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Comparative study on nuclear characteristics of APR1400 between 100% MOX core and UO_2 core

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ABSTRACT

Recently, APR1400 won the European Utility Requirements (EUR) certification proving the capability of 50% Mixed Oxide (MOX) core design with 18 months cycle length. Several researches show that nuclear characteristics of 30% MOX core is similar to UO_2 core. Nonetheless, neutron spectrum hardening effect in MOX core would change many nuclear design parameters related to reactivity in adverse direction as MOX core loading increases up to 100%.

This paper investigates the performance of APR1400 with 100% MOX fuel, regarding reactivity related nuclear design parameters such as Moderator Temperature Coefficient (MTC), Fuel Temperature Coefficient (FTC) and ShutDown Margin (SDM). The investigation begins with evaluating the nuclear design parameters of 16×16 MOX fuel assembly, with respect to Moderator to Fuel Ratio (MFR) and compares with the nuclear design parameters of UO_2 fuel assembly.

APR1400 performance with 100% MOX fuel is also investigated by evaluating the nuclear design parameters of an initial cycle and an equilibrium cycle satisfying nuclear design requirements. For this purpose, loading patterns for the initial cycle and the equilibrium cycle are developed using CASMO-4 and SIMULATE-3. This research reveals that MOX core has larger optimum moderation point, more negative MTC. Furthermore, neutron spectrum hardening effect make BA and control rod worths smaller than UO_2 core and thus SDM becomes the most limiting nuclear design requirements.

Finally, this research proves that 18 months cycle with 100% MOX core can be design for APR1400, without breaking all design requirements: 18 months cycle length, pin peaking factor less than 1.55, negative MTC and FTC, and SDM greater than 5500 pcm.

1. Introduction

APR1400 nuclear reactor is designed to generate 3987 MW thermal power with an average volumetric power density of 100.9 W/cm^3. It loads 241 fuel assemblies named as PLUS7^{TM}. This fuel assembly consists of 236 fuel rods containing UO_2 pellets and burnable absorber rods containing Gd_2O_3-UO_2 in a 16×16 fuel pin array. The remaining locations are 4 control element assembly (CEA) guide tubes and 1 in-core instrumentation tube for monitoring the neutron flux shape in the reactor core. APR1400 aims a cycle length of 18 months or more.

There are many advantages of using MOX fuel. The primary advantage of plutonium recycle in MOX fuel is reduction in the quantity of partially enriched uranium and reduction of radioactive waste produced from nuclear spent fuel (Graves, 1979). A considerable number of pressurized water reactors are licensed, or a license has been applied to use MOX fuel at levels of up to 30% or more of the reactor core (International Atomic Energy Agency, 2003). Korean Utility Requirements (KUR) states the capability of nuclear design with 30% MOX core. Currently, EUR (European Utility Requirements) requires the capability of nuclear design for 50% MOX core (Utility Requirement, 2012) and APR1400 successfully demonstrated the capability of designing 50% MOX core to get the EUR certification.

MOX (UO_2/PuO_2 mixed-oxide) fuel has been used in Light Water Reactors (LWRs) as a partial substitute for low-enriched UO_2 fuel (Agency, 2006). Plutonium has several isotopes where ^{239}Pu and

Abbreviations: APR1400, advance power reactor 1400; BA, burnable absorber; BOC, beginning of cycle; CBC, critical boron concentration; CEA, control element assembly; EOC, end of cycle; EUR, European utility requirement; FTC, fuel temperature coefficient; KUR, Korean utility requirement; LWR, light water reactors; MFR, moderator to fuel ratio; MOX, mixed oxide; MTC, moderator temperature coefficient; OMP, optimum moderation point; PWR, pressurized water reactor; RIA, rod insertion allowance; SDM, shutdown margin; HFP, hot full power.

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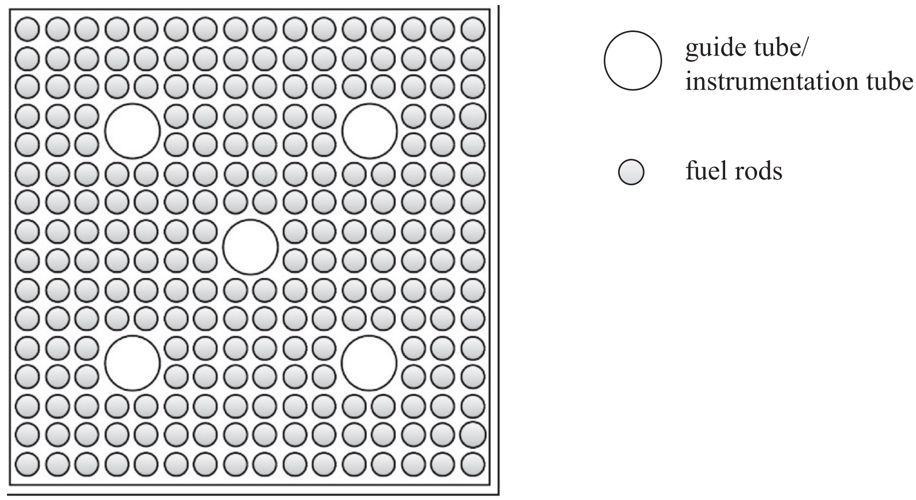

Fig. 1. 16 × 16 fuel assembly layout.

^{241}Pu are fissile plutonium, like ^{235}U. In MOX fuel, Plutonium is mixed with depleted uranium (0.25% ^{235}U) and has very high resonance absorption in thermal energy region, resulting in neutron spectrum hardening in MOX fuel. It was reported that the spent fuel from Pressurized Water Reactor (PWR) consists of 1.0 w/o plutonium of which two thirds are fissile, i.e. about 50% ^{239}Pu and 15% ^{241}Pu (Fehér et al., 2012). Plutonium content is adjusted to take account of its isotopic composition about 63–70% of fissile plutonium (Provost and Debes, 2006) and fissile plutonium content of 74.05% is used in this study.

The purpose of this study is to analyze nuclear characteristics of MOX fuel assembly, thereby exploring possibility of nuclear design with 100% MOX fuel loading in APR1400 reactor. For the analysis of nuclear characteristics of MOX fuel assembly, CASMO-4 (Inc, 2009) is used to characterize various nuclear design parameters such as k_∞ and MTC of MOX fuel assembly with respect to Moderator to Fuel Ratio (MFR), enrichments, fuel burnups and moderator temperatures.

It was reported that partially MOX loaded core shows similar nuclear characteristics to fully UO_2 loaded core (Graves, 1979). However, MOX fuel show much higher resonance absorption and larger negative MTC than UO_2 fuel so that the most limiting nuclear design requirement in MOX core design emerges from ShutDown Margin (SDM) as MOX fuel loading in a core increases. For SDM calculation, loading patterns for an initial cycle and an equilibrium cycle are developed to figure out reactivity balance for full MOX core and the results are compared with full UO_2 core. The initial cycle and the equilibrium cycle are designed to satisfy some nuclear design requirements: 18 months cycle length, pin peaking factor less than 1.55, negative Moderator Temperature Coefficient (MTC) and Fuel Temperature Coefficient (FTC), and SDM greater than 5500 pcm.

CASMO-4 and SIMULATE-3 code (Inc, 2009) are used to evaluate the nuclear design parameters such as Critical Boron Concentration (CBC), MTC, FTC, pin peaking factor and SDM for both 100 %MOX core and UO_2 core.

Table 1
16 × 16 fuel assembly design data.

Assembly type	16 × 16
Fuel rod diameter (cm)	0.950
Fuel pellet diameter (cm)	0.819
Fuel rods pitch (cm)	1.285
Fuel assembly pitch (cm)	20.778
Moderator-to-fuel ratio	1.70

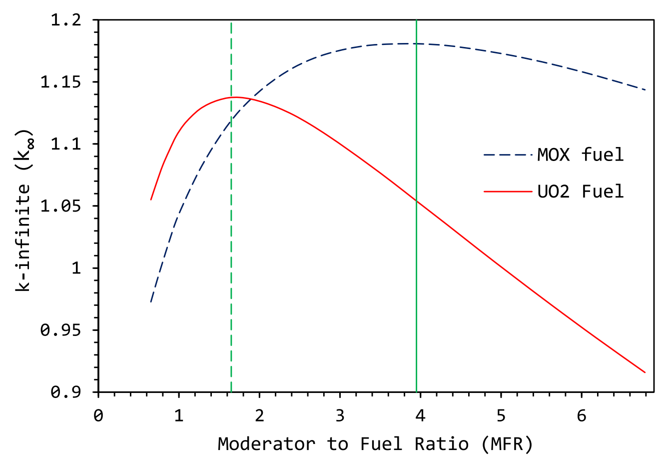

Fig. 2. k_∞ of both MOX fuel and UO_2 Fuel vs. MFR.

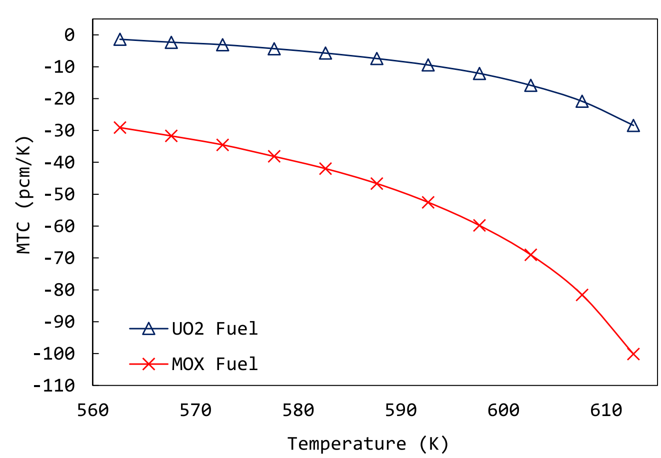

Fig. 3. MTC of both MOX and UO_2 fuel vs. moderator temperature.

2. Impact of MFR on nuclear design parameters of MOX fuel assembly

MFR is a ratio of moderator volume to fuel volume (V_m/V_f). It affects ratio of hydrogen atoms in the moderator to fuel atoms.

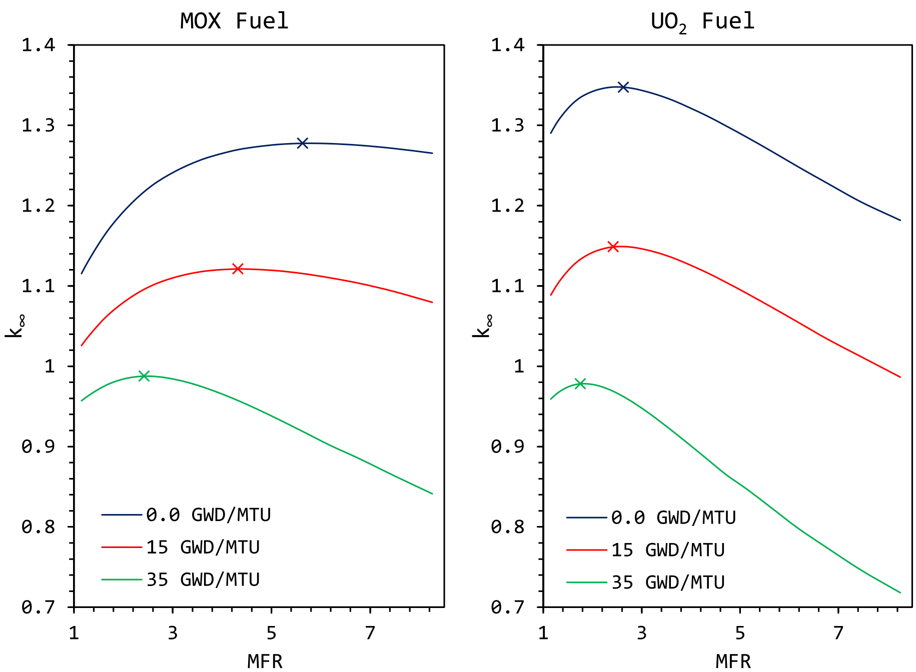

Fig. 4. k∞ curves at various burnups vs. MFR.

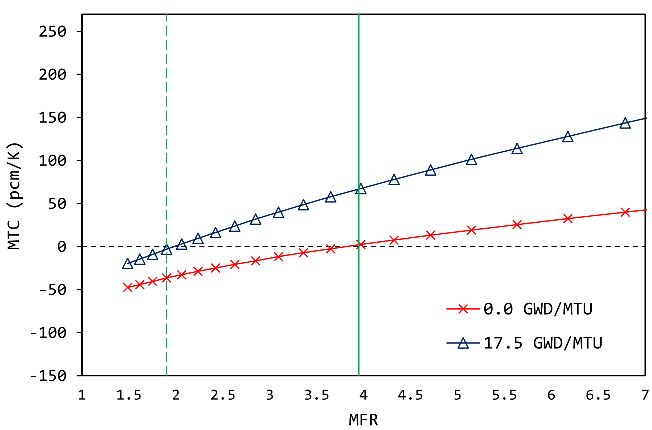

Fig. 5. MTC curves of MOX fuel at various burnups vs. MFR.

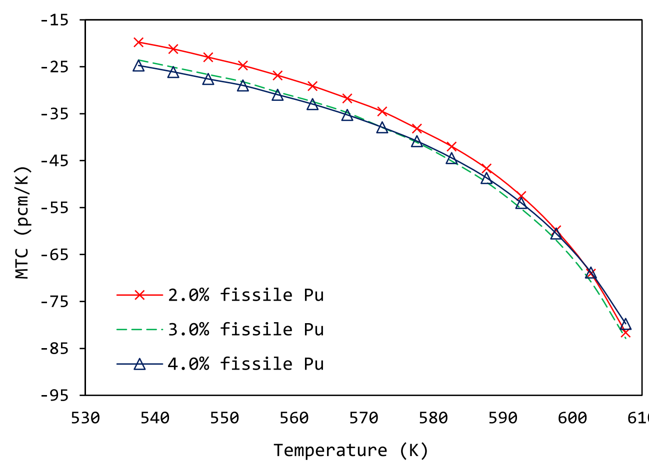

Fig. 7. MTC curves of MOX fuel for various fissile plutonium content vs. moderator temperature.

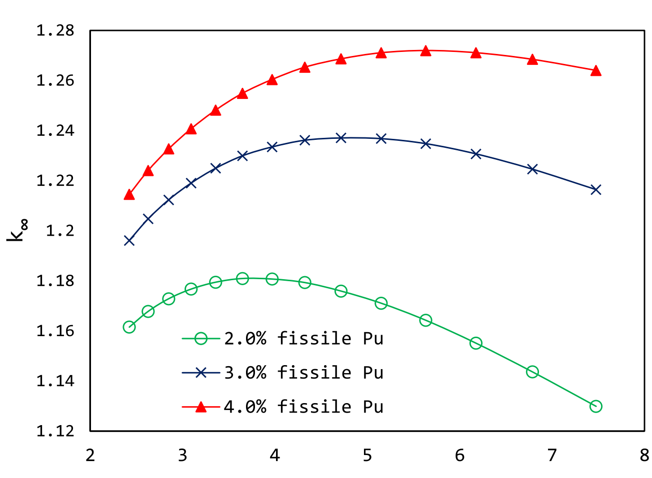

Fig. 6. k∞ curves for various fissile plutonium content vs. MFR.

The conventional definition of MOX fuel weight fraction is the weight fraction of plutonium in the mixture of plutonium and UO_2. In the fuel assembly model shown in Fig. 1 and Table 1, the content of fissile plutonium of MOX fuel is assigned equal to the enrichment of UO_2 fuel in order to clearly compare the effect of MOX fuel on k_∞ with UO_2 fuel. MOX fuel consists of low-enriched UO_2 fuel (0.23%) and plutonium in which the weight percentages of each isotope in the plutonium are 0.86% for ^{238}Pu, 66.47% for ^{239}Pu, 20.77% for ^{240}Pu, 7.56% for ^{241}Pu, 2.95% for ^{242}Pu and 1.39% for ^{241}Am, respectively.

In this analysis, 16 × 16 fuel assembly type presented in Fig. 1 and Table 1 is used to investigate k_∞ variation as a function of MFR for both MOX fuel and UO_2 fuel. MFR varies as fuel pin diameter varies from 0.52 cm to 0.92 cm while the thickness of fuel cladding and fuel rod pitch are kept constant. The impact of MFR on nuclear design parameters of MOX fuel is investigated by analyzing k_∞ behavior for various MFRs. MTC is also analyzed for various MFRs because the most limiting condition encountered in

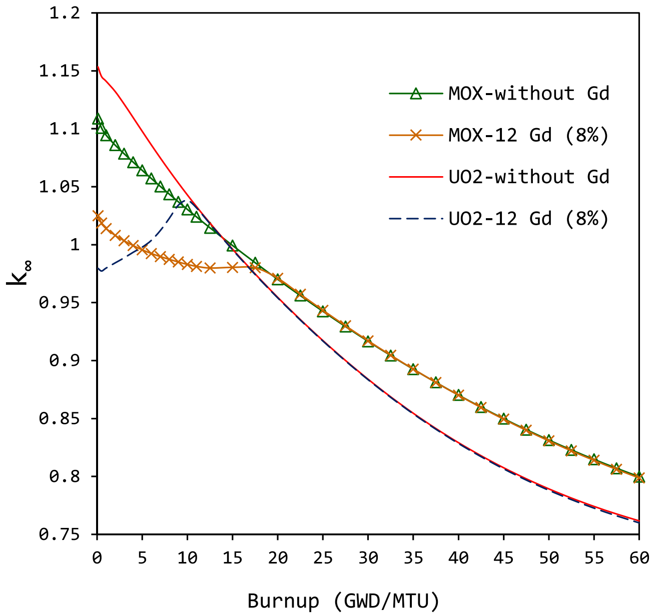

Fig. 8. k∞ curves of MOX fuel and UO_2 fuel with Gd2O3-UO_2 rods vs. burnup.

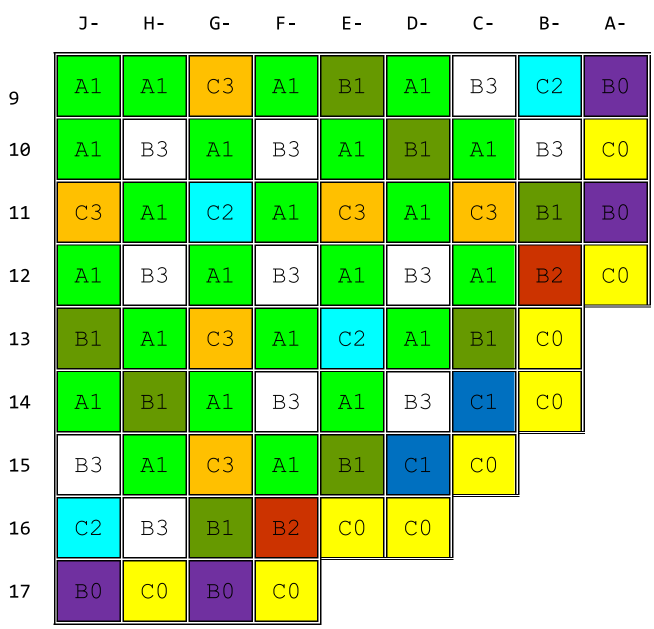

Fig. 9. 100% MOX core loading pattern for initial cycle.

MOX core design comes from SDM in which positive reactivity feedback due to moderator temperature drop is one of major factors. MTC characteristics of MOX fuel is investigated and compared with UO_2 fuel as a function of MFR. The effect of burnup and fissile plutonium content of MOX fuel on MTC is also analyzed.

2.1. MTC vs. MFR

The MFR in PWR affects two competing neutron phenomena: they are resonance escape probability and thermal utilization. Resonance escape probability increases as the MFR increase while thermal utilization decreases. These two phenomena have opposite effects on k_∞.

Fig. 2 depicts k_∞ behavior for various MFR, with the dashed curve representing MOX fuel and the solid curve representing UO_2 fuel. The highest point of this curve is called the Optimum Moderation Point (OMP). Below this point, k_∞ increases as MFR increases because resonance escape of neutron becomes dominant effect. This region is called under-moderated region. Beyond this point is over-moderated region, where k_∞ decreases as MFR increases since the reduction of thermal utilization becomes dominant effect. The vertical solid line and the dashed line in Fig. 2 represent the OMPs for MOX fuel and UO_2 fuel, respectively. The OMP for MOX fuel is 3.8, bigger than that of UO_2 fuel, 1.6.

Fig. 3 depicts MTC curve of MOX fuel as a function of moderator temperature in comparison to UO_2 fuel. The assembly models used for both Figs. 2 and 3 have fissile plutonium of 2% for MOX fuel and enrichment of 2% for UO_2 fuel, respectively, and MOX fuel becomes more negative MTC than UO_2 fuel as moderator temperature increases.

2.2. MTC vs. Burnup

In Fig. 4, k_∞ curves of MOX fuel and UO_2 fuel are plotted for three different burnups, 0.0 GWD/MTU, 15.0 GWD/MTU and 35.0 GWD/MTU. In these models, fissile plutonium (^{239}Pu and ^{241}Pu) of 4.2% in MOX fuel is compared with ^{235}U enrichment of 4.2% in UO_2 fuel. The OMPs of MOX fuel and UO_2 fuel retreat from larger MFRs to smaller MFRs as fuel burnup increases.

Fig. 5 shows burnup effect on MTC as a function of MFR. Burnups shown in Fig. 5 are 0.0 GWD/MTU and 17.5 GWD/MTU. The vertical solid line in Fig. 5 represents the OMP of MOX fuel at zero burnup. The vertical dashed line represents the OMP at burnup 17.5 GWD/MTU. The region below the OMP on each MTC curve has negative MTC, while beyond the point has positive MTC. In other words, the under moderated region leads to negative MTC and the over moderated region leads to positive MTC. It is notable that the OMP retreats from a larger value to a smaller as fuel burnup increases.

Table 2
Fuel assembly specifications used for initial cycles (MFR = 1.7).

Assembly Type	No. of Assembly	Fissile Pu (%) ^{235}U Enrichment (%)		No. of Fuel Rods per Assembly		No. of Gd_2O_3 per Assembly	Gd_2O_3 (%)
MOX/UO_2	MOX/UO_2	MOX	UO_2	MOX	UO_2	MOX/UO_2	MOX/UO_2
A1/A1	77/77	2.42	1.81	224	236	12/–	5.0/–
B0/B0	12/12	4.47	3.21	236	236	–/–	–/–
B1/B1	28/28	3.77/3.27	3.21/2.71	172/52	172/52	12/12	8.0/8.0
B2/B2	8/8	3.82/3.32	3.21/2.71	124/100	124/100	12/12	8.0/8.0
B3/B3	40/40	3.98/3.48	3.21/2.71	168/52	168/52	16/16	8.0/8.0
C0/C0	36/36	4.98/4.48	3.71/3.21	184/52	184/52	–/–	–/–
C1/C1	8/8	4.42/3.92	3.71/3.21	172/52	172/52	12/12	8.0/8.0
C2/C2	12/12	4.07/3.12	3.71/3.21	168/52	168/52	16/16	8.0/8.0
C3/C3	20/20	3.98/3.48	3.71/3.21	120/100	120/100	16/16	8.0/8.0
Total	241/241	3.48%	2.83%			2604/1680	

Table 3
Nuclear design parameters of initial cycles.

Parameter (MFR = 1.7)	MOX		UO_2	
	BOC	EOC	BOC	EOC
CBC (ppm)	1441.35	10	912	10
Max. pin power peaking factor	1.48	1.52	1.51	1.34
MTC (pcm/K)	−33.5	−65.5	−11.8	−54.4
FTC (pcm/K)	−2.83	−2.95	−2.34	−2.74
SDM (pcm)	6973	6996	8104	7981
Cycle length (GWD/MTU)	–	17.8	–	17.8

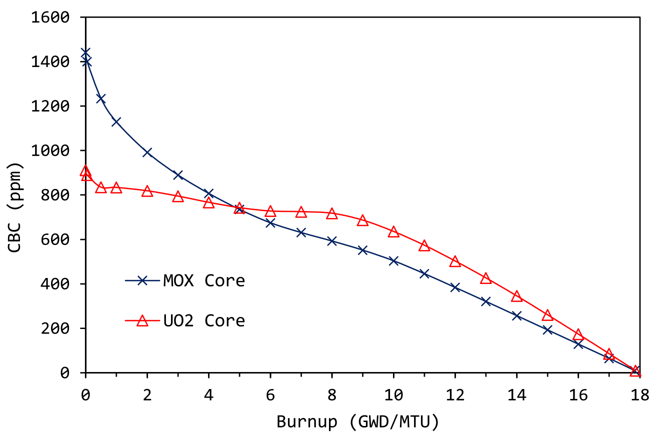

Fig. 10. Critical boron concentration for initial cycles.

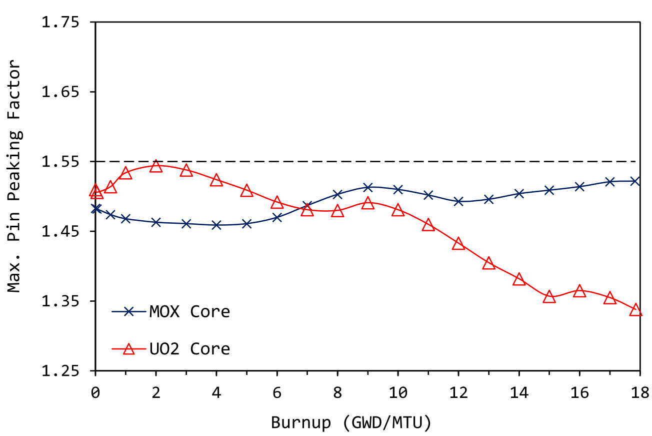

Fig. 11. Maximum pin peaking factor of initial cycles vs. burnup.

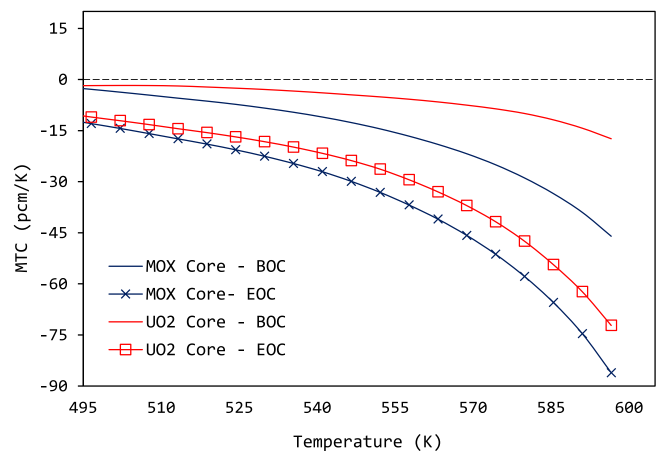

Fig. 12. MTC of initial cycles vs. moderator temperature.

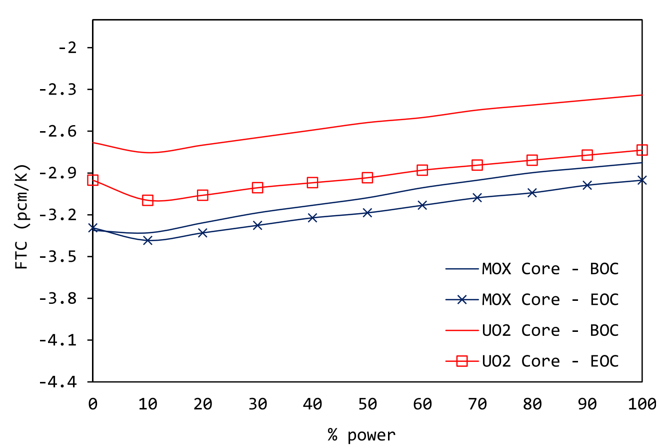

Fig. 13. FTC of initial cycles vs. core power.

2.3. MTC vs. fissile plutonium content

Fig. 6 shows similar trend in k_∞ variation as Fig. 4. In Fig. 6, the OMPs retreat from a larger value of MFR to a smaller as the content of plutonium decreases from 4.0% to 2.0%. This tendency is also observed in UO_2 fuel.

Fig. 7 shows the effect of fissile plutonium content on MTC, where the MTC curves of MOX fuel are plotted for various fissile plutonium contents of 2.0%, 3.0% and 4.0%. It shows that higher fissile plutonium content has slightly more negative MTC at moderator temperature below 590 K.

2.4. Burnup characteristics of Gd_2O_3 burnable absorber (BA) in MOX fuel assembly

Fig. 8 shows k_∞ curves of MOX fuel assembly and UO_2 fuel assemblies having Gd_2O_3 BA rods, as a function of fuel burnup.

Table 4
Reactivity balance table for the SDM calculation of initial cycles at EOC.

	MOX Core HFP	UO_2 Core HFP
A. Control rod requirement (pcm)		
Power defect	2297	2064
Rod insertion allowance	128	183
Total requirement	2425	2247
B. Control rod worth (pcm)		
N-1 Worth	9880	10,727
Uncertainty	459	499
Remaining worth	9421	10228
C. Shutdown margin (pcm)		
Calculated SDM (pcm)	6996	7981
Requirement SDM (pcm)	>5500	>5500

	J-	H-	G-	F-	E-	D-	C-	B-	A-
9	H2	J2	K2	H0	K2	J2	H2	J2	J0
10	J2	H2	J2	J2	H0	H2	K2	J1	K0
11	K2	J2	K2	H1	K2	J2	J2	K2	K1
12	H0	J2	H1	H2	J2	H0	K2	J0	K0
13	K2	H0	K2	J2	K2	H0	J0	J0	
14	J2	H2	J2	H0	H0	J2	K2	K0	
15	H2	K2	J2	K2	J0	K2	K0		
16	J2	J1	K2	J0	J0	K0			
17	J0	K0	K1	K0					

Fig. 14. 100% MOX core loading pattern for equilibrium cycle. (K-type: fresh fuel, J-type: once-burnt fuel, H-type: twice-burnt fuel).

The assembly models used for Fig. 8 have fissile plutonium content of 2% for MOX fuel and enrichment of 2% for UO_2 fuel, respectively.

Without BAs at 0 GWD/MTU, MOX fuel has lower k_∞ than UO_2 fuel and burns slower than UO_2 fuel. For the given number of Gd_2O_3-UO_2 rods, reactivity hold-down power in MOX fuel is about a half of UO_2 fuel at 0 GWD/MTU and lasts approximately twice longer than UO_2 fuel. Because of neutron spectrum hardening caused by larger thermal resonance absorption cross section of plutonium isotopes, the reactivity worth of BA in MOX fuel becomes smaller than in UO_2 fuel. For this reason, MOX core needs larger number of BAs than in UO_2 core.

3. Comparison of nuclear characteristics between MOX core and UO_2 core

To understand nuclear characteristics of MOX core, nuclear parameters such as CBC, pin power peaking factor, MTC, FTC, and SDM are analyzed and compared for both MOX core and UO_2 core having the equal cycle length, 17.8 GWD/MTU. These nuclear parameters are evaluated for an initial cycle as well as an equilibrium cycle. Full core analysis was performed using the initial cycle and the equilibrium cycle of 100% MOX core as well as 100% UO_2 core at HFP (Hot Full Power) condition.

3.1. Initial cycle analysis

Fig. 9 shows the loading patterns of APR1400 initial cycle loading 100% MOX fuel. Total of 241 MOX assemblies are loaded in the core, which consists of 9 fuel assembly types with various plutonium contents as well as various numbers of BAs as listed in Table 2. Since ^{240}Pu in MOX fuel has higher resonance absorption than ^{235}U in UO_2 fuel, average content of fissile plutonium, ^{239}Pu and ^{241}Pu, in MOX core is adjusted to 3.55% for initial cycle while average enrichment of ^{235}U is 2.83% in UO_2 core, in order to achieve equal cycle length, 17.8 GWD/MTU. Table 2 also listed fuel assembly types loaded in MOX core and UO_2 core. Loading pattern of UO_2 core is same as Fig. 9.

Table 3 compares the nuclear parameters between MOX core and UO_2 core. As shown in Table 3, MTC and FTC of MOX core are more negative than UO_2 core, which is similar to the fuel assembly analysis explained in chapter 2. Thus power defect of MOX core tends to be bigger than that of UO_2 core. In contrast to the power defect, control rod worth in MOX core tends to become smaller when compared with UO_2 core. This effect comes neutron spectrum hardening effect in MOX core because ^{240}Pu has very high resonance absorption near 1.0 eV. With equal cycle length, thus, SDM of MOX core generally becomes smaller than UO_2 core and is considered one of the most limiting design criteria to satisfy in nuclear design for MOX core. For the SDM calculation in Table 3, both MOX core and UO_2 core employ the same control rods arrangement as Shin-Kori unit 3&4 in the reference (Nuclear Fuel Company, 2012).

Fig. 10 depicts the CBC curve of MOX core as a function of burnup. MOX core has larger numbers of BA than UO_2 core as shown in Table 2. Nonetheless, CBC of MOX core is higher than that of UO_2 core at Beginning Of Cycle (BOC). Higher fissile plutonium content, smaller boron and BA worths in MOX core can explain this result.

Fig. 11 shows the maximum pin peaking factors of both MOX core and UO_2 core for various fuel burnups, satisfying design limit of APR1400, 1.55.

Fig. 12 shows MTC curves of initial MOX core and initial UO_2 core where MTC of MOX core slightly becomes more negative than UO_2 core as moderator temperature increases. This kind of MTC variation in full core analysis is equally observed in assembly level analysis shown in Fig. 3.

Fig. 13 depicts FTCs for different power level, in which FTC of MOX core are more negative than UO_2 core in all powers. This is caused by Doppler broadening effect in MOX fuel where ^{240}Pu has very high resonance absorption near 1.0 eV. As shown in Fig. 13, FTC variation of MOX core with power is similar to UO_2 core. FTC gradually increases in the positive direction as core power increases.

ShutDown Margin (SDM) is one of important nuclear design criteria. It shows how big negative reactivity can be inserted to maintain nuclear reactor subcritical after shutdown. Two kinds of reactivity contributing SDM come from power defect and control rod worth, as shown in Table 3. Major part of positive reactivity feedback is power defect due to moderator and fuel temperature changes caused by power change. Negative reactivity feedback comes from control rods insertion which is evaluated under the assumption of worst rod stuck. It is called N-1 rods worth. Two assumptions are also applied to SDM calculation. One is Rod Insertion Allowance (RIA) which accounts for the possible maximum insertion of control rod at 100% power. The other is uncertainty in control rod worth calculation. SDM is the difference between

Table 5
Fuel assembly specifications used for equilibrium cycles (MFR = 1.7).

Assembly type	No. of assembly	Fissile Pu (%) ^{235}U enrichment (%)		No. of fuel rods per assembly		No. of Gd_2O_3 per ASSEMBLY	Gd_2O_3 (%)
MOX/UO_2	MOX/UO_2	MOX	UO_2	MOX	UO_2	MOX/UO_2	MOX/UO_2
K0/K0	28/28	6.37/5.87	4.74/4.24	184/52	184/52	–/–	–/–
K1/K1	8/8	6.37/5.87	4.78/4.28	168/52	168/52	16 / 16	6.0/6.0
K2/K2	56/56	4.95/4.45	4.58/4.08	172/52	172/52	12/12	5.0/6.0
Total	92/92	5.43%	4.57%			800/800	

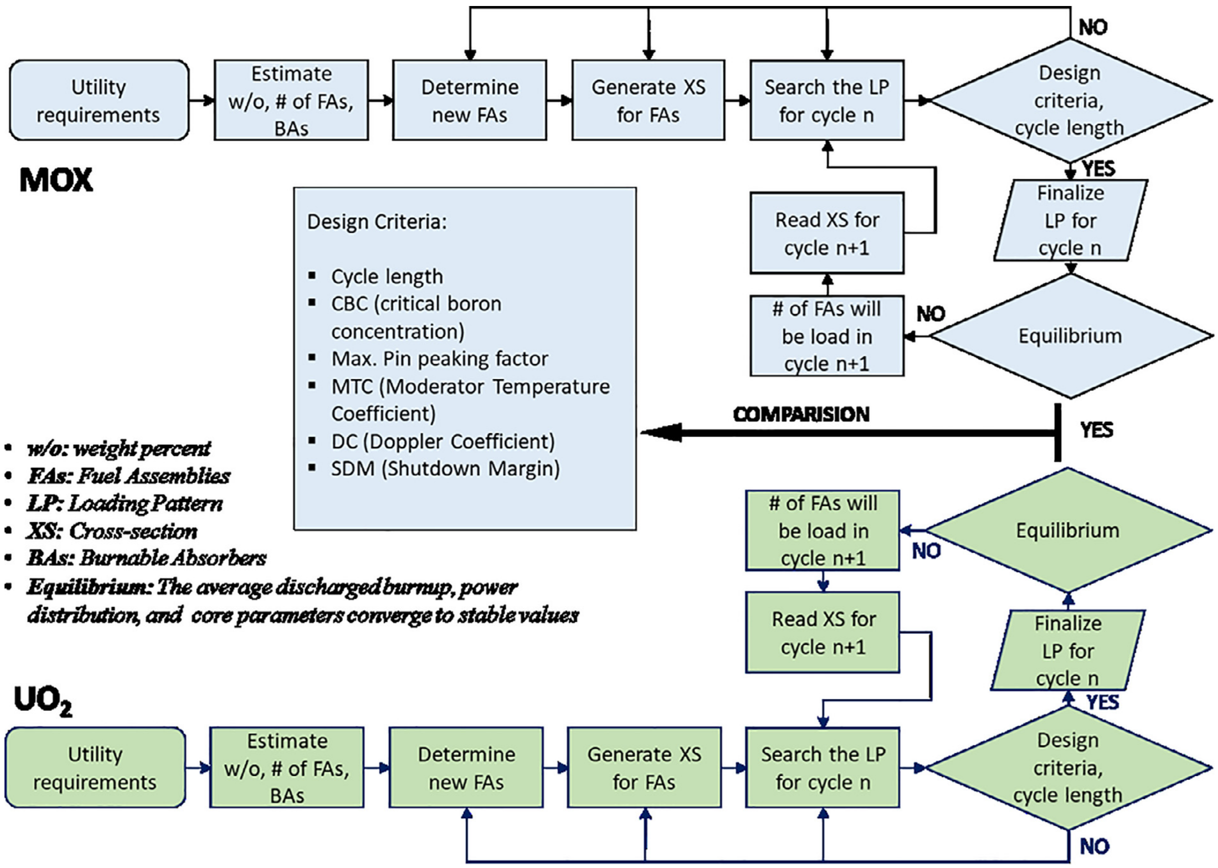

Fig. 15. Nuclear design process to determine an equilibrium cycle.

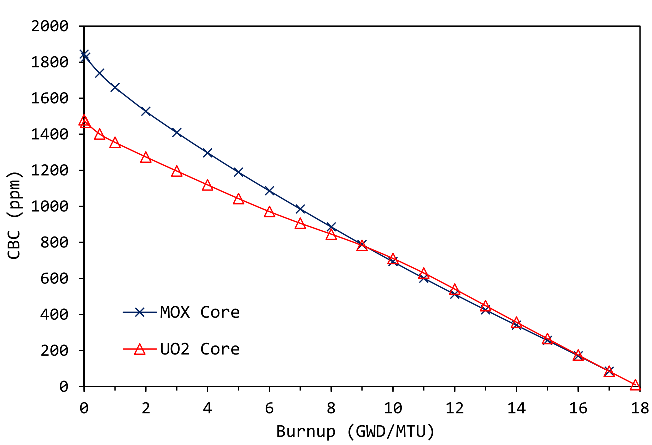

Fig. 16. Critical boron concentration for equilibrium cycles.

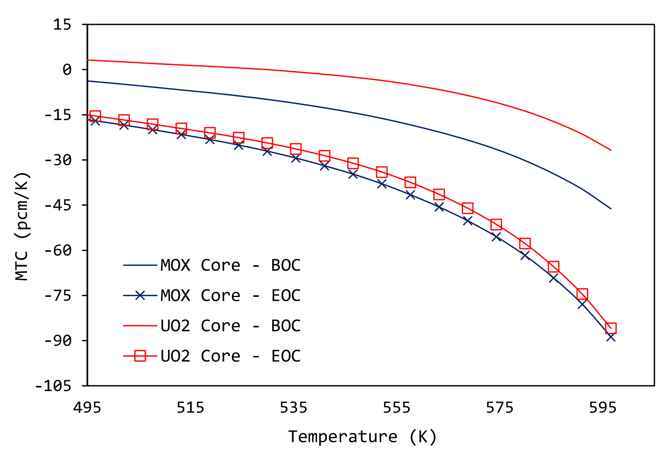

Fig. 17. MTC of equilibrium cycles vs. moderator temperature.

the positive reactivity feedback and the negative reactivity feedback.

Table 4 compares each component of SDM between MOX core and UO_2 core. Total positive reactivity inserted by power change from 100% to 0% is the sum of power defect and RIA, 2425 pcm for MOX core and 2247 pcm for UO_2 core, respectively. Total negative reactivity by control rod insertion is assumed to be N-1 control rod worth under worst rod stuck condition, 9421 pcm for MOX core and 10,228 pcm for UO_2 core, respectively. For conservatism, RIA is assumed to be maximum control rod worth unavailable at 100% power. The calculated SDMs of both MOX core and UO_2 core for the initial cycle are higher than 5500 pcm which is design criteria of APR1400.

3.2. Equilibrium cycle analysis

An equilibrium cycle can be defined as such that every successive cycle with the same loading pattern produces equal cycle length, equal power distribution, equal burnup distribution and equal discharge burnup. The equilibrium cycle for MOX core is designed to produce the same cycle length of UO_2 core, 17.8 GWD/MTU, and to achieve the maximum pin power peaking factor less than 1.55. The equilibrium cycle loading pattern for MOX core is shown in Fig. 14, same as UO_2 core loading pattern. Table 5 shows fuel assembly types loaded in equilibrium MOX core as well as equilibrium UO_2 core. In Fig. 14, K-type is fresh fuel, J-type and

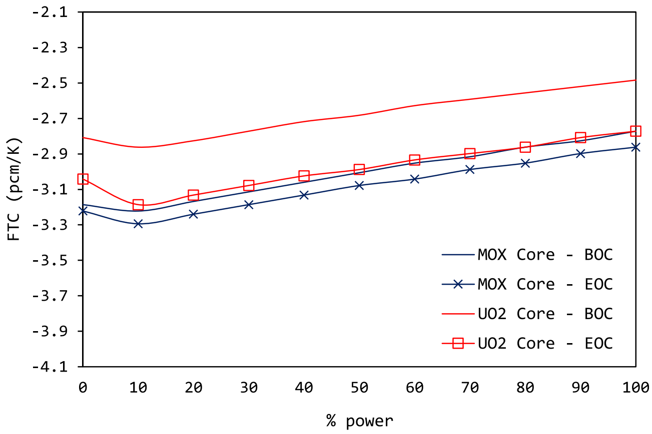

Fig. 18. FTC for equilibrium cycles vs. core power.

Table 6
Nuclear design parameters of equilibrium cycles.

Parameter (MFR = 1.7)	MOX		UO_2	
	BOC	EOC	BOC	EOC
CBC (ppm)	1844.35	10	1480	10
Max. pin power peaking factor	1.534	1.403	1.52	1.38
MTC (pcm/K)	−34.6	−69.2	−17.3	−65.5
FTC (pcm/K)	−2.77	−2.86	−2.48	−2.77
SDM (pcm)	5941	5587	7503	6654
Cycle length (GWD/MTU)	–	17.8	–	17.8
Batch discharge. BU (GWD/MTU)	46.7		46.7	

H-type are once-burnt and twice-burnt fuels respectively. The number of fresh fuel assemblies loaded in the equilibrium cycle is 92 for both cores. The average fissile plutonium content for MOX core is adjusted to 5.43% to achieve 17.8 GWD/MTU while the average ^{235}U enrichment of 4.57% for UO_2 core.

Fig. 15 shows a design process to determine equilibrium cycles for both MOX core and UO_2 core. Given the utility requirement such as cycle length, an estimation on fuel enrichment and number of FAs is performed first, and then the results of the estimation are used to generate cross-section library and loading pattern for initial and subsequent cycles. This procedure continues until an equilibrium cycle reaches.

Fig. 16 shows CBC curves of both MOX core and UO_2 core for the equilibrium cycle. CBC of MOX core is higher and decreases faster than UO_2 core in early stage of depletion. This tendency is similar with the initial cycle and can be explained by higher fissile content, smaller boron and BA worths due to neutron spectrum hardening effect.

As shown in Figs. 17 and 18, the tendency of MTC and FTC variations is almost similar to that of initial MOX core and equally observed in assembly level analysis shown in Figs. 3 and 7.

Table 6 shows nuclear design parameters for both equilibrium cores. Both MTC and FTC of MOX core are more negative than those of UO_2 core. SDMs of MOX core are slightly over design criteria of 5500 pcm and much smaller than those of initial MOX core, while UO_2 core has enough margin to SDM design criteria. SDMs of the equilibrium MOX core and the equilibrium UO_2 core decrease almost 1400 pcm and 1300 pcm from the initial cores, respectively.

4. Conclusions

A comparative study on nuclear characteristics of APR1400 nuclear core loading MOX fuel and UO_2 fuel is performed using CASMO-4 and SIMULATE-3. As a preliminary study, nuclear design parameters such as MTC and FTC are evaluated for both MOX and UO_2 fuel assemblies with respect to MFR. The evaluation on the assemblies with the fissile content of 2% reveals many interesting results: MOX FA has larger optimum moderation point, more negative MTC and smaller BA worth than UO_2 FA, etc. Furthermore, it is observed that MFR of optimum moderation point decreases as fuel depletes.

Loading patterns for initial cycle and equilibrium cycle are also developed to assess nuclear design parameters such as CBC, maximum pin power peaking factor, MTC, FTC and SDM for both 100% MOX core and 100% UO_2 core. The initial cycle as well as the equilibrium cycle are designed to satisfy such design requirements as cycle length of 18 months, pin peaking factor less than 1.55, negative MTC and FTC, and SDM bigger than 5500 pcm for both MOX and UO_2 cores. Equilibrium cycle employs 3-batch scheme loading 92 fresh fuel assemblies and achieved average discharge burnup of 46.7 GWD/MTU for both cores.

As explained in chapter 3, neutron spectrum hardening effect in MOX core due to very high resonance absorption of ^{240}Pu near 1.0 eV causes more negative MTC and FTC, and make BA and control rod worths smaller than UO_2 core. Consequently, SDM of MOX core is lower than UO_2 core and becomes the most limiting design requirement in MOX core design.

In this study, both the initial cycle and equilibrium cycle for MOX core satisfy all design requirements: 18 months cycle length, pin peaking factor less than 1.55, negative MTC and FTC, and SDM greater than 5500 pcm. This study proves that 18 months cycle length with 100% MOX core is viable option for APR1400, satisfying SDM requirement.

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