Preliminary Neutronics Analysis for the Korea HCSB TBM

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1. Introduction

Korea has been developing the Korea Helium Cooled Solid Breeder Test Blanket Module (Korea HCSB TBM) for adoption in ITER. This device uses a pebble material in the tritium breeder, neutron multiplier and neutron reflector. Neutronics analyses should be performed iteratively with the various calculation models to obtain the optimal design parameters Korea HCSB TBM.

In the neutronics analysis, neutron flux and spectra distributions, TBR(Tritium Breeding Ratio), nuclear heating and dose rate should be calculated. Based on these evaluations, material composition, arrays of the TBM inside regions and the thickness of each region for detailed design should be assessed to optimize the design parameters.

In this study, neutronics analyses were performed with the various TBM candidate models as a preliminary analysis.

2. Simulations and Results

MCNP5 ver. 1.40 and FENDL2.1 nuclear data library were used in the Monte Carlo simulation for the neutronics analysis. At first, optimum material composition was estimated using the homogenized model. In these optimal ranges, neutronics analyses were performed according to the arrays of the TBM inside regions. Based on these evaluations, multi-layers array was applied in the TBM inside design as the candidate model. At last, detailed layer thicknesses were analyzed in the view of the neutronics performance of the TBM.

2.1 Evaluation of the Optimized Material Composition

The sensitivity of the homogenized model for TBM design were evaluated in the previous work[1]. Based on this study, Homogenized model was applied in the calculation to decide the optimal material composition. Korea HCSB TBM concept has the three regions of the tritium breeder, neutron multiplier and neutron reflector. Li4SiO4 with 6Li 40 % enrichment was used as the breeder material and Beryllium and graphite were used as the multiplier and reflector respectively. The homogenized TBM model was shown in Fig.1. Dimensions in the Fig. 1 were also applied in the other evaluations in this study except the inside region including breeder, multiplier and reflector.

The results from these simulations were shown in Fig. 2 and Fig. 3. In the view of the TBR achievement, optimal material composition ranges were analyzed. Reflector thicknesses in the range from 12 to 15 cm and the ratio of breeder to multiplier on the range from 0.1 to 0.3 were considered.

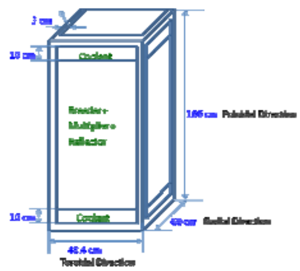

Fig. 1 Dimension of the Korea HCSB TBM.

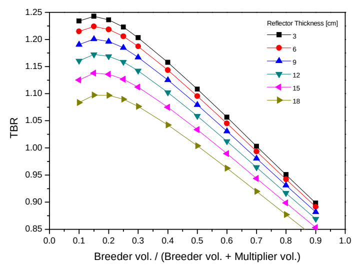

Fig. 2. TBR evaluations according to component ratio of the breeder and multiplier.

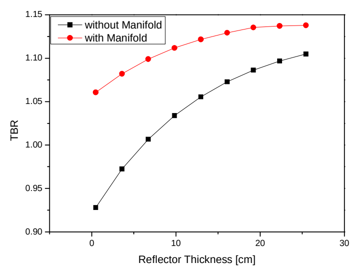

Fig. 3. Reflector effect on the TBR according to the reflector thickness.

2.2 Assessment of the Array of the TBM Inside regions

In the optimal range of the material compositions, various arrays of the TBM inside regions were tested in the view of the neutronics performance. The considered models were shown in Fig. 4. TBR values in these models were shown in Table 1. The type #1 in the Fig. 4 which is the array of the multi layers for the breeder and multiplier regions was considered as the TBM inside design based on the TBR and nuclear heating characteristics.

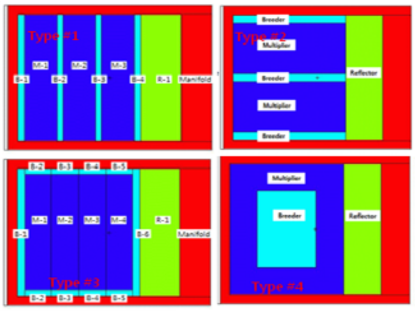

Fig. 4. Array types of the TBM inside regions

Table 1. TBR for the models in Fig. 4.

Type	#1				#2		#3	#4
layers	2+2	4+4	2+1	4+3	3+2	4+3	-	-
TBR	0.98	1.10	0.96	1.14	1.08	1.13	1.14	1.05

The type #1 in the Fig. 4 which is the array of the multi layers for the breeder and multiplier regions was considered as the TBM inside design based on the TBR and nuclear heating characteristics.
To evaluate the optimal number of layers and array order, some kinds of models were considered in the type #1 in the Fig.4. Table 2 and 3 shows the TBR in these considerations. In the view of the nuclear heating, M-B-R layer order in the Table 2 and 2+2 layers in the Table 2 were considered based on this study.

Table 2. TBR in the different array orders

layer	M-B-R		B-M-R	
Reflector	12 cm	15 cm	12 cm	15 cm
Case	MBR12	MBR15	BMR12	BMR15
Total TBR	0.92621700	0.91664400	0.97632500	0.95043800
1st layer	0.00858092	0.00811555	0.46129400	0.43605100
2nd layer	0.65099500	0.63375700	0.00687216	0.00663061
3rd layer	0.00261896	0.00277161	0.50613600	0.50556400
4th layer	0.25402200	0.27200000	0.00202280	0.00219212

2.3 Evaluation of each layer thickness

More detailed models based on the candidate model which M-B-R layer order in the Table 2 and 2+2 layers in the Table 2 were considered in this step to evaluate the thickness of inside each region. When the thickness of each multiplier region or breeder region is changed in terms of 1 cm, TBR and nuclear heating in the TBM inside regions were compared.

The Cases of these detailed models were shown in Table 4 and the results were shown in Table 5 and 6.

Table 3. TBR in the different number of layers

Region	2+2 layers	3+3 layers	4+4 layers	5+5 layers
B-1	0.46	0.35	0.28	0.23
M-1	0.01	0.01	0.00	0.00
B-2	0.51	0.39	0.32	0.27
M-2	0.00	0.00	0.00	0.00
B-3		0.32	0.26	0.23
M-3		0.00	0.00	0.00
B-4			0.23	0.19
M-4			0.00	0.00
B-5				0.18
M-5				0.00
Total TBR	0.98	1.06	1.10	1.11

Table 4. Regions Thicknesses in models

Cases	reference	1M03	1M05	1M07	1M09	1M11	1M13	1M15	1M17	1M19	1M21
1st M	11.55	3.00	5.00	7.00	9.00	11.00	13.00	15.00	17.00	19.00	21.00
1st B	4.95	4.95	4.95	4.95	4.95	4.95	4.95	4.95	4.95	4.95	4.95
2nd M	11.55	20.10	18.10	16.10	14.10	12.10	10.10	8.10	6.10	4.10	2.10
2nd B	4.95	4.95	4.95	4.95	4.95	4.95	4.95	4.95	4.95	4.95	4.95
sum	33.00	33.00	33.00	33.00	33.00	33.00	33.00	33.00	33.00	33.00	33.00

Table 5. TBR from each model in Table 4.

Cases	1st M	1st B	2nd M	2nd B	Total TBR
1M03	0.0024	0.6437	0.0062	0.3751	1.0275
1M05	0.0038	0.6690	0.0052	0.3565	1.0345
1M07	0.0051	0.6793	0.0042	0.3363	1.0249
1M09	0.0062	0.6774	0.0034	0.3147	1.0018
1M11	0.0072	0.6648	0.0027	0.2928	0.9675
1M13	0.0080	0.6447	0.0021	0.2706	0.9255
1M15	0.0088	0.6184	0.0016	0.2489	0.8777
1M17	0.0095	0.5883	0.0011	0.2285	0.8274
1M19	0.0101	0.5539	0.0007	0.2096	0.7742
1M21	0.0106	0.5169	0.0003	0.1929	0.7207

Table 6. Nuclear heating from each model in Table 4. (W/cm^3)

Cases	1st M	1st B	2nd M	2nd B	R
1M03	2.07	6.28	1.06	3.24	0.23
1M05	2.01	6.35	1.01	3.10	0.23
1M07	1.96	6.32	0.96	2.95	0.23
1M09	1.91	6.21	0.91	2.80	0.23
1M11	1.87	6.03	0.87	2.65	0.24
1M13	1.82	5.80	0.84	2.49	0.24
1M15	1.78	5.52	0.80	2.34	0.24
1M17	1.74	5.23	0.77	2.20	0.25
1M19	1.70	4.91	0.74	2.08	0.25
1M21	1.66	4.58	0.72	1.97	0.25

3. Conclusions

Case study of neutronics analysis for the material composition, array type and region thickness was performed to optimize TBM design parameters. As a result, reflector thickness of 15 cm, material composition with ratio of breeder to multiplier with about 0.3, multi layers array type, M-B layer order and optimal each layer thickness in Table 5 were evaluated.

REFERENCES

[1] C. W. Lee, Y. Lee[a], M. Ahn, S. Cho, and D. W. Lee, Study on the Sensitivity of the Homogenized Model in the neutronics Analysis for the Korea Helium Cooled Breeder Test Blanket Module, 10th International Symposium on Fusion Nuclear Technology, Sep.11-16, 2011, Portland, U.S.