Calculation of Tritium Breeding Ratios for the Fusion Reactor Concept

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1. Introduction

Recently, tokamak reactor system analysis code has been developed at KAERI (Korea Atomic Energy Research Institute) to research the concept of a DEMO reactor [1,2]. In this concept, TBM (Test Blanket Module, Tritium Breeding Module) is the dominant device to operate the tokamak reactor in the steady-state. This blanket is installed behind the first wall in a tokamak. The main functions of TBM are, as follows; firstly, to protect the magnets and the vacuum vessel from the collision and heating of neutron and gamma radiation, secondly, to produce the tritium isotope necessary for self-sufficient fusion, and thirdly, to convert neutron energy into heat and generate a electric power. In this work, we introduce the tritium breeding ratios in the TBM for the DEMO tokamak reactor model.

2. Methods and Results

2.1 Tritium Production

The production of tritium is achieved in the TBM from the reaction of

$$Li^6 + n \rightarrow T + He^4 + 4.8\ MeV\ ,$$
$$Li^7 + n \rightarrow T + He^3 + n - 2.47\ MeV\ .$$

The lithium-contained materials may be in liquid state; liquid metal like LiPb, natural Li, or solid state; ceramics such as Li_4SiO_4 or Li_2ZrO_3 or Li_2TiO_3. In the solid state TBM, the neutron multiplier like beryllium is used for the self-sufficiency of tritium, and for liquid TBM, Pb in the tritium breeding material acts as multiplier.

The tritium breeding ratio (TBR) [3,4] is the ratios between the amount of tritium generated in the TBM of the D-T fusion reactor and the amount of tritium consumed in the fusion reaction. The tritium breeding ratio must be greater than unity for self-sufficient operation.

2.2 TBM Model and MCNP Calculation

The 1D model for TBM was considered for the MCNP calculation. Fig.1 shows the schematic drawing of TBM model. Standard Solid type of TBM is composed of 9.8% FMS (FM Steel), 69.2% Be multiplier, 5.5% He coolant, and 15.4% Li_4SiO_4. This model consists of a FW (First Wall), tritium breeder, structure wall, shield blocks, vacuum vessel, etc. The dimensions of each component were indicated in Fig.1, and the initial thickness of breeder was 36.5 cm. MCNP5 [5] was used for the evaluation of TBR, and high performance single and parallel CPU machines were selected to improve the calculation accuracy. FENDL-2.1 [6] nuclear data for fusion reactions was selected from nuclear data library.

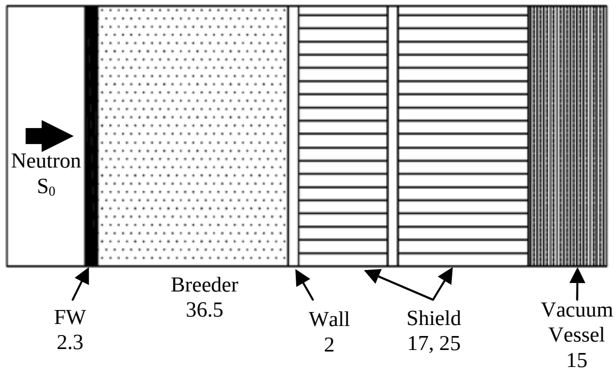

Fig.1. Schematic drawing of TBM and fusion reactor model for MCNP calculation and thickness of the components [cm].

2.3 Results and Analysis

For the self-sufficient operation of the fusion reactor, net TBR must be close to 1.01. So, design TBR value must be greater than net value to account for the deficiencies in nuclear data and uncertainties in design elements [7]. In the typical DEMO fusion reactor, this net TBR should be greater than 1.1 to satisfy the self-sufficiency.

Fig.2 shows the results of MCNP simulation, where each run was performed by varying the thickness of tritium breeder. The TBR for initial thickness was 1.062, and design TBR was 1.11 for the case of thickness 46.5 cm. For the comparison of each model, the TBM parameters were reviewed in the point of compositions and design. The ARIES-AT model has the concept of HCLL (He-Cooled Lithium Lead), the model of Wisconsin University is HCML (He-Cooled Molten Lithium) and HCLL. One of EU PPCS models is HCSB (He-Cooled Solid Breeder) [7]. Table 1 shows the breeder compositions and the calculated TBR at the same geometry of TBM models, the standard model of this work were used in the each calculation. The breeder with Be or Pb multiplier has high tritium breeding ratio, in the HCSB and HCLL model, and the reflector inside the blanket must be installed in the

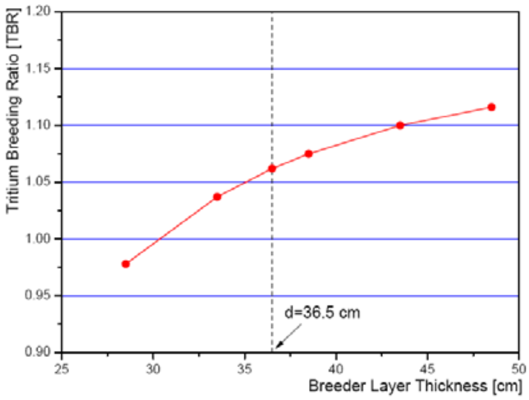

Fig.2. Tritium breeding ratios for the various breeder thicknesses.

HCML model to enhance the tritium breeding ratio and improve the neutron transport.

3. Conclusions

The tritium breeding ratios were calculated by the MCNP neutronics of the DEMO reactor concept. Recent TBM concepts of HCLL, HCML, and HCSB were considered to compare the tritium breeding ratios. The optimum thickness and composition of TBM have been modeled by this evaluation study, and these design parameters will be necessary for the development of the fusion reactor concept.

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Table 1. Various TBM models and the calculated TBR at the standard geometry.

Model	Type	Composition	TBR
K-DEMO	HCPB (HCSB)	PPCS Model B	1.11
PPCS Model B (Pebble Bed)		9.8% FMS 69.2% Be multiplier 5.5% He coolant 15.4% Li_4SiO_4 (30% enriched Li)	1.12
MCCARD	HCML	83% natural Li 7% FS 10% He coolant	0.363
Wisconsin (Li)		90% natural Li 3% FS 7% He coolant	0.288
ARIES-AT	HCLL	81% LiPb 19% SiC	0.837
Wisconsin (LiPb)		90% LiPb (90% enriched Li) 3% FS 7% He coolant	0.948