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Neutronic and Transmutation Analysis for Different Fuel Matrices in ADS

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1. Introduction

The Nuclear Engineering Department (DEN) at UFMG has been perfomed many research on transmutation of transuranics and reprocessed fuels using hybrid systems such as the ADS reactor [1-9]. Transmutation of minor actinides (MAs), represents an important topic in current works [10-12]. MAs correspond to a small fraction of LWR spent nuclear fuel, however, americium, curium, neptunium and plutonium dominate the total radioactivity of the spent fuel after a few hundred years of storage.[13]. The transmutation of transuranics can reduce conditions in the repository and safety impacts in the spent fuel disposal. Studies showed that different nuclear reactors can be used for MAs transmutation, such as the Accelerator Driven System (ADS) [4, 7, 14-23]. There are many features in ADS reactor that can affect the efficiency of reducing MAs to be investigated, such as different nuclear fuels, coolant materials and neutron flux in the core regions.

The typical ADS reactor system is based on a subcritical core cooled by liquid metal coupled to a spallation source [23, 24]. The subcritical core is therefore not able to sustain a fission chain reaction, therefore the spallation source compensate the neutron flux required to maintain the reactor in operational condition. In the external source, neutrons produced by the collision of 1.0 GeV energy proton beam with the heavy metal spallation target multiplies the core neutron population by a factor of $1/(1-k_{eff})$ [25]. In addition, to increase the neutron population fissile isotopes are inserted in the reprocessed nuclear fuel such as plutonium and uranium. Fertile isotopes (^{232}Th and ^{238}U) also can be mixed in the nuclear fuel to breed fissile material by neutron capture, in order to keep the system criticality [8].

Therefore, the aim of this work was to design an ADS reactor dedicated to MAs transmutation using a conceptual subcritical core [23], also to evaluate the criticality behavior and thorium breeding using two different nuclear fuel matrices, based on uranium-233 spiked with thorium and spent fuel reprocessed by GANEX [26]. The ADS geometry proposed have three regions described as Inner Core (IC), Outer Core (OC) and Breeder Core (BC) that provides multipurpose of applications to be investigated according to the chosen nuclear fuel materials and fuel rods configuration in each region.

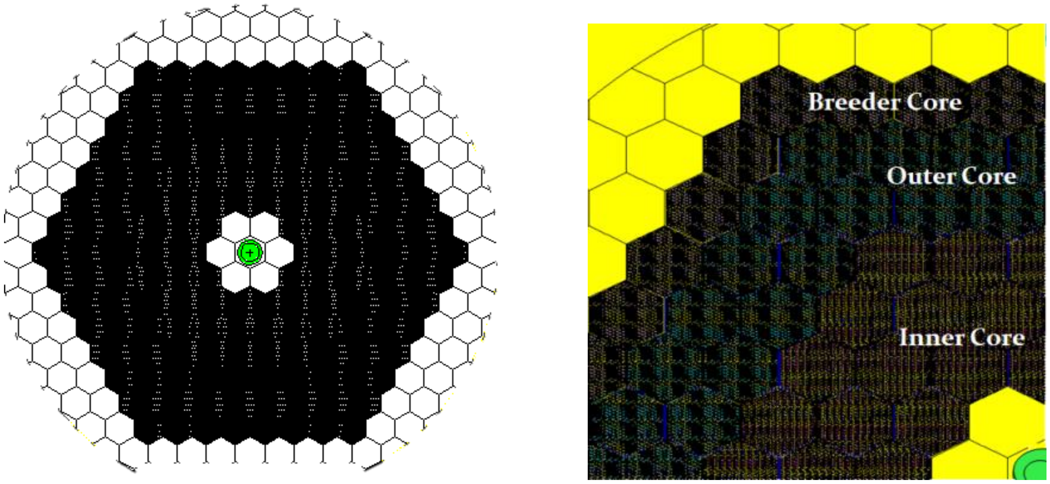
2. Methodology

The ADS reactor systems were carried out in two different steps: The first step of this study was to set and verify geometry specifications, and perform the fissile material adjustments needed to achieve the effective multiplication factor (k_{eff}) of ≈ 0.98 [27] by using nuclear fuels based on thorium [23]. The second step was to assess the MAs transmutation amount and the neutronic behavior of the spent fuel reprocessed by GANEX and spiked with thorium at the Inner and Outer Core and also the thorium regeneration. The Breeder Core was loaded exclusively with thorium to evaluate the ^{233}U production.

The first nuclear fuel choosed was uranium-233 spiked with thorium, in order to balance the fissile material during burnup. The second nuclear fuel was reprocessed by GANEX and spiked in thorium. The spent nuclear fuel matrix was obtained from a PWR standard fuel (33,000 MWd/T burned) with initial enrichment of 3.1% left by 5 years in the pool. The burnup was performed in ORIGEN 2.1 code [28]. The fuel obtained after reprocessing has about 65% of fissile isotopes (^{233}U, ^{235}U, ^{239}Pu and ^{241}Pu) and generates high values of criticality. The reprocessed fuel has been spiked with thorium to reduce the percentage of fissile isotopes and consequently decrease the initial criticality of the system [18].

Geometry

The ADS core consists in a cylinder iron tank of 41.47 m³ volume filled with 162 hexagonal nuclear fuel assemblies and cooled by Pb. As previously cited, the core has three regions (Inner Core, Outer Core and Breeder Core) in which the specifications are described in Table I. The hexagonal assemblies has different quantities of fuel pins (thin rods) and pitches (distance between pins). Fig. 1 shows the radial ADS core view (a) and the respective core regions (b). The nuclear fuel pin radius is 0.365 cm and the active length is 150 cm with a void in the center with 0.1 cm diameter. The external neutron source contains a cylindrical Pb spallation target with radius of 10 cm, placed at the core center. HT9 [29] was used as cladding material, and the nominal power was 1500 MWth.



(a) (b)

Figure 1: ADS core: (a) axial core view with nuclear fuel assemblies in black, coolant and reflector in white and spallation target in green. (b) hexagonal core regions.

Table I: Reactor core specifications [1].

Core Regions	Inner Core	Outer Core	Breeder Core
Fuel pin/assembly	331	397	397
Number of fuel assemblies	54	66	42
Pitch (mm)	12.43	11.38	11.38

Simulation Codes

MCNP5 [30] code was used to neutron calculations and to describe the geometry, temperatures and materials. The isotopes cross section was obtained in NJOY [31] code using JEFF-3.2 library [32] at the temperatures 600 K (coolant, spallation target and reflector), 900 K (cladding) and 1200 K (nuclear fuel). The burnup was performed using ORIGEN 2.1 [33] and MONTEBURNS 2.0 [34] in 40 steps during 10 years.

3. Expected Results

The expected results will show the behavior of the effective multiplication factor during the reactor time operation, also the amount reduced of MAs in the nuclear fuel. After the beging of cycle the ^{233}U production by thorium breeding contributes to the fissile material available in the nuclear as shown in previous studies [35]. The thorium breeding ratio for each reactor zone will be obtained in kilograms. The transmutation will present the amount of MAs reduced in the different core regions.

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