of Th and 1ppm of U. Some gamma rays from the radioactive daughters of these nuclei will interact in the light water region behind the PMT support structure, producing Cerenkov photons which can cause PMT triggers. In general, these triggers will not lead to reconstructible events. So they will not contribute to the background event rate. However, they will increase the PMT trigger rate; hence effectively increasing the noise rate of the PMTs. If this increase in trigger rate leads to substantial deterioration in reconstruction accuracy, a light barrier will be needed to block the PMTs from these photons. This concern was raised during a SNO group meeting at LBL last year. Rough calculations at that time showed that these photons would have a negligible effects on the PMT trigger rates and was duly reported at the meeting. However, the problem was raised again last week and we were asked to study this further. The Cerenkov photon production rate in the light water region outside the PMT support structure is calculated using Monte Carlo simulations and the sensitivity of the R1408 to detect Cerenkov photons incident from the back of the PMT, relative to detecting Cerenkov photons incident from the front of the PMT, was measured.

1. CALCULATION OF CERENKOV PHOTON PRODUCTION RATE

The probability of a 2.6MeV gamma rate escaping from the norite wall to strike the light water region was estimated by Monte Carlo simulations. The gamma rays were generated uniformly in the rock and emitted randomly. The results are listed in the following table.

Escape Probability	Depth in Rock (cm)
47624/200000	0 to 7.5
17102/200000	7.5 to 12.5
5231/200000	12.5 to 25.5
923/200000	25.5 to 47.5

The probability of escaping from rock layers deeper than 47.5cm is much less than 0.5% and is ignored. Thus for 2.6MeV gamma rays generated uniformly inside the rock to a depth of 47.5cm, the average escape probability is about 8.9%.

Assuming secular equilibrium, the production rates of the 2.6MeV and 2.4MeV gamma rays are 1470 per second per gram of Th and 190 per second per gram of U respectively. In this estimate, we assumed the cavity to be a right cylinder 11m in radius and 24m high and the light water was in contact with the norite wall. To simplify the calculation, we also assumed the 2.4MeV gamma ray to have the same probability of escaping from the norite rock as the 2.6MeV gamma ray and to produce the same number of Cerenkov photons in water. The weights of Th and U in the rock surrounding the cavity to a thickness of 47.5cm and the total number of gamma ray interactions in the light water region produced by these Th and U decay series are shown in the following table:

Rock Volume	1200 cubic meter
Density of norite	2.9E+06 g/m*m*m
Weight of Rock	3.47E+09 g
Weight of Th at 4ppm	13900g
2.6MeV production rate	2.04E+07/s
2.6MeV interaction rate in light water	1.81E+06/s
Weight of U at 1ppm	3470g
2.4Mev production rate	6.43E+05/s
2.4MeV interaction rate in light water	0.57E+05/s

The average number of detectable Cerenkov photons produced by a 2.6MeV gamma ray in water is estimated to be 64 (defined as the product of the number of Cerenkov photons produced and the photocathode quantum efficiency, averaged over different wavelengths. This number is likely to be over-estimated). So the detectable Cerenkov photon production rate in the light water region behind the PMT support structure is 1.19E+08/s.

The volume of water behind the PMT support structure is about 6412 cubic meter (using the same geometry as before. The volume is smaller in the SNO detector). With concentrations at the 1.0E-14 levels, the U and Th decay series in the water will contribute another 70 detectable Cerenkov photons per second; a number we can ignore.

Assuming that these photons incident uniformly onto the back surface of the spherical PMT support structure at 8.65m radius, the number of detectable Cerenkov photons striking a 9.5cm radius circular aperture on the PMT support structure is 3700/s. The true rate will be less because not all the detectable Cerenkov photons produced in the light water region behind the PMT will strike the back surface of the PMT support structure. Some will miss the PMT support structure and strike the cavity wall. The geodesic frame will also block some photons.

2. MEASUREMENT OF PMT SENSITIVITY TO CERENKOV PHOTONS INCIDENT FORM THE BACK OF THE R1408 PMT.

This measurement was done using the standard Cerenkov source mounted on a small Hamamatsu R1635 PMT (the monitor PMT, serial number RX6208) placed at a distance of approximately 75cm from a R1408 PMT (serial number GG3130). The resistor divider circuit board is made of 0.005in kapton and is soldered directly onto the PMT pins (same material as the circuit board that will be used in SNO detector). The polypropylene housing was mounted onto the PMT, but the space inside the housing is not filled with silica gel, thus allowing higher transmission of photons through the translucent polypropylene housing. The photons detection efficiencies for a number of geometrical arrangements were measured. First, the PMT was collimated by a 19cm aperture and was placed facing the Cerenkov source. Then the PMT was placed facing away from the Cerenkov source and the PMT axis at different angles to the source. The equator of the PMT bulb was keep at roughly the same distance from the cerenkov source in all measurements. There was no other material that would obstruct the photons from reaching the PMT. The magnetic field was less than 10mG. The coincidence between the monitor and the R1408 PMT were measured. The results are listed in the following table.

Geometry	Coinc. # (in 600s)	Time peak (Cent. in ns)
PMT towards source	62954	84
PMT away from source, 10 deg.	2289	91.3
PMT away from source, 20 deg.	2013	91.4
PMT away from source, -30 deg.	2497	91.4
PMT away from source, 0 deg.	2303	91.1
PMT away from source, 0 deg. block	857	91.9
PMT away from source, 0 deg.	2583	91.3
PMT towards source	62162	90.4
PMT away from source, 0 deg. cover	1542	90.8

In the measurement labelled "block", a piece of cardboard 10cm in diameter was place on the back of the polypropylene housing to block photons from passing through the housing and the neck of the PMT. Because the surfaces in the box are not perfectly black, the coincidence events in the last measurement could be due to photons striking the mounting surfaces and scattered into the front face of the PMT. The shift in the coincidence peak in the time spectrum is in reasonable agreement with such a picture. In the measurement labelled "cover", the photocathode of the PMT was covered by black cloth to prevent scattered photon from incident onto the PMT through the front surface. The data from this "cover" measurement is consistent with the hypothesis that the coincidence events in the "block" measurements are from scattered photons. The results indicate that the sensitivity for detecting Cerenkov photons incident from the back of the PMT is about 2.4% of the sensitivity for detecting Cerenkov photons incident on the front surface of the PMT whose photocathode is collimated by a 9.5cm radius circular aperture.

3. CONCLUSION.

Monte Carlo simulations show that the natural Th and U radioactive decay series in the rock will produce approximately 1.19E+08 detectable Cerenkov photons per second in the light water region behind the PMT support structure. Less than 3700 of these photons will strike a 9.5cm radius circular aperture at the back of the 8.65m spherical PMT support structure per second. With the resistor circuit board and polypropylene housing that will be used and no other opaque material behind the PMT, the sensitivity for detecting photons incident from the back of the PMT is about 2.4% of the sensitivity for detecting photons incident from the front of the PMT whose photocathode is collimated by a 9.5cm radius circular aperture. Thus the U and Th in the rock will effectively increase the PMT trigger rate by less than 90Hz. This is consistent with the rough estimate reported in the LBL meeting last year. Because the flux of detectable Cerenkov photons incident onto the back surface of the PMT support structure is over-estimated and opaque material will be used to cover part the PMTs at the back, the increase in PMT trigger rate due to Th and U decay series in the rock is likely to be less than 60Hz. An optimistic estimate of the average PMT noise rate is 1500Hz. While it is desirable to construct a light barrier behind the PMTs to remove all extra trigger rate, it is not advisable to spend too much manpower and money to design and construct such a barrier. (This report used 7 woman(man)-days already, PLEASE NO MORE).