Comparative Analysis Between UO_2 and MOX Cores for APR-1400

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1. Introduction

Thorium-based mixed-oxide (MOX) fuel has attracted renewed interest as a potential alternative to conventional UO_2 fuel because of its potential resource-utilization and fuel-cycle advantages. This work investigates the feasibility of loading the initial core of the Advanced Power Reactor 1400 (APR-1400), a Generation III+ pressurized water reactor, with ThO_2–UO_2 MOX fuel [1], and examines how its cycle characteristics differ from those of conventional UO_2 fuel.

The objectives of this study are (i) to construct an initial core model of the APR-1400 loaded with UO_2 that reproduces the neutronic parameters reported in the Design Control Document (DCD) [2] and (ii) to compare the nuclear design parameters of UO_2 and MOX cores — cycle burnup, critical boron concentration (CBC), pin-power peaking factor (PPF), moderator temperature coefficient (MTC), and fuel temperature coefficient (FTC).

2. Methodology

2.1 Two-step reactor physics methodology

A two-step methodology was adopted, consistent with the standard KAERI analysis chain for PWR core design. In the first step, DeCART2D [3], a two-dimensional deterministic transport code, performs assembly-level lattice physics and depletion calculations to generate homogenized few-group cross sections for each fuel assembly (FA) type. In the second step, MASTER [4], a three-dimensional nodal diffusion code, uses these cross sections to perform full-core diffusion and depletion analysis.

The workflow proceeds in four stages: (i) all fuel assembly types are designed and cross sections for UO_2-containing assemblies are produced; the MOX isotopic composition of every assembly is then derived by matching its infinite multiplication factor (k_{inf}) to that of the corresponding UO_2 assembly; (ii) the initial core loading pattern of APR-1400 is modeled in MASTER for both fuel types to obtain cycle burnup and CBC curves; (iii) the UO_2 results are verified against the APR-1400 DCD by computing the deviation in burnup and boron concentration; (iv) PPF, MTC, and FTC are compared between the UO_2 and MOX cases.

2.2 Fuel assembly and core design

The initial core consists of 241 fuel assemblies (16×16 type) rated at 1400 MWe. Each assembly is modeled with octant or quadrant-symmetric lattice boundaries. Gadolinium-bearing assemblies contain 12 or 16 Gd_2O_3 burnable-poison rods at a concentration of 8 wt% in fuel pellets. A homogeneous MOX design was selected for its modeling simplicity, as it enables a consistent comparison with the UO_2 core. The enrichments of UO_2 fuel assemblies are given in the DCD.

2.3 Determination of the MOX isotopic composition

The MOX fuel is defined as ThO_2 mixed with uranium in which ^{235}U and ^{238}U make up 80% and 20% of the uranium metal, but this ratio alone does not fix the weight fraction of each isotope in the mixture. The ^{232}Th fraction was therefore treated as a free parameter and adjusted iteratively: for each trial value, the weight fractions of the remaining isotopes (^{235}U, ^{238}U, ^{16}O) were computed, the assembly k_{inf} was evaluated, and the trial was accepted once it reproduced the k_{inf} of the corresponding FA loaded with UO_2 to within 84 pcm. This was repeated for each fuel assembly.

3. Results and Discussion

3.1 Verification of the UO_2 core parameters against the DCD

Table I compares the calculated values with DCD benchmarks at selected burnup points.

Table I: Deviation of calculated CBC (UO_2 calc.) results from the DCD at selected points

Parameter	DCD	Calc.	Deviation
CBC	[ppm]		
0 EFPD	817.00	782.98	34.02
90 EFPD	739.30	685.43	53.87
210 EFPD	682.57	622.58	59.99
450.64 EFPD	46.00	10.06	35.94

The calculated CBC follows the same depletion trend as the DCD reference but consistently underpredicts it, with the deviation growing from 34.02 ppm at the beginning of the cycle (BOC) to a maximum of 59.99 ppm near 210 effective full-power days (EFPD). The

calculated cycle burnup, 17.13 GWd/MTU, is 0.44 GWd/MTU below the DCD value, an agreement consistent with a two-step deterministic methodology and acceptable for extending the model to the MOX case.

3.2 Comparison of k_{inf} trends for MOX and UO_2 fuel assemblies

Fig. 1 compares k_{inf} of the A_0 fuel assembly for UO_2 and MOX fuels as a function of burnup. The values of k_{inf} start at 1.09 and 1.07 for A_0-type and B_2-type fuel assemblies, respectively. Both fuels decrease smoothly and monotonically with burnup, but MOX remains systematically higher throughout, reflecting its enhanced plutonium contribution and slower reactivity degradation.

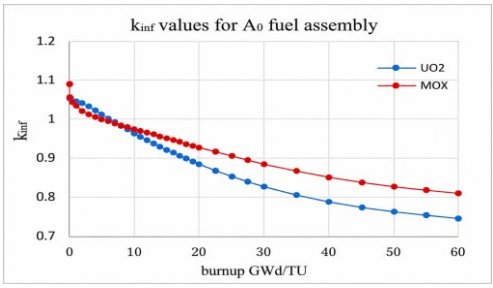


Fig. 1. k_{inf} values of A_0-type fuel assembly for UO_2 and MOX

Fig. 2 shows the same comparison for the B_2 assembly (12 gadolinia rods, 8 wt% Gd_2O_3). Unlike A_0-type FA, k_{inf} rises initially as the burnable poison depletes, then declines sharply; MOX again stays higher than UO_2 over most of the irradiation period, with the clearest distinction appearing at higher burnup.

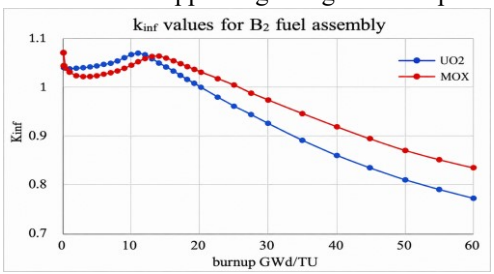


Fig. 2. k_{inf} values of B_2-type fuel assembly for UO_2 and MOX

3.3 Comparison of MOX and UO_2 cores

3.3.1 CBC and cycle burnup.

MOX fuel produces a substantially longer cycle: 549.82 EFPD versus 450.64 EFPD for UO_2, an extension of about 99.18 days, with a corresponding rise in cycle burnup from 17.13 to 22.61 GWd/MTU—an increase of 5.48 GWd/MTU at the end of the cycle. This extension is driven by the fertile-to-fissile conversion of thorium, $^{232}Th + {}^{1}n \rightarrow {}^{233}U$. Based on the end-of-cycle isotopic inventory, the overall fissile conversion ratio is approximately 0.42, of which the $^{232}Th \rightarrow {}^{233}U$ path accounts for about 0.40. Fig. 3 presents the calculated CBC variation with burnup for both UO_2 and MOX configurations in comparison with DCD reference data.

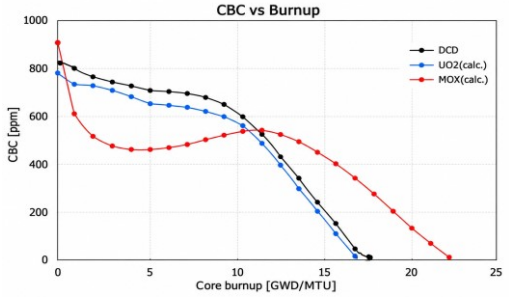


Fig. 3. CBC variation with burnup for UO_2 and MOX fuels

The MOX core requires a higher CBC at BOC—909.1 ppm versus 783 ppm for UO_2, despite having a similar k_{inf}, because its neutron spectrum renders soluble boron of a lower effective worth. Strong absorption by ^{232}Th, ^{239}Pu, and ^{241}Pu means more boron is needed to control the same excess reactivity. With burnup, the MOX curve initially falls below the UO_2 curve, reaching about 212 ppm lower near 90 EFPD, before rising above it near the end of the cycle. This reversal results from burnup-dependent changes in plutonium buildup, depletion, neutron absorption, and spectrum.

The maximum pin-power peaking factor (PPF) is slightly higher for MOX (1.43) than UO_2 (1.39), consistent with the more heterogeneous power distribution from the higher fissile loading needed to match k_{inf} across assembly types. Table II summarizes the core design parameters obtained for the UO_2 and MOX cores.

Table II: Summary of the UO_2 and MOX core designs

Case	CBC at BOC (ppm)	Cyc. burnup (GWd/MTU)	Max PPF	Cyc. length (EFPD)
Target (DCD)	817	17.57	N/A	N/A
UO_2 (calc.)	783	17.13	1.39	450.64
MOX (calc.)	909.1	22.61	1.43	549.82

3.3.2 MTC and FTC

The MTC and FTC are important reactivity feedback parameters for reactor core stability and safety. Figs.4-5 show the FTC and MTC variations with EFPD for the UO_2 and MOX cores.

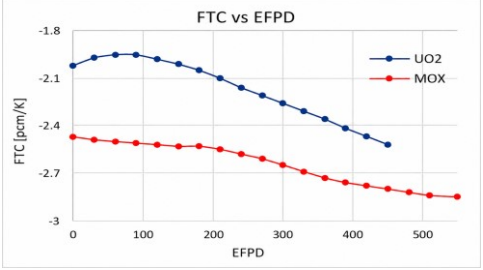


Fig. 4. FTC values for UO_2 and MOX fuels.

The FTC remains more negative for MOX throughout the cycle, ranging from −2.47 to −2.85 pcm/K, compared with −1.95 to −2.52 pcm/K for UO_2. This indicates stronger Doppler feedback in the MOX core.

MTC follows a different pattern (Fig. 5): UO_2 decreases monotonically from −15.92 to −53.20 pcm/K, whereas the MOX curve is non-monotonic, with a weaker variation during the middle of the cycle followed by a sharper decrease near EOC. Overall, both cores maintain negative reactivity feedback throughout the evaluated cycle.

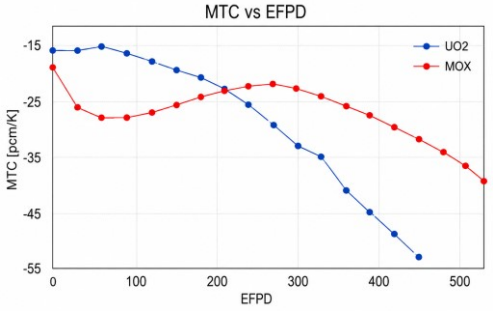


Fig. 5. MTC values for UO_2 and MOX fuels

Table III summarizes the calculated FTC and MTC values at burnups of 0, 8.57, and 17.13 GWd/MTU for UO_2 fuel, and 0, 11.31, and 22.61 GWd/MTU for MOX fuel.

Table III: Comparison of FTC and MTC values

Fuel	Bu [GWd/MTU]	FTC [pcm/K]	MTC [pcm/K]
UO_2	0	-2.02	-15.92
	8.57	−2.13	-22.31
	17.13	−2.52	-53.2
MOX	0	-2.47	-18.43
	11.31	-2.62	-22.01
	22.61	-2.85	-39.45

4. Conclusions

A two-step DeCART2D/MASTER methodology was applied to model the APR-1400 initial core with both UO_2 and ThO_2-UO_2 MOX fuels. The UO_2 model reproduces the DCD reference to within 0.44 GWd/MTU in cycle burnup, validating the methodology for extension to the MOX case.

Compared with UO_2, the MOX core increased the cycle length from 450.64 to 549.82 EFPD and the discharge burnup from 17.13 to 22.61 GWd/MTU. However, it showed a higher CBC and a slightly higher maximum PPF. The MOX core also exhibited more negative FTC values, while its MTC showed a distinct non-monotonic trend. Both cores retained negative reactivity feedback throughout the evaluated cycle.

Acknowledgement

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REFERENCES

[1] A. A. Galahom, A. S. Khaliil, N. Alnassar, S. M. Reda, Discussing the Possibility of Using Thorium-Based Fuels as an Alternative Fuel to Uranium Dioxide Fuel for APR-1400 Reactor, Nuclear Engineering and Design, Vol. 417, 112817, 2024.

[2] Korea Hydro & Nuclear Power Co. (KHNP), APR1400 Design Control Document (DCD), KHNP, Gyeongju, Republic of Korea.

[3] Korea Atomic Energy Research Institute (KAERI), DeCART2D v1.1 User's Manual, KAERI, Daejeon, Republic of Korea.

[4] Korea Atomic Energy Research Institute (KAERI), MASTER Code User's Manual, KAERI, Daejeon, Republic of Korea.