Feasibility of Graphite Reflector in Tritium Breeding Blanket

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Abstract. To achieve higher tritium breeding ratio (TBR) within limited blanket thickness, most of solid blanket concepts employ a combination of lithium ceramic as a breeder and beryllium as a multiplier. However, considering that immense amount of beryllium will be required in fusion power plants, its high toxicity and price can be a major obstacle for commercial use. In this paper, feasibility of new concept which adopts graphite reflector to replace considerable amount of beryllium, is presented by nuclear analysis under the fusion reactor condition. Fixing the breeding zone thickness, sensitivity tests are performed with varying graphite thickness, i.e. increasing graphite while decreasing beryllium or vice versa. It is found that the new concept shows better performance not only from TBR point of view but also from TBR/beryllium amount point of view.

1. Introduction

To realize fusion as a commercial energy source, it is essential to develop a viable breeding blanket system where around 80% of fusion power is collected, tritium is bred and function of neutron and gamma ray shielding is provided. Recent fusion reactor studies have defined a number of critical materials and technological problems for the development of blanket system. And several different types of blanket concepts have been proposed or evaluated ranging from conservative concepts to higher-risk concepts [1, 2]. It is suggested that solid-type blankets are suitable for near-term purpose or “ultra fast track” due to their relatively high technological maturity, whereas liquid-type blankets are potential for more advanced power plants.

Most of solid blankets employ a combination of lithium ceramic as a breeder and beryllium as a multiplier to achieve higher Tritium Breeding Ratio (TBR) within confined blanket thickness. Beryllium has desirable features as a multiplier in that it has high (n, 2n) reaction cross section with relatively low threshold energy while having low neutron absorption cross section. However, it is very toxic and difficult to handle. Moreover, taking into account that huge amount of beryllium is required in a fusion power plant, its limited resource and high price are also problems. Therefore, despite of its excellent performance as a multiplier, it is required to develop the concepts with the reduced amount of beryllium.

Korea has proposed a Helium-Cooled Solid Breeder (HCSB) breeding blanket concept adopting graphite reflector for Test Blanket Module (TBM) program which aims to test and validate the concept relevant to DEMO and/or fusion power plants. It is unique feature among TBMs that the amount of beryllium is considerably reduced by replacing some of them with graphite [3] satisfying the tritium self-sufficiency condition [4, 5]. However, there are still concerns on the graphite reflector related to the nuclear performance as well as material-related issues. It should be shown that tritium breeding capability is improved by adopting graphite reflector in fusion reactor conditions. The neutron shielding capability of a combination of the breeder, multiplier and reflector should be also compatible with a combination of breeder and multiplier only. If it is not, the radial build should be increased or more power is required to drive the helium refrigeration system for the superconducting magnets, both are not desirable. In the present study, a nuclear analysis is performed under the fusion reactor condition to address the feasibility of graphite reflector in breeding blanket. While the breeding zone thickness is fixed, sensitive tests are performed with varying graphite amount, i.e. increasing graphite and decreasing beryllium or vice versa. Introducing an engineering factor, TBR/beryllium weight, improved reflector thickness is obtained on the basis of reduction of beryllium amount and enhancement of tritium breeding capability.

2. Numerical Results

As a numerical model for the calculation of TBR under various ratios of graphite/beryllium, a simple three dimensional D-shape torus model was considered as shown in Fig. 1. The ITER-like neutron source distribution was adopted from the D-T plasma scenario. The MONTEBURNS code, modified to solve fixed source fusion blanket problem [4-5], was used with one million histories, one outer step and one thousand inner steps during one effective full power day.

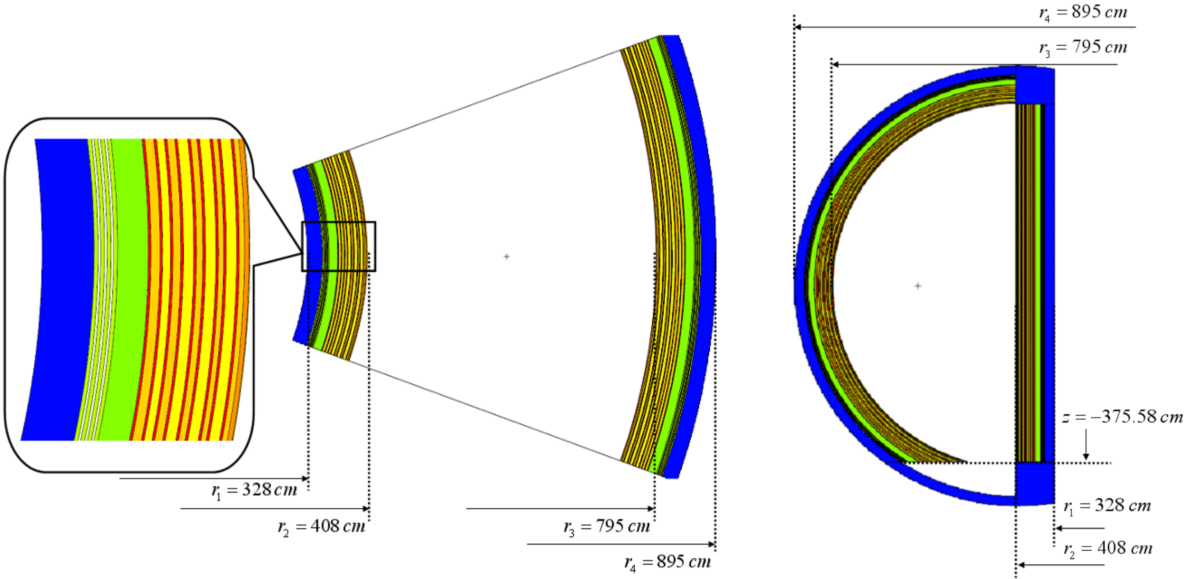

Fig. 1 Three dimensional D-shape torus model.

2.1. Sensitivity Test for Inboard Beryllium Layer Thickness

First, the sensitivity in each beryllium region is considered by reducing each beryllium region thickness while increasing graphite region thickness. Table I shows tendency of TBR and TBR/beryllium values according to each beryllium region thickness.

TABLE I: SENSITIVITY TESTS IN 1ST AND 4th BERYLLIUM LAYER THICKNESS VIA GRAPHITE THICKNESS.

	TBR	TBR/beryllium [#/ton]
Original HCSB design	1.087084	0.288032
Inboard : reducing 1st beryllium region while increasing graphite regin (2cm)	1.078491	0.302215
Inboard : reducing 4th beryllium region while increasing graphite regin (2cm)	1.083573	0.303643
Outboard : reducing 1st beryllium region while increasing graphite regin (2cm)	1.041617	0.299613
Outboard : reducing 4th beryllium region while increasing graphite regin (2cm)	1.066485	0.306892

More detailed sensitivity tests in inboard beryllium layer thickness are shown in Fig. 2, in which the outmost beryllium region is chosen for thickness reduction in preference to other beryllium regions.

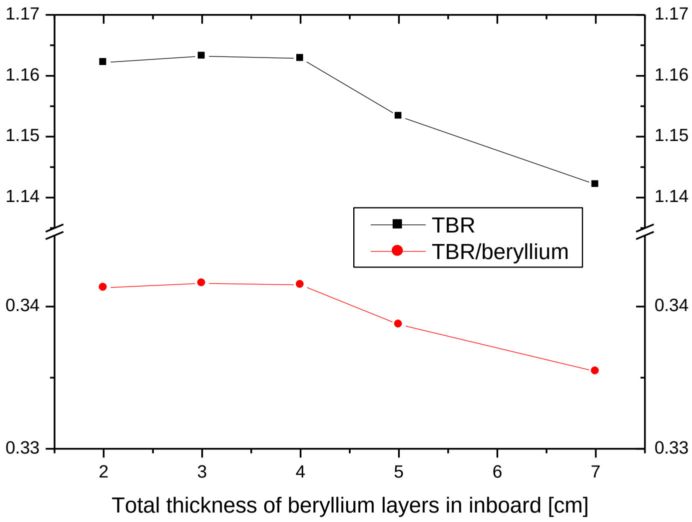

Fig. 2 Sensitivity tests in inboard beryllium regions.

As results of previous sensitivity tests in inboard layers, more efficient inboard breeder blanket design is suggested and it is shown in Table II.

TABLE II: RADIAL DISTRIBUTION of INBOARD BLANKET DESIGN.

Radial regions	Thickness [cm][1]
Beryllium coating	0.3
First wall (Eurofer steel)	1.8
1st Li4SiO4 (40% enriched Li) breeder	2.0
1st beryllium multiplier	2.5
2nd Li4SiO4 (40% enriched Li) breeder	1.0
2nd beryllium multiplier	0.5
3rd Li4SiO4 (40% enriched Li) breeder	14.0
Graphite reflector	22.9
Back wall (Eurofer and helium)	9.0

[1] There is 1 cm Eurofer cooling channel between each region

2.2. Sensitivity Test for Outboard Beryllium Layer Thickness

Next, the sensitivity of outboard beryllium region is considered based on the previous suggested inboard blanket design. Six outboard breeder blanket designs are considered and shown in Table III. For breeder case I, 2 cm thickness of the first 40% enriched lithium breeder region is considered while 1 cm thickness of the first breeder region is considered for breeder case II. The sensitivity to tritium productions on the fixed total breeding zone thickness condition is calculated to be more dominant in outboard than that in inboard. The numerical results are shown in Fig. 3.

Table III: RADIAL DISTRIBUTION OF CONSIDERED OUTBOARD BLANKET DESIGN.

Radial regions	Breeder case I			Breeder case II		
Beryllium coating	0.3	0.3	0.3	0.3	0.3	0.3
First wall (Eurofer steel)	1.8	1.8	1.8	1.8	1.8	1.8
1st beryllium multiplier	10.0	6.0	4.0	10.0	6.0	4.0
1st Li4SiO4 (40% enriched Li) breeder	2.0	2.0	2.0	1.0	1.0	1.0
2nd beryllium multiplier	5.0	9.0	11.0	5.0	9.0	11.0
2nd Li4SiO4 (40% enriched Li) breeder	2.0	2.0	2.0	2.0	2.0	2.0
3rd beryllium multiplier	4.0	4.0	4.0	4.0	4.0	4.0
3rd Li4SiO4 (40% enriched Li) breeder	2.0	2.0	2.0	2.0	2.0	2.0
4th beryllium multiplier	3.0	3.0	3.0	3.0	3.0	3.0
4th Li4SiO4 (40% enriched Li) breeder	4.0	4.0	4.0	5.0	5.0	5.0
Graphite reflector	7.9	7.9	7.9	7.9	7.9	7.9
Back wall (Eurofer and helium)	9.0	9.0	9.0	9.0	9.0	9.0

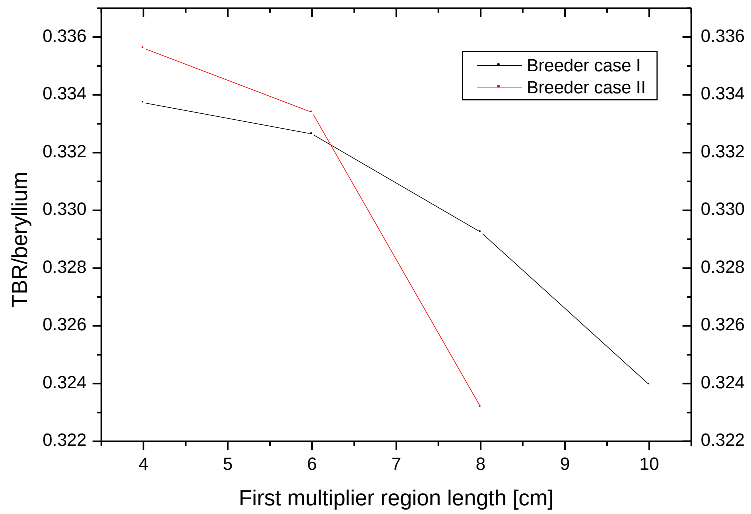

Fig. 3 TBR/beryllium factors of considered outboard breeder blanket designs.

As shown in Fig.3, 4.0 cm thickness of the first beryllium region with 1.0 cm thickness of the first lithium breeder region shows better performance in TBR/beryllium factor than other cases. The comparison with the previous original HCSB design and the original design in which all graphite is replaced by beryllium is shown in Table IV.

Table IV: COMPARISON WITH THE PREVISOU HCSB MODEL.

	TBR	TBR/beryllium weight [#/ton]
The original HCSB design [4] (graphite and beryllium)	1.09	0.288
Case 1 (all graphite replaced by beryllium)	1.14	0.170
Case 2 (newly suggested thicknesses of graphite and beryllium)	1.20	0.335

It is found that the TBR estimated from the optimized thicknesses of graphite reflector and beryllium multiplier is 0.06 higher than the Case1, of which all the graphite is replaced with beryllium. In terms of TBR/beryllium weight, the suggested new model also shows 97 % increased result than the Case 1 and 16.3 % increased results than the original design.

3. Conclusions

In this paper, feasibility of the breeding blanket concept with graphite reflector was investigated in terms of nuclear performance. The Korean HCSB concept was tested under the fusion reactor condition with ITER neutron source distribution and a new radial configuration was suggested based on the neutronic sensitivity tests. In the suggested model, total thickness of inboard beryllium region is 3 cm and total thickness of outboard beryllium region is 22 cm while total breeder blanket thickness is fixed to 60 cm. Hence more graphite reflector is placed in the inboard part. The suggested model shows ~10 % increased TBR and 16.3 % increased TBR/beryllium factor compared to the original model by the rearrangement of the radial region thickness. Similarly, the suggested model also shows ~5 % increased TBR and 97 % increased TBR/beryllium factor compared to the no-graphite blanket model. In other words, the tritium breeding capability of the suggested model with graphite reflector is even enhanced with only ~50 % of beryllium compared to the case with no reflector.

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