Detailed Analysis of *in-situ* Calibration of Neutron Flux Monitors for ITER

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Abstract

Several effects on *in-situ* calibration of neutron flux monitors are analyzed through the neutron transport analysis using a Monte Carlo code for Neutron and Photon transport (MCNP). Results show that the calibration time of the in-vessel flux monitor (Microfission chamber, MFC) is most affected by the change of the position of a neutron calibration source. It has been also found the source supporting rail positioned bottom the source significantly affects the neutron sensitivity of the lower MFC, but the effect of the supporting rail positioned side of the neutron source is slight. Cooling water in the blanket module (BM) could also significantly affect the detection sensitivity. This result suggests cooling water should be flowed in the BM in the same way as the ITER operations when the *in-situ* calibration is performed.

1. Introduction

Fusion power and its time evolution on ITER will be evaluated in terms of the total neutron emission rate as measured with neutron flux monitors (in-vessel, in-port and divertor monitor). Since a level of accuracy to within 10% is required for evaluation of the fusion power in ITER, the relation between the output of neutron flux monitors and the total neutron emission rate must exceed this accuracy level in an absolute sense. In ITER, the absolute calibration factors of the neutron flux monitors will be obtained by means of a neutron *in-situ* calibration procedure. The neutron source (a neutron generator and/or an isotope source) will circulate or be positioned at several points along a toroidal ring located on the plasma axis and/or on several poloidal coordinates for *in-situ* calibration. The basic strategy of the *in-situ* calibration, for example, an optimum neutron source during an appropriate time frame, has been studied in the previous study [1, 2]. However, the calibration factor, that is, detection efficiency, of the neutron flux monitors, especially the in-vessel monitor is affected by surrounding materials and the position of the neutron source. The difference of the condition of the ITER Tokamak between ITER operation and the *in-situ* calibration could also affect. Thus, detailed analysis is necessary for well-planned, *in-situ* calibration. So, several effects on *in-situ* calibration of neutron flux monitors are analyzed through the neutron transport analysis using MCNP. In this paper the analysis results for the in-vessel monitor, Microfission chamber (MFC) [3], is presented. The calculation model and method are described in Chap.2. In Chap.3 the time needed to conduct *in-situ* calibration of the neutron flux monitors is described. The effects of the support structure of the neutron source and cooling water in the blanket module (BM) are presented in Chap.4 and 5, respectively. Finally, a summary is presented in Chap.6.

2. The calculation model and method

In order to analyze *in-situ* calibration for the MFC in detail, MCNP calculation (version of MCNP

5 [4], combined with the nuclear data library FENDL2.1 and JENDL3.3) has been performed using the Alite-ITER model [5], which was the MCNP input model simplified 40° ITER Tokamak, including the vacuum vessel, the blanket module, the divertor cassette and other machine construction. The poloidal cross section of the Alite model with installation position of the MFC, is shown in Fig.1. The MFC is installed upper and lower outboard behind the blanket module. The fission material of the MFC is ^{235}U. We assume the neutron source set as a toroidal ring source to simulate that neutron source circulate along the toroidal direction and the energy of neutrons is 14 MeV.

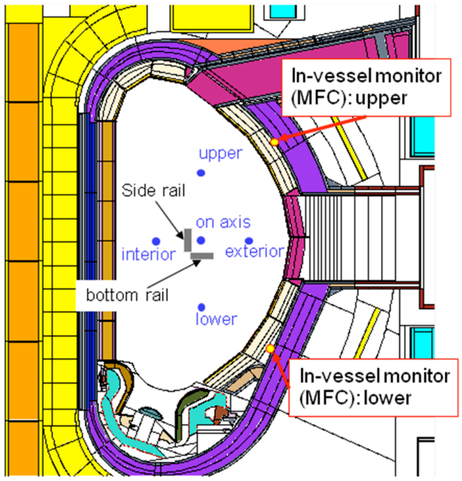

Fig.1 The poloidal cross section of the Alite model and installation position of the in-vessel monitor (MFC); the blue circles means the polodal position of ring source (Chap.3) and the gray rectangles mean the support rail (Chap. 4)

3. Evaluation of the total calibration time

In the previous work, the time needed to obtain the necessary number of counts (1000 [3% statistics error], 10000 [1%])when the neutron source set on the plasma axis was evaluated [1]. However, it is considered that the neutron source should be set at from 5 ~ 9 toroidal rings at several poloidal positions to correct adequately for the effect of the profile change of neutron emissions. Since sensitivities of the MFC are dependent on the source position, time needed for calibration could be different at each source position. Then, the calibration time to obtain the necessary number of counts at each source position is evaluated for the MFC. In this calculation the case that the neutron source is set at 5 poloidal positions (the plasma axis as well as upper, bottom, interior and exterior locations) is assumed as shown as the blue circles in Fig.1 (The supporting rail shown in Fig 1 is not taken into account for this calculation). Table 1 shows calibration time of the MFC at each setting position of the neutron source and the total calibration time, which is normalized for the calibration time of the upper MFC when the neutron source is set at plasma axis. When the source sets at upper the plasma axis, the calibration time of the lower MFC becomes longer than that at the plasma axis and the calibration time of the upper MFC is shorter. On the other hand, when the source sets at lower the plasma axis, the calibration time of the upper MFC becomes longer than that at the plasma axis and the calibration time of lower MFC is shorter. The result also suggests that the effect of the change of the neutron source position on the calibration time is small. Since a longer calibration time is necessary at each source position, as a result, the total calibration time to obtain at the 5 toroidal lings for the MFC is not 5 times, but about 7 times longer than when the source is set at the plasma axis, owing to the change in neutron

Tab.1 Calibration time of In-vessel neutron monitor (MFC) at the each position of the neutron source, which is normalized for the calibration time of the upper MFC at the plasma axis.

generator position	Plasma Axis	upper (+150cm)	lower (-150cm)	interior (-100cm)	exterior (+100cm)	Total
upper MFC	1.0	0.7	1.9	1.1	1.2	5.6
lower MFC	0.9	1.8	0.7	0.9	1.0	5.3
Both MFCs	**1.0**	**1.8**	**1.9**	**1.1**	**1.2**	**7.0**

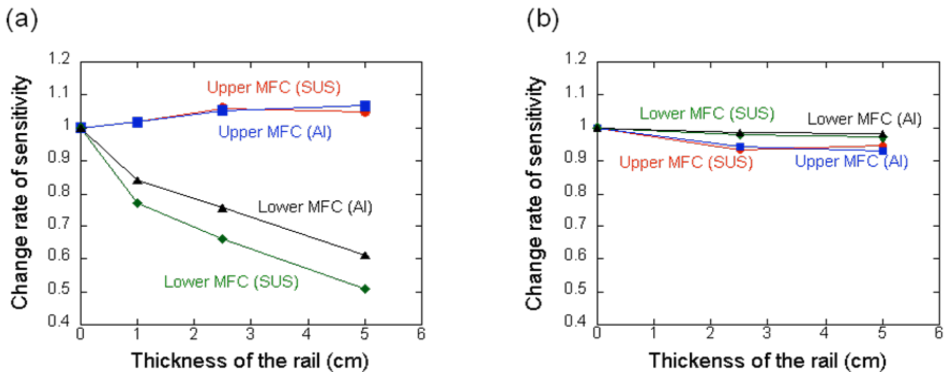

Fig.2 Change rate of neutron sensitivity of the MFC due to the support of the source :(a) bottom rail, (b) side rail

sensitivity as the distance between the neutron source and the MFC varies. Thus, total calibration time is affected by the position of the supporting rail. An optimization of the position of the supporting rail by taking into account the total calibration time is one of important future works.

4. The Effect of the Supporting rail of the Source

The effect of the supporing rail of the neutron source on in-situ calibration to the upper and lower MFC was evaluated. Two cases are considered as the supporting rail, the bottom and the side rail as shown in Fig. 1. The rail set at 10 cm away from the source and the width is 20 cm in this calculation. The change rate of the detection sensitivities of upper and lower MFC due to the supproting rail as a function of the thickness of the supporting rail are shown in Fig. 2. Here the rail material of stainless steal (SUS) or aluminium (Al) is assumed. If the supporting rail is located at the bottom of the source, the neutron sensitivity of the lower MFC is reduced by ~ 50% when the thickness of the SUS rail is 5 cm due to the fact that the support is located between the neutron source and the lower MFC. The neutron sensitivity of the lower MFC is also strongly affected by the bottomo rail in the case of Al rail. On the other hand, the effect of the supporting rail on neutron sensitivity is less than 7% and much slighter than the bottom rail if the supporting rail is located on the inboard side of the source. These results indicate that the supporting rail should be set not to locate between the source and the neutron flux monitor. If the neutron generator is used as the neutron source in *in-situ* calibration, the way for supporting the neutron generator, that doesn't affect the detection sensitivity, should be optimized since the neutron generator is relatively heavy.

5. The Effect of Cooling Water in the BM

Cooling water in the BM is essential to cool the blanket module during ITER operation. However, there is a possibility that cooling water is not flowed in the BM when the in-situ calibration is performed. Since water slows down and scatters neutrons, it may affect *in-situ* calibration. In order to investigate the effect of cooling water, neutron flux at the installation position of neutron flux monitors and those neutron response are compared under the following two conditions; the first one is that the BM consists of SUS316 70% + water 30% (with water) , the other one is SUS316 70% + void 30% (w/o water). Figure 3 (a) and (b) shows neutron spectrum at the upper MFC position and the energy dependence of neutron response of the upper MFC, respectively.

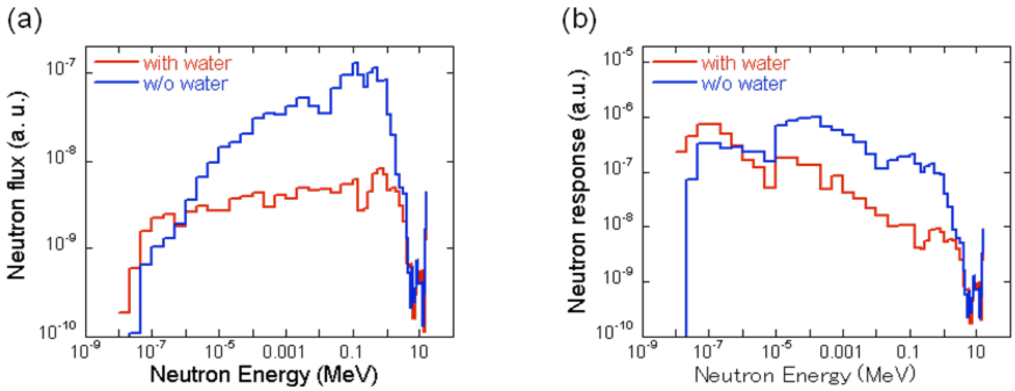

Fig.3 (a) Neutron spectrum at the upper MFC position, (b) energy dependence of neutron response of the upper MFC

Neutron flux in the case of w/o water is about 10 times higher than that of with water because attenuation of neutrons with over 10^{-5} MeV become much weaker due to lack of cooling water. Since ^{235}U fission material in the MFC has large cross section of fission reaction in energy region of thermal neutrons (< 10^{-6} MeV), the effect of cooling water on the calibration factor become smaller than the neutron flux. Nevertheless, the total neutron response over whole energy region in the case of w/o water is about twice as high compared with that of with water. Thus, the result suggests that cooling water could significantly affect the *in-situ* calibration. Therefore, cooling water should be flowed in the BM in the same way as the ITER operations when the *in-situ* calibration is performed.

6. Summary

Several effects on *in-situ* calibration of the in-vessel neutron flux monitor (MFC) are analyzed through the neutron transport analysis using MCNP. When the *in-situ* calibration are performed at 5 poloidal positions, the total calibration time of the MFC is longer than 5 times (about 7 times) of the calibration time when the source sets the center position, owing to the change in neutron sensitivity as the distance between the neutron source and the MFC varies. So, optimization between the number of source setting positions and total calibration time is necessary. we also found that the bottom rail could strongly affect detector efficiency of the lower MFC. On the other hand, the effect of side rail is slight. Cooling water could also significantly affect the *in-situ* calibration. Therefore, it is necessary that cooling water would be flowed in the BM when the *in-situ* calibration is performed.

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