Determination of the ^{232}Th nucleus number using small solid angle method

Presented by Haoyu Jiang

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1. Motivation

1.1 Introducion

^{232}Th: the most stable isotope of thorium (natural abundance 99.98%), is a fissionable nucleus which plays an important role in the Th/U fuel cycle.

^{232}Th (*n, f*) reaction: a important reaction in nuclear engineering applications and it could enhance our understanding in nuclear physics (such as "thorium anomaly" effect, the triple-humped barriers, etc).

1.2 Problems

I. Comparing to other fissile nuclei, such as ^{238}U or ^{235}U, the experimental measurements of ^{232}Th are fewer for the (*n, f*) reaction.

II. There is a systematic difference between the measurement results using different neutron sources (mono-energetic neutron sources and white neutron sources).

1: Motivation

1.3 Experimental data of ^{232}Th(n, f) reaction

The results using mono-energetic neutron sources are obviously higher than those using white neutron sources in the MeV region.

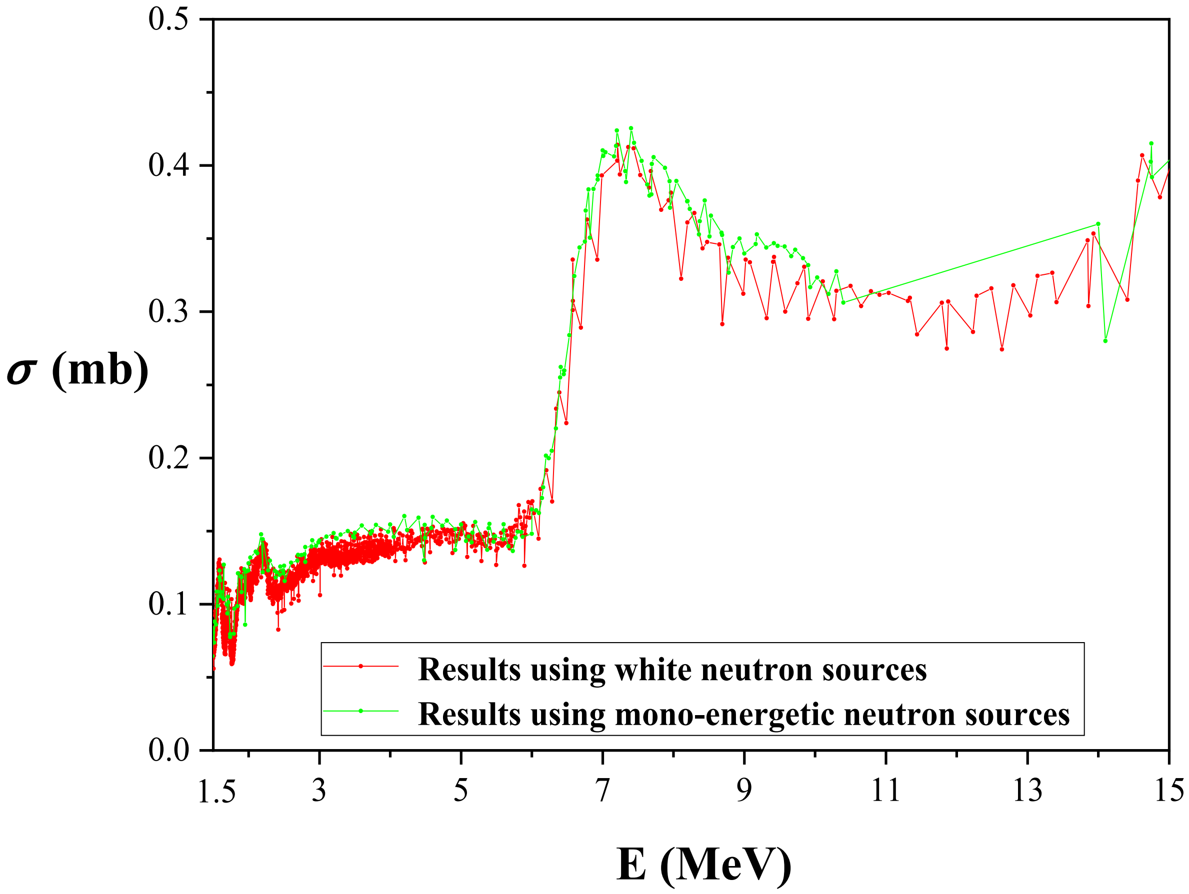

Fig.1 Experimental data from 1.5 to 15 MeV of ^{232}Th(n, f) reaction using white neutron sources and mono-energetic neutron sources. The results were taken from EXFOR library (after 1970s).

1. Motivation

1.4 Differences of (*n*, *f*) cross-section results from different neutron sources

Table I. The Percentage which the (*n*, *f*) cross-section results from mono-energetic neutron sources higher than the results from white neutron sources

Nucleus \ Percentage \ Energy region	0.1 - 3.5 MeV	3.5 - 10 MeV	10 - 20 MeV	0.1 - 20 MeV
^{233}U	-1.76%	-1.66%	1.91%	-1.70%
^{236}U	-1.29%	0.36%	2.79%	-0.45%
^{237}Np	-3.39%	-3.79%	-3.82%	-3.68%
^{238}U	-2.84%	0.11%	0.03%	-1.58%
^{239}Pu	-1.34%	3.70%	-0.05%	-0.32%
^{240}Pu	-0.62%	0.60%	-0.50%	-0.26%
^{235}U	2.20%	-1.80%	-1.13%	1.33%
^{232}Th	-0.51%	4.64%	-0.61%	2.07%

Data were taken from EXFOR (after 1970s)

The measured ^{232}Th(*n*, *f*) cross-section results using mono-energetic neutron sources are obviously higher than those using white neutron sources especially in the 3.5 – 10 MeV region.

1. Motivation

1.5 Future Plan

In order to clarify the existing discrepancies, accurate ^{232}Th(*n, f*) cross-section measurements in the 3.5 – 10 MeV region are being planned.

1.6 Current progress

Determination of the ^{232}Th nucleus number by small solid angle method.

(The emitted α particles with small solid angles would have shorter track in the material, which lead to less energy loss and lower tailing of the peaks.)

1. Motivation

1.6 Current progress

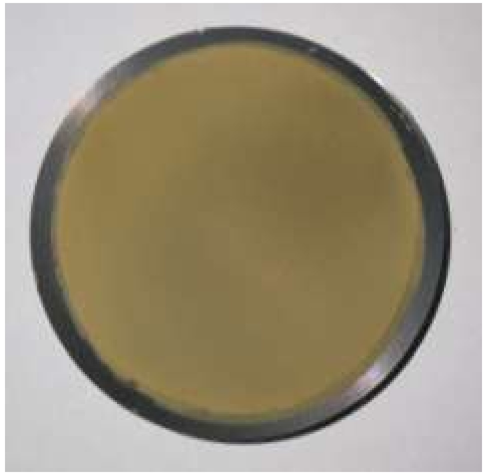

Fig.2 Picture of the $^{232}Th(OH)_4$ sample with tantalum film

- The $^{232}Th(OH)_4$ sample was prepared by Frank Laboratory of Neutron Physics.

- The spectrum from ^{232}Th would be complicated because of the α particles from the daughter nuclides of ^{232}Th (the small solid angle method could reduce the tailing and overlap of peaks).

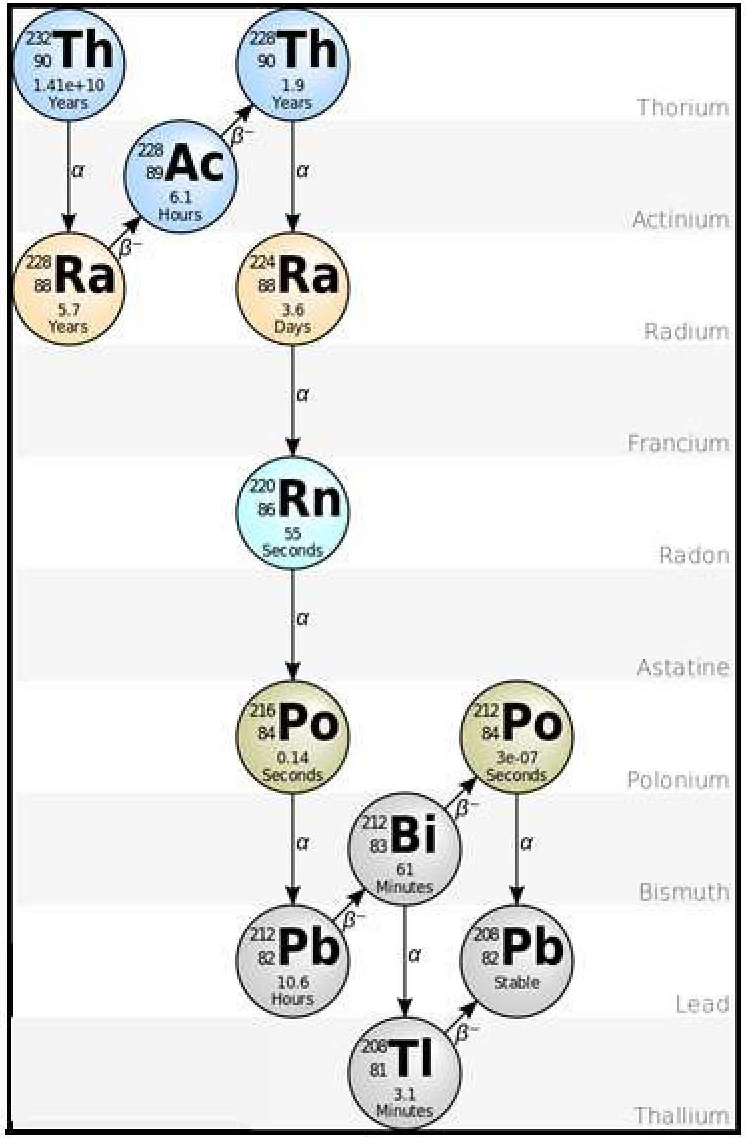

Fig.3 Decay chain of ^{232}Th

2. Details of experiment

2.1 The small solid angle device

2.1.1 Compositions of the small angle device

① The vacuum chamber;
② The vacuum pumping system;
③ The electronics;
④ The digital data-acquisition (DAQ) system.

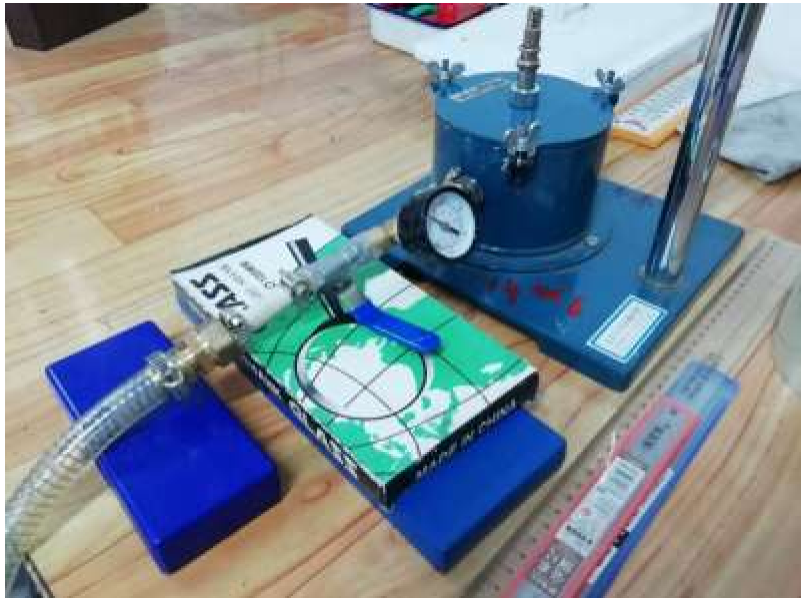

Fig.4 Picture of the device.

Fig.5 Picture of the device.

2. Details of experiment

2.1 The small solid angle device

2.1.2 Compositions of the vacuum chamber

① Three anti-scattering baffles;
② A sample holder;
③ A diaphragm;
④ A Au-Si surface barrier semiconductor detector;
⑤ Three screw rods;
⑥ Screws and nuts.

(The sample holder, detector, diaphragm and anti-scattering baffles are connected by three screw rods which are mounted at the lid of vacuum chamber, and all of them are centered at a common symmetry axis.)

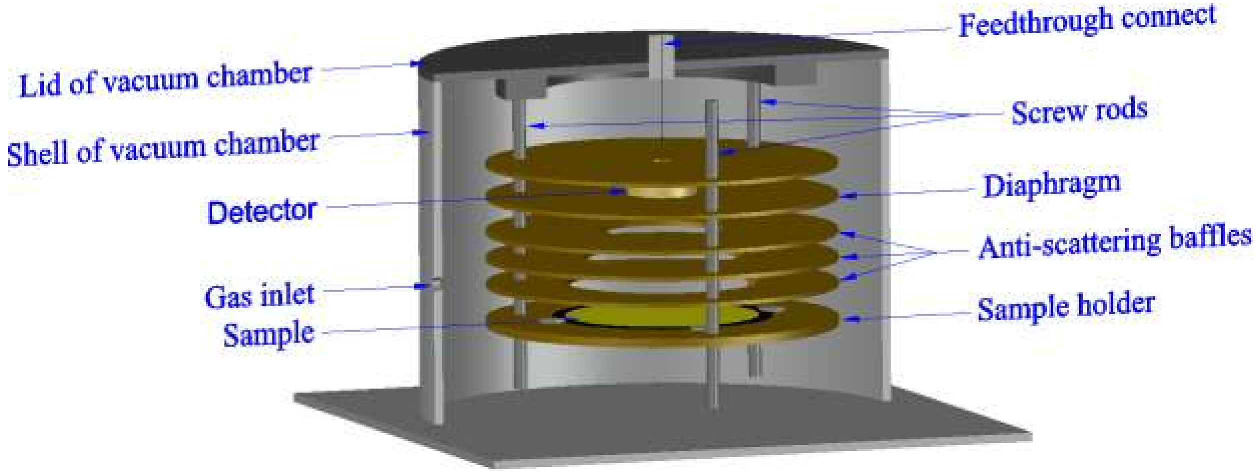

Fig.5 CAD structure of the vacuum chamber.

Fig.6 Picture of the structure inside the vacuum chamber.

2. Details of experiment

2.2 Geometry

① The diameter of diaphragm: 7.00 mm;
② The diameter of $^{232}Th(OH)_4$ foil sample：44.0 mm;
③ The distance from sample to diaphragm: 29.90 mm.
(the sample-to-diaphragm distance (29.90 mm) = the holder-to-diaphragm distance (30.01 mm) − the height of tantalum (0.11 mm))

(The positions of diaphragm and sample holder were fixed by nuts on the screw rods, and an electronic digital caliper measured the distance.)

2. Details of experiment

2.3 The electronics and the DAQ system

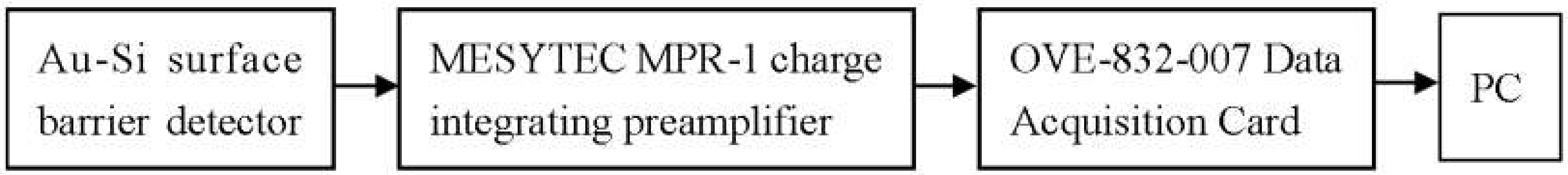

Fig.5 Block diagrams of the electronics and the DAQ system

Ps: A data-acquisition software was developed using the LABVIEW language to control the DAQ system, process the measured results and save the waveform data onto the hard disk of our PC.

2. Details of experiment

2.4 The experimental process:

1) Foreground measurement for α events from ^{232}Th for 1258384s;
2) Background measurement using tantalum film for 601128s.

3. Results

3.1 Spectra from measurements

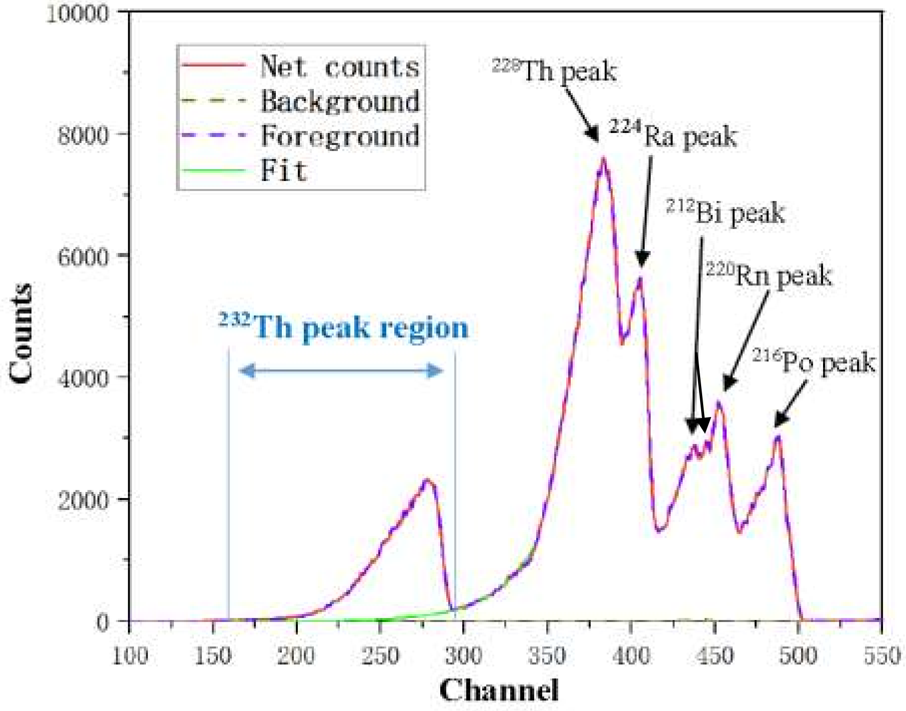

Fig.7 Spectra from measurements

Characteristics

① The background is quiet weak；

② The tailing of the peaks from the daughter nuclides would increase the total counts of the ^{232}Th peak. (We used an exponential function to fit the tailing then subtracted from ^{232}Th peak region. The fitting counts accounted for 4.81% of the total counts of the ^{232}Th peak.)

3. Results

3.1 ^{232}Th nucleus number

The calculated equation of ^{232}Th nucleus number N:

$$N = \frac{n_{fore} - n_{back} \times \frac{t_{fore}}{t_{back}} - n_{fit}}{t_{fore} \times \varepsilon \times \lambda}$$

n_{fore}: the foreground counts in the ^{232}Th peak region;

n_{back}: the background counts in the ^{232}Th peak region;

n_{fit}: the fitting counts in the ^{232}Th peak region;

t_{fore}: the durations of foreground measurements;

t_{back}: the durations of background measurements;

ε: the detection efficiency of the small solid angle device calculated by Monte Carlo simulation (energy loss and back-scattering were taken into account), and the value of ε is 0.0024723 in our measurements;

λ: the α decay constant of ^{232}Th;

The calculated ^{232}Th nucleus number: 1.85×10^{19}

3. Results

3.2 Uncertainties

① The uncertainty of geometry (ε): 0.75% ;

② The uncertainty of Monte Carlo simulation (ε): 0.33%;

③ The uncertainty of and unevenness of sample edge (ε): 0.30%;

④ The uncertainty of ^{232}Th peak region determination (n_{fore}): 0.19%;

⑤ The uncertainty from the statistical error (n_{fore}): 0.35%;

⑥ The uncertainty of fit (n_{fit}): 0.96%;

⑦ The uncertainty of the α decay constant of ^{232}Th (λ): 0.40%.

(Other error sources are very small so we ignored them.)

The total uncertainty: 1.41%

4. Summary

- The ^{232}Th(*n, f*) cross-section data from EXFOR library were collected and analyzed, and the measurement results using mono-energetic neutron sources are obviously higher than those using white neutron sources.
- A small solid angle device was designed and installed.
- The ^{232}Th nucleus number was determined by small solid angle method, and the measured result is $1.85\times10^{19}(1\pm1.41\%)$.

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THANKS