Contamination to CC/NC Signals by Radioactive Backgrounds

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Abstract

The paper presents a Monte Carlo study of contamination to CC/NC signals from radioactive backgrounds in the heavy water, the acrylic vessel and the light water. Rough estimation have been made about such contamination so that an analysis threshold could be determined. I will argue that we should be very cautious of publishing such result based only on pure D_2O data as it heavily depends on tail of the background wall, which we do not and, maybe will never, fully understand.

1 Introduction

Capability of measuring NC event rate is unique to the SNO experiment. The single most important number that SNO will produce is the NC/CC ratio as it may provide an unambiguous answer to the solar neutrino problem: is the standard solar model wrong or do solar neutrinos oscillate? Suggestions have been made to do a rough measurement of this number using pure D_2O data ([1], [2]). Conclusion then was it is possible to carry out such measurement. However, those analyses were done mainly with pure CC and NC event sets. We carried out a detailed MC study of background contamination to neutrino signals using latest SNOMAN code.

2 MC Results from standard SNOMAN

SNOMAN 4_0082 has been used to produce various sets of events: ^{208}Tl and ^{214}Bi decay events in the heavy water, the acrylic vessel and the light water. The time fitter was used in reconstruction. Number of MC events is shown in table 1. For comparison, actual radioactive levels determined by the in-situ background monitoring technique is presented in table 2.

Most of analyses on NC/CC separation carried out before took no or little account of possible contamination to the neutrino signals from radioactive backgrounds. The assumption was that with high nhits threshold and tight fiducial volume cut, such contamination may be ignored. On the other hand, there are limits on how high the nhits threshold and how tight the fiducial volume could be as above such limits, no. of NC events would be too small to produce a meaningful

Table 1: Number of MC events and its equivalent U/Th concentration level with 1 year of data.

Background Type	No. of MC events	Equivalent concentration level (g/g)
^{208}Tl decays in D_2O	4×10^5	Th: 8.7×10^{-15}
^{214}Bi decays in D_2O	4×10^6	U: 1.0×10^{-14}
^{208}Tl decays in AV	8×10^5	Th: 5.8×10^{-13}
^{214}Bi decays in AV	7.5×10^6	U: 6.3×10^{-13}
^{208}Tl decays in H_2O	4×10^6	Th: 6.96×10^{-14}
^{214}Bi decays in H_2O	4.24×10^7	U: 8.6×10^{-14}

Table 2: Radioactive Background levels in D_2O and H_2O determined by the in-situ background monitoring technique.

Date	Background Type	Concentration level (g/g)
1999/11	Th in D_2O	$(3.63 \pm 4.42) \times 10^{-15}$
1999/11	U in D_2O	$(7.84 \pm 0.99) \times 10^{-14}$
1999/11	Th in H_2O	$(-1.36 \pm 6.76) \times 10^{-14}$
1999/11	U in H_2O	$(262.07 \pm 12.02) \times 10^{-14}$
1999/12	Th in D_2O	$(2.84 \pm 2.84) \times 10^{-15}$
1999/12	U in D_2O	$(4.85 \pm 0.64) \times 10^{-14}$
1999/12	Th in H_2O	$(5.68 \pm 1.55) \times 10^{-14}$
1999/12	U in H_2O	$(41.48 \pm 2.63) \times 10^{-14}$
2000/1-2000/3	Th in D_2O	$(3.14 \pm 1.32) \times 10^{-15}$
2000/1-2000/3	U in D_2O	$(1.00 \pm 0.25) \times 10^{-14}$
2000/1	Th in H_2O	$(5.26 \pm 1.26) \times 10^{-14}$
2000/1	U in H_2O	$(29.66 \pm 2.10) \times 10^{-14}$
2000/2	Th in H_2O	$(2.42 \pm 1.57) \times 10^{-14}$
2000/2	U in H_2O	$(38.65 \pm 2.69) \times 10^{-14}$
2000/3	Th in H_2O	$(3.21 \pm 1.42) \times 10^{-14}$
2000/2	U in H_2O	$(39.19 \pm 2.45) \times 10^{-14}$

CC/NC value. Recently, Steve Brice carried out a MC study [3] of NC/CC separation with no background involved. He set the threshold as: nhits $\geq$ 45 and rfit $\leq$ 700cm. His conclusion is that if only 6 months of data are used, the fitted CC/NC value is barely meaningful. Table 3 presents number of NC, CC and background events per year falling inside this window. Clearly the largest contamination come from radioactive backgrounds in the light water region.

In principle tail of the background wall consists of two components:

- Neutrons produced through photo-disintegration and then captured on deuterons.
- "Real" tail of the wall caused by "fluctuation" of radioactive decays.

Neutron captures can be calibrated by various sources. It is possible that the Monte Carlo can be tuned to reproduce the correct characteristic distributions such as the Nhits and the r^3 distribution for such physics process. It is also possible that the water assay and/or the background monitoring technique can determine actual radioactive levels in the detector. Thus, in principle the first component of the tail can be deduced and subtracted from the fitted NC number. Having said that, one should bear in mind that neither the water assay nor the background monitoring technique at the moment is capable of determining radioactive levels in the AV. We may have to use numbers measured years ago and assume no dust are stick to the AV.

The second component of the tail is much more serious. Those events are very rare and even with the calibration sources, chances are we will never be able to tune the Monte Carlo to such accuracies. For example, MC simulation indicates only 1 in every 200,000 H_2O ^{214}Bi decay events fall in the CC/NC separation window. Note there are NO physics reasons at all that a simple extrapolation from low nhits data can give an upper limit on high nhits data. Number of events at the tail in real data can be different to the MC prediction by a large factor. It is very difficult, if not impossible, to determine this factor or even sign of the factor. When estimating contamination of this background tail to the neutrino signals, the best thing we could do may just be to assign a large number to this factor so that we could argue, beyond reasonable doubt, background contamination in reality should not be larger than the "arbitrary inflated" level. There are some ways to verify this hypothesis, as discussed later. It gives us an idea of how large the contamination could be. Table 4 lists contamination of the background wall when photodisintegration was turned off during the simulation. Comparing table 4 with table 3, it is clear that the tail of the D_2O radioactive background is mainly neutron backgrounds while the tail of the AV and the H_2O backgrounds are mainly due to the "fluctuation". As argued before, we should allow a large variation on the MC predictions. NC/CC ratio is the most important number that the SNO experiment can produce, I think we should be very conservative and for this study, I set the factor to be 10 (i.e. I allow the background contamination to be as 10 times as the number predicted by the MC.) It is clear, from table 3 and table 4, that the CC/NC separation is totally impossible as even without scaling, contamination from radioactive background in the light water alone is as large as number of neutral current events. Furthermore, at the radius cut of rfit $<$ 700cm, no matter how high we set the nhits threshold, if we enhance the background tail by a factor of 10, contamination from radioactivity in the light

Table 3: Number of neutrino and radioactive background events per year falling within the CC/NC separation window: nhits ≥ 45 and rfit ≤ 700cm. Neutrinos are assumed to have one full stand solar model values while backgrounds are assumed to have radioactive levels presented in table 1.

Event Type	Nhits ≥ 45	Nhits ≥ 50	Nhits ≥ 55	Nhits ≥ 60	Nhits ≥ 65
CC	8328	7332	6286	5233	4193
NC	612	334	159	74	24
D_2O Th	121	68	37	13	2
D_2O U	19	11	4	2	0
AV Th	73	15	7	2	0
AV U	10	3	1	0	0
H_2O Th	333	45	2	0	0
H_2O U	203	27	3	1	0

water is comparable to the number of NC events. Unlike neutron background, it is almost impossible to characterize these tail events.

One logical modification of the CC/NC separation window is to tighten the rfit cut as largest contamination comes from radioactivity in the light water. Table 5 and 6 present the result. As expected, contamination from H_2O radioactivity are significantly reduced. The largest contamination seems to come from neutrons produced by D_2O radioactivity, which in principle can be calibrated away. However, if we take the conservative approach and allow the contamination from non-neutron background to increase by a factor of 10, then the contamination caused by the H_2O radioactivity again becomes comparable to the number NC events. One can increase the nhits threshold to eliminate affect of tail of the background wall. But no. of NC events also decreased. As table 5 shows, above 60 nhits, NC/CC separation may be meaningless as the number of NC events becomes smaller than statistic fluctuation of the number of CC events.

We haven't carried out detailed studies of CC/NC separation with more optimized cut. One can also argue that with a better fitter such as the grid fitter, contamination from H_2O background may be reduced although for an event with more than 45 hits, improvement of the grid fitter over the time fitter is small and it should not change qualitively the argument presented in this paper. Note the actual radon level in the light water has always been at least three or four times higher than the level assumed in this study (see table 1 and table 2). Especially in 1999/11, because of radon leak, the actual radon level in H_2O was around 30 times higher than the level used in the MC studies, which means that month's data is essentially unusable for CC/NC analysis and this further reduces the statistics. The $u \cdot r$ distribution of real data shows there are many inward coming events with high nhits, which indicates that contamination of the PMT beta gamma events is not small. More importantly, background contamination is just one of many systematic errors that we need to consider in order to determine CC/NC ratio from the pure D_2O data and MC studies already indicated that this single systematic error may be very large.

Table 4: Number of neutrino and radioactive background events per year falling within the CC/NC separation window: nhits ≥ 45 and rfit ≤ 700cm. Neutrinos are assumed to have one full stand solar model values while backgrounds are assumed to have radioactive levels presented in table 1. Photodisintegration was turned off for these simulations.

Event Type	Nhits $\geq$ 45	Nhits $\geq$ 50	Nhits $\geq$ 55	Nhits $\geq$ 60	Nhits $\geq$ 65
CC	8328	7332	6286	5233	4193
NC	612	334	159	74	24
D_2O Th	4	1	0	0	0
D_2O U	5	0	0	0	0
AV Th	58	9	0	0	0
AV U	6	0	0	0	0
H_2O Th	296	38	6	0	0
H_2O U	198	26	2	1	0

Table 5: Number of neutrino and radioactive background events per year falling within the CC/NC separation window: nhits ≥ 45 and rfit ≤ 600cm. Neutrinos are assumed to have one full stand solar model values while backgrounds are assumed to have radioactive levels presented in table 1.

Event Type	Nhits $\geq$ 45	Nhits $\geq$ 50	Nhits $\geq$ 55	Nhits $\geq$ 60
CC	7570	6678	5737	4792
NC	587	318	151	68
D_2O Th	117	66	36	13
D_2O U	17	11	4	2
AV Th	31	12	6	2
AV U	7	3	1	0
H_2O Th	23	5	1	0
H_2O U	17	2	1	0

Table 6: Number of neutrino and radioactive background events per year falling within the CC/NC separation window: nhits $\geq$ 45 and rfit $\leq$ 600cm. Neutrinos are assumed to have one full stand solar model values while backgrounds are assumed to have radioactive levels presented in table 1.Photodisintegration was turned off in the simulations.

Event Type	Nhits $\geq$ 45	Nhits $\geq$ 50	Nhits $\geq$ 55	Nhits $\geq$ 60
CC	7570	6678	5737	4792
NC	587	318	151	68
D_2O Th	4	1	0	0
D_2O U	4	0	0	0
AV Th	3	0	0	0
AV U	1	0	0	0
H_2O Th	20	2	0	0
H_2O U	20	0	0	0

Table 7: Number of MC events and its equivalent U/Th concentration level with 1 year of data.

Background Type	No. of MC events	Equivalent concentration level (g/g)
^{208}Tl decays in D_2O	4×10^5	Th: 8.7×10^{-15}
^{214}Bi decays in D_2O	4×10^6	U: 1.0×10^{-14}
^{208}Tl decays in AV	8×10^5	Th: 5.8×10^{-13}
^{214}Bi decays in AV	7.5×10^6	U: 6.3×10^{-13}
^{208}Tl decays in H_2O	4×10^6	Th: 6.96×10^{-14}
^{214}Bi decays in H_2O	4.0×10^7	U: 8.1×10^{-14}

3 MC Results with Queen's title files

The ^{16}N data already indicate there is a discrepancy between the reality and the prediction from the standard SNOMAN code. Mark Boulay and Brice Moffat tuned the Monte Carlo to reproduce the nhits spectra of the ^{16}N data by adjusting optical parameters and PMT detection efficiency in the code. we repeated the previous simulation with their optical title files and also turned on the grid fitter. Number of MC events generated are listed in table 7. Number of background events falling inside the CC/NC window with different radius cut are presented in table 8, table 9 and table 10. From these tables, it is apparent that, with Queen's title files, radioactive contamination to CC/NC window is suppressed, especially for H_2O β-γ events. Superior performance of the grid fitter over the time fitter could cause the suppression. However, because the Queen's optic title files were generated by fitting the Nhits spectra of the ^{16}N data with source located exclusively in the heavy water region, it is likely that the modified MC artificially enhance the light production from the heavy water region compared with the light water region. This could be the dominant reason behind the suppression of the light water background.

Table 8: Number of neutrino and radioactive background events per year falling within the CC/NC separation window: nhits $\geq$ 45 and rfit $\leq$ 700cm. Neutrinos are assumed to have one full stand solar model values while backgrounds are assumed to have radioactive levels presented in table 7.

Event Type	Nhits $\geq$ 45	Nhits $\geq$ 50	Nhits $\geq$ 55	Nhits $\geq$ 60	Nhits $\geq$ 65
CC	9120	8325	7443	6520	5619
NC	881	616	373	199	82
D_2O Th	213	128	62	28	14
D_2O U	49	18	10	6	2
AV Th	94	29	12	4	2
AV U	10	2	1	1	0
H_2O Th	255	36	8	4	3
H_2O U	168	17	2	1	0

Table 9: Number of neutrino and radioactive background events per year falling within the CC/NC separation window: nhits $\geq$ 45 and rfit $\leq$ 600cm. Neutrinos are assumed to have one full stand solar model values while backgrounds are assumed to have radioactive levels presented in table 7.

Event Type	Nhits $\geq$ 45	Nhits $\geq$ 50	Nhits $\geq$ 55	Nhits $\geq$ 60	Nhits $\geq$ 65
CC	8226	7517	6737	5906	5096
NC	854	594	363	191	79
D_2O Th	201	122	59	27	13
D_2O U	48	18	10	6	2
AV Th	33	22	11	3	2
AV U	4	1	1	1	0
H_2O Th	6	5	4	2	2
H_2O U	6	1	1	1	0

Table 10: Number of neutrino and radioactive background events per year falling within the CC/NC separation window: nhits ≥ 45 and rfit ≤ 550cm. Neutrinos are assumed to have one full stand solar model values while backgrounds are assumed to have radioactive levels presented in table 7.

Event Type	Nhits $\geq$ 45	Nhits $\geq$ 50	Nhits $\geq$ 55	Nhits $\geq$ 60	Nhits $\geq$ 65
CC	6459	5899	5291	4656	4032
NC	768	535	321	167	71
D_2O Th	182	113	56	27	13
D_2O U	43	15	7	4	2
AV Th	19	14	7	1	1
AV U	1	0	0	0	0
H_2O Th	2	2	2	2	2
H_2O U	2	1	1	1	0

4 Comments to CC/NC Separation

Numbers listed in the tables above should only be treated qualitively, especially for estimate of contamination to CC/NC window by background "tail" events because of their extremely low probability. Uncertainties on those estimates are difficult to determine without a calibration source. Note even if radioactive levels inside the water are well determined, we still need to know shape of the background wall in order to do a proper estimation. In this paper, we took a conservative approach, which is to artificially enhance background contamination by a factor of 10 and then compare the numbers with the NC rate. However, it is equally possible that in reality, the background contamination is 10 times smaller than the MC prediction. We suggest to use the numbers presented in this paper as a very rough guide to determine an analysis threshold. Above the threshold, the background contamination could be assumed to be negligible. Then there are two similar methods to verify such hypothesis [5]. We can carry out a statistic separation between the CC and the NC events based on their difference on the r^3 and the $cos\theta_{sun}$ distributions. The separation has to be carried out on different Nhits bins so that in the end a fitted NC spectrum could be produced. Then this spectrum could be compared with the spectrum produced by the neutron calibration source. Alternatively, knowledge of the NC spectrum can be used as a constraint in the fitting and we could use the goodness of the fit to verify the hypothesis that indeed the background contamination can be ignored.

With salt in, CC/NC separation is much easier and more robust than the pure D_2O data. Neutron capture on Chlorine produces a gamma cascade with 8.6Mev energy compared with the 6.25Mev gamma produced by neutron captured on deuteron. An increase of roughly 18 hits means we are essentially free of contamination from tail of the background wall. Furthermore, with salt in we not only significantly increase the number of NC events but also afford to make tight fiducial volume cut as we no longer depend on the r^3 distribution to separate NC and CC events. The only advantage of using pure D_2O data is its time. As the CC/NC ratio is critical, we feel we should always prefer a correct result rather than a quick result. Thus we recommend to be very cautious on publishing any CC/NC result with only pure D_2O data as it heavily depends on magnitude of the background tail, which we don't, and may never, fully understand.

5 Conclusion

We present a MC study of contamination to the neutrino signal by tail of the background wall. We found that the contamination could be significant and deduction of a meaningful CC/NC ratio heavily depends on detailed knowledge of the background tail, which is very difficult, if not impossible at the moment. The estimations presented in this paper can only be used as a very rough guide to determine an analysis threshold. WCA also presents a simple method to verify the hypothesis that above the threshold the background contamination can be ignored.

A background calibration source is essential to understand magnitude of the background tail. Early SNO data, where the radioactive decay events were dominant because of radon leakage, could be used to evaluate contamination from decays in the Uranium chain. Such analyses are still at progress.

References

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