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ARTICLE

Collimator System Design for a DT Neutron Beam at the First Target Room of JAEA/FNS

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A new collimator is designed and optimized to produce a new DT neutron beam with a small target at the first target room of the Fusion Neutronics Source facility in Japan Atomic Energy Agency. The characteristics of the collimator are calculated with the DORT code and the FENDL/MG-2.1 multi-group cross section library. It is concluded that the calculated neutron fluence above 14 MeV at the exit of the collimator is 180 times as large as that at the10 cm offset position from the beam axis.

KEYWORDS: DT neutron beam, collimator, FNS, DORT, FENDL/MG-2.1

I. Introduction

There are two target rooms at the Fusion Neutronics Source (FNS) facility in Japan Atomic Energy Agency (JAEA). The first target room (TR1) has a small tritium target for pulsed and continuous DT (Deuteron-Triton fusion) neutron generation. The second target room (TR2) has a large tritium target for heavy DT neutron irradiation. The existing DT neutron beam is produced with the large tritium target and thick collimators embedded in the wall of TR2.

Recently it becomes increasingly difficult to meet needs for experiments with a DT neutron beam such as instrument development for International Thermonuclear Experimental Reactor (ITER), because of shortage of large tritium targets. Therefore it is planned to construct a new DT neutron beam inside TR1 by using a small tritium target, which is easier to obtain.

In this study, a new collimator to produce a neutron beam is designed and optimized with neutron transport calculations, and the characteristics of the neutron beam are examined.

II. Collimator System

The collimator system is studied based on the assembly used in the previous ITER shielding experiments[1, 2] at JAEA/FNS. This assembly is constructed with a source reflector and hollow plates as shown in **Fig. 1**. Both parts are made of type 316 stainless steel (SS316). The inside of the hollow plates is able to be filled with various (beryllium, SS, lithium oxide, etc.) blocks and the collimator hole of 2 cm in diameter is made with these blocks with a hole that are set on the beam axis. The reflector also has a rectangular hole, which was modeled to a circle hole of 12.7 cm in equivalent diameter, to insert a beam line duct with a tritium target to the distance of 40 cm from the entrance of the collimator hole.

These source reflector and hollow plates are modeled two-dimensionally and neutron spectra are calculated to optimize collimator components by varying materials of the inside blocks. The beam line duct with a tritium target is not included in the calculation model.

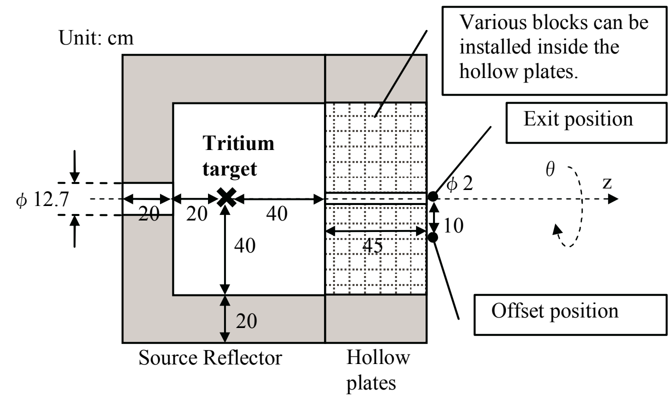

Fig. 1 Collimator assembly 2D model

III. Calculation

A two-dimensional discrete ordinates transport calculation code, DORT[3] and a multi-group neutron cross section library, FENDL/MG-2.1[4] are used to calculate neutron spectra. The first collision source is also calculated with the GRTUNCL[3] code to prevent the ray-effect.

Neutron spectra are calculated at the exit (hereafter called "exit position") of the collimator and at the 10cm offset position (hereafter called "offset position") from the collimator axis as shown in **Fig. 1**.

IV. Results and Discussion

1. All-SS Collimator

At first, as the simplest case, the neutron spectra are calculated for a collimator made of only SS316. This all-SS collimator is constructed by filling the inside of the hollow plates with SS316 blocks and is shown in **Fig. 2**. Neutron spectra at the exit and offset positions with the collimator hole and at the exit position without the collimator hole are shown in **Fig. 3**.

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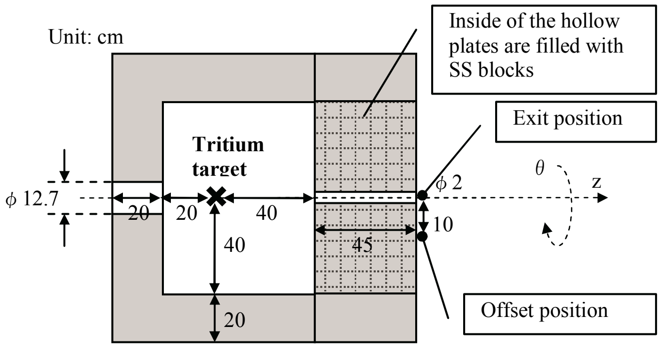

Fig. 2 All-SS collimator

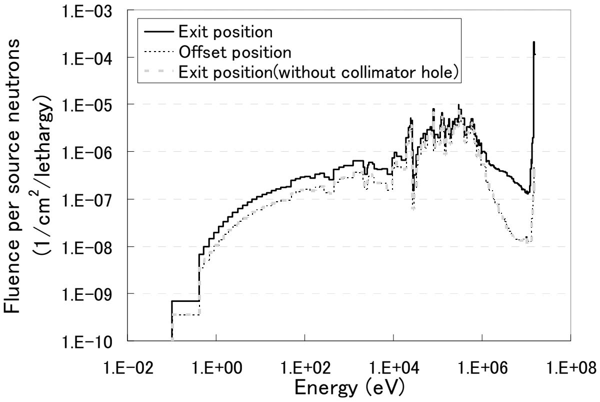

Fig. 3 Neutron spectra for all-SS collimator

The neutron spectrum at the offset position with the collimator hole is almost the same as that at the exit position without collimator hole. This implies that the neutron spectrum at the offset position is not affected by neutrons streaming through the hole. The ratio of the neutron fluence above 14 MeV at the exit position to that at the offset position is 316 : 1.

2. Effect of Wall in TR1

Secondly, to estimate the neutron fluence scattered at the wall of TR1, neutron spectra are calculated in the geometries with and without the wall. The all-SS collimator is used in both calculations. TR1 of FNS is approximated as a concrete cylinder, where the inner radius is 500 cm, the outer radius is 525 cm and the length is 1400 cm as shown in **Fig. 4**.

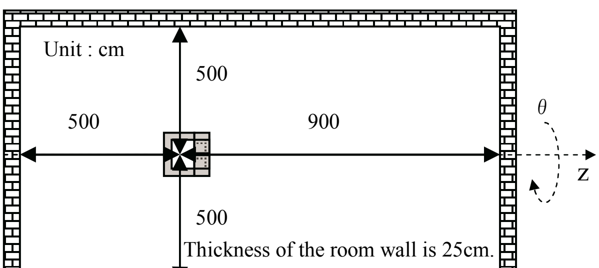

Fig. 4 TR1 model

The calculation results are shown in **Figs. 5** and **6**. The spectrum of scattered neutrons in **Fig. 6** is the subtraction of "Without wall" from "With wall" in **Fig. 5**. This shows that the fluence of the scattered neutron per source neutron per unit lethargy is $1\times10^{-8}\sim1\times10^{-7}$ (1/cm^2) and the neutron spectrum is nearly proportional to 1/v.

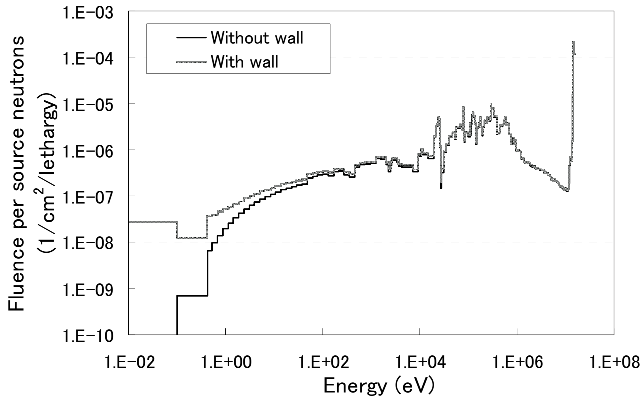

Fig. 5 Neutron spectra with and without wall

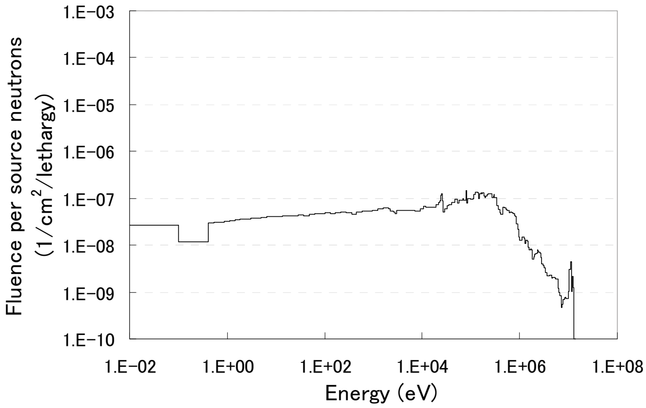

Fig. 6 Spectrum of scattered neutrons

3. Multi-layer Collimator with Moderator

The neutron spectra in the all-SS collimator geometry shown in **Fig. 3** have rather many neutrons below 1 MeV. Some moderators are required in order to reduce these neutrons below 1 MeV. Thus a multi-layer structure is adopted; polyethylene (PE) layers to moderate neutrons in MeV region, SS layers to attenuate 14 MeV neutrons and to absorb thermal neutrons and a lead layer to shield secondary gamma-rays. The multi-layer collimators in **Fig. 7** are examined. In order to make use of neutron absorption reaction of SS, it is desirable to install SS layers behind PE ones. On the contrary, it is desirable to install PE behind SS, where neutrons below 1MeV are significant, in order to make full use of moderating power of PE. Design 1 and Design 2 give weight to the former, while Design 3 does to the latter.

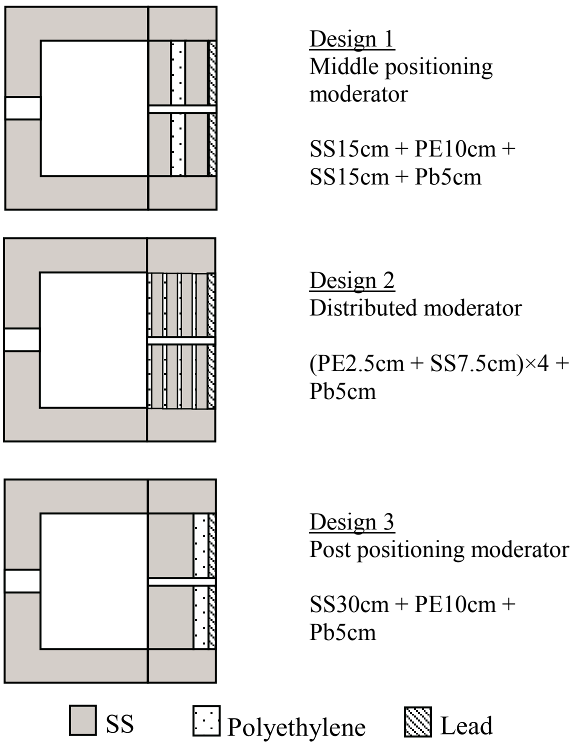

Fig. 7 Multi-layer collimators

The neutron spectrum calculated for Design 1 is compared with that for the all-SS collimator in **Fig. 8**. This figure indicates that Design 1 can attenuate neutrons below 1 MeV to approximately one tenth of that for the all-SS collimator.

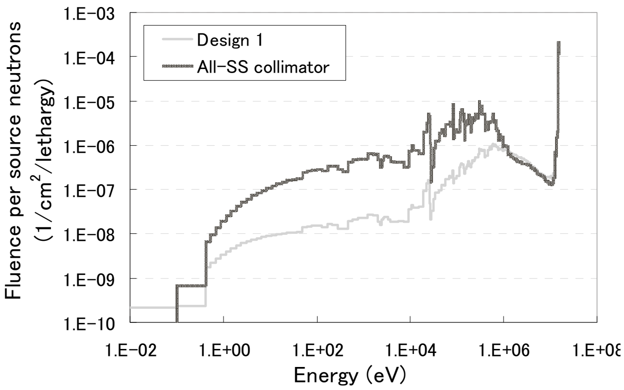

Fig. 8 Comparison between neutron spectra for all-SS and multi-layer collimators

The results calculated in the three multi-layer collimator geometries are in **Fig. 9**. Design 3 is the best for the region above 10 keV in the three geometries, while Design 1 is the best for the region below 10 keV. The neutron spectra at the offset position are displayed with in **Fig. 10**.

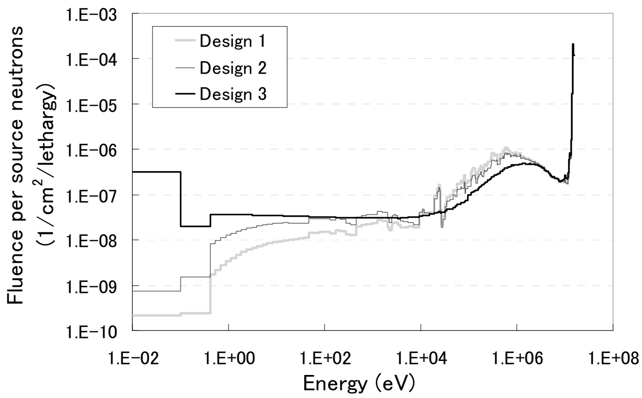

Fig. 9 Neutron spectra in multi-layer collimator geometries at exit position

In Design 3, the difference between the neutron spectra at the exit offset positions is the most significant of the three geometries in almost the whole energy regions. However, it should be noticed that the ratios of the neutron fluence above 14 MeV at the exit position to that at the offset position in **Table 1** are approximately the same in all these multi-layer collimator geometries. These ratios do not depend on the structures of collimators but on the total thickness of the shielding materials, especially SS.

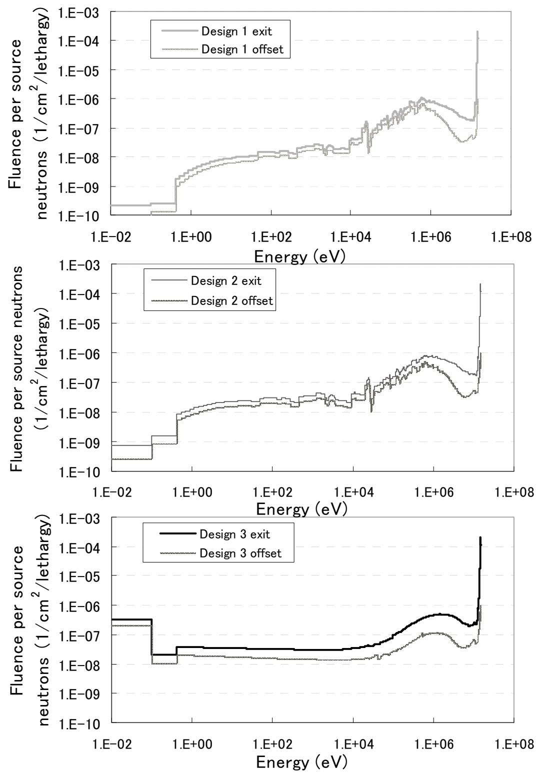

Fig. 10 Neutron spectra at exit and offset positions for multi-layer collimator geometries

Table 1 Ratios of neutron fluence above 14 MeV at exit position to that at offset position

	Design 1	Design 2	Design 3
ratio	151	152	152

4. Collimator Made of Materials at FNS

It is shown in the previous section that the collimator of post positioning moderator is superior as far as energetic and spatial localities are concerned. In this section, considering future experiment, a new collimator is designed with materials which we have at FNS to suppress secondary gamma-ray production and to improve the ratio of the neutron fluence above 14 MeV at the exit position and at the offset position. There are two points in this new collimator. Firstly, to attenuate 14 MeV neutrons at the offset position, some part of the SS layer is replaced with tungsten, the macroscopic cross section of which is larger than that of SS. Because the neutron fluence above 14MeV is not sensitive to the shielding structure, the conclusion of the previous section about moderator position still remains even if the SS layers are replaced with tungsten. Secondly, 5cm thick natural lithium oxide (Li_2O) and lead layers are added into the collimator to absorb thermal neutrons and to attenuate secondary gamma-ray respectively. The collimator (hereafter called "FNS collimator") of five layers is illustrated in **Fig. 11**.

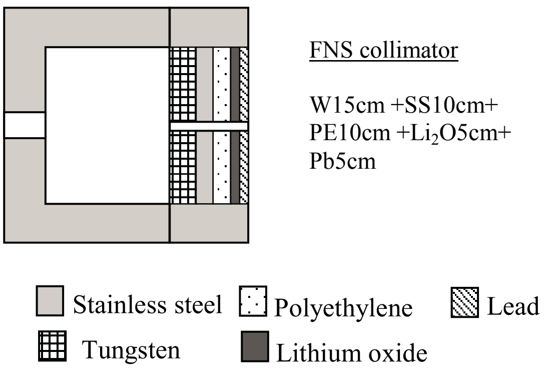

Fig. 11 FNS collimator

The neutron spectra calculated for FNS and Design 3 collimator geometries are shown in **Fig. 12**. In spite of the thinner SS layer than in Design 3, the fluence ratio at the exit position to at the offset position above 10 MeV is 180 owing to the tungsten layer. Moreover, the Li_2O layer reduces thermal and epithermal neutrons.

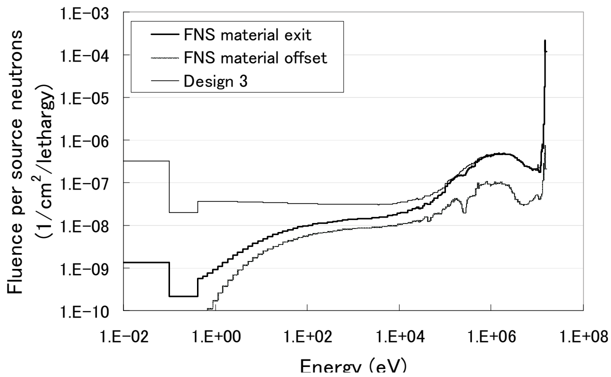

Fig. 12 Neutron spectra for FNS and Design 3 collimator geometries

V. Conclusion

A new collimator is designed for providing a new DT neutron beam at JAEA/FNS TR1. To make the neutron spectra monoenergetic and to concentrate the neutron beam on the axis of the collimator, multi-layer collimators are designed and optimized. Among those multi-layer collimators, the FNS collimator shows especially good performance in the whole energy region and the neutron fluence above 10 MeV at the exit of the collimator is 180 times as large as that at the offset point. Scattered neutrons in the wall of TR1 are very few in MeV region. An experiment of neutron measurement with this FNS collimator geometry is planned.

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