# IMPACT OF CLADDING MATERIAL ON NEUTRONIC BALANCE IN BREED-AND-BURN FAST REACTORS

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**Abstract**

The effect of the cladding on the neutron balance in the Breed-and-Burn fast reactor was investigated. Neutron transport Monte Carlo calculations and burnup calculations were performed. As a result of the analysis, it was found that the cladding has a significant influence on the neutron balance of the Breed-and-Burn fast reactor. In particular, it is found that the neutron balance is greatly improved by decreasing the density or the thickness of the cladding. The same effect was observed in the core with nitride fuel and metal fuel using sodium coolant, lead coolant, and lead-bismuth coolant.

## INTRODUCTION

Breed-and-burn fast reactors (B&Bs) are once-through fast reactors that produce plutonium from natural uranium or depleted uranium and burn it in the reactor without reprocessing process. There have been various studies of B&Bs [1,2,3]. One of the newer B&B concepts is the Rotational Fuel-shuffling Breed-and-Burn fast reactor (RFBB) [4]. The basic core structure of the RFBB is the same as that of conventional fast reactors. In RFBB, natural uranium or depleted uranium is used as the fresh fuel. The fuel assembly of the fresh fuel is loaded at the periphery of the core. After a certain period of operation of the reactor, the fuel assembly is shuffled. During the fuel shuffling, the fuel assembly is always moved to the position of the adjacent assembly. The fuel assemblies first move around the core periphery. Then, they gradually move to the center of the core. After that, they gradually move to the periphery. The fuel assembly is then discharged. When the shuffling pattern and the shuffling interval are appropriate, a burnup equilibrium state can be achieved. In this equilibrium state, the neutron flux and power distribution in the core become almost steady-state. This is advantageous for heat removal by coolant from the core.

In previous studies [5,6], analyses were performed using a lead-bismuth eutectic as the coolant, metal fuel, and ODS cladding with a density of material of 1/10. This was done to reduce the neutron absorption in the cladding in order to clarify the feasibility of the concept. Therefore, it is expected that the neutron economy will be worse if the real ODS is used for the fuel cladding. There is also HT-9 as a candidate for fast reactor fuel cladding, and the neutron economy may be different if HT-9 is used for the cladding. Also, the thickness of the cladding may affect the neutronic balance of B&B. Clarification of these issues will be important in B&B research.

The purpose of study is to clarify the effect of fuel cladding material, density and thickness on neutron balance in B&B.

## ANALYSIS

Neutron balance (NB) in B&B can be discussed by the following defining equation [3].

. , (1)

where is the average number of neutrons emitted per one fission reaction, is the maximum burnup value in a core, is the neutron loss fraction from the system (which is considered zero for an infinite system), and is the infinite neutron multiplication factor.

In this study, we investigate the variation of NB for different materials, densities and thicknesses of fuel cladding. The geometry was assumed to be an infinite system of hexagonal cells. The design of the reference case was as follows. The radius of the fuel pins of the cell was set to 0.45 cm, the thickness of the fuel cladding was set to 0.06 cm, and the fuel pin pitch was set to 0.60 cm. The fuel was U-10Zr metal fuel. The cladding tube was made of ODS. Uranium in the initial fuel was natural uranium. The Monte Carlo code Serpent 2.0 was used for the analysis. The nuclear data were obtained from ENDF/B-VII. In general, the NB changes with burnup as shown in Fig. 1. In the present study, the change of NB is represented by the following three indices. First Neutron Balance Point (FNBP) is the burnup at which the NB becomes zero from negative, Maximum Neutron Balance Point (MNBP) is the burnup at which the NB becomes maximum, and Second Neutron Balance Point (SNBP) is the burnup at which the NB becomes zero from positive. A small FNBP means that the neutron balance can be achieved with a small burnup, and large MNBP and SNBP means that a large number of neutrons can be supplied to other fuel assemblies for long period. In these situations, the neutron economy is superior in B&B. In the analysis, the NB changes with 1/10 cladding thickness, 1/10 cladding density, and HT-9 cladding material were investigated for the reference design. The case of 1/10 density of cladding is the analysis condition in the previous study [5,6]. This cladding is specifically referred to as ideal cladding.

## RESULTS AND DISCUSSION

TABLE 1 shows the FNBP, MNBP, and SNBP in each case. Especially focusing on FNBP and SNBP, it can be seen the following. Initially, when the cladding was changed from ODS to NT-9, there was no significant difference in the NB results because the difference in the composition of each cladding was small, and therefore, there was no significant difference in the absorption of neutrons. Therefore, the results of the discussion using ODS as the cladding material can be applied to the case using HT-9.

From the results of the reference cladding and the ideal cladding, it can be seen that the ideal cladding has a significant improvement in NB. This indicates that the influence of the cladding on the NB is very large. It is important to reduce the neutron absorption by the cladding in order to make B&B feasible.

Next, the differences between the ideal cladding and the cladding with 1/10th of the thickness are discussed. The analysis results show that the NBs are significantly improved over the reference design for all fuels and coolants. This indicates that the reduction of cladding thickness contributes to the improvement of NB.

However, when compared to the ideal cladding, the results show that the NB of the ideal cladding is better than that of the 1/10th thickness cladding. This is because the inner radius was increased while the outer radius remained unchanged when the thickness of the cladding was reduced. As a result, the amount of material in the cladding is smaller in the ideal cladding. This is thought to be because the amount of neutron absorption by the cladding is reduced. This indicates that when the thickness of the cladding is reduced to improve the NB, it is effective to reduce the outer diameter of the cladding at the same time.

In the previous study by Kuwagaki et al. [5,6], the feasibility of RFBB was clarified using metal fuel, lead-bismuth coolant, and ideal cladding of ODS. Adjustment of the fuel assembly shuffling interval or shuffling pattern shall be necessary for the RFBB. It has been shown that RFBB can be achieved with metal fuel and sodium coolant [7]. In this analysis, normal HT-9 is used for the cladding. It means it is possible to have a core in which RFBB is valid.

## CONCLUSIONS

The effect of the material, density and thickness of the fuel cladding of B&B on the NB was investigated by analysis. As a result, it was found that the cladding material from ODS to HT-9 had little effect on the NBs. It was also found that the effect of neutron absorption by the cladding on the NBs was large and the NBs could be significantly improved if the density or thickness of the cladding could be reduced. If the cladding thickness is reduced, it is expected to be more effective if the cladding outer diameter is also reduced. These findings do not change even if the fuel or coolant is changed; the RFBB concept with the ideal cladding of ODS requires changes in the shuffling interval and core design when ordinary ODS is used.

References

1. H. SEKIMOTO, K. RYU, "A New Reactor Burnup Concept CANDLE," Physor 2000, American Nuclear Society, Pittsburgh, Pennsylvania, USA (2000).
2. J. GILLELAND, C. AHLFELD, D. DADIOMOV, R. HYDE, Y. ISHIKAWA, D. MCALEES, J. MCWHIRTER, N. MYHRVOLD, J. NUCKOLLS, A. ODEDRA, K. WEAVER, C. WHITMER, L. WOOD AND G. ZIMMERMAN, "Novel Reactor Designs to Burn Non-Fissile Fuel," Proc. of the 2008 International Congress on Advances in Nuclear Power Plants (ICAPP 2008), ANS, Anaheim, Calif., United States, Paper 8319 (2008).
3. F. HEIDET AND E. GREENSPAN, "Neutron Balance Analysis for Sustainability of Breed and Burn Reactors," *Nuclear Science and Engineering*, **171**(2012) 13-31.
4. T. OBARA, K. KUWAGAKI, J. NISHIYAMA, "Feasibility of Burning Wave Fast Reactor Concept with Rotational Fuel Shuffling," International Conference of Fast Reactors and Related Fuel Cycles: Next Generation Nuclear Systems for Sustainable Development (FR17), Proceedings Proceedings of International Conference of Fast Reactors and Related Fuel Cycles: Next Generation Nuclear Systems for Sustainable Development (FR17), Jun.2017 2005, IAEA-CN245-051.
5. K. KUWAGAKI, J. NISHIYAMA, T. OBARA, "Concept of Stationary Wave Reactor with Rotational Fuel Shuffling," Nuclear Science and Engineering, **191**(2018) 178-186.
6. K. KUWAGAKI, J. NISHIYAMA, T. OBARA, "Concept of breed and burn reactor with spiral fuel shuffling", *Annals of Nuclear Energy*, , **127**(2019) 130-138.
7. Van Khanh Hoang, Odmaa Sambuu, Jun Nishiyama, Toru Obara, "Feasibility of Sodium-Cooled Breed-and-Burn Reactor with Rotational Fuel Shuffling", *Nuclear Science and Engineering*,**196** (2022) 108-120.

Fig. 1. Indices for Neutron Balance Feature

TABLE 1. Impact of cladding on neutron balance

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Coolant | Cladding |  | FNBP (MWd/kg) | MNBP  (MWd/kg) | SNBP  (MWd/kg) |
| LBE | ODS | Reference | 128 | 370 | 554 |
|  |  | 1/10 thickness | 101 | 400 | 612 |
|  |  | Ideal | 94 | 405 | 628 |
| Lead | ODS | Reference | 131 | 366 | 548 |
|  |  | 1/10 thickness | 103 | 400 | 608 |
|  |  | Ideal | 96 | 404 | 624 |
| Sodium | ODS | Reference | 134 | 375 | 546 |
|  |  | 1/10 thickness | 104 | 400 | 608 |
|  |  | Ideal | 89 | 405 | 628 |
| LBE | HT9 | Reference | 130 | 370 | 551 |
|  |  | 1/10 thickness | 101 | 400 | 611 |
|  |  | Ideal | 94 | 410 | 626 |