7.2 Experience of Neutronic Evaluation for In-pile Tests of Fusion Blanket with the JMTR
- Influence of Impurities in Beryllium -

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Impurities in beryllium for fusion blanket application such as armor of the first wall and neutron multiplier is one of important issues to perform its properties. In this study, tritium production rate evaluation was carried out on the base of JMTR irradiation test that simulated the breeding blanket and the impact of impurity on tritium production rate was discussed. Influence of impurities in S200F beryllium was therefore less than 1%, concerning tritium production rate. Accordingly, it is reasonable to estimate extremely small impact on tritium production rate in case of fusion application that uses high purity beryllium such as S65C.

1. INTRODUCTION

Impurities in beryllium (Be) for fusion blanket application such as armor of the first wall and neutron multiplier is one of important issues to perform its properties. Furthermore, it is severely controlled within the prompt specification from the viewpoint of thermal shock resistance and mechanical property under neutron irradiation. For example, a reference grade for ITER application, that is, S65C defines the specification of purity as Be>99.0wt% and the other elements are also severely defined. On the other hand, the influence of impurity on the nuclear property such as tritium production rate has not been discussed almost on the grounds that it has not been significant impact on nuclear evaluation with Be reflectors that use S200F (Be>98.5wt%) that has much impurity than S65C. However, it is essential to understand how critical this impact is on tritium production rate numerically and systematically to assure the feasibility of Be and to clarify the margin of blanket design.

In this study, evaluation of tritium production rate was carried out on the base of JMTR irradiation test that simulated the breeding blanket and the impact of impurity on tritium production rate was analyzed quantitatively.

2. JMTR

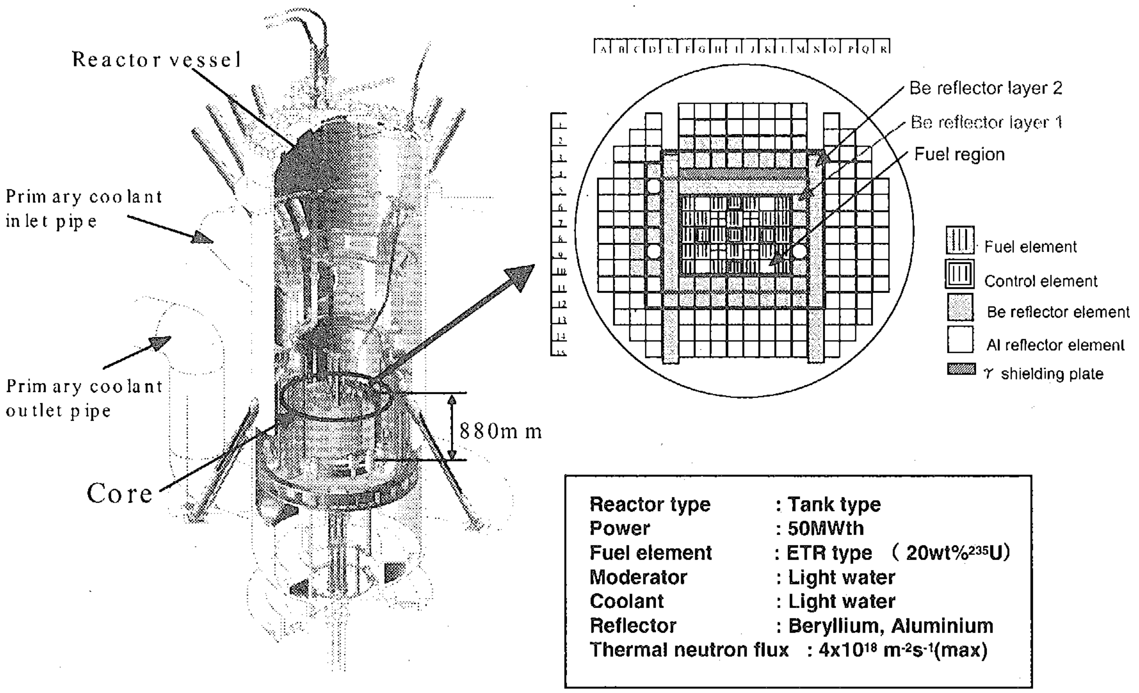
The JMTR is utilized for the basic and the applied researches on the fuels and materials of fission reactors and fusion reactor, and radioisotope productions. The JMTR is a tank-in-pool type reactor with thermal power of 50MW and both coolant and moderator are light water. The typical core configuration is shown in Fig. 1. The reactor core, which is 1560mm in diameter and 750mm in effective height, consists of fuel elements, control rod, reflectors and H-shaped beryllium frame. Each reflector element has irradiation hole, which is loaded with a capsule for irradiation tests or a solid plug of the same material as the reflector element. The H-shaped beryllium frame has also irradiation holes. An irradiation channel can be chosen among 195 possible positions in the core.

3. EXPERIENCE OF NEUTRON FLUX EVALUATION IN VEARIOUS IRRADIATION TESTS OF JMTR

3.1 Measurement

Neutron fluxes at local positions have been measured by using the fluence monitors. The typical fluence monitors used in the JMTR are illustrated in Fig. 2. ^{54}Fe(n,p)^{54}Mn reaction of iron and ^{59}Co(n, γ)^{60}Co reaction of Aluminum-Cobalt (0.11wt% of Cobalt) wires are used as fast and thermal neutron flux/fluence monitors respectively. As usual practice, five fluence monitors are prepared for one irradiation capsule.

After irradiation tests, radiation activities of ^{54}Mn and ^{60}Co are measured with the germanium detector. The reaction rates of ^{54}Fe(n,p)^{54}Mn and ^{59}Co(n, γ)^{60}Co reaction are calculated by using radiation activities, and neutron flux/fluence are obtained from the reaction rates and the weighted neutron cross section with calculated neutron



Reactor type	**: Tank type**
Power	**: 50MWth**
Fuel element	**: ETR type (20wt%^{235}U)**
Moderator	**: Light water**
Coolant	**: Light water**
Reflector	**: Beryllium, Aluminium**
Thermal neutron flux	**: 4x10^{18} m^{-2}s^{-1}(max)**

Figure 1 Outline of JMTR

spectrum at fluence monitor position.

3.2 Calculation

Neutronic calculations were conducted using the 3-D Monte Carlo code MCNP (ver.4B)[1] with continuous energy cross section library FSXLIBJ3R2 [2] (derived from JENDL3.2) for the neutron. The JMTR core for each operation cycle is modeled and whole core of JMTR include irradiation capsules are modeled in detail (see Fig. 3). Fast and thermal neutron fluxes, tritium production rate, etc. at each sample position are calculated by using KCODE option in the MCNP code.

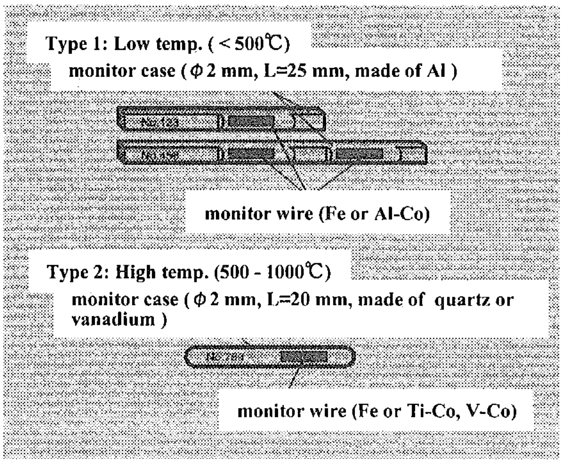


Figure 2 Flux/fluence monitor

3.3 Verification Results

Detailed analyses of neutron flux/fluence in various and many irradiation tests are conducted using the MCNP code and results are verified by comparing with the values estimated using the data of flux/fluence monitors[3-7].

Results of neutron flux were shown in Fig. 4, using data of 174 sets of flux/fluence monitors (27 irradiation capsules) from 1998 to 2001.The calculated fast neutron fluxes agreed with measured ones within about ±10% error. The other hand, the calculated thermal neutron fluxes agreed with measured ones within about ±0 - +30% error.

The calculated thermal neutron fluxes tend to overestimate the measured ones, especially in the range of 10^{13} to 10^{14} n/cm^{2}s. Thermal neutron fluxes in this range correspond to the irradiation region of

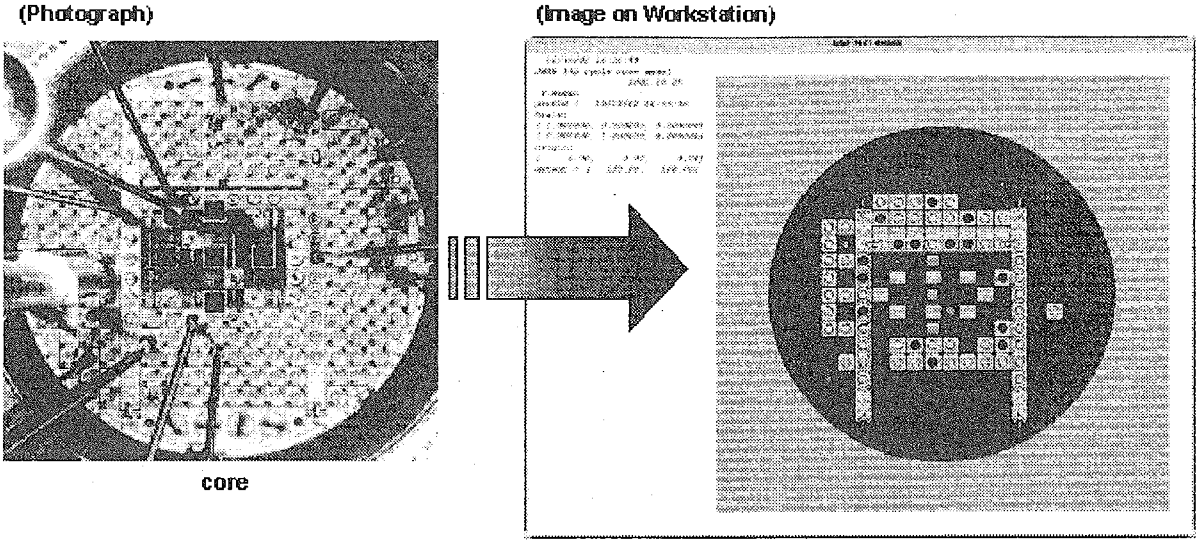


Figure 3 MCNP calculation model of JMTR

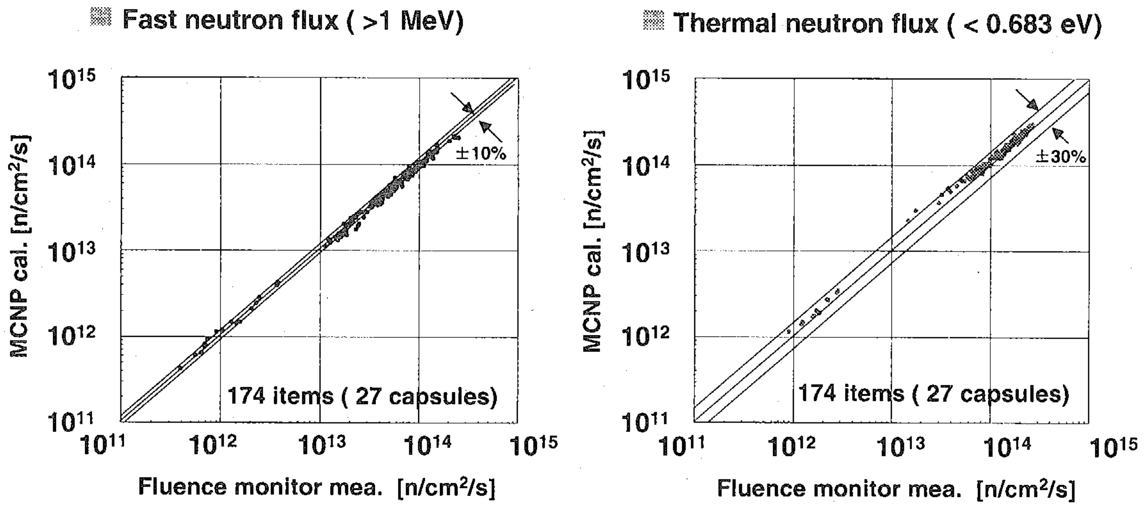


Figure 4 Comparison of calculated and measured neutron flux in irradiation tests of JMTR from 1998 to 2001

the beryllium reflector layer 2 in the JMTR. The difference between calculated thermal neutron flux and measured ones except of the range of 10^{13} to 10^{14} n/cm^{2}s were about 20% at the most. In addition, concerning fast neutron flux, the different between calculated and measured values did not depend on irradiation regions.

As the results, one of the reasons for the overestimation of thermal neutron flux was therefore considered to be an accuracy of the neutron cross section of Be.

4. INFLUENCE OF IMPURITIES IN BERYLLIUM

4.1 Chemical Composition of Beryllium reflector element

In the JMTR, Be reflector elements and Be flame is made from S200F beryllium. According to the inspection certificate of Be(S200F) reflector elements (see Table 1), major impurities that are known to increase the neutron absorption cross section are Lithium(3ppm), Boron(0.9ppm), Nitrogen (260ppm), Iron(620ppm) and Cadmium(2ppm). They

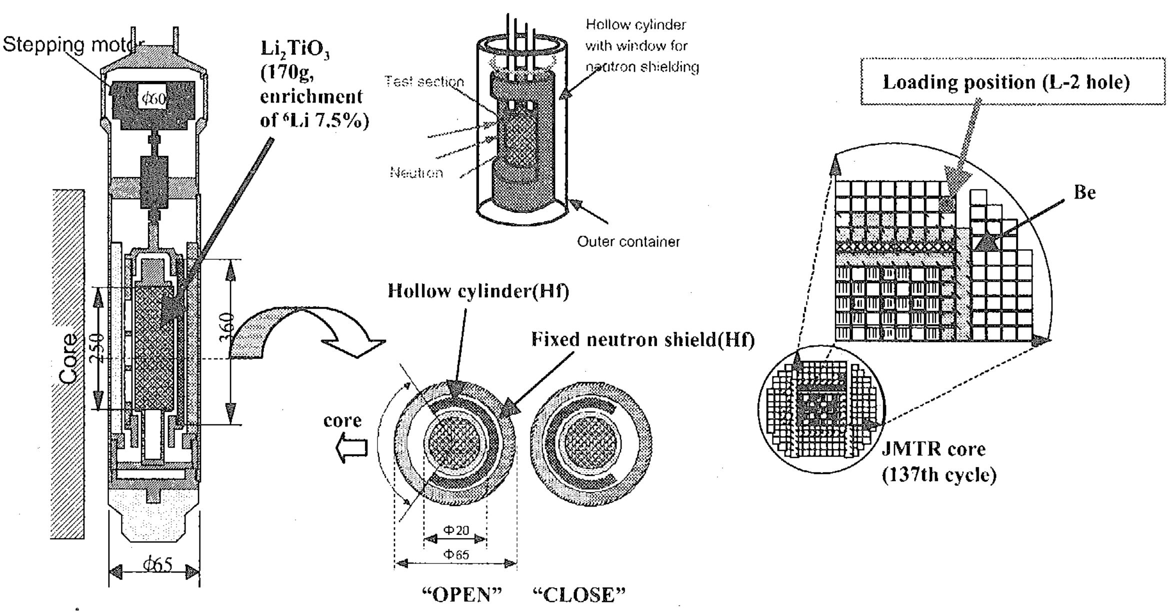


Figure 5 Schematic of pulse operation simulating mockup

are within the specification and typical values as S200F.

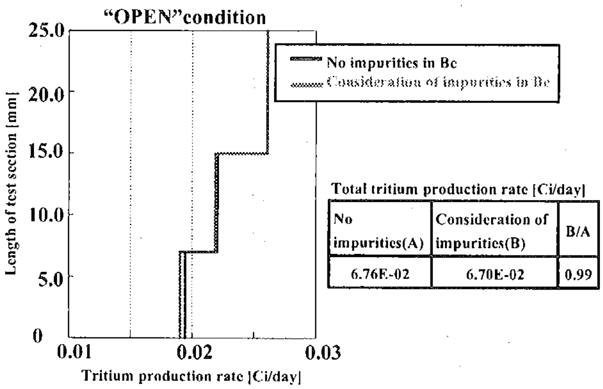
Impurities in the reactor grade Be such as S200F were generally controlled from the view point of neutron absorption cross sections. Each component of impurities converted into the weight of boron and the converted weight was limited to 10ppm. In the case of Be reflector elements, the converted weight was about 4ppm. Therefore, impurities in Be are not considered in neutronic calculations in the JMTR, usually.

Table 1 Chemical composition of Be reflector elements(S200F)

Element	wt%
Be	99.15
O	0.83
Al	0.0315
B	0.00009
Cd	0.0002
Ca	0.0031
C	0.0946
Cr	0.010
Co	0.0008
Cu	0.0022
Fe	0.0615
Pb	0.0020
Li	0.0003
Mn	0.0100
Mg	0.0150
Mo	0.0020
Ni	0.021
Si	0.0242
Ag	0.0004
Cl	0.0025
N	0.0320

4.2 Evaluation of tritium production rate of pulse operation simulating mockup

Figure 5 shows the schematic of the pulse operation simulating mockup[8-9]. The in-pile mockup consists of a test section for the tritium breeder, a pulse operation simulating device (hollow cylinder with window and fixed neutron absorber cylinder) and a stepping motor to rotate the hollow cylinder with window. The dimension of the



Total tritium production rate [Ci/day]

No impurities(A)	Consideration of impurities(B)	B/A
6.76E-02	6.70E-02	0.99

Figure 6 Calculation results of tritium production rate

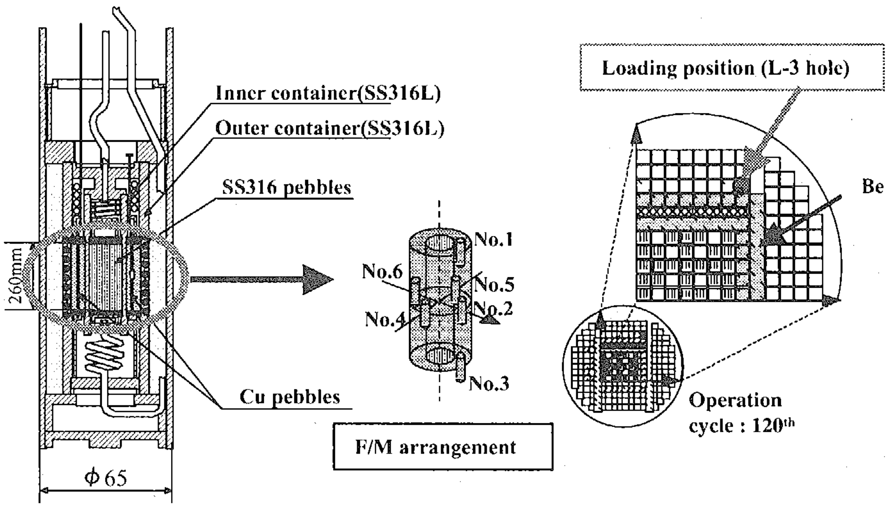


Figure 7 Schematic of preliminary multi-layered pebble bed mockup

irradiated binary Li_2TiO_3 pebble bed was 20 mm in inner diameter X 260 mm in length. The in-pile mock-up was loaded at M-2 hole in the aluminum reflector layer 2.

In this irradiation test, tritium production rate from Li_2TiO_3 pebbles (weight of Li_2TiO_3 pebbles: 170 g) was calculated by MCNP code.

Figure 6 shows the calculation results. tritium production rate in consideration of impurities in Be was 6.70×10^{-2} [Ci/day]. On the other hand, the value in the case of no impurities was 6.76×10^{-2} [Ci/day]. Influence of impurities in Be(S200F) was therefore less than 1%, concerning tritium production rate.

4.3 Neutron flux evaluation of preliminary multi-layered pebble bed mockup

The schematic of the preliminary multi-layered pebble bed mock-up[10-11] was shown in Fig.7. The construction of this in-pile mock-up is simulated as multi-layer typed blanket. The packing region consists of 1st and 2nd layer, and stainless pebbles and copper pebbles are packed in 1st and 2nd layer, respectively. The dimension of packing region is 250 mm in length, 20mm in 1st layer diameter and 40mm in 2nd layer diameter.

The flux/fluence monitors were located outside of the packing region. Four flux/fluence monitors were located in the middle of the packing region along the vertical axis, and two F/M were located in +75mm and -65mm from center of the packing region along the vertical axis.

The mockup was loaded at L-3 hole in Be reflector layer 2, and was irradiated for 25 days in the 120th operating cycle of the JMTR. Figure 8 shows the calculated neutron fluxes comparison between no impurities and consideration of impurities.

As the result, influence of impurities in Be reflector elements was about 2%.

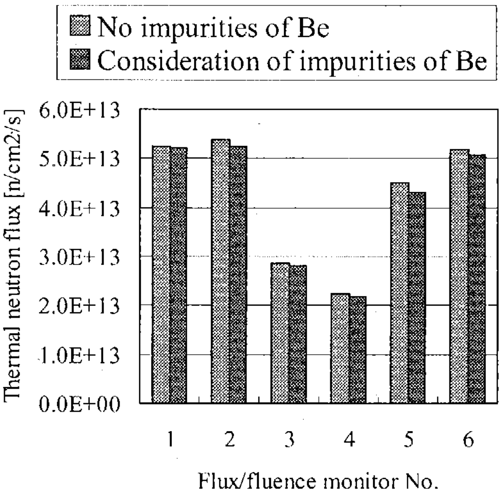


Figure 8 Comparison of no impurities and consideration of impurities in Be concerning thermal neutron flux

6. SUMMARY

The influence of impurities in Be (S200F) was examined concerning tritium production rate and neutron flux for the fusion blanket in-pile tests of the JMTR.

As the results, impurities in Be reflector elements (S200F) could not influence tritium production rate and neutron flux, concerning the fusion blanket in-pile tests in the JMTR. Accordingly, it is reasonable to estimate extremely small impact on tritium production rate in case of fusion application that uses high purity beryllium such as S65C.

Additionally, the reason for the overestimation of calculated thermal neutron flux is considered to be an accuracy of the neutron cross section of Be.

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