Draft

SNO-STR-96-029

First Run of the SNO ^{8}Li Calibration System

A. Hamer, G. Jonkmans, B. Sur, N. Tagg, R. Deal

July 9, 1996

1 Introduction

SNO will be sensitive mainly to solar neutrinos with an end-point energy of 14 MeV from the decay of ^{8}B to the broad first excited state in ^{8}Be. The neutrino energy spectrum will be determined by detecting electrons produced in the Charged Current reaction. β^- particles from the decay of ^{8}Li will be used to calibrate the response of SNO to such high energy electrons [1]. ^{8}Li is the mirror decay of ^{8}B, decaying to the same excited state in ^{8}Be with an end point energy of 13 MeV, and may be potentially used to construct the shape of the undistorted ^{8}B spectrum. The ^{8}Li calibrations should therefore aid in understanding the systematics of extracting the ^{8}B neutrino spectrum.

An ^{8}Li calibration system using the SNO DT generator has recently been assembled and tested at Chalk River Laboratories. It's the first time a complete system has been tested. The ^{8}Li is produced by the ^{11}B(n,α) reaction with 14 MeV neutrons from the deutereum tritium (DT) neutron generator. The ^{8}Li is captured by aerosol particles in a He gas stream and transported from the target chamber to a wire chamber via capillary tubing. The wire chamber is used to tag ^{8}Li decays by detecting the 2-α decay of its daughter ^{8}Be* nucleus. The decay position within the chamber is determined by either one-ended or two-ended charge division techniques.

In these sets of experiments, ^{8}Li production, transport, and tagging were investigated. System operating parameters, such as gas flow rates and pressures, were varied and optimal values found for maximal ^{8}Li yield in the decay

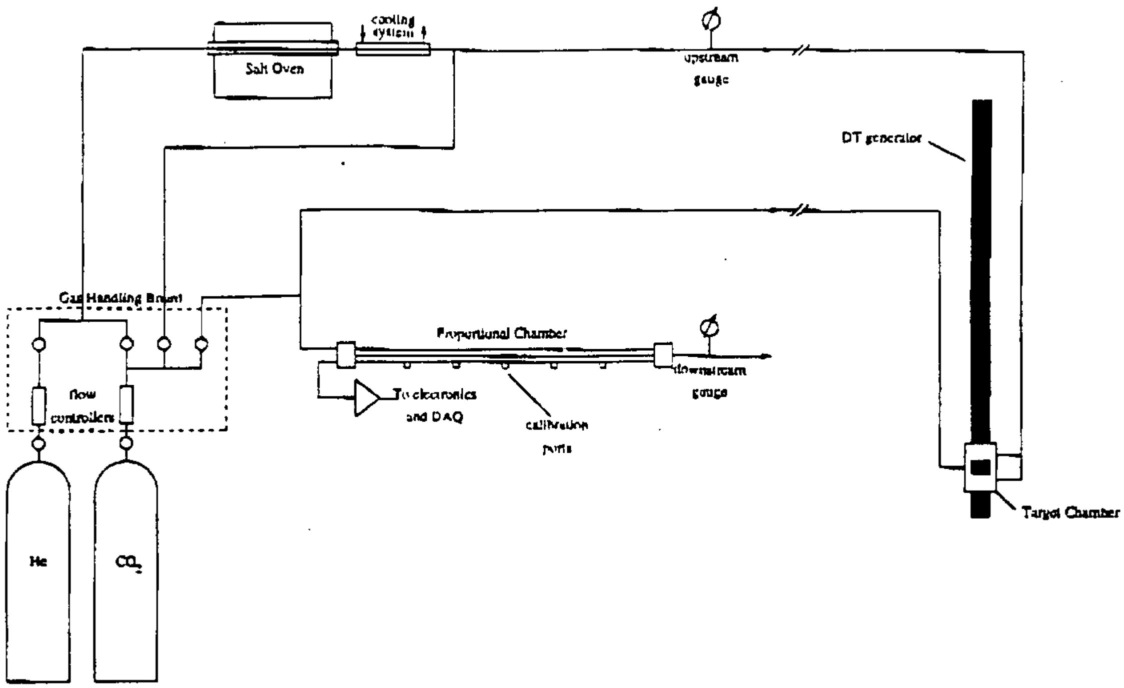

Figure 1: The experimental set up.

chamber. This was done for varying types of capillaries and varying capillary lengths (up to 200 feet). Decay position identification was investigated for both charge division techniques. Longer runs, under optimal operating conditions were performed as well to demonstrate ^{8}Li decay characteristics along the length of the decay chamber.

2 Experimental Setup

2.1 The DT generator and target chamber.

The DT generator (MF Physics A320L) is a sealed tube pulsed neutron generator with a mixed DT beam and mixed DT target. The pulsed source operates at a fixed 10 % duty factor with a variable pulse rate (200 Hz to 1 kHz). The neutron output is isotropic and variable from 0.7 to 1.1x10^8ns^{-1} when high voltage is applied to the target. The neutron output has been verified by two means. For the first, a moderated BF_3 "long counter" was placed 1 m from the DT target. The counter had previously been verified to have a flat response for thermal to ≈20 MeV neutrons. For the second method, an ≈2 g natural Fe foil placed at 10 cm from the neutron source was activated for 1000 sec and the 846 keV ^{56}Mn (2.5 hrs half-life) counted for 4 hours with a Ge detector. The resulting calculated rates were 1.14x10^8 and 1.22x10^{8}ns^{-1}, respectively. For the ^{8}Li runs, the neutron output was not monitored and assumed to be constant at 1.1x10^{8}ns^{-1}. In the final system there will be a 2" by 2" plastic scintillator mounted ≈0.5 m from the source as a fast n flux monitor.

The target chamber shown in Figure 2 is annular (1.8" ID, 4" OD) and placed around the DT generator tube near the DT target. It's mounted on a computer controlled linear table run with a stepper motor. It's position relative to the neutron source can therefore be adjusted for an optimal yield. B target foils are glued to eight flat faces surrounding the inner radius of the chamber annulus. The target foils are made of a mixture of 90 % enriched ^{11}B powder in a 10 % polyethylene matrix. The maximum recoil energy of the ^{8}Li atoms is 5.4 MeV and the maximum range in the target, 2.27 mg cm^2. The outer diameter of the chamber is set by the maximum range of the ^{8}Li ions in 2 atm of He. The chamber was designed to get the short-lived ($\tau_{1/2}$=0.838 sec) ^{8}Li produced at the source latitude out into the transfer capillary as quickly as possible. Gas enters the chamber via distributor plates on either end of the chamber and exits via equatorial holes. The size of the outlet holes are calculated to give equal flow along the circumference of the chamber to the transfer capillary.

2.2 The gas transport system

The primary purpose of the gas transport system (Figure 1) is to transfer ^{8}Li from the target chamber to the decay chamber, and supply a counting (He) and quench gas (CO_2) to the decay chamber. Transfer is achieved by capturing the ^{8}Li recoil atoms on a salt aerosol in a He gas stream flowing through flexible capillary tube. The He first flows though a quartz oven tube containing NaCl, thus picking up the aerosol particles. The line following the oven is water cooled. The He then flows through the target chamber, followed by the decay chamber and an exhaust line. The quench gas can be injected downstream or upstream of the aerosol oven, or directly into the decay chamber. Both the He and CO_2 flow can be varied using MKS gas flow controllers and the pressure upstream of the of the target chamber and

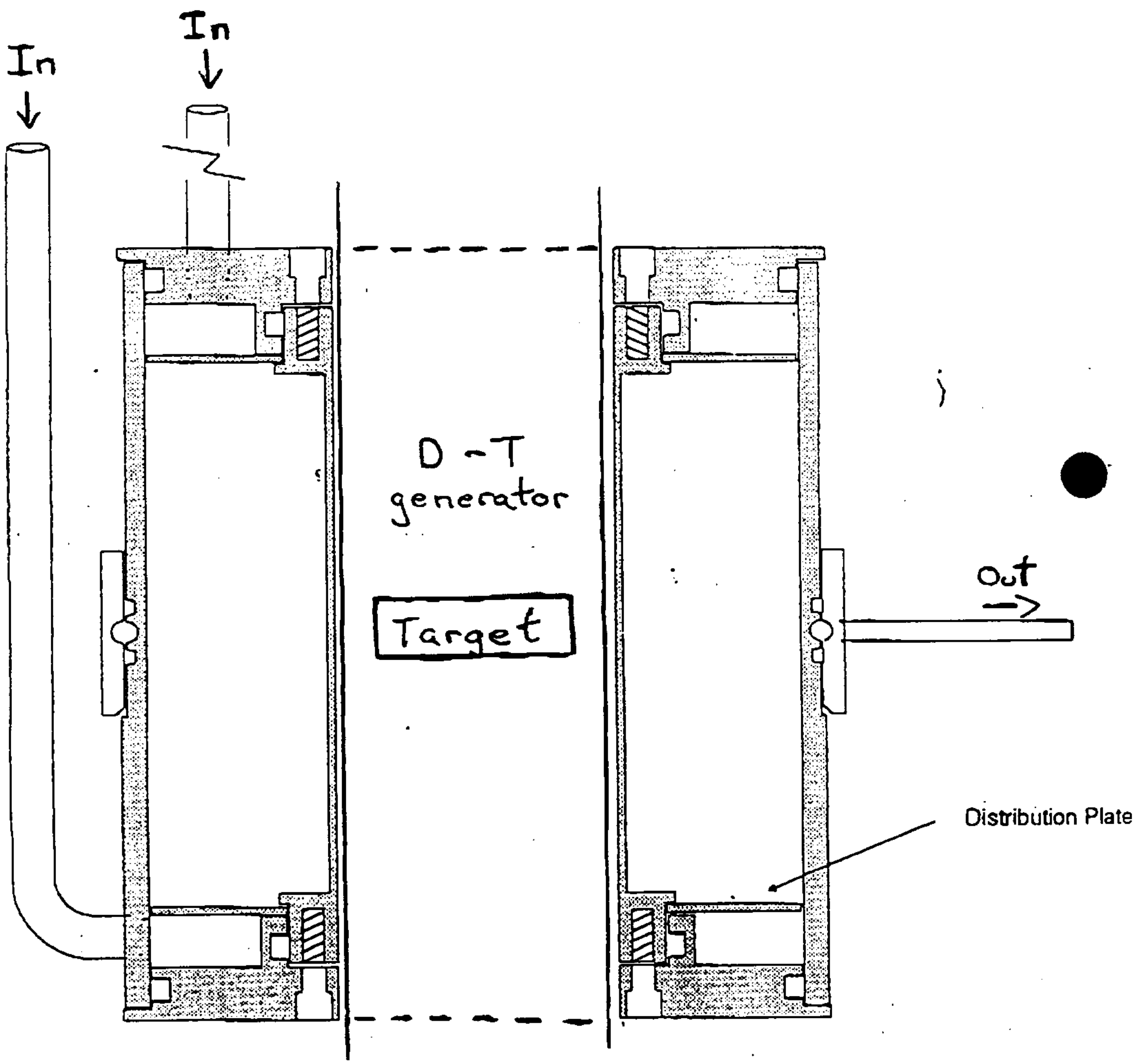

Figure 2: The target chamber.

downstream of the decay chamber monitored with Bourdon gauges.

2.3 The prototype tagged decay chamber

The decay or wire chamber is shown in Figure 3. The length of the sensitive region within the chamber is 1 meter and the inner diameter is ≈1 inch. The wire used is made of 25μm diameter stainless steel. The chamber has gas tight O-ring sealed end caps for high voltage connectors and gas capillary lines. The gas from the capillary is injected directly into the sensitive region through a hole in the G-10 plate used to support the central wire. The chamber also has 5 ports placed at 5.0, 27.5, 50.0, 72.5, and 95.0 cm for a ^{241}Am calibration source producing 5.5 MeV alphas. And 20 equally spaced ports for a ^{55}Fe source producing 5.9 KeV gammas.

2.4 The electronics setup

The position of an alpha decay in the chamber can be determined by two techniques. The first is one-ended charge division which has a pre-amp at one end of the wire chamber and a grounding capicitor (2000 pF) at the other [2]. In this configuration, with the appropriate capacitor, the output signal pulse is observed to have two components with different rise times. The fast component is proportional to x/L with x the distance between the event and the capacitor, and L the total length of the chamber. The slow component, however, is proportional to the total charge collected and is independent of event position. By sending the pre-amp signal to two linear amplifiers with fast and slow time constants respectively, the event position can be determined by taking the ratio of the resultant output pulse heights. Figure 4 shows our electronics configuration for this technique. The third amplifier was used for the trigger to maximize the threshold sensitivity. The other technique is two-ended charge division where both ends of the wire are connected to pre-amps. The ratio of charge collected by any one of the preamplifiers to the total collected by both is a function of position. The electronics configuration for this technique is shown in Figure 5.

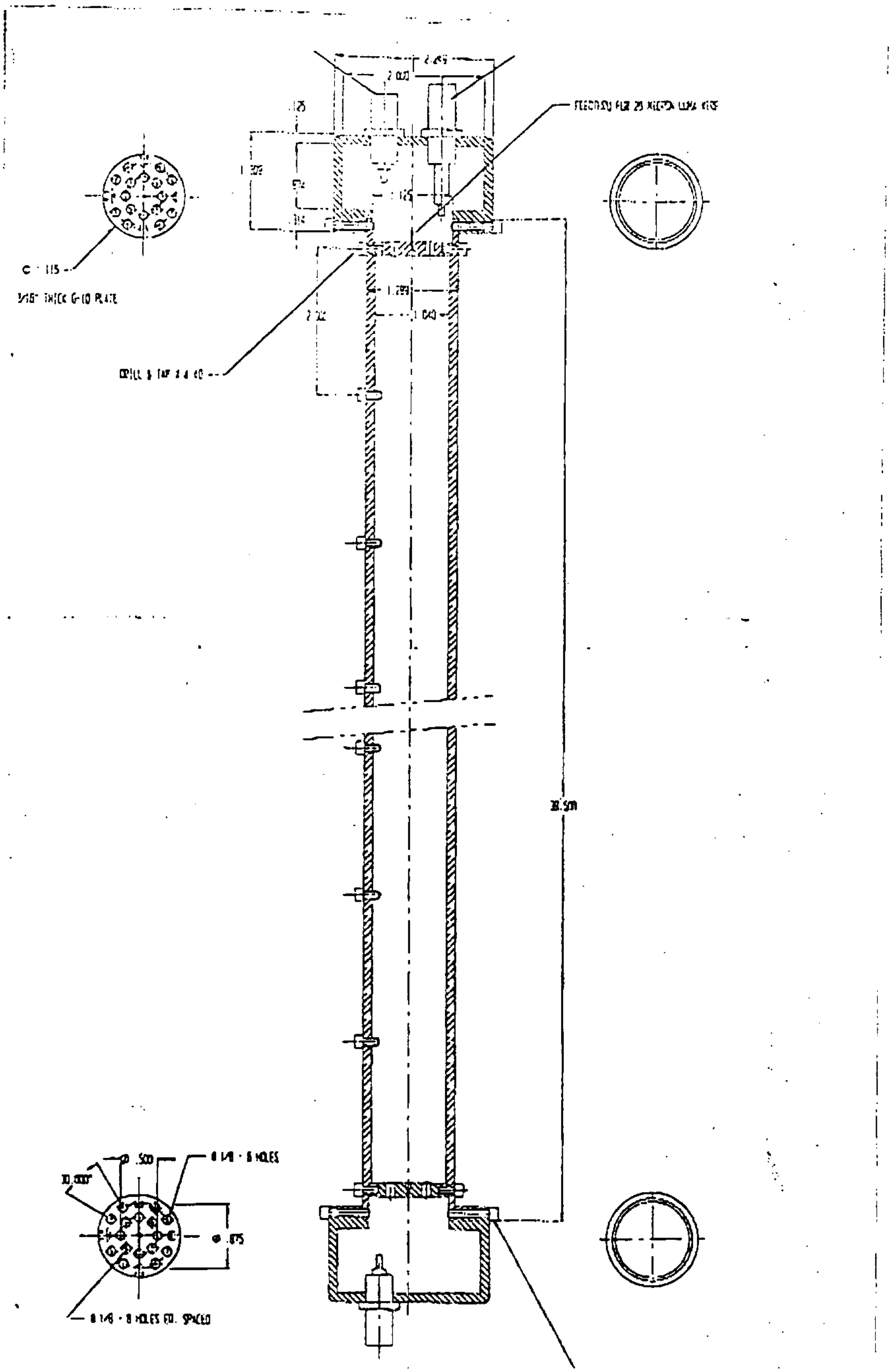

Figure 3: The decay chamber.

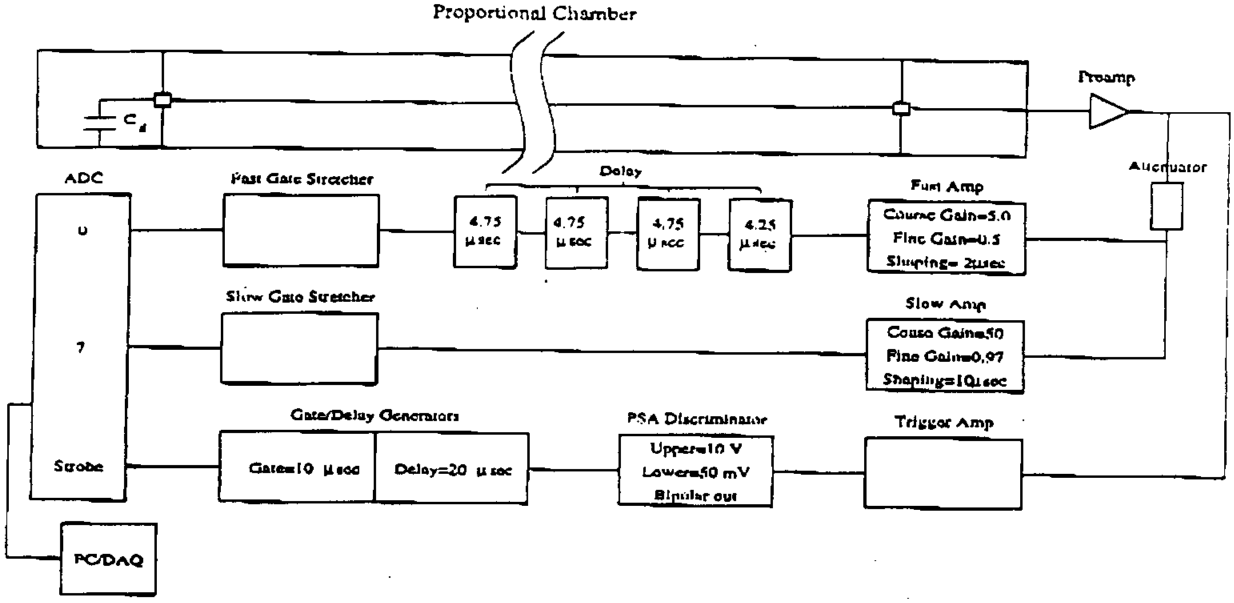

Figure 4: Electronics set-up for one-ended charge division.

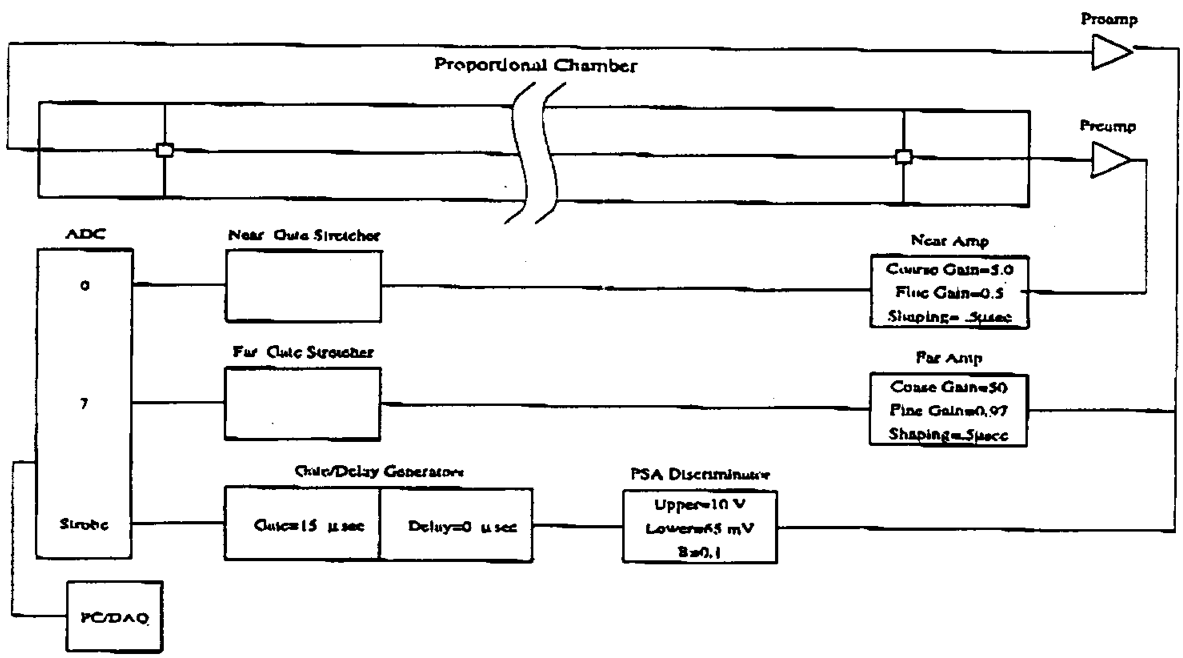

Figure 5: Electronics set-up for two-ended charge division.

3 Experiment

The experiments were performed in the following manner. First the desired capillary was connected between the target and decay chambers. Gas flow through the chamber was then initiated and adjusted for a 5 % mix of CO_2in He. Using the ^{241}Am source the electronics were set up, i.e. the high voltage, amplifier gains, thesholds, timing, etc. were adjusted. Both electronics configurations were used. With the gas mixture flowing, the salt oven was slowly ramped up to 600 C and the cooling system turned on. The ^{241}Am source was used for position calibration. Some background runs were done. The DT generator was then turned on and short optimization runs performed. Target chamber position, gas flow rates, CO_2 injection points, oven temperature, system pressure, etc. were varied. Longer runs were then done under the optimal conditions.

4 Results

4.1 ^{8}Li Detection with two-end charge division

The results of two-ended charge division are illustrated in Figure 6. Position identification was tested with an ^{241}Am source placed at the five calibration port positions. The position identification is approximately linear except for near the exhaust end of the chamber. The non-linearity in the response is small and likely occurs because of saturation of one of the amps as the source gets closer to the edge of the chamber. The resolution would be affected in the same manner but is also believed to be due to the distortion of the field lines at the edge of the chamber. The resolution (FWHM) for the five calibration positions is given in Table 1. Resolution is adequate (less than $\approx$5 cm) for the linear regions but is considerably worse at one end. The ^{8}Li charge collection data for the near pre-amp is shown in Figure 6. There was considerable overflow (cut out in the figure) for both pre-amps. The ^{8}Li charge division data shows an exponential decrease in event rate as one goes from the gas input end of the chamber to the exhaust end. This data was fit for data within $\approx$5 to 10 cm from the ends. From the decay constant and the calibration data one gets the half distance ($x_{1/2}$) for ^{8}Li decay. Using only the linear regions of the calibration data for conversion of the ^{8}Li data

Table 1: Position resolution(FWHM) for both one-ended and two-ended electronics configurations.

Port	One-ended	Two-ended
1	7.1 cm	10.5 cm
2	8.4 cm	5.4 cm
3	8.7 cm	3.1 cm
4	9.3 cm	2.6 cm
5	17.4 cm	4.0 cm

gives $x_{1/2}$=29.4 cm. The ^{8}Li half life can be determined if the gas flow rate is known. Using the manufacturers MKS flow meter calibration the flow rate (corrected for temperature) is 163 cc/sec. For a $\approx$5 cm^2 PC cross sectional area and a 1.1 psi pressure, a rough calculation of the gas velocity gives 29.3 cm/sec. This corresponds to a ^{8}Li half life of $\approx$1 sec compared to the actual value of 0.838 sec. The discrepancy may be partially due to a faulty calibration of the flow meters by the manufacturer, our own wet tests (measures the displacement of water) appear to give lower flow rates. A better flow rate calibration and a more detailed calculation of the gas velocity should, hopefully, give the correct value for the half life.

4.2 ^{8}Li Detection with one-end charge division

The results of one-ended charge division are illustrated in Figure 7. The 5 point calibration data shows a severe non-linearity at the gas input end of the chamber, the origins of this non-linearity are not yet fully understood. The non-linearity occurs on the chamber end nearest the grounding capacitor. The resolution (see Table 1) is worse than the two-ended results as well. Both the fast and slow signal data are given for two different runs, there is an obvious shift in gain. The addition of salt likely effects the gain as well as the position resolution. Work will be required to optimize the stability of the electronics set-up and to understand the detector performance over time. The position curve for the ^{8}Li data deviates noticeably from that of an exponential. The calibration data could be used to linearize the Li charge division data.

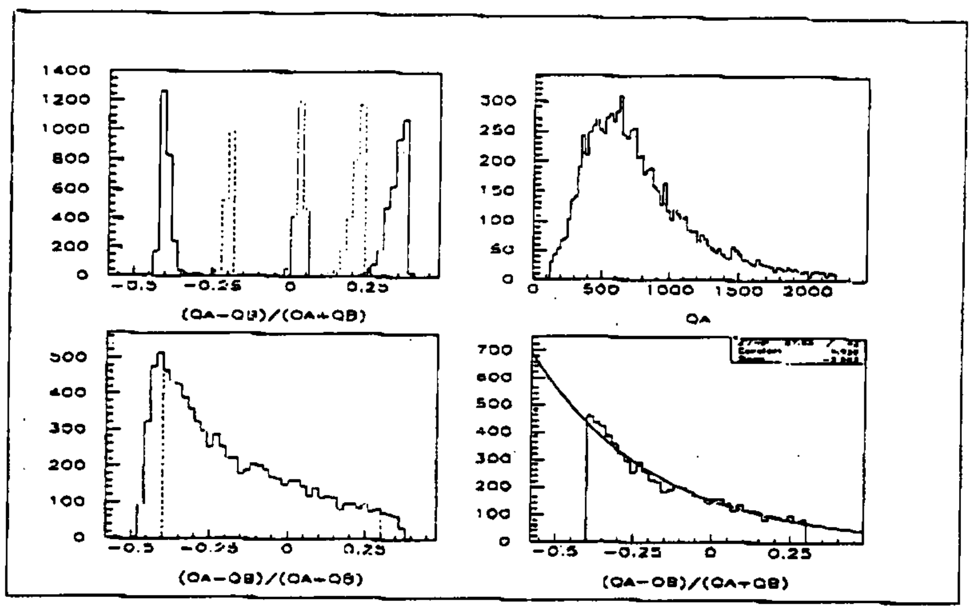

Figure 6: Two ended charge division spectra. A) The five point position calibration. B) The ^{8}Li charge collection data for the near pre-amp. C) Charge division for the ^{8}Li data, the dashed lines show where the cut was made for the fit shown in D).

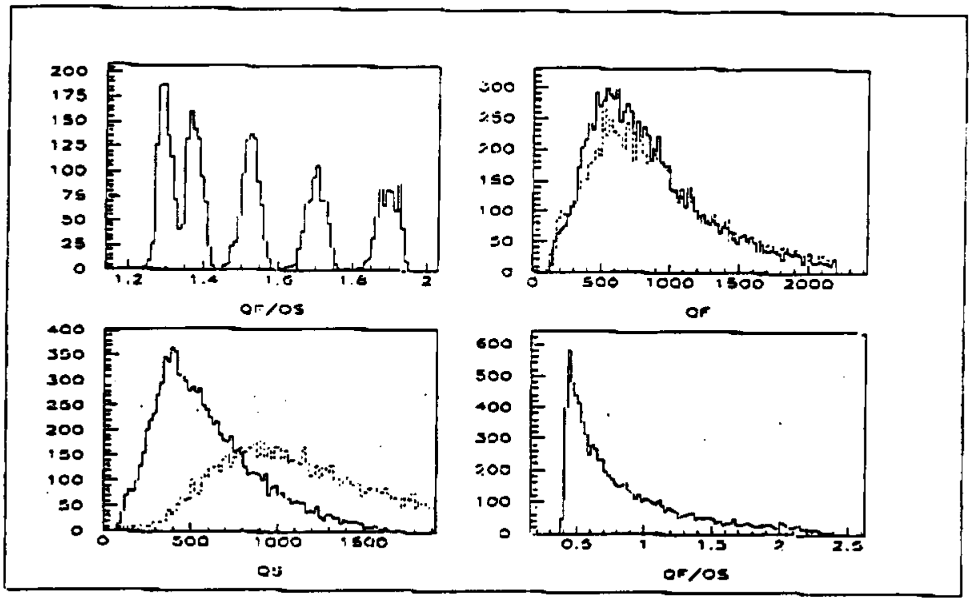

Figure 7: One ended charge division calibration spectra. A) The 5 point calibration. B) The fast signal for runs at the beginning (dashed line) and end (solid line) of the experiment. C) The slow signal for runs at the beginning (dashed line) and end (solid line) of the experiment. D) The ^{8}Li data.

4.3 Optimization of yields for various capillaries

A series of experiments were performed with a variety of capillaries to optimize ^{8}Li decay yield in the proportional chamber. The runs are summarized in Tables 2 through 7. Given in the captions are the type of capillary, its length, the duration of the count, and in certain cases the background count, oven temperature, and other details. The flow rate is given in terms of MKS meter reading; the conversion to cc/s will be made once the flow meters are properly calibrated. For the thick walled 1/8" capillary the maximal count rate for 25' and 175' are $\approx$9 s^{-1} and $\approx$0.5 s^{-1}, respectively. For the short capillary the detection rate is twice what was expected, yet that of the long capillary matches the expectation [1]. More detailed calculations of the yield should be investigated. For the thin walled 2.4 mm capillary the maximal rates are 5.5 s^{-1} for the 25'capillary and close to zero for the 200'capillary. For the 1/8" 200' Swagelok capillary the maximal rate is $\approx$0.33 s^{-1}. With the addition of a 3" collar in the chamber to reduce the volume the rate is 0.49 s^{-1}. There is also evidence of hold up of aerosol in certain parts of the assembly. This is indicated by a noticeable increase in count rate when flow rate conditions are suddenly changed, hence releasing the trapped activity. This suggests that a pulsing gas may improve the transfer efficiency. An oven temperature of $\approx$610 C was used for the runs and appears adequate. There is also some evidence that the CO_2 injection may be optimal upstream of the target chamber.

5 Conclusions

^{8}Li production, transport and tagging, have been demonstrated in the SNO DT generator, the prototype decay chamber and gas handling system. With the short 25' capillary, the detected rate is $\approx 9\ s^{-1}$ and for the long 200' capillary $\approx 0.5\ s^{-1}$. Further optimization of capillary diameter, flow rates, and target chamber dimensions may improve the observed rate. The decay chamber concept works well, the position resolution for one-ended charge division could, however, be improved. The effect of salt in the chamber and the stability of the electronics (gain) over time should be studied. Problems with dynamic range (thresholds and overflows) should be resolved as well.

The next step in the ^{8}Li program is to design and build the decay chamber that will be used in SNO. Plans are to construct one made of stainless steel and another made of acrylic. A new gas handling board (for all gaseous calibration sources) is presently being constructed. Work will be done on stabilizing and finalizing the electronics set-up. This will be done using a 60' signal cable. A concept for calibrating the decay chamber position identification with a gaseous ^{220}Rn source will also be investigated.

References

[1] B.Sur, E. D. Earle, R. Deal and E. Gaudette, ^{8}Li: A β Calibration Source for SNO, SNO-STR-93-041

[2] A. Uritani. et al, Nucl. Instr. and Meth. A299 (1990) 231-233.

Table 2: Thick walled 1/8" capillary: 25 feet. 100 second counts. Bkg.=0.063 Hz (750 sec).

Flow He/CO_2	Event Rates per sec.	Motor Pos. steps	CO_2 Inj.	P_{up}/P_{dn} psi	T C
.200/.05	6.29	0	Prop. Cham.		607
.200/.05	5.71	-200			
.200/.05	5.82	+200			
.200/.05	6.56	+100			
.200/.05	6.57	+50			
.200/.05	7.90		Downstream	4.2/0.5	
.200/.05	7.41				
.200/.05	7.51				
.200/.05	7.88		Upstream	4.2/0.5	
.200/.05	8.25				
.200/.05	6.29		Prop. Cham.	4.1/0.7	
.200/.05	6.60				
.240/.06	6.88			4.9/1.0	
.240/.06	7.00				
.280/.07	4.40			5.5/1.2	
.280/.07	5.04				
.280/.07	4.68				
.270/.06	5.82			5.4/1.1	
.270/.06	6.19				
.220/.05	7.52			4.7/0.9	
.220/.05	7.73				
.220/.05	7.56				612
.220/.05	7.66				
.220/.05	9.02		Upstream	4.8/0.9	
.220/.04	8.40		Prop. Cham.	4.6/0.8	
.220/.055	9.15		Upstream	4.8/.95	
.220/.055	8.17			5.8/2.0	

Table 3: Thick walled 1/8" capillary: 175 feet. Oven Temp.=610. 100 second counts.

Flow He/CO_2	Event Rates per sec.	P_{up}/P_{dn} psi
.220/.055	0.61	13.2/0.8
.220/.055	0.64	
.200/.05	0.61	12/0.9
.240/.06	0.60	14.1/1.0
.280/.07	0.49	16/1
.160/.04	0.58	9.9/0.8
.160/.04	0.51	

Table 4: Thin walled 2.4 mm capillary: 25 feet. Oven Temp.=612. 100 second counts.

Flow He/CO_2	Event Rates per sec.	P_{up}/P_{dn} psi
.220/.055	5.12	9.25/1.0
.220/.055	5.62	9.25/1.0

Table 5: Thin walled 2.4 mm capillary: 200 feet. Oven Temp.=613. 100 second counts. Bkg=0.13 Hz (100 sec).

Flow He/CO_2	Event Rates per sec.	P_{up}/P_{dn} psi
.100/.025	0.20	26.8/0.6
.051/.01	0.14	13.8/0.5

Table 6: Swagelok 1/8" capillary: 200 feet. Oven temp.=610 except * where temp.=615. 100 second counts. Bkg=0.11 Hz (100 sec). ? result is suspect.

Flow He/CO_2	Event Rates per sec.	CO_2 Inj.	P_{up}/P_{dn} psi
.220/.05	0.31	Upstream	17.6/1.1
.220/.05	0.35	Prop. Cham.	16.8/0.95
.200/.05	0.32		15.2/1
.160/.04	0.97 ?		12.7/0.8
.121/.03	0.22		10/0.7
.180/.045	0.42		14.1/0.8
.161/.04	0.33		12.8/0.8
.170/.04	0.36		13.4/0.8
.170/.04	0.44		13.2/0.8
.170/.04	0.32		
.170/.04	0.31	Upstream	13.5/0.85
.180/.045	0.36		14.5/0.8 *

Table 7: Swagelok 1/8" capillary: 200 feet. Target chamber modified, addition of 3" collar to reduce volume. 100 second counts. Bkg=0.15 Hz (100 sec).

Flow He/CO_2	Event Rates per sec.	CO_2 Inj. Oven Temp.	P_{up}/P_{dn} psi
.200/.05	0.30	Upstream(610)	16/1.1
.200/.05	0.25		
.160/.04	0.39		13/1
.120/.03	0.26		10/0.9
.180/.045	0.41		14.3/0.9
.220/.055	0.53		17.5/1.1
.220/.055	0.43		
.240/.06	0.56		18.8/1.2
.240/.06	0.48		
.260/.065	0.55		20/1.2
.260/.065	0.61		
.280/.07	0.49		21.5/1.2
.280/.07	0.40	(610)	
.270/.065	0.64		20.8/1.2
.270/.065	0.55		
.270/.065	0.50	Prop. Cham.	19.8/1.3
.280/.07	0.44		20.5/1.3