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Evaluation of subcritical hybrid systems loaded with reprocessed fuel

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ABSTRACT

Two subcritical hybrid systems containing spent fuel reprocessed by Ganex technique and spiked with thorium were submitted to neutron irradiation of two different sources: ADS (Accelerator-driven subcritical) and Fusion. The aim is to investigate the nuclear fuel evolution using reprocessed fuel and the neutronic parameters under neutron irradiation. The source multiplication factor and fuel depletion for both systems were analysed during 10 years. The simulations were performed using MONTEBURNS code (MCNP/ORIGEN). The results indicate the main differences when irradiating the fuel with different neutron sources as well as the most suitable system for achieving transmutation.

1. Introduction

In recent years, accelerator-driven subcritical (ADS) and fusion-fission systems have been proposed to produce energy, transmute radioactive wastes and fertile to fissile fuel conversion in a future cleaner and safer way. However, both systems have differences in the neutronic parameters, geometry and the fission power. These differences make a bit difficult the comparison of the source effect over the fuel irradiated. To compare the transmutation effectiveness of different systems, one has to compare the system performance at the same power (Salvatores, 2009). Therefore, in this study, two different systems are proposed. One based on a system designed to an ADS (Barros et al., 2012) called system 1 and another designed to a Fusion-Fission system based on inertial confinement (Kramer, 2010) called system 2. Each system has their particular characteristics such as materials, geometries, volume of fuel, fission power and neutron source. The idea is to compare them under the same conditions when submitted to different neutron sources. In other words, each system, 1 and 2, will be simulated three times changing the neutron source: the first one with the fusion source, the second one with evaporation source and the last one as it was a fast reactor using just the fission chain. Then the transmutation results of the reprocessed fuel spiked (RFS) with thorium are compared to each system under same conditions adapting the neutron source to each system.

The loaded fuel is spent fuel from a PWR standard fuel (33,000 MWd/T burned), with 3.1% of initial enrichment left by 5 years in the pool and reprocessed by Ganex process (Cota and Pereira, 1997; Warin, 2010). Then, the reprocessed fuel is spiked with thorium. One reason to choose thorium is that it is a potentially valuable energy source since it is about three to four times more abundant in the earth's crust than uranium, besides being a widely distributed natural source which is readily accessible in many countries (American Nuclear Society, 2006).

In addition, using a fast neutron spectrum is possible to induce fissions over the fissionable actinides reducing their contribution to radiotoxicity (Sanzo et al., 2010). The issue is to take advantage of the neutrons with the mentioned characteristics before to convert fertile isotopes such as ^{232}Th to fissionable or induce fission over them.

The goal is to compare the neutronic and depletion behaviour during the burnup of the system under the irradiation of these different neutron spectra using the same power in the same system and follow the mass variations during the irradiation time.

2. Methodology

The depletion was performed using the MONTEBURNS code (Poston and Trellue, 1999), which links the MCNP with ORIGEN (Croff, 1980). The neutron flux over the fuel obtained from the MCNP (X-5 Monte Carlo Team, 2003) output is used for the

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ORIGEN to perform the burnup. ORIGEN takes a relatively unsophisticated one-group neutronics calculation providing various nuclear material characteristics (the buildup, decay and processing of radioactive materials) in readily comprehensive form (MIT OpenCourseWare). Then the isotopic composition obtained by the ORIGEN goes back to the MCNP to calculate the flux with a new composition that is submitted to the fusion neutron source, so on until finishing each cycle. The fission product yields were taken from ENDF/B-VI. Finally, the MONTEBURNS makes some calculations from the data obtained, such as energy per fission, flux normalization, reactor physics constants, effective multiplication factor, power, and the fractional importance.

The source multiplication factor (k_{src}) of a subcritical assembly, driven by an external neutron source, can be expressed as the ratio of the fission neutrons and the fission neutrons plus the source neutrons. The MONTEBURNS uses the source definition calculated from the value of the net multiplication obtained from the MCNP output file (Poston and Trellue, 1999), as presented following:

$$k_{src} = \frac{f_{mult} - 1}{f_{mult} - 1/\upsilon} \tag{1}$$

where f_{mult} is the total neutron multiplication factor of the system and υ is the ratio of the source neutrons and the lost neutrons to fission. In case of k_{eff} the υ is considered as $\upsilon = \mathrm{fsrc}/\mathrm{floss}$ in which fsrc is the weight of source neutrons gained in fission over the weight lost to fission. It uses just a startup source to begin the fission chain. In other words, the k_{eff} takes in consideration just the fission chain on the multiplier medium.

The ability of transmutation using different external neutron sources, fusion source, evaporation (represents the neutron source from the ADS) and fission chain, in each system will be evaluated. Two powers were chosen according to the typical fission power used by an ADS or Fusion system. The system 1 was set at 515 MW for the three cases, which corresponds to the power for an ADS system using 1 GeV proton beam energy to guide them towards the spallation target. On the other hand, a 3000 MW fission power is used on the system 2 for all cases, which correspond to the power for a fusion system set between 195 MW and 325 MW.

The order of the neutron source for the system 1 was: evaporation source, fusion source and fission chain. For the system 2 was: fusion source, evaporation source and fission chain reaction with a startup neutron source. The fission power for an ADS system was calculated according to (Degweker et al., 2007), as presented in the Eq. (2)

$$P_{th} = F\frac{k}{1-k}\frac{i_p v_{sp} E_f}{v} \tag{2}$$

where i is the accelerator current, E_f is the energy per fission, υ and υ_{sp} stand for the number of neutrons produced in fission and spallation respectively and F is a factor depending on the units used. On the other hand, the fission power by using the fusion source was calculated according to (Stacey, 2011), as presented in the Eq. (3)

$$P_{fis} = \frac{E_{fis}}{E_{fus}}\frac{k}{v(1-k)}P_{fus} \tag{3}$$

This equation relates the fusion power with the fission power by the number of neutrons produced per neutron, $\mathbf{k} = v\frac{\Sigma_{fis}}{\Sigma_{abs}}$, where Σ_{fis} is the fission macroscopic cross section, Σ_{abs} is the absorption plus leakage macroscopic cross section, v is the number of neutrons produced per fission and finally E_{fus} and E_{fis}, the energy emitted by a fusion (17.6 MeV) and fission reaction (200 MeV), respectively.

2.1. Geometries

The system 1 has a basic geometry with the spallation target, a subcritical core, and a reflector. The accelerator tube has a radius of 1.5 cm, and the axial position is in the centre of the target. The simulated core is a cylinder of 6.2 m^3 filled with a hexagonal lattice constituted by 156 fuel rods. The fuel rod diameter is 4.3 cm, the pitch is 12 cm, and rod length is 200 cm (Barros et al., 2012). There is no fuel clad used in this system. The modelled system 1 was designed as shown in Fig. 1, and the geometry parameters are presented in Table 1, where the neutron source is located in the cylinder placed in the central part.

The geometry of the system 2, as shown in Fig. 2 was based on concentrically spheres as purposed by Kramer (2010).

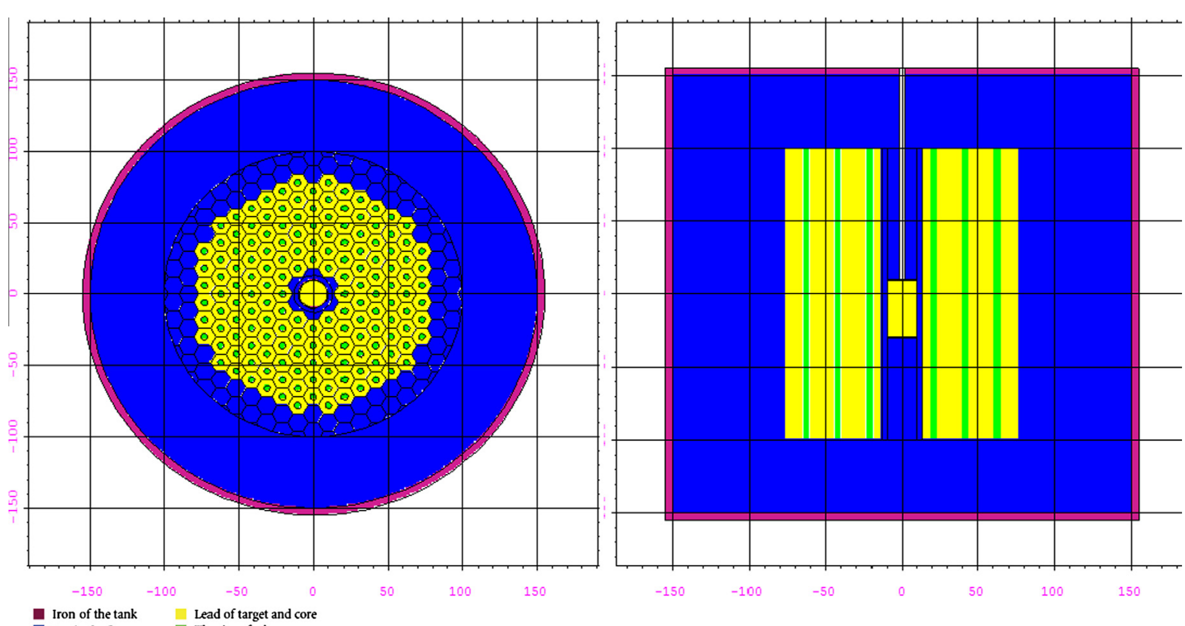

Fig. 1. Horizontal and vertical design of the system 1.

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