Transactions of the Korean Nuclear Society Spring Meeting
Jeju, Korea, May 23-24, 2019

Neutronic Analysis of Fuel Assembly Using Accident Tolerance Fuel

Yunki Jo[a], Eun Jeong[a], Deokjung Lee[a*], Ho Cheol Shin[b], and Kwangho Lee[b]
[a]*Department of Nuclear Engineering, Ulsan National Institute of Science and Technology*
50 UNIST-gil, Ulsan, 44919, Republic of Korea
[b]*Reactor core and Fuel Analysis group, Korea Hydro & Nuclear Power Central Research Institute (KHNP-CRI), 70, 1312-gil, Yuseong-daero, Yuseong-gu, Daejeon, Korea*
[*]*Corresponding author: deokjung@unist.ac.kr*

1. Introduction

Accident tolerance fuel (ATF) using metallic microcell fuel pellet has been suggested by the Korea Atomic Energy Research Institute (KAERI) [1-3]. KAERI developed the ATF with metallic additives such as Molybdenum (Mo) and Chromium (Cr) which increase thermal conductivity of fuel pellet effectively. The high thermal conductivity reduces fuel centerline temperature, and it makes larger thermal safety margin during the operation of nuclear reactor. However, the metallic additives reduce cycle length of nuclear reactor due to their high neutron capture cross sections. It is required to perform neutronic analysis for fuel assembly and reactor core models using ATF. Recently, the neutronic analysis of ATF with Molybdenum and Chromium metallic additives has been performed with DeCART/MASTER code at Kyung Hee university [4].

The main objective of this study is analyzing neutronic properties of ATF fuel assemblies by comparing them with normal UO_2 fuel. The infinite multiplication factor (k-inf) as a function of burnup, normalized pin power distribution, fuel temperature coefficients (FTC) and moderator temperature coefficients (MTC) at the beginning of cycle (BOC) are compared to each other.

2. Methods and Results

2.1 Model description

PLUS7 16×16 fuel assembly model with a boron concentration of 700 ppm in the coolant is used in this study. It doesn't have Gadolinia pins. Fig. 1 shows the configuration of the PLUS7 fuel assembly. Table I shows the specification of fuel assemblies used in this study. One UO_2 fuel assembly and three ATF fuel assemblies are calculated with MCS, which is a Monte Carlo neutron transport code developed at UNIST.

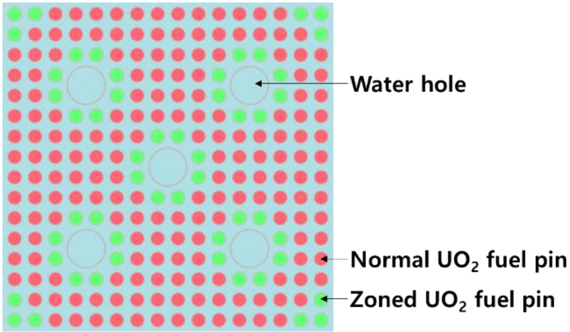


Fig. 1. PLUS7 16×16 fuel assembly model

UO_2 case is the reference case using normal UO_2 fuel. The other cases are ATF cases using microcell fuel with 5 volume% (vol%) of Mo and Cr, respectively. In the ATF cases, the amount of UO_2 fuel is reduced by 5 vol% of fuel due to the metallic additives. UO2+Mo w/ CrAl case represents CrAl coated cladding to UO_2+Mo case.

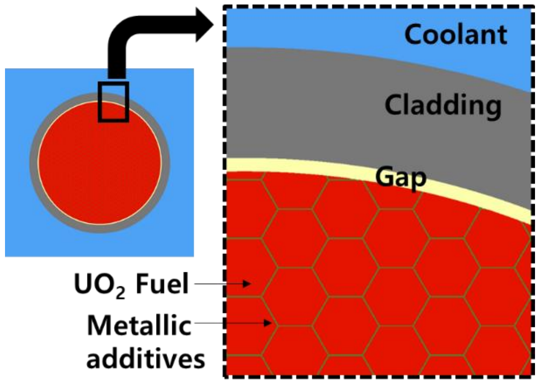


Fig. 2. Heterogeneous ATF microcell structure

Table I: Fuel assembly specification

Case	UO_2	UO_2+Mo	UO_2+Cr	UO_2+Mo w/ CrAl
Fuel assembly type	PLUS7	PLUS7	PLUS7	PLUS7
Fuel type	UO_2	UO_2-Mo (5 vol%)	UO_2-Cr (5 vol%)	UO_2-Mo (5 vol%)
U enrichment [wt%] (normal/zoning)	4.5/4.0	4.5/4.0	4.5/4.0	4.5/4.0
Pellet radius [cm]	0.4095	0.4095	0.4095	0.4095
Cladding thickness [cm]	0.057	0.057	0.057	0.057
Coating thickness [cm]	-	-	-	0.001

Fuel rod radius [cm]	0.4750	0.4750	0.4750	0.4760
Pin pitch [cm]	1.285	1.285	1.285	1.285
Coolant temperature [K]	584	584	584	584
Fuel temperature [K]	850	850	850	850

Fig. 2 shows the heterogeneous ATF microcell structure modelled by MCS. The hexagonal microcell structures are applied to the fuel region. The size of hexagonal grain is 300 μm and the thickness of grain boundary is 7~8 μm. In a single fuel pellet, about 745 microcells exist.

2.2 Numerical results

Fig. 3 shows the infinite multiplication factors (k-inf) as a function of burnup in EFPD. The k-inf of UO_2 case was set as a reference. Depletion calculations are performed with the same power level for every cases. At the BOC, the k-inf of UO_2+Mo case is 3500 pcm lower than the reference case, whereas UO2+Cr case is 2000 pcm lower. It is due to the higher neutron capture cross section of Mo than Cr. UO2+ Mo w/ CrAl case shows slightly lower k-inf due to the neutron capture of Cr in the coating. The difference of k-inf becomes larger with burnup due to the smaller amount of initial fuel loadings in ATF cases.

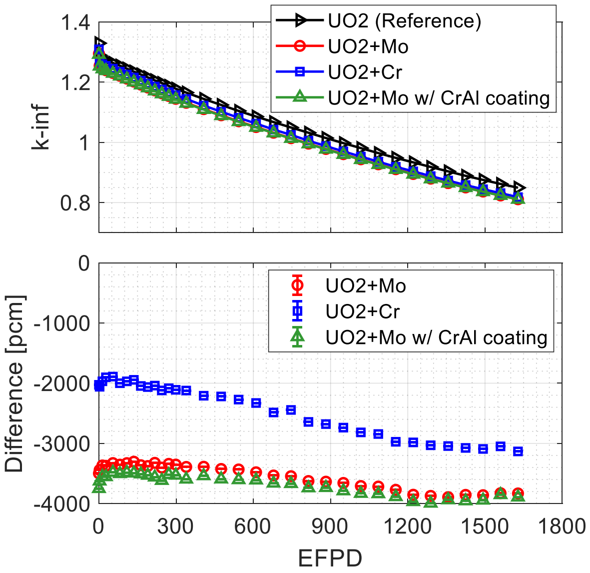


Fig. 3. Comparison of infinite multiplication factors

Fig. 4 shows the normalized pin power distribution of UO_2 case at the BOC. It shows higher pin power near the water hole. The relative standard deviations of pin power are lower than 0.2% at every fuel pin positions. Fig. 5 shows the relative difference of pin power distribution between the reference UO_2 case and each ATF case. The root mean square (RMS) and maximum (MAX) differences are also shown in Fig. 5. The RMS and MAX differences are about 0.2% and 0.65%, respectively.

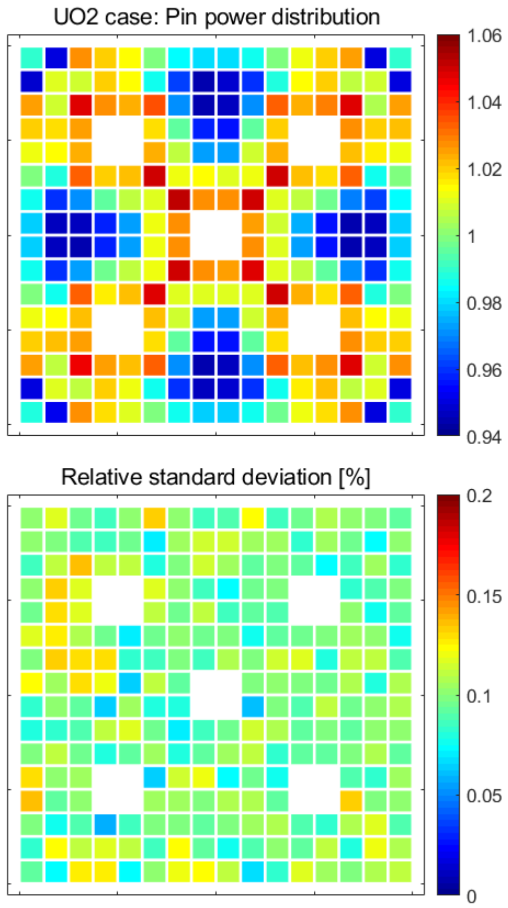
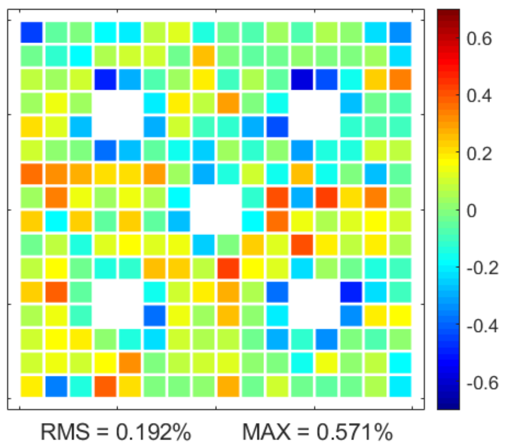
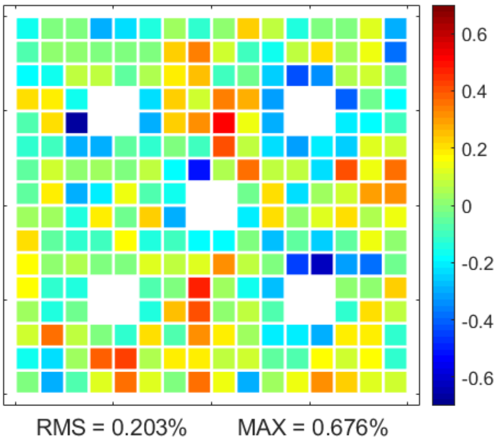


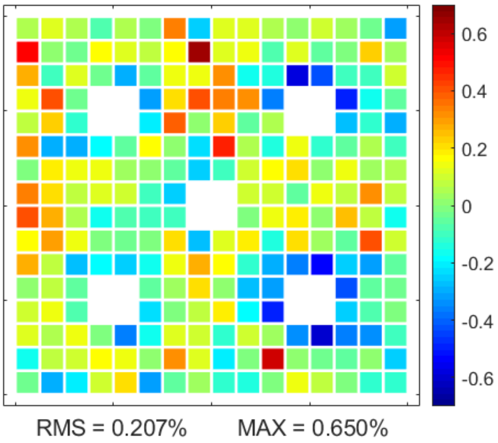
Fig. 4. Normalized pin power distribution and relative standard deviation of UO_2 case at BOC



(a) UO_2+Mo case



(b) UO_2+Cr case



(c) UO2+Mo w/ CrAl case

Fig. 5. Relative difference of pin power distribution at BOC

Table II shows the FTC and MTC summary at the BOC. The boron concentration of 700 ppm is used in the coolant of fuel assembly models. UO_2+Mo case and UO_2+Cr case show a more negative FTC than the reference case due to the high capture cross section of metallic additives. UO_2+Mo case shows more negative MTC than the reference UO_2 case, whereas UO_2+Cr cases shows less negative MTC. The less negative MTC in UO_2+Cr case results from the higher moderator to fuel ratio. The more negative MTC in UO_2+Mo case results from the higher neutron capture cross sections of Mo than Cr.

Table II: FTC and MTC summary at BOC

Case	FTC [pcm/°C]	MTC [pcm/°C]
UO_2	-1.719	-13.348
UO_2+Mo	-2.040	-15.937
UO_2+Cr	-1.931	-12.474

Fig. 6 shows the k-inf comparison of UO_2+Mo case depends on its heterogeneity. They show a good agreement. The k-inf difference is less than 100 pcm between heterogeneous UO_2+Mo model and homogenized UO_2+Mo model.

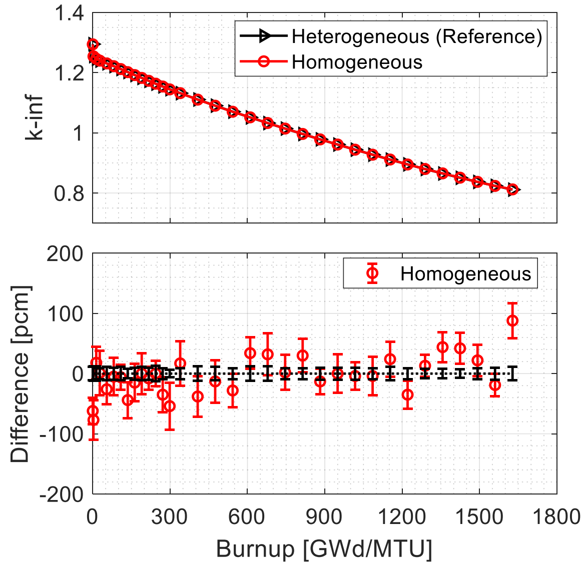


Fig. 6. k-inf comparison depends on heterogeneity of UO2+ Mo case

3. Conclusions

In this study, a neutron analysis of fuel assemblies using ATF has been performed with MCS. The fuel assembly with normal UO_2 fuel is set as a reference case. The k-inf, normalized pin power distribution, FTC and MTC are compared. The k-inf of ATF cases are lower than the reference UO_2 case at BOC due to high neutron capture cross section of metallic additives (Mo and Cr). The k-inf difference increases as burnup increases due to the lower amount of initial fuel loading in ATF cases. Both UO_2+Mo and UO_2+Cr cases show more negative FTC than the reference UO_2 case. For MTC, UO_2+Mo case shows more negative value, whereas UO_2+Cr case shows less negative MTC. Additionally, the effect of heterogeneity in microcell fuel of UO_2+Mo case was analyzed by comparing the k-inf for depletion calculation. The k-inf differences are less than 100 pcm in whole burnup range.

ACKNOWLEDGEMENTS

This research was partially supported by the project(L17S018000) by Korea Hydro & Nuclear Power Co. Ltd.. This research was partially supported by the project(L18S040000) by Korea Hydro & Nuclear Power Co. Ltd..

REFERENCES

[1] D. J. Kim, Y. W. Rhee, J. H. Kim, K. S. Kim, J. S. Oh, J. H. Yang, Y. H. Koo, and K. W. Song, Fabrication of micro-cell UO2-Mo pellet with enhanced thermal conductivity, *J. Nucl. Mater*, Vol. 462, p. 289-295, 2015

[2] OECD-NEA, State-of-the-Art Report on Light water Reactor Accident Tolerant Fuels, NEA No. 7317, 2018
[3] D. J. Kim, K. S. Kim, D. S. Kim, J. S. Oh, J. H. Kim, J. H. Yang, and Y. H. Koo, Development status of microcell UO2 pellet for accident-tolerant fuel, Nucl. Eng. Technol., Vol. 50, p. 253-258, 2018
[4] D. H. Hwang, S. G. Hong, and W. K. In, Physical characteristics of a PWR core loaded with micro-cell UO2 pellet fuels, *Ann. Nucl. Energy*, Vol. 128, p. 33-43, 2019