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A Proportional Counter Source to Calibrate SNO Backgrounds*

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Abstract

It is imperative that if a clean measurement is to be made of the CC/NC ratio. and the CC spectral distortion, the low energy background in SNO must be very well understood. For this reason a technique has been developed, so that each isotope of the background in the D_2O, can be measured. The technique relies on a proportional counter (PCS), which acts both as a detector, as well as a source. If various sources such as ^{228}Th (the source used in the first stage of testing the method) are placed on the anode of the proportional counter, then the β-decay is tagged by the PCS. and the Čerenkov radiation that produced is detected by SNO. The method is a background and distortion free measurement of the NHIT spectrum, of each source in SNO. This report summarizes the use of the technique in SNO, and the work carried out at the CRPP on the development of these sources.

*This work is updated from "A Proportional Counter to Measure the SNO Backgrounds" by C.K. Hargrove,Ira Blevis, and E.Bonvin presented at the Backgrounds Group meeting in Kingston in january 1994

1 Introduction

One of the main contributions to the backgrounds in SNO is from the ^{232}Th and ^{238}U in the D_2O. The Lilac Book [1] background specifications require that the amount of thorium and uranium in the D_2O not to exceed 3×10^{-15} g/g, and 4.5×10^{-14} g/g, respectively. The assumption in the Lilac Book is that their daughters are in secular equilibrium. It is possible that the various daughters (due to thorium plating out on detector components and radon leaching into the detector) in each chain are not in secular equilibrium, and this makes it critical for us to evaluate the actual contribution of each component, to get a realistic estimation of the backgrounds in SNO. This will impact on our ability to calculate and measure both the shape and intensity of the background wall, and the neutral current background from photodisintegration of the deuteron.

One of the important procedures that must be developed is a method of calibrating the background "wall" due to $\beta\gamma$ events occurring in the D_2O[1]. The Monte Carlo calculation of each of the main components of the backgrounds from the ^{232}Th and ^{238}U chains in the D_2O is shown in Figure 1(adapted from [3]). The calculated shapes and relative intensities of each of these components is quite different and thus so will be their contributions to the background "wall". If one measures the shape of each component to an energy well below the upper edge of the background wall, one can fit the observed shape of the wall for each of these components with one parameter, and by fitting this to the background "wall" extract their relative intensities. This technique has been discussed by W. Frati in a previous document [4]. This will also give us the possibility to extract their relative intensities if the various components are in disequilibrium. The PCS will be a method of determining the disequilibrium, or alternatively to use the measured disequilibrium to fit the background wall. At the present time there is still no accepted method of measuring the secular disequilibrium in SNO

In this report a simple, accurate and direct calibration source is described for simulating the contributions to the background wall, and the background neutrons in SNO. A proportional counter with one of the isotopes on the anode that are naturally present in SNO is used to tag the β-decay with negligible effect on the β's Čerenkov radiation, or the resulting

[1] It may be possible to statistically distinguish various isotopes independent of the assumption of secular equilibrium [2], but these also require calibration sources to give confidence in the results obtained in the analysis

γ cascade[2]. One can detect the subsequent Čerenkov light in SNO in coincidence with the PC signal with a resolving time of about 100 ns. The source can be used for four purposes.

- Measuring the spectral shape of each of the individual contributors to the background wall.
- Measuring the efficiency for seeing a beta-n coincidence in the PMT's of SNO.
- Measuring the neutron production probability by the ^{208}Pb 2.615 MeV gamma ray in the ^{232}Th decay chain.
- As a general purpose source for looking at the electro-magnetic spectrum of specific radioactive isotopes in the PMT's of SNO.

The next section will concentrate on measurements made with ^{228}Th source with the prototype, and briefly discuss the results obtained in the first stage of testing the method. The remainder of this report will focus individually on each of the other applications of the source outlined above. Then, the PCS, and changes in the design from experience with the prototype will be discussed. Finally, the main uses of the PCS will be summarized.

2 ^{228}Th Deposited on the Anode

The most significant application of the triggered source technique is for the determination of the response of the SNO detector to the Thorium chain. Consequently, this source, and the analysis of the rates obtained, is described in detail. There are three important isotopes which contribute to the background wall in the ^{232}Th chain (see Figure 2. [5]). They are ^{228}Ac with a Q-value of 2.137 MeV. ^{212}Bi to ^{212}Po with a Q-value of 2.2 MeV and ^{208}Tl with a Q-value of 4.99 MeV. Each of these isotopes can be studied by putting the proper parent isotope on the anode wire of the PC. In the next section we will discuss our experience with ^{228}Th placed on the anode of the prototype PCS

[2]Preliminary calculations where done by T. Radcliffe ("Monte Carlo Simulations of Proportional Counter Source", T.J. Radcliffe) which showed that the mean number of photons produced from a ^{208}Tl source on the anode the prototype PCS will vary in weakness by 4-10% from the case if the source alone is placed in D_2O

2.1 Events Observed by the PCS

An amount ^{228}Th source can be deposited on the anode wire by evaporating a solution of 1% HNO_3 spiked with ^{228}Th onto the wire. This isotope will decay to ^{212}Pb, emitting four α's. The ^{212}Pb will then decay to ^{212}Bi with an eleven hour half life. All of these are β's below the NHIT trigger threshold so that they will not be observed by SNO. ^{212}Bi then decays via two branches. a 36% α-decay branch to the 3.1 minute ^{208}Tl nucleus, and a 64% β-decay to the 300 ns ^{212}Po nucleus. Both branches finally decay to stable ^{208}Pb. The 64% branch can be observed in the PCS. with very little background by observing the β in delayed coincidence with the α produced when the ^{212}Po state decays. Thus, the signal observed in the proportional counter due to the 64% branch of the decay of ^{212}Bi is a low amplitude beta followed several hundred ns's later by a high amplitude alpha saturating the pre-amp of the PCS. Consequently based on amplitude, the electronics (or alternatively the event classification program) can be set-up to select the delayed coincidence events and then observe the subsequent Čerenkov signal in SNO. In this document we refer to this event classification as the $\beta_{PCS} \cdot \alpha_{PCSdel}$ events, that is, the events that satisfy the criteria that a low ionizing β is observed in the PCS, and a delayed α a few 100ns later(See Figure 3 for an example of a ^{212}Bi event that has been classified as a $\beta_{PCS} \cdot \alpha_{PCSdel}$ event.).

The other events observed in the proportional counter are the events when just the highly ionizing pulses are seen, that is the α's that are observed due to the series of decays of ^{228}Th to ^{212}Pb, and the α that is observed due to the 36% branching decay of ^{212}Bi to ^{208}Tl. This event classification we refer to as the α_{PCS} event classifcation. The third type of event that is observed in the proportional counter is a β with no α present. This is due to the decay of ^{212}Pb to ^{212}Bi and the β from ^{208}Tl. These are referred to as the β_{PCS} event classifcation.

To summarize, all the events observed in the proportional counter can be classified into three classes, the events where mostly β's are observed (the β_{PCS} events), the events where mostly α's are seen (the α_{PCS} events) and the delayed coincidence events. It must be mentioned, that event types like the β_{PCS} or α_{PCS}, are not purely β's produced through β-decay, or α's produced through α-decay, rather it is the sum of all the events which satisfy criteria which classify the event as a β_{PCS} or α_{PCS} event. For example a low energy α may be classified as a β_{PCS} event, even though it is an α. Thus it is important to distinguish between β events, and the β_{PCS} event classifcation.

See Table 1 below which summarizes the main isotopes of sensitivity, and their decay products for each event classification.

Event Type Classification	Isotopes of Sensitivity and Particle Detected
β_{PCS}	^{212}Pb ,^{212}Bi ,^{208}Tl β 's
$\beta_{PCS} \cdot \alpha_{PCS_{del}}$	64% ^{212}Bi β 's(α 's survive the wire)
α_{PCS}	^{228}Th ,^{224}Ra,^{220}Rn,^{216}Po, 36% ^{212}Bi α 's
$\beta_{PCS} \cdot SNO$	^{208}Tl and 64% ^{212}Bi β 's(α 's absorbed in wire)
$(\beta_{PCS} \cdot SNO) \cdot \alpha_{PCS_{del}}$	64% ^{212}Bi β 's(α 's survive the wire)
$\alpha_{PCS} \cdot SNO$	64% ^{212}Bi β 's(β and α time diff. less than τ_{cut})

Table 1: Summary of the event types, and how these relate to various isotopes in the ^{232}Th Chain.

2.2 Results Obtained with the Prototype

In the first stage of testing the technique[6], the prototype PCS had ^{228}Th deposited on the anode, and a small cylindrical acrylic cylinder surrounding the proportional counter to act as a Čerenkov radiator. The prototype PCS was placed in the middle of a light-tight cylindrical tank with two SNO PMT's at each end. The signals due to ^{228}Th decay, where then observed with, and without the coincidence with the PMT's. Experience with the prototype has allowed us to fit the rate equations corresponding to the various event classifications to five parameters (various efficiencies that need to be calculated by Monte Carlo, the fraction of the time that an α causes a daughter to recoil out of the source and diffuse toward the walls, and the activity of the ^{228}Th source), and extract an activity with an accuracy better than 6% (χ^2 per degree of freedom of 1.045). In the current design of the PCS, the accuracy is expected to be significantly better in the extraction of the activity than 6%, because the source is coated to prevent the nuclear recoil into the gas, which allows one less parameter in the fit. One significant advantage of this source is that it is essentially self calibrating (since we have a redundancy in the rate equations ie. the event classifications rate equations have common variables) and this allows us to do consistency checks on the extraction of the activity and other parameters. For example a critical parameter in the program that performs the fit, is the fraction of the α 's that are absorbed in the anode wire (F_{wire}), determined by Monte Carlo. One can extract the value for this parameter, by performing a fit to all but one of the rate equations, and then check for consistency by comparing the experimental rate to the last equation.

2.3 Rates Expected for the PCS in SNO

2.3.1 Determining the ^{212}Bi and ^{208}Tl Rates

In this analysis the activity of the ^{228}Th source is assumed to be 10 decays/s [3]. The rates of the PCS.SNO coincidences for the three event type classifications are shown in Figure 4 as a function of the NHIT trigger threshold. Here it is seen that the $\beta_{PCS} \cdot \alpha_{PCSdel}$ and α_{PCS} event type classifications always give the same rate. This is because in the event classification program for a ^{212}Bi decay event to be classified as a $\beta_{PCS} \cdot \alpha_{PCSdel}$ event, the minimum separation time (τ_m) between the β and α needs to exceed 300ns, which is exactly the half-life of the ^{212}Po state. Consequently, the ^{212}Bi decay events where the separation time between the β and α are less that τ_m will be classified as a α_{PCS} event. This allows a consistency check on the rates for ^{212}Bi decay since both the α_{PCS} and the DC rate should be the same. Thus if a background, is present that is correlated with the separation time, it will be experimentally measured [4]. Thus because of the unique signature in the PCS the DC.SNO event classification selects the ^{212}Bi decay with low background, and thus the rate can be recorded as a function of the trigger threshold, allowing the shape to be extracted independent of the activity.

The ^{208}Tl spectrum can also be determined accurately (assuming the fraction, F_{wire}, of the ^{212}Bi decay α's that survive the anode wire can be calculated), not based on its unique pulse shape in the PCS, but by subtracting the various experimental rates. The β_{PCS} event classification contains the the ^{208}Tl events where the β is detected, but it also contains the ^{212}Bi events where the α is absorbed in the anode wire (and hence the α remains undetected). So one must account for the contamination in the β_{PCS} event

[3]This can be scaled up with relatively little consequences, since as will be discussed the chance rates of the PCS.SNO coincidence are expected to be very low

[4]It should be noted that in experience with the prototype it was noticed that some of the ^{212}Bi decays had three pulses, not two. This is assumed to be due to clusters of secondary electrons forming along the β track. However, because of the fast rise-time of the β this will not affect the DC.SNO rate since the secondary clusters are collected at the anode within 250ns< τ_m of the β appearance in the PCS.

classifcation of the ^{212}Bi delayed coincidence events. What can be done to determine the experimental ^{208}Tl spectrum, is to correct the ^{212}Bi decay rates ($R^{Expt}_{(\beta_{PCS}\cdot SNO).\alpha_{PCSdel}} + R^{Expt}_{\alpha_{PCS}\cdot SNO}$) for the fraction of the α 's that are absorbed in the wire:

$$R^{Expt}_{^{208}Tl} = R^{Expt}_{\beta_{PCS}\cdot SNO} - \frac{(R^{Expt}_{\alpha_{PCS}\cdot SNO} + R^{Expt}_{(\beta_{PCS}\cdot SNO).\alpha_{PCSdel}})(1 - F_{wire})}{F_{wire}}$$

where $R^{Expt}_{\alpha_{PCS}\cdot SNO}$ and $R^{Expt}_{(\beta_{PCS}\cdot SNO).\alpha_{PCSdel}}$ are the $\alpha_{PCS}\cdot SNO$ and $(\beta_{PCS}\cdot SNO)$ $.\alpha_{PCSdel}$ coincidence event rates, and $R^{Expt}_{^{208}Tl}$ represents the experimentally observed ^{208}Tl rate. This rate is shown in Figure 5 where the expected experimental rate is graphed as a function of the NHIT trigger threshold for an assumed ^{228}Th activity of 10 decays/s. This method of extracting the shape due to ^{208}Tl is independent of the activity of the source, but depends on knowing the parameter F_{wire}.

We must also quantify the chance rates to the PCS.SNO coincidence since it impacts on our ability to extract the shapes of the components of the background. To determine this, it is assumed that the coincidence time between SNO and the PCS is 100ns, and the singles rate of the SNO PMT's is 1000 Hz. The SNO PMT chance coincidence rate is calculated using the "Learned Formula" [5], and we assume an additional fraction corresponding to the volume ratio of a 0.5 m sphere around the PCS to the active volume of SNO. The latter is assumed, since if the vertex of the event is known, we can place a cut on all the events that do not reconstruct in the vicinity of the PCS. To calculate the chance coincidence rate we must also take into account the background present in SNO. We have done this by integrating the background (sum of the PMT β-γ, internal β-γ, ^{40}K in D_2O, and NC backgrounds) spectrum from the NHIT trigger threshold to 50 hits, for various values of NHIT. Then the chance coincidence rate will be proportional to the sum of the accidental trigger and the background rates in SNO. Under these conditions the chance coincidence rate of the PCS with SNO is expected to be much less than one per day. This demonstrates the advantage of the coincidence technique, since the expected event rates for the other event classifications are 5 orders of magnitude greater than this.

[5] See for ex [7](note that k in denomenator should be t in the formula)

2.4 Neutron Production from the ^{208}Tl Branch

As discussed, when a ^{208}Tl decay occurs, a 2.615 MeV γ is created which may photodisintegrate the deuteron providing a background to the NC measurements. The PCS may provide a quick and accurate measurement of the shape of the initial ^{208}Tl β-γ cascade, and the neutron capture γ spectra. The PCS may also be able to do an estimate of the neutron production efficiency. Detailed Monte Carlo predicts a neutron production rate of 1 neutron per 484 decays[8] for the 2.615 MeV γ , but is important to experimentally measure this probability.

2.4.1 Determination of the ^{208}Tl β -γ Spectra When a Neutron is Produced

There are several methods that one can use to measure the ^{208}Tl spectra when the 2.615 MeV γ is missing from the detector (referred to as the $^{208}\text{Tl}_{\bar{\gamma}}$ events in this report) due to neutron production. The first is to every time a $\beta_{PCS} \cdot SNO$ event occurs look forward in time for the neutron capture γ 's. The γ 's should produce on average about 50 hits, so that it is expected not to be difficult to distinguish these from other backgrounds. This measurement will be difficult because the efficiency for detecting the $\beta_{PCS} \cdot SNO$ coincidence is very small. At a hardware trigger of 10 hits, the efficiency obtained by integrating the $^{208}\text{Tl}_{\bar{\gamma}}$ (modelled in SNOMAN 2.09) for seeing this coincidence is only 3-4%, which should be compared to 81 for the ^{208}Tl decay when a neutron is not produced. If one also includes the neutron production probability of 0.21 then the rate expected in SNO due to a prompt $^{208}\text{Tl}_{\bar{\gamma}}$ coincidence, followed by a neutron several ms later is expected to be about 22/day (^{228}Th activity of 10 Hz). These rates as a function of the NHIT hardware trigger definition are shown in Figure 6. It should be mentioned, that we will have a lot to gain in efficiency of detecting this coincidence, if we decide to put the hardware trigger at a very low NHIT. If for example we choose to set NHIT trigger threshold at 7, we have a very high PMT NHIT rate of 7 PMT's firing in 100 ns of 4000 Hz. But since we have a very fast coincidence, we can afford the high PMT NHIT rate, with the benefit of seeing a larger part of the $^{208}\text{Tl}_{\bar{\gamma}}$ NHIT spectrum. This will allow us to increase our efficiency for seeing the PCS.SNO prompt coincidence when a neutron is produced.

Many of the β 's do not produce enough Čerenkov light to be detected above the trigger threshold, but they may still produce a neutron. Thus a second option is to use the coincidence between a β_{PCS} event and SNO and place the hardware trigger at about 40 hits. At this trigger position we are free from most backgrounds, and we only detect the NC signal and NC background. To detect this coincidence one can observe the neutron in SNO and then look back in a 10 ms (Chlorine additive) window for a β_{PCS} signal in the PCS. The problem is that the β_{PCS} rate in the PCS is high (for example for a ^{228}Th activity of 10 Hz, the β_{PCS} rate is 20 Hz), so that the average time difference between events is 50 ms. Since the time window for the coincidence between the PCS and a neutron detection in SNO is 10 ms, it will be difficult to distinguish the neutron producing event from other β_{PCS} events occuring in the time window. Thus we need to be able to distinguish the ^{208}Tl$_{\gamma}$ events from other events that appear in the β_{PCS} classifcation (^{212}Pb β 's, and ^{212}Bi events where the α has been absorbed into the wire) to keep the signal to chance rate low.

2.4.2 Extraction of the Neutron Production Efficiency

To determine the neutron production efficiency one needs to know many efficiencies, such as the ^{208}Tl$_{\gamma}$ spectrum fraction above the trigger threshold, and the neutron capture efficiency. The neutron capture efficiency can be accurately modelled in SNOMAN, and may also be measured experimentally by utilizing the known variation of the capture efficiency with position. The ^{208}Tl$_{\gamma}$ spectrum will be measured as discussed in the previous section as a function of NHIT, so that the fraction above a prescribed trigger threshold will also be known. We also know as a function of NHIT the experimental ^{208}Tl shape, so that we can determine the fraction of the spectrum above a decided trigger definition. Once these efficiencies as a function of NHIT are quantified, we can set the trigger threshold at a low NHIT threshold, and observe the prompt coincidence between the PCS and SNO with, and without observing a neutron. The relative rates of the two event cases will allow us to extract the neutron production efficiency. Alternatively, one can move the hardware threshold to about 25 hits, just above the ^{208}Tl$_{\gamma}$ β-γ endpoint. We then observe the neutron rate using the PCS.n coincidence as discussed in the previous section, and simultaneously measure the ^{208}Tl spectrum above NHIT 25. This means that about 80% (20% of the ^{208}Tl spectrum is above the NHIT threshold) of the ^{208}Tl events will not be detected, and we need to correct the rates for this efficiency, but in principle this is measurable.

3 ^{228}Ac Source Deposited on the Anode

As can be seen in Figure 1 ^{228}Ac is an important component to the background "wall". We need to be able to measure the shape of this isotope so that we can determine whether the lower part of the ^{232}Th chain is out of equilibrium with this isotope (ie. due to Radon leaching into the detector). The background spectrum from this isotope can be studied by putting ^{228}Ra on the anode wire. Radium has a half life of 5.8y. It will β-decay to ^{228}Ac which has a half life of 6.1h and that will feed ^{228}Th which has a half life of 1.9yr. The long life of the ^{228}Th will block any further steps in the chain as long as the source is changed every month. Since the Q value from the β-decay ^{228}Ra to ^{228}Ac is 45.6 keV, the only coincidence that we will detect with SNO will be due to the ^{228}Ac β. Therefore one can measure with this source the shape of the ^{228}Ac contribution to the background, and its absolute amplitude for a known amount of ^{232}Th.

4 ^{238}U Chain Background Measurements

There are two important isotopes which contribute to the background wall in the U chain. They are ^{234}Pa with a Q-value of 2.3 MeV and ^{214}Bi with a Q-value of 3.27 MeV. Each of these isotopes can be studied independently by putting the proper parent isotope on the anode wire of the PC. This chain is shown in Figure 7 and the contribution to SNO in Figure 1. With the exception of ^{208}Tl decay, these two are the most important contributors to the background "wall".

4.1 ^{234}Pa Source Deposited on the Anode

This isotope beta decays to the ground state of ^{238}U with a 1.2m half life and a Q-value of 2.3 MeV. Therefore the background all comes from the Čerenkov light from this single β particle. This source can be made from either the ^{238}U parent or the 24 day ^{234}Th. There will be no further decays since the daughter, ^{234}U, has a life time of 2.5x10^5 years. The spectrum of decay as observed by the PMT's can easily be measured. The efficiency measurement requires a well calibrated source.

4.2 ^{214}Bi Source Deposited on the Anode

This isotope with a Q-value of 3.27 MeV is the main β-decay which can cause major backgrounds in the ^{238}U chain. It can be made by depositing ^{226}Ra which has a half life of 1602y on the anode of the PCS. The total EM energy is 3.27 MeV. Just as in the ^{232}Th chain by observing the $\beta_{PCS} \cdot \alpha_{PCS_{del}}$ events one can absolutely calibrate this chain, since the daughter nucleus of ^{214}Bi, ^{214}Po, decays by α emission with a half life of 164 μsec. Therefore by observing the prompt coincidence of the PCS with SNO due to ^{214}Bi decay, and the delayed alpha in the PCS, one can uniquely tag this isotope, and select it from the other β-decays. One would produce this source by putting ^{226}Ra on the anode wire. The decay chain ends with ^{210}Pb which has a 22y half life. Therefore the ^{214}Bi decay would be preceded by two α 's and a β-α delayed coincidence as mentioned above.

5 Other Sources

5.1 ^{40}K Source

In the analysis to fit the background "wall", it is critical to understand the contribution of ^{40}K. W. Frati has emphasized that the ability to extract the activity in SNO due to components in the ^{232}Th and ^{238}U chain, depends critically on having low levels of K in the MgCl, otherwise to extract the activity by fitting the shapes of ^{232}Th and ^{238}U isotopes to the background "wall" would be very difficult. A ^{40}K source could be used in the PCS to measure the shape of the ^{40}K spectrum, to help in understanding the systematic error imposed when fitting the background wall. ^{40}K decays either by K capture (10.7%), or by beta decay (89.3%), with Q-values of 1.505 MeV, and 1.311 MeV, respectively. One could look for the Čerenkov light associated with the β-decay branch and measure the spectrum associated with this decay in the PMT's.

5.2 ^{24}Na Source

This isotope decays with a half life of 15 hr and a Q-value of 5.513 MeV. It has a 99% branch which goes through 2.75 and 1.37 MeV gamma-ray cascade. One could use this source to measure the neutron production probability for the 2.75 MeV gamma ray and its associated spectrum in the PMT's. What one could do is coat the anode wire with a thin layer of a Na compound, and activate the Na through the ^{23}Na(n,γ) reaction (0.10 b [9]) to produce the ^{24}Na. This isotope will then decay allowing the β to be detected in the PCS in prompt coincidence with the β-γ cascade in SNO [6].

5.3 ^{252}Cf Source

This isotope has a well known fission branching ratio of 3% and produces 3 neutrons per fission. Such a source on a counter is useful as a tagged-neutron source. The fissions are readily tagged through the large amount of energy produced by the fission and also the γ-ray energy released by the fission products in the PMT's.

6 Development of the PCS at the CRPP

6.1 The Proportional Counter Source

The active component of the PCS is a 17 cm long 1 cm diameter cylindrical proportional counter providing an active volume of about 4 cm^3 (see Figure 8). The anode of the PCS is a 12.5 μ stainless steel (AISI 304) wire with a tension corresponding to a weight of 18g. The gas used in the detector is 46 psi P10 (90% Ar, 10% Methane). The active volume is housed inside a lexan cylinder. The thickness and length of the cylinder is chosen, primarily by engineering (safety) restrictions, and what the technicians at the science and Technology Centre, where the PCS is built, can do. We have settled on a design of 50 mm long and a lexan thickness of 0.7 mm. If it is made any longer or thiner it would compromise the integrity of the housing under

[6] For an alternative use of this reaction as a low energy γ source, see [10, 11].

a internal pressure of 46 psi. The primary advantage for an internally pressurized PCS, is that the most likely failure mode is on the deck, not in the D_2O. This is because the PCS, when pressurized internally is never under compression, the condition when the PCS is the most likely to break. On both sides of the lexan cylinder is a 12 degree cone pointing to the place on the wire where the source is deposited.

The cathode is a 25 μ layer of aluminized mylar that serves a dual function: to be the cathode of the proportional counter and to provide a light tight barrier. In experience with the prototype one major problem was encountered. This is the scintillation light caused by the electron avalanche, because the avalanche has enough kinetic energy to excite the Argon gas[7]. This is the motivation for requiring the PCS to be light-tight, because the amplitude of the scintillation light is an order of magnitude higher than the signal due to Čerenkov light.

The applied DC voltage to the anode is about 2000V providing an electron multiplication gain of about 3000. The signal and the high voltage is carried through the same cable (RG-RG-58/U), and the signal is extracted using a DC blocking capacitor, and sent to the pre-amp for further amplification. Consequently combining primary ionization with the electron multiplication factor, capacitance in the detector, and pre-amp gain, a signal of several volts are expected for β's traveling through the gas toward the detector. The signal out of the pre-amp is connected to one of the channels of a digital recording oscilloscope and is triggered just above the noise. The digital oscilloscope can then be put into a mode where the time of occurrence relative to the trigger, and the amplitude and times, of an event can be written to a file. The event classification is then done in off-line analysis as was described in previous sections.

The PCS has been designed, and is close to being built. There are still some details that have to be worked out regarding the method of depositing the various sources on the anode wire, and the technique used to constrain the nuclei from leaving the source when a decay occurs. The method suggested is to coat the source with a thin layer of gold or aluminum to provide a "window", so that the nuclear recoil will be stopped, but the alpha decay will be detected. A full simulation modelling the PCS performance has yet to be modelled in SNOMAN, and various DAQ details need to be finalized.

[7]The quench gas added to the Argon is not enough to absorb all the photons so that scintillation light is still visible

6.2 Amplitude Cuts to Reject β's Travelling Toward Endcaps

It might be possible to reject events that go toward the endcaps of the proportional counter by amplitude analysis. To understand this, it is only necessary to consider a β that travels nearly horizontal to the anode wire. This β will produce more electron-ion pairs than if the β would have traveled along the radius of the proportional counter, because its track is longer. This will increase the number of primary ion pairs that will create avalanches so that the total charge collected is increased proportionally. This is demonstrated in Figure 9, where the β pulse shape is shown for various track angles [8]. In this way, by rejecting high amplitude β's these events that are more difficult to understand (because they interact with the endcaps) are rejected [9].

Some simple EGS4 simulations of 1.5 MeV electrons through a slab of lexan were done, and demonstrates that if random track angles with respect to the anode exceeding 30° are simulated, then only 30% of the energy will be deposited in the lexan [10]. The EGS4 simulations also show that with this cut about 4.5% of the β's would scatter back into the gas, and produce more ion-pairs. In principle, this introduces a potential ambiguity, because events with a large track angle which scatter back, will have the same track length (and thus signal, neglecting timing cuts) as events with a small track angle. But based on simplistic arguments about 1/3 of the 4.5% will be ambiguous events, the rest can be discriminated against, based on pulse height alone. It is assumed in this analysis that the cut will be an amplitude (track length) cut alone, a 100% efficiency is assumed in rejecting the events greater than a set amplitude, and no timing information was used. It should be mentioned that it is planned to use a combination of amplitude and rise-time cuts because as can be seen in Figure 9 β's traveling almost horizontally to the anode wire, produce ionization close to the wire so that the avelanche occurs faster than if the β travels radially

[8] To calculate the pulse shape, it was assumed that the drift velocity is as given in [12], and that the amplitude of the drifting electrons as a function of time, is given by equation 35 of [13].

[9] It should be mentioned, that it is planned to use a combination of amplitude, and rise-time cuts, because as can be seen in Figure 9 β's traveling at small angles to the anode wire have faster rise-times, then β's travelling at larger angles to the anode wire.

[10] This energy is not lost. Since the lexan is translucent, and has an index of refraction close to water, the effect of the lexan wall for radially outward β's is to add an average of 10 photons to the Čerenkov light

7 Summary

This source can be used for 5 purposes:

- To measure the shape of the ^{232}Th and ^{238}U background spectra. By utilizing the coincidence between the PCS and SNO, the shape of each component can be measured well below the background "wall".
- To calibrate the neutron production efficiency
- To measure the neutron response in SNO. It is possible to use this source as a means to measure the neutron NHIT spectrum.
- To put a constraint on the number of background neutrons that are being produced by the background wall. Once the activity is known of each of these components, then one has a constraint on the number of background neutrons that are produced in SNO.
- As a general purpose source used for tagging a number of useful background and neutron calibration sources.

References

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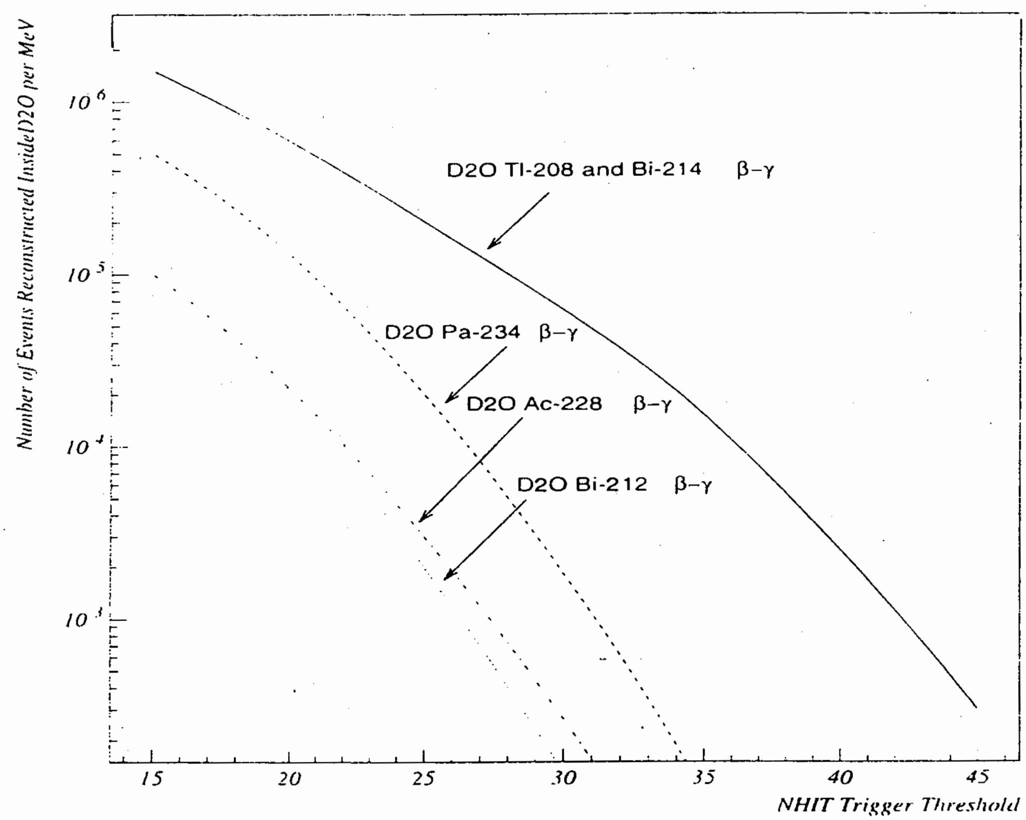

Figure 1: The contribution to the background "wall" of various ^{232}Th and ^{238}U chain isotopes found in the D_2O.

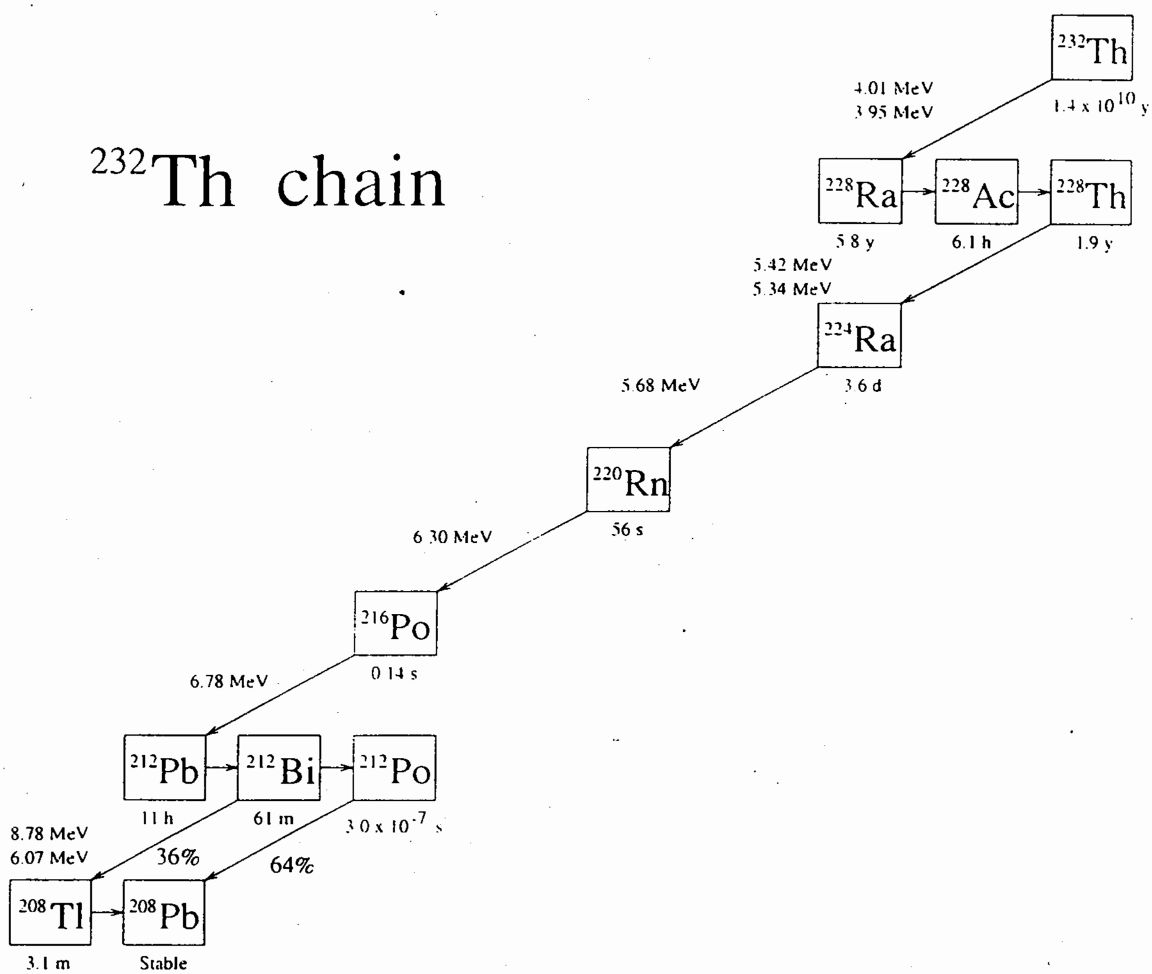

Figure 2: The ^{232}Th Chain

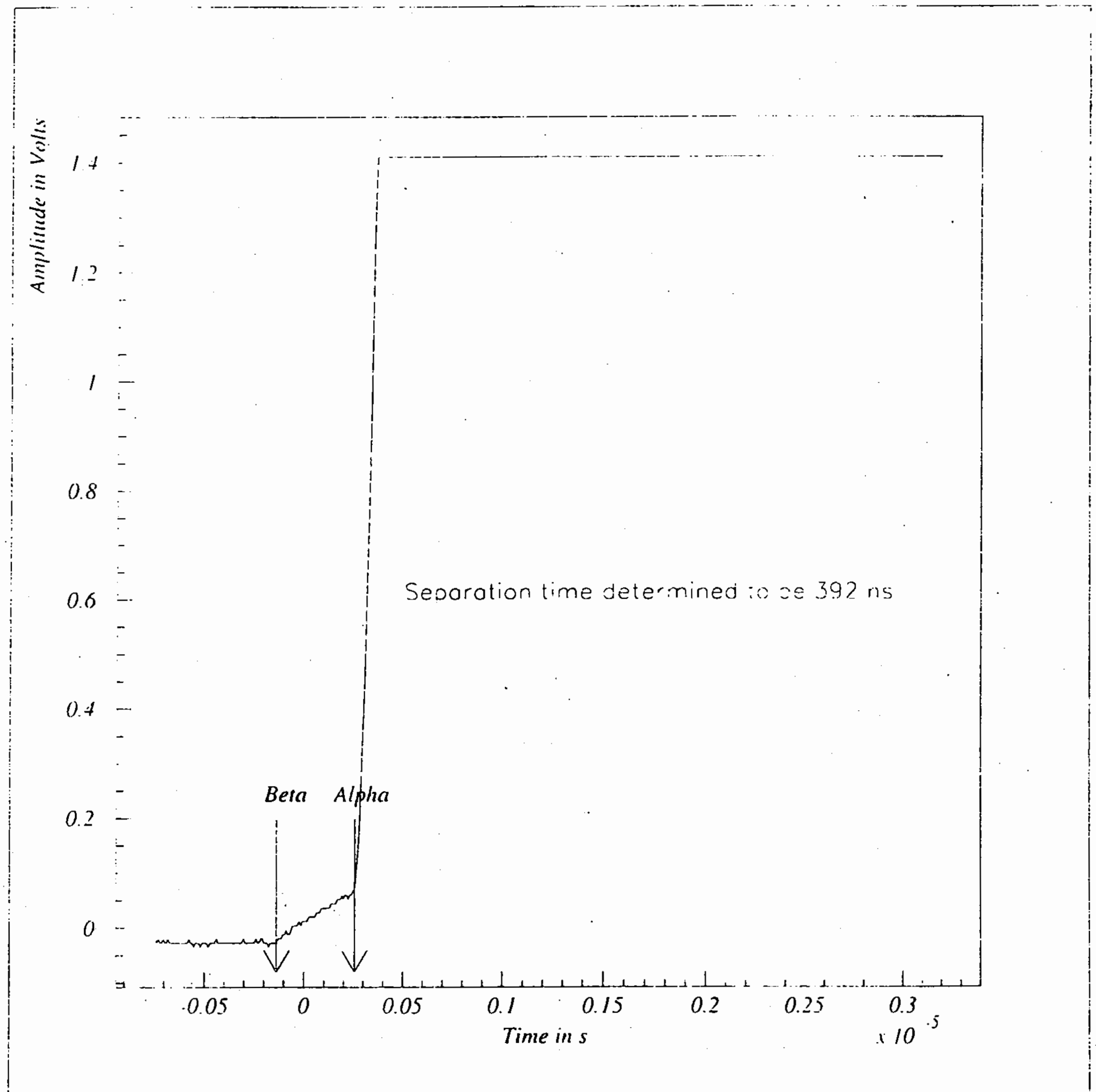

Figure 3: Figure showing a delayed coincidence event as selected by an off-line analysis program. The arrows correspond to the times determined by the program of the start of the β and α pulses.

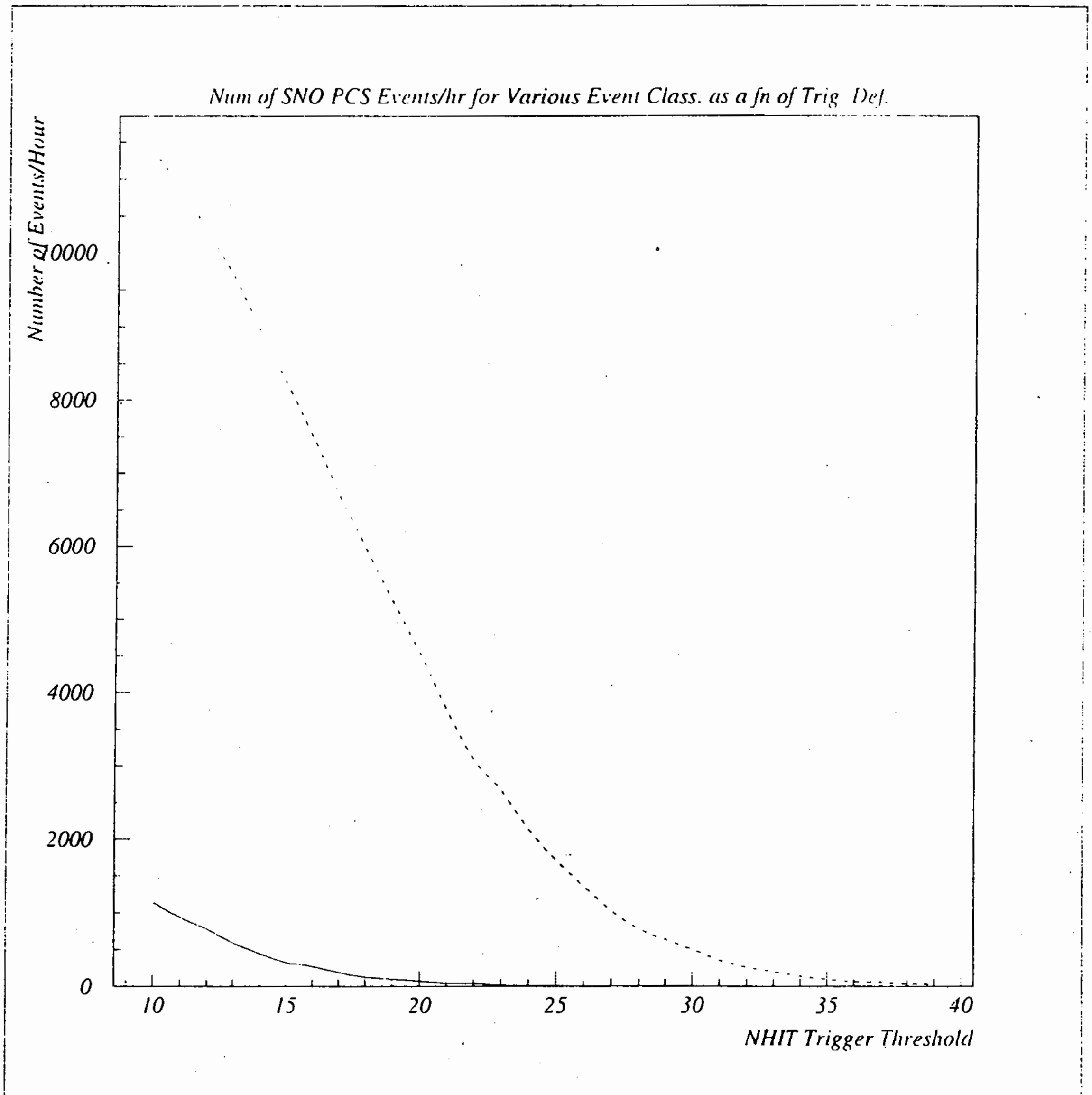

Figure 4: The PCS.SNO ^{228}Th source rate expected as a function of the trigger threshold (NHITS) for the β_{PCS} events (dashed line) and the α_{PCS} and $\beta_{PCS} \cdot \alpha_{PCSdel}$ events (solid line). The ^{228}Th activity is assumed to be 10 Hz and the rates were obtained by integrating the NHIT spectra modelled in SNOMAN 2.09.

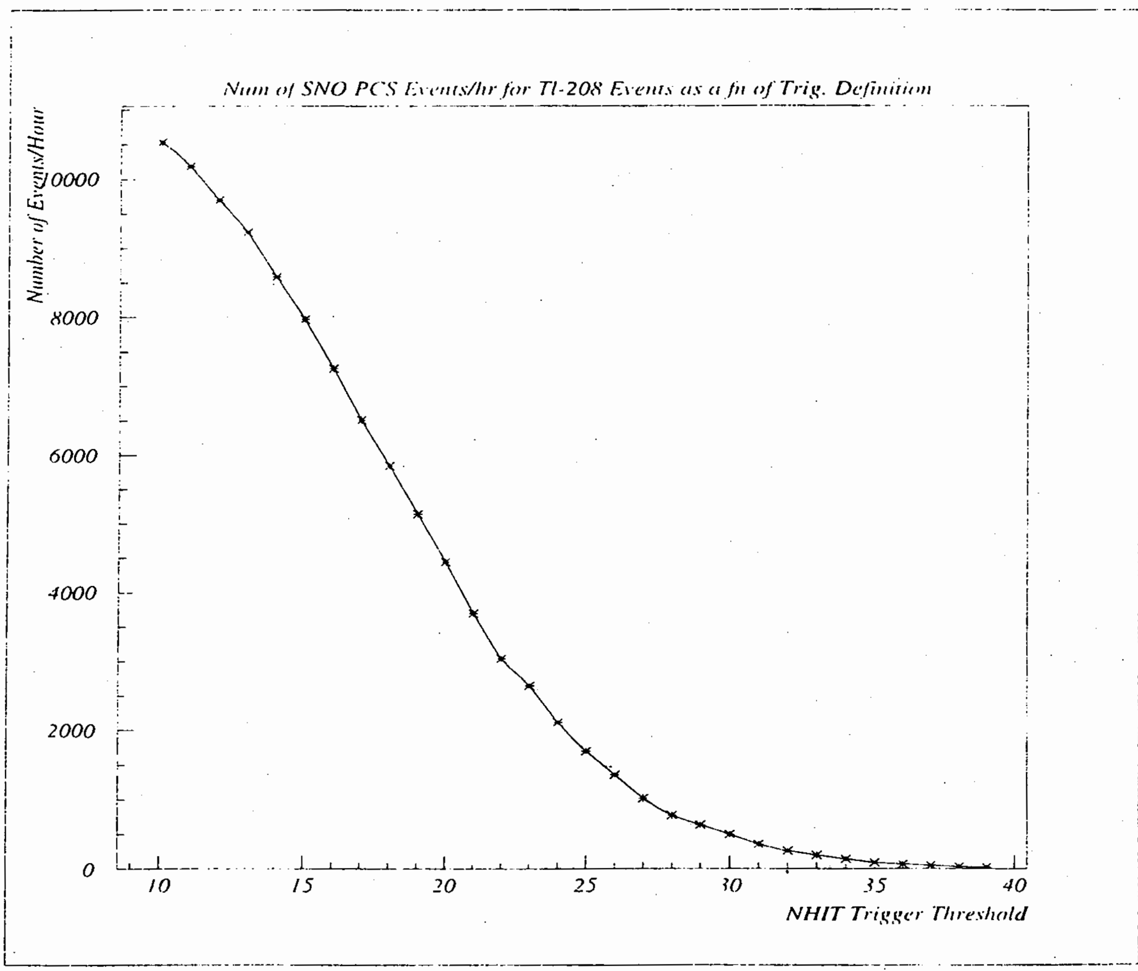

Figure 5: The PCS.SNO ^{208}Tl rate expected as a function of the trigger threshold (NHITS). ^{228}Th activity is assumed to be 10 Hz, and the rates were obtained by integrating the NHIT spectra modelled in SNOMAN 2.09.

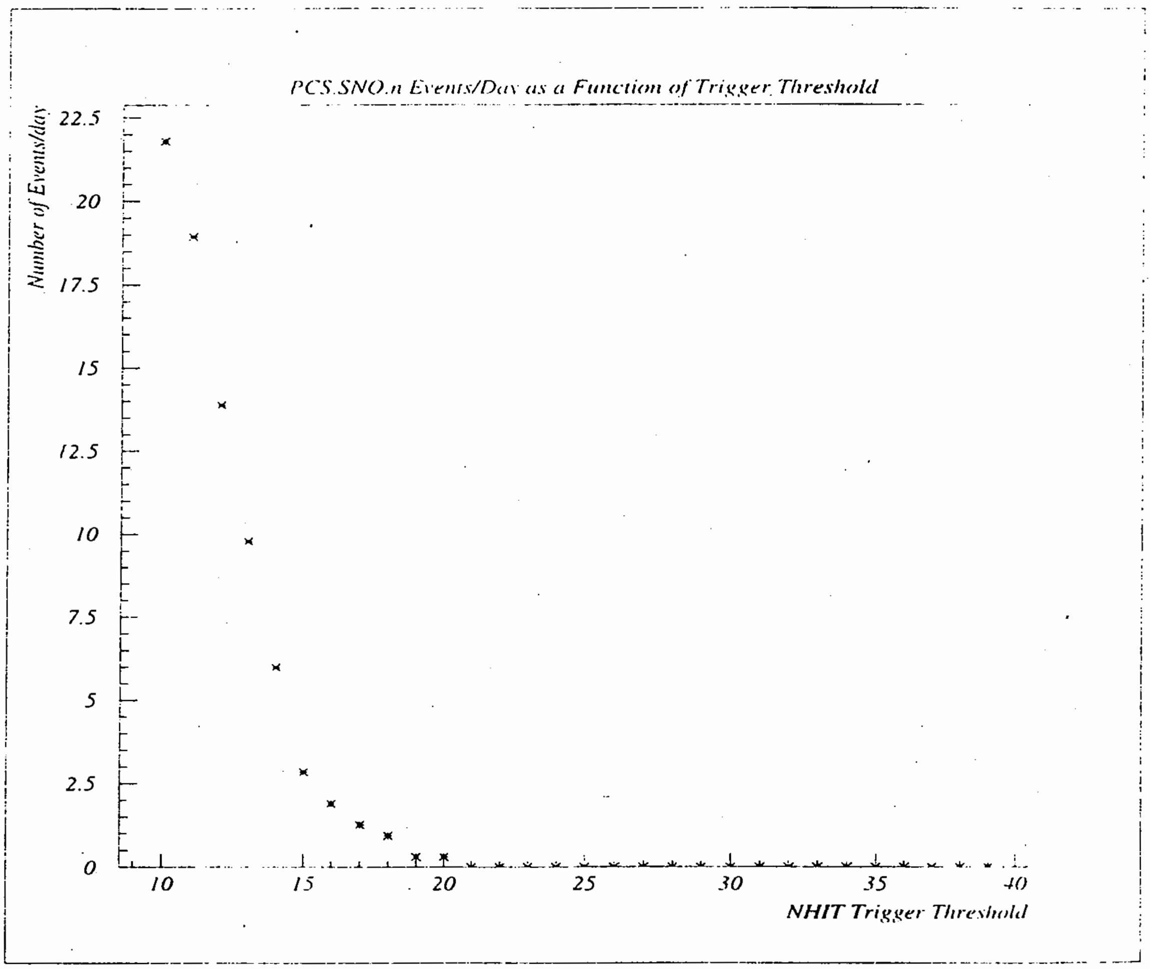

Figure 6: The number of events/hour as a function of the trigger threshold (NHITS), where there is a prompt coincidence of the β_{PCS} event classification and SNO, and a neutron signal several ms later. ^{228}Th activity is assumed to be 10 Hz, and the rates were obtained by integrating the NHIT spectra modelled in SNOMAN 2.09.

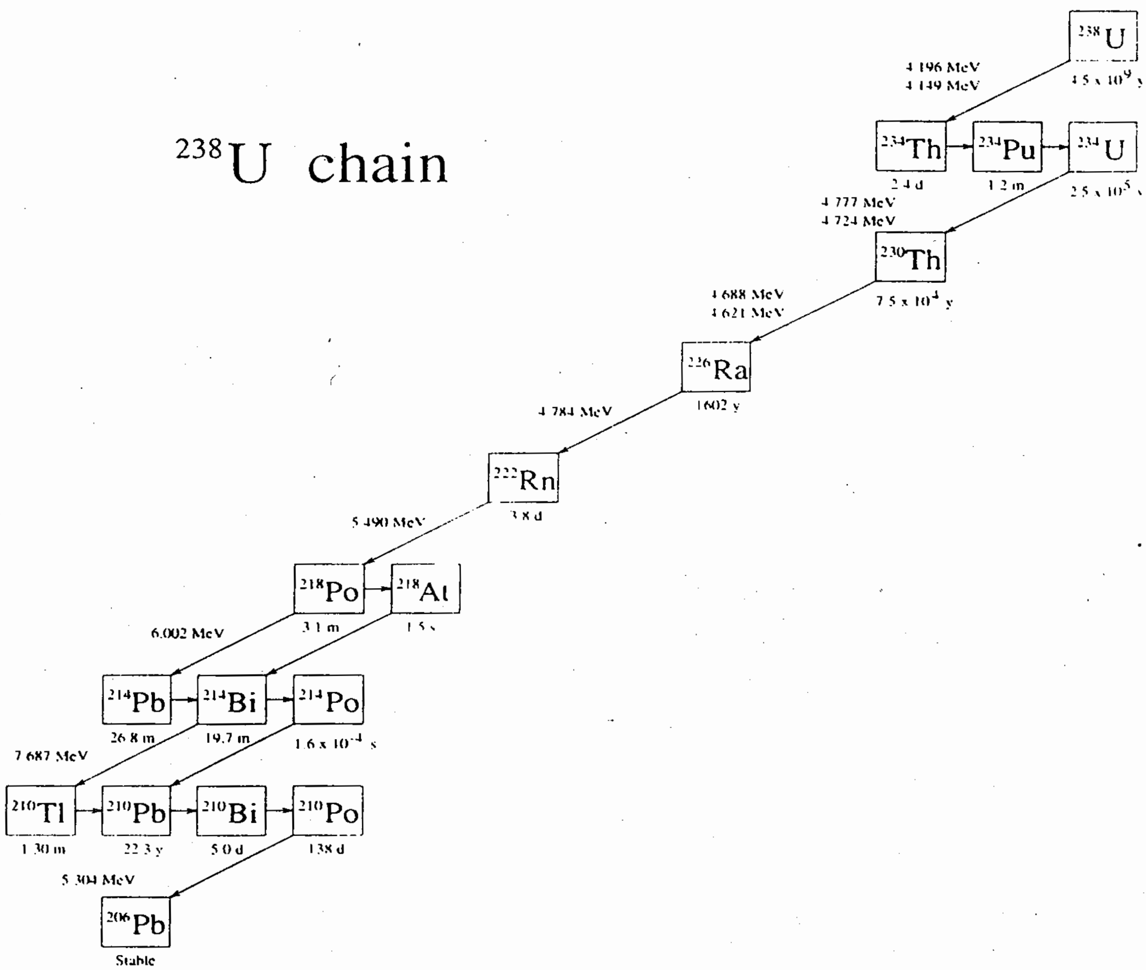

Figure 7: The ^{238}U Chain

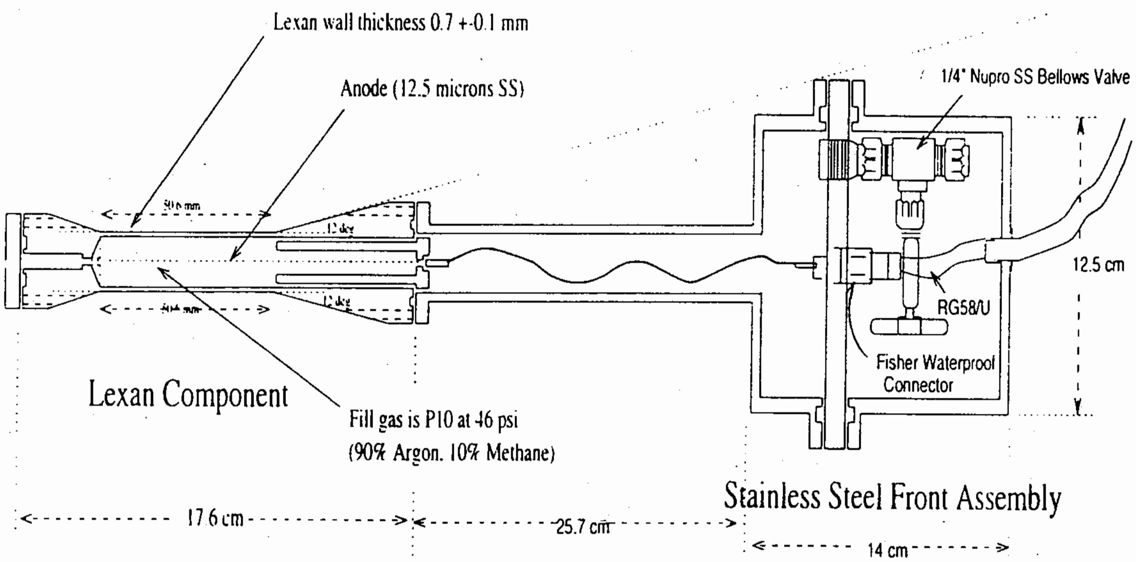

Figure 8: A sketch of the PCS

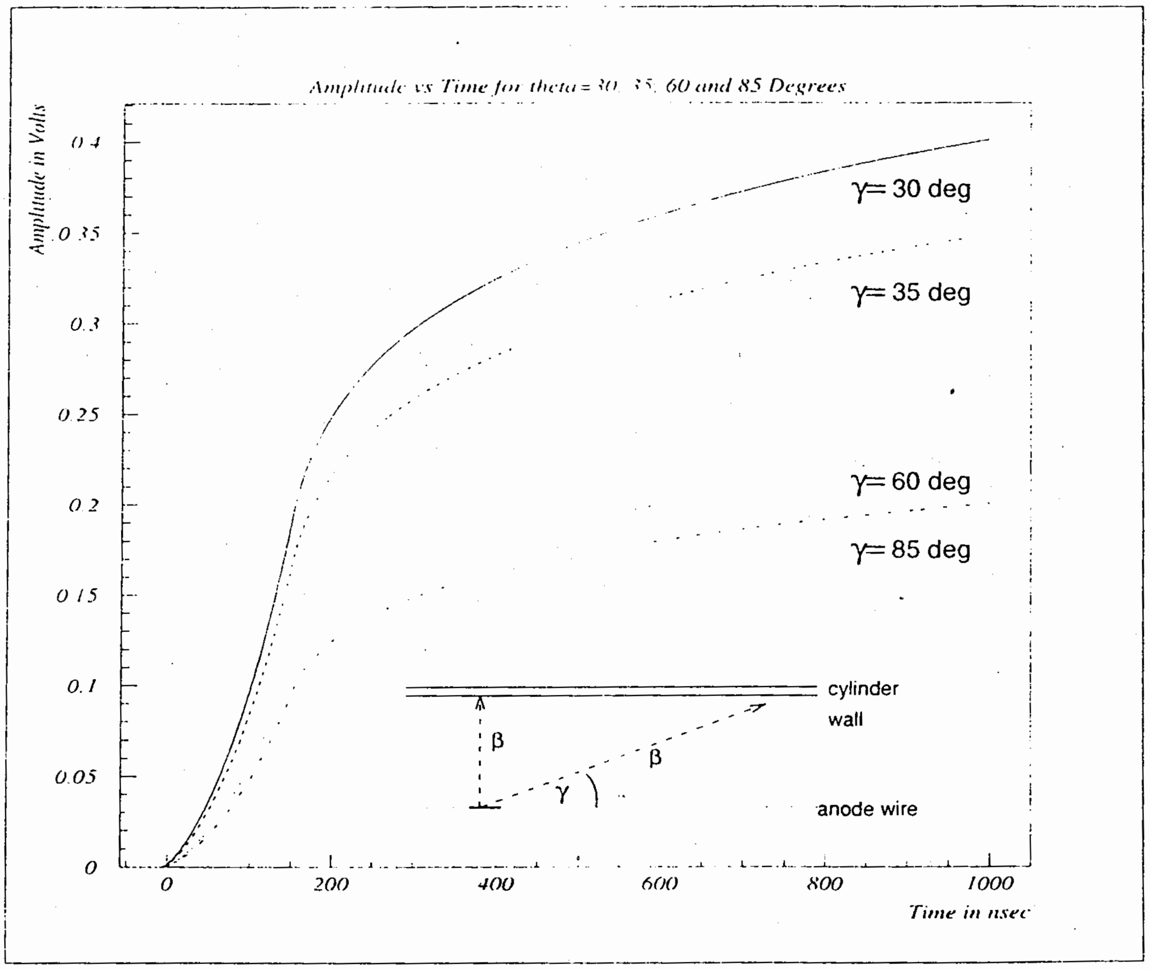

Figure 9: Diagrams showing the possibility of applying cuts to the amplitude of the β for events going toward the endcaps. The pulse amplitude is shown as a function of time for various track angles, α, with respect to the anode (see inset for track orientation). Notice that for low angles, the amplitude difference increases which will make it easier to apply this amplitude cut.