Centre for Energy Research

ÓBUDAI EGYETEM
ÓBUDA UNIVERSITY

MODELLING CALCULATIONS OF ACTIVATION OF OBJECTS IN NOVEL RESEARCH FACILITIES

By

RADI ACHRAF

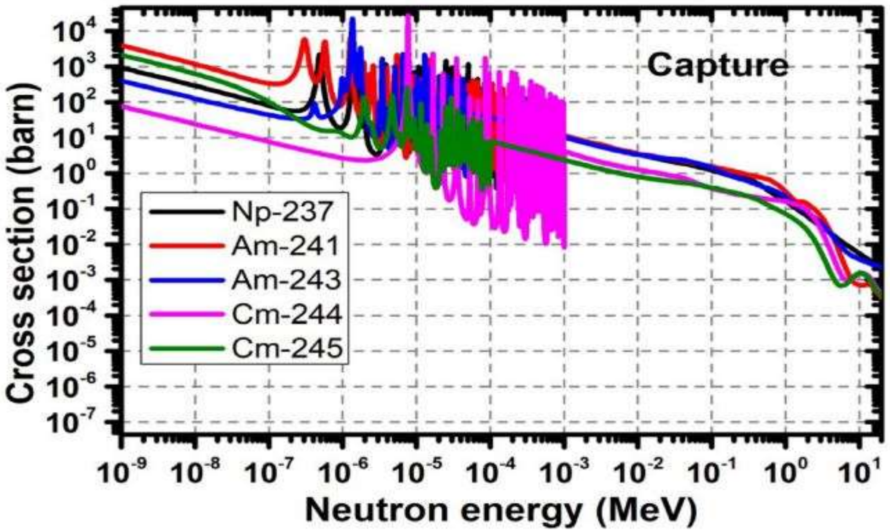
Ph.D. Student

Dr. Zagyvai Péter / Dr. Szentmiklósi László

Supervisors (EK-CER)

AIMS AND SCOPE OF THE RESEARCH

- This study examines the use of a new type of nuclear fuel, specifically a potential fuel composition for future research- and energy-producing reactors
- alternative fuels to replace uranium, with a focus on the possibility of incinerating plutonium and other minor actinides in a duplex configuration with thorium using an existing fuel geometries.
- The study aims at evaluating the effect on fuel cycle length and safety-related parameters. The use of minor actinides as burnable absorbers can reduce reactivity excess and transmute to plutonium isotopes that are of much shorter half lives.



Capture cross-sections of MAs

$$^{237}\mathrm{Np} + \mathrm{n} \rightarrow \beta^- + {}^{238}\mathrm{Pu} \quad (1)$$

$$^{241}\mathrm{Am} + \mathrm{n} \rightarrow {}^{242}\mathrm{Am} \rightarrow \beta^- + {}^{242}\mathrm{Cm} \rightarrow \alpha + {}^{238}\mathrm{Pu} \quad (2)$$

WHY IS THE THORIUM

- Uranium fuel is the only one widely used in fission reactors, but thorium and plutonium are also of interest.
- Thorium has the potential to improve the long-term viability of nuclear power by breeding U-233 in reactors and reducing the amount of plutonium generated per unit energy. Plutonium raises concerns about proliferation, but higher burnup could improve its proliferation resistance by reducing the amount per unit energy and degrading the isotopic mixture.

→Is more abundant (3 to 4 times more abundant) in Earth's crust than uranium, in form of Th-232 ≈100%.

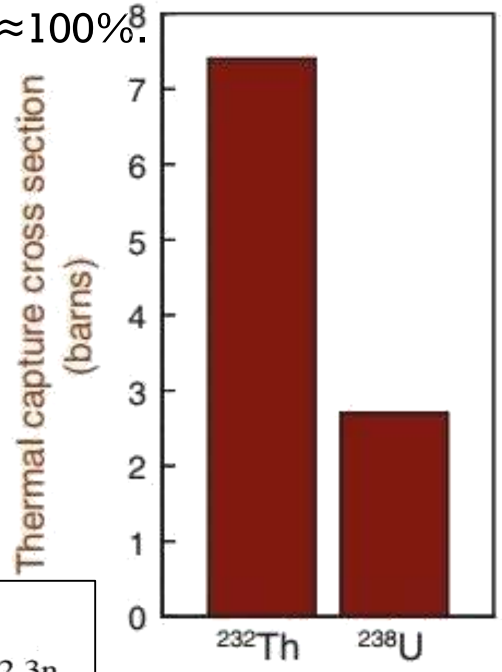
→Has favourable physical and chemical properties

→Produces waste that is lower in volume, less toxic, and less long-lived

→Potential to reprocess and reuse

→The use of thorium fuel offers a way to burn up large stocks of plutonium.

→Thorium fuel does not give rise to materials that can be used for bombs



Properties	U	Pu	Th	UO_2	PuO_2	ThO_2
Melting point (°C)	1130	632	1750	2760	2400	3300
Theoretical density (g/cm3)	19.10	19.80	11.70	10.96	11.50	10.00
Crystalline structure				FCC (CaF2 type)	FCC (CaF_2 type)	FCC (CaF_2 type)

Thorium Breeding Cycle

$$^{232}\mathrm{Th} + \mathrm{n} \rightarrow {}^{233}\mathrm{U}; \quad {}^{233}\mathrm{U} + \mathrm{n} \rightarrow \mathrm{fission} + 2.3\mathrm{n}$$

Uranium Breeding Cycle

$$^{238}\mathrm{U} + \mathrm{n} \rightarrow {}^{239}\mathrm{Pu}; \quad {}^{239}\mathrm{Pu} + \mathrm{n} \rightarrow \mathrm{fission} + 2.5\mathrm{n}$$

OBJECTIVES OF THE STUDY

Burning of plutonium and other MAs plays an important role in the sustainability of the nuclear fuel cycle. In this computational study, we combine the well-known micro-heterogeneous duplex configuration with a possible PuO2-ThO2-based fuel to investigate the MAs transmutation characteristics in an energy-generating reactor. We focus on the MAs transmutation characteristics in the VVER-1200 assembly, which include the assembly designs, the effects on assembly k_{INF} after adding MAs, the transmutation rate, and the discharge burnup.

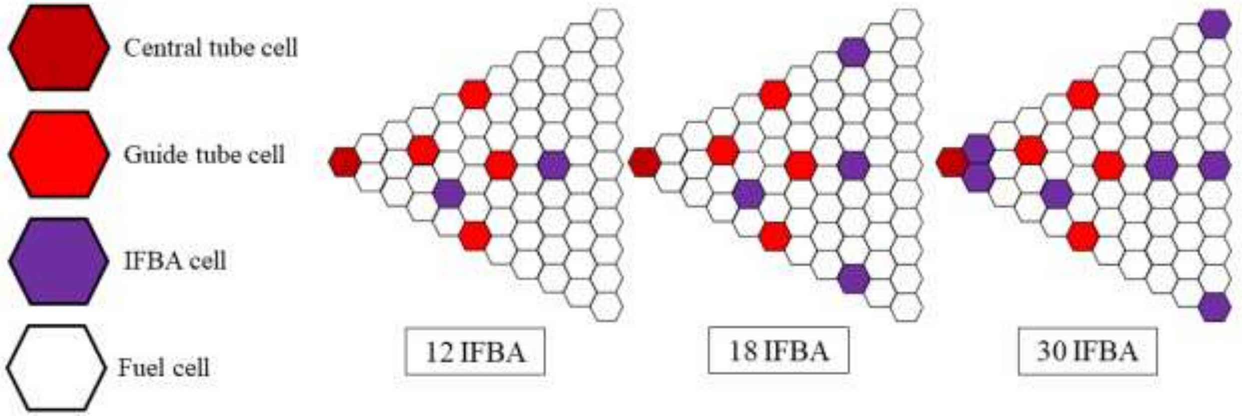
Weapons-grade plutonium isotopic composition

Isotope	Pu-238	Pu-239	Pu-240	Pu-241	Pu-242
Wt. %	0.02	93.80	5.80	0.35	0.03

Minor actinides isotopic composition

Isotope	Np-237	Am-241	Am-243	Cm-244	Cm-245
Wt. %	56.20	26.40	12.00	5.12	0.28

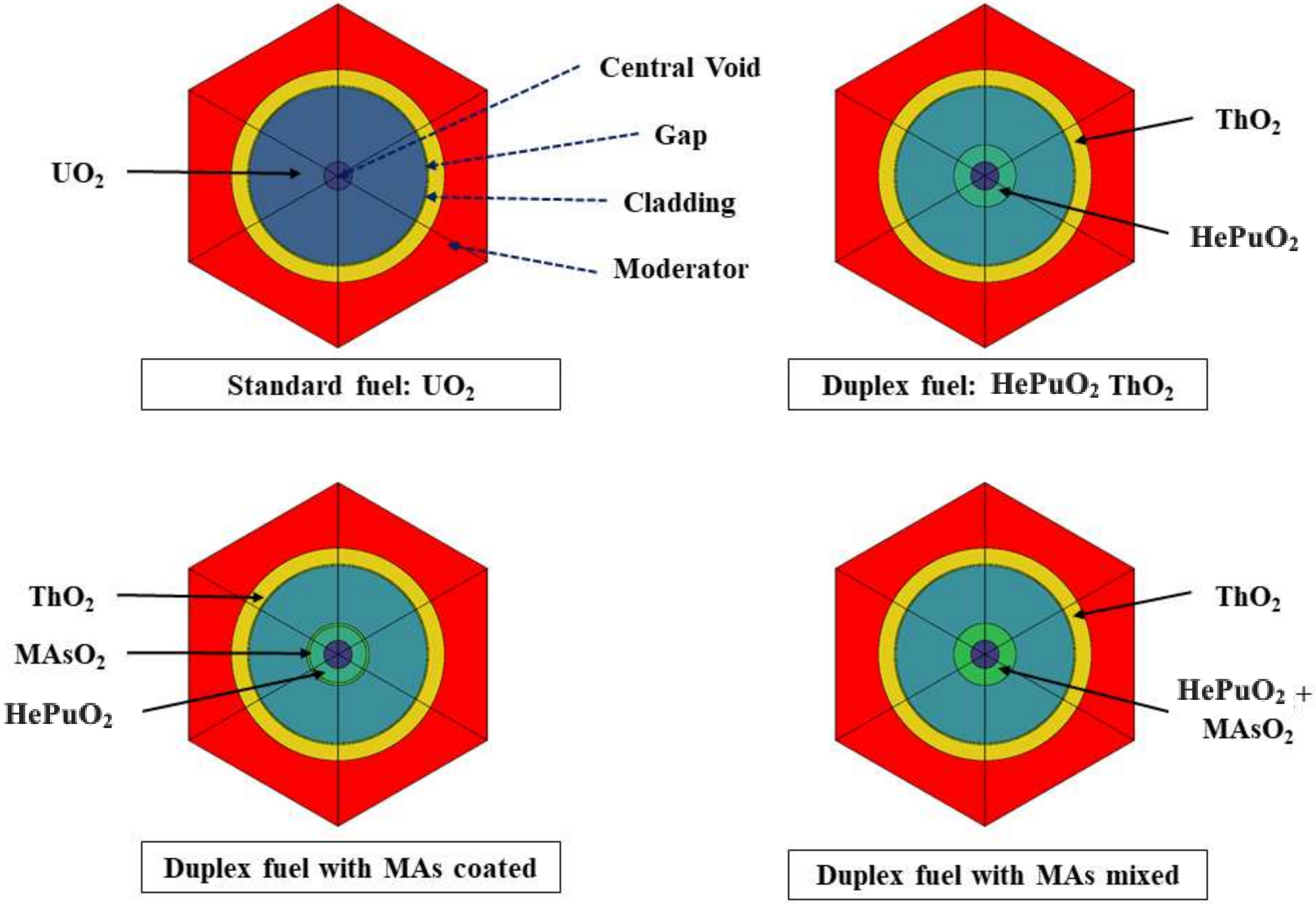
For simulation purposes, the neutronic Lattice Physics Code DRAGON (being developed at Ecole Polytechnique de Montreal) was used for modelling a 1/6 segment of the core using the multi-group cross-section library ENDFB-VIII ref.0 and HBC SA60 REFL settings



Horizontal cross-section of minor actinide introduction approaches in the VVER-1200 **integral fuel burnable absorber** rods (IFBA).

DEFINITIONS

- k_{inf}: the k-infinity is a measure of the energy released per fission event also used to indicate the point of achieving criticality in a reactor, when the reactor is able to sustain the fission reactions without the need of external neutron source.
- criticality in a nuclear reactor context refers to the point at which a self-sustaining chain reaction of nuclear fission is achieved and maintained within the reactor, resulting in a stable level of activity and a sustained and controlled release of energy.
- Burnup is a measure of the amount of fuel that has been consumed in a nuclear reactor. It is typically measured in megawatt-days per metric ton of initial heavy metal (MWd/tHM). The burnup of a fuel assembly is determined by measuring the amounts of radioactive isotopes remaining in the spent fuel, and comparing that to the original composition of the fuel. A higher burnup indicates that more energy has been extracted from the fuel before it needs to be replaced.
- The criticality period is the period of time during which the reactor is in a critical state. The criticality period can be divided into two phases: the initial criticality phase, where the reactor is first brought to a critical state, and the steady-state criticality phase, where the reactor maintains a constant level of reactivity.

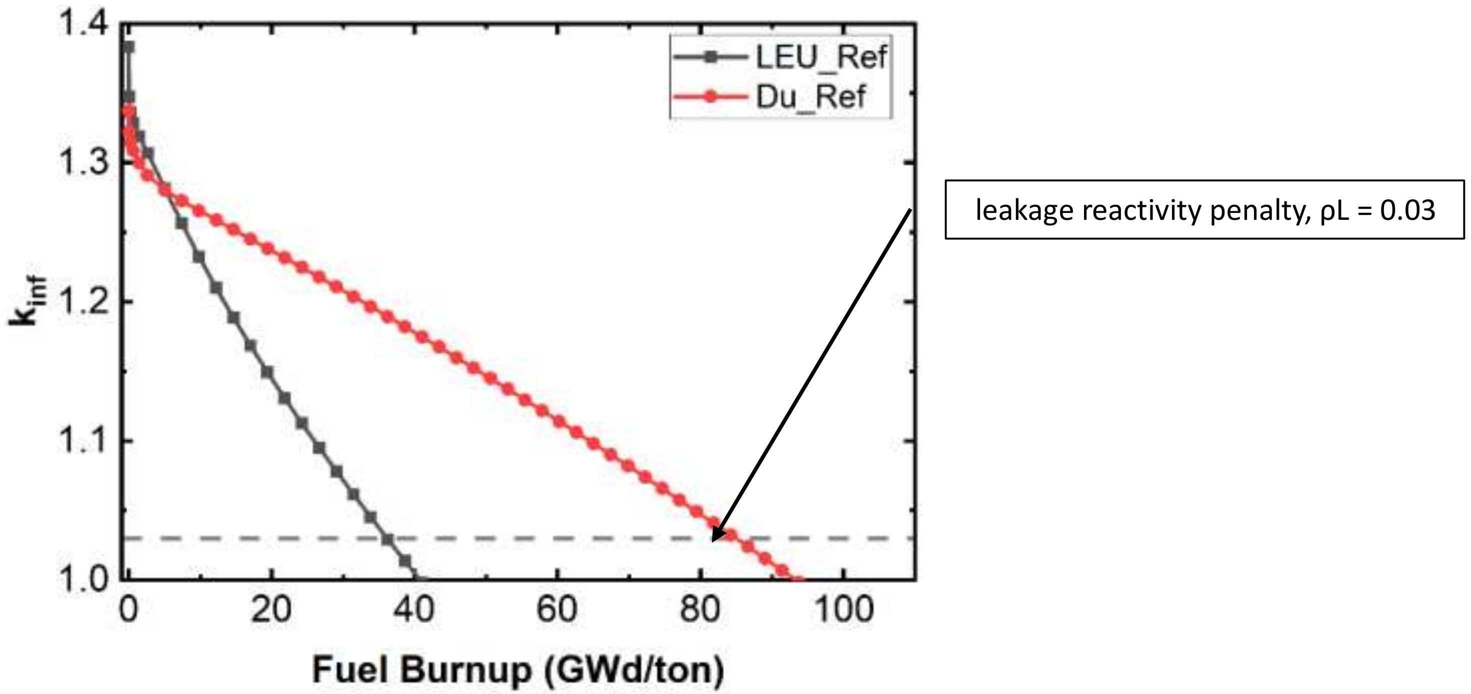


Geometry of standard, duplex and IFBA rods in the VVER-1200 assembly

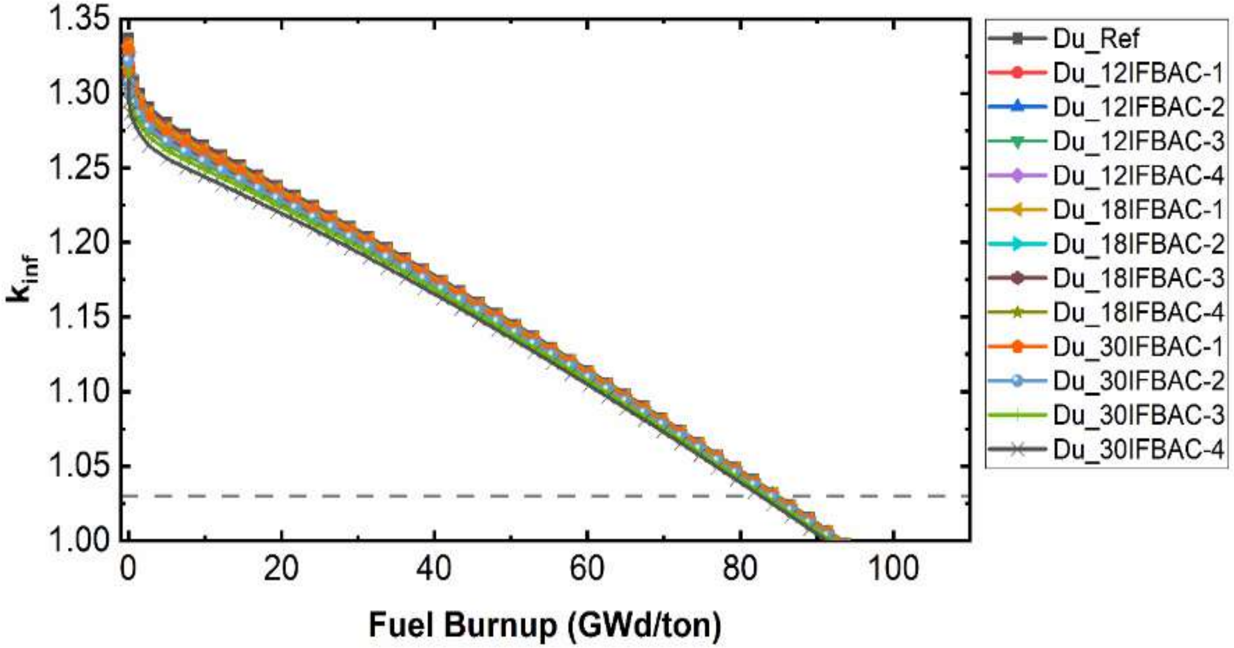
CASES CONSIDERED FOR THE NEUTRONIC STUDY OF THE VVER-1200 TYPE ASSEMBLY

Case Name	Description
LEU_Ref	312 Fuel rods per assembly [4.95 wt.% enriched UO_2]
Du_Ref	312 Fuel rods [duplex PuO_2-ThO_2]
Du_12IFBAC-1 to 4	Du_Ref case with 12 IFBA MAs coated on the outer surface (1) 0.003 cm, (2) 0.005 cm, (3) 0.008 cm, and (4) 0.011 cm.
Du_18IFBAC-1 to 4	Du_Ref case with 18 IFBA MAs coated on the outer surface (1) 0.003 cm, (2) 0.005 cm, (3) 0.008 Cm, and (4) 0.011 cm.
Du_30IFBAC-1 to 4	Du_Ref case with 30 IFBA MAs coated on the outer surface (1) 0.003 cm, (2) 0.005 cm, (3) 0.008 cm, and (4) 0.011 cm.
Du_12IFBAM-1 to 4	Du_Ref case with 12 IFBA MAs mixed with PuO_2 (1) 5%, (2) 10%, (3) 15%, and (4) 20%.
Du_18IFBAM-1 to 4	Du_Ref case with 18 IFBA MAs mixed with PuO_2 (1) 5%, (2) 10%, (3) 15%, and (4) 20%.
Du_30IFBAM-1 to 4	Du_Ref case with 30 IFBA MAs mixed with PuO_2 (1) 5%, (2) 10%, (3) 15%, and (4) 20%.

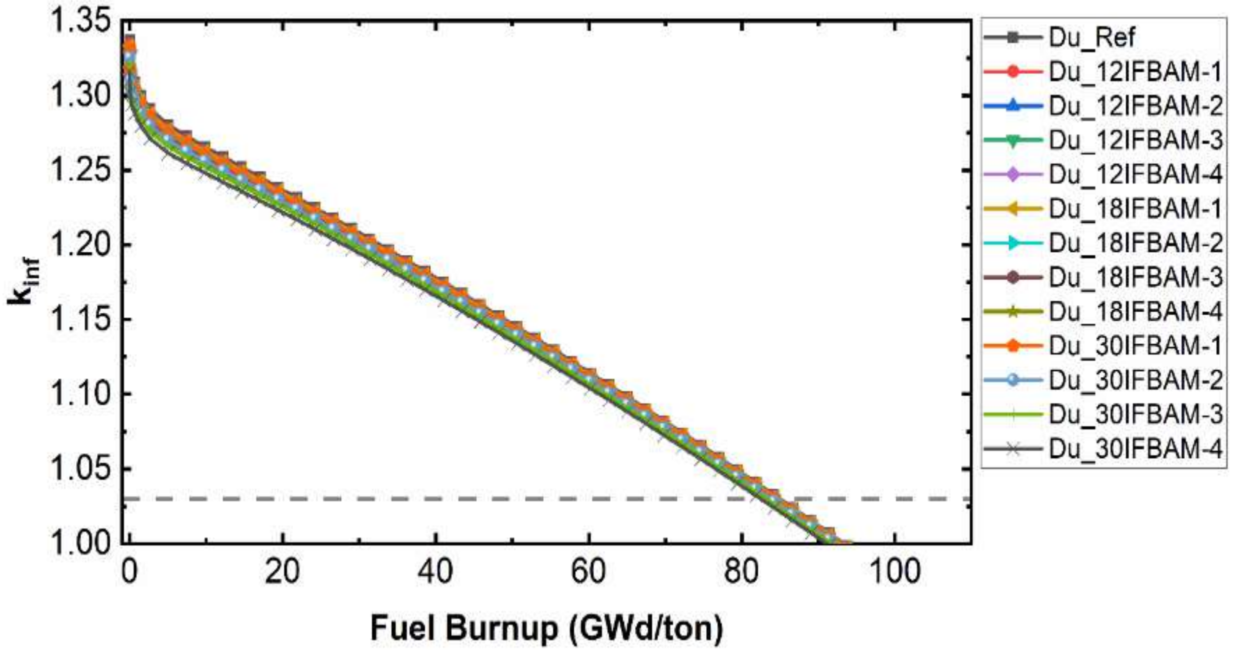
RESULTS



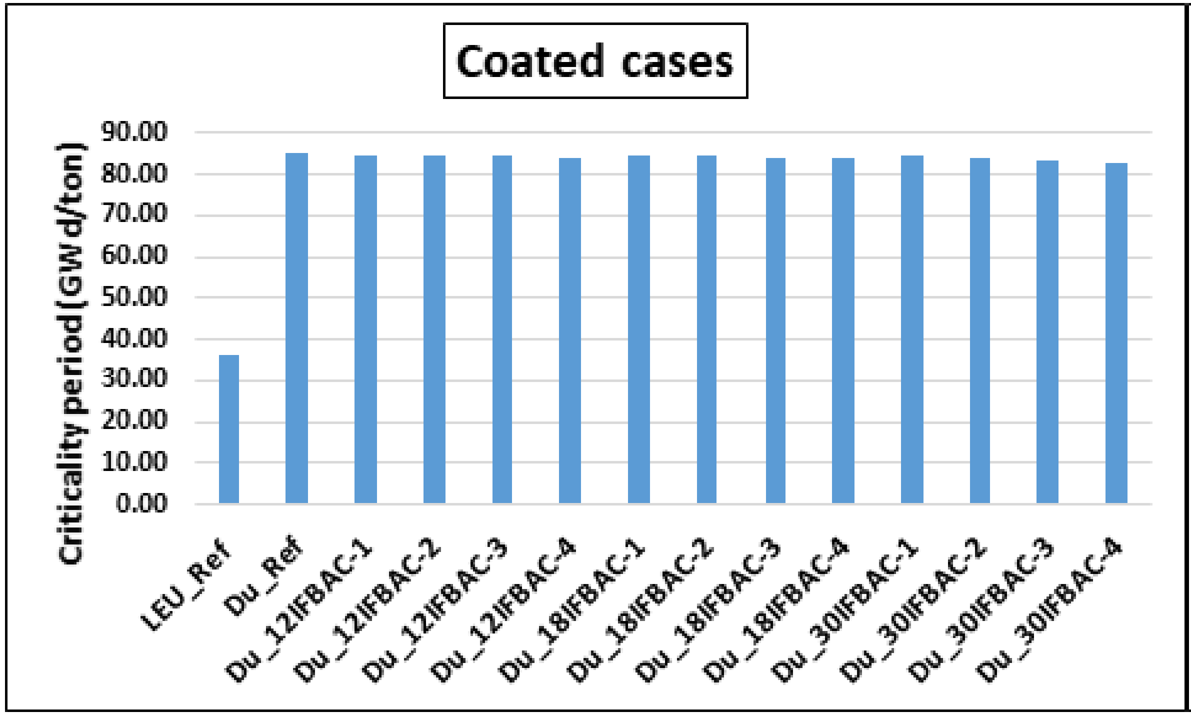
LEU_Ref
Du_Ref
k_inf
Fuel Burnup (GWd/ton)
leakage reactivity penalty, ρL = 0.03

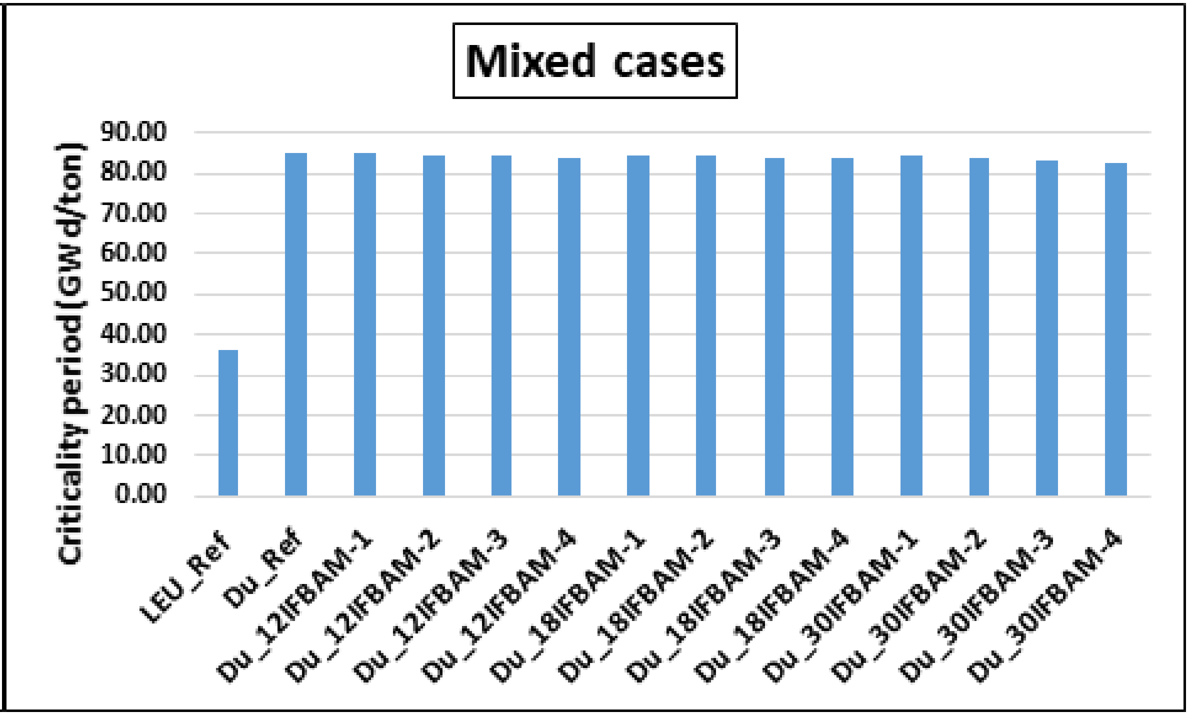


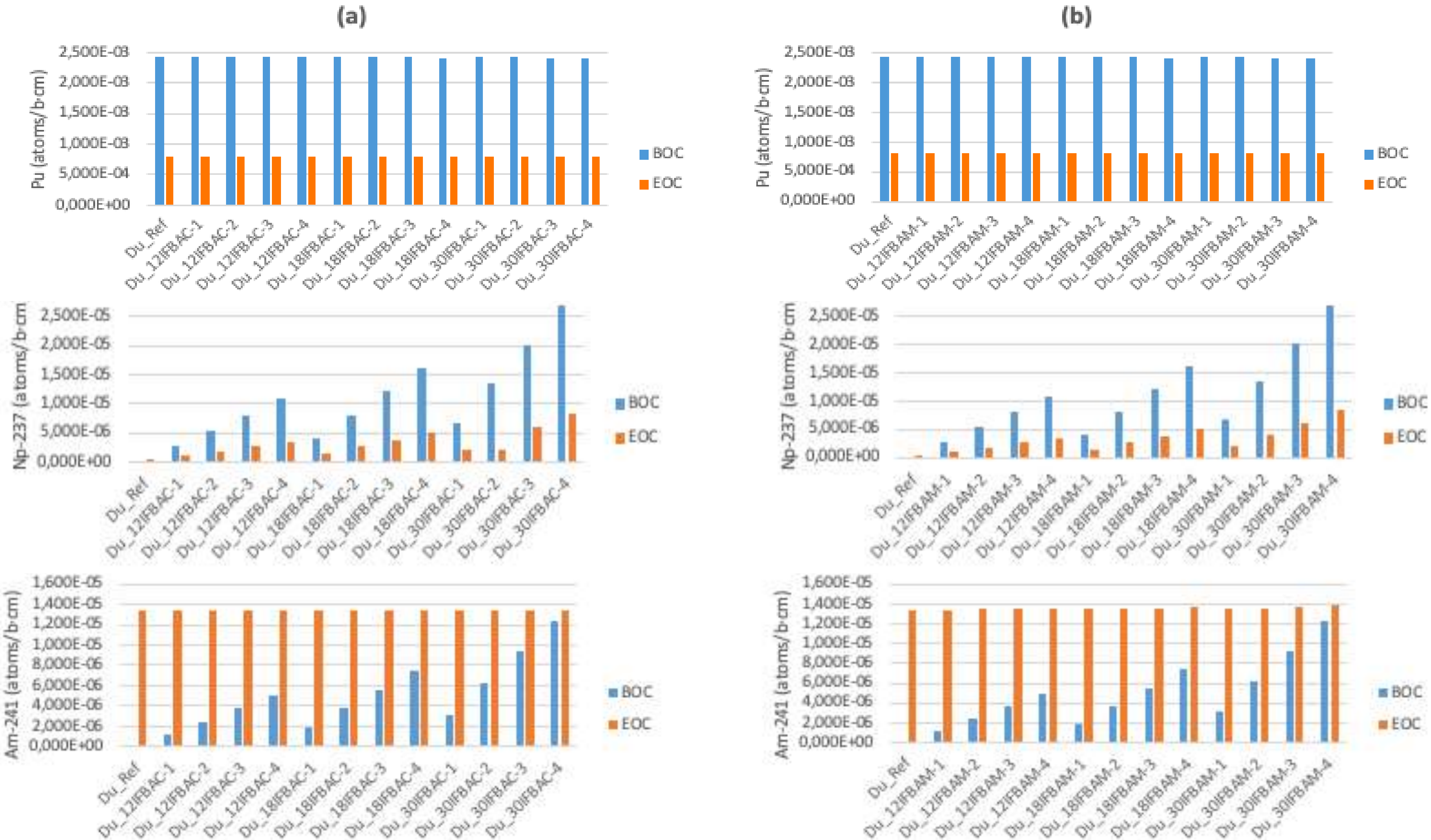
Du_Ref
Du_12IFBAC-1
Du_12IFBAC-2
Du_12IFBAC-3
Du_12IFBAC-4
Du_18IFBAC-1
Du_18IFBAC-2
Du_18IFBAC-3
Du_18IFBAC-4
Du_30IFBAC-1
Du_30IFBAC-2
Du_30IFBAC-3
Du_30IFBAC-4
k_inf
Fuel Burnup (GWd/ton)



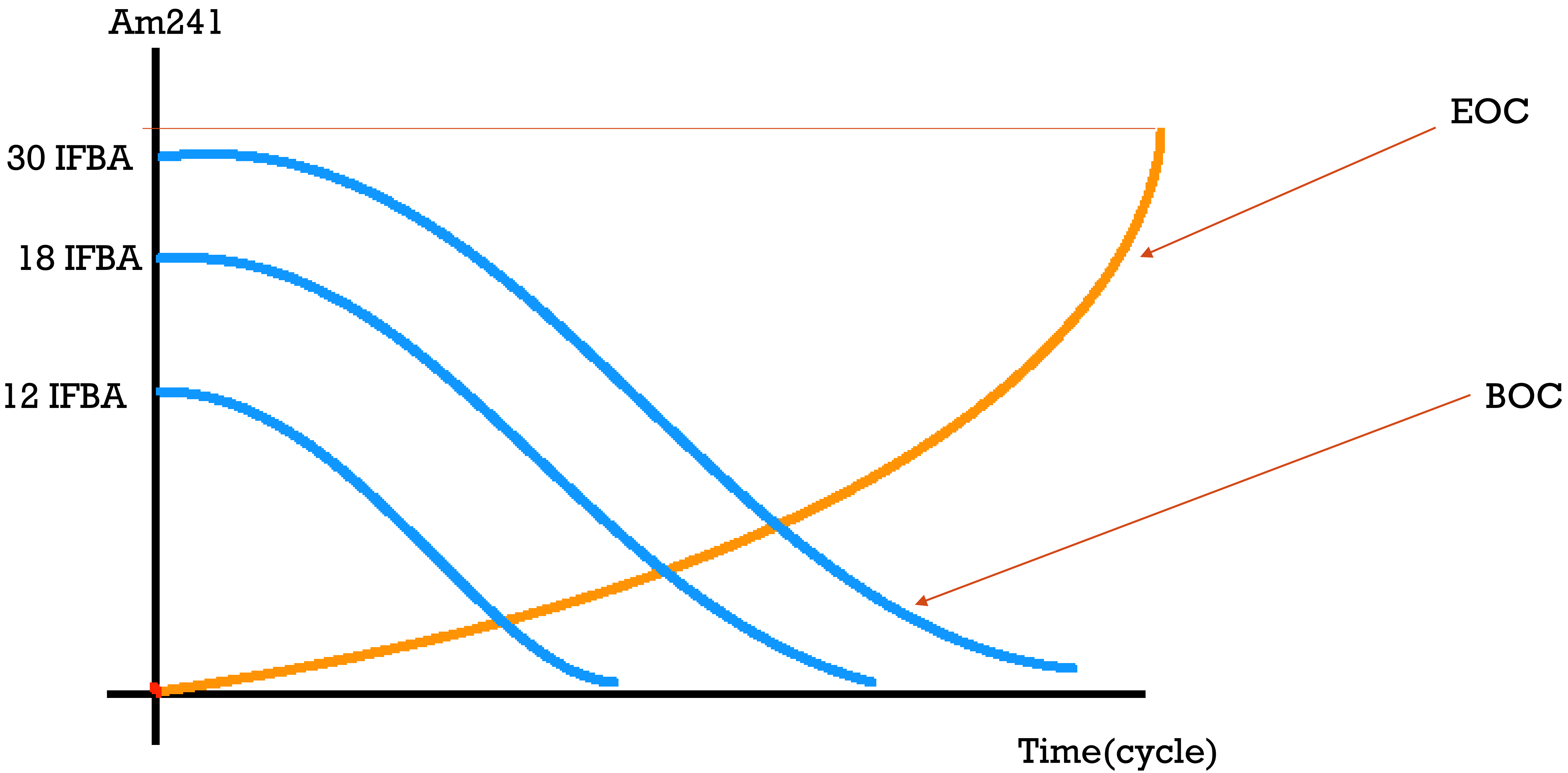
Du_Ref
Du_12IFBAM-1
Du_12IFBAM-2
Du_12IFBAM-3
Du_12IFBAM-4
Du_18IFBAM-1
Du_18IFBAM-2
Du_18IFBAM-3
Du_18IFBAM-4
Du_30IFBAM-1
Du_30IFBAM-2
Du_30IFBAM-3
Du_30IFBAM-4
k_inf
Fuel Burnup (GWd/ton)


Coated cases
Criticality period (GWd/ton)
90.00
80.00
70.00
60.00
50.00
40.00
30.00
20.00
10.00
0.00
LEU_Ref
Du_Ref
Du_12IFBAC-1
Du_12IFBAC-2
Du_12IFBAC-3
Du_12IFBAC-4
Du_18IFBAC-1
Du_18IFBAC-2
Du_18IFBAC-3
Du_18IFBAC-4
Du_30IFBAC-1
Du_30IFBAC-2
Du_30IFBAC-3
Du_30IFBAC-4


Mixed cases
Criticality period (GWd/ton)
90.00
80.00
70.00
60.00
50.00
40.00
30.00
20.00
10.00
0.00
LEU_Ref
Du_Ref
Du_12IFBAM-1
Du_12IFBAM-2
Du_12IFBAM-3
Du_12IFBAM-4
Du_18IFBAM-1
Du_18IFBAM-2
Du_18IFBAM-3
Du_18IFBAM-4
Du_30IFBAM-1
Du_30IFBAM-2
Du_30IFBAM-3
Du_30IFBAM-4



MAs isotopes at beginning of cycle (BOC)and discharged (EOC)



Am241
30 IFBA
18 IFBA
12 IFBA
EOC
BOC
Time(cycle)

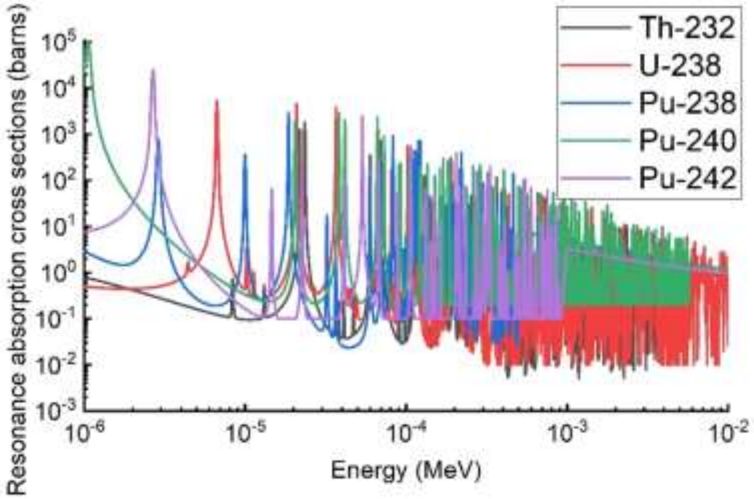
SAFETY PARAMETERS (REACTIVITY COEFFICIENTS)

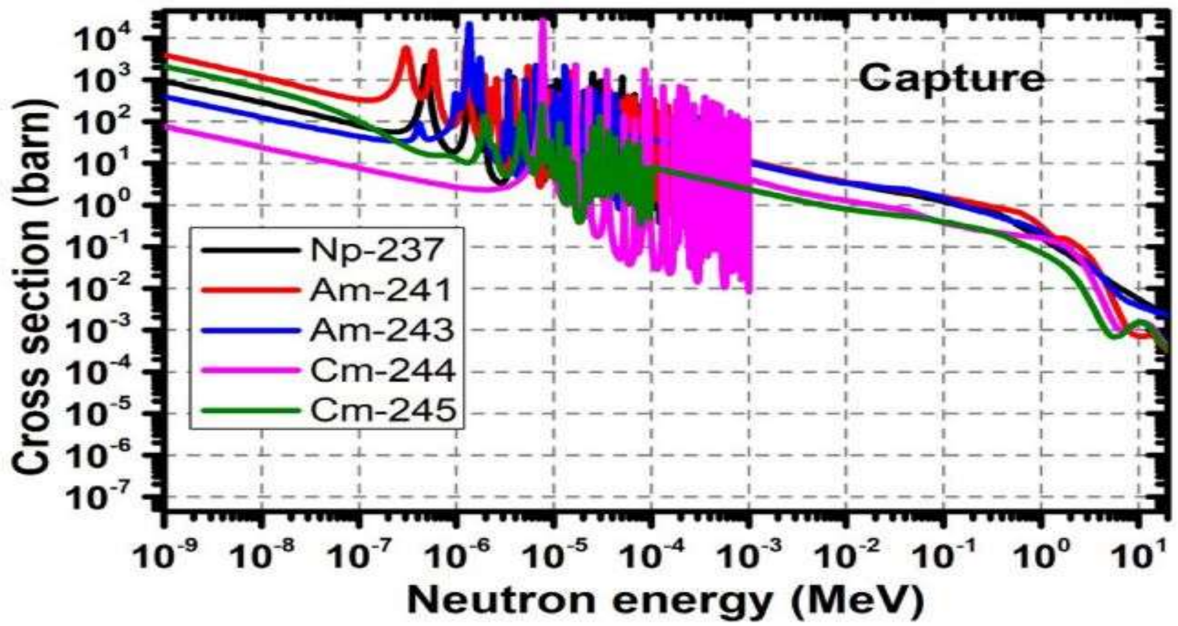
A temperature coefficient describes the changes in reactivity that occur when the operating temperature of a reactor changes. Negative temperature coefficients are preferable in terms of safety because they prevent reactor excursions (rapid increases in power level)/(avoid core meltdown).

<u>For the Fuel temperature coefficient (FTC):</u>

More captures = less neutrons available for fission = negative coefficient

This effect is related to the number of neutrons captured by non-fissile nuclei (e.g., Th-232, U-238, Pu-238 and Pu-240) due to the broadening of the Doppler resonance as the core temperature increases.



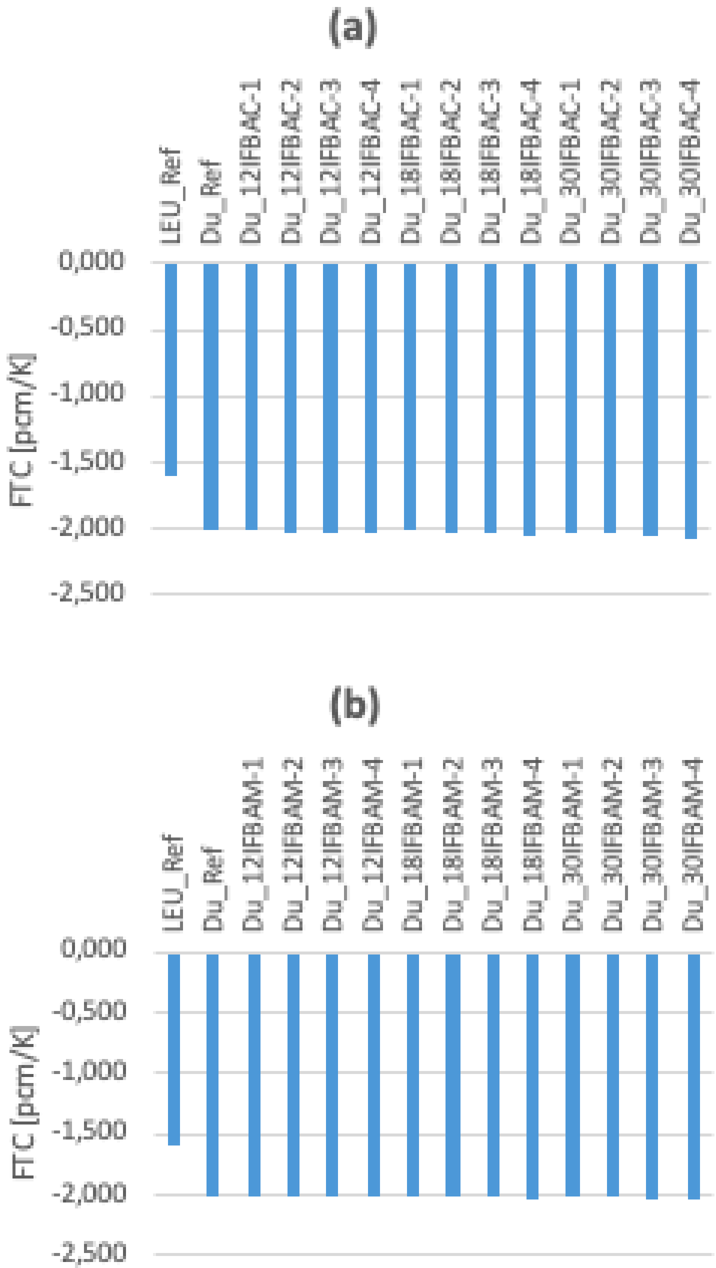


For the Moderator temperature coefficient (MTC):

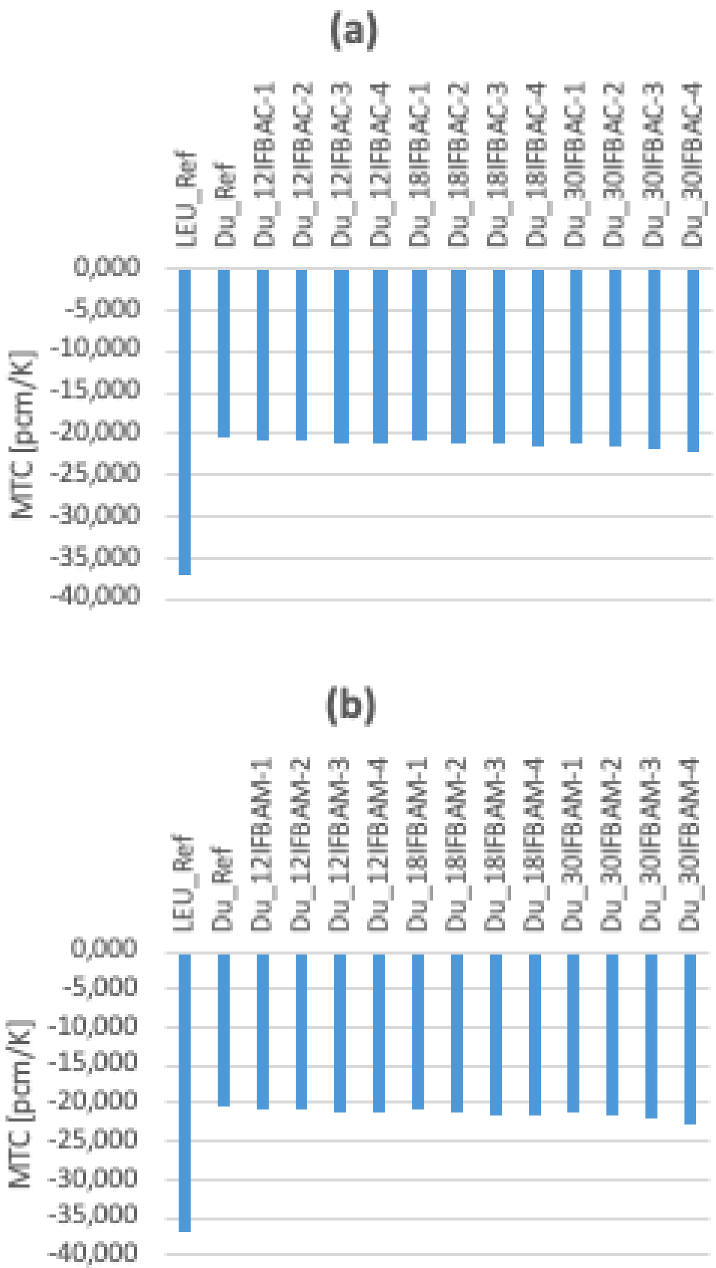
→An increase in moderator temperature causes thermal neutrons to move to slightly higher energies.

→The higher energy thermal neutrons will have reduced fission cross sections = negative coefficient.

Fuel temperature coefficient



Moderator temperature coefficient



CONCLUSIONS

- The first result shows that the considered micro-heterogeneous duplex PuO2-ThO2 fuel assembly can reach more than 84 GWd/ton discharge burnup which is equivalent to 5.5 effective full power years assuming a constant specific power of 40 KW/kg (36.12 GWd/ton) for the LEU (4.95 wt.% case).
- Our study shows that MA nuclides actually can act as burnable absorbers (with a negligible cycle length penalty 1.13% GWd/ton on average for all the evaluated cases).
- MAs therefore may be used to partially substitute for the burnable absorber in the LWRs, or reduce the concentration of the boric acid in the coolant.
- As presented in the results MAs can be used to increase the negative temperature coefficients. This is a distinct advantage to transmuting MA nuclides in the PWRs.

Thank You