New Monte Carlo Calculations for Neutron Detection in SNO

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July 7, 1992

SNO-STR-92-058

Our neutron transport code(1,2) has been modified to investigate previously unstudied aspects of neutron detection using ^{3}He proportional counters:

1) Effect of finite sized detectors separated by a fixed distance between each element.

2) The two neutron producing reaction

$$\bar{\nu}_e + d \rightarrow n + n + e^+$$

1. Finite Sized Detectors.

Our previous calculation have assumed that the ^{3}He counters extended vertically from the inner surface of the sphere in a continuous rod which touched the top and bottom of the vessel walls. This is clearly not feasible and the counters will have to be made in discrete sizes and coupled together. Therefore, the code has been modified to use discrete counters which come in 1 and 2 meter lengths and are separated from each other vertically by a fixed distance (SD). In all calculations the counters are assumed to have the following properties:

1) Counter body made of 10 mil Ni from the thermal decomposition of nickel carbonyl.

2) An active gas mixture consisting of 3 atm ^{3}He, 0.6 atm Xe and 0.2 atm of CH_4

3) A square lattice spacing of tubes (of dimension L cm) which does not have a tube at the center of the vessel (i.e. the position x,y =0,0 is vacant, the first array element is at $|x,y| = (L/2,L/2)$).

Other detector parameters were varied to study neutron capture response:

1) The spacing between detector elements ($0 \le SD \le 150$ cm).

2) The square lattice spacing ($100 \le L \le 250$ cm)

3) The diameter of the tube ($2 \leq D \leq 10$ in)

4) The D_2O purity ($100\% \leq D_2O \leq 90.40\%$)

Not all of this parameter combinations were investigated. The default choices are listed below and unless otherwise stipulated were the values used in a calculation:

SD = 5 cm

L= 100 cm

D= 2 in

$D_2O = 99.92\%$

The capture efficiency is very sensitive on the purity of the D_2O. At the Kingston collaboration meeting it was stated that the Bruce heavy water would be 99.92% (this is an improvement from the White Book value of 99.85%). Figure 1 presents the ^3He capture

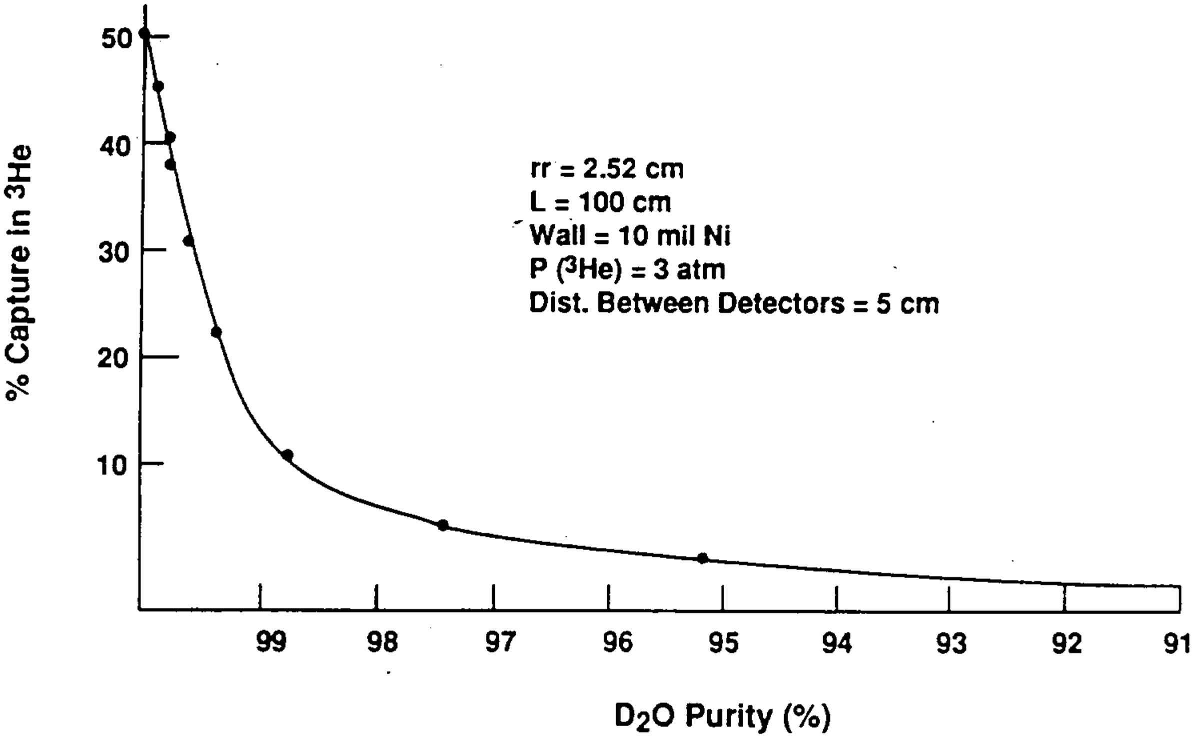

Fig. 1. Neutron Capture Efficiency vs. D_2O Purity (with respect to H_2O).

probability as a function of D_2O purity. Going from 99.85% to 99.92% raises the ^{3}He capture efficiency from 40% to 45%.

The detector array is assumed to be made up of 1 meter and 2 meter long segments. For each lattice position the available vertical distance was filled with as many 2 meter long segments as possible (having a distance SD between each segment). If there were sufficient space remaining a 1 meter long segment was added. After all segments were included the remaining distance was divided by 2 and allocated to the top and bottom of the vertical string. The effect of varying SD is presented in Figure 2. As can be seen, for small values of SD, this is a fairly insensitive function. We feel a realistic value for the dead area required to couple the detector segments will be on the order of 5 cm.

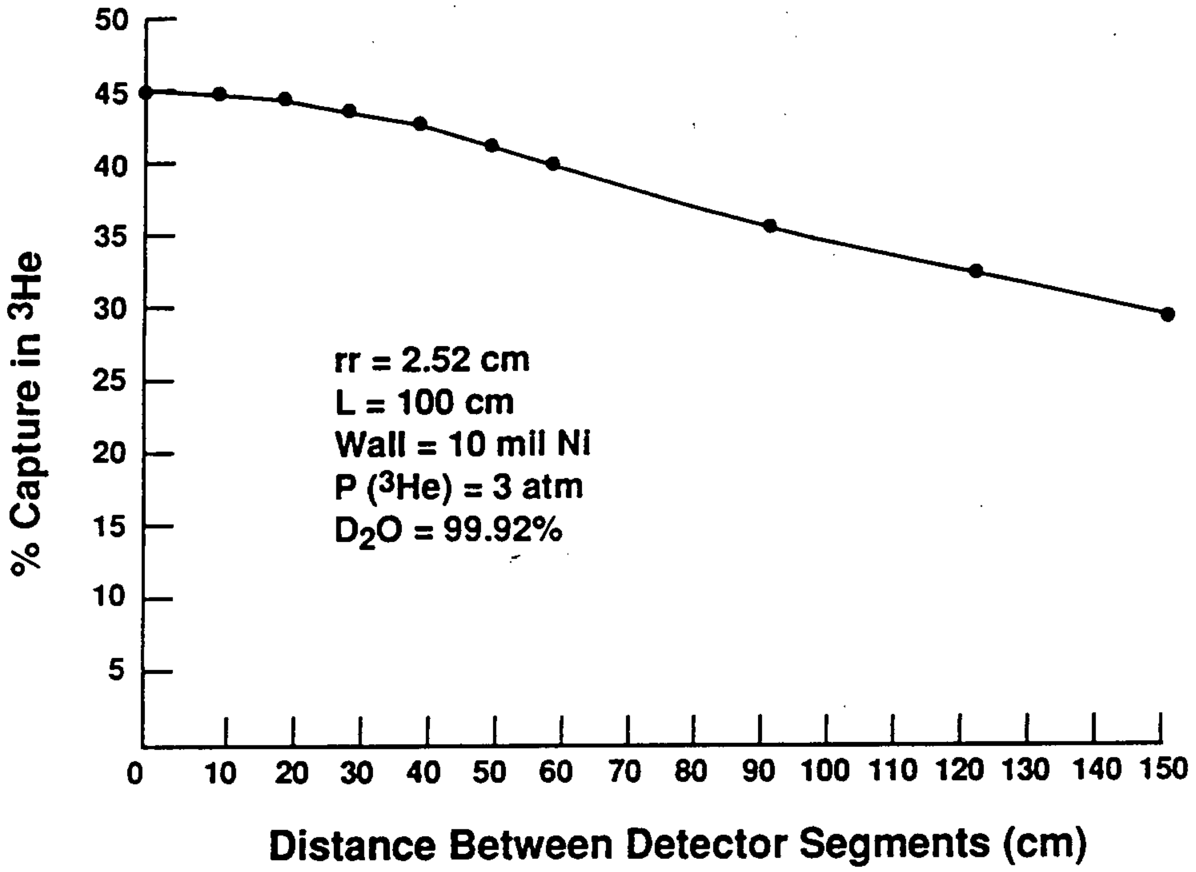

Fig. 2. Neutron Capture Efficiency vs. Separation
Distance Between Individual Detector Segments

The other aspect of tube deployment that was considered was the effect of increasing the array constant and also increasing the diameter of the tubes to (somewhat) compensate for the decrease in efficiency. The default spacing (L= 100 cm, 2 inch diameter tubes, and SD = 5 cm) requires 112 strings containing in total: 380 2 meter segments and 64 1 meter segments) This configuration uses 174 standard cubic feet (scf) of ^{3}He and has a neutron detection efficiency of 45.3 ± 0.7%. The efficiency for the larger spacing arrays is presented in Figure 3. Though a larger array could certainly decrease the number of required tubes it would be at a substantial decrease in detection efficiency and a corresponding increase in ^{3}He usage.

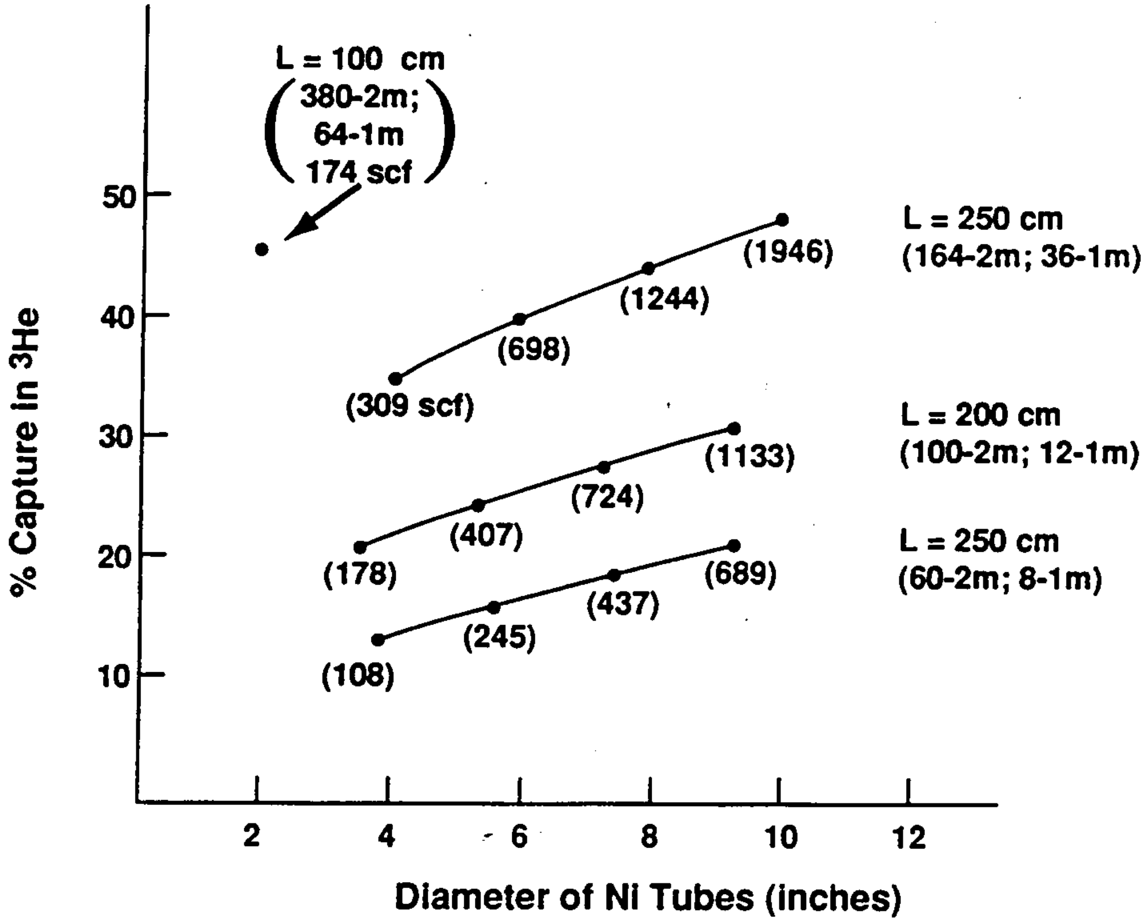

Fig. 3. Neutron Capture Efficiency vs. Diameter of ^{3}He Containing Ni Tubes. The ^{3}He pressure is 3 atm. The number of 2 meter and 1 meter detector segments used is listed for each lattice spacing. The number in parenthesis below the lines is the number of standard cubic feet of ^{3}He required for all of the tubes.

2. Two Neutron Producing Reactions.

Though the solar spectrum should provide only neutrinos, a supernovae event could provide a significant flux of anti-neutrinos. With our heavy water detector the dominate anti-neutrino reaction should be:

$$\bar{\nu}_e + d \rightarrow n + n + e^+$$

This reaction will be characterized by detecting Čerenkov radiation from the relativistic positron in coincidence with neutron capture. For our default configuration (see above) the one and two neutron detection efficiencies are presented in Table I for three D_2O purity levels.

Table I
Neutron Capture Efficiencies

D_2O (%)	1 Neutron Eff (%)	2 Neutron Eff (%)
100.00	99.7	28.4
99.92	90.7	23.2
99.85	78.7	17.4

The probability of having at least a single neutron capture following an anti-neutrino interaction is quite high (again high purity D_2O does make a large difference). If both neutrons can be captured and a coincidence observed with the Čerenkov radiation from the positron, then the signal will be very distinctive. It does, however, take a finite time for the thermalization, diffusion and capture of the neutrons. Table II summarizes the mean and sigma (square root of the variance) for; the separation distance between the capture positions of the two neutrons, the time difference between the two captures, and the average absolute time (the time from the $\bar{\nu}_e$ + d reaction) for capture of the two neutrons. These calculations are for the default detector configuration (see above).

Table II
Two n Capture Parameters

Parameter	Mean	Sigma
Δ Capture Dist. (m)	1.59	0.94
Δ Capture Time (ms)	24.1	25.8
Avg. Cap. Time (ms)	37.0	28.3

The general conclusion is that the ^{3}He detectors will be quite viable for detecting supernovae events. The diffusion in space and time could lead to some reconstruction problems if a large number of events occurred simultaneously. Even in this case, we should be able to use the positron track information to obtain precise time of arrival information.

References:

1.) J.B. Wilhelmy and M.M. Fowler, STR 90-92 (1990).

2.) J.B. Wilhelmy and M.M. Fowler, STR 91-035 (1991).

LA-UR-92-2447

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