CROSS SECTIONS OF THE $^{148}Sm(n,\alpha)^{145}Nd$ REACTION IN THE 4.8–5.3 MEV NEUTRON ENERGY REGION

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ISINN-31, May 26 to 30, 2025, China

Introduction

- The investigation of the **^{148}Sm(n,α)** reaction cross-sections is highly relevant for several key areas:

Nuclear Engineering & Material Science

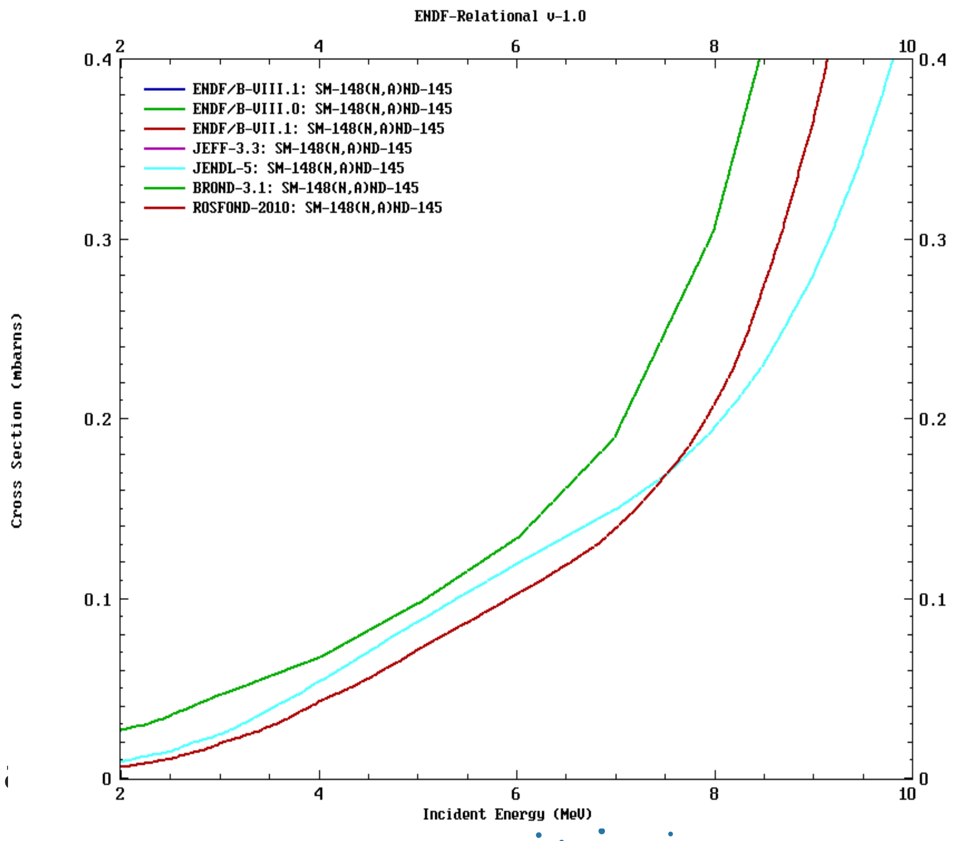
Essential for assessing **radiation damage** in structural materials (e.g., embrittlement and void swelling caused by helium accumulation).
Critical for the design and safety of **nuclear reactors**, particularly in fast neutron spectra (e.g., Gen-IV reactors, fusion systems).

Nuclear Data Accuracy

Current nuclear databases **(ENDF, JENDL, JEFF, ROSFOND)** show **large discrepancies** (up to an order of magnitude) in ^{148}Sm(n,α) cross-sections.
High-quality experimental data is needed to reduce uncertainties in neutronics simulations.

Astrophysics & Nucleosynthesis

Samarium isotopes play a role in **s-process (slow neutron capture) nucleosynthesis** in stars.
Precise (n,α) data improves models of **stellar evolution and elemental production**.



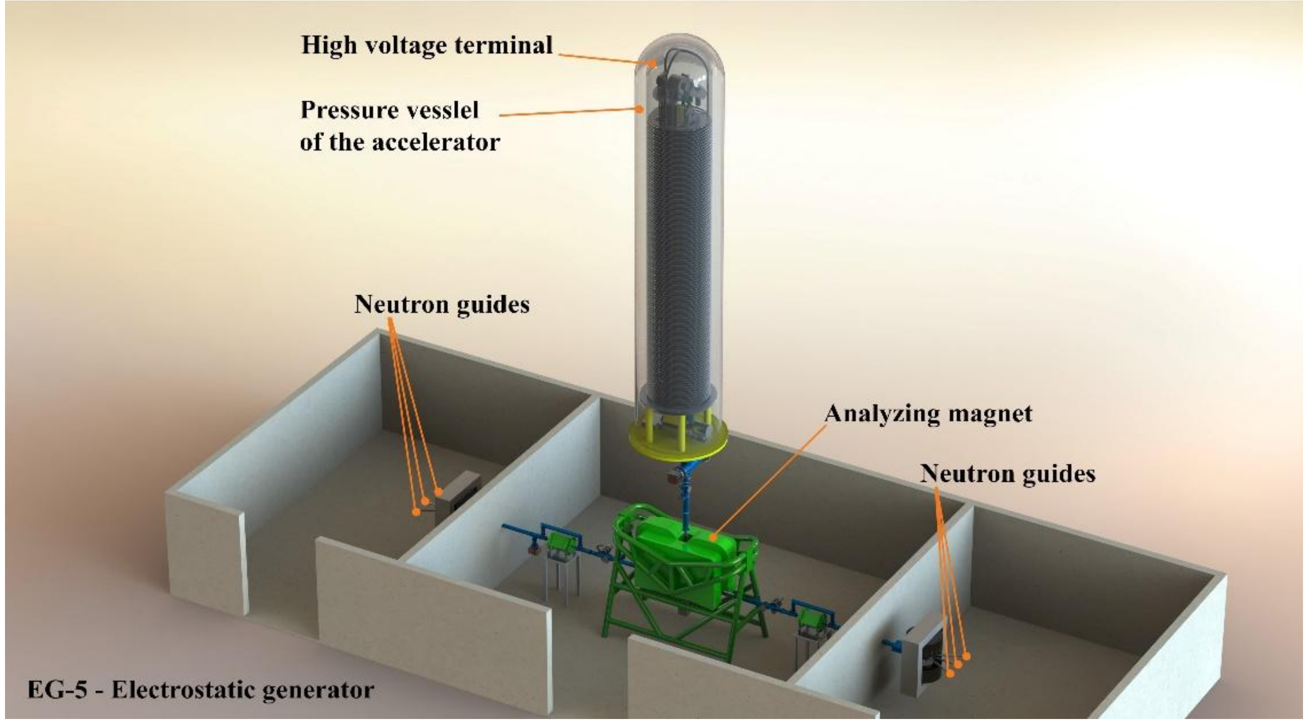
- Natural **^{nat}Sm** contains **^{144}Sm, ^{149}Sm, ^{150}Sm, ^{152}Sm, and ^{154}Sm**, a well as two long-lived radioisotopes: **^{147}Sm** (half-life **1.06×10^{11} years**) and **^{148}Sm** (half-life **7×10^{15} years**, abundance **11.24%**).

- **Previously,** we measured the **(n,α) reaction cross-sections** in the **MeV energy range** for the isotopes **^{144}Sm, ^{147}Sm, and ^{149}Sm**.

- **Currently, there are no experimental data** for the **^{148}Sm(n,α)^{145}Nd** cross-section in the MeV neutron energy range.

Accelerator EG-5

The Van de Graaff electrostatic accelerator, as one of the main experimental installations of the Frank Laboratory of Neutron Physics, was built in 1965.



Characteristics of the EG-5 accelerator:

- Energy region: 0.9 – 3.5 MeV
- Beam intensity for $H+$: 30 μA
- Beam intensity for $He+$: 10 μA
- Energy spread < 500 eV
- Number of beam lines: 6

Main research areas:

Nuclear Physics
- Investigations of neutron-induced reactions with the emission of charged particles

Radiation materials science

Radiation biology

Condensed matter physics

Before modernization	After modernization
Terminal voltage – 2.5 MV Beam current – 100nA Ion Energy – 1-2.5 MeV	Terminal voltage – **4.1 MV** Beam current – **50-100mkA** Ion Energy – **0.8-4.1 MeV**

600 hours/year

Experimental setup

1. Neutron source

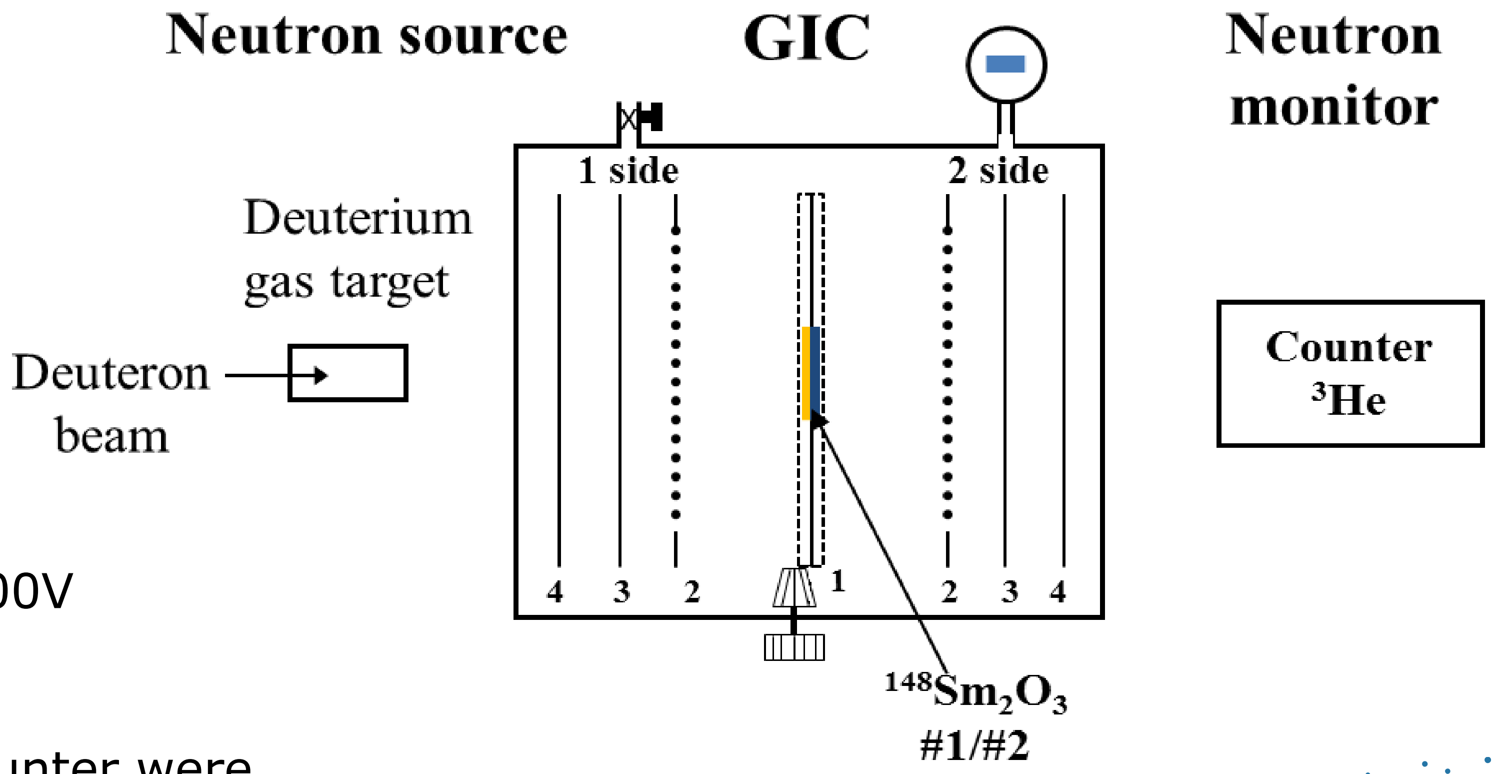
- $^{2}H(d,n)^{3}He$ reaction
- Gas pressure – 2.5 atm.
- Current– 2.5 μA
- E_d = 2.4-2.8 MeV
- E_n=4.8–5.3 МэВ
- F_n~6.5x10^5(n/sm^2*sec)

2. GIC parameters with grid:

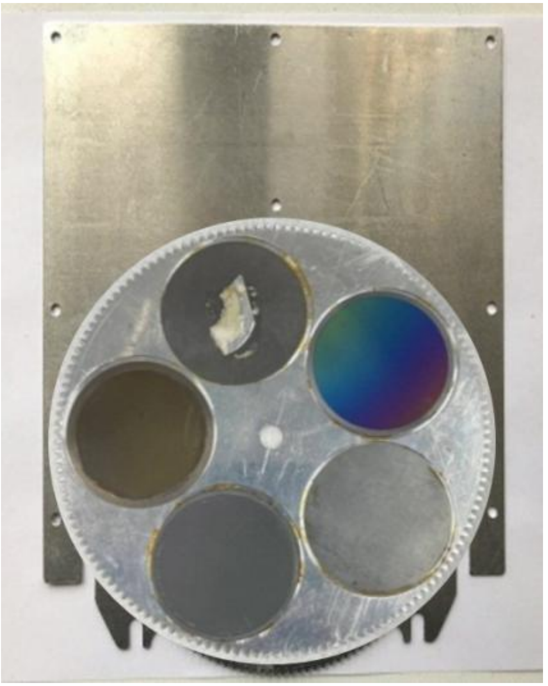
- Forward-backward: ~ 4П
- Working gas: Ar + 3.0%CO_2
- Gas pressure:3.0 atm.
- Voltage of GIC:U_a=+1800V, U_c=-2700V

3. Neutron monitors

- A fission chamber and a long ^{3}He counter were used as neutron flux monitors
- The absolute neutron flux was determined from the registration of ^{238}U fission fragments



Samples



Sample	Abundance (%)	Thickness (mg/cm²)	Diameter (mm)
$^{148}SmO_2$ 01	91.20	2.94±0.04[a]	44.0
$^{148}SmO_2$ 02	91.20	3.10±0.03[a]	44.0
$^{238}U_3O_8$	99.999	0.475	44.0

a) Thickness of samarium only

All samples were deposited on tantalum backings, 48 mm in diameter and 0.10 mm in thickness.

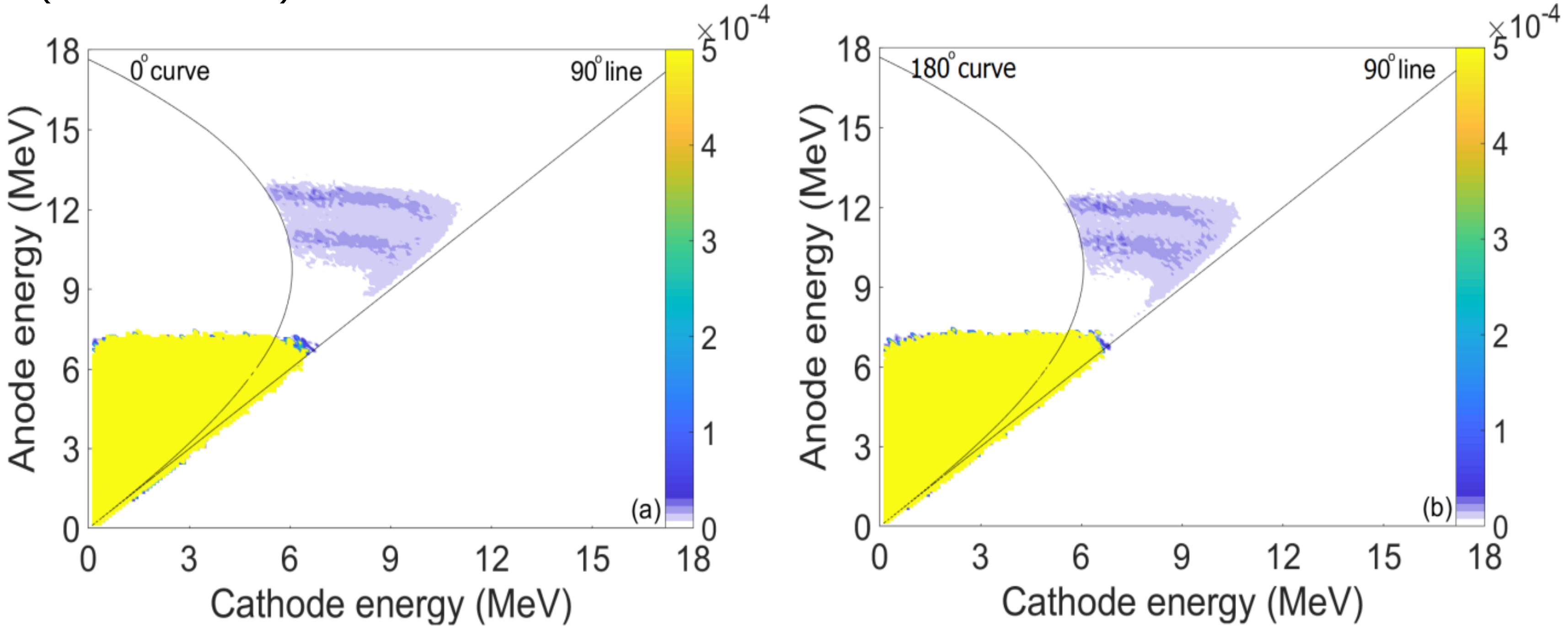
The content of Sm isotopes in the samples are as follows: ^{144}Sm (0.04%), ^{147}Sm (2.05%), ^{148}Sm (91.20%), ^{149}Sm (5.27%), ^{150}Sm (0.55%), ^{152}Sm (0.60%), and ^{154}Sm (0.29%).

The characteristics of the two $^{148}SmO_2$ samples and the $^{238}U_3O_8$ sample (for neutron flux measurement) are given in Table.

Simulation of $^{148}Sm(n,\alpha)^{145}Nd$ reaction measurements

Before performing measurements, simulations were conducted to predict the experimental spectra of the $^{148}Sm(n,\alpha)^{145}Nd$ reaction and potential interference reactions from other **samarium isotopes**, such as **^{147}Sm** and **^{149}Sm**, including (n,α) reactions involving the working gas. These simulations were carried out using **Matlab software** and **TALYS–1.96 c**ode.

Simulations were performed using a solid sample of samarium with a **thickness of 2.94 mg/cm²**, and a **mixture of Ar + 3.0%CO_2** used as the working gas at a **pressure of 3.0 atm**. The calculations covered the neutron energy range from 4.8 to 5.3 MeV and determined the expected positions of events for the studied reaction, as well as background reactions that can mask the effect. The results quantitative assessment showed that the interference from $^{147}Sm(n,\alpha)$ and $^{149}Sm(n,\alpha)$ reactions is negligible (less than 3%).



Calculated two–dimensional cathode–anode spectra of alpha particles from the $^{148}Sm(n,\alpha)^{145}Nd$ reaction at 5.3 MeV neutron energy: (a) forward and (b) backward directions.

Measurements of the $^{148}Sm(n,\alpha)^{145}Nd$ reaction with fast neutrons

The cross-section measurements were performed at **neutron energies of 4.8, 5.1, and 5.3 MeV** using the following step-by-step methodology:

1. System Calibration
- **Alpha source calibration** was conducted prior to measurements to ensure detector accuracy.

2. Foreground Measurements
- Back-to-back ^{148}Sm samples were positioned at the common cathode of the GIC to detect (n,α) reaction products.

3. Neutron Flux Determination
- The absolute neutron flux was measured using the $^{238}U(n,f)$ reaction (fission reference).
- A $^{238}U_3O_8$ sample (same dimensions and position as ^{148}Sm) was irradiated, and fission fragment counts were recorded (see Fig. 3 for anode spectrum).
- Measurement duration: ~2 hours per energy point.

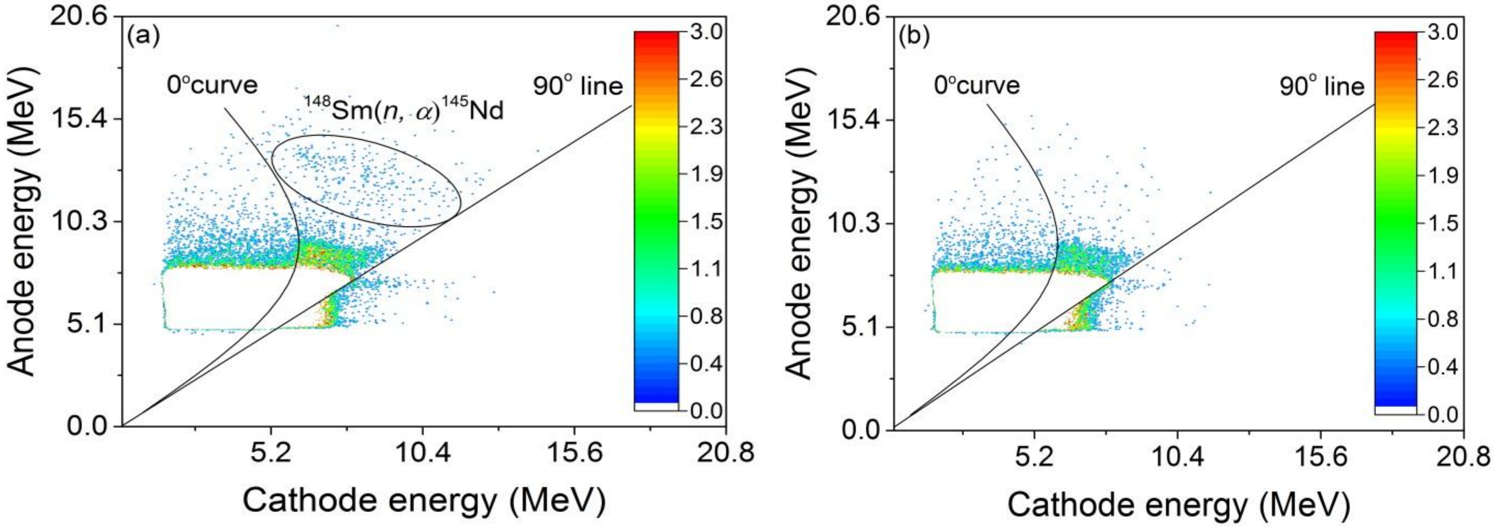
4. Background Measurements
- Pure tantalum backings were used under identical conditions to determine background contributions.
- Background data were collected at each neutron energy point.

5. Post-Measurement Recalibration
The system was recalibrated with the alpha source after each run to ensure consistency.

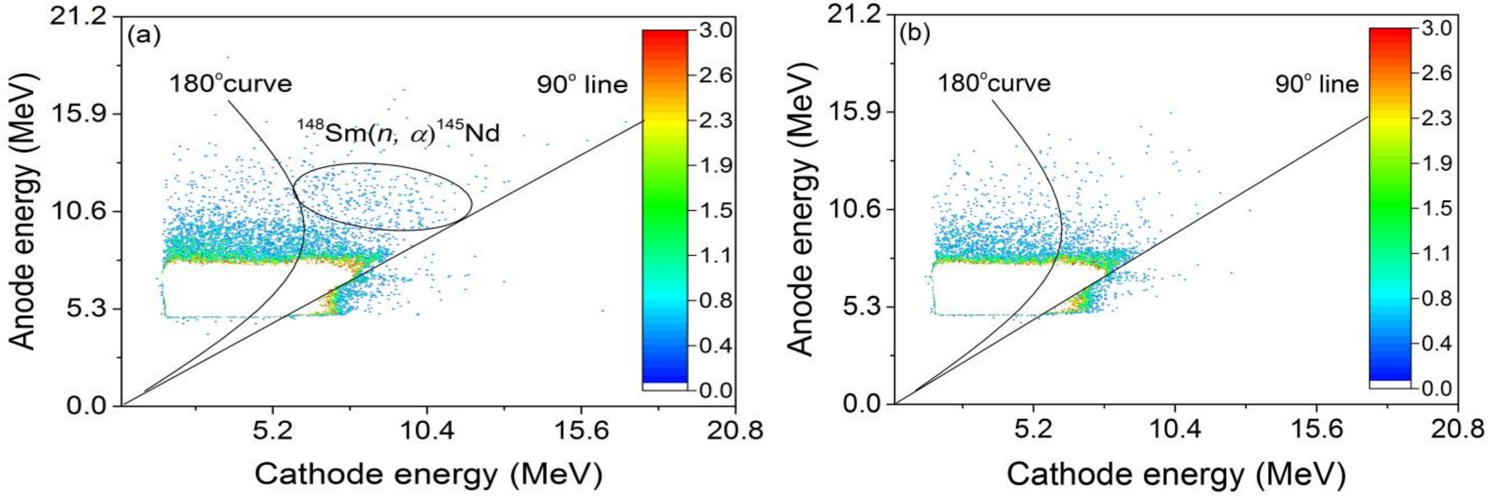
Neutron Flux Monitoring
- A ^{3}He long counter served as a neutron flux monitor, placed 3 meters from the source for all measurements.
- ^{3}He counts were used as a normalization factor in cross-section calculations.

The measurement durations for the **foreground measurements** were **36, 60, and 36 hours at 5.3, 5.1, and 4.8 MeV**, respectively.
For the **background measurements**, the durations were **19, 39, and 19 hours** at the corresponding energy points.
For the **absolute neutron flux measurements**, the duration is about **2 hours for each energy point**

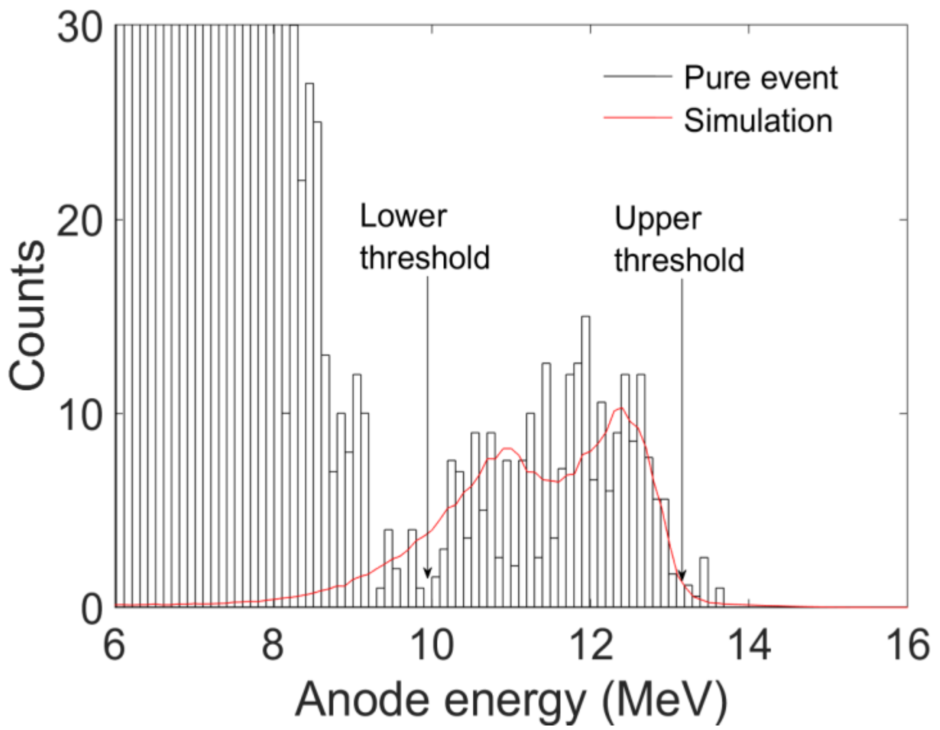
Results



Two–dimensional foreground (a) and background (b) spectra of the $^{148}Sm(n,\alpha)^{145}Nd$ reaction in the **forward** direction at **5.3 MeV** neutron energy.



Two–dimensional foreground (a) and background (b) spectra of the $^{148}Sm(n,\alpha)^{145}Nd$ reaction in the **backward** direction at **5.3 MeV** neutron energy.



The anode projection spectrum of the $^{148}Sm(n,\alpha)^{145}Nd$ reaction in the forward direction at 5.3 MeV neutron energy.

Results

The cross section ($\sigma_{n,\alpha}$) for the $^{148}Sm(n,\alpha)^{145}Nd$ reaction was determined using the following formula:

$$\sigma_{n,\alpha} = K \cdot \sigma_{n,f} \frac{N_\alpha}{N_f} \frac{\varepsilon_f}{\varepsilon_\alpha} \frac{N_{238U}}{N_{148Sm}}$$

where:

$K = He_f/He_\alpha$, with He_f and He_α are representing the counts of the ^3He counter during the measurements of the $^{238}U(n,f)$ and $^{148}Sm(n,\alpha)^{145}Nd$ reactions, respectively.

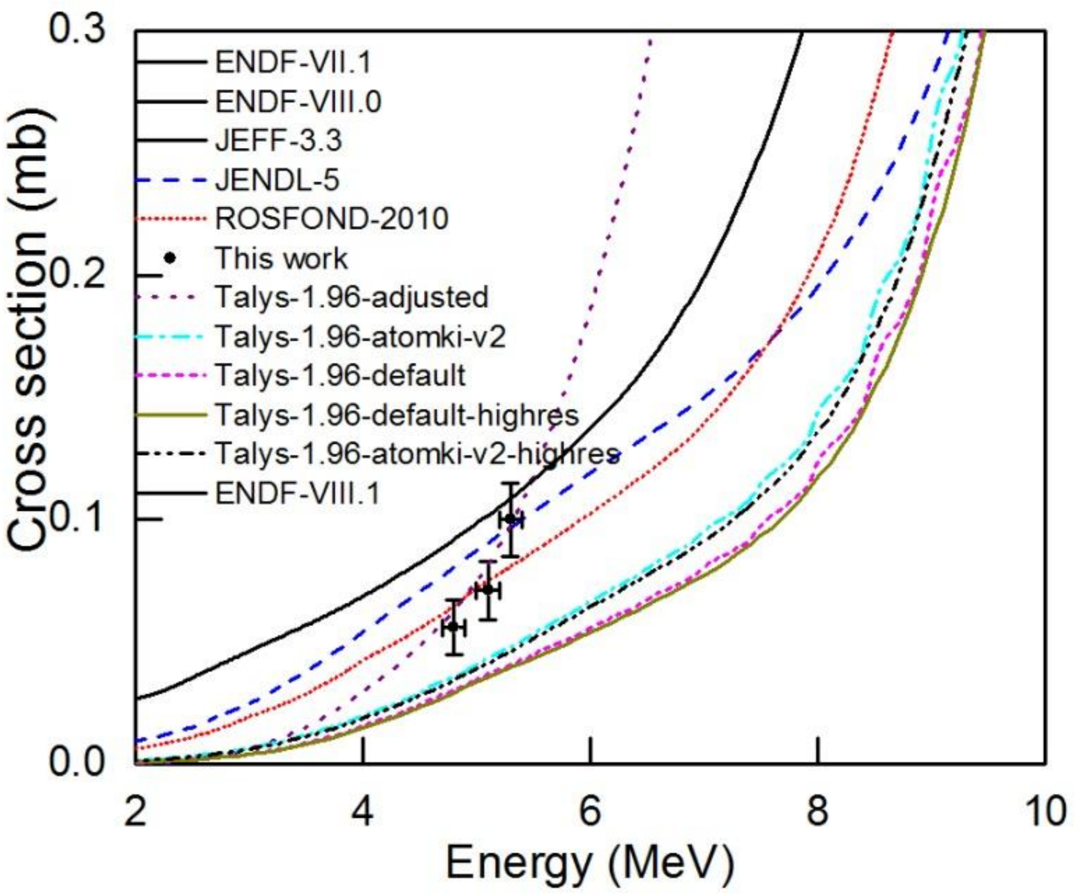
$\sigma_{n,f}$ is the cross section for the $^{238}U(n,f)$ reaction from ENDF/B–VIII.0 library.

N_α and N_f refer to the number of alpha and fission events, respectively, values of which are determined after distinguishing background events within the specified energy thresholds for the reactions.

ε_f and ε_α are the detection efficiencies of the fission and alpha events.

N_{238U} and N_{148Sm} are the atom numbers in the ^{238}U and ^{148}Sm samples, respectively.

Results



Experimental and evaluated cross sections for the $^{148}Sm(n,\alpha)^{145}Nd$ reaction, compared with the calculated results from TALYS–1.96

Energy, MeV	Cross sections, mbarn			
	Forward	Backward	forward/backward ratio	Total
4.8	0.033±0.008	0.023±0.007	1.43	0.056±0.011
5.1	0.042±0.008	0.029±0.007	1.45	0.071±0.012
5.3	0.06±0.01	0.04±0.008	1.50	0.1±0.013

The $^{148}Sm(n,\alpha)^{145}Nd$ reaction cross sections are shown in fig, which compared with the data from different evaluation libraries and TALYS–1.96 calculation.

The total uncertainty in the $^{148}Sm(n,\alpha)^{145}Nd$ reaction cross sections ranges from 13% to 20%.

Conclusions

- ✓ The cross section for the $^{148}Sm(n,\alpha)^{145}Nd$ reaction was systematically measured with high accuracy at neutron energies of 4.8, 5.1, and 5.3 MeV.
- ✓ These measurements represent the first experimental results in the MeV energy region.
- ✓ The present experimental data are significantly lower than the evaluated values in the ENDF/B–VIII.0, ENDF/B–VII.1, ENDF-VIII.1 and JEFF–3.3 libraries by a factor of 1.2 to 1.4. Our experimental data are consistent with the ROSFOND–2010 evaluations at the two lower energy points and with the JENDL–5.0 library at 5.3 MeV neutron energy and the TALYS–1.96 calculations using the adjusted parameters produced results that were consistent with our experimental data across the 4.8–5.3 MeV neutron energy range.
- ✓ The results are accepted in the journal **Chinese Physics C, 2025** https://doi.org/10.1088/1674-1137/add09a

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