Impact of Reflector on Calculation Accuracy of Tritium Production in DT Neutronics Blanket Experiment

Satoshi SATO, Masayuki WADA[1)], Takeo NISHITANI[2)] and Chikara KONNO

Japan Atomic Energy Agency, Tokai, Ibaraki 319-1195, Japan

[1)]*Startcom Co., Ltd., Tokyo 179-0085, Japan*

[2)]*Japan Atomic Energy Agency, Naka, Ibaraki 311-0102, Japan*

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Tritium production rates were measured using a DT neutron source for solid breeder blanket mockups under conditions without and with a neutron reflector at Fusion Neutronics Source facility in Japan Atomic Energy Agency in our previous studies, and the experimental results were compared with the calculated ones. Uncertainties of the calculation results for the experimental condition with the reflector were larger than those without one. We have studied influence of reflector on calculation accuracy for tritium production rate in the present study. From the Monte Carlo calculation results evaluating the tracked path of each neutron, it can be clarified that the ratios of the tritium production due to neutrons scattered by the reflector to that due to all neutrons are 0.24 ~ 0.57. The divergence of the ratio of the calculation result to the experimental one on tritium production from unity increases with the ratio of the tritium production due to neutrons scattered back from the reflector. It can be concluded that this increase is due to neutrons scattered by the reflector, and the calculation accuracy is enhanced by improving the calculation for back-scattered neutrons.

Keywords: blanket, tritium production rate, neutronics experiment, Monte Carlo Calculation, neutron reflector

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1. Introduction

In the course of fusion reactor blanket development, tritium production rates (TPRs) have been measured by using a DT neutron source for solid breeder blanket mockups under conditions without and with a neutron reflector made of SS316 at the Fusion Neutronics Source (FNS) facility in Japan Atomic Energy Agency (JAEA), and the experimental results were compared with the calculated ones [1, 2]. The neutron reflector surrounds the DT neutron source, and it simulates the effect of back-scattered neutron in actual fusion reactors. The calculation uncertainty of the TPRs was studied in the previous studies. The ratio of the calculation results to the experimental ones (C/E) on the integrated tritium production without the neutron reflector was 1.02. It was concluded that the integrated tritium production could be very accurately predicted for the experimental condition without the neutron reflector. On the other hand, the C/Es were 1.04 ~ 1.12 for the experimental condition with the neutron reflector. It was speculated that the inaccurate treatment of the back-scattered neutron flux caused the larger calculation uncertainty. In order to further investigate this issue, we evaluate the tritium produced by neutrons scattered back from the reflector with Monte Carlo calculation with identification of their contribution. From this result, we study effects of the neutron reflector on the calculation uncertainty for TPR.

author's e-mail: sato.satoshi92@jaea.go.jp

2. Overview of Neutronics Experiment and Analysis

Experiments were performed using a one-breeder layer mockup shown in Fig. 1 under conditions without and with a neutron reflector, and a two-breeder layer mockup shown in Fig. 2 under a condition with a neutron reflector, at FNS in JAEA [3]. The arrangement of the breeder and beryllium layers in the two-breeder layer mockup is different from that in the one-breeder layer mockup. Contributions of the incident neutrons scattered by the reflector to the breeder layers in the two-breeder layer mockup are expected to be less than those in the one-breeder layer mockup. The one layer mockup is composed of a 16 mm-thick F82H, a 12 mm-thick Li_2TiO_3 and a 203 mm-thick beryllium layer. The two-layer mockup is composed of two 12 mm-thick Li_2TiO_3 and three 102 mm-thick beryllium layers. 40% ^{6}Li enriched lithium was used in these mockups. The mockups are 660 mm in width and 660 mm in height in maximum. The mockup was installed inside the mockup enclosure made of SS316. The outer diameter of the enclosure is 1.2 m, and there is a space in its inside for installation of the blanket mockup. The distance from the DT neutron source to the mockup surface is around 450 mm. An annular neutron reflector of SS316 was installed around the DT neutron source. Its inner and outer diameters are 0.8 and 1.2 m, respectively. Li_2CO_3 diagnostic pellets were used for measurements of TPRs. Li_2CO_3

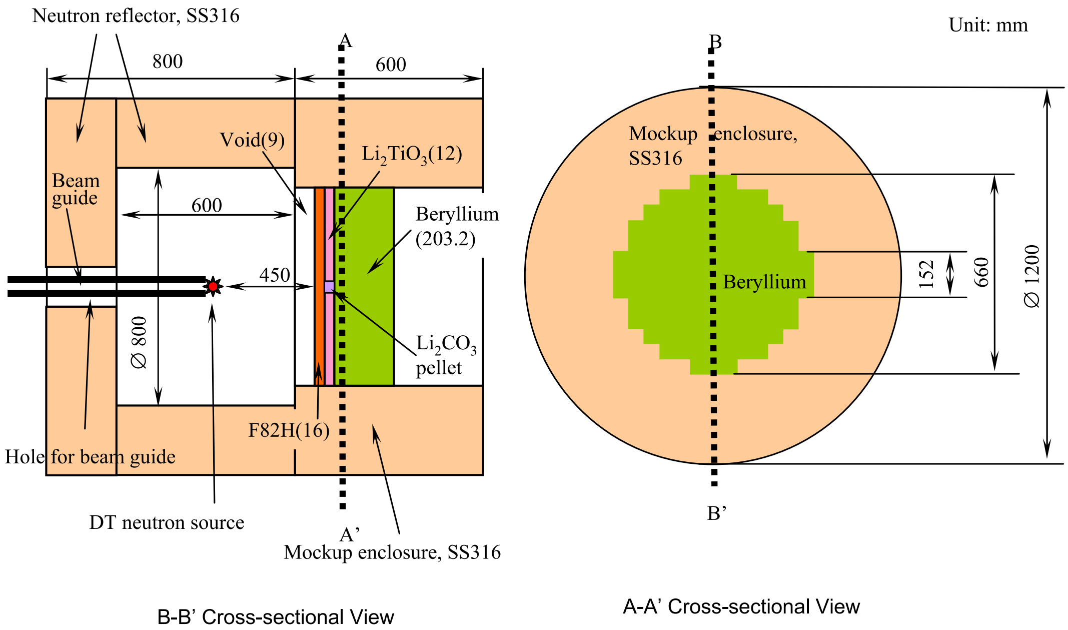

Fig. 1 Schematic view of the experimental assembly on the one-breeder layer mockup.

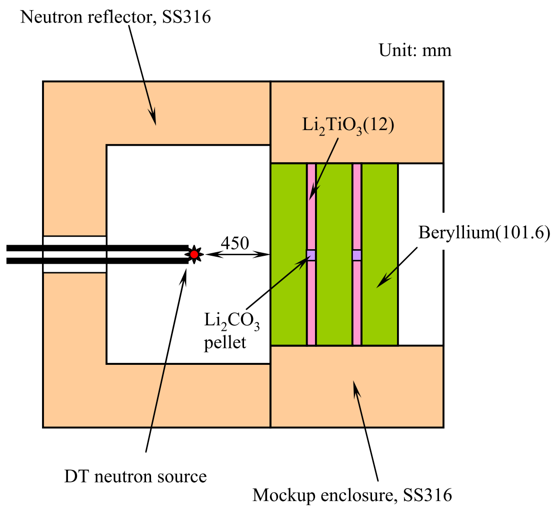

Fig. 2 Schematic view of the experimental assembly on the two-breeder layer mockup.

pellets with the dimensions of 13 mm in diameter and 0.5, 1 and 2 mm in thickness were fabricated by cold pressing of powders and slicing, and these 15 pellets were embedded inside the center of the Li_2TiO_3 layers. After the DT neutron irradiation, these pellets were dissolved by nitric and acetic acids, and a scintillation solution was mixed. Beta-rays from tritium generated in these pellets were measured by a liquid scintillation counter, and the TPRs were deduced from the beta-ray counts [4–6].

Numerical simulations were performed by the Monte Carlo Neutral Particle calculation code MCNP-4C [7] with the Fusion Evaluated Nuclear Data Library FENDL-2.0 [8]. Figures 3 and 4 show the C/Es for the one-breeder and two-breeder layer mockups, respectively. The experimental error is 7%, and the Fractional Standard Deviations (FSDs) are 0.01 ~ 0.04 for local TPR in the Monte Carlo calculation. The ranges of C/E on each pellet are 1.02 ~ 1.20 and 0.96 ~ 1.08 in the one-breeder layer mockup under conditions with and without a neutron reflector, respectively. The ranges are 1.03 ~ 1.17 and 0.97 ~ 1.15 in the first and second layers, respectively, of the two-breeder layer mockup. The C/Es on the tritium production integrated over the breeder layers are 1.12 and 1.02 in the one-breeder layer mockup under conditions with and without a neutron reflector, respectively. These are 1.08 and 1.04 in the first and second layers, respectively, of the two-breeder layer mockup. Divergence of the C/E from unity is the largest in the one-breeder layer mockup under condition with a neutron reflector.

3. Influence of Reflector on Calculation Uncertainty for TPR

In the Monte Carlo calculation, the history of each particle is tracked so that we can recognize each path which a particle passes through [9, 10]. Here, only particles passing through a flagged cell are identified. Flagging technique was applied for the present study to calculate TPR due to neutrons scattered back from the reflector ($TPR_{scattered}$), and to evaluate contribution to TPR_{all} due to the $TPR_{scattered}$. TPR_{all} means TPR due to all neutrons. The reflector was assigned to the flagged cell, and neutrons reflected back from the reflector were identified. Figure 5 shows spectra of the neutron current at the two-breeder layer mockup surface. The solid line presents the total neutron current (total current), and the dotted line presents

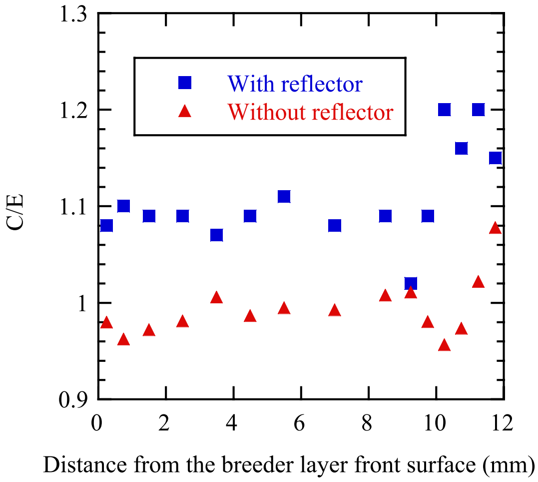

Fig. 3 Ratio of calculation results to experimental ones (C/E) on TPR in the one-breeder layer mockup under conditions without and with a neutron reflector.

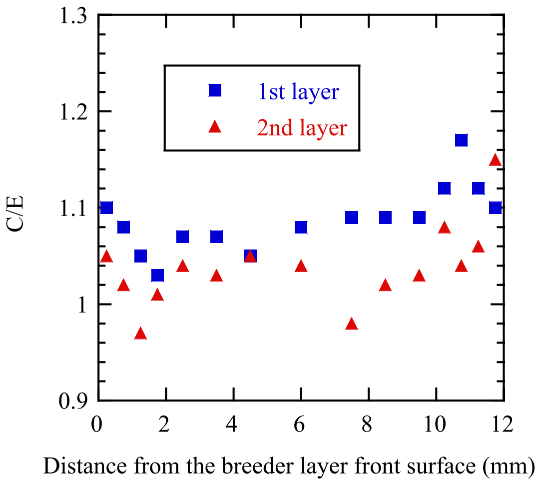

Fig. 4 Ratio of calculation results to experimental ones (C/E) on TPR in the first and second breeder layers of the two-breeder layer mockup.

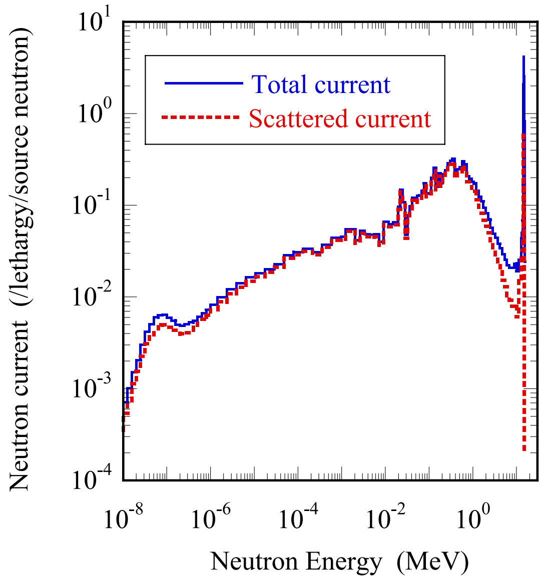

Fig. 5 Spectra of the neutron current at the two-breeder layer mockup surface. The solid line presents the total neutron current (total current). The dotted line presents the neutron current scattered back from the reflector (scattered current).

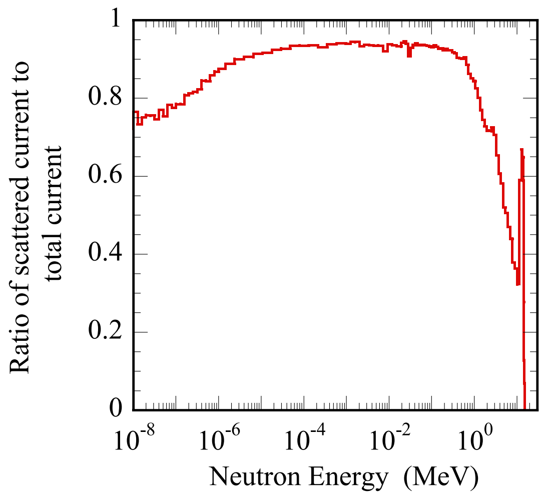

Fig. 6 Ratio of the scattered current to the total neutron current as a function of neutron energy at the mockup surface.

the neutron current scattered back from the reflector (scattered current). Figure 6 shows the ratio of the scattered current to the total current as a function of the neutron energy. The scattered current is more than 90% of the total current for the energy range from 0.4 eV to 0.7 MeV. The scattered current is more than 80% of the total current integrated over the whole energy range. The neutron reflector increases the neutron current remarkably.

Figure 7 shows ratio of $TPR_{scattered}$ to TPR_{all}. The ranges of the ratio are 0.48 ~ 0.70 in the one-breeder layer mockup, 0.36 ~ 0.59 in the first layer of the two-breeder layer mockup and 0.19 ~ 0.31 in the second layer. Similarly to the divergence of the C/E from unity mentioned in Sec. 2, $TPR_{scattered}/TPR_{all}$ ratio is the largest in the one-breeder layer mockup.

The ratios of the integrated $TPR_{scattered}$ to integrated TPR_{all} are 0.57, 0.46 and 0.24 for the one-breeder layer mockup, and the first and second layers in the two-breeder layer mockup, respectively. Figure 8 shows C/E of the integrated TPR_{all} as a function of the ratio of the integrated $TPR_{scattered}$ to the integrated TPR_{all}. For comparison, this figure shows result without the reflector. The C/E was 1.02 for the experimental condition without the reflector, a condition corresponding to the $TPR_{scattered}/TPR_{all}$ ratio of 0. The C/E increases with the integrated $TPR_{scattered}/TPR_{all}$ ratio. From these results, it can be considered that neutrons scattered back from the reflector cause the increase

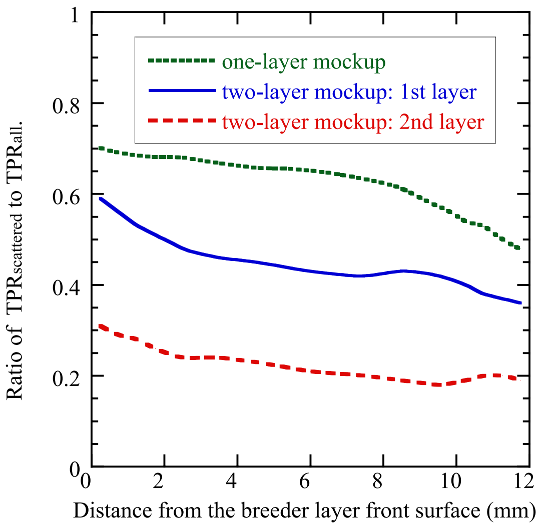

Fig. 7 Ratio of TPR due to neutrons scattered back from the reflector ($TPR_{scattered}$) to TPR due to all neutrons (TPR_{all}).

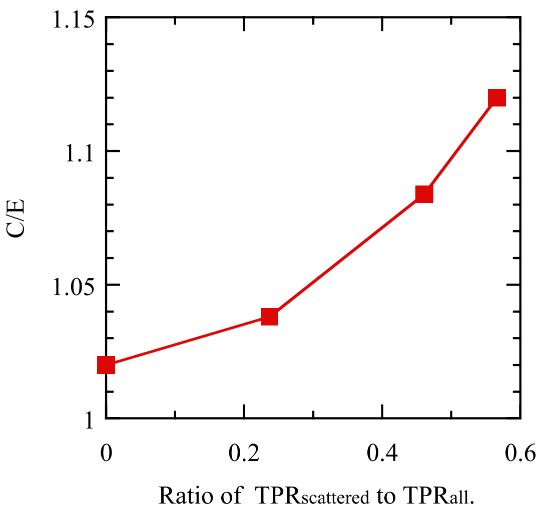

Fig. 8 C/E of the integrated TPR_{all} as a function of the ratio of the integrated $TPR_{scattered}$ to the integrated TPR_{all}.

of divergence of C/E from unity. It is discussed that the divergence of C/E from unity is due to uncertainty in calculation of back-scattered neutrons. This suggested that angular distributions to rear directions in the nuclear data libraries have some problems because there are only a few experimental data on the double-differential cross section to backward directions [11, 12].

4. Conclusion

Based on results from DT neutronics experiments using solid breeder blanket mockup with a neutron reflector, we have studied influence of reflector on calculation accuracy for TPR. From the present study, the following findings were obtained.

(1) From the Monte Carlo calculation results evaluating the tracked path of each neutron, the ratios of the integrated tritium production due to neutrons scattered back from the reflector to that due to all neutrons are 0.57 for the one-breeder layer mockup, and 0.46 and 0.24 for the first and second layers, respectively, in the two-breeder layer mockup.

(2) The divergence of the C/E from unity increases with the ratio of the integrated tritium production due to neutrons scattered back from the reflector. It can be concluded that this increase is due to neutrons scattered by the reflector, and that the calculation of back-scattered neutrons has some problems. The calculation accuracy can be enhanced by improving the calculation for back-scattered neutrons.

(3) The Tritium Breeding Ratio (TBR) has been assessed to be around 1.1 for the present JAEA DEMO reactor design. The contribution of the back-scattered neutrons mentioned in the present study is similar in the actual fusion reactor. In order to guarantee the TBR larger than unity, the calculation uncertainty should be reduced for the back-scattered neutrons.

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