# Reutilization of PWR Spent Fuel in a Small Breed-and-Burn Fast Reactor

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## 1. Introduction

The breed and burn fast reactor (B&BR) is gaining more interest and under development [1,2]. The B&BR has advantage in the high fuel utilization and long-life core. In a B&BR, the initial criticality is achieved by using an LEU (Low-Enriched Uranium) fuel, and either natural [3] or depleted uranium is used as the blanket fuel. The LEU active core will move very slowly toward the blanket region and the fertile nuclides in the blanket region are slowly converted into fissile nuclides.

In this work, the spent fuel of the pressurized water reactor (PWR) is used as the blanket fuel in a small B&BR. A preliminary study of using spent nuclear fuel in a 2600 MWth B&BR has been performed [4]. Fast spectrum reactor like B&BR has the capability to re-utilize the spent nuclear fuel (SNF). The objective of this work is to characterize a small-sodium cooled B&BR reactor loaded with a PWRs spent fuel blanket and identify the major technical issues and challenges. Important reactivity coefficients, kinetic parameters, power profiles, fast neutron fluence, and Pu composition at discharge burnup are analyzed. The neutronic analyses are all performed by the Monte Carlo code McCARD [5].

## 2. Compact B&BR Concepts

The reactor configuration and concept in this study is come up through wide range of numerical optimization. The reactor power is 250 MWth, roughly leading to 100 MWe. 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.

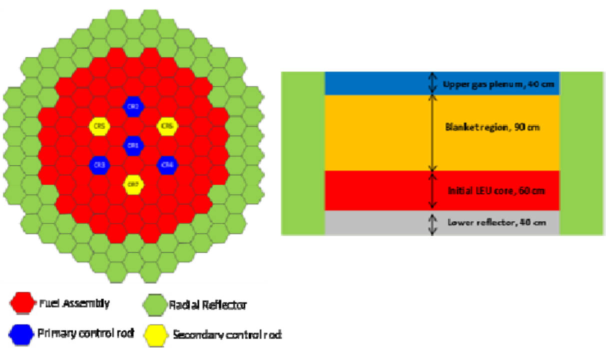


Figure 1. Layout of B&BR the reactor

The fuel assembly (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 0.05 cm. The radial reflector consists of 91 reflector pins and lead is used as the reflector to minimize the neutron leakage [3].

The U-Zr metallic fuel with a 75% smear density is used in this study. The SNF in the blanket region is assumed to be metalized through a reduction process and the resulting metallic material is simply melted to fabricate an SNF-Zr metallic fuel. The composition of the metalized PWR SNF is obtained by assuming that the discharge burnup is 50 GWd/MTU and the cooling time is 10 years. The SNF composition is shown in Table I. It should be noted that the remaining fission products is still about 3.4 wt%.

Table I. Blanket fuel composition from PWR spent fuel

| Element or Isotope | wt.% | Element or Isotope | wt% |
|---|---|---|---|
| Ge | 9.000E-05 | Tb | 3.000E-04 |
| Rb | 1.000E-01 | Dy | 1.600E-04 |
| Sr | 6.000E-02 | Ho | 1.400E-05 |
| Zr | 5.100E-01 | Er | 3.100E-06 |
| Nb | 5.500E-07 | U-234 | 1.950E-03 |
| Mo | 3.300E-01 | U-235 | 9.720E-01 |
| Tc | 1.050E-01 | U-236 | 5.890E-01 |
| Ru | 2.960E-01 | U-238 | 9.400E+01 |
| Rh | 6.000E-02 | Np-237 | 5.760E-02 |
| Pd | 1.760E-01 | Pu-238 | 1.940E-02 |
| Ag | 9.300E-03 | Pu-239 | 5.220E-01 |
| In | 3.800E-04 | Pu-240 | 2.470E-01 |
| Sn | 1.100E-02 | Pu-241 | 8.380E-02 |
| Sb | 2.300E-03 | Pu-242 | 6.270E-02 |
| Ba | 2.470E-01 | Pu-244 | 1.830E-06 |
| La | 1.680E-01 | Am-241 | 5.820E-02 |
| Ce | 3.220E-01 | Am-242m | 1.340E-02 |
| Pr | 1.530E-01 | Am-243 | 1.350E-04 |
| Nd | 5.550E-01 | Cm-242 | 2.620E-07 |
| Pm | 1.500E-03 | Cm-243 | 2.580E-05 |
| Sm | 1.110E-01 | Cm-244 | 2.860E-03 |
| Eu | 1.710E-02 | Cm-245 | 2.420E-04 |
| Gd | 1.680E-02 | Cm-246 | 2.640E-05 |

## 3. Analysis Results and Discussion

The evolution of the effective multiplication factor for 5 types of fuels is shown in Fig. 2. The initial LEU enrichment in the active core is 12.70% with U-10Zr fuel, 12.25% with U-8Zr fuel, 12.00% for with U-7Zr fuel. The achievable burnup for the U-8Zr core is ~187 GWd/MTHM and it is equal to ~85 effective full power years. It is worthwhile to note that the excess reactivity can be very small with appropriate choice of the initial core size and the Zr content in fuel.

Core characterization is performed only for the reactor loaded with U-8Zr fuel. Time evolution of important reactivity coefficients are evaluated, as shown in Table II. In addition, both the axial and radial power distributions are identified over the core lifetime as shown in Figures 3 and 4. These parameters are calculated at 3 burnup points: at BOC (0 GWd/MTHM), at MOC (Middle of Cycle/96.45 GWd/MTHM), and at EOC (End of Cycle/186.87 GWd/MTHM).

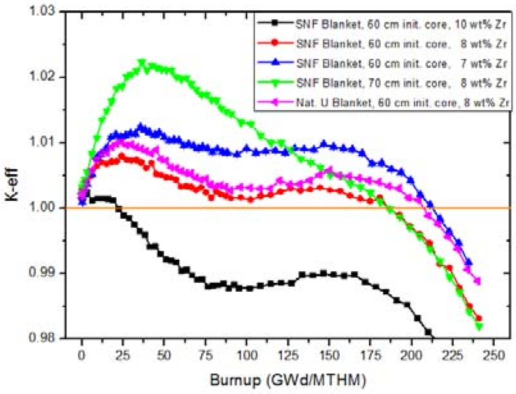


Fig. 2. Evolution of k-eff during burnup

The Doppler coefficient, axial expansion coefficient and radial expansion coefficient remain negative for the whole lifetime. However, the sodium density coefficient is positive, as is usually the case in the sodium-cooled fast reactor. The sodium density coefficient are slightly negative at the BOC because the core is U-dominated. At EOC, the sodium void worth is relatively high, about 7$, which is mainly ascribed to the rather high axial dimension of the B&BR. Figure 3 clearly shows that the core is slowly moving upward with burnup.

Table II. Reactivity coefficients

| Parameters | BOC | MOC | EOC |
|---|---|---|---|
| Delayed neutron fraction | 7.13e-3 ± 5.12e-5 | 4.06e-3 ± 3.77e-5 | 3.70e-3 ± 3.89e-5 |
| Prompt neutron lifetime, sec | 3.70e-7 ± 1.54e-9 | 3.06e-7 ± 9.21e-10 | 2.99e-7 ± 8.95e-10 |
| Doppler coefficient, cents/K | -0.078 ± 0.008 | -0.105 ± 0.012 | -0.069 ± 0.013 |
| Sodium void worth, cents | -28.813 ± 3.68 | 466.71 ± 5.69 | 635.75 ± 5.96 |
| Axial expansion coefficient, cents/K | -0.023 ± 0.007 | -0.076 ± 0.009 | -0.070 ± 0.011 |
| Radial expansion coefficient, cents/K | -0.328 ± 0.007 | -0.527 ± 0.011 | -0.555 ± 0.011 |

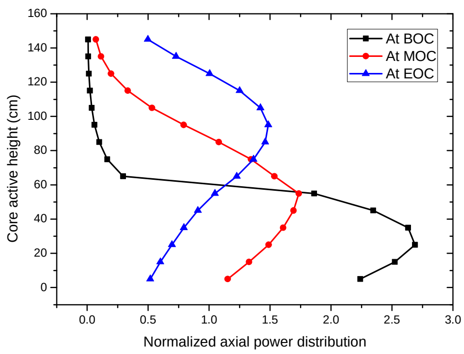


Fig. 3. Axial power profile at BOC, MOC, and EOC

In the current B&BR, the fast peak fast neutron fluence is estimated to be 4~5 times higher than the typical allowable limit of HT-9 structural material, $4.0 \times 10^{23}$ neutrons/cm$^2$. It is very clear that a new material or an innovative fuel design should be developed to realize such a long-life B&BR.

The fuel composition at the end of lifetime is also analyzed and the maximum Pu fraction is found to be about 12.33%, which may indicate that a lower Zr content (e.g., 8 wt% as in this work) may be allowable for the metallic fuel of the B&BR.

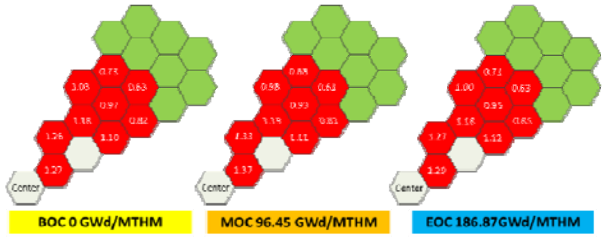


Fig. 4. Normalized assembly-wise power distribution

## 4. Conclusions

For a small long-life B&BR, the fuel volume fraction should be extremely high, e.g., over 60%. Although fuel pins are tightly arranged, the sodium void worth is ~ 6.5 dollars at EOC due to the relatively high H/D ratio. The core-average fuel burnup is near 20% and the local peak burnup is close to 35%. The burnup reactivity swing of the core can be very small by adjusting the height of the initial LEU core. However, the power density in the initial core is much higher than in the burned core. The high fuel burnup results in a very high fast neutron fluence exceeding the current limit of the structural materials. It is obvious that an innovative fuel design should be developed for the realization of the B&BR. Optimization study is underway to improve the safety and performance of core design. Also, a vented fuel concept is being developed to cope with the high fast neutron fluence of the B&BR.

## REFERENCES

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

[2] H. Sekimoto, K. Ryu, and Y. Yoshimura, "CANDLE: The New Burnup Strategy," *Nucl. Sci. Eng.*, **139**, 306, 2001

[3] Y. Kim and D. Hartanto, "A Compact Sodium-cooled Traveling Wave Reactor," Transactions of the Korean Nuclear Society Autumn Meeting, Gyeongju, Korea, October 27-28, 2011.

[4] Y. Kim, " Semi-direct Recycling of LWR Spent Fuel in Ultra-long-life Core Fast Reactor (UCFR)," *Trans. of Am. Nucl. Soc.*, 2010.

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