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Thorium and reprocessed fuel utilization in an accelerator-driven system

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ABSTRACT

The aim of this study is to investigate the nuclear fuel evolution and the neutronic parameters of a lead-cooled ADS used for fuel breeding and transmutation of reprocessed fuel. The fuel used in some rods was $^{232}ThO_2$ for ^{233}U production. In the other rods, a mixture based upon Pu-MA was used. It was obtained from PWR-spent fuel, reprocessed by GANEX, and finally spiked with thorium or depleted uranium. In order to simulate the neutronic aspects, Monteburns 2.0 code (MCNP/ORIGEN 2.1) was used. The results indicated that the simultaneous use of $^{232}ThO_2$ and reprocessed fuel allowed the ^{233}U production without initial requirement of ^{233}U enrichment and the reduction in the amount of high radiotoxicity isotopes from reprocessed fuel.

1. Introduction

In recent years great interest has been displayed for accelerator-driven subcritical systems (ADS) to produce energy, nuclear fuel regeneration and transmutation of radioactive wastes in a cleaner and safer way. Pioneers in this revival have been Furukawa et al. (1982), Bowman et al. (1992) and Rubbia (Carminati et al., 1993). Similar ideas were proposed almost 50 years ago (Lewis, 1952; Lawrence et al., 1960; Atta et al., 1976; Oak Ridge National Laboratory, 1977).

In an ADS, an accelerator is coupled to a subcritical core loaded with nuclear fuel. The accelerated particles are injected into a spallation target that produces neutrons with high energies. The spallation process is a nuclear reaction where high-energy particles hit target nuclei of heavy elements. The main purpose of spallation target in an ADS is to provide the primary neutron flux for driving the fission process in the subcritical core.

The feasibility of thorium utilization in ADS has been investigated (Carminati et al., 1993; David et al., 2000; Ismail et al., 2008). There are many reasons for the resurgence of the interest in the thorium fuel cycle nowadays. Thorium is about three times more abundant than uranium and is distributed in nature as an easily exploitable resource in many countries. The main issue verified in the adoption of this fuel is the initial enrichment requirement, since the use of natural thorium (^{232}Th) is not feasible due to the very low values of achieved criticality.

In previous studies, the same ADS design was investigated for the use of a mixture based on ^{232}Th and ^{233}U (Barros et al., 2011), and for combined use of thorium-based fuel rods (^{232}Th + ^{233}U) and spent fuel rods (Barros et al., 2012). A complete account of these studies can be found in Ref. (Barros, 2014).

In this study, the goal is to investigate the potentials of fissile breeding and high radiotoxicity isotopes transmutation for an ADS loaded with thorium and reprocessed fuel. The simultaneous use of thorium and reprocessed fuel allows to get appropriate values of criticality and still the recycling of reprocessed fuel. The fuel used in some rods was $^{232}ThO_2$, the fuel used in the other rods was spent nuclear fuel reprocessed by GANEX (Group ActiNide EXtraction) reprocessing (Miguirditchian et al., 2008; Warin, 2010) and spiked with thorium. For comparison purposes, it also used reprocessed fuel spiked with depleted uranium. The neutron spectra were obtained at BOL (Begin of Life) and the criticality and fuel evolution were investigated during ten years, at 515 MW of thermal power. During this time, the ^{233}U production and the isotopes transmutation were evaluated.

2. Methodology

2.1. Computer code description

Monteburns 2.0 (Poston and Trellue, 1999) was used to couple MCNP (Briefmeister, 2005) with ORIGEN2.1 code (O.R.N. Laboratory, 1991). The neutron flux over the fuel obtained from

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the MCNP output is used by the ORIGEN2.1 to perform the burnup. Then the isotopic composition obtained by the ORIGEN2.1 goes back to the MCNP to calculate the new flux with the new composition submitted to the neutron source and so on until finishing each cycle.

In Monteburns code, the value of the multiplication factor for an external source definition (spallation source) is calculated from the value of the net multiplication obtained from the MCNP output file (Poston and Trellue, 1999):

$$k = \frac{fmult - 1}{fmult - 1/v} \quad (1)$$

where:

$fmult$ = net multiplication in the system, and

$v = \frac{\text{weight of source neutrons gained in fission}}{\text{weight of neutrons lost to fission}}$.

2.2. System parameters

The simulated geometry is shown in Figs. 1 and 2. It includes the lead spallation target (central cylinder), the subcritical core and the reflector. The accelerator tube has a radius of 1.5 cm, and the axial position is in the center of the target. The spallation source is represented by a cylindrical neutrons source (in the central cylinder) with a characteristic spectrum of spallation reactions produced by a protons beam of 1 GeV. More details of the spallation source can be found in Barros et al. (2010).

The simulated core was a cylinder of 12.0 m^3 filled with a hexagonal lattice formed by 156 fuel rods. The fuel rod radius is 3 cm and rod height is 400 cm. The fuel used in 120 rods was $^{232}ThO_2$, the initial mass of $^{232}ThO_2$ was 11,900 kg. The fuel used in the other 36 rods was reprocessed fuel spiked with thorium and depleted uranium. The ratio between the number of thorium fuel rods and reprocessed fuel rods and the positions of the reprocessed fuel rods were determined to maximize the amount of thorium and achieve appropriate criticality values.

The reprocessed fuel was obtained from spent fuel discharged from the Brazilian PWR ANGRA-I, with initial enrichment of 3.1%. This fuel was burned in ORIGEN 2.1 code for three cycles, with the burnup of approximately 11.000 MWd/t in each cycle, following the ANGRA-I power historic of real cycles 1, 2, and 3. More details of this spent fuel can be found in Cota and Pereira (1997). After cooling by five years, the spent nuclear was reprocessed by GANEX technique. The GANEX process developed by *Commissariat l'energie atomique et aux energies alternatives* (CEA) for the reprocessing of Generation IV spent nuclear fuels is composed of two extraction

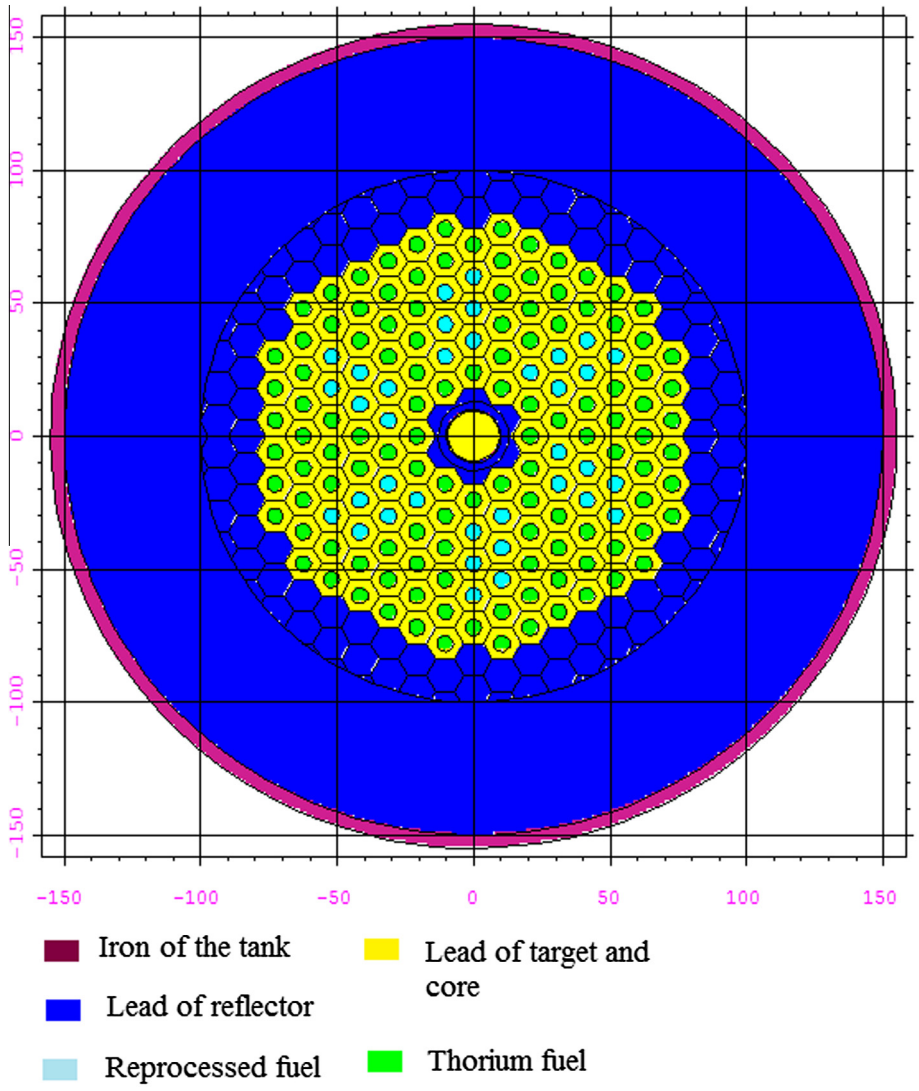

Fig. 1. Horizontal cross section of the ADS.