Study on In-Situ Calibration for Neutron Monitor in the Helical Type Fusion Experimental Device Based on Monte Carlo Calculations*)

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Monte Carlo simulations in design of neutron monitors for fusion experimental devices play an important role to evaluate the influence of scattering from various structures and to correct differences between neutron energies from calibration source and fusion plasma. We have developed an automated input file generation code based on finely segmented helical coil approximation. In this paper, we study the optimal number of divisions of segmented geometry from viewpoints of simulation precision and required calculation time. We conclude that results with more than 360 divisions saturate into the result with fully fine simulation. And we evaluate influence of neutron scattering from a miniature train, a railroad and supporting structures used in in-situ calibration experiments at LHD.

Keywords: helical type fusion experimental device, neutron monitor, Monte Carlo simulation, in-situ calibration

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1. Introduction

In fusion experimental devices operating deuterium experiments, ^{2}H(d,n)^{3}He fusion reactions generates 2.45 MeV neutrons, referred to as DD neutrons [1]. Therefore, total neutron yield can be a measure of the DD fusion output. Neutron monitoring is quite important not only to evaluate the plasma properties but also to manage safety of a facility. Monte Carlo simulations play an important role to evaluate the influence of scattering from various structures and to correct differences between neutron energies from calibration source and fusion plasma. However, it is not easy to create input file for simulation geometry of the helical type fusion devices such as Large Helical Device (LHD) in Monte Carlo code, such as MCNP5 [2], because helical type devices have quite complex three-dimensional structures. We, therefore, have developed an automated input file generation code based on finely segmented helical coil approximation [3]. This approximation model simulates a helical coil structure by dividing areas with an equal angle in toroidal direction. So far, the neutron spatial distributions and neutron spectra around the device were successfully calculated by using this approximation model [3, 4]. Although the uncertainty of the calibration constant was preliminarily evaluated for a neutron monitor placed on the center axis of LHD [3], the calculation condition in order to obtain adequate precision and accuracy of simulations has not been discussed in detail. The precision and accuracy of simulations can be improved by increasing the number of divisions. However, time required for simulations also increases with the number of divisions. In this paper, we study the optimal number of divisions from viewpoints of simulation precision and required calculation time. We, additionally, evaluate influence of a miniature train and rails and supporting structure used in in-situ calibration experiments at LHD. In the in-situ experiments at LHD, a ^{252}Cf standard source with known intensity is planned to be rotated on the rail built in a vacuum vessel. And, ENDF-6 is selected as calculation library for nuclear data library.

2. Optimal Calculation Condition

Figure 1 shows the schematic view of the simulation geometries. Two helical coils of LHD have five cycles. This means that LHD has periodic structure with ten cycles, corresponding to 36 degrees cycle. Simulation model is made by setting surfaces to divide areas by each angle interval in the toroidal direction, and then rotating the poloidal position of the coil in order to simulate a helical coil structure. The joint of the coil segments can be smoother when number of divisions increase. Number of divisions should be large from the viewpoint of calculation precision. Figure 2 shows the relationship between the required time and the number of divisions in calculation. The time required to perform calculations also increases. We

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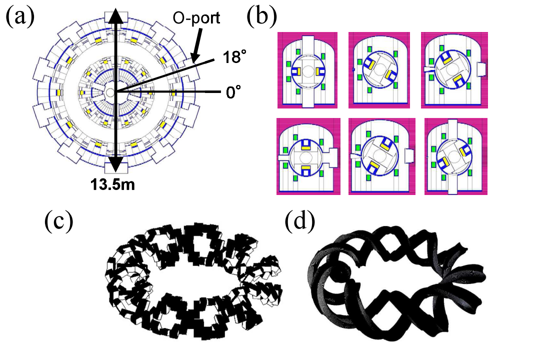

Fig. 1 Schematic view of the geometry used in MCNP code. (a) Horizontal section on the equatorial plane of LHD. (b) Vertical sections at different angle positions. (c) Coils divided into 60 areas. (d) Coils divided into 1440. When number of divisions increases, the shape of coils can be smooth from a square shape segmented coil to a seamless coil.

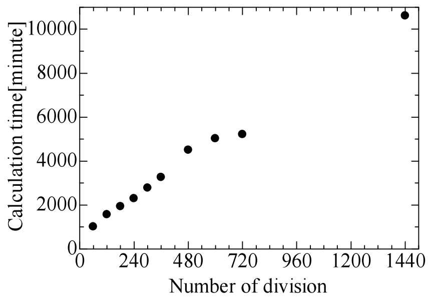

Fig. 2 Relationship between time required to perform 25,000,000 histories calculations and number of divisions in simulations.

should optimize the number of divisions in order to improve precision and efficiency of calculations. As an evaluation index, we calculated total neutron fluences outside the vacuum vessel at the O-port, where neutron monitors would be placed. A DD neutron source with the energy of 2.45 MeV has doughnut shape which simulates fusion plasma. Figure 3 shows the mean neutron fluences around O-port. Fluences at various heights from the equatorial plane are plotted. As number of divisions increase, neutron fluences also increase. Fluences saturate around 360 divisions. These trends depend on smoothness of helical coil shape. In particular, shape of structures between the ring neutron source and the O-port are important because many neutrons go out through the O-port directly. A square shape segmented coil structure used in a rough geometry has larger volume coil within the field of view from the O-port to the plasma than a smooth coil. Figure 4 shows the coil partial volume between heights of the top and bottom ends of a plasma doughnut. As the number of divisions increase, the partial volume decreases and saturates around 360 divisions. In a rough geometry, the neutron fluence observed outside the O-port decreases because neutrons are shielded by the larger volume coil structure. From Figs. 3

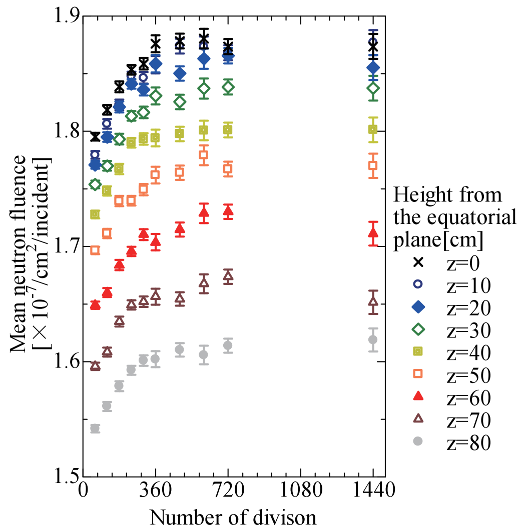

Fig. 3 Mean neutron fluences in the region of toroidal angles from 15 to 21 degrees. Results at various heights from the equatorial plane are plotted. Error bars show statistical uncertainty.

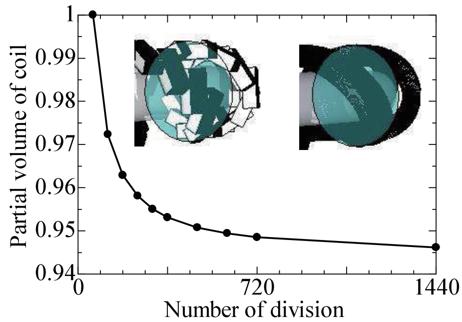

Fig. 4 Dependence of the partial coil volume between heights of the top and bottom ends of a plasma doughnut on the number of divisions. The ellipse of two pictures shows the area of coils we can see from an angle of 30 degrees for the O-port.

and 4, we conclude that simulation results with more than 360 divisions saturate into the result with fully fine simulation. We consider that the simulation model with the number of divisions of 360 is desirable to be used from viewpoints of simulation precision and required time.

3. Structures for In-Situ Calibration Experiments

In the in-situ calibration experiments for neutron monitors at LHD, a ^{252}Cf standard source, from which broad fission spectrum neutrons with the average energy of 2.11 MeV [5] were emitted with known intensity is planned to be rotated on the rail built in a vacuum vessel. The source is mounted on a miniature train equipped with an electric motor and is rotated on the rail. Figure 5 shows the schematic view of the geometry of rail supporting structures. The heights of rail and supporting struc-

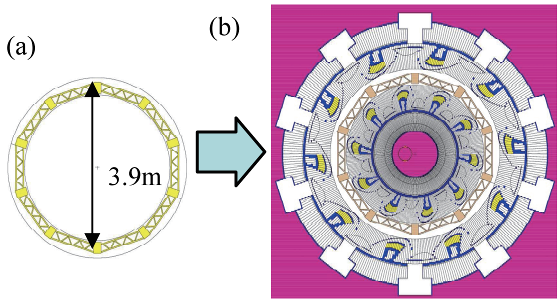

Fig. 5 (a) Schematic top view of the geometry of supporting structures. A large circle indicates the area of the vacuum vessel. (b) Horizontal section with supporting structures, which colored pink, at the 50 cm low position from the equatorial plane of LHD.

tures are just below the center of the vacuum vessel. A radius of the center line of the rail is 1,872 mm. This is slightly smaller than the major radius of the vacuum vessel of LHD, which is 1,950 mm. The bottom plate of the rail has 18 mm width and 1 mm thickness and is made from bakelite, in which 54% carbon and 46% hydrogen are contained. The rail supporting structures consists of ten segmented parts made of aluminum frames in this simulation. The major radius of the rail supporting structures is also 1,950 mm and its width is 541.6 mm.

In this section, we evaluate influence of these structures. To simplify the simulation model, we only simulate bottom plate of the rail and supporting structures. A train, a rail and railroad ties are omitted in this simulation.

First, we calculated total neutron fluences above and below the supporting structures in the geometry setting only supporting structures and a ring ^{252}Cf neutron source, which simulates a rotating point source, without the LHD structure. Fluences at toroidal angles from 0 to 359 degrees were calculated. We also compared the results obtained from the model with and without supporting structures. Figure 6 shows relative neutron fluence distribution above and below the supporting structures. In the geometry with the supporting structures, fluences above the structures increase. On the other hand, fluences below the structures decrease. This is because of neutron scattering by the supporting structure materials.

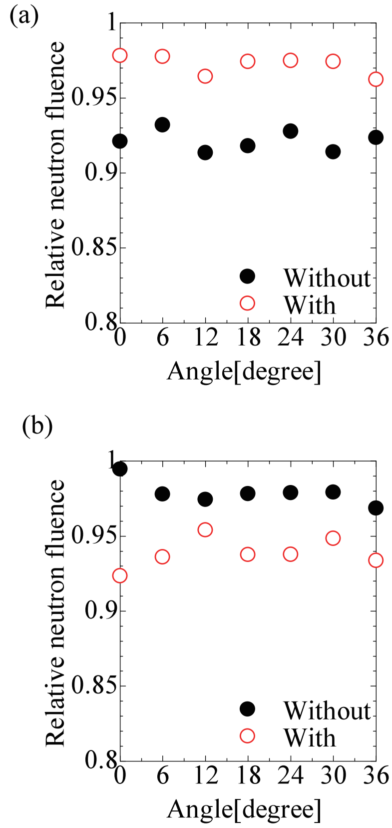

Fig. 6 Neutron fluence distribution. (a): above the supporting structures. (b): below the supporting structures. Fluences with and without the structures are plotted. Statistic uncertainty is less than 1%.

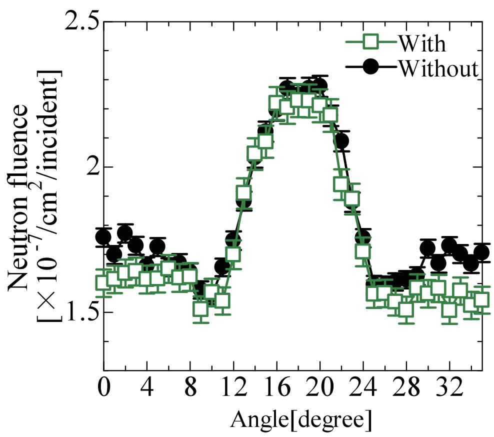

Fig. 7 Neutron fluence distribution outside the O-port. Open squares and closed circles show the neutron fluences with and without the supporting structures, respectively. Statistic uncertainty is less than 5%.

4. LHD Model Calculations

As the next step, we incorporated these structures into the LHD model and calculated neutron fluence distribution outside the O-port. A neutron source was a ring and isotropic ^{252}Cf source. Figure 7 shows the neutron fluence distribution outside the O-port. Neutron fluence strongly depends on the helical coil structures. Positions around 18 degrees correspond to the O-port position. In the direction of the O-port, neutrons can go out without interruption of the helical coil. On the other hand, neutrons are interrupted by the coil structure in the direction around 0 and 36 degrees, corresponding to the region between the O-ports. In the case with the supporting structures, neutron fluences outside the O-port decrease compared with those without these structures. This influence is emphasized near 0 and 36 degrees, where the contribution of scattered neutrons by the supporting structures is significant. Figure 8 shows

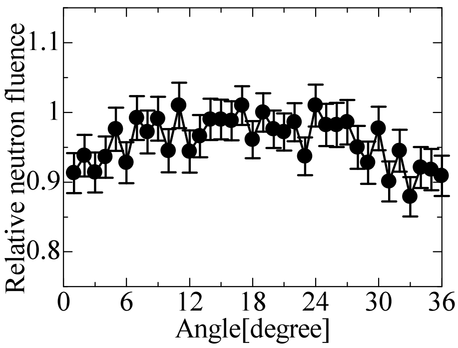

Fig. 8 Relative neutron fluence distribution with the supporting structures to without the structures.

the relative neutron fluence distribution with the supporting structures to without the structures. Averaged reduction ratio by the supporting structures is about 4%. Although statistical fluctuation is relatively large, the trend that the fluence reduction is emphasized between the O-ports can be seen. These differences are mainly of a few MeV regions. At 18 degrees, correction for the measurements is not necessary. At 0 degree or 36 degree, however, it is necessary to correct approximately 8% differences. In this estimation, influences of a miniature train, rail and railroad ties are neglected. In a simple calculation including these structures, neutron fluence is higher at the upper part by 2% compared with that at the lower part. This difference does not have much influence on the results of this paper. The estimation of the influence from these objects in detailed calculations will be future works.

5. Conclusion

We optimized the Monte Carlo calculation condition on the number of divisions in the segmented helical coil approximation model. Neutron fluences evaluated outside the O-port of LHD increase with increasing the number of divisions and saturate around 360 divisions. We can conclude that simulation results with more than 360 divisions saturate into the results of fully fine simulation. We recommended that the model with 360 divisions should be used from the viewpoints of simulation precision and required time.

In addition, we estimated the influence of the rail supporting structures which is planned to be used in in-situ calibration experiments. In the case with the supporting structures, neutron fluences outside the O-port decrease compared with those without these structures. Averaged reduction ratio of the neutron fluence by the supporting structures is about 4%.

As future works, we will try to incorporate small objects, such as a miniature train, rail and railroad ties, near a neutron source into the calculation model. In addition, experimental verification, which might be performed in mock-up structures, will be the next important task.

Acknowledgements

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