Design of a new shadow bar to improve the accuracy of benchmark experiments of large angle elastic scattering reaction cross sections by 14MeV neutrons

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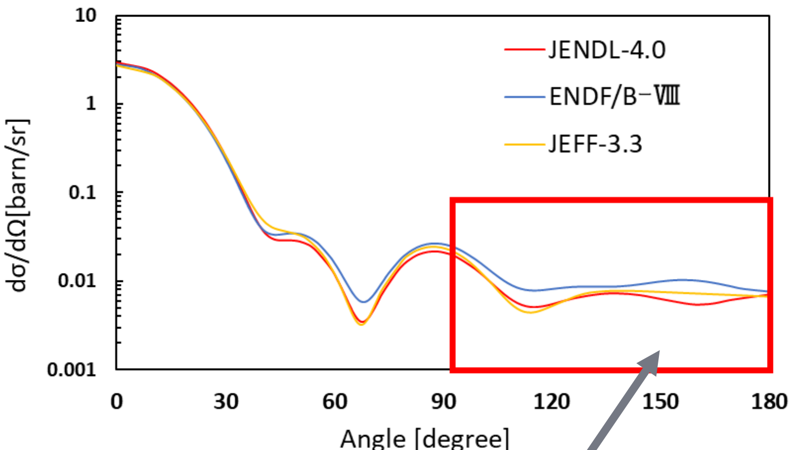
Symposium on Nuclear Data 2021/11/18

1.Introduction

Uncertainty in large angle scattering cross section

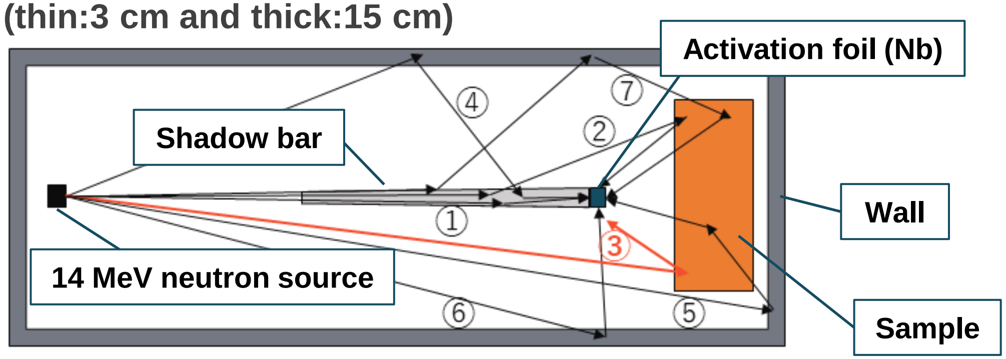


Not negligible in neutronics design for high neutron flux field such as in fusion reactors. [1]

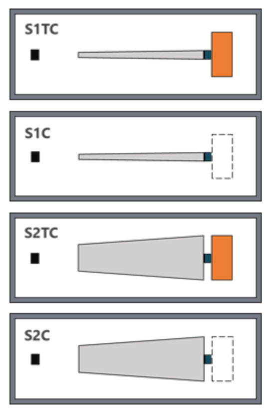
Necessity of accurate evaluation of back scattering cross sections of material elements used in fusion reactors design.

Benchmark Experiment Method [2]

Theory : Extracting large angle scattering neutrons using two shadow bars (thin:3 cm and thick:15 cm)



Path ③ is the path we want to see.



$$①_{S_{1TC}}\ ②_{S_{1TC}}\ ③_{S_{1TC}}\ ④_{S_{1TC}}\ ⑤_{S_{1TC}}\ ⑥_{S_{1TC}}\ ⑦_{S_{1TC}}$$

$$①_{S_{1C}}\ ④_{S_{1C}}\ ⑤_{S_{1C}}\ ⑥_{S_{1C}}\ ⑦_{S_{1C}}$$

$$①_{S_{2TC}}\ ④_{S_{2TC}}\ ⑤_{S_{2TC}}\ ⑥_{S_{2TC}}\ ⑦_{S_{2TC}}$$

$$①_{S_{2C}}\ ④_{S_{2C}}\ ⑤_{S_{2C}}\ ⑥_{S_{2C}}\ ⑦_{S_{2C}}$$

$$S_{1TC} - S_{2TC} - (S_{1C} - S_{2C})$$

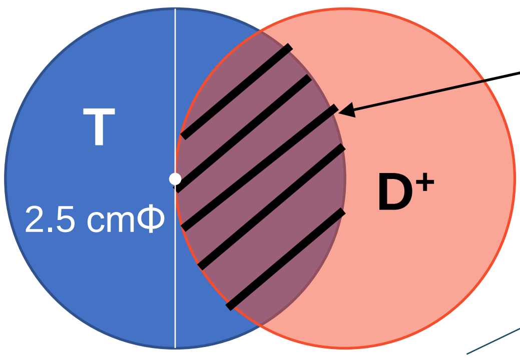
$$= ③_{S_{1Tc}} + \underbrace{(②_{S_{1Tc}} + ⑦_{S_{1Tc}} - ⑦_{S_{2TC}} - ⑦_{S_{1c}} + ⑦_{S_{2c}})}_{\text{Experimental Error}}$$

[1] S. Ohnishi et al., Fusion Eng. Des., 87, pp. 695-699(2012)
[2]Naoya HAYASHI et al., Plasma and Fusion Research, 13, 2405002, 4p (2018).

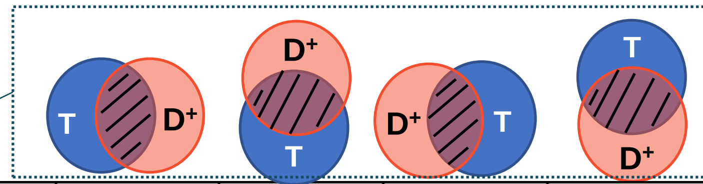
2.Problem

Local irradiation of a tritium target

Originally, the experimental system was designed with a point source.
In fact, Neutrons are generated by irradiating D^+ beam onto a tritium target with a diameter of 2.5 cm.



Local irradiation
to generate neutrons as many as possible



The position and shape of the surface source varies in each experimental system

PATH	S_{1TC}	S_{2TC}	S_{1C}	S_{2C}	$S_{1TC}-S_{2TC}-(S_{1C}-S_{2C})$
①	0.72	0.09	0.70	0.09	0.02
②	0.06	0.00	0	0	0.06
③	**2.49**	0	0	0	2.49
④	0.66	0.54	0.64	0.47	-0.05
⑤	0.78	0.60	1.96	1.94	0.16
⑥	0.52	0.13	0.49	0.15	0.06
⑦	0.00	0.01	0.01	0.03	0.01
TOTAL	5.23	1.36	3.81	2.68	**2.75**

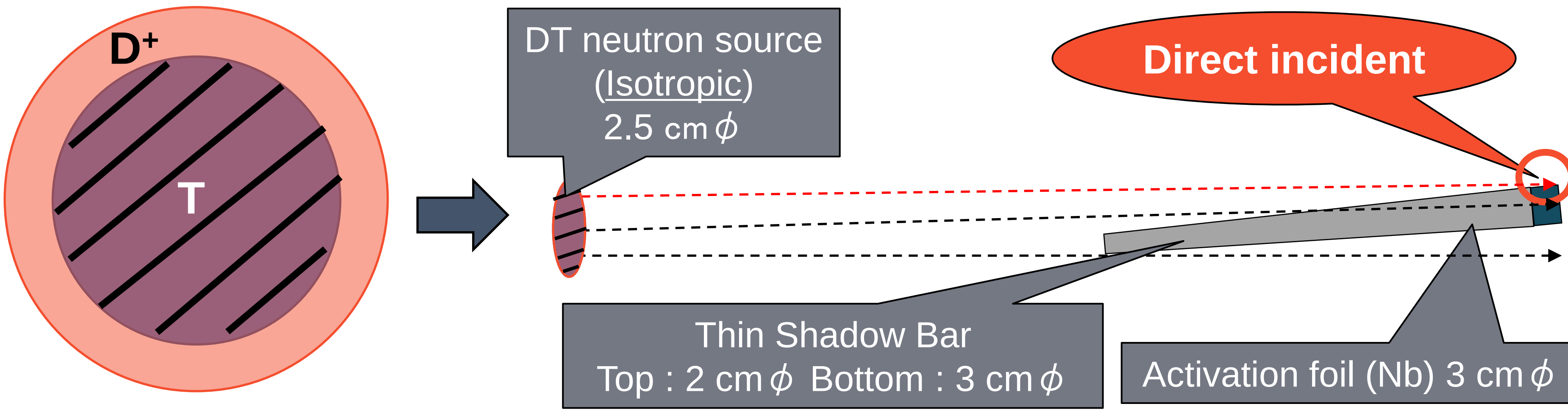
Reaction rates [$10^{-9}/cm^3$・neutron source]

The subtracted value doesn't match the path ③.

We decided to irradiate the D^+ beam to the tritium target uniformly rather than locally.

3.Objective

Negative effects of uniform irradiation



Neutrons may be directly incident on the detection foil due to a small installation error of the shadow bars.
→**Overestimation of the reaction rate**

Objective

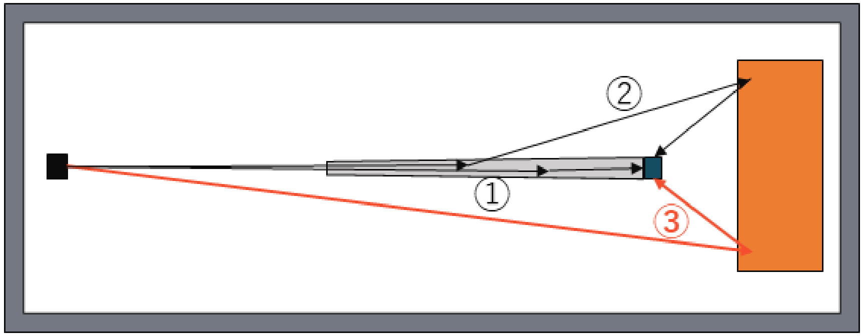
Designing a new thin shadow bar that prevents neutrons from entering the Nb foil directly.

4. Examination method

How to design a new shadow bar

Based on the previous studies, carried out with evaluation index $\boldsymbol{R}$[2]

$$\boldsymbol{R} = \frac{\boldsymbol{R_n} \ (③)}{\boldsymbol{R_f} \ (① + ②)}$$

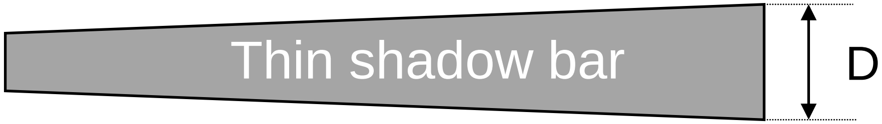


$\boldsymbol{R_n}$:Reaction rate by neutrons incident on Nb foil without going through the shadow bar→③

$\boldsymbol{R_f}$: Reaction rate due to neutrons incident on an Nb foil through a shadow bar →①②

- Since we just changed from a point source to a disk-shaped source, the diameter of the shadow bar is an issue.

→ We aim for a thin shadow bar diameter where the detection foil is **sufficiently activated** and has a **large** $\boldsymbol{R}$.



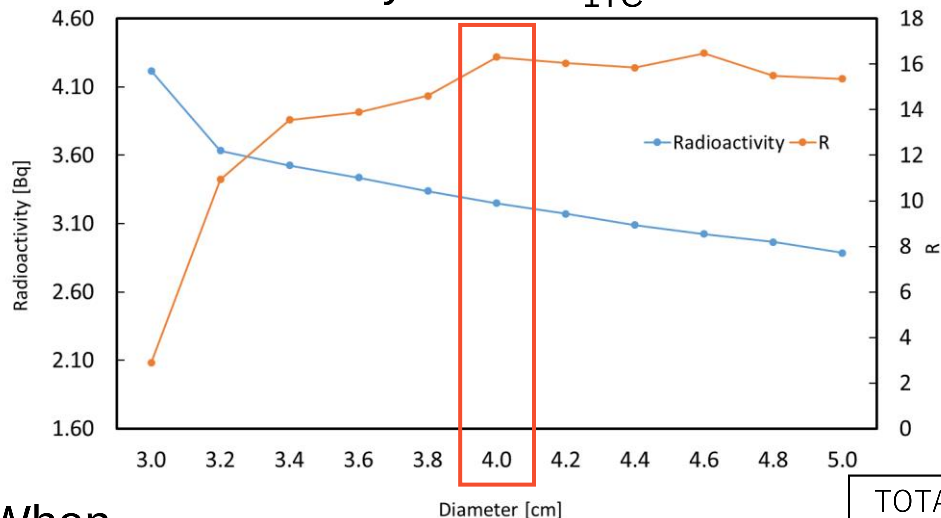
Designed to be changed by more than 3 cm

[2]Naoya HAYASHI et al., Plasma and Fusion Research, 13, 2405002, 4p (2018).

5. Examination result

Simulation result using MCNP5

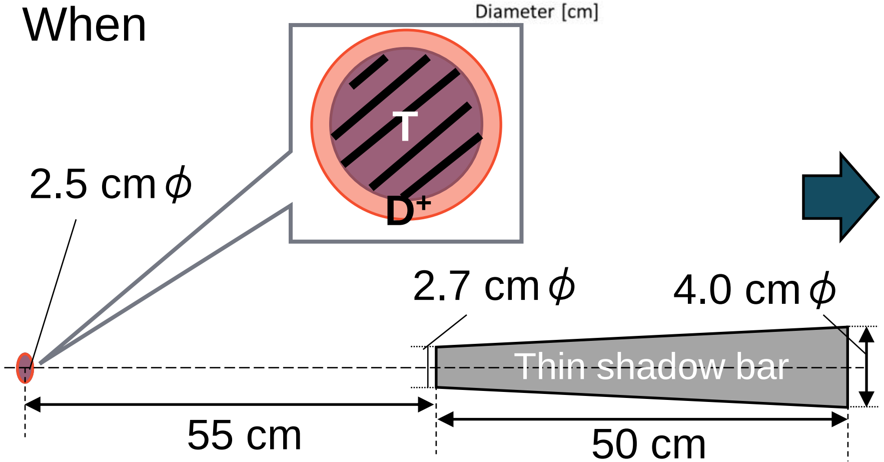
System : S_{1TC}



- **Radioactivity** of the foil decreases linearly with increasing diameter.
- **R-value** saturated to a maximum value of 16 after 4.0 cm
  → 8 times higher than at 3.0 cm

Decided at 4.0 cm

When



TOTAL	S_{1TC}	S_{2TC}	S_{1C}	S_{2C}	$S_{1TC}-S_{2TC}-(S_{1C}-S_{2C})$
①	0.06	0.09	0.06	0.09	0.00
②	0.06	0.00	0	0	0.06
③	**2.07**	0	0	0	2.07
④	0.76	0.46	0.76	0.46	0.00
⑤	0.67	0.66	1.89	1.86	-0.03
⑥	0.43	0.20	0.43	0.20	0.00
⑦	0.01	0.01	0.01	0.03	0.01
TOTAL	4.06	1.43	3.16	2.64	**2.12**

Reaction rates [10^{-9}/cm^3・neutron source]

If the installation error can be reduced to ±1 mm with respect to the beam axis, it can be subtracted without any problem.

6. Conclusion / Future work

Conclusion

- The design of a new thin shadow bar, which prevents neutrons from directly entering the Nb foil, was investigated using MCNP5.
- It was found that a diameter of 4 cm at the bottom of a thin shadow bar ensures an enough Bq value for gamma-ray measurement and large R-value for accuracy of the present benchmark experiment.

Future work

- Manufacturing of a new shadow bar based on the design
- Experiment with the new shadow bar for light nuclei such as Li and O, and medium and heavy nuclei such as Fe and W.