A Neutonic Study on $Be_{12}Ti$ as an Neutron Multiplier for the K-DEMO HCCR Blanket

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1. Introduction

In Korea, a helium-cooled ceramic reflector (HCCR) blanket concept is one of candidates for a future Korean demonstration fusion power reactor (K-DEMO) [1, 2]. The main parameters of the K-DEMO studied so far were in the Ref. [2, 3]. For self-sufficiency of tritium that will be used as a fuel for D-T fusion reaction, the HCCR blanket concept employs the Li_2TiO_3 breeder, beryllium multiplier, and graphite reflector. Among them, the beryllium multiplier plays a role of neutron multiplier as well as neutron moderator by (n, 2n) reaction. Due to the irradiation swelling characteristics, pebble type beryllium metal with 63 % packing fraction was considered as a multiplier.

However, low thermal conductivity and average density in pebble type beryllium degrades performance as multiplier of HCCR Blanket. Recently, $Be_{12}Ti$ has drawn strong interest as a candidate for a multiplier material in fusion breeding blanket owing to the enhanced irradiation-swelling characteristic [4].

In this paper, the effect of $Be_{12}Ti$ as a multiplier material are studied based on the Korean HCCR blanket concept.

2. Calculation Model and Codes

A neutronics calculation model was established by inserting HCCR blanket model into the 3-D K-DEMO model as shown in Figs. 1 and 2 [3, 5]. The MCNP6.1 code with FENDL ver.3.0 library were used [6].

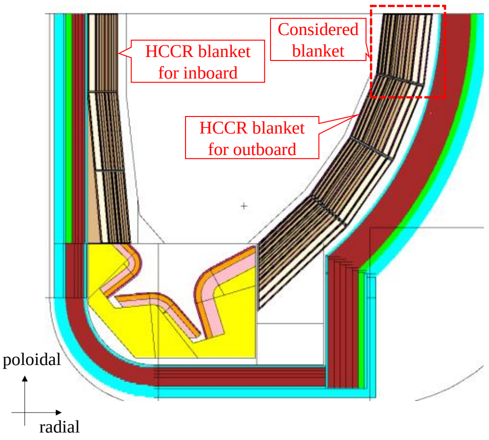

Fig. 1. Neutronics calculation model of K-DEMO HCCR Blanket (poloidal view)

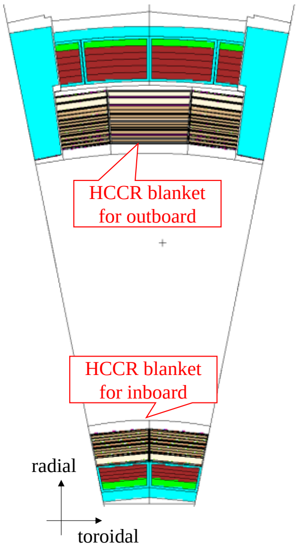

Fig. 2. Neutronics calculation model of K-DEMO HCCR Blanket (toroidal view)

Tables I and II show compositions of beryllium pebble and $Be_{12}Ti$. The impurities of beryllium pebble was based on the Ref.[3]. Impurities of $Be_{12}Ti$ was assumed as identical to those of beryllium pebble since detailed impurity information of $Be_{12}Ti$ is not available yet.

Table I: Compositions of beryllium with impurities

Isotopes		Atomic fraction, %
Be-metal	Be-9	9.92E-01
Impurities	O-16	5.40E-03
	O-17	2.06E-06
	Al-27	3.36E-04
	C-12	1.12E-03
	C-13	1.26E-05
	Fe-54	1.24E-05
	Fe-56	1.94E-04
	Fe-57	4.48E-06
	Fe-58	5.96E-07
	Mg-24	2.36E-04
	Mg-25	2.99E-05
	Mg-26	3.29E-05
	Si-28	1.79E-04
	Si-29	9.06E-06
	Si-30	6.01E-06

Used densities of pebble type beryllium with 63% packing fraction and $Be_{12}Ti$ in neutronics analysis are 1.167 g/cm^3 and 2.26 g/cm^3, respectively. The $Be_{12}Ti$ is assumed as block in multiplier region due to its enhanced irradiation-swelling characteristic.

Table II: Compositions of $Be_{12}Ti$

Isotopes	Atomic fraction, %
Ti-46	6.14E-03
Ti-47	5.60E-03
Ti-48	5.66E-02
Ti-49	4.22E-03
Ti-50	4.14E-03
Be-9	9.21E-01

3. Numerical Results

Fig. 3 shows layer-wise tritium breeding ratios (TBRs) in both cases of beryllium pebble and $Be_{12}Ti$ block used as multipliers. In both cases, impurities were not considered. Since K-DEMO HCCR was composed of inboard and outboard blankets, breeder layer numbers up to 9 were for outboard breeder layers and layer numbers between 10 to 16 were for inboard breeder layers. Small layer number indicates closer breeder layer to the first wall (FW).

Comparing the $Be_{12}Ti$ multiplier with typical beryllium pebble multiplier, due to the better moderating and multiplying performance of $Be_{12}Ti$, breeder layers near the FW shows improved TBRs. Breeder layers far from the FW shows degraded results due to reduced neutron flux, which already contributes to the breeder layers near the FW as shown in Figs. 4 and 5. Identical tendencies are shown in both inboard and outboard breeder layers. As results, the total TBR in case of beryllium pebble and $Be_{12}Ti$ block are 1.175 and 1.125, respectively.

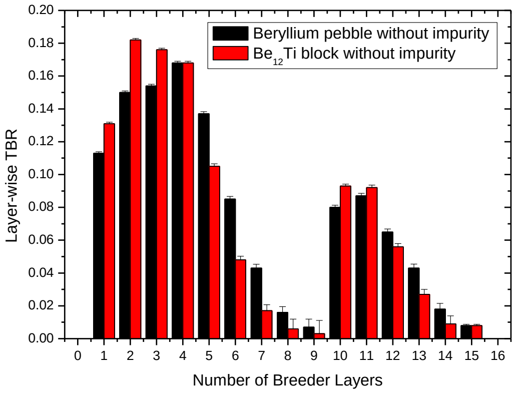

Fig. 3. Layer-wise TBRs in both beryllium pebble and $Be_{12}Ti$ block multiplier cases

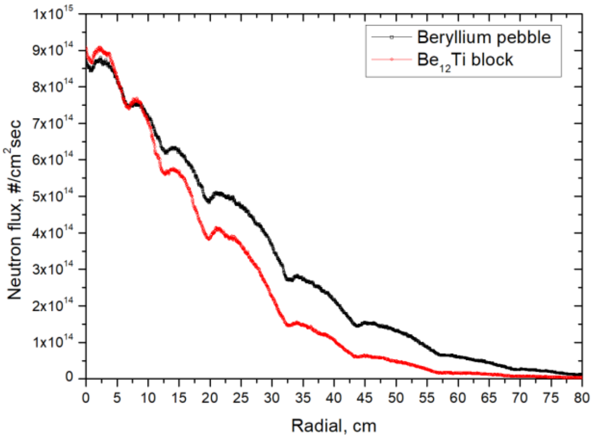

Fig. 4. Neutron flux distributions at outboard

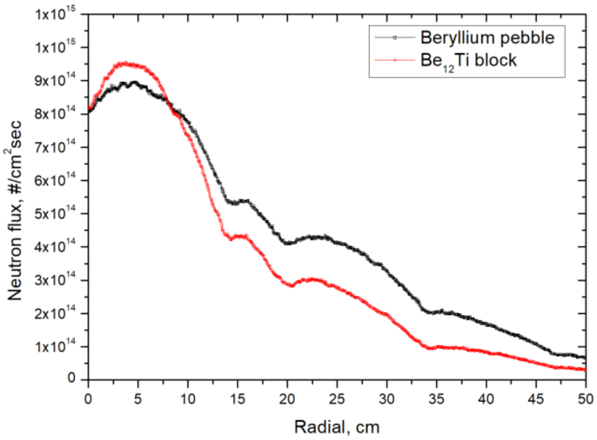

Fig. 5. Neutron flux distributions at inboard

Figs.6 and 7 show total power distributions in both cases of beryllium pebble and $Be_{12}Ti$ block multipliers. Similar tendency-higher power at regions near the FW and lower power at regions far from the FW in $Be_{12}Ti$ block case- is resulted. The discrepancies in power distributions between pebble type beryllium and $Be_{12}Ti$ block multipliers are more clearly shown in multiplier layers than breeder layers, because of increased Be-9(n,2n)Be-8 reactions and related decay energy of Be-8 to He.

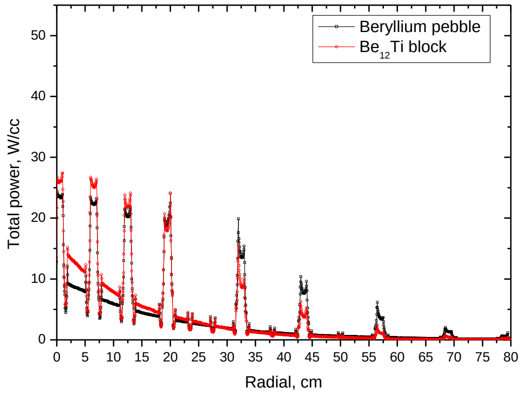

Fig. 6. Total power distributions at outboard

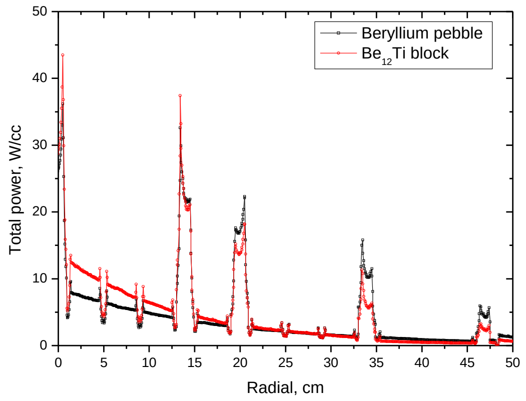

Fig. 7. Total power distributions at inboard

Fig. 8 shows layer-wise tritium breeding ratios (TBRs) in beryllium pebble multiplier case with and without impurities.

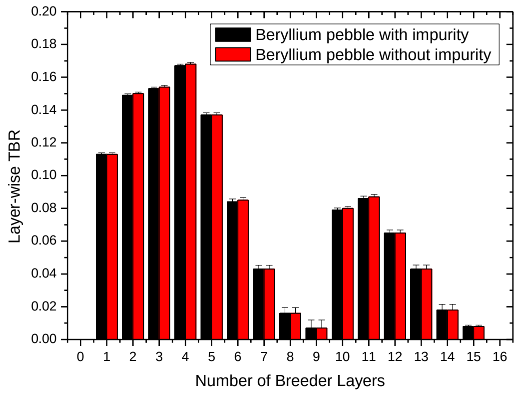

Fig. 8. Layer-wise TBRs in beryllium pebble with and without impurities

The total TBR in beryllium pebble multiplier cases with and without impurities are 1.172 and 1.175, respectively. Due to the neutron absorption by impurity isotopes, pure beryllium multiplier shows a little bit better TBRs in high-TBR layers, however the improved magnitude is not significant.

Fig. 9 shows layer-wise tritium breeding ratios (TBRs) in $Be_{12}Ti$ block multiplier case with and without impurities. The identical total TBR, 1.125, is obtained in both of with and without impurity cases.

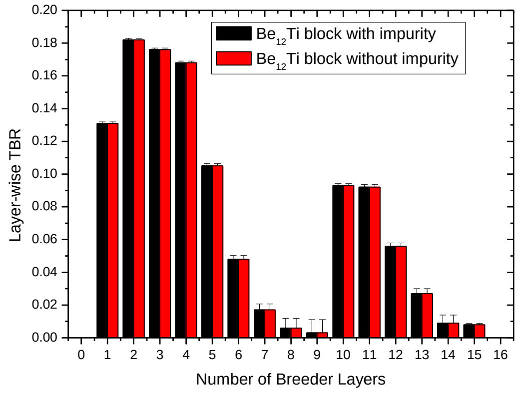

Fig. 9. Layer-wise TBRs in $Be_{12}Ti$ block multiplier with and without impurities

3. Conclusions

In this paper, neutronics analysis was performed to evaluate effect on use of $Be_{12}Ti$ as a multiplier material for the HCCR loaded K-DEMO reactor.

Although the improvement of total TBR by adopting $Be_{12}Ti$ block as multiplier is not shown, the enhanced TBRs at breeding layers near the FW shows feasibility of $Be_{12}Ti$ block. In addition to that, relatively higher power at multiplier regions than that in breeder regions is a good design characteristic since the temperature increase at breeder layer is more significant than multiplier layer as reported in the Ref. [3].

Due to the better neutron multiplication performance of $Be_{12}Ti$ block, direct application of $Be_{12}Ti$ block to the layered breeder blanket concept is not easy. However, application of $Be_{12}Ti$ block for other types of breeding blanket has a feasibility to enhance tritium production performance in breeding blanket. Hence, application of $Be_{12}Ti$ block for other types of breeding blanket including thermo-hydric analysis is believed worthwhile and planed as a future study.

4. Acknowledgments

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