Technical Meeting on Neutron Data Standards

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Ratios of the cross sections for the $^{10}B(n, \alpha)^{7}Li$ reaction to the $^{6}Li(n, t)^{4}He$ reaction

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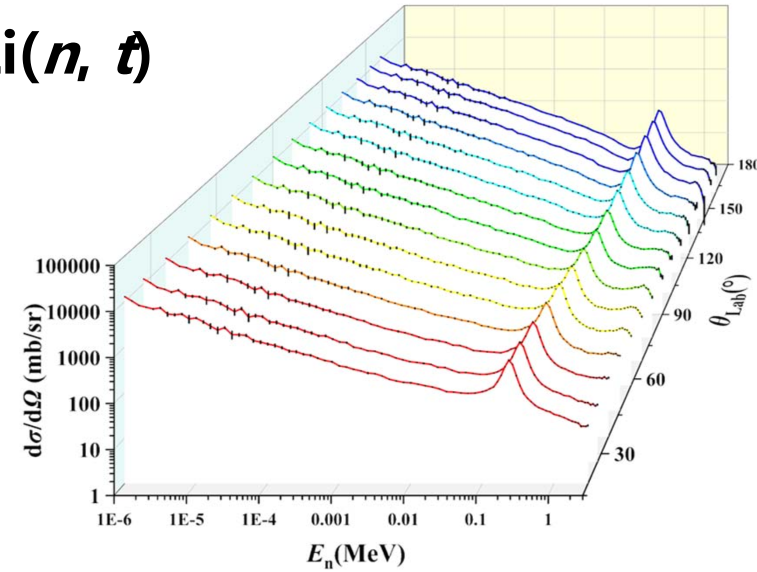
Contents

1. Introduction

- Neutron cross-section standards are the basis for measurements and evaluations of nuclear data[1]. ----$^{10}B(n, \alpha)$ and $^{6}Li(n, t)$.

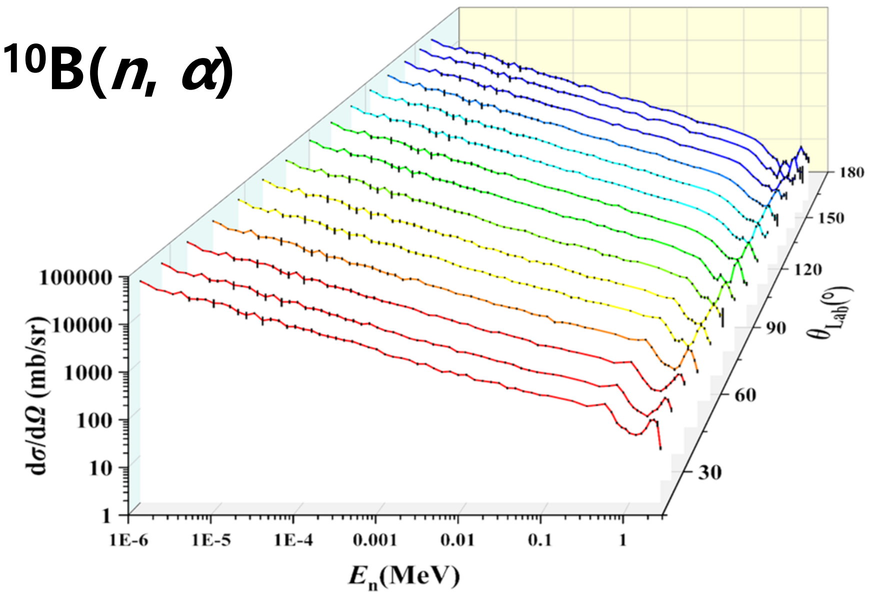
- In 2019, our group measured the differential and angle-integrated cross sections of the $^{6}Li(n, t)$[2] and $^{10}B(n, \alpha)$[3] reactions in the 1.0 eV – several MeV region.

$^{6}Li(n, t)$



The differential cross sections of the $^{6}Li(n, t)$ reaction

$^{10}B(n, \alpha)$



The differential cross sections of the $^{10}B(n, \alpha)$ reaction

[1] A.D. Carlson et al., Nucl. Data Sheets 148, 143 (2018). **[2] H. Jiang et al., Chinese Phys. C 43, 124002 (2019). [3] H. Bai et al., Chinese Phys. C 44, 014003 (2020).**

1. Introduction

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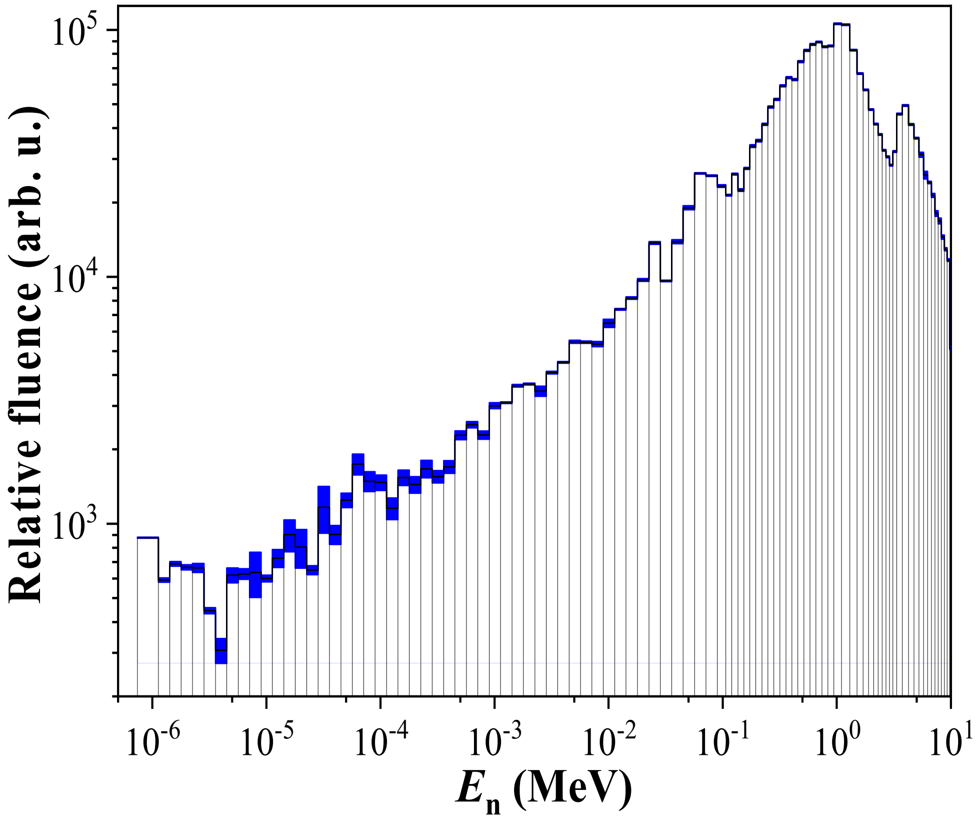
- The relative big uncertainties for the relative neutron flux of CSNS Back-n
- Especially in the 1.0 eV – 1.0 keV neutron energy region (the resonances of $^{235}U(n, f)$ cross sections)



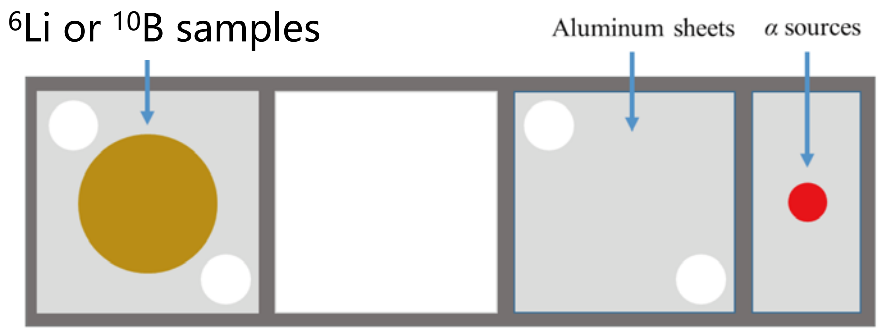
The relative neutron flux of CSNS Back-n

2. Experiments

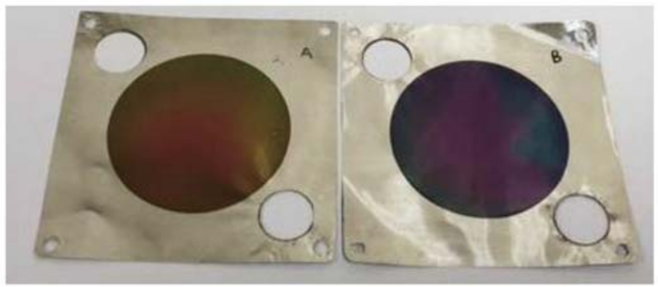
The experimental conditions for the measurements of the two reactions were exactly the same (same experimental setup, same detectors, same electronics, same sample holder, same relative neutron flux, same beam power...).

Some experimental information:

- CSNS Back-n white neutron source
- Enriched (90%) double ^{10}B samples and double ^{6}LiF samples



^{6}LiF samples

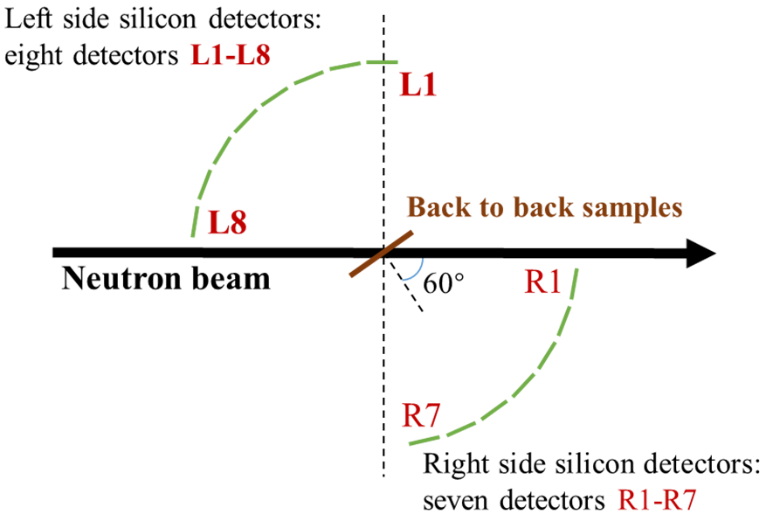


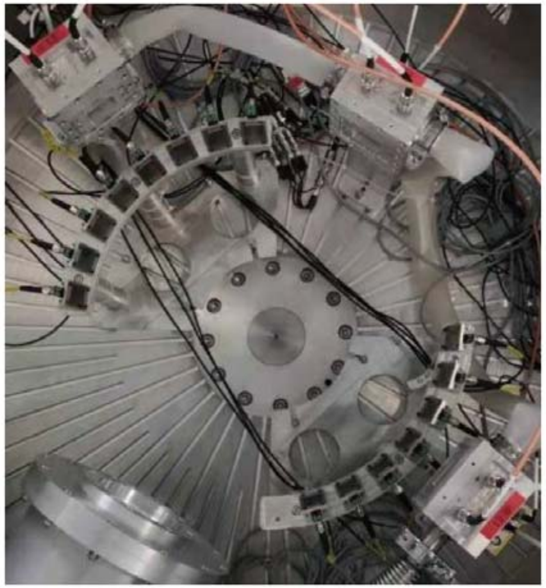
^{10}B samples

2. Experiments

Some experimental information:

- A silicon detector array consisting of 15 silicon detectors, detection angle from 19.2° to 160.8°.
- The angle between the normal of the samples and the neutron beam line was 60°.
- The DAQ system is based on PXIe platform[4].





[2] H. Jiang et al., Chinese Phys. C 43, 124002 (2019).
[3] H. Bai et al., Chinese Phys. C 44, 014003 (2020).

- Re-analyzed the experimental data
- Obtained the ratios of the cross sections of the ^{10}B(n, α) reaction to the ^{6}Li(n, t) reaction
- Avoid the big uncertainties from neutron flux

[4] B. He et al., Chinese Phys. C 41, 016104 (2017).

3. Data analysis

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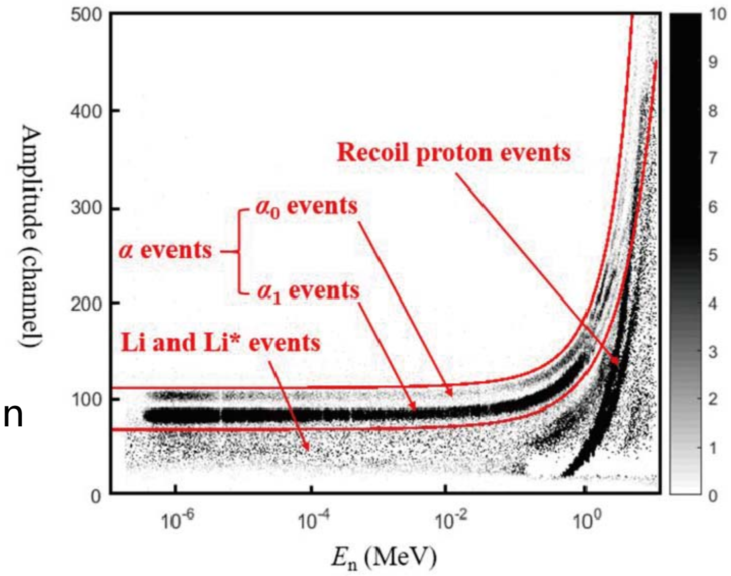
The first step:

a. The two-dimensional spectrum (signal amplitude vs. E_n)
b. The valid area of α or t events in the two-dimensional spectrum
c. The "weight" of each event
d. background subtraction
e. The weighted counts of the net events in each neutron energy bin



The relative ratios of the differential cross sections for the two reactions were obtained by

$$\text{Relative ratio} = \frac{W_{E\_bin,\theta}^{^{10}B}}{W_{E\_bin,\theta}^{^{6}Li}}$$

where $W_{E\_bin,\theta}^{^{10}B}$ is the weighted counts of the net events from the ^{10}B(n, α) reaction corresponding to the neutron energy bin E_bin and the detection angle of θ. $W_{E\_bin,\theta}^{^{6}Li}$ is the weighted counts of the net events from the ^{6}Li(n, t) reaction. The relative ratios of the angle-integrated cross sections were calculated via integration using Legendre polynomials.

3. Data analysis

The second step:

a. The experimental mean relative ratio of the cross sections for the $^{10}B(n, \alpha)$ reaction to the $^{6}Li(n, t)$ reaction in the 1.0 eV – 1.0 keV region was calculated as R_1.

b. The mean ratio of the standard $^{10}B(n, \alpha)$ cross sections to the standard $^{6}Li(n, t)$ cross sections[1] in the 1.0 eV – 1.0 keV region was calculated as R_2 (4.083).

c. The normalizing factor k was determined as the ratio of R_2 to R_1.

d. The normalized ratios of the differential and angle-integrated cross sections were obtained by

$$\text{Normalized ratio} = k \times \text{Relative ratio}$$

Uncertainty analysis:

The uncertainties of the normalized ratios:

1. the uncertainties of the counts of the net events for the two reactions:
   - the statistical uncertainties
   - the background subtraction
   - the unfolding of the neutron energy bin width and the double-bunched proton beams

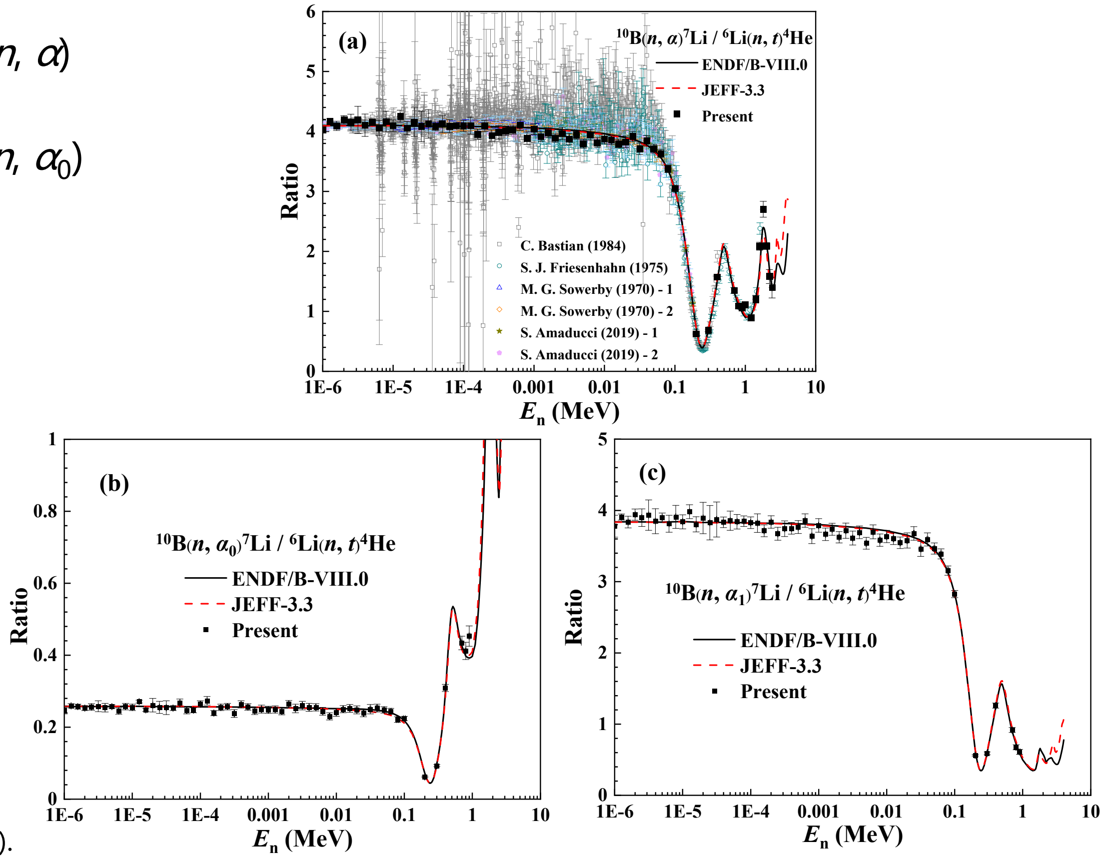
2. the uncertainties of the normalizing factor (1.0%)

4. Results

4.1 Normalized ratios of the angle-integrated cross sections

- E_n is from 1.0 eV to 2.4 MeV for the ratios of the $^{10}B(n, \alpha)$ reaction to the $^{6}Li(n, t)$ reaction.
- E_n is from 1.0 eV to 0.9 MeV for the ratios of the $^{10}B(n, \alpha_0)$ and $^{10}B(n, \alpha_1)$ reactions to the $^{6}Li(n, t)$ reaction.

- The uncertainties of the present ratios are much smaller than those of other existing measurements [5-8].
- Cover a large neutron energy region.
- In good agreement with the ratios from the evaluation data of ENDF/B-VIII.0 and JEFF-3.3 libraries [9-10].



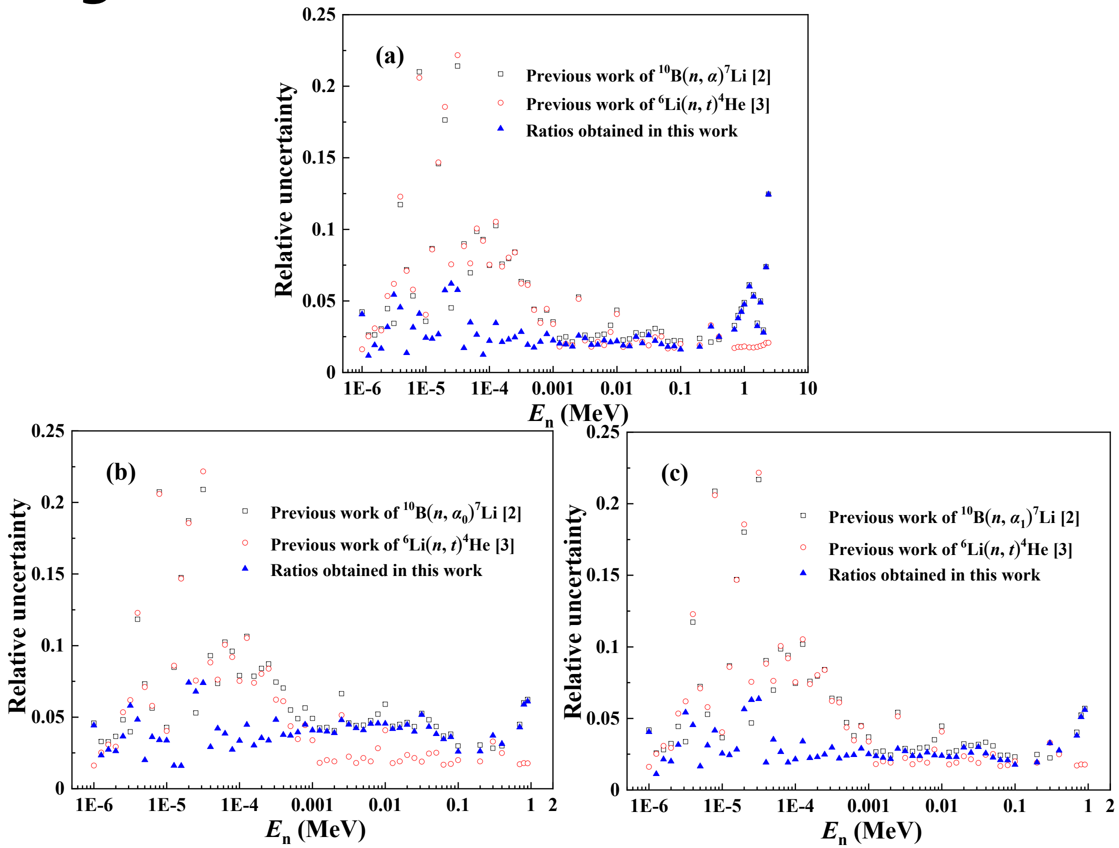
The normalized ratios of the angle-integrated cross sections for the $^{10}B(n, \alpha)$ (a), $^{10}B(n, \alpha_0)$ (b), and $^{10}B(n, \alpha_1)$ (c) reactions to the $^{6}Li(n, t)$ reaction.

[5] M.G. Sowerby et al., J. Nucl. Energy 24, 323 (1970).
[6] S.J. Friesenhahn, Conf. on Nucl. Cross-Sect. and Techn., Vol.1, p.232 (1975).
[7] C. Bastian, IAEA technical report, Vienna, No.335, p.118 (1984).
[8] S. Amaducci et al., Eur. Phys. J. A 55, 120 (2019).
[9] D.A. Brown et al., Nucl. Data Sheets 148, 1 (2018).
[10] JEFF-3.3, https://www.oecd-nea.org/dbdata/jeff/jeff33/index.html

4. Results

4.1 Normalized ratios of the angle-integrated cross sections

- 1.0 eV - 1.0 keV, the relative uncertainties of the present ratios are **significantly smaller** than those of our previous measurement data.
- 1.0 keV - 0.5 MeV, the relative uncertainties of the present ratios come **close** to those of our previous measurements data.
- > 0.5 MeV, the relative uncertainties of the present ratios are **dominated** by those of the ^{10}B(n, α) cross sections.



The relative uncertainties of the normalized ratios of cross sections for the ^{10}B(n, α) (a), ^{10}B(n, α_0) (b), and ^{10}B(n, α_1) (c) reactions to the ^{6}Li(n, t) reaction compared with those in our previous works.

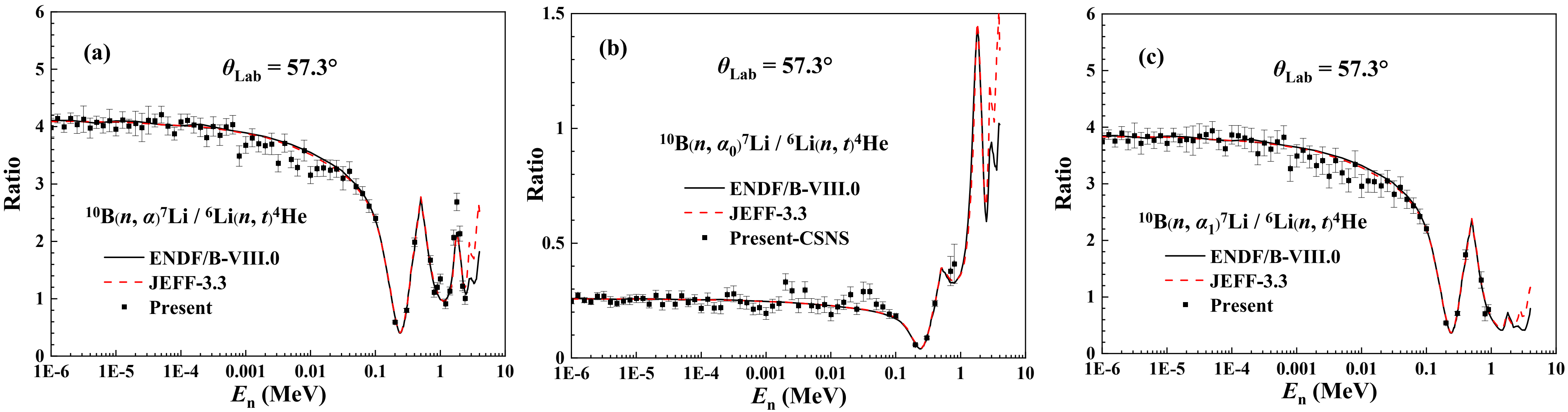
4. Results

4.2 Normalized ratios of the differential cross sections

The normalized ratios of the angular differential cross sections:

- ^{10}B(n, α)^{7}Li to ^{6}Li(n, t)^{4}He: 15 angles × 67 energy points
- ^{10}B(n, α_0)^{7}Li to ^{6}Li(n, t)^{4}He: 15 angles × 57 energy points
- ^{10}B(n, α_1)^{7}Li to ^{6}Li(n, t)^{4}He: 15 angles × 57 energy points

Examples for θ_{lab} = 57.3° :

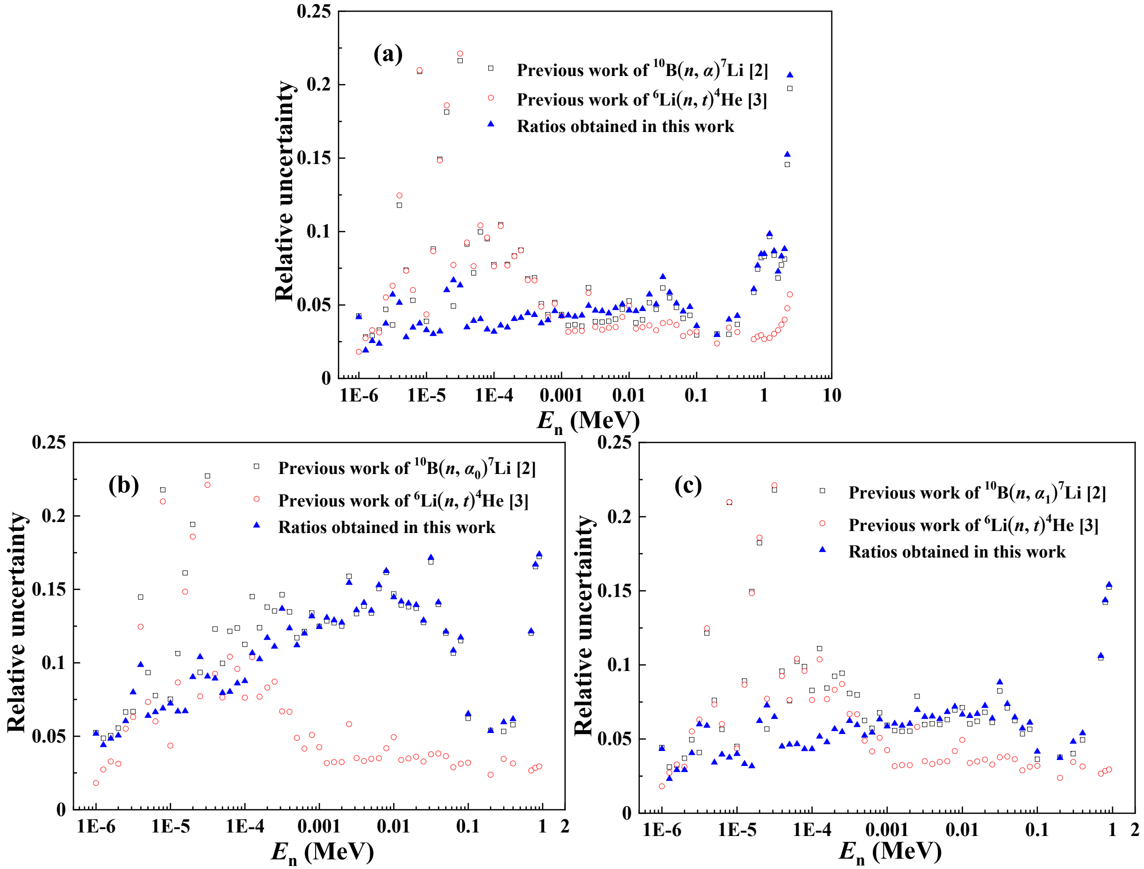


The normalized ratios of the angular differential cross sections for the ^{10}B(n, α)^{7}Li (a), ^{10}B(n, α_0)^{7}Li (b) and ^{10}B(n, α_1)^{7}Li (c) reactions to the ^{6}Li(n, t)^{4}He reaction for θ_{lab} = 57.3°.

4. Results

4.2 Normalized ratios of the differential cross sections

- 1.0 eV-1.0 keV region, the mean relative uncertainties of the present ratios are **obviously smaller** than those of our previous data.
- 1.0 keV-0.5 MeV region, the mean relative uncertainties of the present ratios are **close** to those of the previous $^{10}B(n, \alpha)$ differential cross sections.
- > 0.5 MeV, the mean relative uncertainties of the present ratios are **dominated** by the previous $^{10}B(n, \alpha)$ differential cross sections.



The mean relative uncertainties of the normalized ratios of the differential cross sections compared with those in our previous measurements.

5. Conclusions

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- The ratios of the angle-integrated and differential cross sections for the $^{10}B(n, \alpha)$ to the $^{6}Li(n, t)$ reaction were obtained in the 1.0 eV to several MeV region.
- The present ratios are in good agreement with the ratios calculated using the evaluation data in ENDF/B-VIII.0 and JEFF-3.3 libraries.
- The relative uncertainties of the present ratios are significantly reduced compared with our previous measurement data in the 1.0 eV – 1.0 keV region.
- In the region higher than 0.5 MeV, the relative uncertainties of the present ratios are dominated by those of the $^{10}B(n, \alpha)$ cross sections.
- Improved measurements on the $^{10}B(n, \alpha)$ reaction are demanded.

We are indebted to Dr. A. D. Carlson from National Institute of Standards and Technology of USA for his inspiration and helpful discussions.

Future works

- **Improved measurement of the $^{10}B(n, \alpha)$ reaction**
- **Higher neutron energy region**

Thank you!

References

[1] A.D. Carlson et al., Nucl. Data Sheets 148, 143 (2018). https://doi.org/10.1016/j.nds.2018.02.002

[2] H. Jiang et al., Chinese Phys. C 43, 124002 (2019). https://doi.org/10.1088/1674-1137/43/12/124002

[3] H. Bai et al., Chinese Phys. C 44, 014003 (2020). https://doi.org/10.1088/1674-1137/44/1/014003

[4] B. He et al., Chinese Phys. C 41, 016104 (2017). https://doi.org/10.1088/1674-1137/41/1/016104

[5] M.G. Sowerby et al., J. Nucl. Energy 24, 323 (1970). https://doi.org/10.1016/0022-3107(70)90051-1

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[9] D.A. Brown et al., Nucl. Data Sheets 148, 1 (2018). https://doi.org/10.1016/j.nds.2018.02.001

[10] JEFF-3.3, https://www.oecd-nea.org/dbdata/jeff/jeff33/index.html