2021 International Nuclear Atlantic Conference – INAC 2021
Virtual meeting, Brazil, November 29 – December 2, 2021

ISBN: 978-65-594-1256-3

FUSION-FISSION HYBRID SYSTEM – NEUTRON FLUX ANALYSIS AFTER DIVERTOR INSERTION

Natália G. P. L. Oliveira, Carlos E. Velasquez, and Claubia Pereira

nataliagplofis@gmail.com, *carlosvelcab@nuclear.ufmg.br, claubia@nuclear.ufmg.br*

Departamento de Engenharia Nuclear
Universidade Federal de Minas Gerais - UFMG
Av. Antonio Carlos, 6627 Pampulha
31270-901, Belo Horizonte, MG, Brazil

1. Introduction

Hybrid fusion-fission reactors are currently being studied due to their ability to transmute actinides through fission reactions. Because it has a high hardened neutron flux (about 14.1 MeV of energy) originating from the deuterium and tritium (D-T) fusion reactions in the fusion reactor core, it increases the probability of inducing fission in the transuranic nuclides [1] decreasing its high radiotoxicity and long decay half-life.

The fission system coupled to the fusion reactor is inserted after the Plasma Chamber in the core of the reactor operating in subcritical mode [2]. This region, loaded with reprocessed fuel from LWR plants, is submitted to two spectra of neutron fluxes: the first, corresponding to the fission reactions that occur in the transmutation layer (TL) and the second one is due to the D-T fusion reactions which produce neutrons with high energy and flux. The combination of these neutrons sources increases the probability of transuranic transmutation.

The Nuclear Engineering Department at the Federal University of Minas Gerais (DEN/UFMG) has been developing works on computer simulations for different nuclear reactors and hybrid systems, to study alternatives for the closed fuel cycle. A Fusion-Fission Hybrid System (FFHS) model developed is based on the materials and radial dimensions proposed by ITER [1] but with certain modifications made to its dimensions to introduce a transmuting layer (TL) into the system [3, 4]. In a previously developed work [5], modifications in the modeling of the fusion reactor were studied, specifically the insertion of the Divertor system, which is a component on a Tokamak type fusion reactor, and which are of extreme importance. This Divertor system inserted in the SHFF model was also based on the ITER Divertor system, which is currently being manufactured [6]. Its main function is to extract impurities that accumulate in the plasma, mainly due to erosions in the materials that make up the first wall of the Plasma Chamber.

Since changes in the geometry or material of the fusion system can affect the neutron flux in the fission system, this work intends to monitor and analyze the neutron spectrum corresponding only to the neutrons that are scattered along the bottom of the Plasma Chamber, until they reach the initial surface of the TL. For this, a comparison of hybrid fusion-fission systems with and without the Divertor component is performed, in order to verify the fraction of neutrons that reach the initial surface of the TL: the fraction of neutrons that undergo scattering with the materials of inter coating; and the fraction of neutrons that do not suffer any collision on the way until they reach the initial surface of the TL (E ~ 14.1 MeV).

2. Methodology

Fig. 1 shows the two-dimensional modeling of the hybrid fusion-fission reactor, without the Divertor component. The geometry is represented by the intersection of cylinders and planes limiting the different fusion device layers, as well as the TL [7]. The materials used were according to the ITER guidelines [6] and the paper [8].

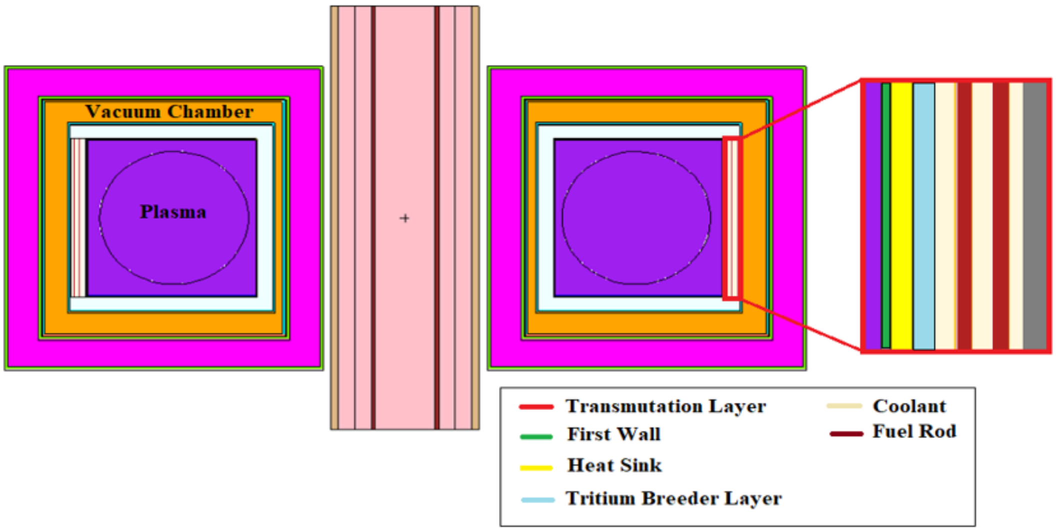

Figure 1: System 1 with the transmutation layer and no Divertor.

The model above was modified to insert the Divertor component in the lower part of the Plasma Chamber, based on the reference ITER Divertor [6, 9] and is represented by intersections of flat and cylindrical surfaces.

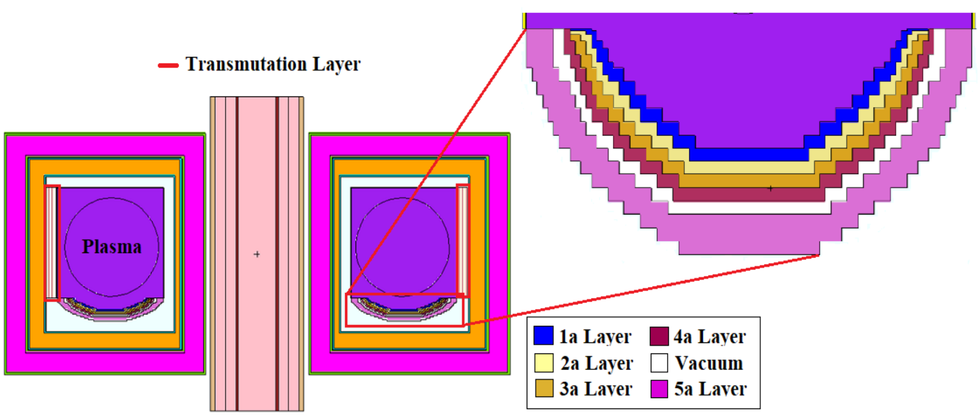

Figure 2: System 2, the modeled Divertor with cylinders and planes.

The two systems have the same volume for the TL of 105.194 m^3, for the Plasma Chamber of 837.000 m^3 and for the volume fuel about 74.050 m^3. The TL is load with a hexagonal lattice containing the fuel rods and the coolant, its location is inside the block shield and next to the heat sink component. The fuel used in the TL was a spent fuel from a PWR reprocessed by the GANEX technique and then spiked with thorium until reach 11.5% of fissile material such as uranium-233 [9].

To calculate the neutron flux resulting from the scattering in the bottom of the Plasma Chamber, SSW and SSR cards available by code MCNP5. They allow writing and reading surface source files, respectively, enabling tracking of particles by a system. Initially the two systems will run with a value of 1.0E+08 particles.

3. Expected Results

The objective of this work is to make a comparative analysis of the fusion neutron spectrum that reach the initial surface of the TL after making changes in the geometry of the fusion reactor. The fusion neutron spectrum can influence the neutron flux in the TL volume, thus affecting the transmutation of actinides present in the fuel. In a previously carried out study [5], an increase in the neutron flux in the volume of the TL was verified for the hybrid system modeled with the Divertor component, as can be seen in Figure 3 and Table 1, for the fuel at Beginning of Life (BOL).

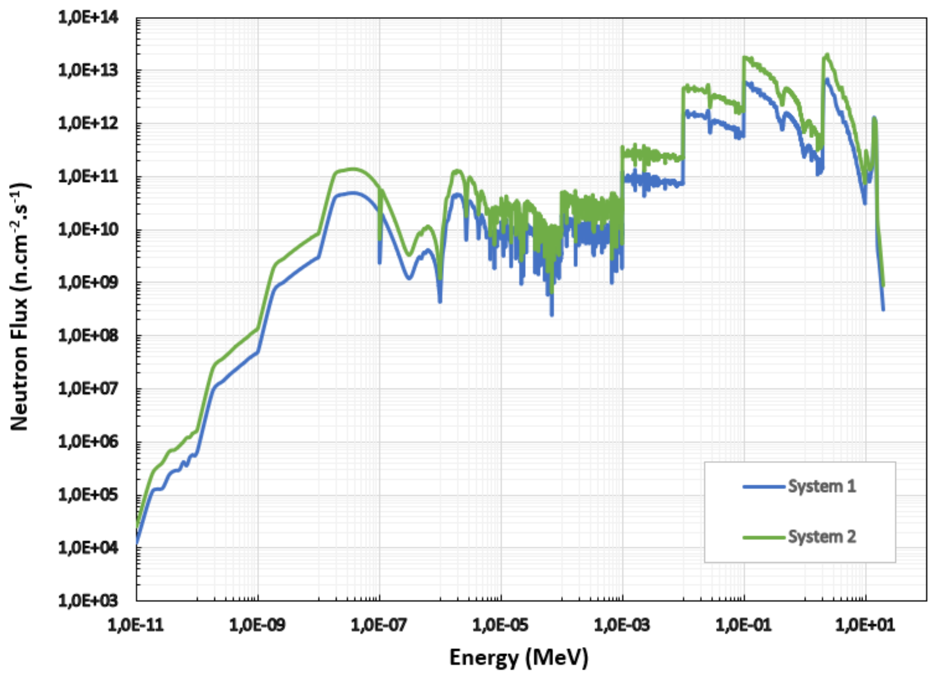

Figure 3: Neutron fluxes for the two systems in the TL region and for fresh fuel.

Table 1: Neutron fluxes and relative errors calculated for fresh fuel systems.

	System 1	System 2
Thermal Neutrons (%)	0,037	0,036
Intermediate Neutrons (%)	69,642	70,186
Fast Neutrons (%)	30,321	29,779
Total Flux ($n.cm^{-2}.s^{-1}$)	1.619E+15	4.799E+15
Total Flux Relative Error	7.000E-04	1.200E-03

The population of neutrons, for the most part, corresponds to neutrons with intermediate energies (0.5E-06 < E < 0.5 MeV), being larger for the system with the Divertor component. Therefore, we intend to track the fusion neutron spectrum that reaches the initial surface of the TL and its influence on the fission neutron spectrum.

4. Conclusions

The probability of inducing fission in transuranic nuclides is higher for systems that produce hardened neutron fluxes. Hybrid fusion-fission systems can produce neutrons of 14.1 MeV of energy through D-T fusion reactions, reactions with a larger fusion cross section at low kinetic energies of the particles. Therefore, changes in the source of fusion neutrons, whether due to changes in the geometry or materials of the fusion system, directly impact the spectrum of fission neutrons.

Acknowledgements

The authors are grateful to the Brazilian research funding agencies, CNEN – Comissão Nacional de Energia Nuclear (Brazil), CNPq – Conselho Nacional de Desenvolvimento Científico e Tecnológico (Brazil), CAPES – Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (Brazil) and FAPEMIG – Fundação de Amparo à Pesquisa do Estado de Minas Gerais (MG/Brazil), for the support.

References

[1] C.E. Velasquez et al., "Fusion–Fission Hybrid Systems for Transmutation", *Journal of Fusion Energy*, vol. 35, N. 1, pp. 1-134 (2016).

[2] W.M. Stacey et al., "A Fusion Transmutation of Waste Reactor", *Fusion Science and Technology,* vol. 41, (2002).

[3] C.E. Velasquez et al., "Layer thickness evaluation for transuranic transmutation in a fusion– fission system", *Nucl. Eng. Des.*, vol. 286, pp. 94–103 (2015).

[4] C.E. Velasquez et al., "Modelling effects on axial neutron flux in Tokamak device", *Prog. Nucl. Energy*, vol. 78, pp. 388–395 (2015).

[5] Natália G. P. L. Oliveira, "Sistema híbrido fusão-fissão baseado no Tokamak - análise neutrônica da inserção do diversor", Master's Thesis, (2021), 64 pages, UFMG-Brasil, https://repositorio.ufmg.br/handle/1843/36215 (acessado em Agosto, 2021).

[6] "ITER", https://www.iter.org/ (2021).

[7] R.V.A. Marques et al., "Tritium Breeder Layer Evaluation of Fusion-Fission Hybrid System", *Fusion Science and Technology*, vol. 76, pp. 145-152 (2020).

[8] Y. Wu and FDS Team, "CAD-based interface programs for fusion neutron transport simulation", *Fusion Engineering and Design*, vol. 84, pp. 1987-1992 (2009).

[9] S. Cota and C. Pereira, "Neutronic evaluation of the non-proliferating reprocessed nuclear fuels in pressurized water reactors", *Annals of Nuclear Energy*, vol. 24, pp. 829-834 (1997).

[10] T. Hirai et al., "ITER tungsten divertor design development and qualification program", *Fusion Engineering and Design*, vol. 88, pp. 1798-1801 (2013).