NEUTRONIC INFLUENCE FROM NEW FUEL AND NEW NUCLEAR CLADDINGS IN PWR REACTORS

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Purpose

- To evaluate the neutronic influence caused by the new fuel, U_3Si_2, combined with new claddings, FeCrAl (metallic) and SiC HNS (ceramic) in addition to compare with standards fuel and cladding in PWRs reactors.
- To compare the behavior of fuel element with different fuels, claddings and reactivity control devices.

Motivation

- Previous studies have pointed to the use of other nuclear fuel, such as U_3Si_2 to replace UO_2, and its combination with new accident tolerant claddings.

Presentation Topics

- Simulations

a) Steady state

b) Fuel depletion

- Reactivity control devices (only steady state).

a) Boron

b) Control Rods Insert (CRI)

Introduction

• CLADDINGS AND FUELS

- Claddings in light water reactors (LWR) are so important that core performance is largely limited by the need for protection due to the high level of thermal and mechanical stress that the cladding undergoes.
- Thus, it is important to analyze materials, whether they are new fuels or new claddings, that do not change the geometry of the fuel elements, which maintains or improves the efficiency of the burnup of the fuel without compromising the safety of the nuclear installations.

I. UO_2

II. U_3Si_2

III. Zircaloy(Zirc4)

IV. FeCrAl

V. SiC HNS

Modeling/Parameters

CODE: SCALE 6.0

Modules: CSAS, TRITON

Particles: 10,000

Active cycles: 2,000

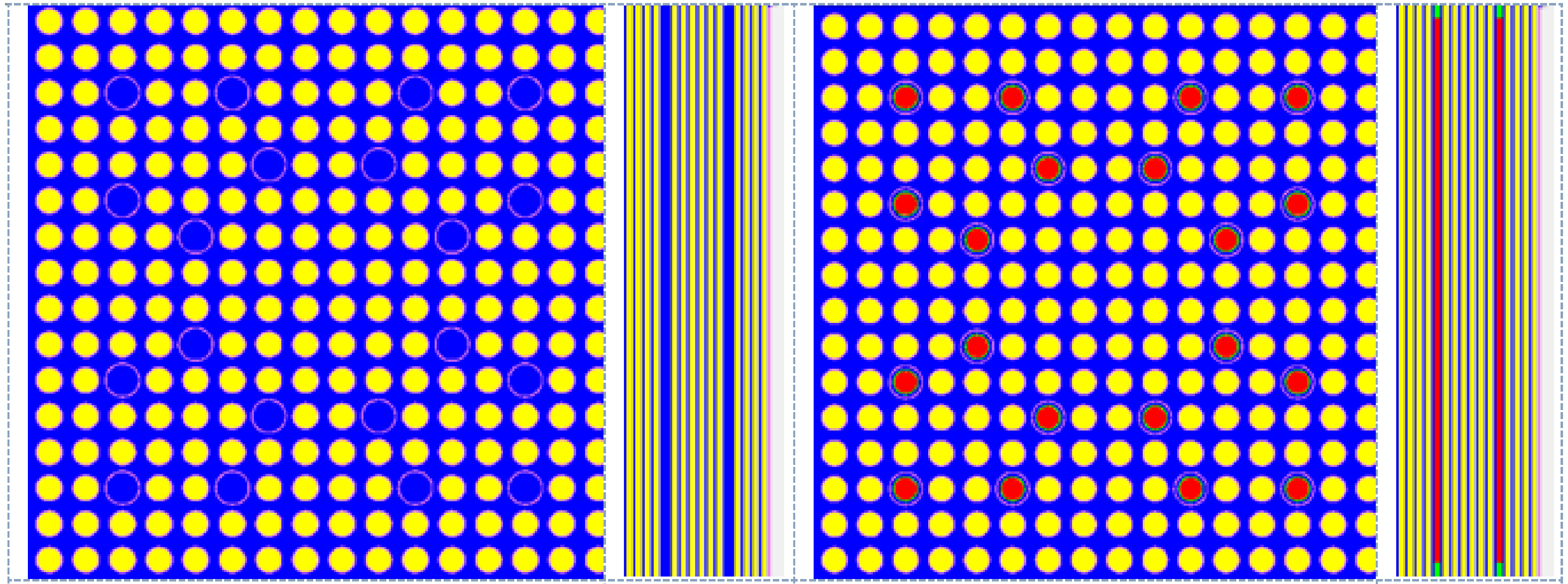
Library: 238 GROUP – ENDF/B-VII.0

Enrichment (%) 4.9						
Fuel	Moderator Boron (ppm)	CRI (cm)	Claddings	Fuel	Moderator Boron (ppm)	CRI (cm)
UO_2	0	0	Zirc4 FeCrAl SiC HNS	U_3Si_2	0	0
	500	372	Zirc4 FeCrAl SiC HNS		500	372

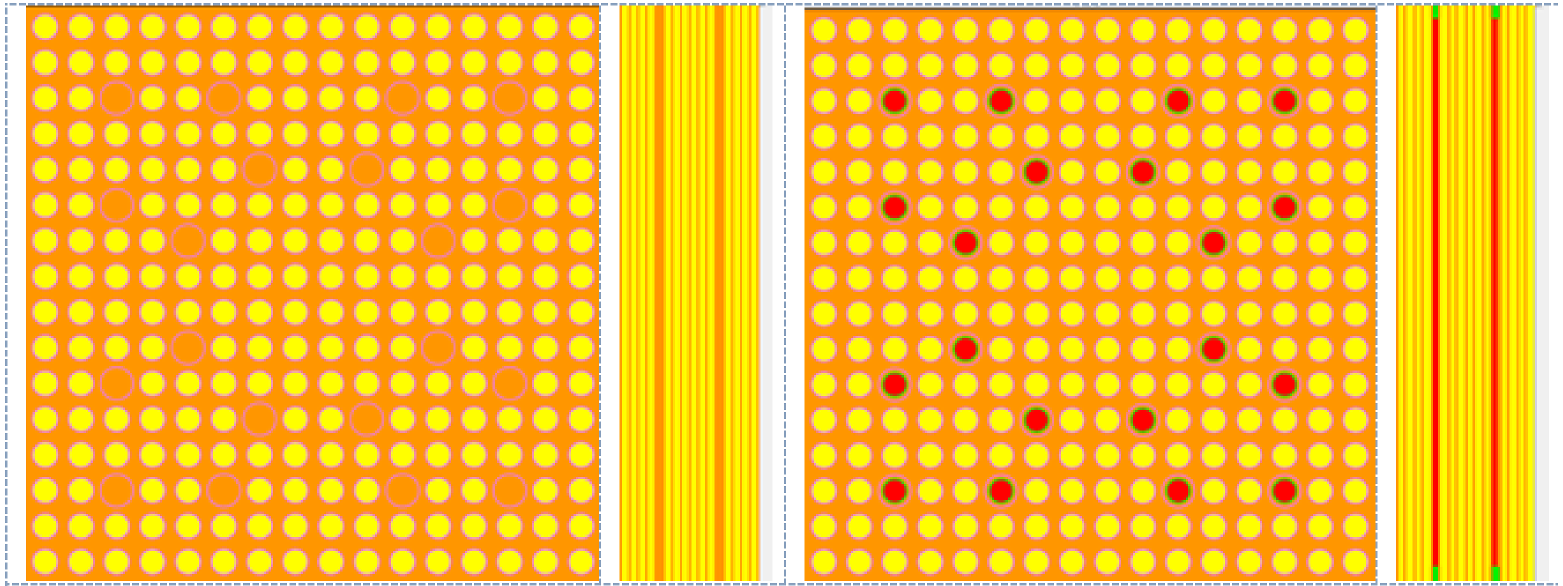
Modeling/Geometry considerations

DESCRIPTION	VALUE	DESCRIPTION	VALUE
Active length fuel rod or guide tube	391.60 cm	Radius coolant inside guide tube	0.6210 cm
Fuel radius	0.4583 cm	Radius guide tube	0.6911 cm
Absorbers radius	0.4435 cm	Pitch (p) distance	1.43 cm
Cladding inside radius absorber	0.4480 cm	Pitch fuel element	23.11 cm
Cladding outside radius absorber	0.5100 cm	Composition of Neutron Absorber	Ag-In-Cd (80-15-5)%
Radius claddings fuel: Zirc4 FeCrAl SiC HNS	0.5385 cm	Control Rods Insert (CRI)	0 cm 372 cm

Fuel rod assembly geometry without boron



(a) Top view without absorbers (b) (c) Top view with 20 absorbers (d)



(a) Top view without absorbers (b) (c) Top view with 20 absorbers (d)

Fuel rod assembly geometry with boron

Modeling/Parameters

MODULE: CSAS

$$\Delta\rho\,(\text{pcm}) = \rho_2 - \rho_1 = \left(\frac{k_2 - k_1}{k_2 \times k_1}\right) \times \frac{1}{\Delta CRI}$$

MODULE: TRITON

To a specific power density constant of 38 W/gU for 386.05 days

A total burnup of 14.67 GWd/tU

$$\Delta k_{\text{inf}}\, fuel(\%) = \left(\frac{k_1 - k_2}{k_1}\right) \times 100$$

Modeling/Parameters: TRITON MODULE

Fuel enrichment (%)	
UO_2 U_3Si_2	4.9 4.9
Fuel with Zirc4 and FeCrAl claddings: Temperatures (K)	
UO_2 U_3Si_2	875 708
Fuel with SiC HNS cladding: Temperatures (K)	
UO_2 U_3Si_2	860 700
Claddings Temperatures (K)	
Zircaloy-4 (Zirc4)	600
FeCrAl	600
SiC HNS	600
Coolant and Moderator temperature	573 K
Specific power density	38 W/gU

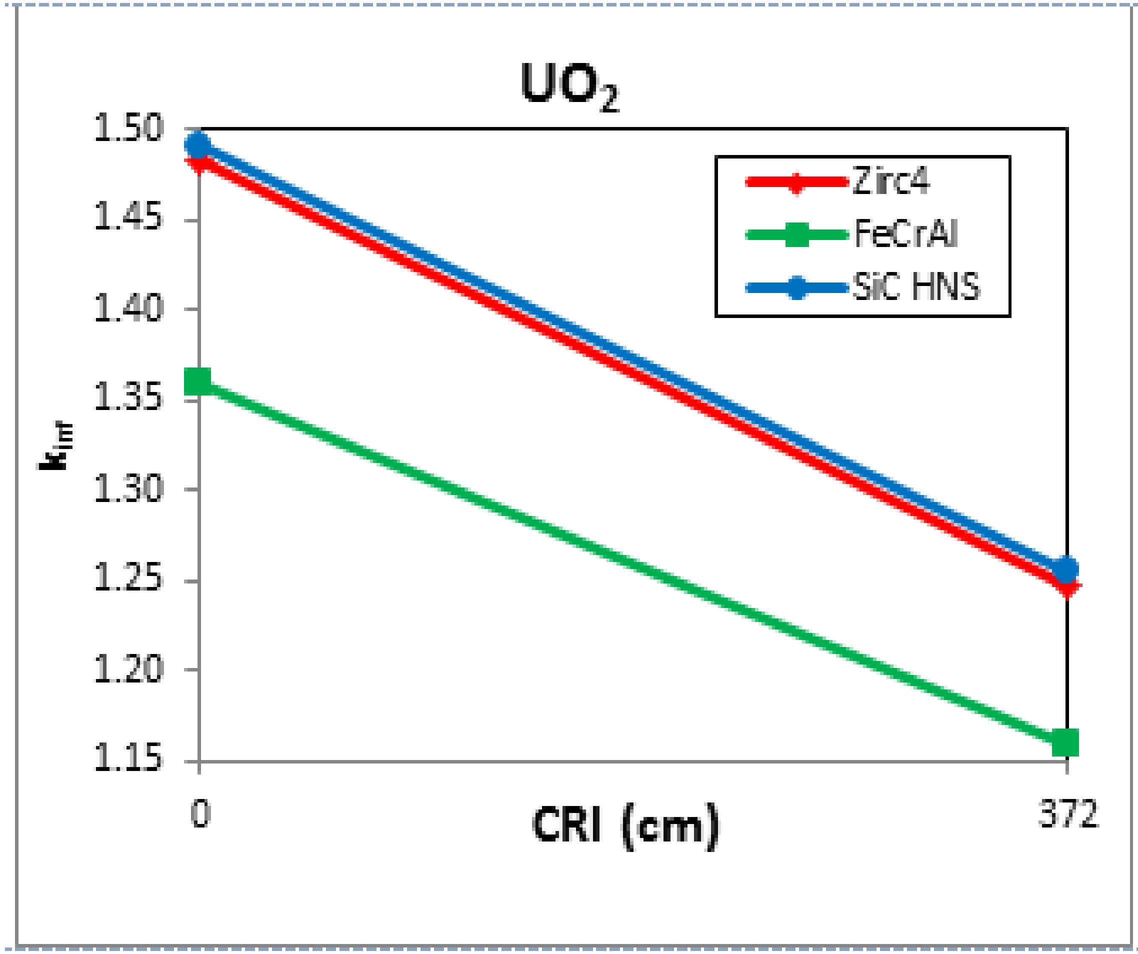
Results

Neutronic Analysis: Steady state

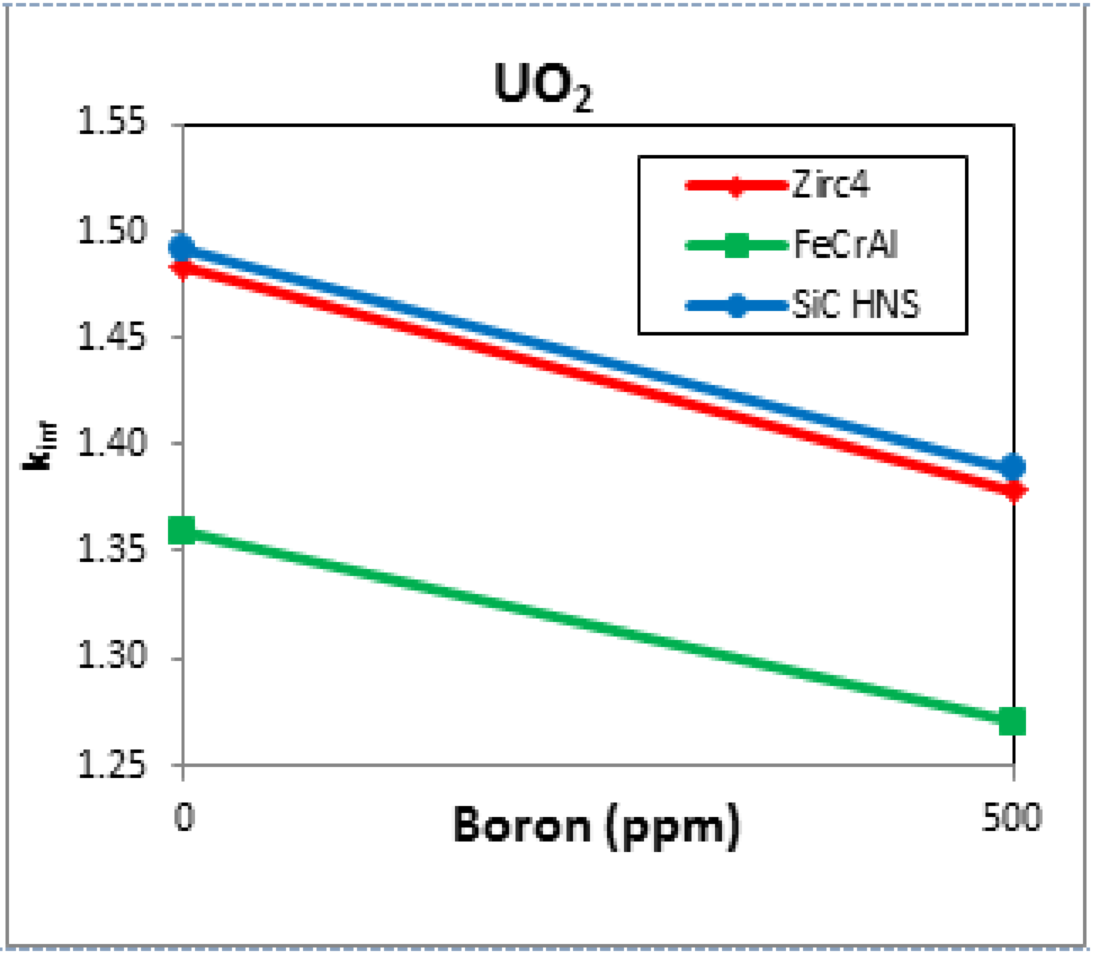
UO_2				U_3Si_2			
Cladding	Boron (ppm)	CRI (cm)	Deviation	Cladding	Boron (ppm)	CRI (cm)	Deviation
	0	0			0	0	
Zirc4	1.48321		0.00013	Zirc4	1.48465		0.00012
FeCrAl	1.35917		0.00012	FeCrAl	1.37562		0.00013
SiC HNS	1.49152		0.00013	SiC HNS	1.49240		0.00013
Cladding	Boron (ppm)	CRI (cm)	Deviation	Cladding	Boron (ppm)	CRI (cm)	Deviation
	0	372			0	372	
Zirc4	1.24657		0.00019	Zirc4	1.25896		0.00018
FeCrAl	1.15861		0.00016	FeCrAl	1.18144		0.00019
SiC HNS	1.25445		0.00016	SiC HNS	1.26635		0.00017
Cladding	Boron (ppm)	CRI (cm)	Deviation	Cladding	Boron (ppm)	CRI (cm)	Deviation
	500	0			500	0	
Zirc4	1.37821		0.00012	Zirc4	1.38347		0.00014
FeCrAl	1.27036		0.00012	FeCrAl	1.28895		0.00012
SiC HNS	1.38813		0.00013	SiC HNS	1.39291		0.00012
Cladding	Boron (ppm)	CRI (cm)	Deviation	Cladding	Boron (ppm)	CRI (cm)	Deviation
	500	372			500	372	
Zirc4	1.13182		0.00019	Zirc4	1.14764		0.00016
FeCrAl	1.05930		0.00015	FeCrAl	1.08361		0.00014
SiC HNS	1.14056		0.00019	SiC HNS	1.15633		0.00018

RESULTS

Comparisons between reactivity control devices for same fuel



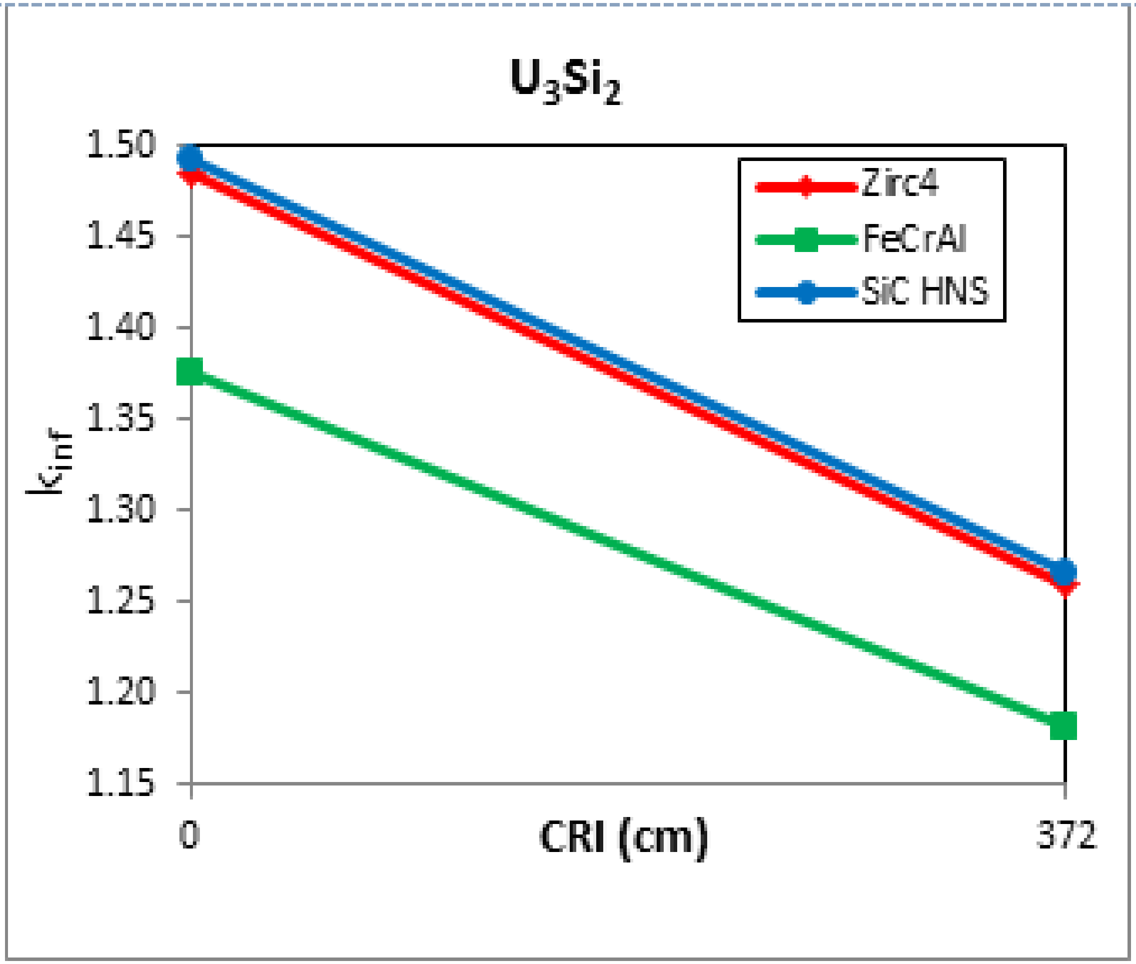
(a)



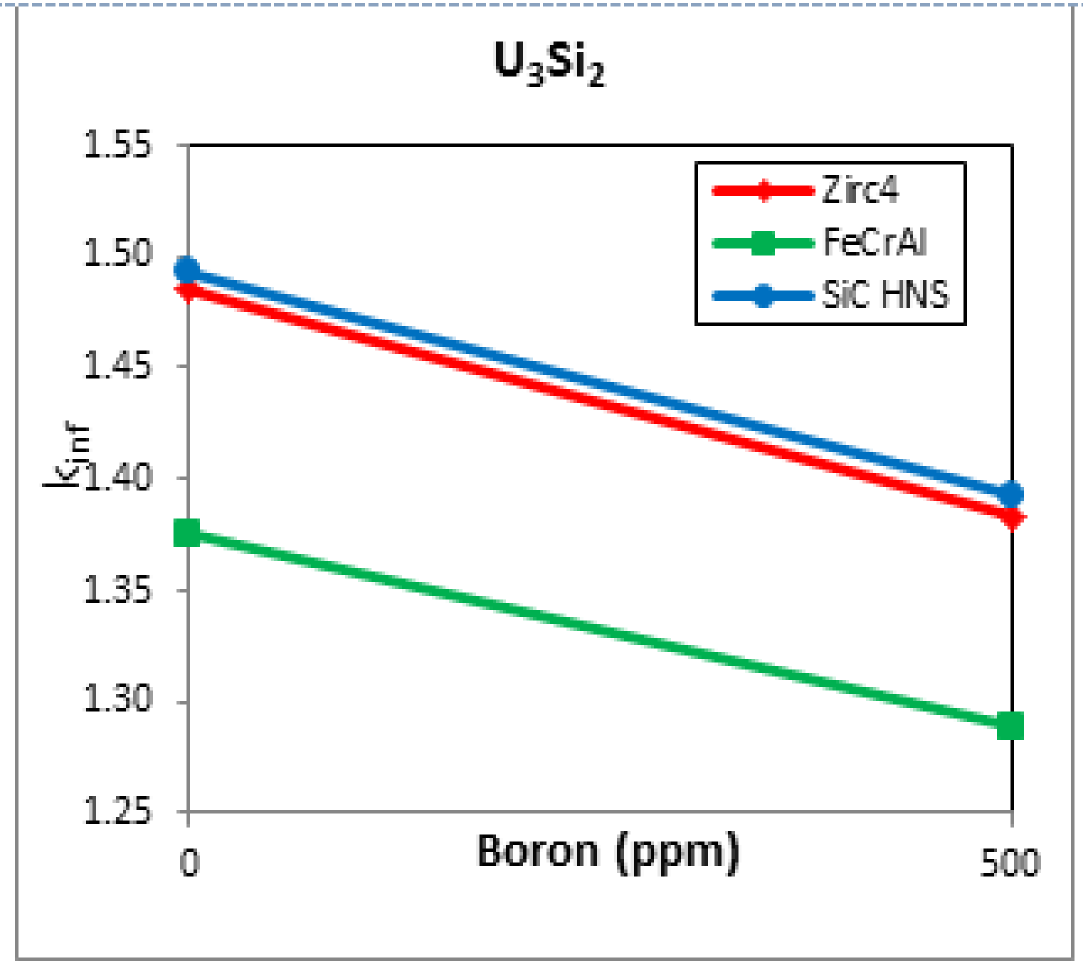
(b)

RESULTS

Comparisons between reactivity control devices for same fuel



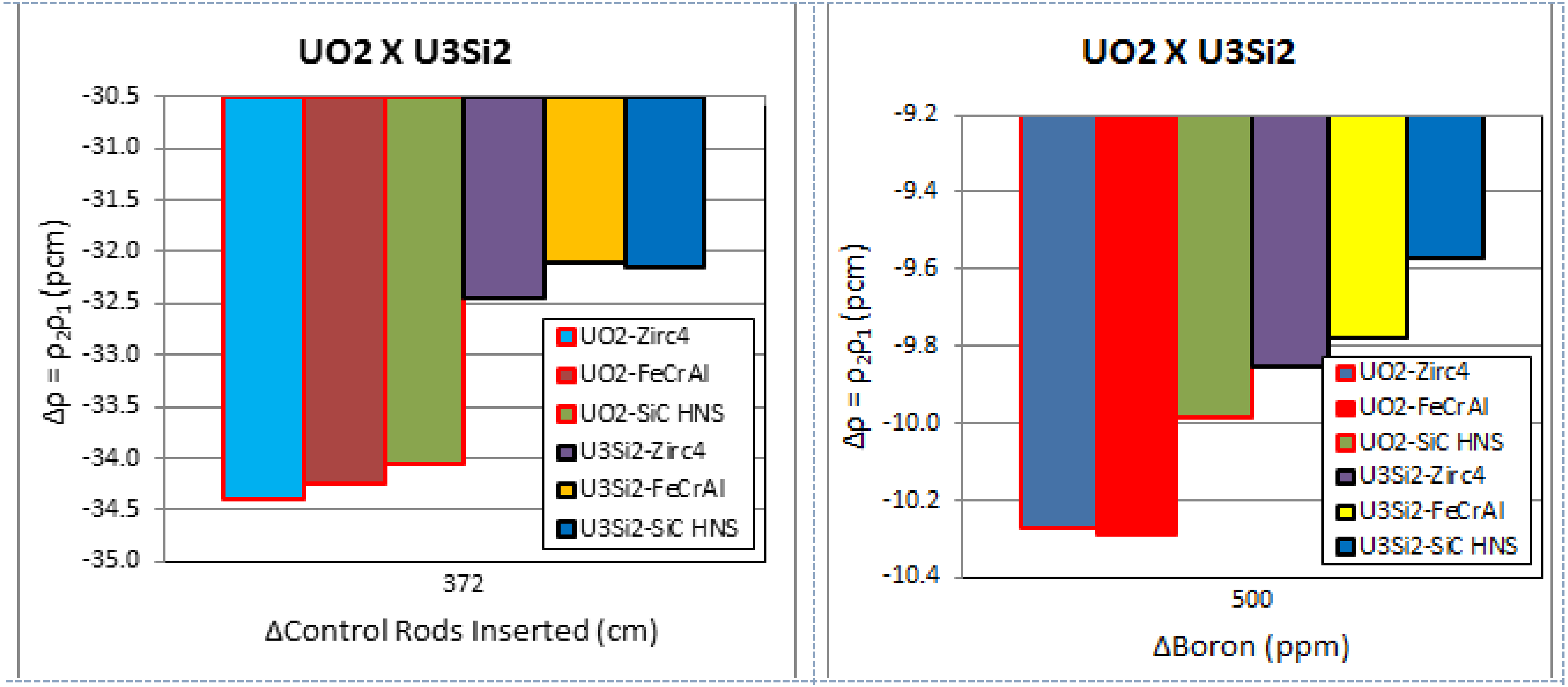
(a)



(b)

RESULTS

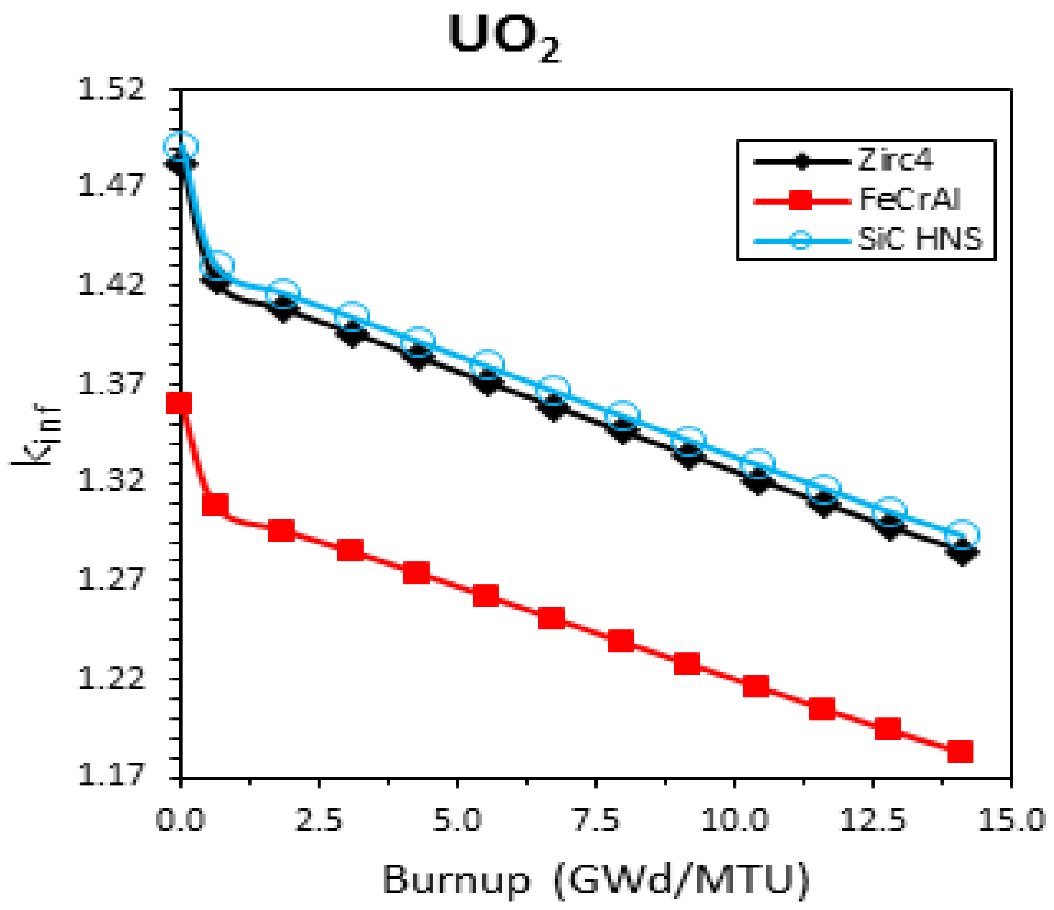
Comparison between reactivity control devices and the combinations fuel + cladding.



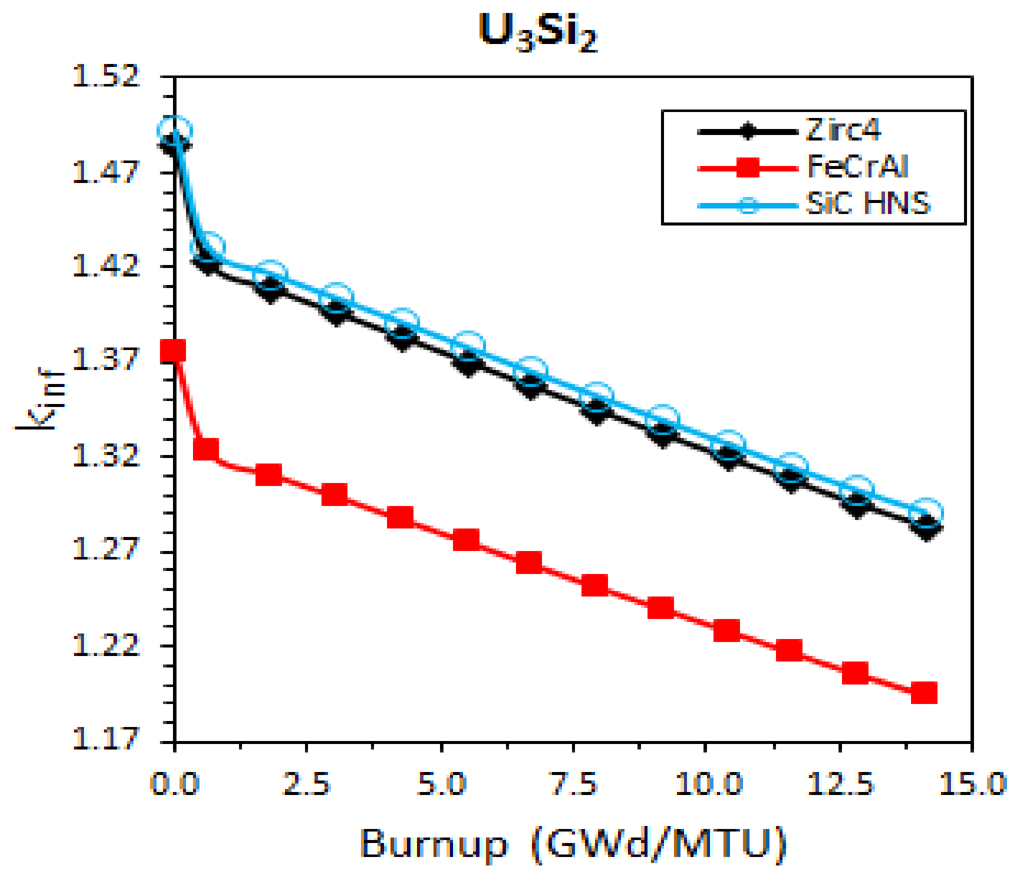
(a) (b)

RESULTS

Neutronic Analysis: Fuel depletion



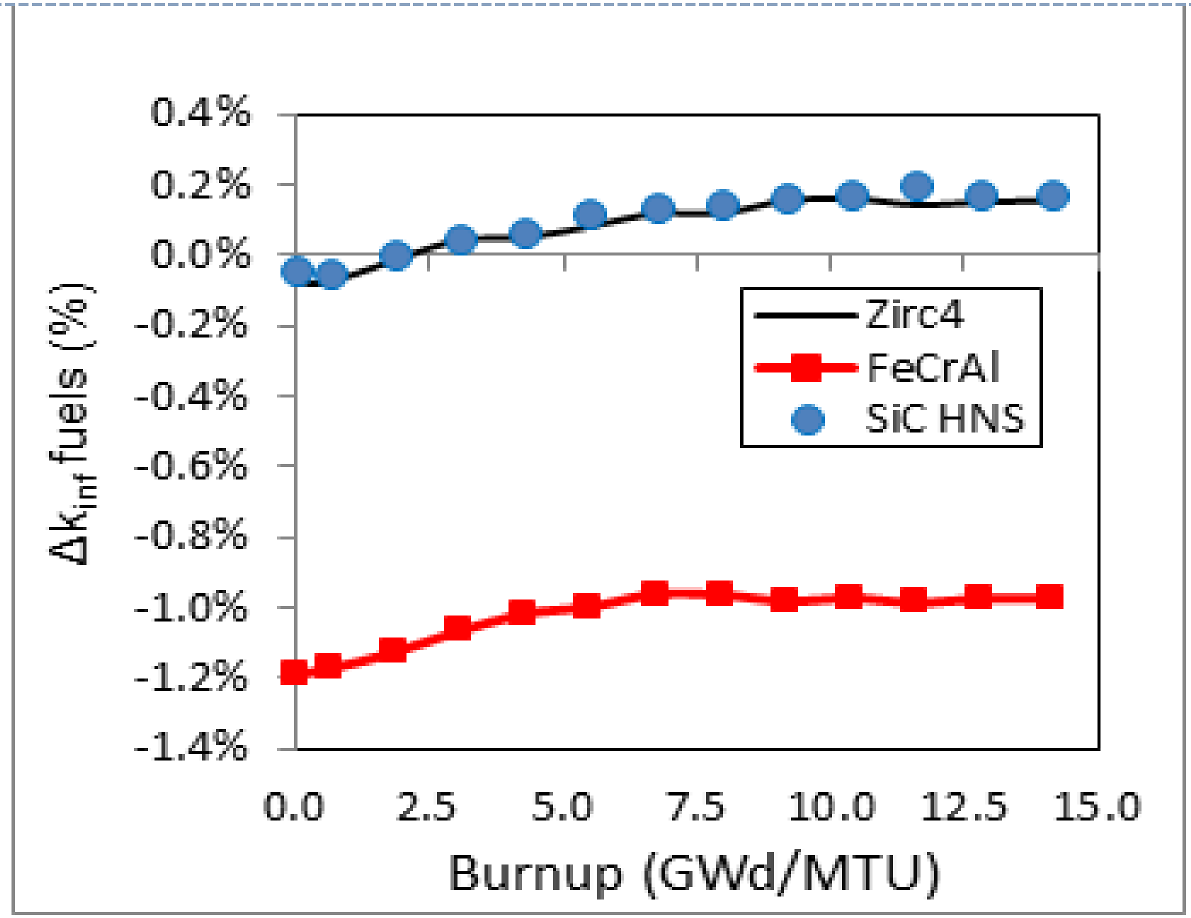
(a)



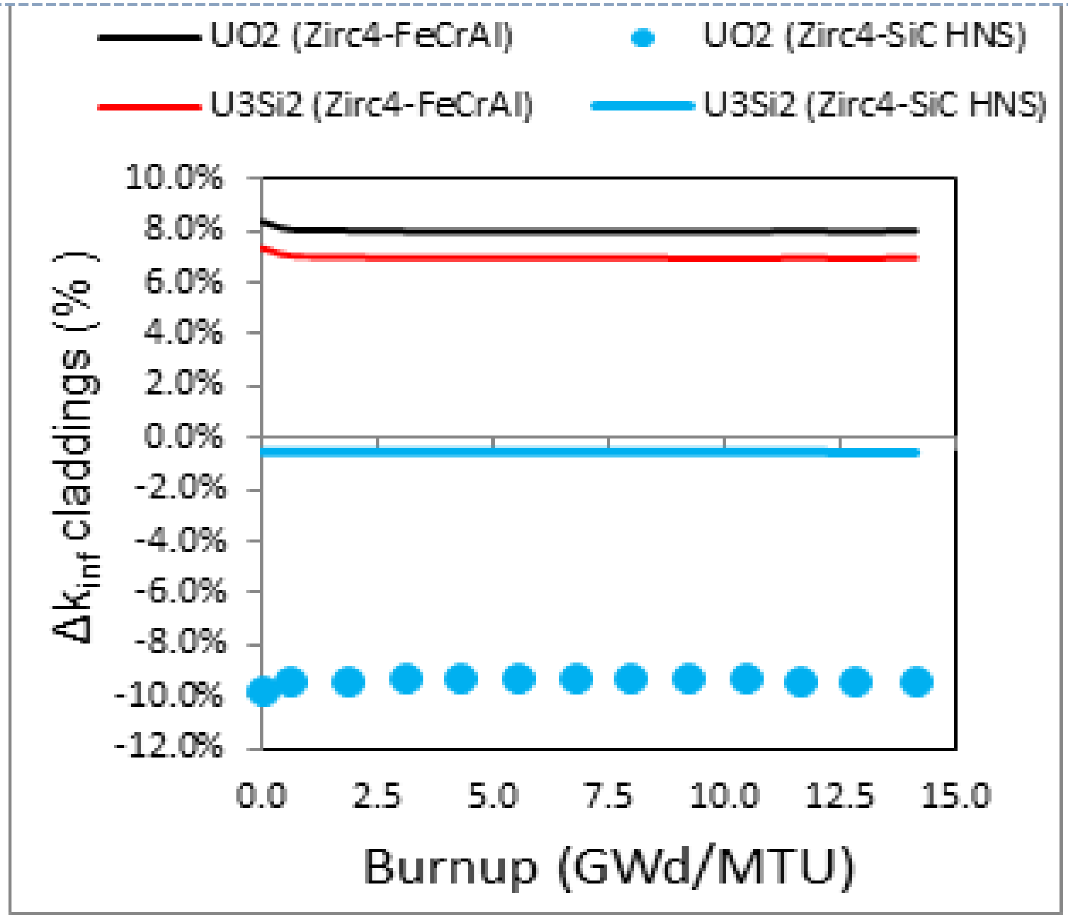
(b)

RESULTS

The percentage difference between the neutron infinite multiplication factor values.



(a) Fuel comparisons



(b) Cladding comparisons

Conclusions/Future studies

- This neutronic study, it was shown that there is no discrepancy between UO_2 (standard) and U_3Si_2 (proposed)

- For the claddings, in all analyzes on which the fuel element has been subjected, regardless of the combination (fuel + cladding), the ceramic cladding, called SiC (silicon carbide) reinforced with Hi-Nicalon type S (SiC HNS) fibers, presented superior performance in relation to cladding, Zirc4 (standard) and FeCrAl (proposed).

- Although this study is still in early stages and is aware of the need for further studies, including neutronics and thermal-hydraulics, since the k_{inf} values reached very high values for a typical Angra 2 fuel element, thus demonstrating a latent need for hit an enrichment or adequate amount of boron in the Angra 2 core. In addition to other studies that can prove the feasibility of application of U_3Si_2 (proposed) and cladding SiC HNS (proposed).

- Still, it is important to note that in none of the neutronic parameters evaluated in this work, such materials have been disapproved, which shows that they have consistent and important properties in possible applications in PWR reactors around the world.

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