SNO-STR-94-037

^{17}N: A Tagged Neutron Source for SNO

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Abstract

We have investigated the feasibility of using the beta-delayed neutron emitter ^{17}N to measure the neutron detection efficiency of SNO. The neutrons would be "tagged" in SNO by Cerenkov or scintillation light produced by the beta particle which would precede by several milliseconds the Cerenkov light produced as a result of the neutron capture. We find that using the proposed SNO D-T generator, the ^{17}O(n,p) reaction on enriched ^{17}O gas will provide up to 10 ^{17}N decays per second within the SNO D_2O volume. This offers a relatively simple and clean way to determine the neutron detection efficiency of SNO.

A system to produce and deliver short-lived radioisotopes for calibrating the SNO detector has been developed at Chalk River Laboratories.[1] Using 14-MeV neutrons from a small D-T generator and a gas transport scheme, calibration sources such as ^{16}N ($E_\gamma = 6.13$ MeV) and ^{8}Li ($Q_\beta = 13$ MeV) can be produced via (n,p) and (n,α) reactions, respectively, and delivered into the SNO detector. Knowing the neutron detection efficiency of SNO is crucial to the success of the neutral-current aspect of the experiment. Thus, it seemed worthwhile to investigate the possibility of using this same gas-transport system to measure this important quantity.

As can be seen in Figure 1, the short-lived isotope ^{17}N ($t_{1/2} = 4.17$ s) is a β-delayed neutron emitter.[2] More than 95% of the beta decays of ^{17}N populate levels in ^{17}O that are unbound with respect to neutron decay. This leads to the emission of monoenergetic neutrons with energies (and intensities) of 0.383 MeV (34.8%), 0.884 MeV (0.6%), 1.171 MeV (52.7%), and 1.170 MeV (7.0%). A single ^{17}N decay inside the D_2O volume of SNO could thus produce two signals: a prompt signal associated with the beta emission, followed some milliseconds later by the capture of the moderated neutron. One can imagine either letting the beta go into the D_2O to produce Cerenkov light, or stopping the beta in the walls of a decay chamber made out of scintillator. In either case, one would have a "tagged" source of neutrons for determining the neutron detection efficiency of SNO.

In order to determine if sufficient quantities of ^{17}N could be produced via the ^{17}O(n,p) reaction using 14-MeV neutrons, a test was carried out at the D-T generator in the Health Physics Department at AECL Research, Chalk River. 14-MeV neutrons from this generator were used to irradiate known mixtures of ^{16}O and ^{17}O gases. A closed gas loop continuously flowed the gas from a target cell to a decay chamber. A 1" thick plastic scintillator paddle and a 40% efficient Ge detector were placed up against the decay chamber to measure the betas and gammas emitted in the decays of ^{16}N and ^{17}N. As can be seen in the gamma-ray spectra shown in Figure 2, with the gas loop filled with natural isotopic composition oxygen, the only gamma-rays observed above room background were those from the decay of ^{16}N. However, when we used a mixture of 39.5% ^{16}O + 55.9% ^{17}O, + 4.6% ^{18}O, we also observed the 871-keV gamma ray characteristic of ^{17}N decay. By measuring the relative yields of the 871- and 6129-keV gamma-rays we determined the ^{17}O(n,p) cross section to be 28±5 mb (Ref. 3).

During our run, the Chalk River D-T generator emitted approximately 2.6×10^9 neutrons per second into 4π. This produced an observed ^{17}N decay rate in our decay chamber of approximately 300/second. Taking 10^8 neutrons/second into 4π as being within the reach of the planned SNO D-T generator, allowing (pessimistically) for a 50% loss of the ^{17}N due to decay in the transport capillary at SNO, and assuming that we would use 100% enriched ^{17}O gas, then we could confidently produce up to 10 ^{17}N decays/second inside the SNO D_2O volume. Thus, ^{17}N offers a relatively simple and clean way to measure the neutron detection efficiency of SNO.

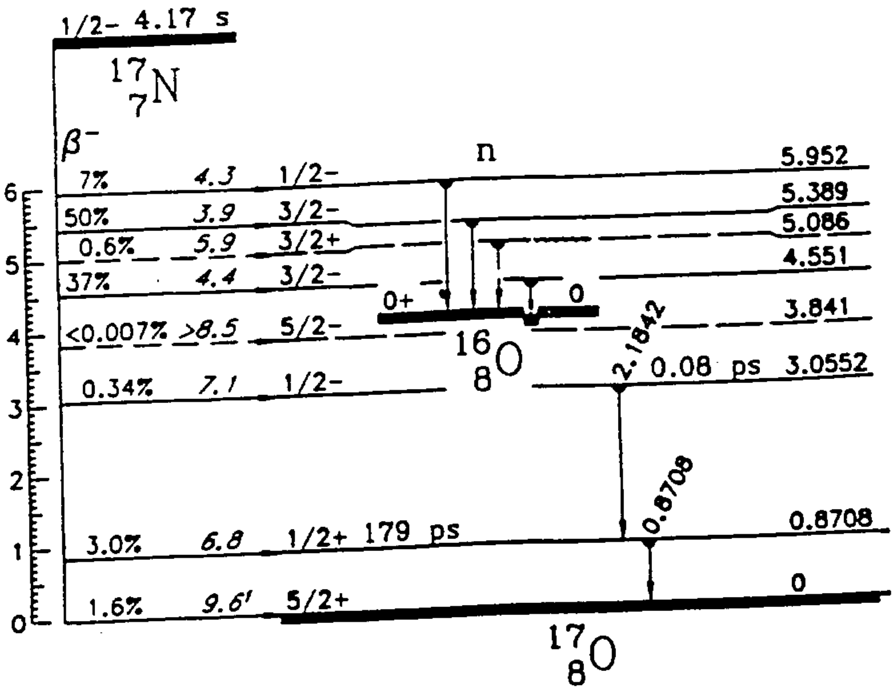
References

1. B. Sur *et al.*, BAPS 39, 1389 (1994).
2. C. M. Lederer and V. S. Shirley, Table of Isotopes, 7th ed. (J. Wiley & Sons, NY, 1978).
3. E. B. Norman and B. Sur, BAPS 39, 1423 (1994).

Figure Captions

1. Decay scheme of ^{17}N.

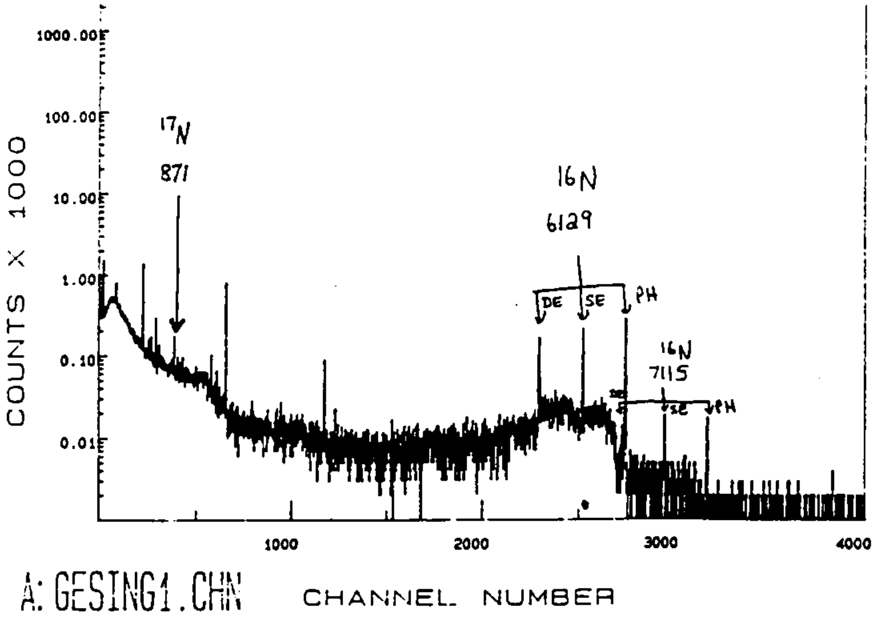
2. Gamma ray spectra observed from 14-MeV neutron irradiations of enriched $^{17}O_2$ and natural O_2 gas. a) full spectrum observed from the enriched $^{17}O_2$, b) expanded region of the spectrum observed from the enriched $^{17}O_2$ illustrating the 871-keV line from ^{17}N decay, c) the same expanded energy region from the natural O_2 gas illustrating the absence of the 871-keV line.



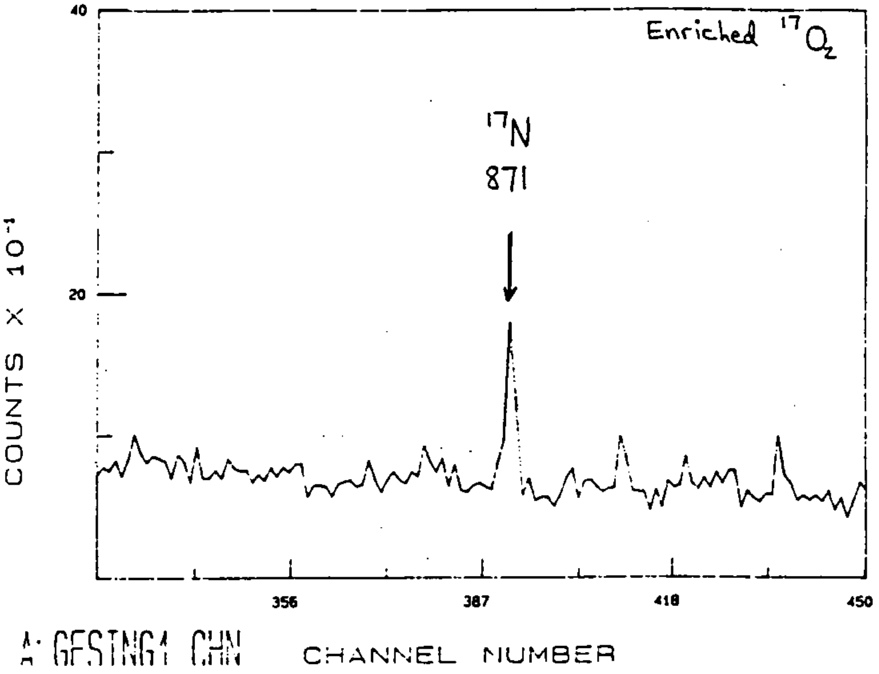
Δ: 7.870 *15* {ANDT 19 175(77)}
ψ: β^-, β^-n 95.1 *7*% {PR C13 835(76)}
$t_{1/2}$: 4.174 *4*s {NP A274 45(76)}; 4.169 *8*s {PR C6 2019(72)}; **others:** {NP A259 493(76), NSEg 40 136(70), PR 139 B1513(65), PRL 6 113(61), PR 82 511(51), PR 74 1217(a)(48)}
Class: A; **Ident:** chem, cross bomb {PR 75 1127(49), PR 74 1217(a)(48), PR 74 1217(b)(48)}
Prod: ^{15}N(t,p) {PR 134 B16(64), PR C6 2019(72)}; ^{14}C(α,p) {PR 82 511(51)}; ^{17}O(n,p) {PR 76 1255(49)}; ^{10}Be(^{11}B,α) {NP A259 493(76)}
β^-: 3.7 *2* (coinc ^{16}O recoils from delayed neutron emission) *abs* {PR 75 1127(49)}
others: {PR 134 B16(64)}
n: 0.3828 *9* (34.8 *25*%), 0.884 *21* (0.6 *4*%), 1.1709 *8* (52.7 *33*%), 1.7003 *17* (7.0 *5*%) *^{3}He(n,p) ion ch* {NP A274 45(76)}
0.385 *4* (37.9 *16*%), 1.163 *14* (51.1 *15*%), 1.675 *24* (5.8 *6*%) *time of fl, ^{3}He(n,p) ion ch* {PR C8 1285(73)}
0.39 (39.2 *20*%), 1.16 (48.0 *15*%), 1.69 (7.9 *7*%) *^{3}He(n,p) ion ch* {PR C13 835(76)}
0.390 *16* (27 *5*%), 1.19 *3* (57 *4*%), 1.71 *4* (11 *2*%) *^{3}He(n,p) ion ch* {NP A209 424(73)}
others: {PR 134 B16(64), BAPS 8 320(63), PR 122 899(61), PR 75 1127(49), PR 75 917(49)}
γ with β^-: (norm: $\gamma_{0.871}$ (γ 3.05%)) $\gamma_{0.871}$ (†,960 *40*), 2.1842 *2* (†,100), no $\gamma_{3.055}$ (†,<1.5), no $\gamma_{3.841}$ (γ <0.007%) *Ge(Li)* {PR C13 835(76)}
$\gamma_{0.871}$ (†,636 *20*), $\gamma_{2.184}$ (†,100) *scint* {PR C8 1285(73)}
$\gamma_{0.871}$ (†,680 *90*), $\gamma_{2.184}$ (†,100) *scint, scint-scint γβ coinc* {PR 134 B16(64)}

$Q_\beta(^{17}N) = 8.680$ MeV

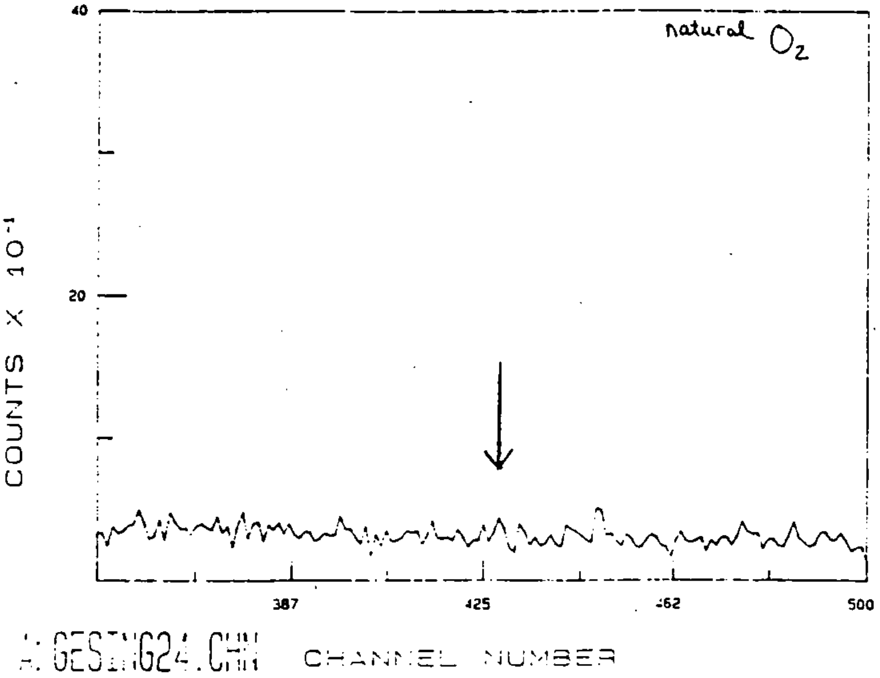
(a)


1000.00
100.00
10.00
1.00
0.10
0.01
COUNTS X 1000
17N
871
16N
6129
DE
SE
PH
16N
7115
SE
PH
1000
2000
3000
4000
A: GESING1.CHN
CHANNEL NUMBER

(b)


40
20
COUNTS X 10-1
Enriched 17O2
17N
871
356
387
418
450
A: GESING1.CHN
CHANNEL NUMBER

(c)


40
20
COUNTS X 10-1
natural O2
387
425
462
500
A: GESING24.CHN
CHANNEL NUMBER