Determination of the ^{232}Th(n, γ) cross section from 10 keV to 200 keV at the Back-n facility at CSNS

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I. Introduction

- **Thorium-uranium (Th-U) nuclear fuel cycle**, The fissile ^{233}U is generated through the ^{232}Th neutron capture reaction and the subsequent two consecutive β decays. Compared to the conventional uranium-plutonium cycle, the lighter nucleus ^{232}Th in the Th-U cycle is used, significantly reducing the radioactive of the spent fuel by greatly reducing the accumulation of heavy transuranium isotopes[1,2].
- **Large parity-nonconservation effects** were observed in the p-wave resonance of ^{232}Th[3-5].

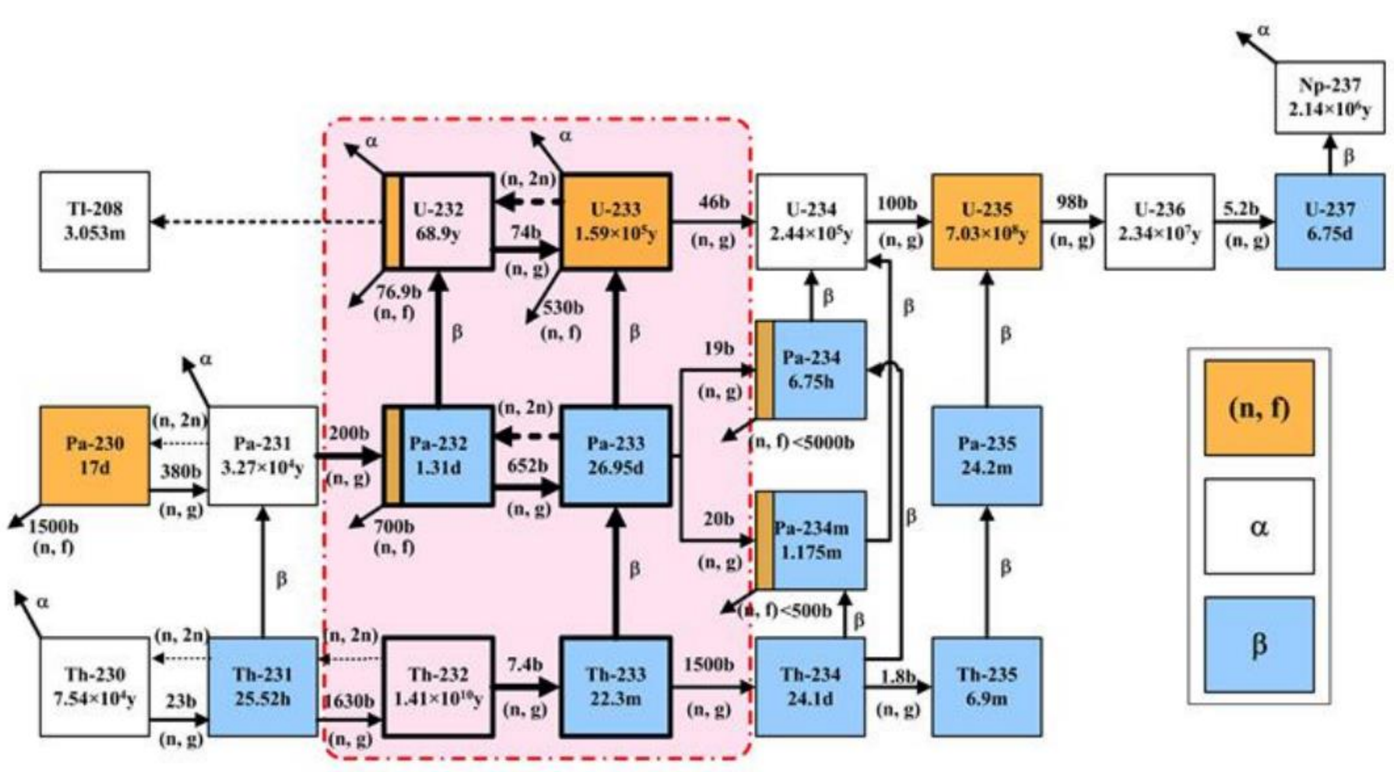
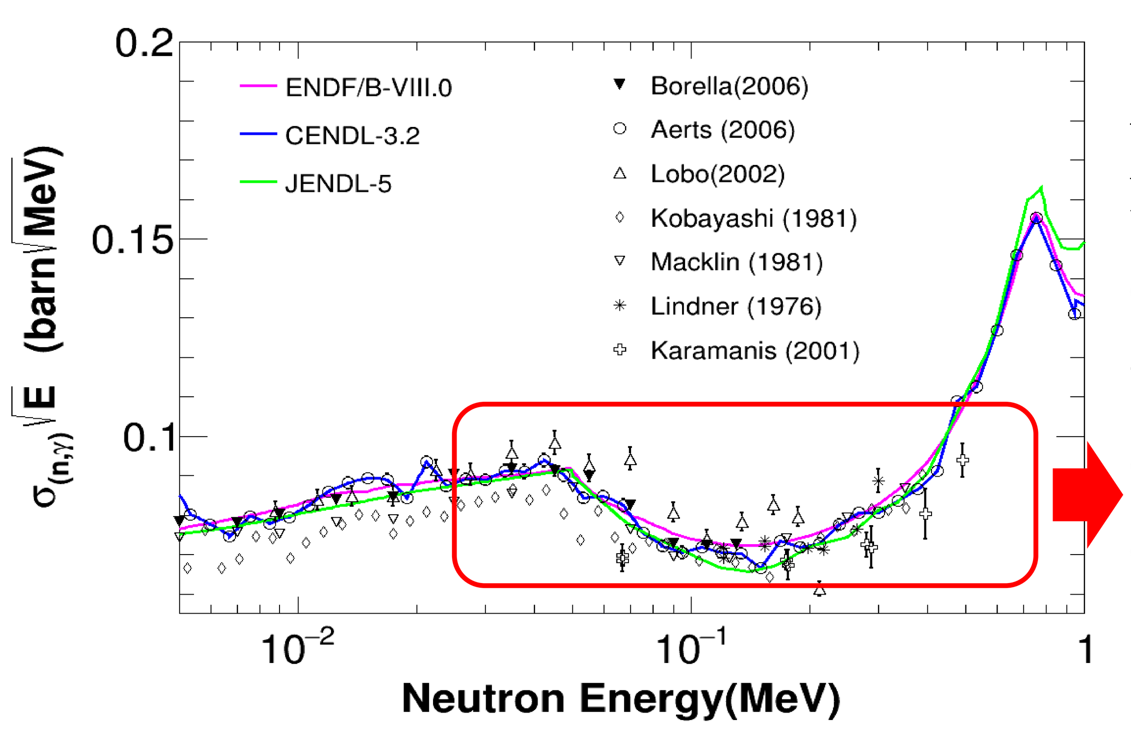


FIG1. The fissile ^{233}U is generated through the ^{232}Th.

- **Existing experimental data**



Although many measurements have been performed, there are still differences in the ^{232}Th(n,γ) cross section from 30 to 500 keV, the differences are up to 10%[5-10].

FIG2. Existing experimental data of ^{232}Th .

II. Experimental

- **The back-streaming white neutron beam-line (Back-n) of China Spallation Neutron Source (CSNS)**

The Back-n of the CSNS became fully operational in March 2018. At the Back-n of the CSNS, neutrons are produced by spallation reactions induced by double bunches per pulsed, 41 ns wide (FWHM) and the interval between the two bunches is 410 ns, 1.6 GeV/c proton beam with a typical repetition rate of 25 Hz, impinging on a tantalum-cladded and water-cooled sliced tungsten target.

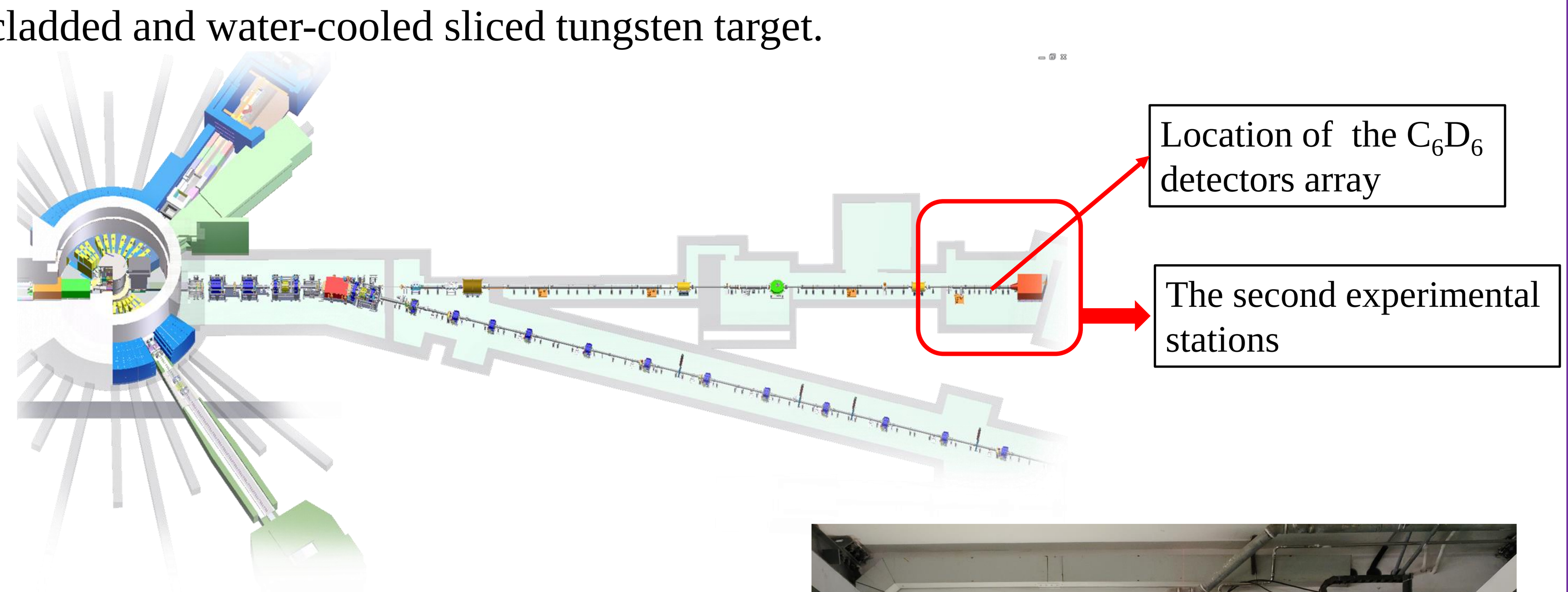


FIG3. Layout of Back-n at CSNS.

- **The C_6D_6 detectors array**

The C_6D_6 detectors array are 12.7 cm in diameter and 7.62 cm in length, contained in a 1.5 mm thick aluminum capsule and coupled with a photomultiplier tube (ETEL 9390 KEB PMT). The array was placed upstream of the sample relative to the neutron beam. The angle between these detectors and the beam direction was 125 degrees, and the angle between adjacent detectors was 90 degrees.

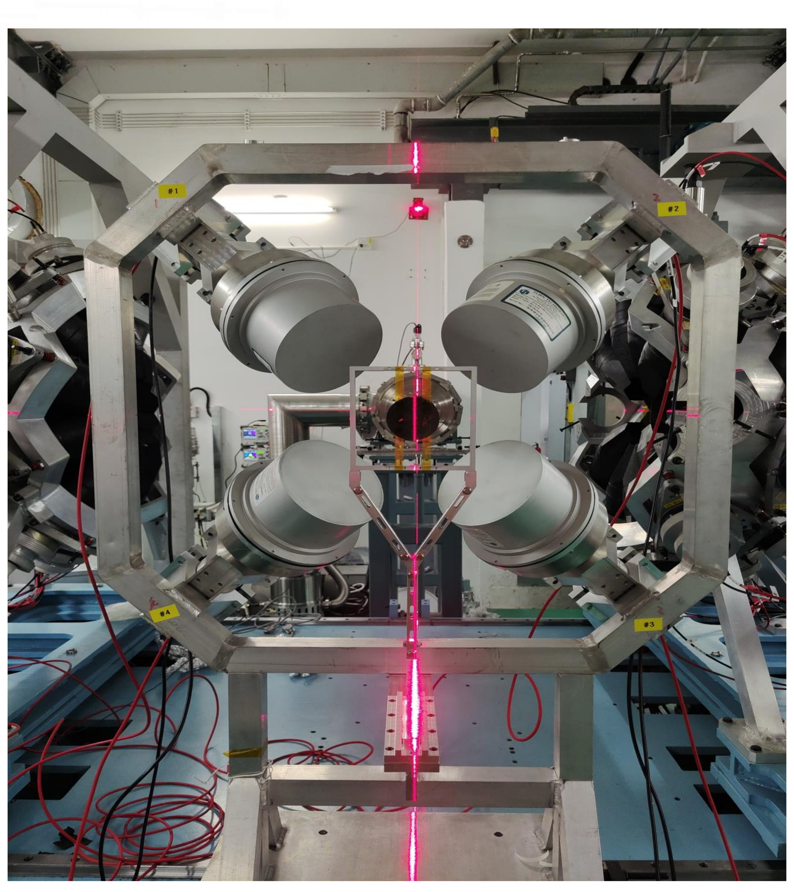


FIG4. Photo of the C_6D_6 detector system at Back-n.

III. Data Analysis

- **The time-of-flight (TOF) technique.**
- **The pulse height weighting technique**[10] was applied to determine the number of capture reactions from the measured complex γ-rays cascade spectrum following neutron capture in this work.
- **The Saturated Resonance technique (SR)** is conveniently applied to calibrate the efficiency of the γ-rays detector and neutron flux monitor.
- **The background** was determined by a lead sample measurement and detailed Monte Carlo simulations.
- **To normalize these background components**, the black resonance filter technique was applied.

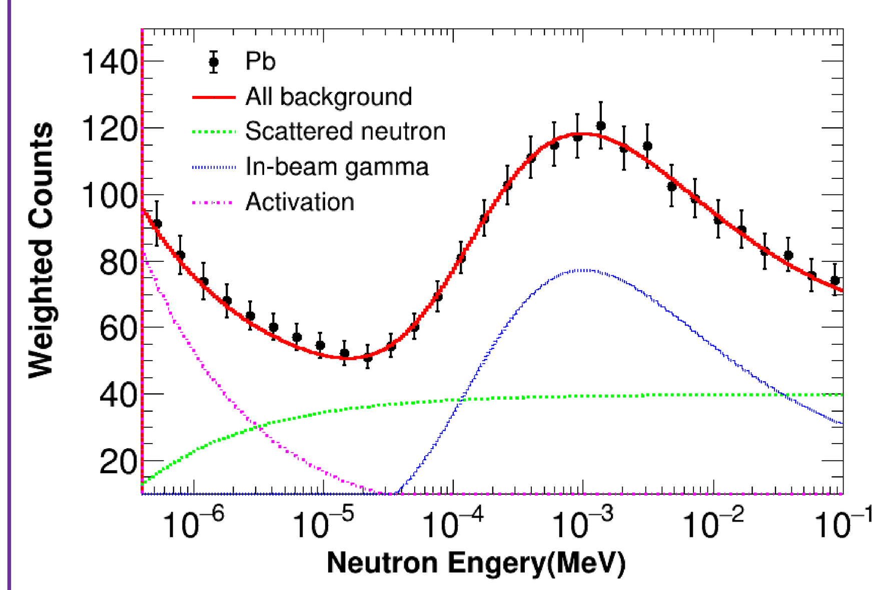


FIG5. Decomposition of the spectrum measured with the ^{nat}Pb sample into the scattered neutron background and the contribution from in-beam γ rays.

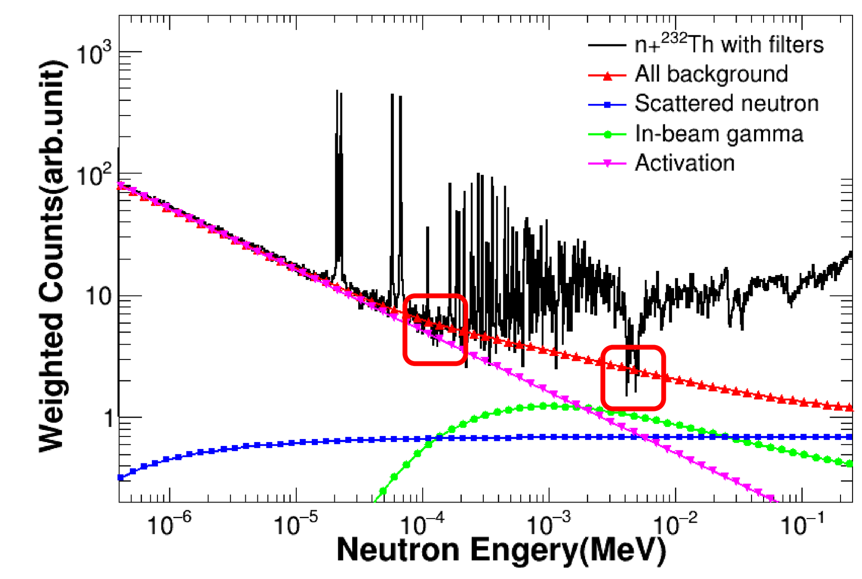


FIG6. ^{232}Th spectra with filters in the neutron beam. The three background components have been fitted to match the minimum of the filter dips.

- **The correction factor** consisted of the normalization correction factor, the threshold correction factor, the dead-time correction factor, and the multiple scattering correction factor.
- In this work, the ^{232}Th(*n*, *γ*) average cross section is obtained from the experimental data and the ENDF/B-VIII.0 evaluation data, which can be expressed as

$$\sigma_{Th} = \frac{\langle \sigma_{Th} \rangle}{\langle \sigma_{Au} \rangle} \cdot \sigma_{Au}$$

IV. Summary & Conclusions

- This work also carefully evaluated the uncertainties of PHWT, normalization, background subtraction, correction, and relative measurement. The total uncertainty is in the range of 4.5% - 4.8%.

Table 1 Different components of estimated uncertainty in the measured cross section.

<table>
<tr><th>Source of uncertainty</th><th>^{232}Th (%)</th><th>^{197}Au (%)</th></tr>
<tr><td>PHWT</td><td colspan="2">1.2</td></tr>
<tr><td>Normalization</td><td>2.0</td><td>1.0</td></tr>
<tr><td>Background subtraction</td><td>1.5</td><td>1.0</td></tr>
<tr><td>Correction</td><td colspan="2">1.3</td></tr>
<tr><td>Counting statistics</td><td colspan="2">1.0</td></tr>
<tr><td>Relative measurement</td><td>3.2-3.9</td><td></td></tr>
</table>

- The determined experimental data by taking ^{197}Au(n, γ) cross sections as reference are consistent with the evaluations of the CENDL-3.2 and JENDL-5 within the uncertainties from 10 to 200 keV.
- TALYS calculation agrees very well with the experimental data.

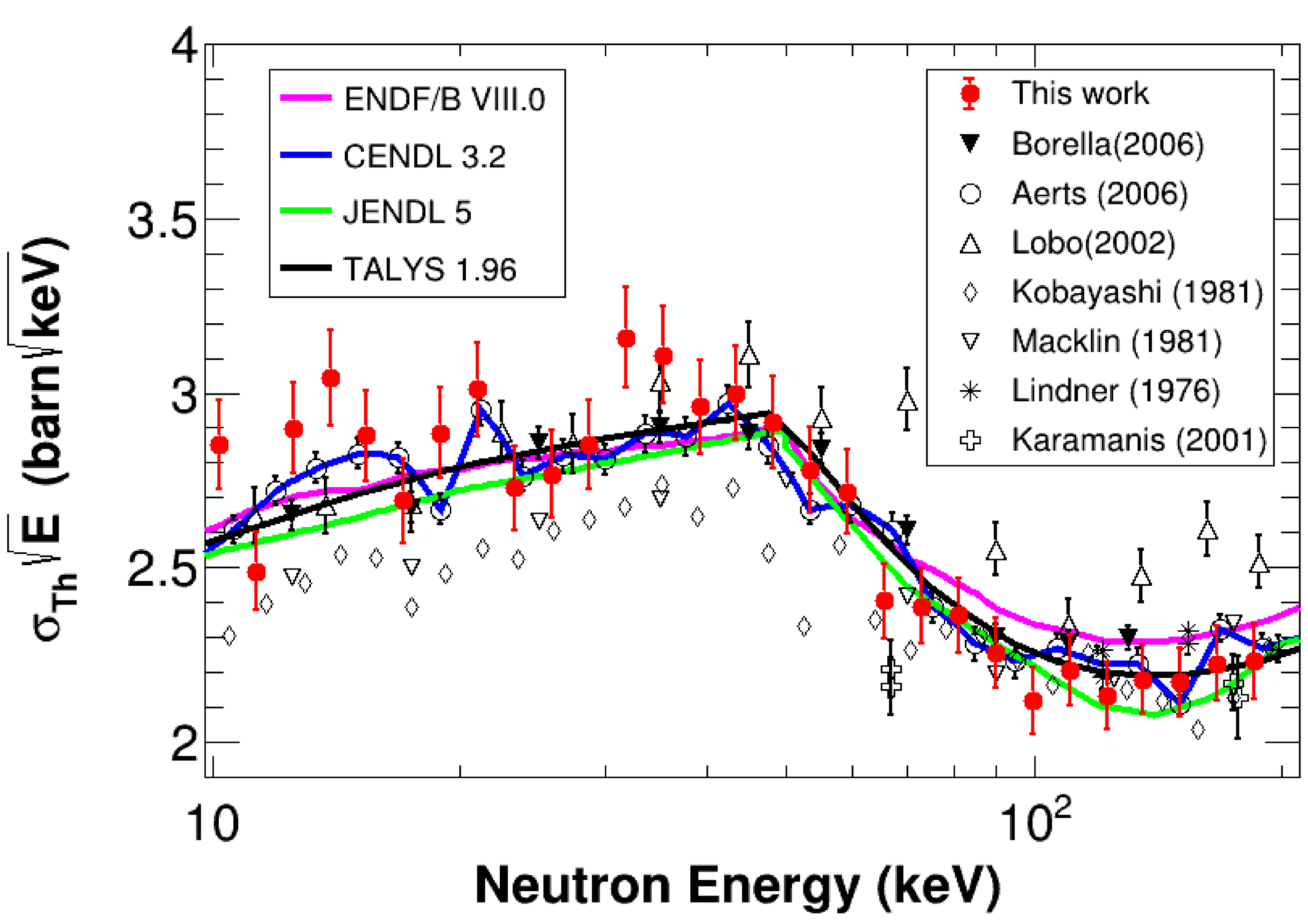


FIG. 7 The capture cross sections of ^{232}Th multiplied by the square root of the neutron energy.

V. Acknowledgments

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