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Neutronic Evaluation of Th as Absorber on Reprocessed Fuel Bundles on DUPIC Fuel Cycle

Michel C. B. de Almeida[1],
Rochkhudson B. de Faria[2], Clarysson A.
M. da Silva[1] and Cláubia Pereira[1]

[1] blendernardo@yahoo.com, *Universidade Federal de Minas Gerais. Av. Antônio Carlos, 6627, Campus UFMG PAC 1 – Anexo Engenharia, Pampulha, 31270-901 Belo Horizonte, MG*
[2] rochkhudson.faria@ufes.br, *Departamento de Educação e Ciências Humanas. Centro Universitário Norte do Espírito Santo– CEUNES. Universidade Federal do Espírito Santo (UFES). BR 101, km 60, Litorâneo, CEP. 29932-540, São Mateus, ES, Brazil.*

1. Introduction

Optimization processes for nuclear fuel utilization is a subject widely related in the nuclear fuel cycles topics since the early decades of nuclear power development. Reprocessing method has been taken in account to enhance the cycle efficiency specially in sense of reduce actinide amounts such Pu from UO_2 PWR spent fuel [1]. In this sense, Korea Atomic Energy Research Institute (KAERI), Atomic Energy Canada Limited (AECL) and U.S. Department, developed a concept called Direct Use of Spent PWR Fuel in CANDU (DUPIC) as proposal for LWR-CANDU fuel cycles [2].
The DUPIC cycle is a set of reprocessing techniques where the most promising is the Oxidation and Reduction of Oxides method (OREOX). The OREOX method is a dry process that use redox reaction cycles in pyrochemical process in oxidation reduction furnaces having no need of solvents and which make the proliferation impossible due no extraction or separation of fission content in fuel material [2-7].
CANDU reactors employ natural uranium (NU) –sintered UO_2 pellets, as fuel which makes this advanced cycle possible because the reprocessed fule (RF) from PWR spent fuel has a fissile content around 1.5%, depending the burnup [2], but safety design is required for reactivity control [8–10]. Due CANDU reactors peculiarity, it is not common the use of burnable poisons (BPs), but fuel materials with higher amount of fissile content may consider BPs without causing major problems in fuel burnup [11].
In previous works [12,13], the assessment of BPs and fuel savings was considered in fuel design approach. In this work thorium has considered as absorber material since the harder neutron spectrum in RF is favorable for ^{233}U production [14]. The aim is to verify possible advantages when thorium is attached in the DUPIC fuel cycle. The deterministic module of SCALE 6.0, NEWT, [15] was used for spectrum and four-factors for neutronics approaches.

2. Methodology

Calculations were performed using NEWT code by composing 50×50 discretization matrix for a fuel cell 28,575cm diameter of a standard 37-element CANDU-6 fuel bundle. Geometry and material data used for the 2D model (Fig. 1) are described in [16]. The rods were subdivided to be a length shorter than neutron free mean path on deuterium to obtain an accurate result on fuel region. The case for thorium evaluation consider 4 and 7 pins substitutions as shown in Fig. 1. The convergence error was set to 10^{-5}.

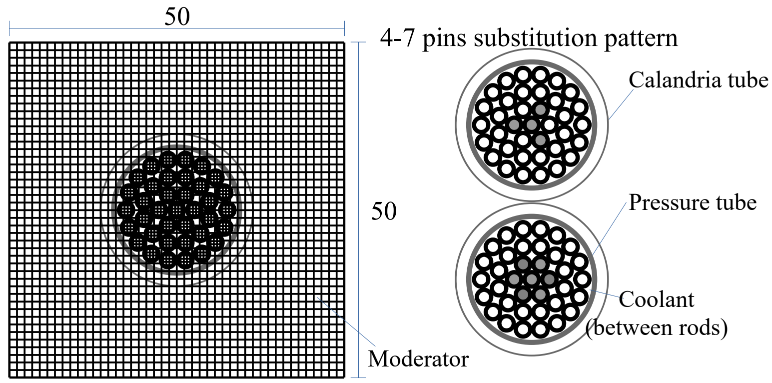

Fig. 1. CANDU-6 fuel cell NEWT model scheme and 4-7 absorbers pins setup.

The thorium pins was made as a solid rod of ThO_2 with a physical density of 10.0 g·cm^{-3}.

3. Results and Discussion

In Fig. 2 is depicted the normalized neutron flux spectra for NU and RF (scaled by NU max flux). One can see the hardening expected due presence of Pu isotopes and minor actinides. In Fig. 3 is shown the comparison of RF bundle (red line) and the bundle of RF (black line labeled "RF pins") with thorium pins (gray line labeled as "Thorium pins"). The fact of interest is that the use of Th in the center region reveal a gain in the thermal flux intensity on fuel region, specially with 7 pins, that even with less fuel material potentiality improve fuel consumption and increase fission power.

Table I is a summary of the four factor parameter of system criticality. In fact of the hardening on neutron energy spectrum the fission density tend to be lower than NU but in other hand the higher fissile content results in a bigger system η, naturally leading to higher values of the system multiplication factor.

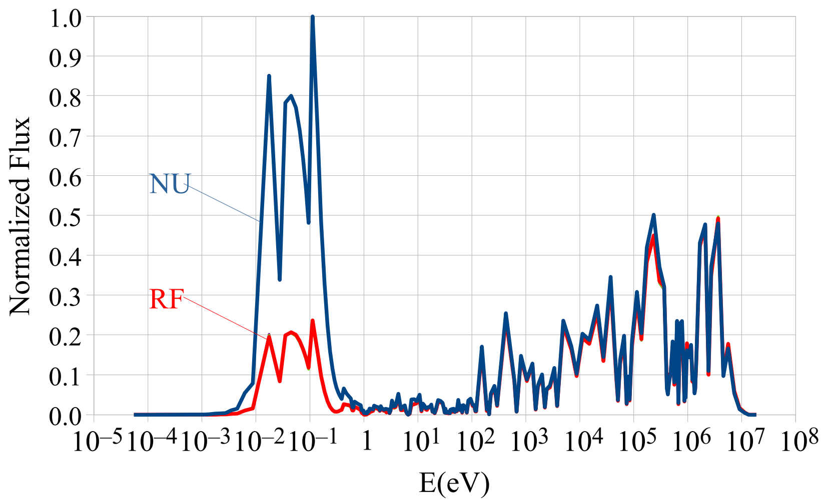

Fig. 2. Normalized flux spectrum comparison NU-RF.

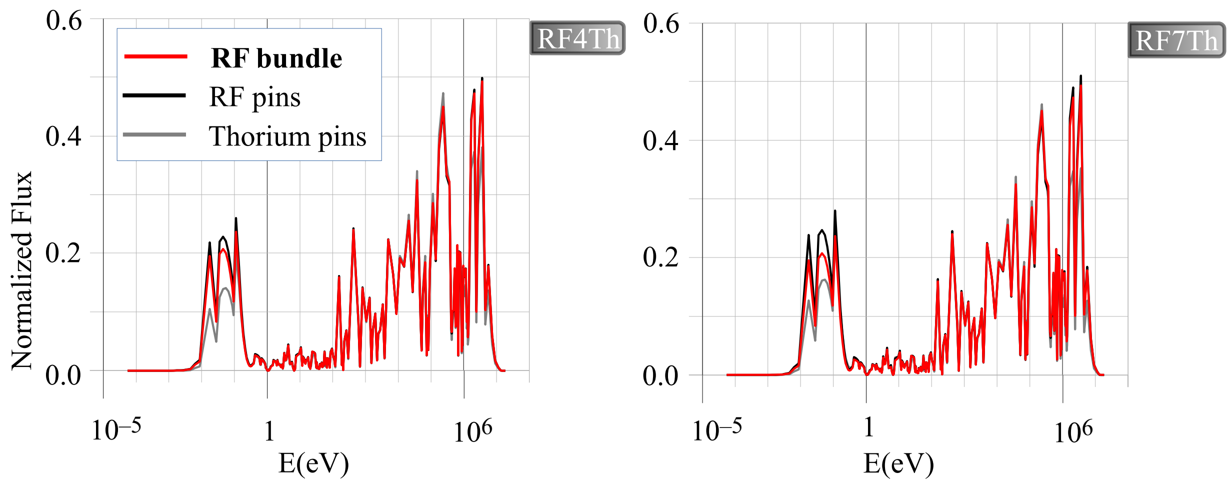

Fig. 3. Normalized flux spectrum comparison NU-RF.

Table I. Criticality and four factors summary.

	NU	RF	RF4Th	RF7Th
k_{eff}	1.04214252	**1.21192096**	1.18748132	1.16437771
k_{∞}	1.04230800	**1.21202200**	1.18757700	1.16447500
η	1.31363700	1.49199700	1.46613600	1.43878300
f	0.86656200	0.92664000	0.92599300	0.92528400
p	0.84196300	0.77314700	0.77794100	0.78242600
ε	1.08749700	1.13388500	1.12443200	1.11793500

For *p* and *ε* variations, one can note the *p* factor is lower on RF due the presence of several isotopes that can actuate as neutron absorbers withing the fuel rod that could cause the reduction on resonance escape probabilities. The fast fission factor decrease is due the substitution of RF because the fast fission contribution due throrium are negligible if compared with the other actinides present in the fuel bundle.

4. Conclusions

The DUPIC cycle is presented as proposal for advanced fuel cycle along the decades as a potential improvement on resources utilization. As expected the RF shown expressive higher values on criticality due the higher fissile content and lower thermal flux. As it contais several actinides and among them Pu isotopes, it can be a threat for security and reactor stability. The use of Th was proposed because the observed hardening on neutron spectrum of RF can be favorable for ^{232}Th to ^{233}Pa conversion, so ^{233}U production, which can result in a boost on fuel resource. In this context the aim was verify the potential use of thorium as absorber to reach a suitable CANDU neutronics requirements.

A fact of interest is that the replacement of RF pins on fuel bundle reduces the fuel requirements keeping the system supercritical. In future works the determination of influence of power generation will be assessed.

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