Targets for the N-16 Calibration Source
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1 Introduction

The Nitrogen-16 source will produce a 6.13 MeV γ-ray following the β-decay of ^{16}N ($t_{1/2}$=7.13 sec). The gamma will be used for energy calibration of the SNO detector and will be tagged by the detection of the accompanying β. The ^{16}N will be produced by either the ^{16}O(n,p)^{16}N reaction or the ^{19}F(n,α)^{16}N reaction with fast neutrons produced with the SNO DT generator. The resulting activity will be transported in a gas stream, via capillary tubing, to a decay chamber placed within the SNO detector. The decay chamber will contain a scintillator for the detection of the tagging βs. For more details see [1].

In earlier tests, ^{16}O gas was used as both target and carrier gas with success. However, because of the safety concerns of high pressure oxygen systems and mine regulations, alternative target materials and carrier gases have been sought. This report summarizes the results of tests with such alternatives.

2 Targets and Transfer Gases

The targets come in three categories, oxygen containing gases, oxygen containing solids, and fluorine containing solids. The oxygen containing gases are CO_2 and Air. The oxygen containing solids are quartz (SiO_2), cotton and viscose ($C_6H_{10}O_5$), and the fluorine containing material is teflon (C_2F_4).

Table 1: Target Fibers

Material	Mass	Effective Mass	Diameter	Mean Range
Quartz A	19.0 g	9.8	4-8 μ	2.0 μ
Quartz B	2.3 g	1.2		
Quartz C	41.3 g	21.2		
Cotton	24.1 g	7.5	18 μ	3.5 μ
Viscose	47.4 g	19.1	9 μ	2.6 μ
Teflon	34.7 g	20.6	12 μ	3.2 μ

Earlier tests with solid targets suggested much lower yields then pure oxygen gas [1]. The explanation is that a large fraction of the ^{16}N recoils could not penetrate out of the solid target. We attempted to improve the yield by filling the decay chamber with thin fibers made from the oxygen or fluorine containing target materials. Table 1 lists the target fibers, their diameters, and shows the mean range of the maximum recoil energy ^{16}N atoms calculated using the program TRIM (Ziegler et. al.). The fiber sample masses are given along with the effective target mass. The effective target mass is the target material mass (O or F) in the fibre that can potentially recoil out of the fiber. A very simplistic model has recoils produced only in the outer shell of the fibres (assumed tubular) with a thickness equal to the maximum range. For quartz, cotton, viscose, and teflon, only 97, 63, 82, and 78 % of the recoils produced can escape out of the fibres, respectively.

If a recoil escapes the fiber, there is also the probability it becomes buried in an adjacent fiber. This probability is a function of the packing density of the fibers and the stopping power and pressure of the carrier gas contained in the target chamber. Table 2 shows the recoil range for the maximum energy ^{16}N recoils produced in the ^{16}O(n,p)^{16}N reaction at 3.6 Atm pressure absolute (TRIM). This operating pressure was used in the experiments that follow to measure relative yields

For the gas targets, the target gas was used as the carrier gas. For the solid targets, He, Air, CO_2, N_2 were used. Mixes such as He and N_2 were also used. The optimal choice of gas depends on its transfer characteristics, its oxygen content, and its stopping power. The ability for the ^{16}N ion produced to be entrained into the gas flow may also be a factor.

Table 2: Ranges for various gases at 3.6 Atm absolute pressure.

Gas	Range μm
O_2	898
He	4810
CO_2	551
N_2	907
Air	916

3 Experimental Setup

Basically our system was a mock up of what will eventually sit inside the SNO detector (see Figure 1). Gas was delivered to the target chamber which surrounds the DT generator target, then to a decay chamber followed by an exhaust. Gas flow and pressures were controlled and monitored using the gas calibration control board and its associated instrument boxes. The DT generator output was monitored with the fast neutron flux meter. The decay chamber was a 5" by 5" cylinder with a NaI detector placed in front of it for detecting the ^{16}N gammas. Two transfer line configurations were used. The first had short transfer lines for comparing yields for various targets. The transfer line between the target chamber and decay chamber for this configuration consisted of roughly 25 feet of thick 1/8 inch ID teflon tubing. The second had long transfer lines to simulate the eventual SNO configuration. Here the transfer line consisted of roughly 150 feet of thick 1/8 inch ID teflon tubing and roughly 100 feet of thin 2.4 mm ID teflon capillary.

4 Results

The results are summarized in Tables 3 and 4 for the short and long transfer configurations, respectively.

The Table 3 results reflect the relative ^{16}N production yields in the target chamber. The target chamber pressure was kept constant at roughly 3.6 Atm absolute for all the runs as was the decay chamber pressure and the flow (200 cc per sec). If no solid target is used, the yield scales with the oxygen content of the gas. If solid targets are used, the yield generally increases

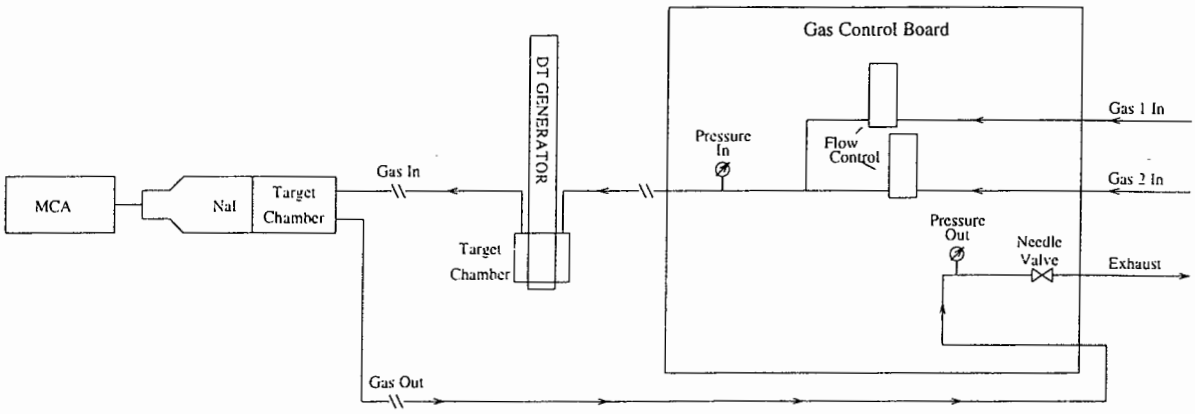

Figure 1: Experimental set-up for ^{16}N tests

with increased oxygen content in the gas as well. However, the total yield is generally less than that with a pure oxygen carrier and an empty chamber. The reasons are that less oxygen gas is permitted in the chamber when fibres are present, and that the yield from the fibres is smaller than that of the gas in the same volume. It may also be that many of the recoils bury themselves into the adjacent fibres. This suggests that the pure oxygen target gives the maximum yield, at least when compared to the solid targets used. The results with N_2 indicate that the greater the solid target mass, the greater the yield. The relative results for N_2 and He indicate that the greater the stopping power of the gas the greater the yield. The lower yield for Teflon with N_2 is likely due to the lower cross section for the $^{19}F(n,\alpha)^{16}N$ reaction. It should be noted that our supply of teflon fiber was limited and that much more material could have been stuffed into the chamber.

There are a few inconsistent results that deserve at least some interpretation. The viscose result has a higher yield for air than for CO_2. A likely explanation is that the fibre contains a lot of trapped water and that the flow of dry gas though the fibre gradually decreases the water content. The

Table 3: Resulting 6 MeV count rate per second for the short transfer line set-up.

Targets	He	He + N_2	N_2	Air	CO_2	O_2
None	-	-	0.5	-	16.8	26.4
QuartzB(1.2 g)	1.3	1.5	2.1	7.7	17.1	26.8
Cotton(7.5 g)	1.1	2.3	7.2	-	11.4	7.8
QuartzA(9.8 g)	2.3	2.8	8.4	12.8	16.3	21.8
Viscose(19.1 g)	3.8	3.9	10.7	13.4	12.8	18.3
QuartzC(21.2 g)	1.9	-	10.6	14.6	20.9	19.8
Teflon(20.6 g)	2.6	2.5	4.1	9.6	17.1	24.7

oxygen atoms in the water increases the target mass. Air flow yield was tested prior to the CO_2 yield, so more water was present. Yield with He was tested at the beginning and end of the gas sequence giving a more than 50 % difference in yield. The result for He presented in Table 3 is the end of sequence yield. Also of interest is the greater yield for CO_2 versus O_2 for cotton and the largest quartz target mass. In these instances the optimal yield appears to be influenced by the stopping power of the gas.

The Table 4 results give the product of the production yield times the transfer efficiency for various gases. Only the empty and viscose filled chamber configurations were tested; all others should scale with the relative production rates given in Table 3. The results indicate that the maximal yield for a transfer gas, other than with pure oxygen, is with CO_2. The lower pressures with CO_2 are due simply to limitations of the regulator used on the gas supply. If the target chamber pressures were equal for both O_2 and CO_2 the results would have scaled according to the oxygen content of the gas.

5 Conclusions

In choosing the optimal alternative to pure oxygen gas as carrier and target one must consider the oxygen content of the gas, the stopping power of the gas, and the solid target mass. In many instances an increase in yield due to one factor is at the expense of an another. In all cases, however, CO_2 is the best alternative carrier gas. This because of its stopping power and oxygen

Table 4: Resulting 6 MeV count rate per second for the long transfer line set-up. The flow rate is in cm^3 per second.

Target	Gas	Pin	Pout	Flow	Rate (Hz)
Viscose	O_2	83.5	18.8	200	4.2
	Air	79.7	18.9	200	2.8
	N_2	79.2	18.9	200	2.3
	He	54.1	18.6	200	0.9
	He	68.7	18.8	300	1.0
	He	82.3	18.7	400	1.1
	CO_2	66.4	18.6	266	2.9
Empty	CO_2	64.1	18.7	256	3.7
	Air	79.9	18.8	200	1.8
	O_2	83.5	18.5	200	6.8

content. Its transfer characteristics are also good. In most instances, an empty chamber gives a respectful result with CO_2. However, densely packed quartz wool gives a 24 % increase in yield, and a larger teflon sample may have given a higher yield as well.

For the commissioning of the DT generator and gas system, pure CO_2 with no solid target will be used. This should give at least 50 % of the yield given with pure oxygen. The introduction of quartz wool or teflon into the target chamber will not require any modification to the system, but will be postponed until commissioning underground is complete and more in-depth tests and analysis are done.

References

[1] B.Sur, E. D. Earle, R. Deal and E. Gaudette, ^{16}N: A Calibration Source for SNO, SNO-STR-93-041