A Systematic Study of the Background Analysis using SNOMAN Code

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Abstract

Neural network technique and Chi square fit method have been used to determine the major radioactivity background in SNO and got good results. Studies have been done to check the robustness of these techniques against the systematic errors of the SNOMAN code. Some results are presented here.

1 Introduction

Major neutral current backgrounds in SNO are neutrons from photodisintegration of deuterons by γ-rays with more then 2.223Mev energy. Most of these γ-rays come from the decay of ^{208}Tl in the Thorium chain and ^{214}Bi in the Uranium chain. One way to determine the number of ^{208}Tl and ^{214}Bi decay events is to measure the Uranium and Thorium concentration level in the water by chemical ways, then deduce the number of decay events with the assumption of the secular equilibrium[1]. There is another possible way to determine the number of ^{208}Tl and ^{214}Bi decay events on site and without the assumption of the secular equilibrium[2].The main procedure is:

1. Make a cut window on the data(eg: $30 < nhits < 40$, $0 < r_{fit} < 640cm$). Be sure that the dominant events inside this window are the ^{208}Tl and ^{214}Bi decay events from D_2O, the acrylic vessel and H_2O.

2. Neural network technique and Chi square fit method are used to determine the relative ratio of these 6 classes of events, than deduce the definite number of these 6 classes of events inside the window.

3. Deduce the total number of ^{208}Tl and ^{214}Bi decay events with the help of the Monte Carlo.

Up to now, this technique fully relies on the Monte Carlo data. Whether this technique is robust against the systematic error in the Monte Carlo should be checked. Some results are presented here.

2 Systematic Study

In order to make things simple, the following study is under the conditions:

- The cut window is chosen as: $30 < nhits < 40$ and $0 < r_{fit} < 640cm$.
- The numbers of 6 classes of events inside the window are same.

See table 1 for the detail.

2.1 Impurity of the Testing Data Set

The first step of this technique is to make sure that the selected window is clean except events from the ^{208}Tl and ^{214}Bi decay in D_2O, the acrylic vessel and H_2O. This is almost true[2]. Major unclean signals come from ^{234}Pa decay events in the Uranium chain. Make the following assumption :

- The impurity of the ^{208}Tl and ^{214}Bi decay events in D_2O is 5%, all of which come from the ^{234}Pa decay.
- The impurity of the ^{208}Tl and ^{214}Bi decay events in the acrylic vessel is 5%, all of which come from the ^{234}Pa decay.
- The impurity of the ^{208}Tl and ^{214}Bi decay events in the H_2O is 10%(because of the possible extra contamination of pmt background events), all of which come from the ^{234}Pa decay.

Check the performance of the neural network and chi square fit, see table 2. The number of free neutrons produced by the ^{208}Tl and ^{214}Bi decay changed by -1.59%.

2.2 Impurity of the Training and Calibrating Data Sets

If the training and calibrating data sets to the network come from the calibration source, there will be some impurity due to the mixing of the 6 classes of events. For example, when using ^{222}Rn gas in D_2O to get the training and calibrating sets for the ^{214}Bi decay events in D_2O, the other 5 classes of events existed in the detector and so mixed in the data sets(i.e., the network is told some events from the other 5 classes are the ^{214}Bi decay events in D_2O.).

Assume the impurity of the training and calibrating data sets is 10%, check the robustness of this technique(See table 3). The number of free neutrons produced by the ^{208}Tl and ^{214}Bi decay changed by 5.7%.

2.3 Scattering of Cerenkov photons in the detector

If the scattering efficiency of the Cerenkov photon in the detector is changed, obviously it will change the angular distribution of the events and hence the hitted pattern. Whether this pattern recognition technique is robust against this sort of change should be checked.

Improve the isothermal compressibility of both D_2O and H_2O by 20% and redo the analysis. See table 4. The number of free neutrons produced by the ^{208}Tl and ^{214}Bi decay changed by 4.76%.

2.4 Change of the Attenuation Probability

If the attenuation probability of Cerenkov photons in the detector is changed, there will be some errors in deducing the total number of decay events from the number of events inside the window.

Increase the attenuation probability of Cerenkov photons in D_2O and H_2O by 10% and acrylic vessel by 20%. Note this is a very dramatical systematic change. Redo the analysis and the results are presented in table 5. The number of free neutrons produced by the ^{208}Tl and ^{214}Bi decay changed by -18.9%.

2.5 Complexity of the Acrylic Vessel

In the SNOMAN Monte Carlo code, the most complex part of the detector is the acrylic vessel. In default, it only is simulated as a spheric shell. But in fact it is made up of several hundred acrylic tiles and some appendixes. It is very difficult to simulate the detector exactly. So whether the simplifying in the Monte Carlo will make affects on this technique should be checked.

The checking procedure is as the following:

1. Produce the training and calibrating data sets with the simulation of the acrylic vessel as a spheric shell.

2. Produce the testing data sets with the full simulation of the acrylic vessel(i.e. turn on the tiles of the acrylic vessel and some appendixes to the vessel).

3. Redo the analysis .

The results are presented in Table 6. The number of free neutrons produced by the ^{208}Tl and ^{214}Bi decay changed by 0.8%.

2.6 Direction of the PMTs

In the SNOMAN Monte Carlo code, all pmts are simulated to be exactly vertical to the pmt panels. In fact this can not be true. If there is some fluctuation of the direction of the pmts, it means the angle of the incident photon is changed and so does the probability to detect this photon.

A gaussian jitter($mean = 0^o$ and $1\sigma = 2^o$) was added to the direction of the pmts and then produced the testing data sets. Redid the analysis and the results are presented in table 7. The number of free neutrons produced by the ^{208}Tl and ^{214}Bi decay changed by 7.84%.

2.7 Noise of the PMTs

In SNOMAN code, the pmt noise(1khz) is distributed normally in all pmts. But in fact, there should be some pmts more or less noisy than others and this will distort the hitted pattern. Whether this technique is robust against this systematic change should be checked.

Let 900 pmts have higher noise rate(2khz) and then get the testing data sets. The results are as table 8.1 and 8.2. Higher noise rate means higher nhits and the number of events inside the cut window is increased. There are also some errors due to the performance of the neural network and chi square fit.The number of free neutrons produced by the ^{208}Tl and ^{214}Bi decay changed by 11.2%.

2.8 Detecting Efficiency of the PMTs

Up to now, the information about the detecting efficiency of the pmt only came from the measurement of 4 Hamamatsu eight inch pmts[3]. The corresponding value in the SNOMAN code is the average one. The average RMS deviation is approximately 4.5%[3]. Obviously the change of the detecting efficiency of the pmts will make affects on the number of hits produced by the decay events and may distort the hitted pattern.

Decrease the detecting efficiency of 3030 pmts by 5% and these pmts all locate in a band ($300cm < z < 900cm$).Did the systematic study and results are presented in table 9.1 and 9.2. The number of free neutrons produced by the ^{208}Tl and ^{214}Bi decay changed by 4.1%.

3 Conclusion

See table 10. The total systematical change in the number of background neutrons is 24.9%. If the ratio between the number of events and the number of backgrouds is 10%([1]), the total systematical change to the SNO results is only 2.49%. So this technique is robust against the systematic changes(note here some systematic changes are very dramatic) and can be used to determine the neutral background rates in SNO.

References

[1] SNO PROPOSAL.October 1987 *white book*

[2] X.Chen *Sep. 1,1996; Neural Network and Statistical Study of the* ^{208}Tl *and* ^{214}Bi *decay events in SNO* (SNO-STR-96-004)

[3] M.Lay *Creation and Detection of Cerenkov Light in the Sudbury Neutrino Observatory* (Ph.D Thesis,1994)

Table 1

The assumption of this study

		Number of decay per year	Number of events in the window	Number of neutrons produced per year
D_2O	^{208}Tl decay	505890	29031	759
D_2O	^{214}Bi decay	$4.78 * 10^6$	29031	80
Acrylic	^{208}Tl decay	$5.26 * 10^5$	29031	263
Vessel	^{214}Bi decay	$1.57 * 10^7$	29031	63
H_2O	^{208}Tl decay	$1.28 * 10^7$	29031	256
H_2O	^{214}Bi decay	$9.66 * 10^7$	29031	48

The total number of neutrons produced by the ^{208}Tl and ^{214}Bi decay per year is 1469.

Table 2

The systematic study of the impurity of the testing set

		The percentage change of the results of the network	Change of the number of the neutrons
D_2O	^{208}Tl	5.29%	40.2
D_2O	^{214}Bi	-9%	-7.2
Acrylic	^{208}Tl	-14%	-36.8
Vessel	^{214}Bi	6.2%	3.9
H_2O	^{208}Tl	-13.7%	-35
H_2O	^{214}Bi	24.2%	11.6

The total number of neutrons produced by the ^{208}Tl and ^{214}Bi decay changed by -1.59%.

Table 3

The systematic study of the impurity of the training and calibrating data sets.

		The percentage change of the results of the network	Change of the number of the neutrons
D_2O	^{208}Tl	8.28%	62.8
D_2O	^{214}Bi	-4.4%	-3.5
Acrylic	^{208}Tl	14.7%	38.7
Vessel	^{214}Bi	2.3%	1.45
H_2O	^{208}Tl	-9.44%	-24.2
H_2O	^{214}Bi	17.5%	8.4

The total number of neutrons produced by the ^{208}Tl and ^{214}Bi decay changed by 5.7%.

Table 4

The systematic study of the change of the isothermal compressibility

		The percentage change of the results of the network	Change of the number of the neutrons
D_2O	^{208}Tl	6.5%	49.3
D_2O	^{214}Bi	-12.6%	-10.1
Acrylic	^{208}Tl	5.9%	15.5
Vessel	^{214}Bi	2.8%	1.76
H_2O	^{208}Tl	6.7%	17.2
H_2O	^{214}Bi	-7.7%	-3.7

The total number of neutrons produced by the ^{208}Tl and ^{214}Bi decay changed by 4.76%.

Table 5

The systematic study of the change of the attenuation probability of photons in the detector.

		The percentage change of the results of the network	Change of the number of the neutrons
D_2O	^{208}Tl	-20%	-151.8
D_2O	^{214}Bi	-16.1%	-12.9
Acrylic	^{208}Tl	-33.8%	-88.9
Vessel	^{214}Bi	-12.2%	-7.7
H_2O	^{208}Tl	-4.4%	-11.3
H_2O	^{214}Bi	-10.1%	-4.85

The total number of neutrons produced by the ^{208}Tl and ^{214}Bi decay changed by -18.9%.

Table 6

The systematic study of the simulation of the acrylic vessel(see text).

		The percentage change of the results of the network	Change of the number of the neutrons
D_2O	^{208}Tl	3.83%	29.1
D_2O	^{214}Bi	1.6%	1.28
Acrylic	^{208}Tl	-8.41%	-2.21
Vessel	^{214}Bi	1.33%	0.84
H_2O	^{208}Tl	-6.87%	-17.6
H_2O	^{214}Bi	0.65%	0.31

The total number of neutrons produced by the ^{208}Tl and ^{214}Bi decay changed by -0.8%.

The systematic study for the change of the direction of the pmts.

table 7.1

Systematic error when using the neural network and chi square technique to determine the relative ratio of 6 classes of the events

		The percentage change of the results of the network	Change of the number of the neutrons
D_2O	^{208}Tl	20.2%	153.3
D_2O	^{214}Bi	-17.8%	-14.2
Acrylic	^{208}Tl	-11.6%	-30.5
Vessel	^{214}Bi	5%	3.2
H_2O	^{208}Tl	-1.7%	-4.35
H_2O	^{214}Bi	1.3%	0.62

table 7.2

Systematic error when deducing the total number of decay events from the number of the events inside the cut window.

		The percentage change of the results of the network	Change of the number of the neutrons
D_2O	^{208}Tl	0.7%	5.3
D_2O	^{214}Bi	-0.5%	-0.4
Acrylic	^{208}Tl	6.2%	16.3
Vessel	^{214}Bi	1.3%	8.2
H_2O	^{208}Tl	0.3%	7.7
H_2O	^{214}Bi	5%	2.4

The total number of neutrons produced by the ^{208}Tl and ^{214}Bi decay changed by 7.84%.

The systematic study for the change of the noise rate in pmts

table 8.1

Systematic error when deducing the total number of decay events from the number of the events inside the cut window.

		The percentage change of the results of the network	Change of the number of the neutrons
D_2O	^{208}Tl	8.4%	63.8
D_2O	^{214}Bi	9.3%	7.4
Acrylic	^{208}Tl	6.4%	16.8
Vessel	^{214}Bi	12.5%	7.88
H_2O	^{208}Tl	8.1%	20.7
H_2O	^{214}Bi	11.4%	5.47

table 8.2

Systematic error when using the neural network and chi square technique to determine the relative ratio of 6 classes of the events

		The percentage change of the results of the network	Change of the number of the neutrons
D_2O	^{208}Tl	13.9%	105.5
D_2O	^{214}Bi	-11%	-8.8
Acrylic	^{208}Tl	2%	5.26
Vessel	^{214}Bi	1.9%	1.2
H_2O	^{208}Tl	4.9%	12.5
H_2O	^{214}Bi	-10%	-4.8

The total number of neutrons produced by the ^{208}Tl and ^{214}Bi decay changed by 11.2%.

The systematic study for the change of the detecting efficiency of the pmts

table 9.1

Systematic error when using the neural network and chi square technique to determine the relative ratio of 6 classes of the events

		The percentage change of the results of the network	Change of the number of the neutrons
D_2O	^{208}Tl	-0.93%	-7.1
D_2O	^{214}Bi	-8.9%	-7.1
Acrylic	^{208}Tl	-3.6%	-9.35
Vessel	^{214}Bi	-6.3%	-3.99
H_2O	^{208}Tl	-2.87%	-7.36
H_2O	^{214}Bi	-5.67%	-2.72

table 9.2

Systematic error when using the neural network and chi square technique to determine the relative ratio of 6 classes of the events

		The percentage change of the results of the network	Change of the number of the neutrons
D_2O	^{208}Tl	1.2%	9.2
D_2O	^{214}Bi	5.27%	4.2
Acrylic	^{208}Tl	-9.75%	-2.6
Vessel	^{214}Bi	-5.54%	-3.5
H_2O	^{208}Tl	16.2%	41.5
H_2O	^{214}Bi	-3.15%	-1.5

The total number of neutrons produced by the ^{208}Tl and ^{214}Bi decay changed by 4.1%.

table 10

The conclusion of the systematic study

Systematical Change	change in the number of the neutrons
Impurity of the testing set	-1.59%
Impurity of the training and calibrating sets	5.7%
Scattering efficiency of the photons	4.76%
Attenuation probability of the photons	-18.9%
Simulation of the acrylic vessel	0.8%
Direction of the pmts	7.84%
Noise of the pmts	11.2%
Detecting efficiency of the pmts	4.1%

The total change in the number of the neutrons is 24.9%.