Spectral Optimization of He-cooled Liquid Li Breeding Blanket

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1. Introduction

In the International Thermonuclear Experimental Reactor (ITER) project, various blanket concepts are under consideration to demonstrate the technical feasibility of a fusion power plant.[1]

A He-cooled liquid lithium blanket, without a neutron multiplier, is considered to be attractive due to no tritium permeation issue, alleviated material problems, and marginal MHD (Magneto-Hydro-Dynamic) effects. In a previous study[2], a graphite reflector has been introduced to improve the tritium (T) breeding ratio (TBR) and neutron shielding of a liquid Li blanket and a significant improvement has been achieved.

Self-sufficiency of tritium is a crucial requirement of a fusion breeding blanket. In general, TBR should be greater than at least 1.31 for a self-sufficient T fuel cycle.

The objective of this study is to unveil underlying neutronic physics of the graphite-reflected blanket and to optimize the concept further in terms of TBR. Neutron transport calculations are performed by a Monte Carlo code, MCCARD[3].

2. Blanket with a Graphite Reflector

To investigate the performance of a He-cooled liquid-Li blanket, a 1-D blanket model[2] is considered, which is depicted in Fig. 1. In the shield, the original TiC was replaced by WC for a better shielding.

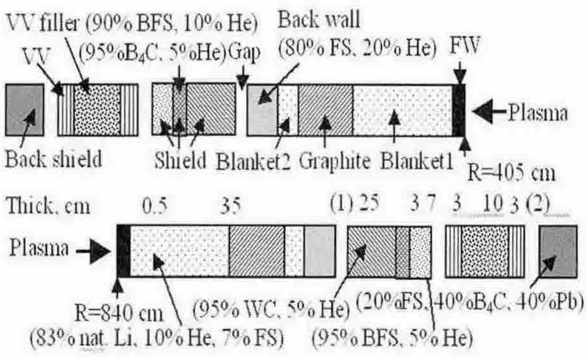

Figure 1. Radial builds of the reference blanket.

In the MCCARD simulations, both inboard (IB) and outboard (OB) blankets are modeled simultaneously and a flat isotropic neutron source (14.05 MeV) is used.

Table 1 shows major characteristics of the reference blanket and values in parentheses are for a blanket without any neutron reflector such as graphite[2]. Table 1 shows that introduction of the graphite reflector substantially improves TBR, by ~17%, and neutron shielding. It is observed that Li-6 is the major contributor to TBR, and contribution of the Li-7(n, $n\alpha$)T reaction to TBR is ~30.4% for the reflected blanket, while it is ~36.2% for the non-reflected case. The different Li-7 contribution is due to neutron spectrum shift in the blanket zone.

Table 1. Characteristics of the Reference Blanket

Local TBR			
	IB	OB	Total
Li-6	0.262(0.214)	0.665(0.515)	0.927(0.729)
Li-7	0.096(0.097)	0.309(0.316)	0.405(0.413)
Total	0.358(0.311)	0.974(0.831)	1.332(1.142)
Flux Attenuation, IB: 2.5E-4(6.8E-3), OB: 2.6E-4(6.3E-3)			

Figure 2 shows the spatial distribution of tritium production rate and distribution of neutron fluxes is shown in Fig. 3 for the OB blanket. Similar results are obtained for the IB blanket.

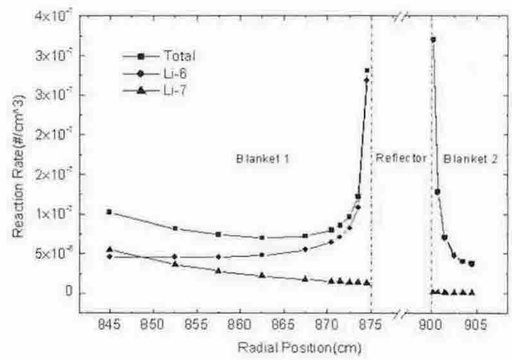

Figure 2. Distribution of T production rate.

Figure 2 explains why TBR is higher with a graphite reflector. The T production rate by Li-6 is significantly higher in the vicinity of the reflector region, 875~900cm. One can note from Fig. 3 that the neutron flux is attenuated by a four-order of magnitude in the reflected blanket and shield. For evaluation of the impacts of fast neutrons on the vacuum vessel (VV), a quantitative analysis needs to be performed.

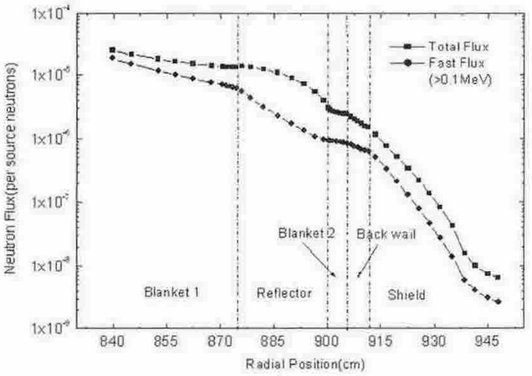

Figure 3. Distribution of neutron fluxes.

3. TBR Optimization

In order to improve the TBR and shielding, the neutron leakage from the blanket region should be minimized. TBR is sensitive to the neutron spectrum since the favorable spectrum is different for the tritium generators, soft one for Li-6 and hard one for Li-7.

An optimization study was done on the graphite reflector in terms of its thickness and position. In this analysis, the total thickness of the breeding zones was kept constant, and variation of reflector thickness was compensated by changing the shield thickness to maintain the total thickness of the blanket/shield fixed. The total volume of the breeding blankets also remains almost constant. The results are shown in Fig. 4.

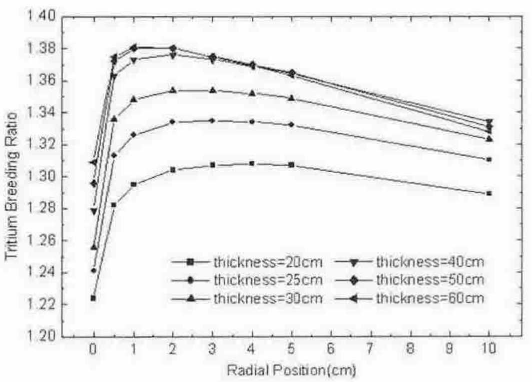

Figure 4. Impacts of graphite reflector on TBR.

It is clearly noted that there exists an optimal distance between the reflector and the back wall, i.e., thickness of Blanket 2 in Fig. 1, and TBR increases with the reflector thickness. The optimal thickness of Blanket 2 is quite narrow (1~4 cm) and it is smaller for a thicker reflector. If the Blanket 2 thickness is greater than the optimal one, TBR starts to decrease gradually due to reduced contribution of Li-7 in a softened spectrum. The maximum TBR for a given reflector shows an asymptotic behavior for a thickness above 50 cm.

Up to now, the natural lithium was used as the breeding material. Similar analysis has been done for two different Li-6 compositions (3.0 w/o and 13 w/o). Figure 5 shows that TBR curves are similar to those of the natural lithium. It is noteworthy that the natural lithium proves the highest TBR among the 3 compositions.

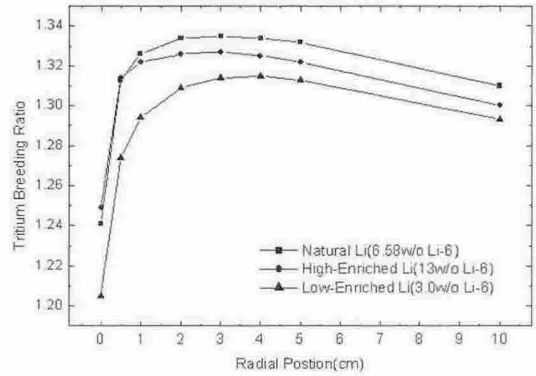

Figure 5. TBR behavior for different Li-6 fractions.

4. Conclusions

A graphite reflector significantly improves the TBR and neutron shielding in a He-cooled liquid Li breeding blanket. For an optimal TBR gain, the reflector should be placed such that the blanket region is divided into a thick front region and a thin back region (1~4cm). The optimal thickness of the rear blanket is inversely proportional to the reflector thickness. The TBR gain is marginal for a reflector thickness above ~40 cm.

REFERENCES

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