Calibration and Neutral-Current Detectors

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1 Neutron Efficiency

It will be necessary to determine the neutron efficiency of the NC array. This is a fundamental number that appears directly in the deductions about neutrino oscillations. The factors that affect the final precision are:

1.1 Source Standardization

The statistical accuracy of the NC rate will be about 2.5% per year. Determination of the photodisintegration background will raise this to some larger number, perhaps 5%. It would be best to minimize the importance of the source accuracy at this level, i.e., a precision of 2% or better is highly desirable. How accurately can a neutron source be measured? (For thermal neutron beams the precision limit is presently a little better than 1%. For non-thermal sources, larger errors can be expected.) Chalk River, LANL, and LBL all likely have standardization groups that could tell us the best type of source to use.

One interesting possibility is ^{252}Cf. The mean number of neutrons emitted per fission (3.86) is known to better than 2%, and so a comparison of the singles rate to coincidence rate (really all the "folds") in SNO can give the neutron efficiency without any need to standardize the source strength. This is the method used by Reines, Pasierb, Gurr and Sobel.

The advice of Geoff Greene at NIST has been requested. Here is the response from Dave Gilliam at NIST:

"February 7, 1992

Dr. Hamish Robertson:

I understand from Geoff Greene that you would like to borrow a calibrated neutron source for determination of a detector efficiency at the Sudbury experiment. We have neutron sources that range in strength from 40 neutrons/second to 2×10^9 neutrons/second. In the range of 6×10^3 to 10^5 n/s, calibration is difficult. Above and below this range, calibration to an accuracy of about 1.5% is possible. Most of these sources are ^{252}Cf spontaneous fission sources, but there are a few (γ,n) sources on hand also. The strong sources ($\geq 10^7$ n/s) are difficult and expensive to ship.

What range of emission rate do you need? When and for how long do you want it?

We would be very happy to be help with the calibration of your system.

Kind regards... David Gilliam

Telephone 301-975-6206 (FTS 879-6206)

FAX 301-921-9847"

The required source strength to give a detected singles rate of 6 s^{-1} (10 years data in an hour) is 20 s^{-1}. The weakest of the NIST sources would be suitable.

1.2 Monte Carlo Uncertainty

Unless it is possible to find a source that produces a completely uniform distribution of neutrons throughout the heavy water volume, and mimics exactly the energies of the primary unmoderated neutrons from NC events with a laboratory source, we must make the connection between measured neutron rates in detectors and NC neutron efficiency through Monte Carlos. (J. R. Leslie has pointed out that it is possible to dissolve short-lived radioactivity, e.g. ^{66}Ga, in the heavy water. This would address most of the concerns very well, if the distribution of activity were sufficiently uniform.) There are four critical aspects that can be verified:

1. Absolute Normalization. The efficiency for a point source depends on its location within the NC array. Closer to a detector string, the efficiency is higher. Jerry Wilhelmy has calculated this by Monte Carlo, as indicated in Table 1. A source that made 10,000 thermal neutrons was placed on the equatorial plane at various (x,y) grid points (in cm) from a counter string at the center of the vessel. The lattice constant was 100 cm. The quantity r_f is the Fermi Age thermalization length and w the acrylic wall thickness, both in cm. (These are the old-design acrylic counters.)

   It is apparent that there is some sensitivity to source position, about 1% per cm close to a detector string, decreasing to zero at the center of a lattice cell. Positioning of a source to an accuracy of 20 cm near the center of a cell will provide an accuracy of about 2% to fix the normalization of the Monte Carlo

Table 1: Detected counts (from 10,000 generated) in NC array for various source positions

(x,y)	r_f	w	He	Wall
0,25	0	0.3	5237	187
12.5,0	0	0.3	5988	208
25,25	0	0.3	4850	188
50,0	0	0.3	4887	173
50,50	0	0.3	4566	166
50,25	0	0	5429	-
50,25	27	0	5374	-
NC	27	0.3	3688	139
NC	27	0	4209	-

efficiency. There are additional uncertainties associated with the actual position of NC strings, which can be displaced from their nominal positions due to errors in locating the attachment points, circulation in the heavy water, and lateral forces from signal cables. These uncertainties are still under evaluation.

2. Neutron Transport. The spatial dependence of neutron capture from a point source is another testable prediction of the Monte Carlo. Table ?? shows the (x, y) projection for the source located at (50 cm, 50 cm).

3. Efficiency Near Wall. It is obvious from Table ?? that a single source position will not put neutrons into every detector. The detectors nearest the acrylic vessel wall will not be illuminated. The neutron rate is down to 10% of the maximum at a distance of 1.25 m from the source. The MC predictions for the way in which the neutron efficiency falls off near the wall are particularly relevant because there will be a strong (anti-)correlation between that and the behavior of acrylic-generated neutrons. Failure of the MC to get the radial dependence for NC-generated neutrons right would be a systematic error. To verify the Monte Carlo predictions near the wall of the vessel, it would be sufficient to be able to move the neutron source vertically. While the radial dependence will be different along the z-axis than in the x-y plane, confirmation of the dependence in one direction would be strong verification of the Monte Carlo in general (when taken with other verifications).

Table 2: Detected counts (from 10,000 generated at (50,50)) in NC array in detector strings. Detector string coordinates are in m.

	-5	-4	-3	-2	-1	0	1	2	3	4	5
5	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	2	0	0	0	0
3	0	0	1	1	0	2	3	1	1	0	0
2	0	0	0	2	5	14	16	9	3	0	0
1	0	0	1	10	40	116	118	43	6	4	0
0	0	1	3	11	124	830	826	111	13	1	1
-1	0	2	1	12	111	792	809	121	13	0	0
-2	0	0	2	9	32	121	119	32	13	1	0
-3	0	0	0	1	6	12	20	7	3	0	0
-4	0	0	0	1	1	3	1	1	0	0	0
-5	0	0	0	0	0	0	1	0	0	0	0

2 Proper Operation of Neutron Detectors

Neutral-current detectors will be assembled, filled with ^{3}He and tested for neutron efficiency before installation. Thereafter, an internal source will confirm (or disprove) the continued integrity of the detector continuously. It is very difficult to imagine a way the calibration line could remain stable but the ^{3}He disappear.

The proposed use of ^{147}Sm (2.23-MeV α) with a rate of about 1 event per hour as a calibration source has been shown to create some difficulties with the neutron signal. Even at that low rate, a few events will have degraded energy owing to wall collisions or backscatter, and will underlie the neutron peak at 0.76 MeV. They may be rejected by position, but that in effect creates a dead region of several percent of the counter length, with an undesirable loss in neutron efficiency. Whether that is an acceptable penalty will depend on what alternative sources might be identified, and on the usefulness of a continuously present source.

Provided that a satisfactory line source can be found, it is superfluous to put neutrons into each detector with a calibration source in the heavy water. Vertical motion alone of a neutron source at a variety of points within the 1.5-m diameter neck would allow direct illumination of 30-40% of the NC detectors (assuming that rates down to 10% of the largest are sufficient).

3 Backgrounds

3.1 Acrylic Background

The acrylic background may have to be treated somewhat empirically because its radial dependence will be a (very weak) function of the relative amounts of U (2.44 MeV) and Th (2.62 MeV), and a (stronger) function of the intensity of external high-energy gamma backgrounds (up to 9 MeV). The U and Th function can be calibrated, but there will be a residuum of uncertainty from external backgrounds in the range 3-5 MeV. Above 5 MeV, external backgrounds will be obvious in Čerenkov light.

Calibration of the U and Th neutron radial function can most easily be achieved by lowering a source through a light-water access port on the deck until it rests on the acrylic vessel wall, and then letting it slide down the acrylic to various positions between the top and the equator. The source should be at the center of a Teflon sphere 6 cm in diameter and attached to a line. The required source strength is (for Th):

$$N_{Th} = 4\pi n(\eta_n \eta_{photo} b\omega A)^{-1},$$

where n is the desired neutron rate, η_n the neutron detection efficiency near the wall, η_{photo} the neutron production efficiency for 2.6-MeV photons, b the branch to 2.6-MeV photons, ω the solid angle subtended at the source by the D_2O, and A the γ transmission through the acrylic and Teflon. A detected neutron rate of 1 s^{-1} is satisfactory (10 years data at a point would take an hour), which implies a source strength of about 6×10^4 Bq, or 2 μCi. The corresponding U source would be 30 μCi.

3.2 Photodisintegration Background

In order to determine the photodisintegration background from U and Th in the heavy water and in construction materials of the NC detectors, the PMT "wall" will be used. Response in this region needs to be calibrated. Although it will not likely be possible to unfold the U and Th contributions individually, it will be necessary to establish the PMT response for each separately in order to set upper and lower bounds on this background. The Th and U sources needed for this application can be lowered down the neck, because only the central region of the detector is likely to be useful for this determination in any case.

The required source strengths are weak. A detected rate of 100 s^{-1} would imply a Th source of 300 Bq (10 nCi), and a U source of 3000 Bq (100 nCi).

4 Čerenkov Calibration

With the detectors in place, time and energy calibrations of the PMT array and the water transmission become more difficult. It may be possible to use a light pulser suspended down the neck at various places, but a calculation is needed to see if all PMTs can be seen from at least some point in a 75-cm diameter circle. If not, the pulser source needs to be moved further off-axis.

Energy calibrations with Cl(n,γ) sources may also need off-axis access, because events originating on one side of the vessel and heading across it to the other side encounter many detectors. Again, MC calculations are needed to tell us how serious a problem this might be. If a compact source can be made, the scheme described below might do.

5 Source Deployment

Even though it may not be essential to reach off-axis points with a neutron source, it is desirable to do so, and it may not be so difficult. The original "LANL" keel-hauler (a string running around the inside of the vessel with floats and weights on it) is complicated and not very versatile. A better and easier scheme might be to suspend a lightweight spar in the vessel by two strings a neck-diameter apart (1.5 m). The spar would be about 5 m in length, carrying the (very small) source at one end, and a weight at the other end, where one string is attached. The other string (or telescoping tube), then, is attached about 1/3 to 1/4 the way along toward the source. Raising and lowering the strings independently allows the spar, once down the neck, to be tilted horizontal, putting the source a long way off axis.

Resistance to rotation in a horizontal plane would be very slight, so the D_2O would have to be very still for this to work. If that were a problem, the telescoping-tube option would be more rigid. The actual source position at any time would be determined from an ultrasonic transmitter packed with the source.