Conceptual Design of Low Fusion Power Hybrid System for Waste Transmutation

Seong Hee Hong and Myung Hyun Kim*
Kyung Hee University 1732 Deogyeong-daero, Giheung-gu, Yongin-si, Gyeonggi-do, Korea, 446-701
**mhkim@khu.ac.kr*

1. Introduction

Hybrid system having energetic and neutron rich is one of the most effective option in order to waste transmutation of SNF (Spent Nuclear Fuel) in the nuclear industry.

However, a big disadvantage of hybrid system is increasing plasma power for compensating decreasing keff level. In order to overcome this problem, using of DRUP (Direct Reuse of Used PWR) fuel is suggested and feasibility of DRUP fuel is checked in previous study [1].

DRUP fuel has same process with DUPIC (Direct Use of spent PWR fuel Into CANDU reactor) [2]. There are 2 big benefits by using DRUP fuel in Hybrid system. One is fissile production during operating period. Required power is decreased by fissile production from DRUP fuel. When the fusion power is reduced, integrity of structure materials is not significantly weakened due to reduction of 14.1MeV high energy neutrons. In addition, required amount of tritium for self-sufficiency TBR (Tritium Breeding Ratio ≥ 1.1) is decreased. Therefore, it is possible to further loading the SNF as much as the amount of lithium decreased. It is effective in transmutation.

The other one is that DRUP fuel is also SNF. Therefore, using DRUP fuel is reusing of SNF, as a result it makes reduction of SNF from PWR.

However, thermal neutron system is suitable for using DRUP fuel compared to fast neutron system.

Therefore, transmutation zone designed (U-TRU)Zr fuel and fissile production zone designed DRUP fuel are separated in this study. As a result, hybrid system that has high transmutation performance in spite of low plasma power was designed.

2. Calculation Model

This study has been applied Hyb-WT model [3]. MCNPX modeling is shown in Fig.1 and design parameters is listed in Table I.

1st transmutation zone is designed (U-TRU)Zr fuel and PbBi coolant. The fuel is composed of 10 years cooled PWR spent fuel reaching to burn-up grades of 55,000MWd/t. TRU is enriched at 30wt% in (U-TRU)Zr [4]. PbBi is aimed for high neutron economy.

2nd fissile production zone is designed DRUP fuel and FLiBe coolant that makes not only thermal neutron system but also tritium. This model can enough satisfy self-sufficiency TBR despite of using natural lithium. In DRUP pin design has difference compared to (U-TRU)Zr pin. Be is coated for high neutron economy in DRUP pin instead of SiC coating of (U-TRU)Zr. Because MHD pressure drop is negligible with FLiBe coolant in hybrid system.

Neutronics calculations are performed with MCNPX 2.6.0 with ENDF/B-Ⅶ.0 neutron cross section library.

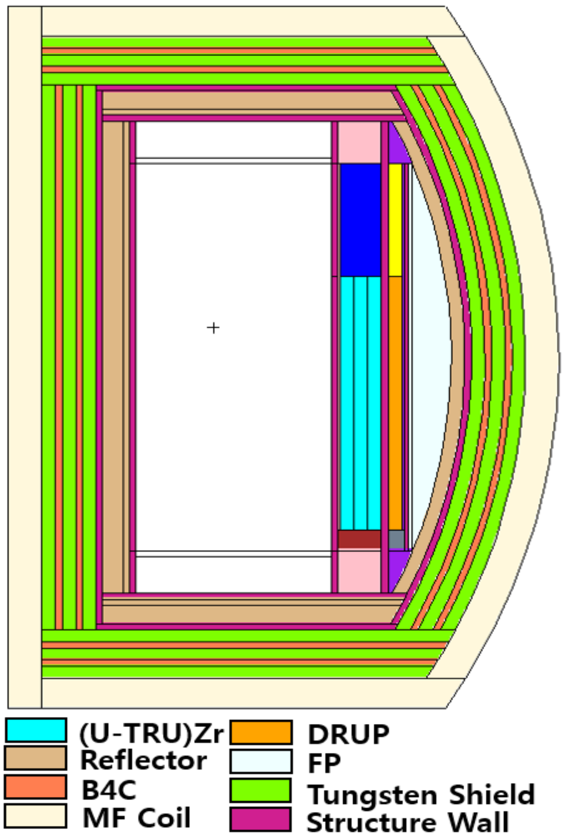

Fig 1. MCNPX Modeling of Low Plasma Power Hybrid System.

Table I. Design Parameters of Low Plasma Power Hybrid system.

Region	Thickness (cm)	Composition (%)
(TRU-U)Zr Fuel Zone	31.8	(U-30TRU)Zr: 31.23; PbBi:33 ; SiC: 6.37; Clad: 14.54; Bonding: 14.82
DRUP Fuel Zone	10.6	DRUP: 14.39; FLiBe:59; Be: 4.94; Clad: 10.96; Bonding: 10.52
Structure Wall	5	ODS steel(MA957):70; He-gas:30

FP zone	32	CsI (129I: 0.42; 35Cs: 1.76); 99Tc: 0.82; SiC: 2.5; C: 78; He-gas:16.5
Tungsten Shield	10	W (W182:26.5; W183:14.3 W184:30.7; W186:28.5)
B4C Shield	5	B (B10:16; B11:64; C:20)
Super conductor Toroidal MF Coil	20	Nb93:70; Sn116:5; Sn117:2.6; Sn118:8.3; Sn119:2.9; Sn120:1.1; He:10.1
Reflector	20	C:90; He-gas:10

3. Neutronic Performance Analysis

In this section, neutronic performance parameters such as required fusion power, keff level variation, EM (Energy Multiplication factor), flux density variation on radial and transmutation performance are checked.

Neutronic parameters are listed in Table Ⅱ. Keff level is increased during cycle length by fissile production from DRUP fuel. As a result, required fusion power is significantly low compared to Hyb-WT [3]. In addition, energy multiplication factor is high, therefore this system plays a role not only transmutation but also power production. Although large variation of EM factor has problem to plasma operation, expansion of reactor period and high power production capability are more beneficial. TBR is satisfied design condition for self-sufficiency in spite of using natural lithium. Because thermal system by FLiBe coolant is suitable for tritium breeding.

Table Ⅱ. Neutonic Parameters.

Cycle length (days)	500
Fission Power (MW)	2000
K_{eff} [BOC (sd.) / EOC(sd.)]	0.86871 (0.00012) /0.96344(0.00034)
Required Fusion Power (MW)	18 – 75
Energy Multiplication Factor	~ 134
TBR	1.34

Flux density on radial direction is shown in Fig. 2. Flux is increased by passing the TRU zones through fission reaction compared to flux with first wall. Fast neutron flux with 2nd TRU zone is significantly high by fission reaction. On the other hand, flux with DRUP zone is rapidly softening by moderation effect of FLiBe coolant.

Mass variation of fuel in the blanket is listed in Table Ⅲ. TRUs are separated LL TRU and SL TRU depending on half-life of nuclides. LL TRU transmutation is increased on radial direction. However, fission to capture ratio is the highest in 2nd TRU region. Therefore, amount of generated SL TRU with 2nd TRU region is low. And this trend suitable for waste transmutation.

DRUP fuel also transmuted by fissile production.

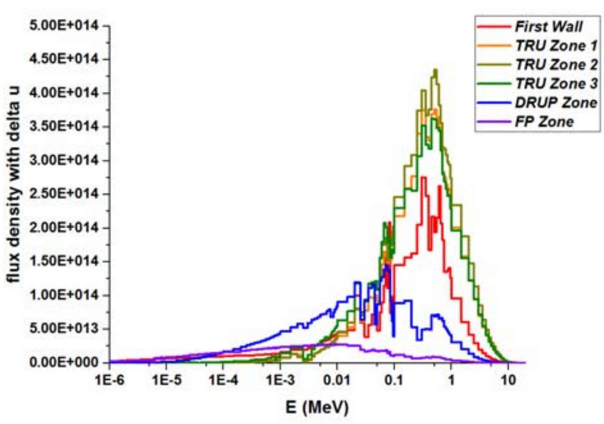

Fig 2. Flux Density on Radial Direction.

Table Ⅲ. Mass Variation during Cycle Length.

Region	LL TRU (kg)	SL TRU (kg)	Fission to Capture Ratio
1st TRU	-531 (-3.5%)	97.2 (19.3%)	1.57
2nd TRU	-559 (-4.0%)	64.6 (12.4%)	1.76
3rd TRU	-699 (-4.9%)	113 (21.0%)	1.38
4th DRUP	-162 (-8.3%)	22.7 (20.7%)	0.076

* SL : Short-lived TRU (10 years ≤ half-life < 100 years)
* LL : long-lived TRU (100 years ≤ half-life)

4. Conclusions

In this paper, using DRUP fuel for low fusion power in hybrid system is suggested. Fusion power is decreased by using DRUP fuel. As a result, TBR is satisfied design condition despite of using natural lithium. In addition, not only (U-TRU)Zr fuel but also DRUP fuel are transmuted.

However, it is required that longer cycle length and small variation of keff level through further study.

REFERENCES

[1] S. H. Hong and M. H. Kim, Spent Nuclear Fuel Option Study on Hybrid Reactor, Korea Nuclear Society Spring Meeting Jeju, Korea, May 12-13, 2016.
[2] M.S. Yang, et al., The Status and Prospect of DUPIC Fuel Technology, Nuclear Engineering and Technology, Vol 38, pp.359-374, 2006.

[3] M. T. Siddique and M. H. Kim, Conceptual design study of Hyb-WT as fusion–fission hybrid reactor for waste transmutation, Annals of Nuclear Energy, Vol 65, pp. 299–306, 2014.
[4] W. S. Yang, Fast Reactor Physics and Computational Methods, nuclear Engineering and Technology, Vol 44, pp. 177-198, 2012 .