Comparative Study on Nuclear Characteristics of APR1400 Nuclear Core Loading MOX Fuel and UO_2 Fuel

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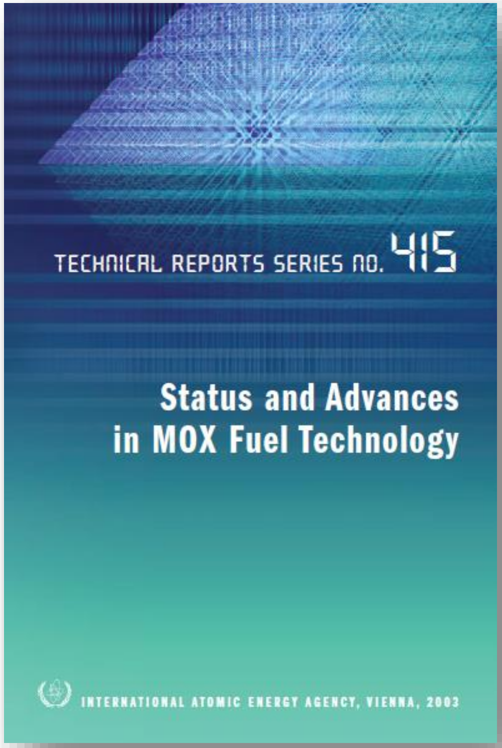
Overview

- A considerable number of pressurized water reactors are licensed for MOX fuel, up to 30% or more of the reactor core loading.
- EUR (European Utility Requirements) also requires capability to design MOX fuel loading up to 50%.
- However, the most limiting requirement of using MOX fuel emerges from Shut Down Margin (SDM) requirement as MOX fuel loading in a core increases.
- The control rods reactivity worth of MOX fuel is lower than UO_2 fuel, causing lower shutdown margin.



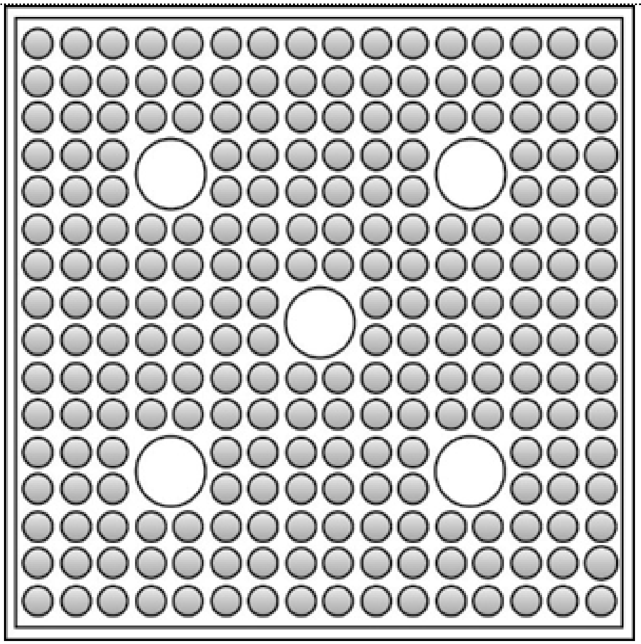
Objective

- The purpose of this study is to explore the possibility of 100% MOX fuel loading in APR1400 reactor by investigating nuclear characteristics such as:
  - ✓ k_∞ and MTC as a function of Moderation-to-Fuel Ratio (MFR)
  - ✓ Critical Boron Concentration (CBC)
  - ✓ pin power peaking factor
  - ✓ Moderator Temperature Coefficient (MTC)
  - ✓ Doppler coefficient and
  - ✓ Shut-down Margin (SDM);

Compared for both MOX fuel and UO_2 fuel.

Fuel Assembly Level Analysis

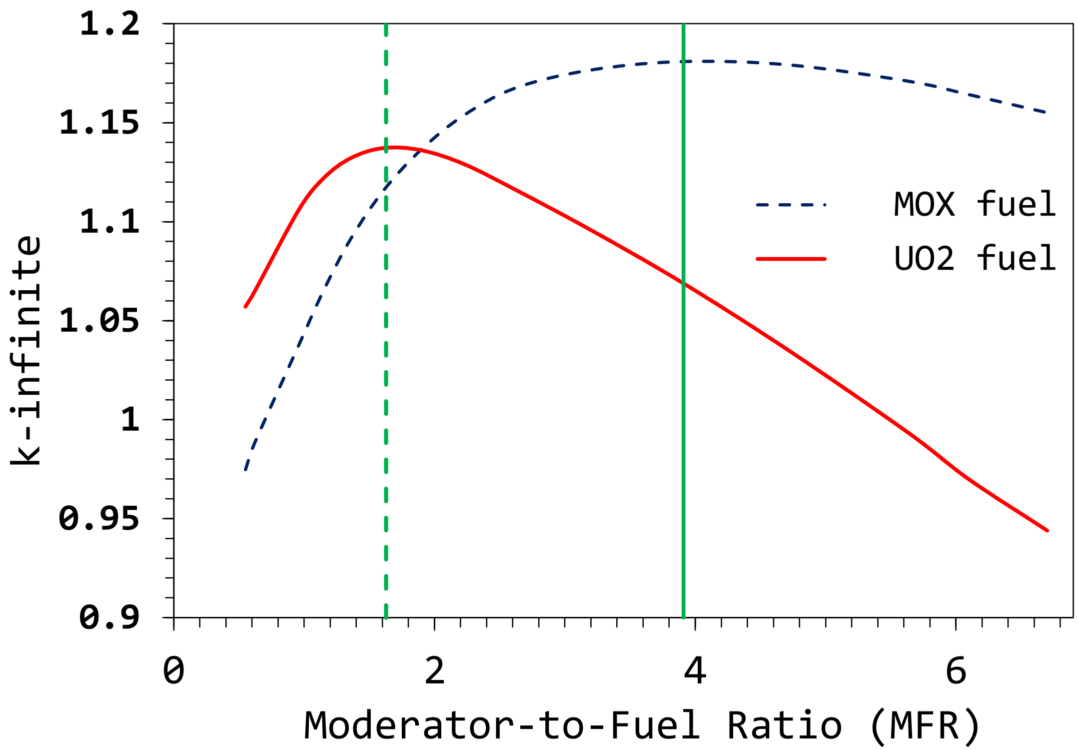
Fuel Assembly Model



Type	16 x 16
Fuel rod diameter (cm)	0.970
Fuel pellet diameter (cm)	0.826
Fuel rods pitch (cm)	1.285
Fuel assembly pitch (cm)	20.778
MFR	1.7
Fissile plutonium content (MOX fuel)	2.0%
^{235}U enrichment (UO_2 fuel)	2.0%

Fuel Assembly Level Analysis

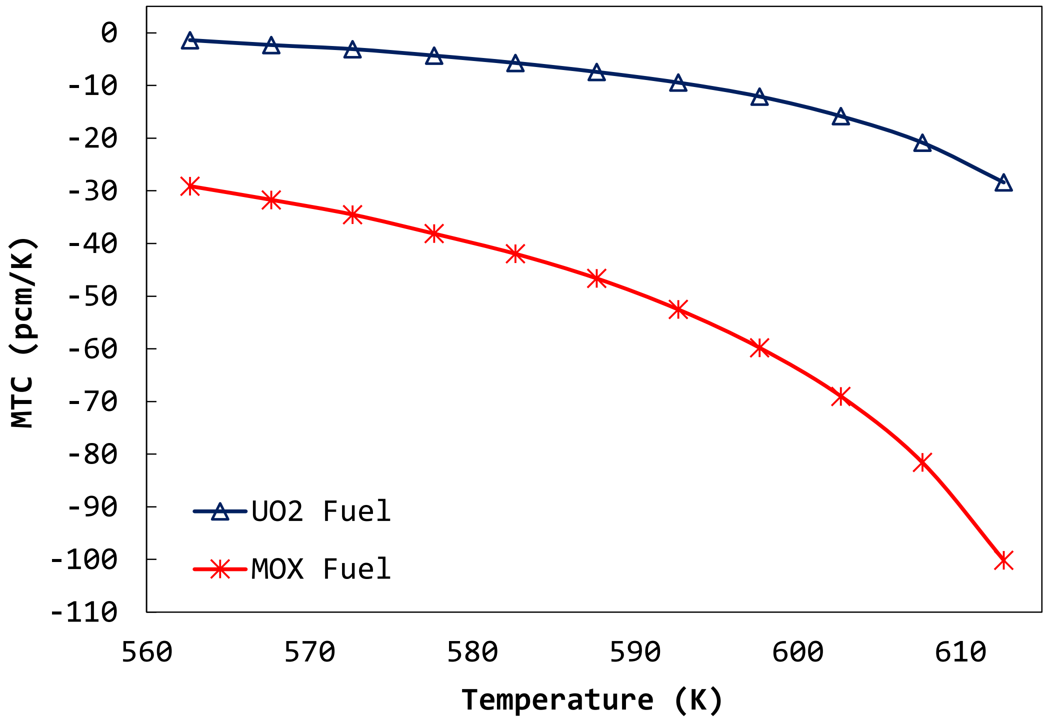
k_∞ behavior vs MFR



MOX fuel has higher MFR than UO_2 fuel to reach the optimum k_∞.

Fuel Assembly Level Analysis

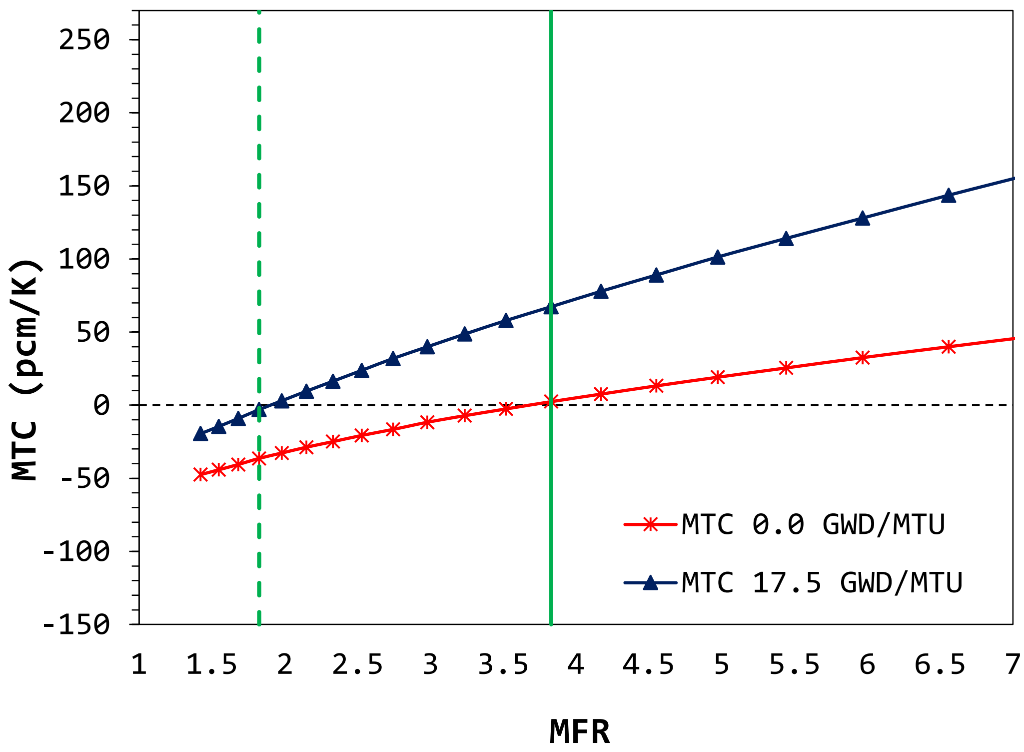
MTC vs. Moderator Temperature



- The assembly models have fissile plutonium of 2.0% for MOX fuel and ^{235}U enrichment of 2.0% for UO_2 fuel, respectively.
- It shows that MOX fuel has more negative MTC than UO_2 fuel.

Fuel Assembly Level Analysis

Burnup Effect on MTC



- The under moderated region leads to negative MTC and the over moderated region leads to positive MTC.
- the optimum moderation point retreats from larger MFR to smaller MFR as fuel burn-up increases
- This results suggests smaller radius than OMP for MOX assembly.

Full core level analysis

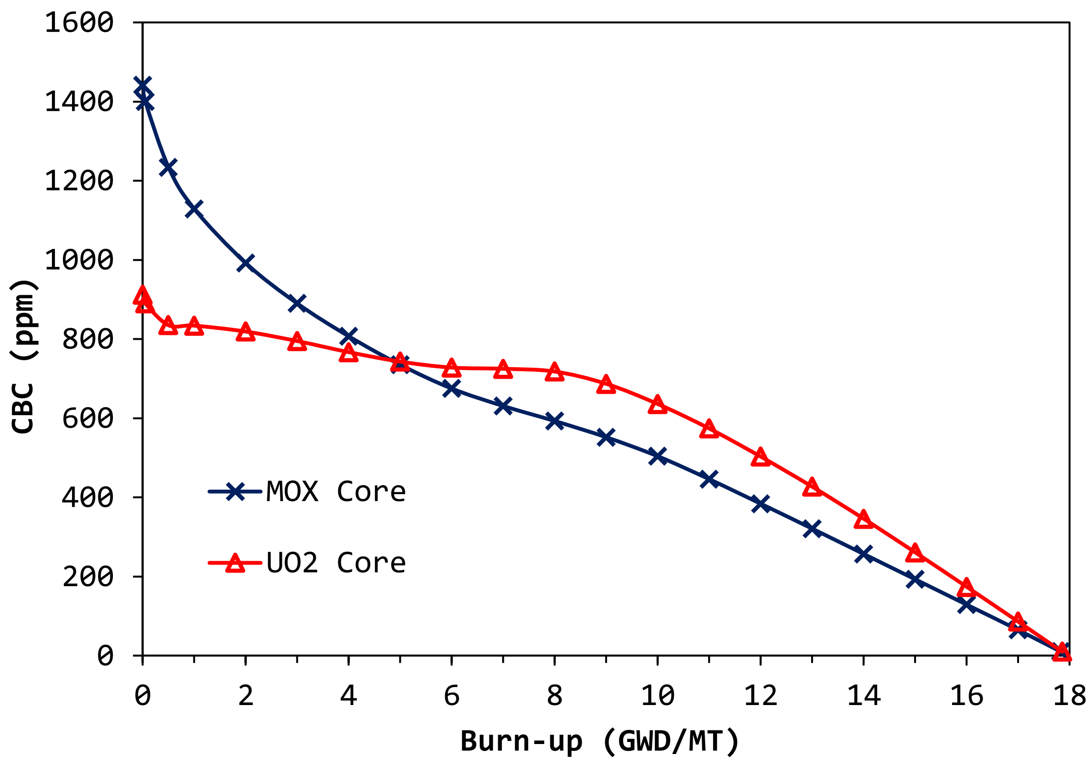
Nuclear Data for Core Loading Pattern

Assembly Type	No. of Assembly	Fissile enrichment (%)		No. of Gd_2O_3 per Assembly	Gd_2O_3 (%)
	MOX/UO_2	MOX	UO_2	MOX/UO_2	MOX UO_2
A1	77 / 77	2.42	1.72	12/0	5.0/0.0
B0	12/12	4.47	3.14	0/0	0.0/0.0
B1	28/28	3.77/3.27	3.14/2.65	12/12	8.0/8.0
B2	8/8	3.82/3.32	3.15/2.64	16/12	8.0/8.0
B3	40/40	3.98/3.48	3.14/2.64	16/16	8.0/8.0
C0	36/36	4.98/4.48	3.64/3.14	0/0	0.0/0.0
C1	8/8	4.42/3.92	3.64/3.14	12/12	8.0/8.0
C2	12/12	4.07/3.12	3.65/3.14	16/16	8.0/8.0
C3	20/20	3.98/3.48	3.64/3.14	16/16	8.0/8.0
Total	241/241	3.48%	2.81%	2636/ 1680	

Target cycle length 17.5 GWD/MT

Full core level analysis

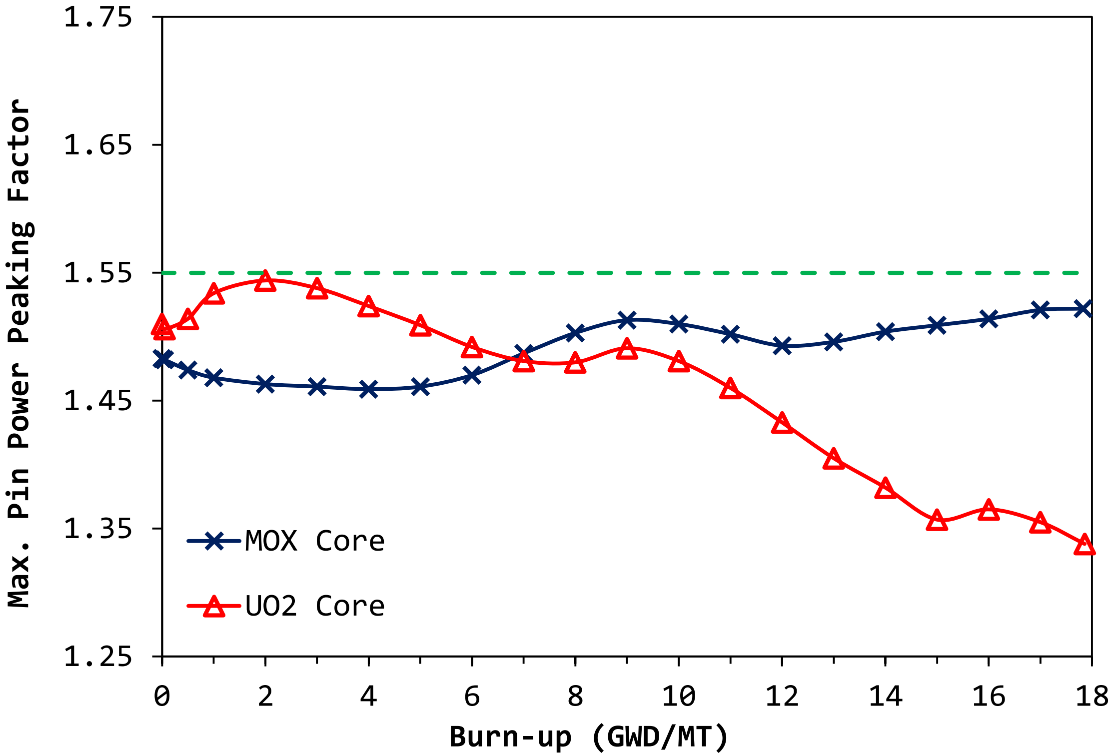
Critical Boron Concentration (CBC)



- At BOC, CBC of MOX core is higher than UO_2 core because higher fissile content and lower boron worth of MOX core.

Full core level analysis

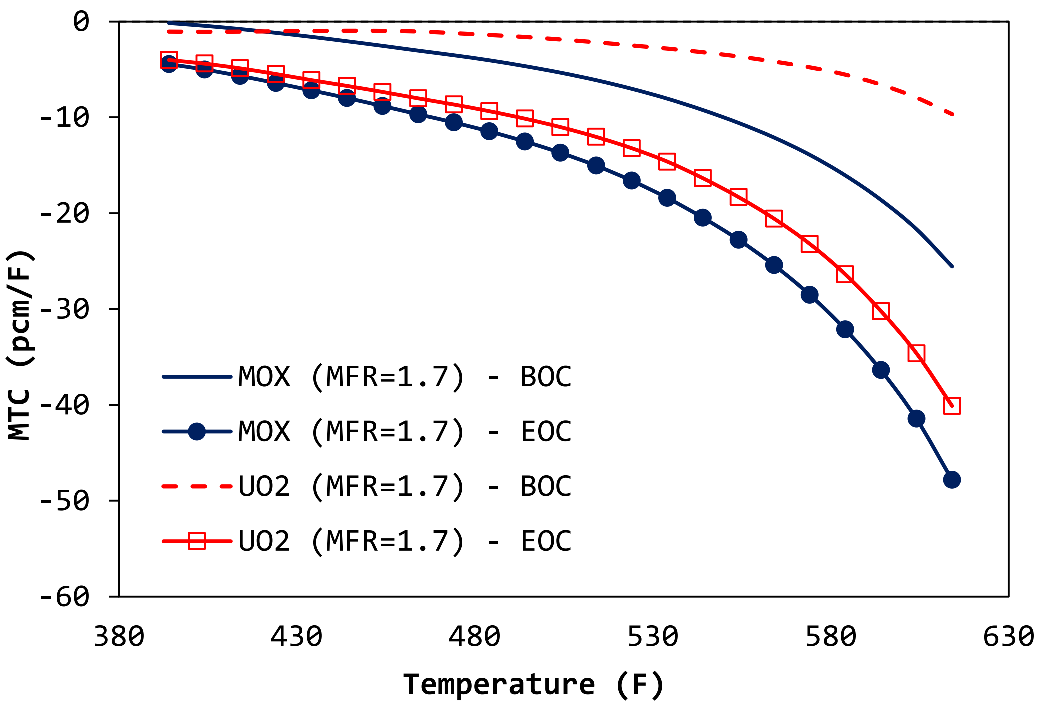
Pin power peaking factor



- Both MOX and UO_2 fuel are below 1.55 (safety design requirement of APR1400 for UO_2 core.

Full core level analysis

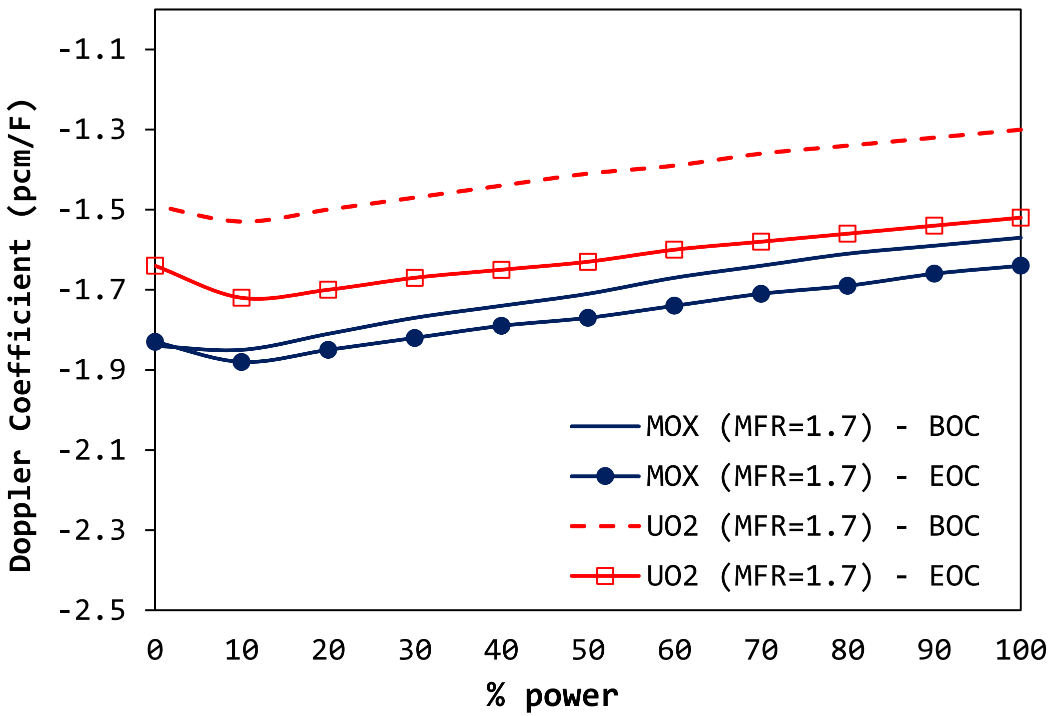
Moderator Temperature Coefficient (MTC)



- MTC of MOX core at Beginning Of Cycle (BOC) becomes less negative than that of MTC at the End Of Cycle (EOC).
- MOX core has more negative MTC than UO_2 core

Full core level analysis

Doppler coefficient



- Doppler coefficient of MOX core trough all power level are more negative than UO_2 core.

Result & Summary

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/◦F)	-18.62	-36.38	-6.58	-30.21
DC (pcm/◦F)	-1.57	-1.64	-1.3	-1.52
SDM (pcm)	6973.47	6995.85	8104.45	7981.58

- The CBC of MOX core at BOC is higher than UO_2 core although it has larger number of gadolinia rods than UO_2 core.
- The maximum pin peaking factor for 100% MOX core is possible to manage below 1.55.
- MTC and DC of 100 % MOX core are more negative than UO_2 core, providing inherent safety feature like conventional UO_2 core.
- The calculated SDM of 100 % MOX initial core is smaller than UO_2 core, nonetheless SDM satisfy the required SDM of APR1400.

Backup Slide

MOX fuel loading pattern (1/4 core)

	J-	H-	G-	F-	E-	D-	C-	B-	A-
9	A1	A1	C3	A1	B1	A1	B3	C2	B0
10	A1	B3	A1	B3	A1	B1	A1	B3	C0
11	C3	A1	C2	A1	C3	A1	C3	B1	B0
12	A1	B3	A1	B3	A1	B3	A1	B2	C0
13	B1	A1	C3	A1	C2	A1	B1	C0	
14	A1	B1	A1	B3	A1	B3	C1	C0	
15	B3	A1	C3	A1	B1	C1	C0		
16	C2	B3	B1	B2	C0	C0			
17	B0	C0	B0	C0					