Tritium Contamination in NCDs

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SNO-STR-99-006

Introduction

Under construction, for the Sudbury Neutrino Observatory, is an array of Neutral Current Detectors (NCDs). These proportional counters contain a mix of 85% ^{3}He and 15% CF_4, allowing for the detection of neutrons via the reaction:

$$^3\text{He} + \text{n} \qquad \text{t} + \text{p} + 764\ \text{keV}$$

Approximately 6×10^3 STP-liters of ^{3}He are required to fill the array. The helium itself was recovered from the decay of tritium and now contains a T/^{3}He ratio of around 8×10^{-7}. The endpoint of tritium is 18.6 keV, well below the 764 keV deposited by neutron capture. However, the pileup of pulses can lead to an unacceptable level of background events near the neutron capture energy. Contamination at the above level is equivalent to 4.4×10^8 tritium decays per second in a 200 cm NCD, or 1.2 mCi/STP-liter. Targeting a 1% probability for an event to occur in a 10 μs integration time, we need to reduce this activity to around 10^3 per second, or 2.7 nCi/STP-liter. [1]

The contaminating tritium is in the form of HTO, as well as some free hydrogen. The ^{3}He gas is passed through a heater getter, which removes much of the free hydrogen and water vapor. This is followed by a pass through a cooled sieve trap to remove any additional water vapor. The gas is re-circulated for three hours using a bellows pump. [2]

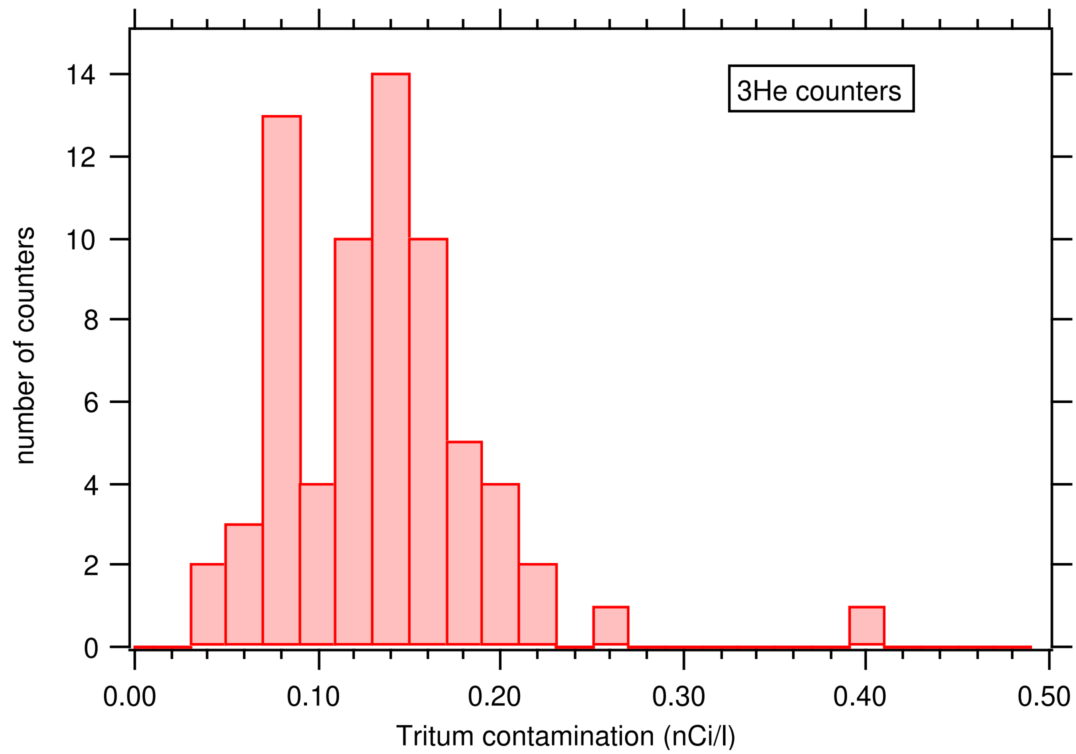
Measurement technique

The above purification scheme has already been established as providing the required tritium levels [1]. However, it is important to verify that the NCDs do indeed meet the specification of less than 2.7 nCi/STP-liter. The tritium level for each detector can be measured by looking at its low energy spectrum. Operating the detector at 2225 V, we pass the signal through a charge integrating preamp, followed by an Oretec 855 variable gain amplifier, and finally into an Ortec ADC. The gain of the 855 is adjusted to study the 2–25 keV energy range. A 10 minute run provides ample statistics and the spectrum is integrated to give an approximate measure of the tritium contamination.

Results

Following are the results for the first 68 ^{3}He counters built.

Counter Name	Tritium (nCi/STP-liter)		Counter Name	Tritium (nCi/STP-liter)
A3-200A-1	0.20		D3-200-2	0.13
A3-200C-2	0.13		D3-200C-3	0.12
A6-200A-1	0.15		D4-250A-1	0.15
A6-200C-2	0.12		D4-200-2	0.40
A7-200A-1	0.06		D4-200C-3	0.12
A7-200C-2	0.06		D5-250A-1	0.18
B1-250A-1	0.07		D5-200-2	0.15
B1-300C-2	0.07		D5-200C-3	0.15
B2-250A-1	0.17		D6-250A-1	0.07
B2-300C-2	0.13		D6-200-2	0.07
B3-250A-1	0.08		D7-250A-1	0.22
B4-250A-1	0.08		D7-200-2	0.07
B4-300C-2	0.25		D7-200C-3	0.06
B5-250A-1	0.07		D8-250A-1	0.13
B5-300C-2	0.07		D8-200-2	0.13
B6-250A-1	0.04		D8-200C-3	0.13
B6-300C-2	0.04		M7-250A-1	0.13
B7-250A-1	0.17		M8-250A-1	0.13
B7-300C-2	0.10		M8-300-2	0.12
B8-250A-1	0.17		N1-200A-1	0.22
B8-300C-2	0.17		N1-300-2	0.12
C1-300A-1	0.13		N1-300-3	0.19
C1-300C-2	0.07		N1-300C-4	0.12
C2-300A-1	0.19		N2-200A-1	0.16
C2-300C-2	0.15		N2-300-2	0.16
C3-300A-1	0.13		N2-300C-4	0.12
C3-300C-2	0.09		N3-200A-1	0.13
C4-300A-1	0.09		N3-300-2	0.15
C4-300C-2	0.09		N3-300-3	0.15
D1-200-2	0.12		N4-200A-1	0.07
D2-250A-1	0.13		N4-300-2	0.11
D2-200-2	0.13		N4-300-3	0.08
D2-200C-3	0.20		N4-300C-4	0.08
D3-250A-1	0.15		S1-200-3	0.11



Errors

Statistical Errors
The statistics are Poisson and so the statistical error goes as √N. For a measurement of 0.1 nCi, in a 200 cm counter, this corresponds to a 2% error. For longer counters or higher contamination, the fractional error is smaller. Thus we see that the statistical error is unimportant in determining whether a given counter has met the specification.

Backgrounds
The most significant background is from cosmic rays as these measurements were done at sea level. Assuming a constant flux of cosmic rays, they must contribute less than an equivalent 0.04 nCi/STP liter to the measurements, as this is the lowest rate obtained for any counter. Knowing that the cosmic ray flux only *adds* to the result, we can be satisfied in knowing that our measurements provide an *upper limit* to the tritium contamination above 2 keV.

Other Systematic Errors
Initially dead time was discovered to be a problem. However, after removing a nearby neutron source and adjusting the pole zero on the 855 amplifiers, the dead time was reduced and was shown to be less than a 1% effect. Also, the integration over energy is not done from zero but rather from some threshold energy. This threshold energy is approximately 2 keV. To find the total tritium contamination, one would need to correct for the missed events from 0-2 keV. These events contribute less than about 10% of the total tritium decays. They also play a less significant role in pileup, contributing little to a summation of pulses.

^{4}He detectors

In addition to building ^{3}He detectors, we are also filling some detectors with ^{4}He, so that we may study alpha backgrounds in the NCD array. The same gas system is used to fill both types of counters and this allows for the ^{4}He counters to also become contaminated with tritium. The tritium, in the form of water vapor, can adhere to the stainless steel walls of the gas system and then be flushed out during a ^{4}He fill. Thus far we have built 8 ^{4}He counters, listed in the table below.

Counter Name	Tritium (nCi/STP-liter)
A1-200A-1	Unreliable data*
A1-200C-2	Unreliable data*
A4-200A-1	0.09
A4-200C-2	0.12
A5-200A-1	0.18
A5-200C-2	0.25
A8-200A-1	0.88
A8-200C-2	0.08
D1-200C-3	0.13**

*These counters were measured and sent to SNO before we understood the dead time issues.
** Temporary ^{4}He fill.

The large variation in results reflects the variation in tritium contamination of the gas system. Contamination, once picked up, is hard to remove as the ^{4}He has only a single pass through a heater getter. Heating the system under vacuum can help reduce the cross contamination of ^{4}He counters. Some counters were given a temporary ^{4}He fill before being given their final ^{3}He. This may explain the relatively large tritium contamination of the ^{3}He counter D4-200-2.

Discussion

We see that the NCDs are typically an order of magnitude cleaner than the specified 2.7 nCi/STP-liter of tritium. As construction of the array continues, we will be measuring the tritium levels of each NCD as it is built.

References

[1] Neutral Current detection in the Sudbury Neutrino Observatory, LANL 1992
[2] UW Gas-Fill Procedures