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Analysis of Tritium Breeding in the Test Module

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1. Introduction

Fusion-Fission Hybrid Reactor (FFHR) is combined reactor small size tokamak as neutron source and subcritical fission reactor as blanket. It has higher realization than pure fusion reactor because is required low neutron irradiation and thermal environments. FFHR has been mentioned since 1950s, active researches are conducted for various purposes such as waste transmutation, power production and fissile breeding [1]. Recently, as spent fuel disposal problem is issued in nuclear industry, FFHR is one of the most fascinating candidates for solving this problem through waste transmutation.

Our research team also was designed a full core FFHR for waste transmutation [2]. However, in this study, Test Module (TM) as test bed of FFHR for various purposes are analyzed. Analysis of tritium breeding on the TM was conducted as a first phase among TMs having various purposes. Because there are no fissionable materials in the TM for tritium breeding, geometry and neutronic reactions of its simpler compared to TM for waste transmutation and power production. Additionally, it is important database for tritium self-sufficiency as basic design condition of TM.

In the previous study, neutronic analyses are conducted on these various TMs: Helium cooled solid breeder (HCSB), water cooled solid breeder (WCSB), Helium cooled dual breeder (HCDB) and molten-salt cooled liquid breeder (MSLB) in order to understand design characteristics [3]. In this paper, neutronic analyses are conducted on redesign of TMs which have high tritium breeding performance based on results of previous study. Calculation model is simplified, there is no effect to cover very complex geometry of fusion reactor for this study [4].

Neutronics calculations are performed with MCNPX 2.6.0 with ENDF/B-Ⅶ.0 neutron cross section library and activity and time-dependent tritium production calculations are performed with CINDER'90.

2. Analysis of Tritium Breeding in the TM for high Tritium Breeding

Redesign of TMs for high tritium breeding is conducted from results of previous study [3].

2.1 Design of WCHESL and WCHELL

TM for high tritium breeding is designed on 2 models. One is redesign of WCSB which has the most effective tritium breeding performance for high tritium breeding as WCHESL (Water Cooled High Enriched Solid Lithium) TM [3]. Design purpose of WCHESL is having high efficiency of tritium breeding. Namely, number of tritium per unit volume is high.

The other is design maximized tritium breeding as WCHELL (Water Cooled High Enriched Liquid Lithium) TM. Design purpose of WCHELL is tritium production as much as possible. Namely total tritium breeding is high. This is only focus on tritium breeding, does not consider aspects of structural, technical, safety etc.

Design conditions of WCHESL and WCHELL are listed in Table I. Design condition of WCHESL comes from HCSH TM which has the highest T production rate per unit volume performance [3]. On the other hand, design condition of WCHELL comes from MSLB TM which has the highest total tritium production performance [3].

MCNPX modeling of WCHESL and WCHELL is shown in Fig. 1. and Table Ⅱ. represents design parameters of WCHESL and WCHELL.

Table I: Design conditions of WCHESL and WCHELL.

TM	WCHESL	WCHELL
Total T Production Rate (#/sec)	NC	Min.3.36E+16
T Production Rate (#/cm3-sec)	Min.3.57E+11	NC
From Total T production Rate	NC	Man.1.09E+10
From T production Rate	Max.1.13E+15	NC

*NC : No condition

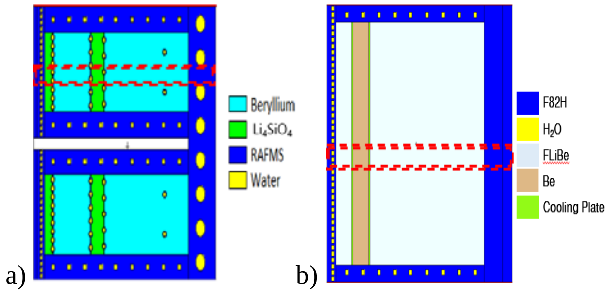

Fig. 7. MCNPX Modeling:
a) WCHESL (xy plane), b) WCHELL(xy plane)

Table Ⅱ: Design Parameters of HEWCSB and HEWCLB.

TM	WCHESL	WCHELL
Structure Material	F82H	
Coolant	Water(H_2O)	
Tritium Breeder (Li6 %)	Li4SiO4 (90)	FLiBe (90)
Neutron Multiplier	Be-Ti alloy	Be
Neutron Wall Loading (MW/m^2)	0.78	

Li_4SiO_4 which has high number density of Li is used as tritium breeder in design of WCHEBL, it is shown in Fig. 1-a). Li6 which mainly produces tritium enrichment is 90% for high tritium production as shown in Fig 2. Neutron Multiplication material is changed from various Be and Ti alloy to only $Be_{12}Ti$ alloy in order to increase neutron multiplication performance.

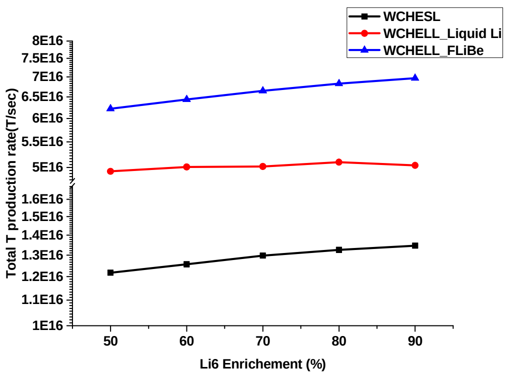

Fig. 2. Total Tritium Production Rate (T/sec) depending on Li6 enrichment.

2 sub-modules in WCSB are changed to one module for loading more amount of Li design of WCHELL as shown in Fig. 7-b). Also, liquid Li breeder is used instead of ceramic Li breeder as pebble shape which has geometry loss. Candidates of Liquid Li breeder are liquid Li which has the highest number density of Li and FLiBe which has neutron multiplier as the same time. FLiBe is selected because of high tritium breeding performance as shown in Fig. 2. Li6 enrichment is 90%. From this result, not only amount of Li but also neutron multiplication performance are affect tritium breeding. Neutron multiplier consist of only Be for high neutron multiplication performance.

2.2 Neutronics Analysis

2.2.1 Neutron Flux Spectrum

Neutron flux spectrum depending on radial direction is shown in Fig. 3.

Low energy flux spectrum in Li_4SiO_4 (red and pink lines) with WCHESL and in FLiBe (red and pink lines) with WCHELL are low, because of neutron absorption of Li for tritium breeding. Be zone increases neutron economy through (n, 2n) reaction.

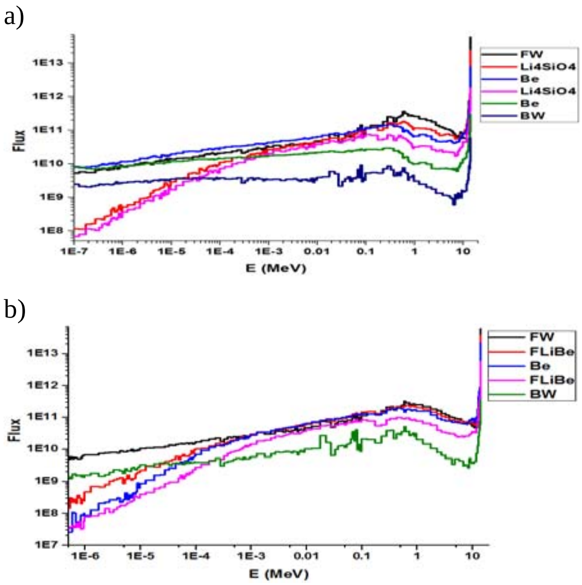

Fig. 3. Neutron Flux Distribution of each FTBMs depending on Radial Direction: a) WCHESL, b) WCHELL.

2.2.2 Tritium Production Performances

Tritium production performance is listed in Table Ⅲ, Required Li6 mass for Production of 1g Tritium is listed in Table Ⅳ.

Table Ⅲ: Tritium Production Performance with HEWCSB and HEWCLB.

TM	WCHESL	WCHELL
Total T Production Rate (#/sec)	1.35E+16	6.97E+16
T Production Rate (#/cm3-sec)	3.74E+11	3.19E+11
Li vol. % in TBM	2.15	19.38
Li6 vol. % in TBM	2.13	17.69
Li7 vol. % in TBM	0.02	1.69
Tritium Production from Low Energy Neutron	1.31E+12	1.49E+11
Tritium Production from Intermediate Energy Neutron	9.78E+11	1.06E+11
Tritium Production from High Energy Neutron	6.05E+11	6.43E+10

* Low Energy: E < 300ev
* Intermediate Energy: 300eV ≦ E < 0.1MeV
* High Energy: 0.1MeV ≦ E

T production rate with WCHESL satisfies the design condition and also Total T production rate is high. Especially, tritium from low energy neutrons increases by high Li6 enrichment. In addition, required Li6 mass from T production rate satisfies the design condition, it is listed in Table Ⅳ. Therefore it has effective tritium breeding performance.

Total T production rate with WCHELL satisfies design condition. Also, T production rate is significantly high compared to WCHESL. Also required Li6 mass from total T production rate satisfies design condition. Therefore, WCHELL effective design for high tritium breeding performance.

Table Ⅳ: Required Li6 Mass (g) for Production of 1g Tritium.

TM	WCHESL	WCHELL
From Total T production Rate	2.49E+10	1.00E+10
From T production Rate	8.97E+14	2.18E+15

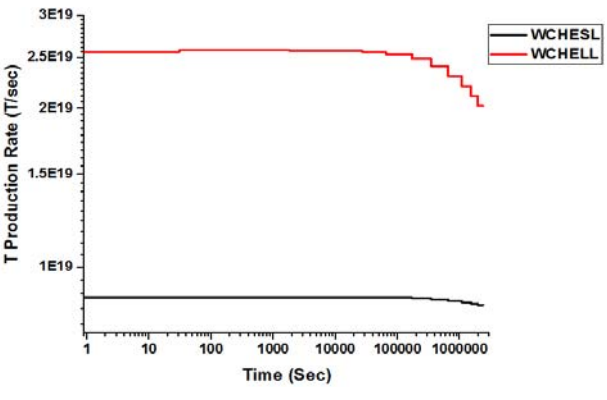

Fig. 4. Time-Dependent Tritium Production Rate.

Fig. 4 represents tritium production rate. Tritium production rate with WCHESL decreases from 3.45E+05 and with WCHELL decreases from 6.48E+04 sec. However, tritium with WCHESL and WCHELL is produced continuously during period time.

Fig. 5 shows number of tritium atoms with WCHESL depending on time function. WCHESL consist of ceramic Li breeder. Period of ceramic Li breeder is important in design of TM. Tritium is produced continuously until 4.15E+08 sec. From this time, number of tritium atoms is constant. Therefore, period of WCHESL is 4.15E+08 sec, it is about 13 years.

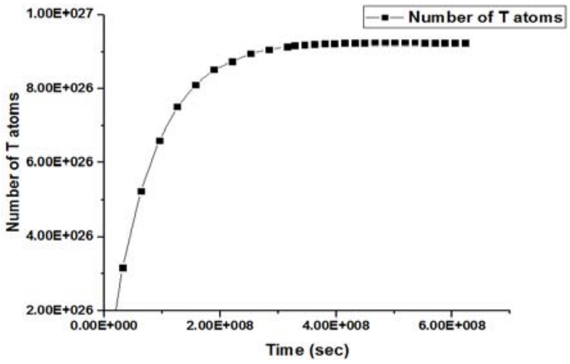

Fig. 5. Time-Dependent Number of Tritium Atoms with WCHESL.

2.2.3 Neutron Multiplication Performances

Neutron multiplication performance with WCHESL is still lower compared to the others mentioned in previous study [3], because of same design of rare Be zone for shielding.

Total (n, 2n) RR with WCHELL is very low because of low volume fraction of Be. However, (n, 2n) RR is significantly high in spite of low Be amount.

Table Ⅴ: Neutron Multiplication Performance with HEWCSB and HEEWCLB.

TM	WCHESL	WCHELL
Total (n, 2n) RR (reaction/sec)	1.19E+15	7.88E+15
Neutron (n, 2n) RR (reaction/ cm3-sec)	2.98E+10	4.46E+10
Be Vol.%	28.3	8.06

2.2.4 Activity Analysis

Activity assessment is conducted when operating time is 30 days and cooling time is about 3 years (1100days), it is shown Fig. 6. Most of activities are generated from Be region. Activity does not reduce significantly after 3 years. Activity with WCHELL is higher than WCHESL, although low Be amount in TM. Because Be reacts with neutrons actively.

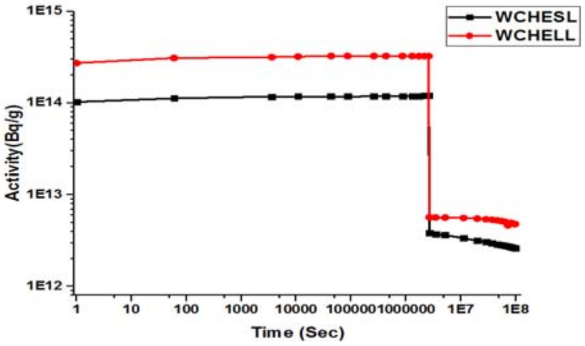

Fig. 6. Time-Dependent Activity.

3. Conclusions

In this paper, analysis of tritium breeding on WCHESL and WCHELL as TM is conducted.

WCHESL is designed for effective tritium breeding performance and it satisfies design conditions. On the other hand WCHELL is designed for tritium breeding as much as possible and it also satisfies design conditions.

However, neutron multiplication performance with these TM is not outstanding.

WCHESL consist ceramic Li breeder, its period is 4.15E+08 sec.

Activity of these does not reduce significantly for 3 years.

However, more detailed analysis of depletion calculation is required about WCHESL and WCHELL.

REFERENCES

[1] Ed Gerstner, Nuclear energy: The hybrid returns, Nature 460 (2009) 25-28.

[2] Muhammad Tariq Siddique, Myung Hyun Kim, Conceptual design study of Hyb-WT as fusion–fission hybrid reactor for waste transmutation, Annals of Nuclear Energy 65 (2014) 299–306.

[3] SeongHee HONG, YunSeo PARK and Myung Hyun KIM, Neutronic Analysis of Fusion Blanket Module for Design Optimization, International Symposium of Fusion Nuclear Technology, Jeju, Korea, September 14-18, 2015

[4] SeongHee HONG, YunSeo PARK and Myung Hyun KIM, Comparative Performance Evaluation of ITER TBM Concepts, Korean Nuclear Society Spring Meeting Jeju, Korea, May 7-8, 2015