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Characterization of a Metallic-Fuelled B&BR with Non-uniform Smear Density

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1. Introduction

A small and compact 250 MWth sodium-cooled breed-and-burn fast reactor (B&BR) for recycling PWR spent fuel has been studied from the neutronic point of view. The PWR spent fuel is used as the blanket fuel, and the Low Enriched Uranium (LEU) is used in the initial core. It was found from the previous study [3][4] that the peak discharge burnup in the initial LEU core region and in the blanket region is about 35% and 20%, respectively. This high discharge burnup particularly in the initial LEU core could lead to the fuel/cladding mechanical interaction (FCMI). The smear density concept usually is introduced for the metallic fuel in the fast reactor to accommodate this swelling due to high burnup. It is concluded from the Ref. 5 that a 75% smear density will allow the fuel to achieve burnup up to ~20% without any FCMI occurring. In the previous work [3][4], the uniform 75% smear density was used for both fuels in initial LEU core and blanket region.

In this work, non-uniform smear density is proposed. For the region with over 20% burnup, a lower smear density of 70% is applied, and for the region with a lower burnup <20%, the standard smear density of 75% is applied. Several important reactor parameters are characterized to identify the major technical issues and challenges. The neutronic analyses were all performed by the Monte Carlo code McCARD [6].

2. Compact B&BR Concepts

The compact sodium-cooled B&BR core configuration is similar to the one in Ref. 4. The reactor power is 250 MWth. The fuel assemblies and the reflector assemblies are arranged in the 8-ring hexagonal core as shown in Fig. 1. The core consists of 78 fuel assemblies, 78 reflector assemblies, and 7 control rods assemblies. In the axial region, a 40 cm axial HT-9 reflector is located at bottom of the core, while 40 cm-thick bonding sodium is placed at the top of the core. The equivalent core radius is 115 cm.

The fuel assembly configuration (FA) consists of 127 fuel pins. The fuel pin and P/D is 1.9 cm and 1.064, respectively. The HT-9 cladding thickness is 0.06 cm. The radial reflector consists of 91 Pb-containing pins. The pin diameter is 2.32 cm. The HT-9 cladding thickness in the reflector pin is 0.10 cm.

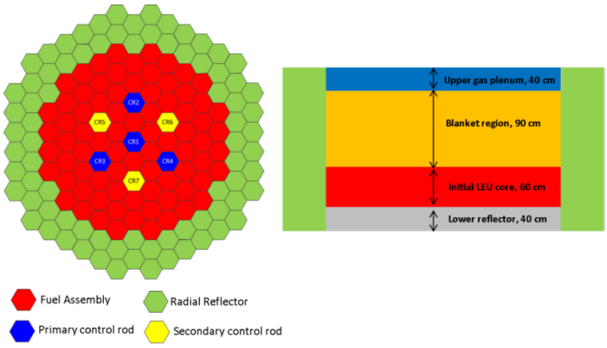

Figure 1. Layout of the reactor

For the initial LEU core, the U-Zr metallic fuel with a 70% smear density is used, and 75% smear density is used for the SNF-Zr metallic fuel. The SNF in the blanket region is assumed to be metalized through a reduction process and the resulting metallic material is melted to fabricate a SNF-Zr metallic fuel. The composition of the metalized PWR SNF is obtained by assuming the discharge burnup is 50 GWd/MTU and the cooling time is 10 years.

3. Analysis Results and Discussion

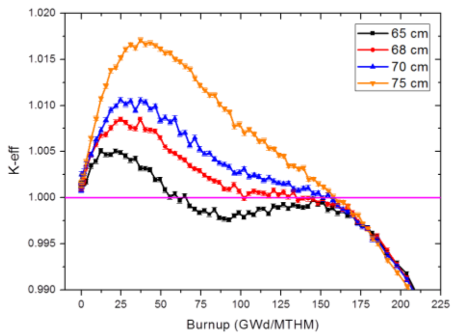

Figure 2. Evolution of k-eff for several initial core heights.

In the first step, several calculations were performed to determine the optimal initial LEU core height and the Zr content of the metallic fuel. The fuel temperature used in this calculation is 800 K, and the temperature for the cladding, structural materials, and coolant, are determined to be 700 K. In these calculations, the active core height was fixed to be 150 cm. The weight fraction of the Zr in the fuel for the initial LEU core and the blanket region is 7 wt%.

The change of the multiplication factor for the 7 wt% in the fuel is shown in Fig. 2 as the function of the initial LEU core height. The enrichment needed varies from 11.630% to 12.33% depending on the initial LEU core height.

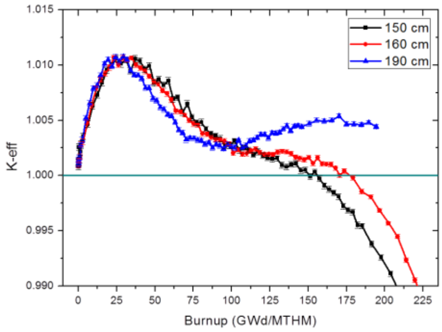

Figure 3. Evolution of k-eff as function of the core height.

The B&BR core with 70 cm initial LEU core and with 7 wt% Zr in the fuel provides the best performance in term of low excess reactivity and long core lifetime. The achievable burnup of this configuration is about 154.46 GWd/MTHM or around 68.45 EFPY (effective full power years). Since in the B&BR, the core lifetime and fuel burnup increase with the core height, the total active core height is increased to 160 cm and 190 cm while the height of the initial LEU core is 70 cm. The result of these new configurations is shown in Fig. 3. By adding the 10 cm blanket, the core lifetime is increased by about 14 years, from 68.45 years to 82.14 years and the achievable discharge burnup is now increased to 173.59 GWd/MTHM. The 160 cm B&BR with 70 cm initial LEU core is the reference core in this study and is used to characterize the important reactor parameters.

Time evolution of important reactivity coefficients are evaluated, as shown in Table I, for the reference core. The parameter is calculated at 3 burnup points: at BOC (0 GWd/MTHM), at MOC (Middle of Cycle/86.79 GWd/MTHM), and at EOC (End of Cycle/173.59 GWd/MTHM).

Table I. Reactivity coefficients

Parameters	BOC (0 GWd/ MTHM)	MOC (86.8 GWd/ MTHM)	EOC (173.6 GWd/ MTHM)
β_{eff}	7.10E-3 ± 3.17E-5	4.24E-3 ± 2.39E-5	3.73E-3 ± 1.57E-5
l, s	3.85E-7 ± 1.36E-9	3.15E-7 ± 9.21E-10	2.98E-7 ± 8.95E-10
α_D, cents/K	-0.033 ± 0.005	-0.066 ± 0.006	-0.069 ± 0.013
α_{Na}, cents/K	-0.064 ± 0.001	0.157 ± 0.001	0.165 ± 0.001
α_{void}, cents	-59.01 ± 3.59	556.53 ± 4.72	832.74 ± 5.50
α_H, cents/K	-0.027 ± 0.006	-0.067 ± 0.008	-0.054 ± 0.009
α_R, cents/K	-0.312 ± 0.007	-0.508 ± 0.009	-0.534 ± 0.011

Figure 4 shows the average discharge burnup for 10 cm-thick 16 axial layers of the core. From Fig. 4, it is clear that non-uniform smear density fuel is necessary to cope with the very high burnup in the initial core .

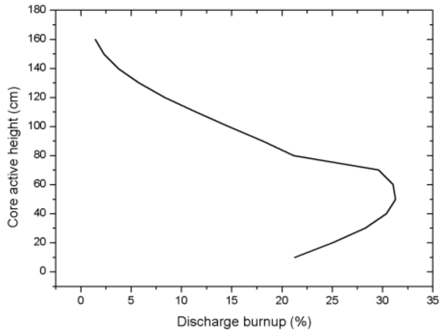

Figure 4. Average core discharge burnup.

4. Conclusions

The B&BR with non-uniform smear densities for initial LEU core and blanket region has been adopted in order to accommodate the local high burnup which can lead to FCMI. The local peak burnup now is about 31% and a low smear density of 70% may accommodate the metallic fuel swelling. Several characterizations of the core were carried out. It was found that the sodium void reactivity is relatively large, ~8$, at EOC, even though the tight lattice fuel assembly is adopted. This is due to the relatively high H/D ratio and the high fuel burnup. An optimization study will be performed to improve the safety and the initial core design.

REFERENCES

[1] T. Ellis et al., Traveling-Wave Reactors: A Truly Sustainable and Full-Scale Resource for Global Energy Needs, Proceedings of ICAPP'10, June 13-17, 2010, San Diego, CA, USA.

[2] H. Sekimoto, K. Ryu, and Y. Yoshimura, CANDLE: The New Burnup Strategy, Nuclear Science and Engineering, Vol.139, p.306, 2001.

[3] D. Hartanto and Y. Kim, Reutilization of PWR Spent Fuel in a Small Breed-and-Burn Fast Reactor, Transactions of the Korean Nuclear Society Spring Meeting 2012, May 17-18, 2012, Jeju, Korea.

[4] D. Hartanto and Y. Kim, A Compact Breed and Burn Fast Reactor Using Spent Nuclear Fuel Blanket, Proceedings of PHYSOR 2012, April 15-20, 2012, Knoxville, Tennessee, USA.

[5] G. L. Hofman, L. C. Walters, and T. H. Bauer , Metallic Fast Reactor Fuels, Progress in Nuclear Energy, Vol.31, p.83, 1997.

[6] H. J. Shim and C. H. Kim, "McCARD User's Manual", Version 1.0, Nuclear Design and Analysis Laboratory, Seoul National University, 2010.