SNO-STR-94-022

Flowpatterns and Spikes

W. Frati and C. Hargrove

July 02 1994

1 Introduction

A problem in SNO is the distribution of radio isotopes in the D_2O and its effect on the methods we are contemplating to determine the levels of these isotopes. When the water recirculation system is on, the flow patterns may be such that the turn around time of various parts of the vessel can vary by an order of magnitude. Since the purification system will remove various components of the decay chains in different ways, it is highly possible that different regions of the vessel will have very different levels of radioactivity.

In this document we address:

1. Use of spikes to understand the flow patterns in SNO under normal operating circumstances and to calibrate the methods under consideration to measure the U/Th content in the water.
2. Setting up small test areas in the D_2O which allow us to measure effects like convection and pumping currents there and the use of these small regions to isolate both spikes and background activity in the circulation system.

Three spikes (^{24}Na , ^{222}Rn and ^{224}Ra) are discussed each for their own reason and all intimately connected to the D_2O flow pattern.

2 Flow Patterns

Calculations of the flow pattern of the D_2O within the acrylic vessel (AV) are being attempted by Ira Blevis. The program is necessarily complicated and one must make certain to understand both convective flow with sensitivities in the 0.01 degree range and pump flow. Given the complexity of these calculations it is important that they be coupled with the experimental determination of the flow patterns.

A knowledge of the flow patterns is necessary if we are to use the results of the chemical assays to determine the U/Th content in the D_2O , especially if a principal source of the ^{208}Tl and ^{214}Bi backgrounds is from Radon introduced at the D_2O inlet. Further if we are unable to use MgCl and are forced to use NaCl, then we must be able to demonstrate that we understand the level and distribution of ^{24}Na in the detector.

The addition of ^{222}Rn , ^{224}Ra and ^{24}Na spikes under normal running conditions is considered first after which the addition of spikes under special flow conditions is discussed.

3 ^{222}Rn Spike

Table I summarizes the event rate for NPMT ≥ 14 (≈ 1.4 MeV) within the AV from contamination in the D_2O . White Book values of 11×10^{-15} gm/gm are taken for the U and Th levels and 1 ppm K (all isotopes) for the NaCl. The ^{24}Na level is taken from Table 10 in SNO-STR-94-13, with the γ ray flux multiplied by five to conform to a pessimistic upper limit. The contribution from the misreconstructed PMT $\beta\gamma$ events is ignored. The 18K/Day from ^{40}K dominates the counting rate above 10 NPMT and thus for this report 20K events/day is taken as the minimum counting rate required for a spike. This is an upper limit since the ^{40}K NPMT spectrum falls much faster than that of the ^{238}U and ^{232}Th .

A ^{222}Rn ($\tau_{\frac{1}{2}} = 3.8$ days) spike will seed the bottom half of the ^{238}U chain and will serve to calibrate the chemical assay and the central low energy trigger (CLET). It will not calibrate the β-neutron coincidence (BNC) since the event rate will be too low. The chemical assay will measure the ^{222}Rn content directly. The CLET can be used to sample different parts of the detector, so not only will a calibration be achieved, but a spatial distribution can be determined as well since the half life of ^{222}Rn is comparable to the D_2O cycle time for the 1 kilotonne of D_2O . This calibration will require a careful unfolding of the half life and flow rate. Thus for example at the injection point, there should be sharp rise in counting rate at injection time and then a fall off that is a combination of flow rate and decay rate. At the ejection point there will be a slow rise in counting rate as the ^{222}Rn reaches that part of the detector, followed by the decay rate fall off. The ^{214}Bi NPMT spectrum is structureless (SNO-STR-94-005) being characterized by an almost exponential fall off. Here a careful calibration of the shape is necessary using the PC sources. The PC source will also provide for an absolute rate calibration and serve as a double check on the spike calibration.

There is an outside chance we could observe the neutron captures induced by the spike which amounts to about 4/day, compared to the 15/day from solar neutrinos and background.

0.3×10^6

0.38

This could serve as a consistency check.

Since only 30% of the ^{214}Bi decays have NPMT ≥ 14 , a spike producing about 70K decays/day is required or about $\frac{1}{3} \times 10^6$ ^{222}Rn atoms. It will take 23 days for this spike to decay to a level where it is 1/10 that of the Uranium content in the D_2O . This level of spiking is required for the NaCl run because of the 1 ppm of K in the salt. Should the ^{40}K level in the pure D_2O be less than 2 ppb then a proportionately less intense spike would suffice for that phase of the experiment.

4 ^{224}Ra Spike

Since the ^{224}Ra half life of 3.6 days is virtually the same as ^{222}Rn , the numbers quoted above would serve just as well for a ^{224}Ra spike to calibrate the ^{232}Th chain. Here one has several advantages over the equivalent intensity ^{222}Rn spike.

1) The ^{208}Tl spectrum is characterized by a peak at 2.0 MeV and is much easier to discern.
2) Calibration of the β-neutron trigger.
3) 40 Cl captures/day and 10 pure D_2O captures/day.
4) A weaker spike can be used because 80% of the ^{208}Tl events have NPMT ≥ 14 as compared to the 30% from ^{214}Bi .

A ^{224}Ra spike is the only means we have of calibrating the chemical assay of the ^{232}Th chain and double checking the flow pattern one obtains from the ^{222}Rn spike. The BNC and CLET can be calibrated with PC sources, but the spike is preferable since both the ^{222}Rn and ^{224}Ra spike can be inserted simultaneously and provide a more realistic check on the various measuring schemes. The simultaneous spike also saves three weeks of running time. Further the BNC and CLET measurements are fitter dependent and a distributed source provides for a more realistic calibration.

The fly in the ointment is that we must convince ourselves that we are not introducing contamination from the long lived Radium, Uranium and Thorium isotopes.

5 ^{24}Na Spike

^{24}Na presents several problems.

1) It's high energy γ of 2.75 MeV, while large enough to break up 30% more deuterons than the 2.62 MeV γ from ^{208}Tl , is not large enough to be distinguishable from it in the NPMT spectrum. Thus a measurement of intensity in the 2.5 MeV region will not tell us the num-

ber of background deuteron breakups unless we know the relative intensity of the two. This renders the numbers derived from the BNC and CLET meaningless.

2) SNO-STR-94-13 shows that the 500 meters of D_2O piping will produce about 1.8 NC events/day (using the factor of five pessimistic gamma ray flux limit), which is well above our self imposed limit of 0.25/day. This is assuming that the 2 tonne holding tank is shielded well enough to reduce the γ ray flux by a factor of 100 and that the exposed neck is kept stagnant.

Should we be forced to use NaCl, we must convince ourselves that the activity is low enough not to bother us. Since the half life of ^{24}Na is only 15 hrs, it would be impossible to determine the flow pattern by following its activity as it moves through the detector, so one must rely on the flow patterns obtained from the ^{222}Rn spike. Knowing this one can then observe the 15 hr decay rate in the region where the D_2O is injected. This should be performed with a known spike and then again just after the 2 tonne tank is cycled.

6 Special Flow Patterns

We now turn to the case for the establishment of special flow situations which can be used to isolate test regions in the AV to address special problems. The establishment of these regions requires a detailed knowlege of water flow in the AV. As discussed above, the calculation of this flow is difficult and therefore the possibility of their establishment has to be determined. In what follows, we will assume that they can be established and understood. The main point is that the inherent background relative to the total background in the PMT's from such a small region reduces by the ratio of its volume to the total volume of SNO. This will make it possible to measure activities in that region with a much lower background.

We envisage two methods of setting up regions in the D_2O . The first is by adjusting the flow between an input and output pipe and limiting the flow to a region between the two pipes. The second would bring the input from the circulation system in at a different density such that the effluent is confined to a small region. This region could be a moving one in which the effluent drifts up in the D_2O or a static one in which it collects, for instance, either at the top or bottom of the AV. The density could be established either by temperature manipulation or in the case of the salt by varying its concentration.

The test region could be used for a number of purposes.

1. To isolate the effluent from the circulation system and measure the background contami-

nants in it with the PMT's of SNO.

2. To measure the PMT response to a distributed source from different regions in SNO.
3. To measure the flow patterns in SNO in specific regions.

For this to work one must have some special conditions: 1. We must be able to isolate the effluent to a small region. That is we must arrange that this region is not disrupted by convective or other flow patterns in the D_2O .

2. The volume must be large compared with the volume of the external circulation system.
3. The residence time in the volume should long enough to measure the activity which we introduce.

As an example, imagine that we arrange the NaCl input from the circulation system flows into the bottom of the AV at a slightly higher density than the rest of the D_2O . Under these conditions it will settle at the bottom of the AV. We can extract the appropriate rates for the effectiveness of this procedure from Table I, which is described below. The background in a 10 cubic metre region from Th, U, and K will be 1% of the total from the D_2O in SNO, about 233 per day. The signal from ^{24}Na will be 5800 per day. The background number assumes the full rate for the ^{40}K , most of which is below the ^{24}Na in energy. Therefore this estimate for the background is very high. The conclusion is that one could measure by this method the amount of ^{24}Na introduced by the circulation system down to the limit allowed in SNO of 2.4 n/day.

It is clear that any spikes could be measured by this method in a specific region. Further, if the circulation system is introducing some background, we could isolate it and amplify its signal to background by this method.

The main uncertainty is the stability of the test region. It could be difficult to stabilize. Of special concern are the convection currents which might spread the test volume over much more than the 10 m^3 assumed above.

It is obvious that the test volume could be measured by introducing a spike of sufficient strength. A spike could be also be used to measure the stability of the test region. Backgrounds could be easily measured for such a region.

7 Calculations Required

Detailed calculations are required as to spike intensities and rates as a function of time and position for the ^{222}Rn , ^{224}Ra and ^{24}Na spikes, using the best approximation we have for the flow pattern. This is true whether we use the NaCl option or not, but doubly important if we do use it. Such calculations are required for both normal running conditions and for special flow patterns created to study small volumes within the detector.

TABLE I

Element	γ Event/Day E > 1.4 MeV	Cl captures/Day
^{238}U	3.3K	0.2
^{232}Th	1.0K	2.3
^{40}K	18.0K	-
^{24}Na$^{(1)}$	5.8K	20.0
^{24}Na$^{(2)}$	0.53K	1.8

- (1) Includes contributions from the 2 Tonne tank, 500 meters of pipe, acrylic in which the circulation system passes the water from the inlet to the outlet through a small volume of the D_2O . vessel neck and R.O. unit. Uses R. Norman's measurement of the γ flux which is 5 times that used in Table 10 of SNO-STR-94-13 from which these numbers are derived. This factor of of five is now believed to be understood and is the basis of the pessimistic upper limit used in this report.
- (2) 500 meter pipe only