FAMER-OpenMC Linked Fission Product Removal Burnup Calculations

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***Keywords :** FAMER, OpenMC, Fission Product, Burnup

1. Introduction

As seen in Fig. 1, FNC is developing a nuclear design calculation system for MSR analysis and design. This system includes linked nuclear cycle code FAMER (Flowing fuel based Advanced MSR fuel cycle analyzer) and a Monte Carlo neutronics analysis code, OpenMC. This study describes how this linkage system was utilized in the KARPA reactor design to calculate the reactivity gains for each nuclide while the reactor is operated and to eliminate fission products generated during reactor operation. To compare the burnup calculation results, ENDFB.vii.1 and ENDFB.viii.0 libraries were utilized, and each result was determined to be within the error range.

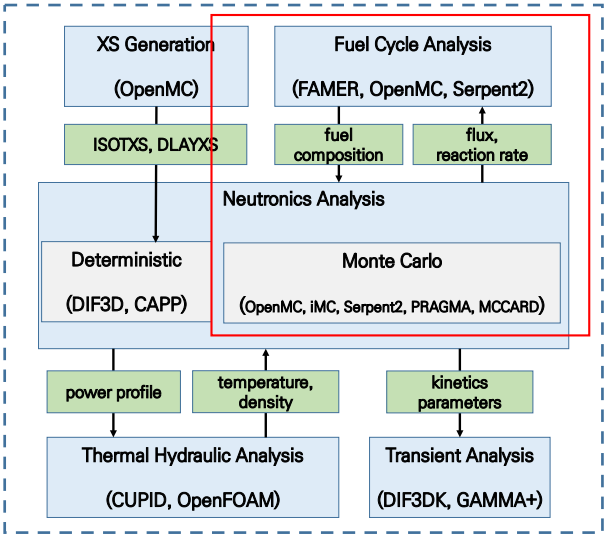


Fig. 1. Entire MSR Nuclear Design Calculation System.

2. Calculation Condition

2.1 Geometry and Materials Conditions

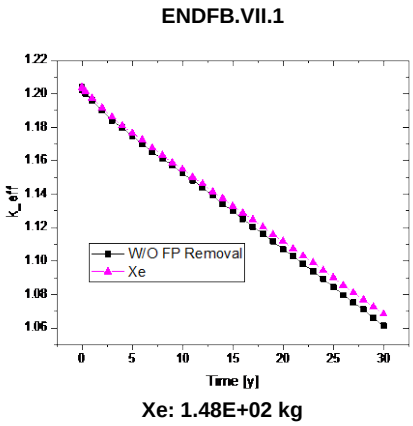
Using the initial KARPA reactor data, the reactor size for calculation was set to 180.0 cm for both the cylinder's diameter and height. Table 1 provides an overview of the initial nuclear fuel composition. The core was initially loaded with 1547.657 kg of U-235. The volume ratio between the inner and outer core was assumed to be 1.44.

Table I: Initial Fuel Number Density

Nuclide	Number Density [#/(cm·barn)]	Nuclide	Number Density [#/(cm·barn)]
U-235	8.657E-04	K-39	2.232E-03
U-238	3.473E-03	K-40	2.800E-07
Cl-35	2.047E-04	K-41	1.611E-04
Cl-37	2.026E-02	Na-23	5.058E-03

2.2 Fission Products Removal

The effects on the noble gases Xe and Kr were first examined. By making the virtual half-life to be extremely short, the nuclide was simulated to be removed as soon as it was formed. In a thermal reactor, Xe is a potent poison. However, in the fast reactor KARPA, its effects were less pronounced than those of other fission products, which will be discussed subsequently. The removal of Kr had almost no effect, and the results have been omitted. Fig. 2 shows a graph of the increase in reactivity due to the removal of Xe for each library. At the end-of-cycle (30 y), the estimated reactivity gains resulting from Xe removal were 662.22 and 668.60 pcm, respectively. Xe production was estimated to be approximately 148 kg in both cases when Xe was not removed.



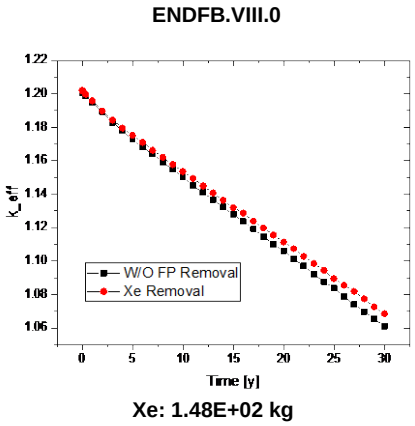


Fig. 2. Xe Removal Results.

Second, FP(Fission Product) removal burnup calculations were performed for the six nuclides expected to have the plate-out, Mo, Tc, Ru, Rh, Pd, and Ag. The results are given with the exception of Pd and Ag, which are expected to have little effects. Table II summarizes the inventory of each nuclide at the end of the cycle when no fission products are removed, while Table III summarizes the end-of-cycle reactivity gain when each nuclide is removed. Figures 3 to 6 illustrate the k_eff values over time when each nuclide was removed.

Table II: Fission Product Inventory (EOC)

	Mo [kg]	Tc [kg]	Ru [kg]	Rh [kg]
Inventory (endfb7.1)	119	28.9	66.3	17.0
Inventory (endfb8.0)	119	28.9	66.3	17.1

Table III: Reactivity Gain (EOC)

	Mo[pcm]	Tc[pcm]	Ru[pcm]	Rh[pcm]
Δρ (endfb7.1)	1122.10	863.92	718.12	461.22
Δρ (endfb8.0)	1079.28	840.81	658.08	447.37

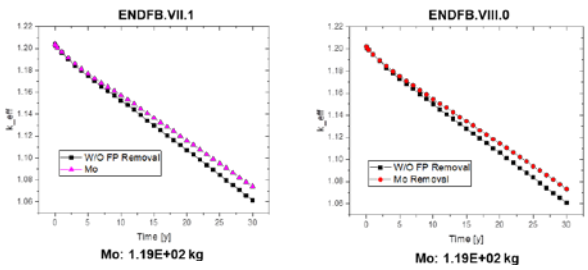


Fig. 3. Mo Removal Results.

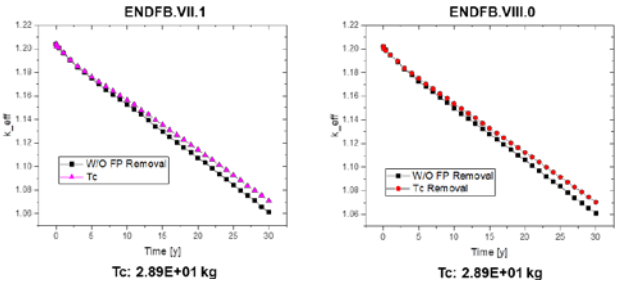


Fig. 4. Tc Removal Results.

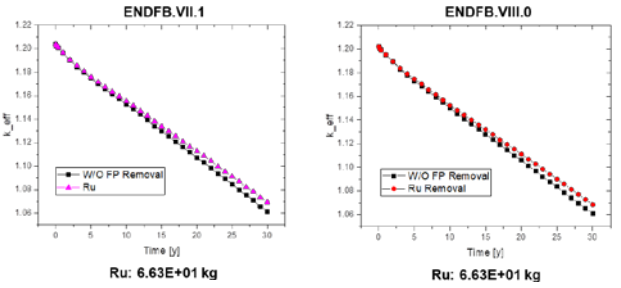


Fig. 5. Ru Removal Results.

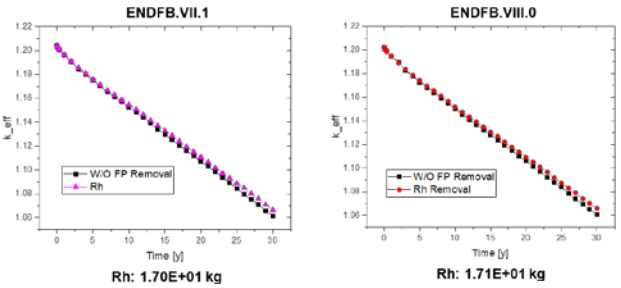


Fig. 6. Rh Removal Results.

Finally, FP removal burnup calculations were performed for various FPs such as Ba, Cs, La, Zr, Ce, Nd, Pr, Sr, Y, Rb, Te, Pm, Sm, I, Se, Nb, Br, Eu, Sn, Sb, Gd, and Cd, and we discuss the results for the elimination of Nd, Pr, Pm, Sm, and Ce, which were estimated to have a significant effect. Table IV describes the inventory of each nuclide at the end of the cycle when no fission products are removed, while Table V summarizes the end-of-cycle reactivity gain when each nuclide is removed. Figures 7 to 11 show the k_eff values over time when each nuclide was removed.

Table IV: Fission Product Inventory (EOC)

Inventory	Nd [kg]	Pr [kg]	Pm [kg]
endfb7.1	145	40.7	1.97
endfb8.0	145	40.6	1.96
Inventory	Sm [kg]		Ce [kg]
endfb7.1	29.1		84.4
endfb8.0	29.1		84.5

Table V: Reactivity Gain (EOC)

Δρ	Nd [pcm]	Pr [pcm]	Pm [pcm]
endfb7.1	1783.14	1606.75	1280.47
endfb8.0	1706.16	1597.26	1242.21
Δρ	Sm [pcm]	Ce [pcm]	
endfb7.1	1261.46	1139.44	
endfb8.0	1216.25	1144.35	

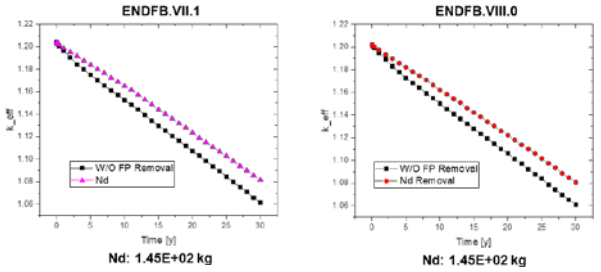


Fig. 7. Nd Removal Results.

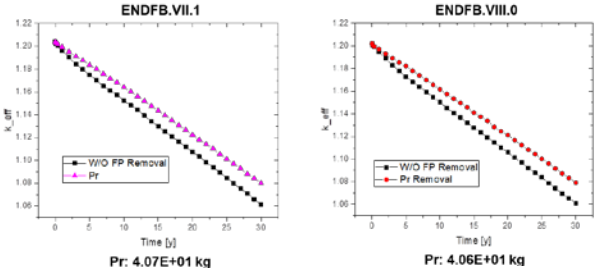


Fig. 8. Pr Removal Results.

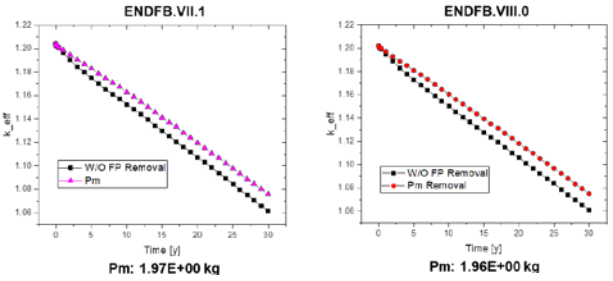


Fig. 9. Pm Removal Results.

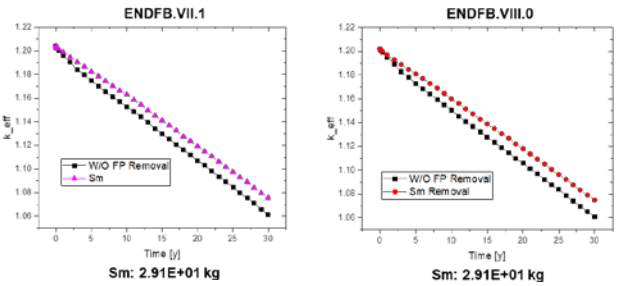


Fig. 10. Sm Removal Results.

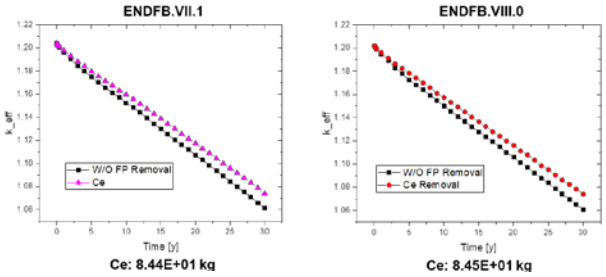


Fig. 11. Ce Removal Results.

3. Conclusions and Future Works

Utilizing the linked system of FAMER and OpenMC codes, the impact of removing fission products generated during reactor operation on the excessive reactivity at EOC was assessed. The effect of Xe, which had a significant influence as a poison in thermal neutron reactors, was greatly reduced; however it was confirmed that reactivity losses might be generated by a variety of nuclides that were not considered in thermal reactors. Among the nuclides that can be easily removed by plate-out Mo, Tc, Ru, and Rh were poisonous, and it was confirmed that other nuclides that had a significant impact on reactivity loss were Nd, Pr, Pm, Sm, and Ce. To meet the 30-year operation requirement, KARPA is being designed with a large amount of excess reactivity. However, this poses several issues, thus a method of replenishing nuclear fuel during operation is also being considered. To this end, a detailed burnup calculation that takes nuclear fuel replenishment into consideration will be carried out in the future using the linked system of FAMER and OpenMC codes.

ACKNOWLEDGMENT

This work was supported by the National Research Foundation of Korea (NRF) grant funded by the Korea government (MSIT) (RS-2023-00260898).

REFERENCES

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