Radioactivity in Ropes

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Abstract

Measurements by neutron activation analysis of Th and U intrinsic to the ropes to be used in the acrylic vessel support system are described. Activities from other trace elements in the matrix of the ropes which interfere in the measurement of Th and U are identified. Results on a few ropes are presented.

1. Introduction

The D_2O containment vessel of the Sudbury Neutrino Observatory (SNO) detector is made out of acrylic panels transparent to Cerenkov light produced by neutrino interaction inside the D_2O. The panels are bonded together to give a spherical vessel which is water tight. The spherical vessel is held in place by a support framework which has to keep the vessel in a fixed spatial relationship with the photomultipliers set up around the vessel for detecting the Cerenkov light produced in the D_2O vessel. Of the several designs considered for the support framework a net suspension or a cable suspension design seem to be gaining favour over others[1,2]. In these designs the materials of the net or cables come in close contact with the acrylic vessel. Therefore, they are subject to intrinsic radioactivity specifications similar to the acrylic panels used in the fabrication of the vessel[3].

SNO design team chose several prospective materials for fabricating the net or cables in the support framework. The present work reports the results from radioactivity measurements made at Guelph for the SNO collaboration by neutron activation analysis (NAA).

2. Materials

The rope materials received for radioactivity measurements are known by the trade names as follows: 1. Kevlar with a Dacron sleeve, 2. Spectra with a oleofin sleeve, 3. Kevlar 29 type 960, and 4. Vectran. The ropes which have a core with a sleeve on the outside were separated into individual components for analysis. The first two rope materials were screened initially by radiometric counting[4] in our low background γ-ray spectrometer before analyzing NAA.

3. Experimental Details

Ten to fifteen gram samples of rope materials were irradiated at McMaster Nuclear Reactor in a thermal neutron flux of 1.5E13 $s^{-1}cm^{-2}$ for 2h each, or in a Cd shielded configuration at the same position in the reactor. Aluminum foil standards (~0.05 g) were irradiated simultaneously with the samples to serve as comparators in the relative method of determining elemental concentrations in

the samples.

The samples and the standards were counted on a shielded high resolution HPGe γ-ray detector (55% relative efficiency) coupled to a Wilkinson type ADC and a PC based data acquisition and analysis system. The net peak areas in the samples and standards corresponding to γ rays from ^{233}Pa (312 keV) for thorium and ^{239}Np (106 keV) for uranium were determined from the pulse-height spectra from each sample. They were corrected for radioactive decay during the delay between the median times of the counting intervals of samples and corresponding standards.

4. Results

γ-ray spectra recorded after an average delay of approximately 17.5d from the end of irradiation from two samples taken from the same Kevlar rope but irradiated in the reactor with or without Cd shielding are shown in figures 1 and 2. It can be seen from figure 1 that there are several activities in the sample which produce prominent γ-ray peaks at energies greater than 312 keV. These activities produce the Compton background under the peak region at 312 keV used for determining Th. In addition, there is a rapidly increasing continuum towards energies lower than 312 keV which indicates a background arising from bremsstrahlung radiation produced by a beta-ray activity in the sample. A search through the germanium detector γ-ray spectra of activities from neutron activation products of natural elements compiled by Adams and Dams[5] showed that none of the activities producing the prominent γ-ray peaks in figure 1 (like ^{51}Cr, ^{198}Au, $^{122,124}Sb$, ^{59}Fe, ^{65}Zn, ^{60}Co) is likely to produce the rapidly rising continuum in the γ-ray detection system used in the present work. However, a minor peak at 1077 keV in figure 1 may be assigned to ^{86}Rb activity ($T_{1/2}$18.7d:E_B-Max 1774 keV) which is found to produce bremsstrahlung continuum in the γ-ray spectra[5]. In addition, the presence of ^{32}P activity ($T_{1/2}$14.3d:E_B-Max 1710 keV) cannot be ruled out on the basis of half-life and maximum E_B-energy considerations alone.

The γ-ray spectrum shown in figure 2 shows the same activities as in figure 1. However with

respect to the 603 keV peak the relative intensities of the prominent γ-ray peaks above 312 keV in figure 2 is different compared to the same in figure 1. The ^{51}Cr (320 keV), ^{59}Fe (1099, 1292 keV), ^{65}Zn (1115 keV) and ^{60}Co (1173, 1332 keV) peaks have reduced dramatically in intensity relative to ^{124}Sb (603 keV) peak. It means that the Cd shielded irradiation is significantly reducing the resultant activities from these elements and not from Sb. However, the continuum size is not changed relative to that in figure 1 (also see data in table 2 in the peak regions for Th and U). A summary of the activities from figures 1 and 2 is given in table 1 together with elemental concentrations determined, wherever possible, relative to the aluminum foil standard.

γ-ray spectra from Oleofin and Dacron samples were completely dominated by the ^{122}Sb and ^{124}Sb activities estimated to be a thousand times more than in the Kevlar samples. Unlike Kevlar samples which were counted on top of the detector, these samples had to be counted at approximately 20 cm from the top of the detector. The vectran rope sample was similar to Kevlar samples in Cd, and Sb contents.

In spite of the interfering activities shown in table 1 from other trace elements in the Kevlar samples, Th could be determined with a reasonable error, while this was not the case with U. The γ-ray peak regions for determining U and Th from ^{239}Np 106 keV and ^{233}Pa 312 keV are shown in figures 3 and 4 respectively. A summary of the relevant experimental data is given in table 2. It can be seen from table 2 that the intrinsic background at 312 keV peak region from the shielded detector is approximately a factor of 30 times smaller than the background produced by the activities in the sample. The background from the activities in the sample is approximately 20% smaller in Cd shielded irradiation than in regular irradiation. The counting sensitivity is approximately a factor of two times the one sigma background counts in the regular irradiation while it is only 65% of the one sigma background in the Cd shielded irradiation. The net peak area of the peak at 312 keV in figure 4 from the regular irradiation gives a finite value for Th in the Kevlar rope sample as also the Cd

shielded irradiation.

The counting sensitivity in the Cd shielded irradiation is approximately four times less than in the regular irradiation, and seems to be unfavourable with respect to the one sigma background at 312 keV. Figure 5 shows the calculated background in the 312 keV peak region from the spectrum recorded with the Kevlar sample employing Cd shielded irradiation. In addition, the 312 keV peak shape from the Aℓ foil standard corresponding to 100 pg/g and 300 pg/g is shown added to the interpolated background to obtain a feel for counting sensitivity and peak to background ratio. From this comparison it can be seen that there is sufficient counting sensitivity to detect 100 pg/g in the Cd shielded irradiation even though the background is only reduced by 20% relative to the regular irradiation in the reactor. Therefore, the value of Th quoted in table 2 from Cd shielded irradiation may be taken to be reliable. The difference between the two values of Th for two samples of Kevlar from the same rope may be purely statistical. However, the difference may also be taken to be real because of the possibility of incidental contamination afforded by the large surface area of the fibres used in spinning the rope, and the consequential possibility to trap dust in the braided rope during manufacture. In addition, from the point of view of radiation exposure of the analyst the Cd shielded irradiation may be the preferred choice.

Unlike the thorium values, the uranium values could not be obtained with any degree of certainty. As can be seen from figure 3 and table 1, the conditions are not favourable for determining U values. However, the counting sensitivity may be used to place limits on U content of the Kevlar rope samples. One sigma fluctuations of the background in the peak region at 106 keV are of the order of 100 pg/g. However, the critical level[7] and the lower limit of detection[8] are higher.

A summary of Th and U values determined in this work for three types of rope materials is given in table 3. The trace elements in Kevlar ropes and the practical aspects of the braided rope structure being a trap for dust are limiting factors in the interpretation of the results in table 3.

Otherwise, the present work shows that NAA even with Cd shielded irradiations has the required sensitivity for SNO purposes.

Table 1. Comparison of counts h^{-1} g^{-1} at 17 day delay in spectra recorded from Kevlar rope samples irradiated in regular or Cd shielded positions in the reactor. Errors are one sigma counting statistics.

Isotope	$T_{1/2}$*	E_g(keV)*	Regular	Cd shielded	Average elemental concentration (ppm)
^{51}Cr	27.7d	320	6979 ± 0.1%	255 ± 0.7%	2
^{115}Cd	53.4h	336	86 ± 4.1%	417 ± 0.5%	
^{198}Au	2.696d	412	886 ± 0.5%	93 ± 1.4%	
^{82}Br	35.34h	554 776	216 ± 1.4% 197 ± 1.1%	110 ± 0.8% 99 ± 1.0%	
^{122}Sb	2.68d	564	3679 ± 0.2%	1262 ± 0.1%	0.02
^{124}Sb	60.2d	603	5882 ± 0.1%	1956 ± 0.1%	
^{134}Cs	2.062y	796	78 ± 1.5%	69 ± 0.8%	
^{110m}Ag	252d	658 885	68 ± 1.7% 38 ± 2.5%	68 ± 1.1% 40 ± 1.2%	
^{58}Co	70.8d	811	237 ± 0.6%	171 ± 0.4%	
^{54}Mn	312d	835	54 ± 1.9%	65 ± 0.9%	
^{59}Fe	44.6d	1099 1292	402 ± 0.4% 272 ± 0.5%	25 ± 1.5% 20 ± 1.5%	15
^{65}Zn	244.1d	1115	840 ± 0.3%	98 ± 0.6%	4
^{60}Co	5.271y	1173 1332	508 ± 0.3% 458 ± 0.3%	42 ± 1.0% 39 ± 1.0%	0.04
^{86}Rb	18.8d	1077	48 ± 1.9%	19 ± 1.8%	

* $T_{1/2}$ values and energies from reference 6.

Table 2. Comparison of counts h^{-1} g^{-1} at 17 day delay in spectra recorded from Kevlar rope samples at 312 and 106 keV regions for Th and U determinations respectively.

	312 keV region (Th)		106 keV region (U)	
	Regular	Cd shielded	Regular	Cd shielded
Net counts in peak region $h^{-1}.g^{-1}$ of sample weight	17 ± 13%		8 ± 72%	
Counting sensitivity: Net counts in peak region $h^{-1}.ng^{-1}$ of Th or U	55	14	6	
Background Counts:				
1. from activities in the sample h^{-1} g^{-1}	538	446	4077	
2. from shielded detector h^{-1}	18	18	28	28
Concentration pg/g	359 ± 43	134 ± 64		124 ± 189

Table 3. Summary of radioactivity in ropes considered for use in SNO.

Material	ID	Analyzed weight (g)	Th (pg/g)	U(pg/g)
Kevlar	J01	13.5	359 ± 183	< 72
	J07	13.1	134 ± 64	124 ± 189
Spectra	J09	6.4	250 ± 108	173 ± 130
Vectran	J13	12.0	675 ± 117	139 ± 16
	J19	11.4	611 ± 237	173 ± 13

References:

1. J.D. Stachiw, Report Apr. 17, 1990.
2. J.D. Stachiw, Report Oct. 27, 1990.
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4. N.A. Tamblyn, Report Aug. 19, 1990.
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7. L.A. Currie, Anal. Chem. 40 (1968) 586.
8. G. Bernasconi, E.D. Greaves, and L. Sajo-Bohus, Nucl. Instr. and Meth. A307 (1991) 491.

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J01-0002: Kevlar rope : count

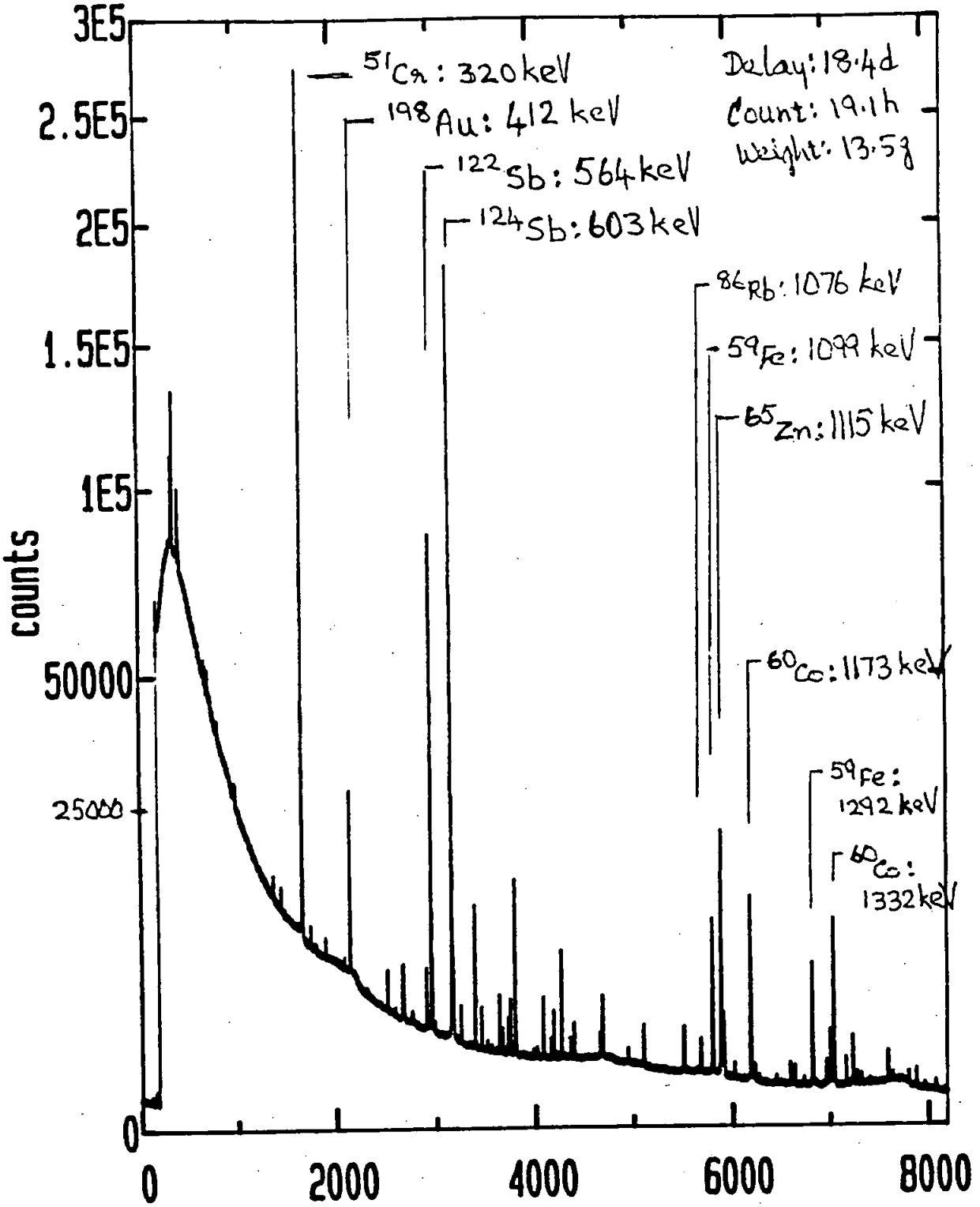

Figure 1

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J07-0004: Kevlar rope: count

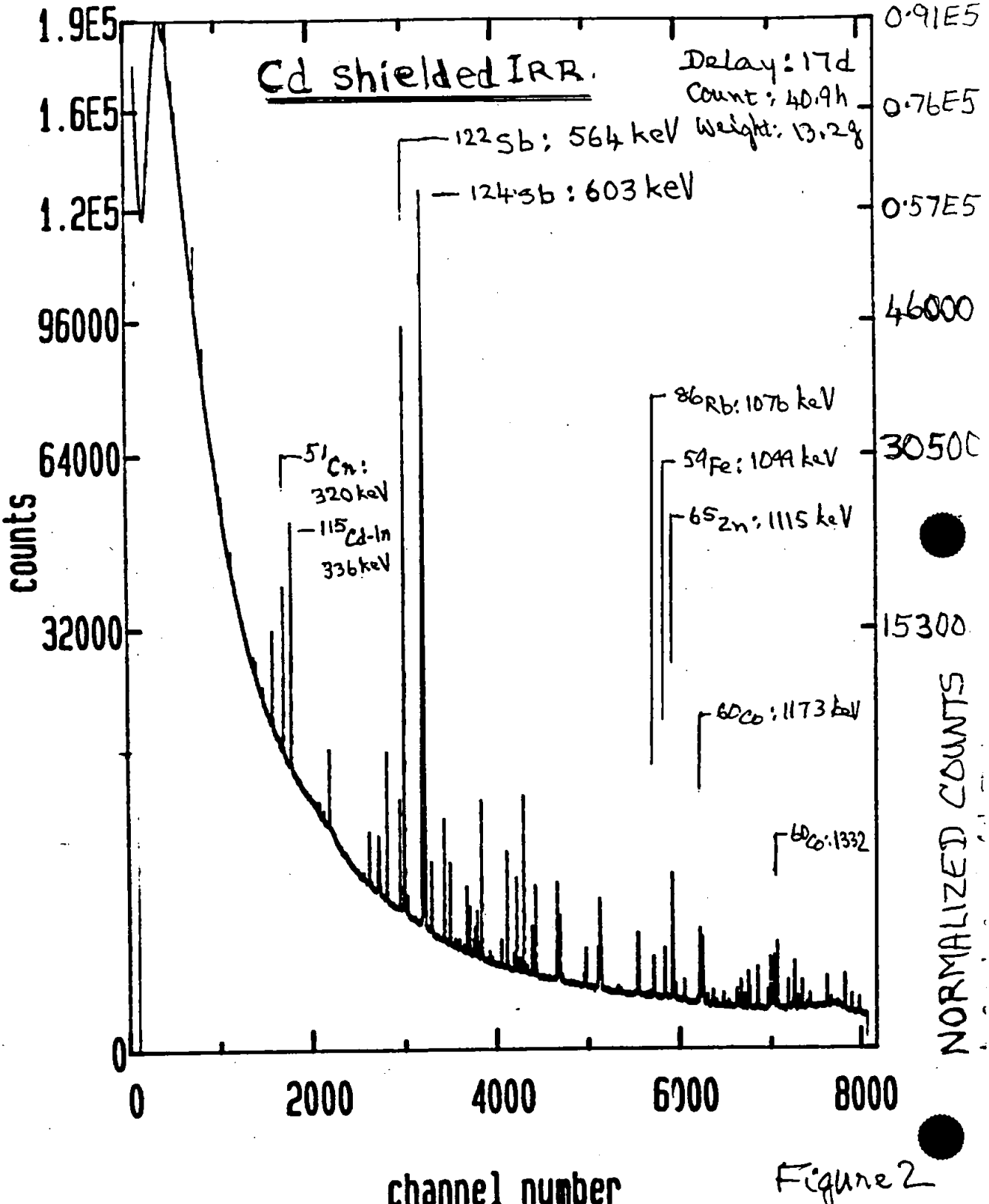

Figure 2

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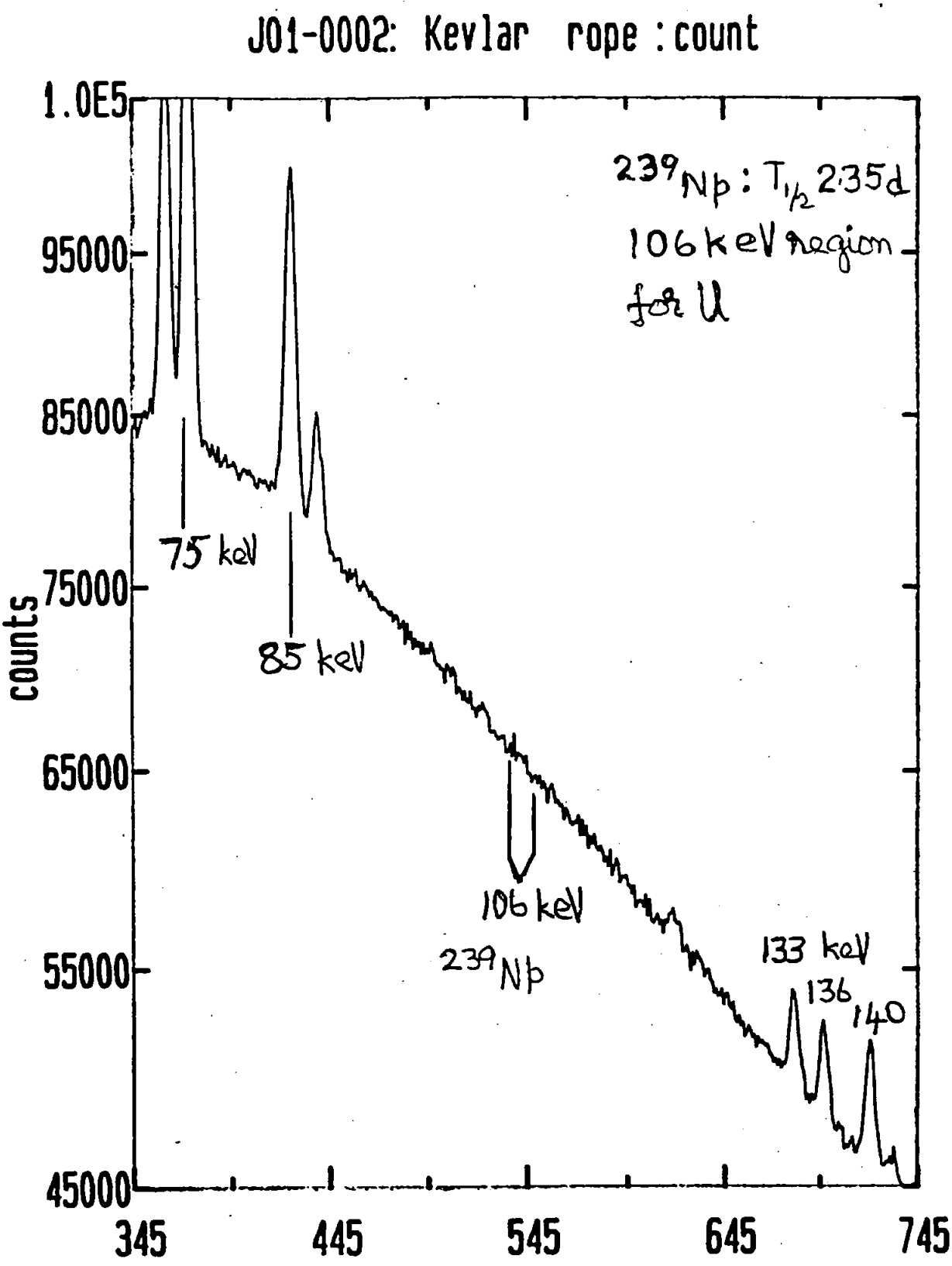

Figure 3

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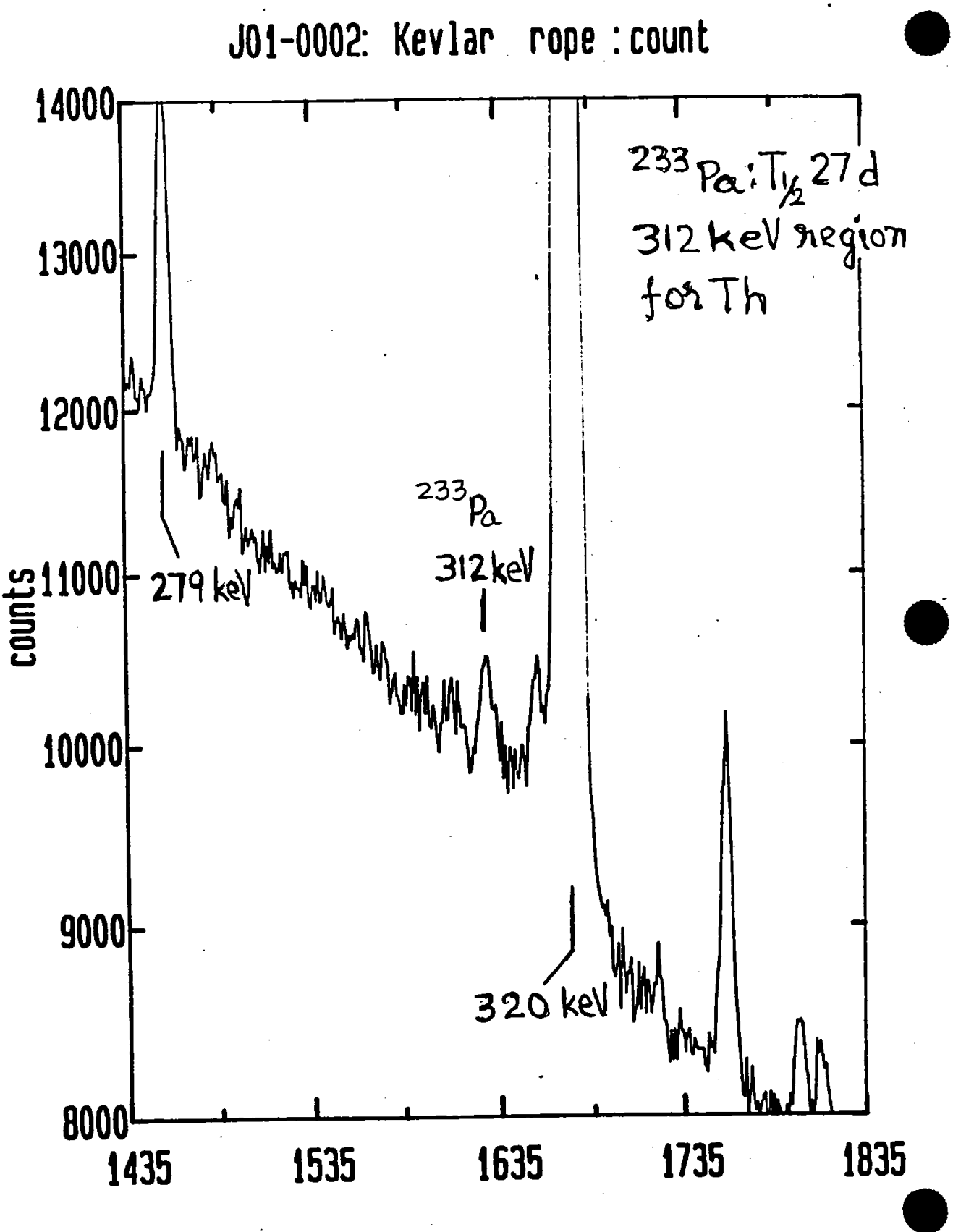

Figure 4

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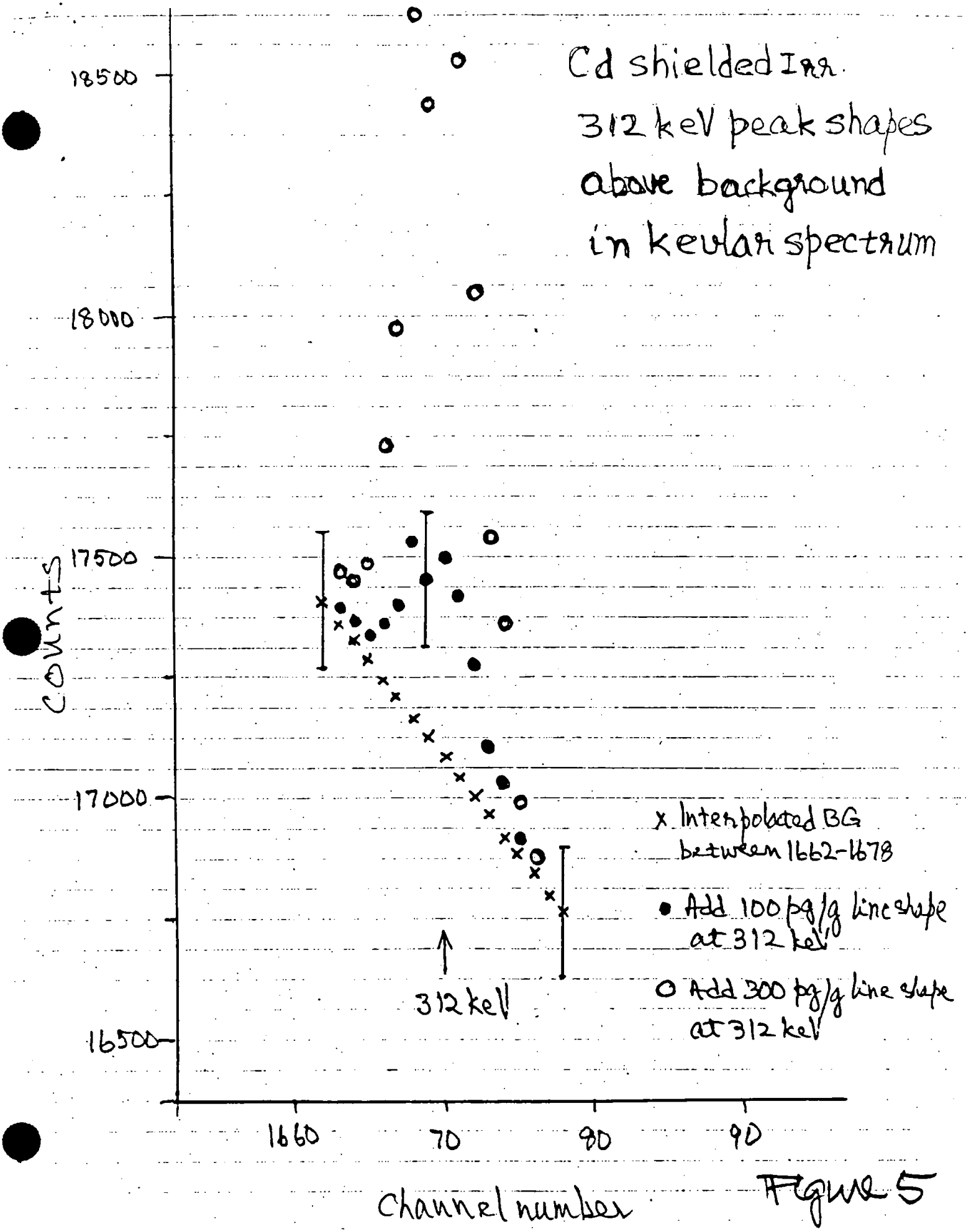
Cd shielded Inn.
312 keV peak shapes
above background
in kevlar spectrum
18500
18000
17500
17000
16500
counts
x Interpolated BG
between 1662-1678
• Add 100 pg/g line shape
at 312 keV
o Add 300 pg/g line shape
at 312 keV
312 keV
1660
70
80
90
channel number

Figure 5