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Nuclear Design Characteristics of Thorium-Plutonium Fueled Soluble Boron-Free Small Modular Reactor

Plutonium-239

Fission neutrons

Thorium-232

Transmute decay

Uranium-233

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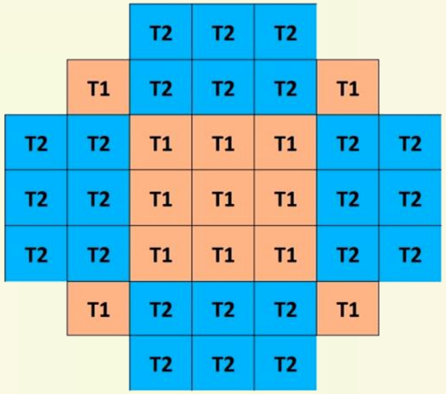
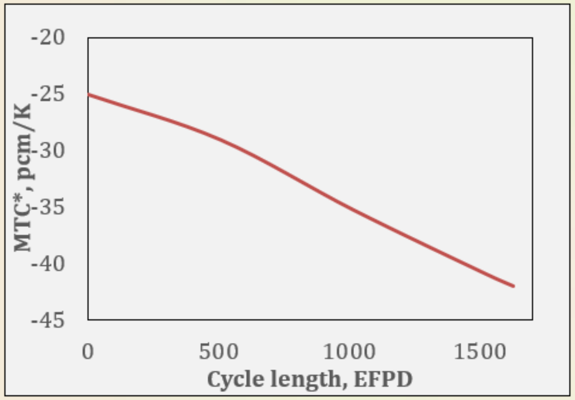


		T2	T2	T2		
	T1	T2	T2	T2	T1	
T2	T2	T1	T1	T1	T2	T2
T2	T2	T1	T1	T1	T2	T2
T2	T2	T1	T1	T1	T2	T2
	T1	T2	T2	T2	T1	
		T2	T2	T2		

2. Core Configuration



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BACKGROUND

Background (1/2)

Nowadays, Small Modular Reactors (SMR) are being developed rapidly due to increased interest in them from potential customers.

Key features of modern SMRs are long cycle length, safety, compact size, operation without adding soluble boron.

Background (2/2)

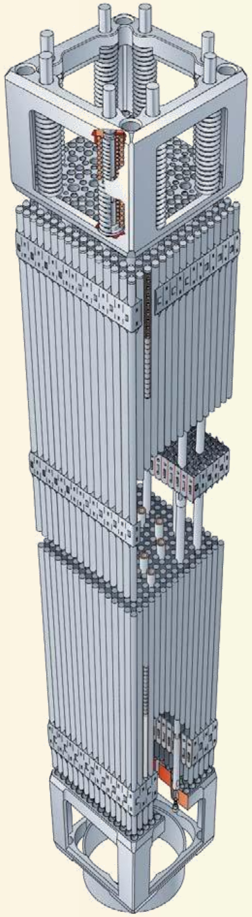
For showing given features in studied SMR, Thorium-Plutonium (Th-Pu) fuel could provide numerous advantages over Uranium (U) fuel:

- No limitations in terms of maximum fissile material content.
- Lower value of excess reactivity in the beginning of cycle due to effects of Th and Pu (beneficial for soluble boron-free operation).
- It is possible to reach very long cycle length using improved burnable absorber strategy.
- Conversion of fissile Pu into fissile U without necessity of using natural U or any forms of enrichment.
- Non-nuclear advantages of ThO_2 over UO_2 such as higher thermal conductivity, higher chemical stability, lower release of fission gases and corresponding fuel swelling etc.

CORE CONFIGURATION

Core Configuration (1/4)

Chosen Fuel Assembly Type



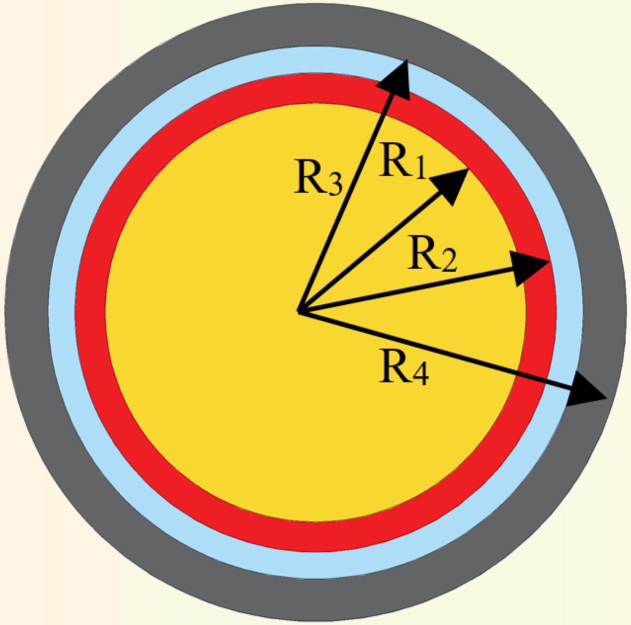
Fuel Assembly type	Lattice configuration	Fuel composition				Active height, cm	Type of BA
		Pu	^{232}Th	^{16}O	^{241}Am		
T1	17x17 Westinghouse	12.596	75.268	12.072	0.064	200	IFBA
T2	17x17 Westinghouse	12.596	75.268	12.072	0.064	200	IFBA

Burnup, GWD/MTU	Pu-238	Pu-239	Pu-240
43.0	2%	52.5%	24.1%
	Pu-241	Pu-242	Am-241
	14.7%	6.2%	0.5%

Generation of cross-sections was performed using Studsvik CASMO-4.

Core Configuration (2/4)

Fuel Rod Design – IFBA* coated fuel with air gap



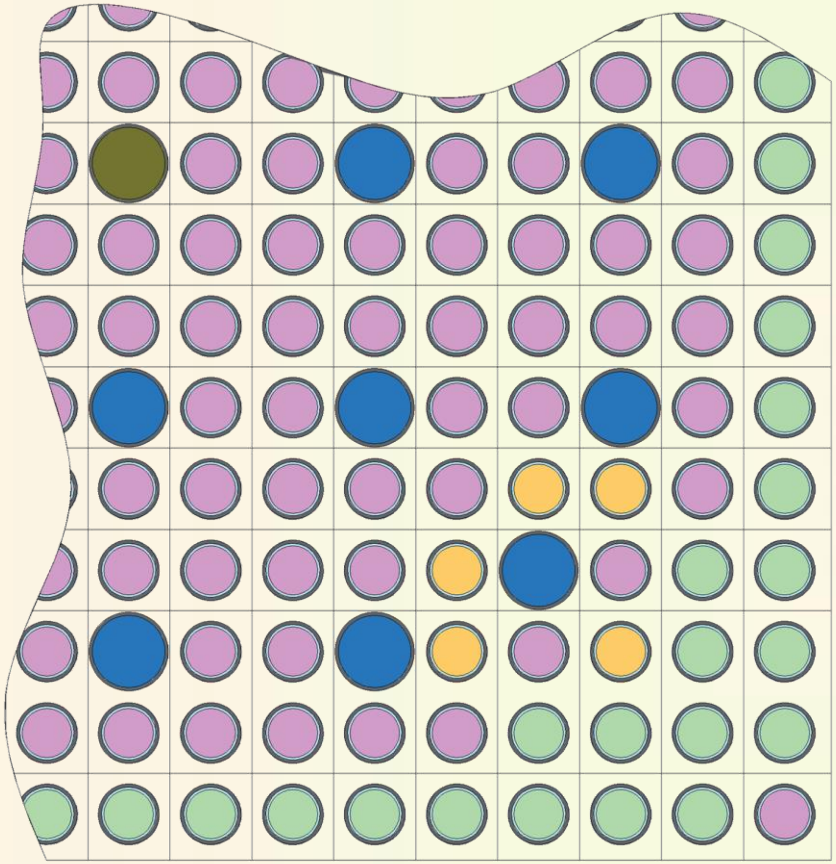
Radius	Value, cm
R_1	0.40058
R_2	0.40958
R_3	0.41783
R_4	0.47498

Introducing air gap could prevent deformation and cracking of fuel rod cladding caused by fuel swelling.

*IFBA – Integral Fuel Burnable Absorber

Core Configuration (3/4)

Fuel Assembly Design – fuel rods zoning

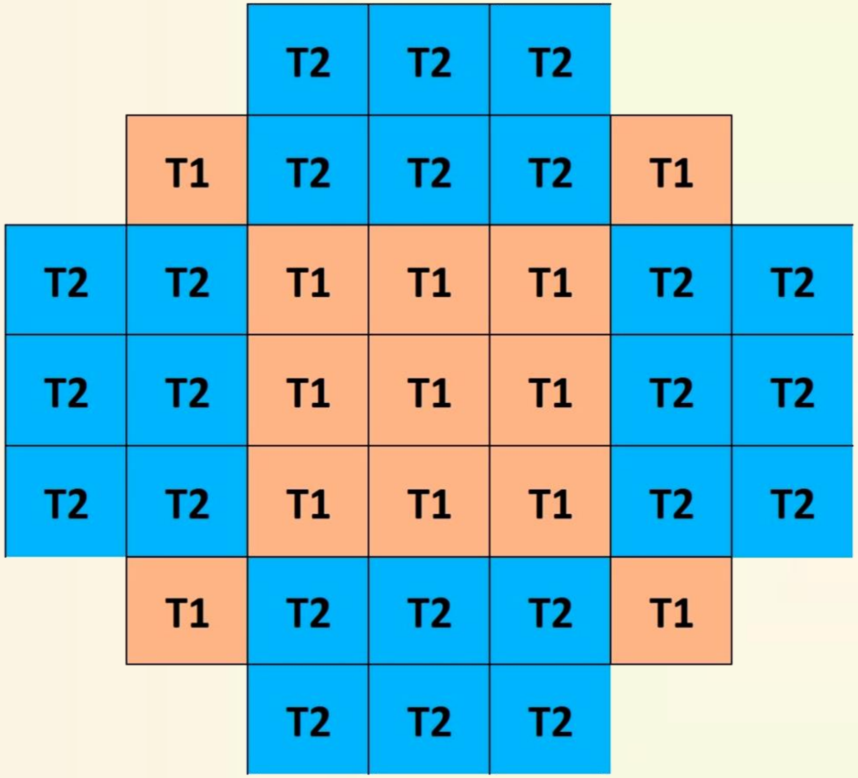


FA type	IFBA type	Boron wt% in IFBA
T1	High (Yellow)	2.4
	Medium (Pink)	1.85
	Low (Green)	0.4
T2	High (Yellow)	1.9
	Medium (Pink)	1.4
	Low (Green)	0.2

Fissile part in all rods – 8.498wt%. All fuel rods have equal Pu composition.

Core Configuration (4/4)

Core Design of Bandi-50 SMR



		T2	T2	T2		
	T1	T2	T2	T2	T1	
T2	T2	T1	T1	T1	T2	T2
T2	T2	T1	T1	T1	T2	T2
T2	T2	T1	T1	T1	T2	T2
	T1	T2	T2	T2	T1	
		T2	T2	T2		

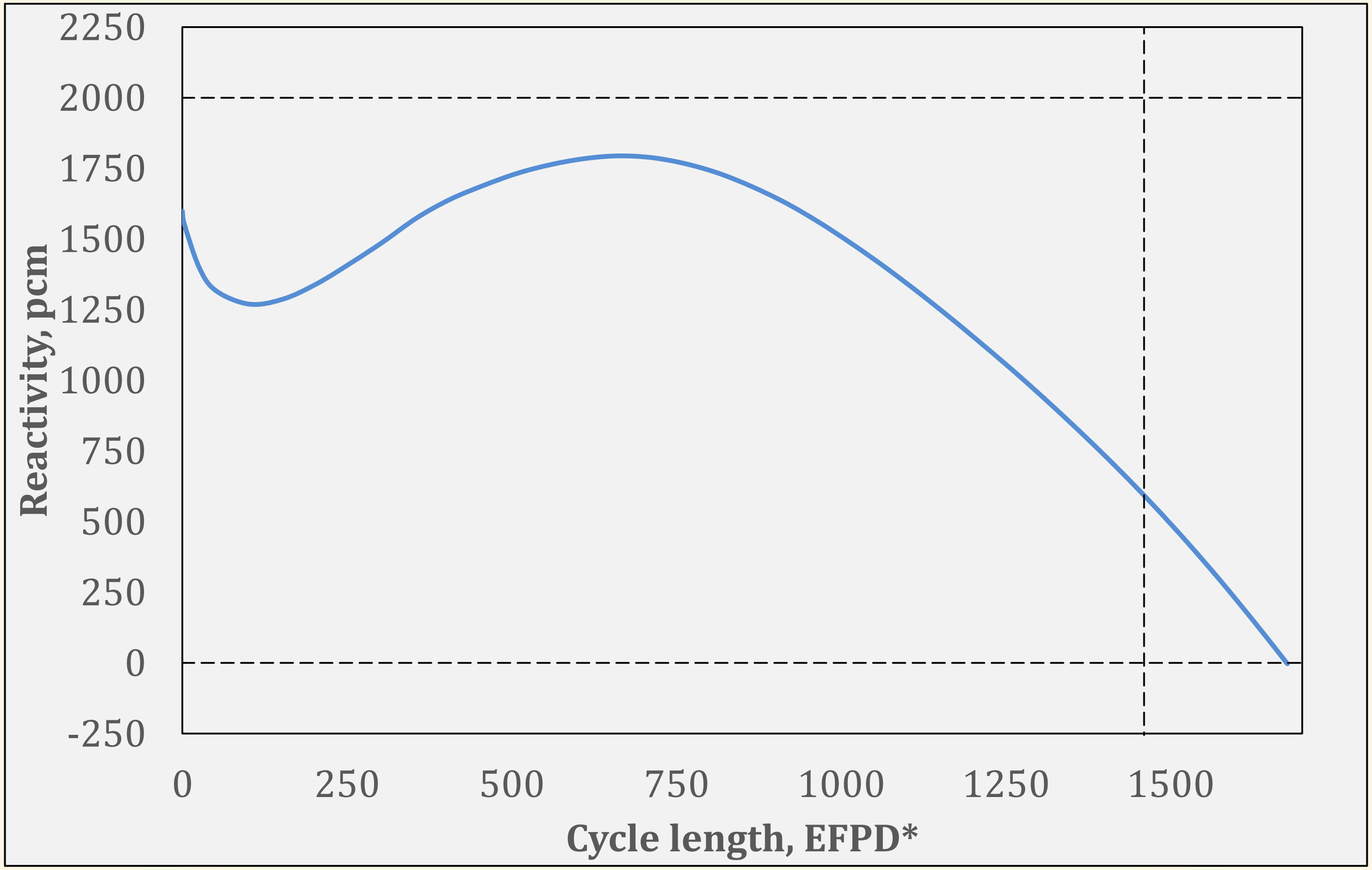
FA type	IFBA type	Boron wt% in IFBA
T1	High	2.4
	Medium	1.85
	Low	0.4
T2	High	1.9
	Medium	1.4
	Low	0.2

For reactivity control, Ag-In-Cd control rods are used.
Full-core calculations were performed using Studsvik SIMULATE 3.0.

RESULTS

Results (1/5)

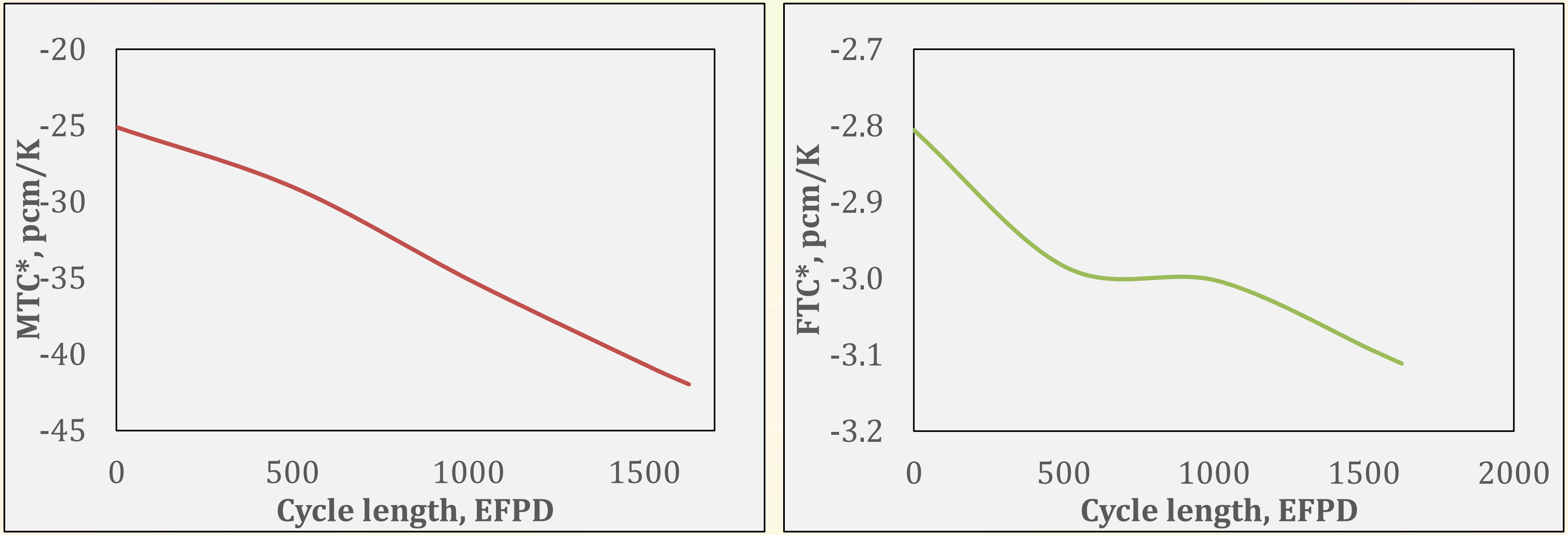
Cycle length – more than 4 EFPY*



*EFPY – Effective Full-Power Year, EFPD – Effective Full-Power Day

Results (2/5)

Safety-related nuclear characteristics



Maximum $F_{\Delta H}$ – 1.55. Maximum F_q – 2.03.

*MTC – Moderator Temperature Coefficient, FTC – Fuel Temperature Coefficient

Results (3/5)

Safety-related nuclear characteristics

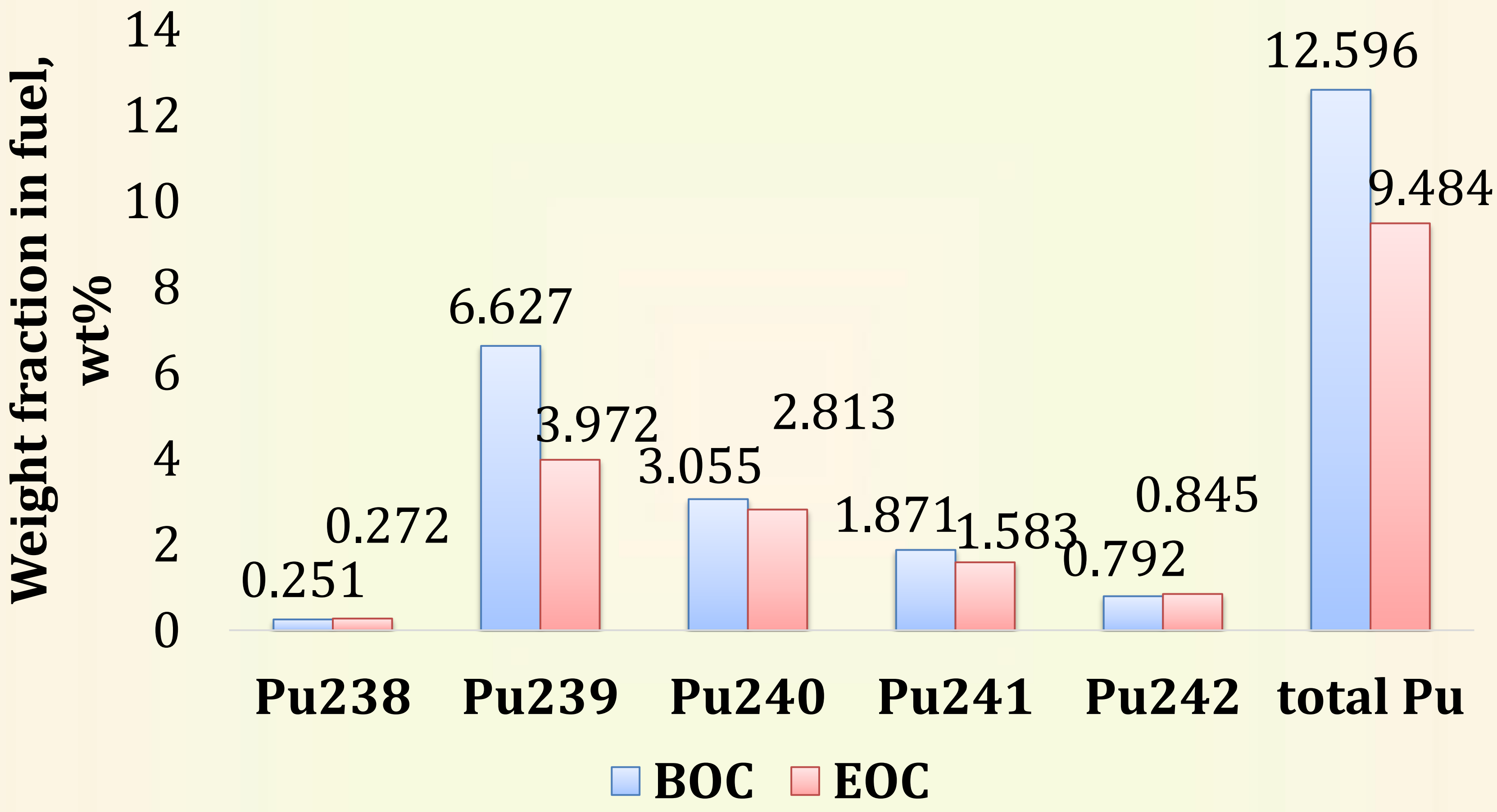
	BOC* 0 GWD/MTH	MOC* 16 GWD/MTH	EOC* 32 GWD/MTH
Excess reactivity control, pcm	1599	1746	190
Power Defect, pcm	1513	1584	1942
Control Rod Worth, pcm	12240	13760	16667
N-1 Control Rod Worth, pcm	11491	12925	15610
Uncertainty in calculation, 5%	575	647	781
Shutdown Margin, pcm	**9403**	**10694**	**12887**

Control Rod Worth found with consideration of required excess reactivity control by control rods.

*BOC – Beginning of Cycle, MOC – Middle of Cycle, EOC – End of Cycle

Results (4/5)

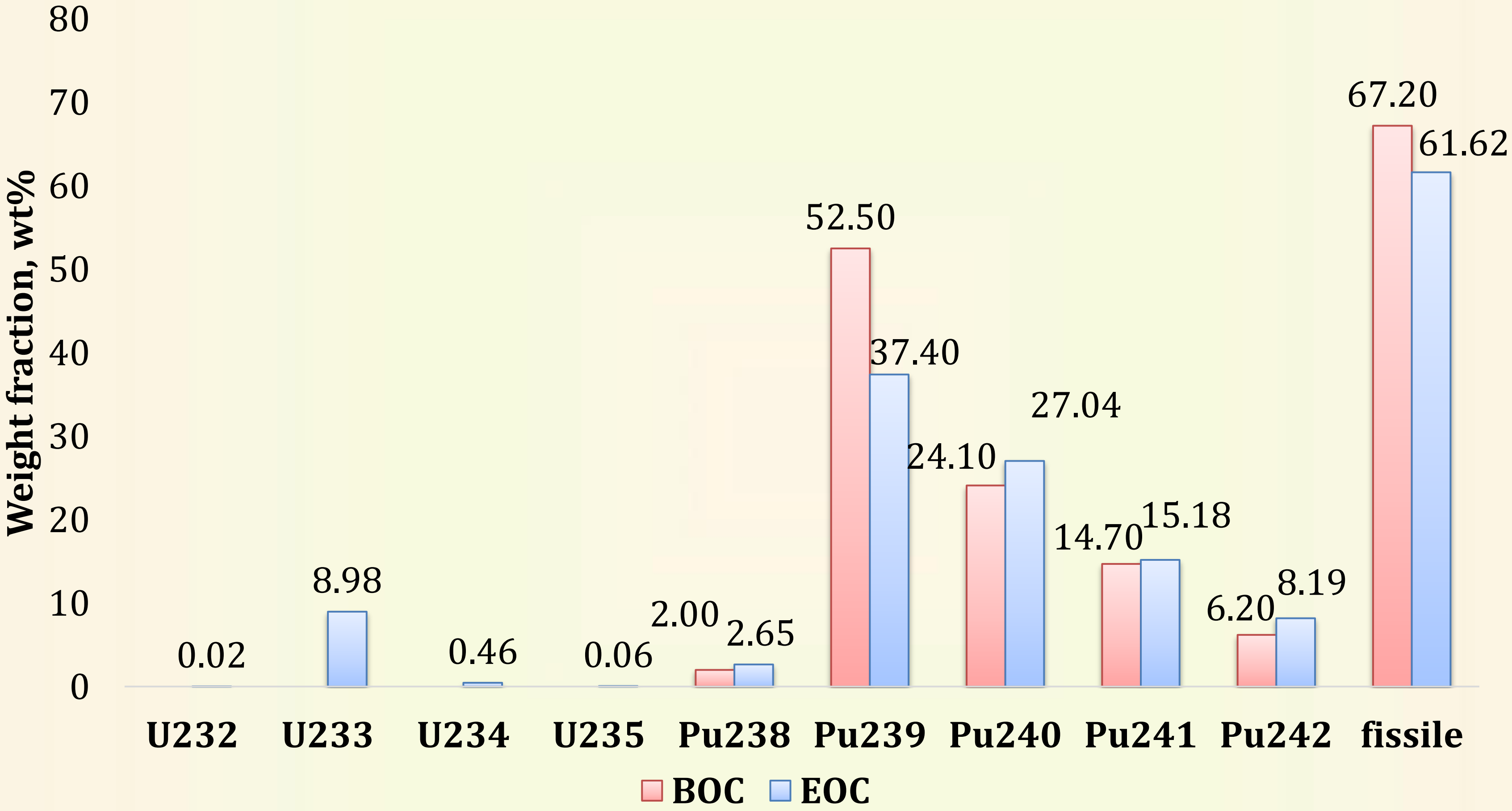
Utilization of Pu



Total amount of loaded Pu is reducing noticeably during cycle length.

Results (5/5)

Change of U-Pu composition over cycle length



Potentially extractable U-Pu composition shows good applicability for being used for new fuel manufacturing.

CONCLUSION

Conclusion

- Cycle length is longer than 4 EFPY. It is possible to make it much longer in future work.
- Temperature coefficients of reactivity show negative values over the entire cycle length.
- Control rod worth is sufficient for maintaining soluble boron-free operation mode with large shutdown margin.
- Noticeable decrease of loaded Pu, which could be used for Pu utilization.
- High amount of fissile material in potentially extractable U-Pu composition – could be used for new fuel manufacturing.

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EXTRA

Computer Codes

Used Computer Codes – Studsvik CASMO-4/SIMULATE 3.0

CASMO

state-of-the-art lattice physics

CASMO-4 is a multigroup two-dimensional computer code for burnup calculations at fuel pin or fuel assembly level.*

SIMULATE 3.0 is an advanced two-group nodal code with QPANDA neutronics model. ** This code is used for full-core simulations and loading pattern search.

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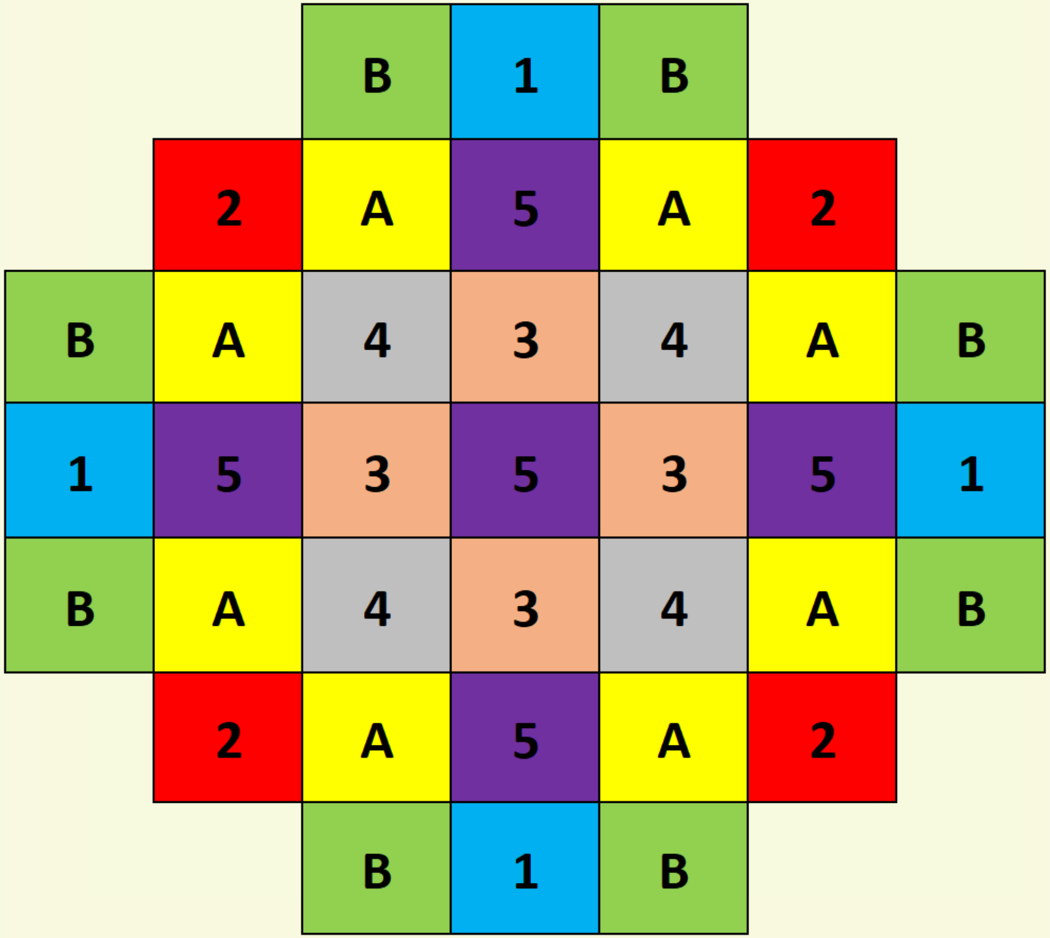
*Studsvik Scandpower, “CASMO-4: A Fuel Assembly Burnup Program - User's Manual (University Release)”, SSP-09/433-U Rev 0 (2009).

**Studsvik Scandpower, SIMULATE-3: Advanced Three-Dimensional Two-Group Reactor Analysis Code - User's Manual (University Release), SSP-09/447-U Rev 0, 2009.

Control Rod Configuration

All Fuel Assemblies use Ag-In-Cd rods



		B	1	B		
	2	A	5	A	2	
B	A	4	3	4	A	B
1	5	3	5	3	5	1
B	A	4	3	4	A	B
	2	A	5	A	2	
		B	1	B		