Transactions of the Korean Nuclear Society Autumn Meeting
Gyeongju, Korea, October 25-26, 2012

Characteristics of LAR Tokamak Transmutation Reactor

B.G. Hong*
[a] *Chonbuk National University, Deokjin-dong, Deokjin-gu, Jeonju, Korea 561-756*
**Corresponding author: bghong@jbnu.ac.kr*

1. Introduction

The concept of a fusion-driven transmutation reactor based on LAR (Low Aspect Ratio) tokamak as a neutron source is studied based on ITER physics and technology. The radial build of transmutation reactor components are self-consistently determined by coupling the systems analysis with radiation transport analysis and an optimal configuration of a transmutation reactor for aspect ratio [1], A in the range of 1.5 to 2.0 is found. The performance of a transmutation reactor is investigated and shows that a transmutation reactor with a neutron source producing fusion power less than 150 MW can destroy the transuranic actinides contained in the spent fuels produced from more than two 1 GWe PWRs with production of the fission power being greater than 2 GW

2. Optimum Radial Build of a Fusion Neutron Source

We investigate the radial build of a LAR tokamak neutron source with the aspect ratio, A in the range of 1.5 to 2.0. The plasma performance is assumed to provide a fusion power of 150 MW with $q_a = q_{a,min}$, $\beta_N = \beta_{N,max}$, a confinement enhancement factor, $H = 1.2$, and the line average electron density to the Greenwald density limit, $n/n_G = 1.0$. The maximum fusion power of 150 MW produces ~ 5 x 10^{19} neutrons (14 MeV)/sec which suffice to transmute waste.

Figure 1 shows the dependence of the minimum major radius, which satisfies all the physics and engineering requirements illustrated in Sec. II and the required auxiliary heating power on the aspect ratio, A when the transuranic actinides are not loaded in the outboard blankets. In this case, the minimum major radius can be mainly determined by the inboard components [12]. The minimum major radius decreases as the aspect ratio increases but the required auxiliary heating power slightly increases with the aspect ratio. As the aspect ratio increases, the magnetic field at the magnetic axis increases. Also, the maximum elongation, κ and the plasma surface area decrease, so the neutron wall loading is increased. A required inboard shield thickness of 39 cm for A=1.5, 43 cm for A=1.8, and 49 cm for A=2.0 were found to provide adequate shielding for a 40 FPY lifetime within a fast neutron fluence limit of 10^{19} cm^{-2}, radiation dose limit of 10^9 rads and a displacement damage limit of 5x 10^{-4} dpa.

Table 1 shows plasma performance and machine parameters of a LAR tokamak neutron source when A = 1.5, 1.8 and 2.0.

With transuranic actinides loaded in the outboard blankets, neutron flux from fission of actinides will be added and have an impact on the shield. However, the neutronic impact for 40 years at 75% availability will not be worse since the required source strength, i.e the fusion power is minimum at the beginning of the cycle (BOC) where k_{eff} is maximum and it increase as actinides burn.

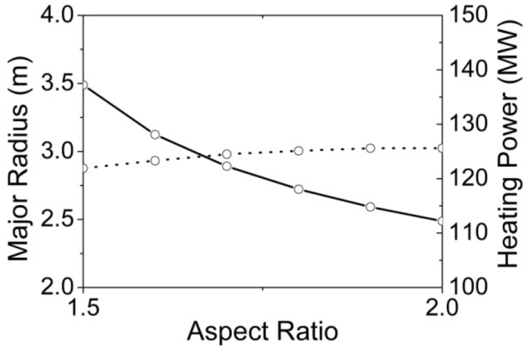


Fig. 1. Minimum major radius and required auxiliary heating power as a function of aspect ratio.

Table 1. Parameters of a Neutron Source

Parameters	A = 1.5	A = 1.8	A = 2.0
Fusion power (MW)	150	150	150
Major radius (m)	3.49	2.72	2.49
Minor radius (m)	2.32	1.51	1.24
Plasma elongation	3.2	2.9	2.7
Triangularity	0.3	0.3	0.3
Plasma current (MA)	12.3	9.2	7.9
Plasma beta	0.491	0.297	0.22
Edge safety factor	2.6	2.7	2.8
Neutron wall load (MW/m^2)	0.18	0.38	0.51
Heating power (MW)	122	125	126
H factor	1.2	1.2	1.2

3. Performance of a Transmutation

With the radial build of the LAR tokamak neutron source determined following the procedure in Sec. III, we investigate the performance of the transmutation reactor when A = 1.5, 1.8 and 2.0.

The radial build of the outboard blankets are adjusted in order to achieve the neutron multiplication, k_{eff} = 0.95 at the BOC and to satisfy Tritium self-sufficiency. The source strength, i.e. the fusion power is determined to produce a fission power density of 10 MW per blanket height (cm). As shown in Fig. 1, by locating the Tritium breeding blanket after the transmutation blanket, Tritium self-sufficiency is easily satisfied due to abundant thermal neutrons. Natural Li can be used, while enrichment of Li-6 is required for a fusion reactor [12].

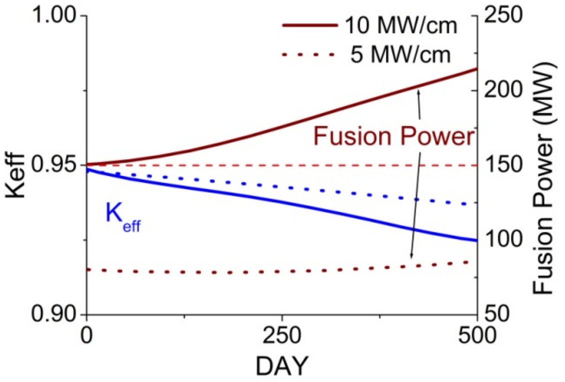
Figures 2, show the variation of k_{eff}, fusion power and TBR as actinides burn when A=1.5, 1.8 and 2.0. The k_{eff} decreases as actinides burn and the fusion power, i.e., source strength increases to keep fission power density constant. Radial thickness of blanket 1 and blanket 2 is set to be equal and it is 13 cm for A = 1.5, 14.3 cm for A = 1.8 and 15.2 cm for A = 2.0. The required fusion power is bigger in the case for the smaller A since the surface area of plasma is large and the required neutron wall loading is large at the same k_{eff} for the small A case. TBR at the BOC is the largest at A=2.0 and also the rate of TBR decrease is larger at A=2.0

In Fig. 2(a), we compared different fission power density, 10 MW/cm and 5 MW/cm. When fission power density is 10 MW/cm, the TRU transmutation capability is improved. When fission power density is 10 MW/cm, the required fusion power is greater than 150 MW, which is a source capacity. With reduced fission power density, transmutation rate is reduced.

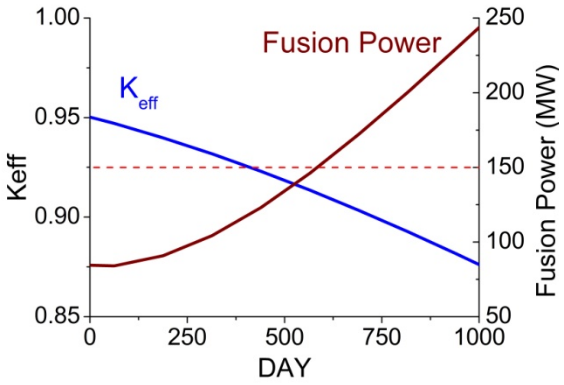
We assumed that the cycle of TRU loading ends when required fusion power reaches 150 MW. As shown in Fig. 2(b) and 2(c), it is 610 days for A=1.8, 760 days for A=2.0 with the fission power density of 10 MW/cm. After this period of time, fission energy decreases and transmutation rate also decreases. With the given fission power density, the transmutation rate is almost the same for 3 different A cases; 0.01048 kg/(day·cm) for the fission power density of 10 MW/cm and 0.0052 kg/(day·cm) for the fission power density of 5 MW/cm.

With the blanket height of 200 cm for A=2.0 and the fission power density of 10 MW/cm, the fission power of 2.0 GW is produced and approximately 574 kg of TRU is transmuted for a one year operation. From the fact that TRUs produced from 1 GWe PWR reach about 250 kg/year, one unit of a transmutation reactor can support more than 2.0 PWRS. For a smaller A, a larger blanket height is possible and a large amount of actinides will be transmuted since the blanket height is proportional to κ·a.

(a)



(b)



(c)

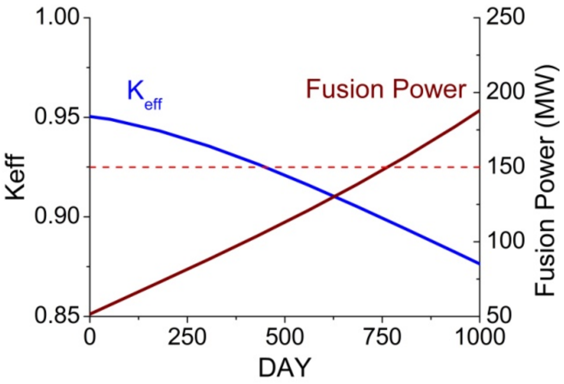


Fig. 2. Variation of k_{eff} and fusion power, during the transmutation operation

4. Conclusions

The concept of a transmutation reactor was studied by coupling the coupled system analysis with the one dimensional radiation transport code, BISON-C. It was shown that within the limit of ITER physics and technology, a compact transmutation reactor based on the superconducting LAR tokamak neutron source with an aspect ratio less than 2 can be used for transmutation of TRUs produced from the spent fuel of PWR. One unit of a transmutation reactor based on the LAR tokamak neutron source can support more than 2.0 PWRS with the production of fission power greater than 2.0 GW.

REFERENCES

[1] B.G. Hong et al., "Conceptual design study of a superconducting spherical tokamak reactor with a self-consistent system analysis code", *Nucl. Fusion,* **51,** 113013 (2011).
.