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Evaluation of $Th0_2/U0_2$ Fuel Behavior at Different Temperatures in ADS

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1. Introduction

Subcritical hybrid systems include Accelerator Driven Reactor Systems (ADS). In these systems charged particles (protons, ions, among others) produced by an accelerator induce spallation reactions in targets, in general, with high-Z materials, resulting in the production of neutrons that are used in a subcritical reactor core. These systems have been studied by the Department of Nuclear Engineering at UFMG since the last decade, for application in transmutation of nuclear waste and breeding fissile material [1- 3].

Other studies [4, 5] suggest the use of ADS to produce fissile fuel from fertile isotopes, using as fuel mixtures based on thorium for the production of ^{233}U or, to a lesser extent, depleted uranium for the conversion of ^{238}U into ^{239}Pu. The Th/U cycle has aroused interest in recent decades due to the extensive known reserves and the need to replace in the long term, even partially, the use of uranium by another fuel.

During the development of previous studies [1, 2] for ADS, the libraries available in the MCNPX 2.6.0 package were used. However, when producing new libraries with NJOY99.396 at full power for other hybrid systems in studies [4, 5], it was verified that this system should be reevaluated. Additionally, in a previous study [6], it is shown that systems that use Th as fertile material are sensitive to the data libraries used.

Therefore, starting from the open questions previously presented, the objective of this work is to evaluate a more adequate cross-section data library to be used in the studied ADS reactor [1] with the use of thorium. The system will be analyzed under different temperatures. Neutronics parameters such as the effective multiplication factor k_{eff}, the reproduction factor η, thermal utilization factor f, the resonance escape probability p and the fast fission factor ϵ will be evaluated. The codes NJOY99.396 [7] and MCNPX 2.6.0 [8] will be used to generate cross-section data at different temperatures and to simulate the ADS system, respectively. The cross-section data libraries that will be analyzed are: ENDF/B-VII.1, ENDF/B-VIII, JEFF-3.2, JEFF-3.3, CENDL-3.2, JENDL-4.0, BROND-3.1 and TENDL-2019.

2. Methodology

2.1 Geometry and Fuel Composition

A simplified ADS is modelled containing the spallation target, the fuel rods, as well as the coolant and reflector, seen in Figure 1. It is a model inspired by Rubbia *et al.* [10] and adequately described by Nifenecker, Meplan and David [1]. The geometry describes the simulated core as a 6.0 m^3 cylinder filled with a hexagonal mesh with 156 fuel rods with a 2.00 cm internal. The volume of fuel and coolant are, respectively, 0,392 m^3 and 3,5 m^3. It's used a mixture of $(Th,^{233}U)O_2$ contained 15% ^{233}U as fuel surrounded by lead as coolant [1, 11]. The model taken as a starting point in Rubbia *et al.* homogenizes the fuel rods in order to make the initial study simpler.

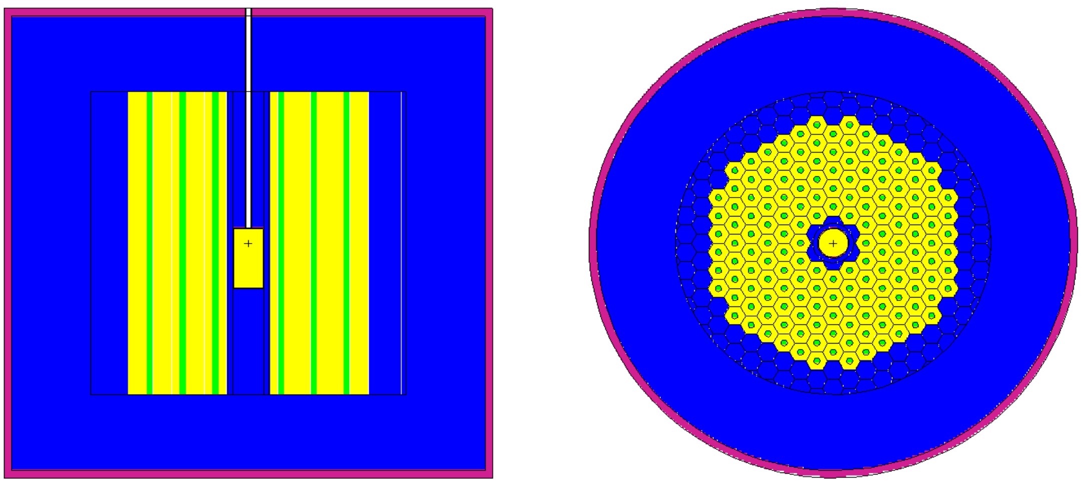

Figure 1: Radial and axial configuration of the simulated ADS reactor.

2.2 Modelling

For the initial stage of this work, five temperature points will be analyzed, namely, 293 K, 600 K, 900 K, 1200 K and 1500 K, available for the libraries to be studied. Then, the data of cross sections of these libraries and the values obtained for k_{eff} with code MCNPX 2.6.0 will be analyzed under the same geometry conditions of the worked system. From the analysis of the most suitable library to be used in the system, the study of the behavior of the effective and infinite k (η, p, f and ϵ) with temperature variation will be carried out. Initially, only the fuel temperature is varied, keeping the coolant at full power (873.15 K). Subsequently, it is analyzed the behavior of the system by varying only the coolant temperature, keeping the fuel at full power (1200 K). These studies will be done in BOL (Beginning Of Life) and using the MCNPX 2.6.0.

3. Expected Results

Table 1 shows the effective multiplication factor k_{eff} for libraries JEFF-3.2 and ENDF/B-VI.1 at temperatures of 293.6 K.

Table 1: Comparative data for libraries JEFF-3.2 and ENDF/B-VI.1 at temperatures of 293.6 in respect to k_{eff}.

	ENDF/B-VI.1	JEFF-3.2
k_{eff}	0.95353	0.90242
Standard Deviation	0.00059	0.00050
Percentage Difference (%)	5.36	
Δ k_{eff} (pcm)	5111.00	

From the data presented in Table 1, it can be seen there is a considerable difference in the values calculated for the percentage difference and k_{eff} variation for the JEFF-3.2 and ENDF/B-VI.1 libraries. This is explained by the greater amount of cross-section data for ^{233}U in the JEFF-3.2 compared to ENDF/B-VI.1, as can be seen in Figure 2.

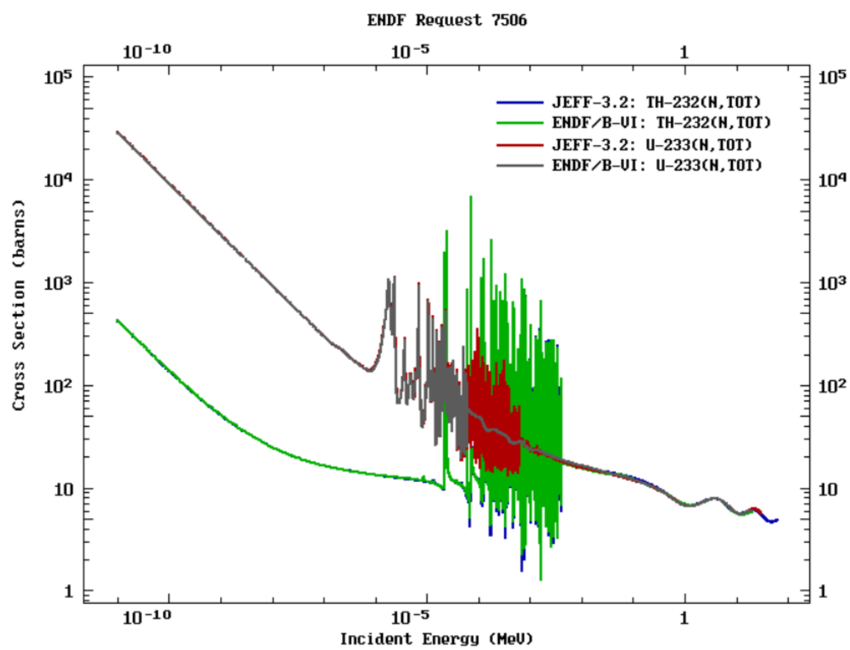

Figure 2: Total cross section for ENDF/B-VI and JEFF-3.2.

Therefore, such results show the importance of evaluating the modelled system as a function of both the temperatures and the libraries used in the simulations.

4. Conclusions

In a previous study [1], the burn and transmutation of fuel for this ADS reactor studied at zero power (293.6 K) was evaluated. However, this is not the most suitable temperature to be used, since the melting temperature of the lead (Pb), material used as a coolant, is 601.15 K. Therefore, the system k_{eff} value must be analyzed at zero and full power, in order to verify if the system remains subcritical and also if it can sustain fuel burn. Subsequently, studies will be carried out for the heterogenization of the core, including cladding material for the fuel rods maintaining the volume ratio of coolant and fuel.

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References

[1] BARROS, Graiciany de Paula et al. Study of an ADS loaded with thorium and reprocessed fuel. Science and Technology of Nuclear Installations, v. 2012, 2012.

[2] BARROS, Graiciany P. et al. A comparative study of MONTEBURNS and MCNPX 2.6. 0 codes in ADS simulations. 2013.

[3] NIFENECKER, Hervé; MEPLAN, Olivier; DAVID, Sylvain. Accelerator driven subcritical reactors. CRC Press, 2003.

[4] VELASQUEZ, Carlos E. et al. Fusion–fission hybrid systems for transmutation. Journal of Fusion Energy, v. 35, n. 3, p. 505-512, 2016.

[5] VELASQUEZ, Carlos E. et al. Layer thickness evaluation for transuranic transmutation in a fusion–fission system. Nuclear engineering and design, v. 286, p. 94-103, 2015.

[6] VELASQUEZ, Carlos E. et al. Cross section evaluation for a LWR pin lattices with thorium applications. Annals of Nuclear Energy, v. 107, p. 89-102, 2017.

[7] MACFARLANE, Robert E. NJOY 99/2001: new capabilities in data processing. Los Alamos National Laboratory, 2002.

[8] HENDRICKS, John S. et al. MCNPX 2.6. 0 Extensions. Los Alamos National Laboratory, p. 73, 2008.

[10] RUBBIA, Carlo et al. Conceptual design of a fast neutron operated high power energy amplifier. 1995.

[11] VELASQUEZ, Carlos E. et al. Neutron Irradiation of Thorium-Based Fuels: Comparison Between Accelerator-Driven Systems and Fusion–Fission Systems. In: Thorium Energy for the World. Springer, Cham, 2016. p. 379-381.