SNO-STR-90-3

Neutron Activation Measurement Using a Compton-Suppressed Ge-detector

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January 9, 1990

1 Introduction

The concentration of thorium allowed in the acrylic for the SNO detector is very low, $\sim 2 \times 10^{-12}$. At these levels neutron activated acrylic samples produce γ-ray strengths which approach backgrounds. A Compton suppressed germanium detector at Queen's University was used to detect activity in a neutron activated sample of acrylic to see if the suppression could help reduce the background. Two components of the background would be expected to be reduced. First, high energy γ-rays from the source produce a Compton tail and this should be removed. Second, the background from cosmic rays should dissappear.

2 Acrylic Preparation and Activation

The acrylic samples were cut from sheets in the carpenters' shop at Chalk River. They were washed in isopropyl alcohol and then in double-distilled de-ionized (DDD)water.

The container which was to hold the acrylic in the reactor was made of polyethylene. It was cleaned by boiling for 48 hours in 1:1 nitric acid and water, and then in a 1:10 solution for 48 hours, followed by a rinse in DDD water.

The sample was placed in the container which was then closed by welding the polyethylene using a hot nitrogen stream. There was a second chamber in the container where a known sample of thorium and uranium was placed and sealed. The container was placed in the NRU reactor at Chalk River for approximately 6 hours. Then the container was cut open; the acrylic, which after the irradiation had fragmented into a coarse powder, was poured out into a bottle which was transported to Queen's University for γ-ray counting. The standard sample was dissolved in aqueous solution and put into a similar bottle.

A second sample was irradiated in the same manner and then chemically separated to remove uninteresting background activities. This source was also taken to Queen's University for γ-ray counting.

3 The Compton-Suppressed Spectrometer

The Compton suppressor is a sodium iodide crystal of length 30.5 cm, and diameter 30.5 cm, with an 8.9 cm hole along the central axis. Inside the NaI crystal was a germanium γ-ray detector with an efficiency of 18% for ^{60}Co Each source was placed in front of the germanium detector, and 2.5 cm of lead was placed behind the source to shield the detector from room background. Standard modular electronics were used to provide an energy signal and also an anti-coincidence signal for the Compton suppressor. The data was acquired using the PDP-15 computer. Several runs were taken for each source.

4 Analysis

The Compton suppression is very effective at removing the most intense background, namely the activity from ^{24}Na. Figure 1 shows a comparison between a suppressed and an un-suppressed spectrum. It can be seen that the suppression reduces the background by a factor of about four in the regions of interest. Arrows indicate where the peaks are expected due to the uranium and thorium at 228 keV and 312 keV respectively. Figure 2 shows the same comparison for the chemically separated source. The suppression is not as effective here but it still helps.

Peak areas were obtained from the suppressed spectra for each of the acrylic sources as well as the standard sources. (See Figure 3.) From the known masses of the standards the thorium and uranium concentrations were deduced.

5 Results and Conclusions

The thorium and uranium concentrations in the acrylic samples are given in Table 1. An estimate of the ultimate sensitivity of the method was obtained by analysing the background near the peaks of interest in the suppressed spectrum. The counting rates in these regions are given in Table 2 for each source. The improvement of the background with time is mostly due to the decay of the background activity, ^{24}Na. Assuming that the background will dominate the uncertainty for a weak source, the minimum detectable concentration of thorium and uranium has been estimated for a counting time of 24 hours, and the results are given in Table 3.

These results indicate that with the combined methods of chemical separation and Compton suppression it is possible to reach the sensitivity needed for the SNO experiment.

Table 1: Thorium and Uranium Concentrations in Acrylic

Sample	Thorium $\times 10^{-12}$ g/g	Uranium $\times 10^{-12}$ g/g
Dec 3 [a]		
Run 2	185 ± 4	186 ± 48
Run 3	173 ± 4	$<$105
Run 4	184 ± 4	$<$102
Dec 10 [b]		
Run 3	190 ± 13	73 ± 18
Run 8	169 ± 7	80 ± 13
Run 9	171 ± 7	91 ± 16

[a] Chemically separated sample
[b] no separation

Table 2: Backgrounds

Sample	at 312 keV (Th) Counts/keV/min.	at 228 keV (U) Counts/keV/min.
Separated		
Unseparated:		
3 days	1.60	2.22
4 days	0.68	0.92
5 days	0.55	0.74
Room Bkg.	0.03	0.02

Table 3: Minimum Concentration Detectable

Sample[a]	Age[b] $\times 10^{-12}$ g/g	Thorium $\times 10^{-12}$ g/g	Uranium
Separated	2 weeks	1.0	40.
Unseparated:			
Run 3	3 days	7.7	17.
Run 8	4 days	5.0	11.
Run 9	5 days	4.5	9.9

[a] Scaled to 24 h data collection
[b] Age since neutron irradiation

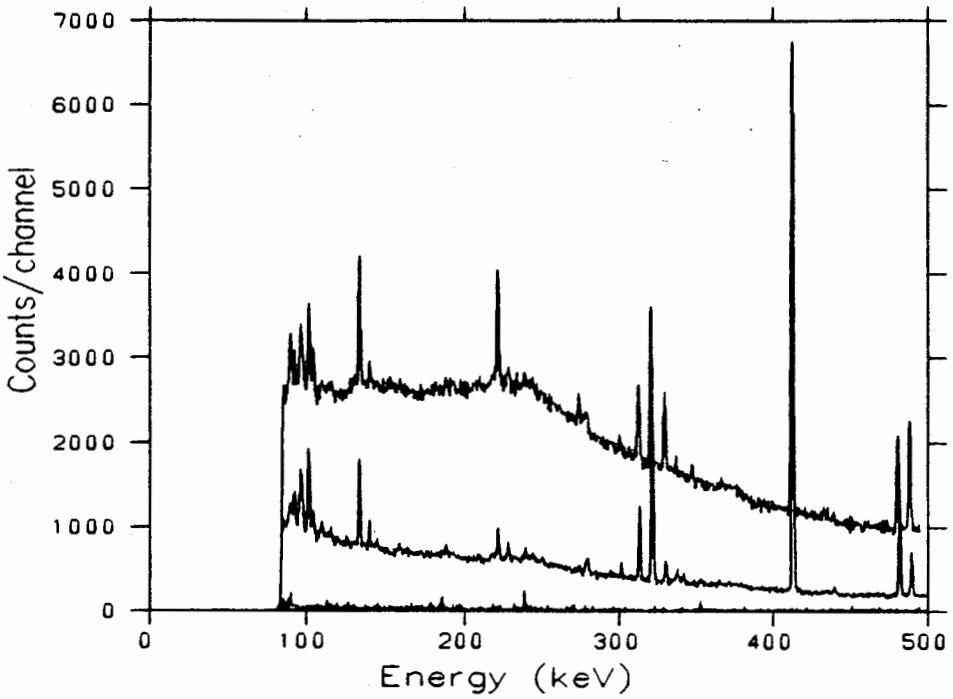

Figure 1: γ-ray spectrum of acrylic sample: the top curve was obtained with the germanium detector in "normal" mode; the middle curve shows the results of Compton suppression. The bottom curve shows the room background. The three curves have been normalized to the same collection time.

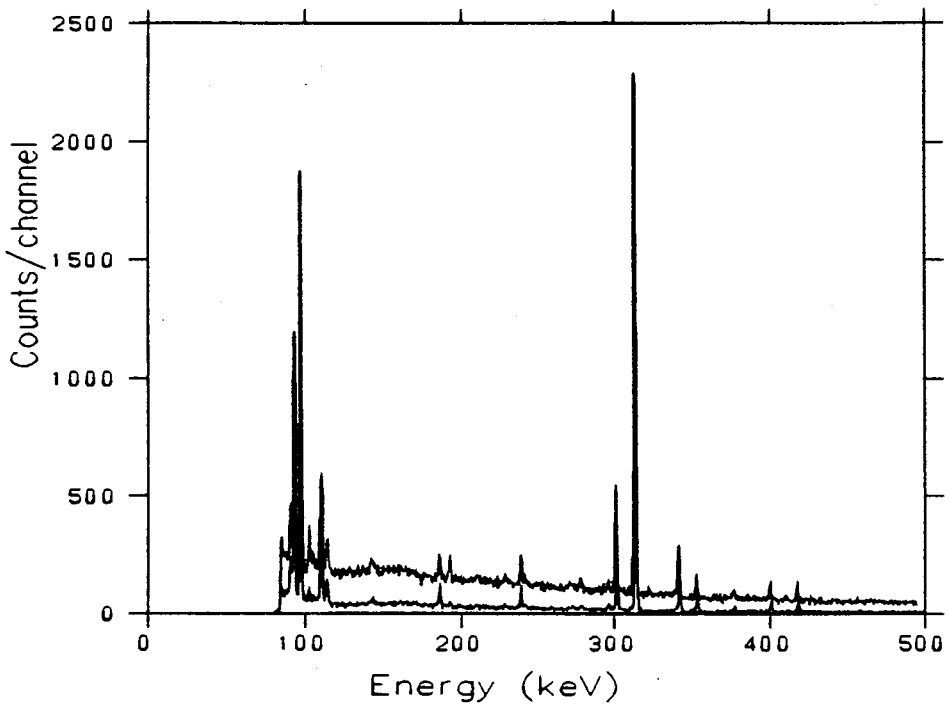

Figure 2: γ-Ray spectrum of chemically separated acrylic sample. Compton suppression was used to obtain the lower curve.

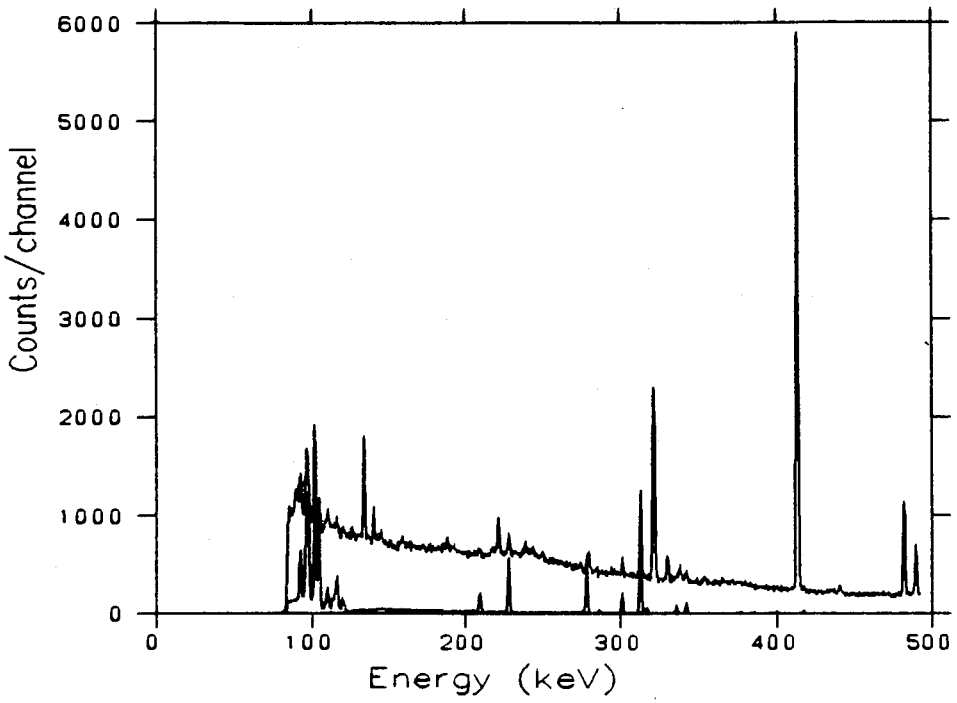

Figure 3: Compton suppressed spectrum of acrylic. (Same as middle curve in figure 1.) The lower curve is the calibration source which contained known amounts of thorium and uranium.