Detailed examination of benchmark method for large angle scattering reaction cross section at 14MeV for a flake target

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Large angle scattering reaction cross sections are crucial in neutronics design of a fusion reactor. However, there are differences observed in the large angle elastic scattering reaction cross section among different nuclear data libraries. In order to confirm the cross section accuracy, the authors' research group developed a benchmark method focusing on the large angle scattering reaction cross section. And the first benchmark experiment was conducted on iron, the most important fusion material, at a DT neutron source facility, OKTAVIAN, of Osaka University, Japan. In this benchmark experiment, the target was a lump of iron. However, it is expected that in future flake targets should be used especially, for example, light materials. In the present study, we examine the benchmark method to be able rigorously to treat a flake target. In the case of a flake target, we need to additionally consider a container and lid for flakes. We finally found that the same process of the massive sample case could be used, that is, conducting four experiments to extract only the contribution of neutrons scattered at large angles by the target correctly. In the next step, we will carry out a benchmark experiment for silicon with the present benchmark method.

1. Introduction

Reaction cross section data of back scattering are normally not focused on in fusion reactor design, because the reaction cross section of large angle elastic scattering is much smaller than that of forward scattering especially when the energy of incident neutrons is as high as fusion neutron. However, in the case of the gap streaming phenomenon around the blanket of ITER, the reaction cross section value of large angle scattering may have a large effect on the design calculation results.

For instance, the elastic scattering reaction cross sections of ^{56}Fe at 14 MeV, which is the

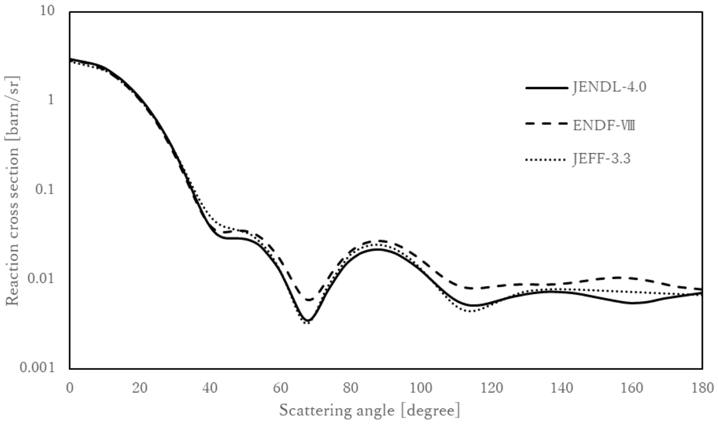

Fig. 1. 14MeV neutron elastic scattering angular distribution of iron.

most important fusion material, vary for large angle elastic scattering among nuclear data libraries as shown in Fig. 1. For improvement of the cross section, previously, there were measurements of double differential cross sections of secondary neutrons at 14 MeV [1]. It also contained the angular differential cross section. However, such measurements are technically difficult, because the large angle elastic scattering reaction cross section is very small as shown in Fig. 1, so that there were very few experimental approaches reported so far to directly measure or benchmark large angle scattered neutrons.

For the last few years, the benchmark method was proposed by the group of authors to test large angle scattering reaction cross sections, which was an integral experiment with an activation foil of niobium to cover wide scattering angles. Using the experimental method, a benchmark experiment of iron was performed in a previous study [2]. In the present study, we try to benchmark silicon in SiC that would be a candidate material for the first wall. However, it is difficult to prepare a large massive sample of silicon. We thus need to cope with flake silicon sample. In future, for benchmarking of other materials like light elements, we expect that benchmarks should be performed using flaky targets. In the present study we hence investigate in the exact benchmark method for flaky targets by the numerical analysis.

2. Previous Study

Figure 2 shows the experimental system of the benchmark method for iron, which was proposed in the previous study [2]. This experimental system consists of a DT neutron source, an iron shadow bar, a cylindrical iron target plate and Nb foil as a neutron detector. The shadow bar plays a role in blocking neutrons from directly entering the detection foil. The shadow bar is made of iron and has a truncated cone shape. The distance between the shadow bar and target plate is 1 cm. If the target plate thickness is appropriate, the neutrons incident on the target plate will have at

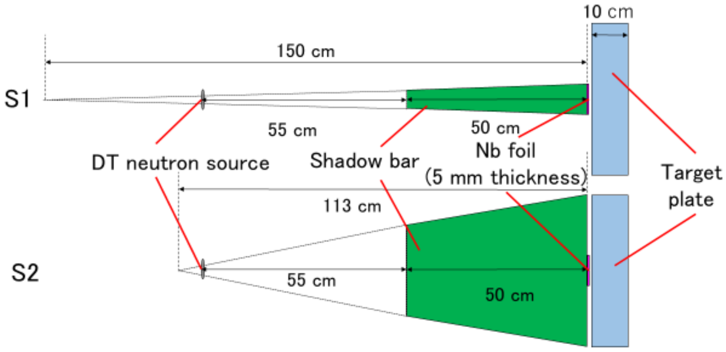

Fig. 2. Iron benchmark experiment system.

most one scattering. If the scattering is forward, neutrons can pass through the target plate after the scattering. And if it is a back scattering, neutrons can enter the detection foil directly without another scattering. Therefore, the Nb foil can detect only large angle elastic scattering neutrons from the target plate. However, the irradiation room used for this experiment is not so large and surrounded by a 1 m thick shielding wall. So it is necessary to consider the contribution of neutrons scattered in the wall, so-called room return neutrons. Therefore, we use two types of shadow bars having different shapes represented by S1 and S2 as in Fig. 2.

The narrow shadow bar of S1 is 50cm, 2cm in diameter at the top, 3cm in diameter at the bottom and measures all neutron contributions except direct incidence on the target plate through the shadow bar. On the other hand, the thick shadow bar of S2 has a length of 50cm, a top diameter of 8.3cm, and a bottom diameter of 15cm. The diameter of the target plate is set so as to be equal to the bottom diameter of the shadow bar. Therefore, the contribution of neutrons that are directly incident on the target and back-scattered in the target plate is removed, and only the contribution of neutrons from the surrounding wall is measured. The dimensions in Fig. 2 were optimized by parameter survey calculations using MCNP-5 [3]. Then, four types of experiments, TC with the target and C without the target, using these two types of shadow bars are performed as shown in Fig. 3.

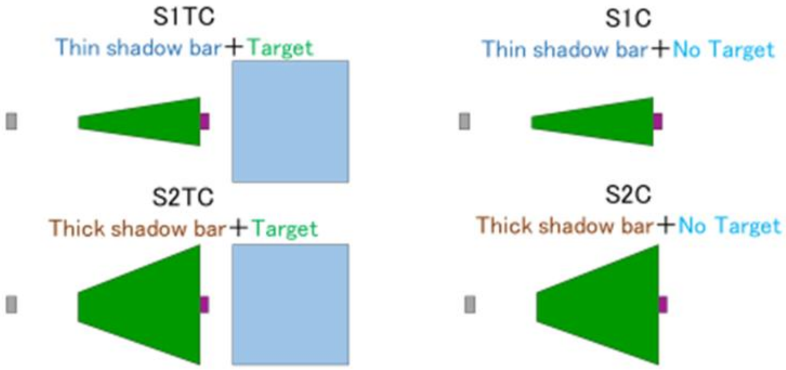

Fig. 3. Four types of iron benchmark experiments.

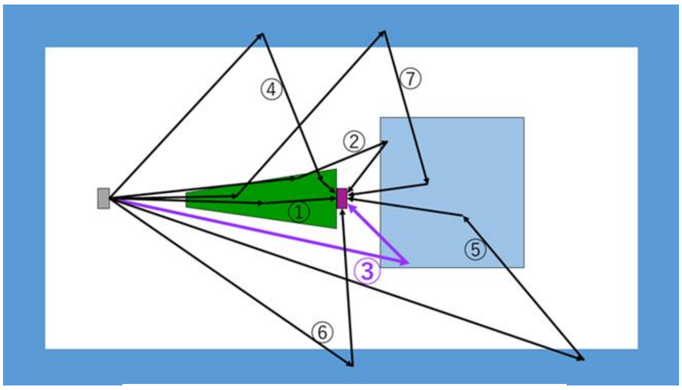

Fig. 4. Neutron path at iron target.

In the iron benchmark experiment, we carried out neutron transport path analysis with MCNP-5 in advance. In the analysis, three cells should be considered, that can be passed by neutrons, i.e., shadow bars, walls, and targets. As paths through which neutrons pass, seven paths $(={}_3C_1+{}_3C_2+{}_3C_3)$ in total should be taken into account as shown in Fig. 4. Out of these seven paths, path ③ is the path of large angle scattering neutrons that we want to measure. Clearly the contribution of path ③ appears only in the S1TC experimental system. By performing the four experiments shown in Figure 3, the contribution of neutron paths other than path ③ can be estimated and removed. Practically, by substituting the total reaction rate of niobium for each experiment into the following equation (1), the contribution of neutrons other than path ③ is canceled out, and only the contribution of path ③ can be extracted.

$$\text{Path ③} = (\text{S1TC}) - (\text{S1C}) - ((\text{S2TC}) - (\text{S2C})) \cdot\cdot\cdot (1)$$

3. Experimental System for Flake Target

In the case of a flake-form silicon target, a container for containing the flakes and its lid are required. The container is made of iron and the lid is made of aluminum, and both are 1 mm thick. The target thickness is 28 cm including the container and lid. Figure 5 shows the experimental system when a container and a lid are added. The red part facing the Nb foil is the lid. Experimental conditions other than the container and lid, such as the neutron source and shadow bar, are the

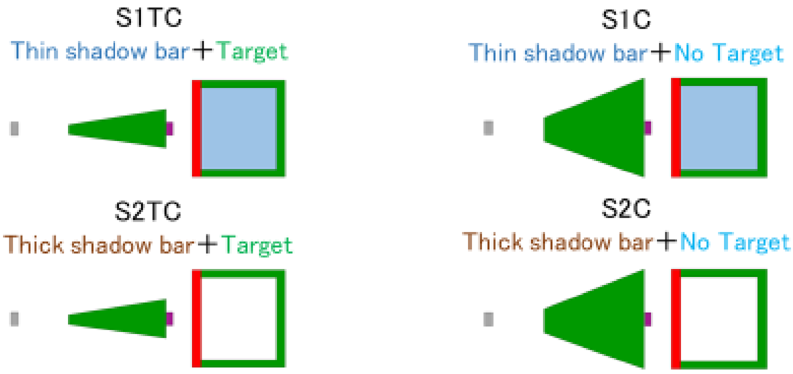

Fig. 5. Four types of benchmark experiments for flake silicon targets

same as those for the iron system. In the calculation, it was assumed that silicon was uniformly packed with the density, which was estimated as a bulk density measured after packing silicon flakes into the container.

In this experimental system, cells that can be passed through by neutrons are the shadow bar, the wall, the target, and in addition, the container and its lid. Initially, we considered that there were 31 paths mathematically calculated by ${}_5C_1+{}_5C_2+{}_5C_3+{}_5C_4+{}_5C_5$ as transporting paths through which neutrons passed. However, it was found that there were 12 paths where neutrons could not physically pass. For example, a path does not exist, in which a neutron enters the detection foil via the target plate without passing through the lid. Therefore, we removed such paths and finally considered 19 paths (31-12) through which neutrons can pass. Figure 6 shows all the 19 paths. Among the 19 paths, path ⑥ is the path of large angle scattering neutrons that we want to measure.

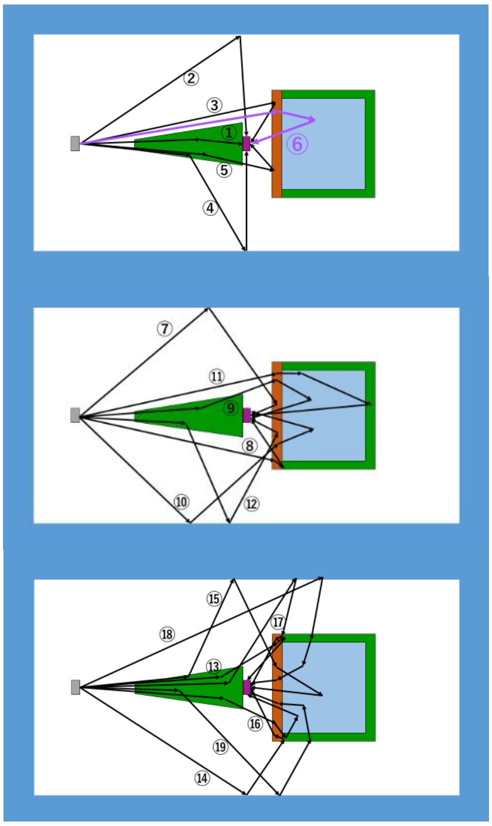

Fig. 6. Neutron pathways for flaky silicon targets.

4. Numerical Simulation Result

Table 1 shows the results of MCNP-5 simulation of the four experimental systems shown in Fig. 5 using the nuclear data library of JENDL-4.0 [4]. In most routes, there are two pairs

Table 1. Reaction rate of 19 paths in simulation of each experimental system [unit: 10^{-9} reaction/source neutron].

	S1TC	S1C	S2TC	S2C	S1TC-S1C-(S2TC-S2C)
①	0.02	0.02	0.13	0.13	0.00
②	0.79	0.79	0.25	0.25	0.00
③	0.24	0.24	0	0	0.00
④	1.09	1.09	0.67	0.67	0.00
⑤	0.01	0.01	0.00	0.00	0.00
⑥	3.82	0	0	0	3.82
⑦	0.04	0.04	0.04	0.04	0.00
⑧	0.00	0.00	0	0	0.00
⑨	0.07	0	0.00	0	0.07
⑩	0.01	0.00	0.00	0.00	0.01
⑪	0.10	0.16	0	0	-0.06
⑫	0.00	0.00	0.00	0.00	0.00
⑬	0.00	0.00	0	0	0.00
⑭	0.00	0.00	0.00	0.00	0.00
⑮	0.00	0	0.00	0	0.00
⑯	0.00	0.00	0.00	0	0.00
⑰	0.00	0.00	0.00	0.00	0.00
⑱	2.05	3.08	2.03	3.02	-0.04
⑲	0.02	0.01	0.04	0.05	0.02
Total number of reaction	8.26±0.06	5.44±0.06	3.16±0.05	4.16±0.05	3.82±0.12

observed. For example, in path ①, reaction rates of S1TC and S1C are the same to become a pair, and S2TC and S2C are also in pair. In addition, it can be seen that the neutron contribution of path ⑥ only appears in the experimental system of S1TC.

The bottom values for columns S1TC, S1C, S2TC and S2C are the sum of reaction rates in 19 paths and correspond to obtained reaction rates in the four experiments. By substituting these four reaction rates into equation (1), the value of "3.82" is deduced, which is exactly the same as the reaction rate of the route ⑥. Consequently, this result proves that the present benchmark method of the large angle scattering cross section could be utilized even in the case of a flake target.

5. Conclusion

In this study, the benchmark experiment method for large angle elastic scattering reaction cross section using flake target was numerically investigated. MCNP-5 simulations by setting flags to five cells including shadow bar, wall, target plate, and in addition, container and lid, we successfully extract the contribution of large angle scattering neutrons with a simple equation in Eq. (1) with four experimental reaction rates. It can thus be concluded that the present benchmark technique could be used even with a flake silicon target. In the future, we will conduct experiments various samples including silicon and discuss the practical feedback method from the experimental results to the nuclear data library.

Acknowledgments

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