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Research Article

The Comparison of Effect on Neutronic Calculations of ENDF/B-VIII.0 Nuclear Library and Am-Cm Additive Fluids in a Hybrid Reactor System

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Abstract

In this study, a fusion-fission hybrid reactor system was designed by using V₄Cr₄Ti Ferritic steel structural material and the molten salt-heavy metal mixture 79,9% Li₁₇Pb₈₃ + 20% ThF₄ + 0,1% AmO₂ and 79,9% $Li_{17}Pb_{83} + 20\%$ ThF₄ + 0,1% CmO₂ as fluids. The fluids were used in the liquid first wall, blanket and shield zones of a fusion-fission hybrid reactor system. Beryllium (Be) zone with the width of 3 cm was used for the neutron multiplication between the liquid first wall and blanket. In this study was investigated the nuclear parameters such as tritium breeding ratio (TBR), energy multiplication factor (M), heat deposition rate, fission reaction rate in liquid first wall, blanket and shield zones. Threedimensional analyses were performed by using the Monte Carlo code MCNPX-2.7.0, NJOY and ENDF/B-VIII.0 nuclear data library.

Keywords: fusion-fission hybrid reactor, Monte Carlo, tritium breeding ratio.

1. Introduction

The fuels used in hybrid reactor systems are generally deuterium–tritium (D-T) or deuterium–deuterium (D-D) fuels. When D-T fuel enters the fusion reaction, 14.1 MeV fusion neutrons and 3.5 MeV alpha particles are released. The plasma is surrounded by a wall made of fertile material, which cannot undergo the fusion reaction with thermal neutrons, but can undergo conversion with high energy neutrons, such as the 14.1 MeV neutrons produced by the fusion reaction. Thus, the high energy fusion neutrons convert fertile materials to fissile fuel, fission neutrons, and produce energy. The hybrid reactor produces 30 times more nuclear fuel per nuclear energy quantity than fast reactors [1-7]. In this study, a hybrid reactor system was designed. The hybrid reactor system can generate secure energy in large quantities with D-T fuel usage and subcritical study. Furthermore, it enables the production of a self-sufficient fuel for the reactor through the reaction of the neutrons released by the plasma. The main objective of this study is to investigate tritium breeding ratio (*TBR*), energy multiplication factor (*M*), heat deposition rate, fission reaction rate in the designed hybrid reactor system for the selected fluid, library and structural material.

2. Method

2.1. Numerical Calculations

Hybrid reactor system used in the study is in the shape of a torus. The radial structure of designed the hybrid reactor system is shown in Table 1. Calculation of all the parameters of the fission and fusion reactors and other areas of nuclear technology depend on the cross-section data [8-10]. In this study, we calculated nuclear parameters in liquid first wall, blanket and shield zones with nuclear data library currently the most recent: ENDF/B-VIII.0 T = 300 K with the help of Monte Carlo method the MCNPX-2.7.0 in three-dimensional. The NJOY was used for processing of ENDF/B-VIII.0 library. The NJOY code is a modular nuclear data processing system for producing libraries of nuclear data for reactor physics calculations from evaluated data. Analysis was performed for neutron wall loading 10 MW/m² and fusion power 4000 MW.

Inboard side		Outboard side			
Zone	r (cm)	Zone	r (cm)		
SS316LN	276	Plasma	667		
Vacuum vessel ^a	278	SOL	695		
SS316LN	294	Liquid First Wall ^d	697		
GAP	296	Be ^e	700		
Shield ^b	301	Blanket ^d	750		
Ferritic Steel ^c	350	Ferritic Steel ^c	754		
Blanket ^d	354	Shield ^b	804		

 Table 1. The radial build of the hybrid reactor system design

				-
Be ^e		404	GAP	838
Liquid Wall ^d	First	407	SS316LN	840
SOL		409	Vacuum vessel ^a	866
Plasma		437	SS316LN	868

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^a 80% SS316LN, 20% H₂O

^b 60% V₄Cr₄Ti, 40% (79,9% Li₁₇Pb₈₃ + 20% ThF₄ + 0,1% AmO₂, 79,9% Li₁₇Pb₈₃ + 20% ThF₄ + 0,1% CmO₂)

- ^c 100% V₄Cr₄Ti
- $^{d} \quad 79,9\% \ Li_{17}Pb_{83} + 20\% \ ThF_{4} + 0,1\% \ AmO2, \ 79,9\% \ Li_{17}Pb_{83} + 20\% \ ThF_{4} + 0,1\% \ CmO_{2}$
- ^e 100% Be

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2.2. Tritium Breeding

The tritium breeding ratio (*TBR*) is defined as the ratio of the rate of tritium production in the system to the rate of tritium burning in the plasma. The hybrid reactor has to breed the tritium it requires [11,12]. Tritium is bred through the reaction of lithium with neutrons. The ⁶Li(n, α)T reaction is produced with thermal neutrons, and the ⁷Li(n, α n')T reaction with fast neutrons. In the hybrid reactor system, the working liquid must be a lithium-containing medium to provide adequate tritium. The required *TBR* for a fission reactor conceptual design must be 1.1 [11-15]. *TBR* can be given as follows:

$$TBR = T_6 + T_7 \tag{1}$$

 $T_6 = \iint \Phi \cdot \Sigma_{(n,\alpha)T} dE dV, \text{ for } {}^6\text{Li}$ (2)

$$T_7 = \iint \Phi \cdot \Sigma_{(n,n'\alpha)T} dE dV, \text{ for } {}^7\text{Li.}$$
(3)

In this study $Li_{17}Pb_{83}$ molten salt was used, which has low melting temperatures and low vapor pressure, to acquire sufficient tritium breeding.

2.3. Energy Multiplication Factor, Heat Deposition Rate and Fission Reaction Rate

The energy multiplication factor M is the ratio of nuclear heating and source neutron energy incident on the first wall [16]. The energy produced must exceed the energy produced by the plasma. To obtain high thermal power, the M value should be as large as possible. It is desirable that M is greater than 1.2 in a D-T fueled reactor [17]. M can be defined as follows:

$$M = \left[\left(200x(\Phi \cdot \Sigma_{\rm f}) + 4.784xT_6 - 2.467xT_7 \right) / 14.1 \right] + 1 \tag{4}$$

$$(\Phi \cdot \Sigma_f) = \iint \Phi \cdot \Sigma_f dE dV$$
, total fission rate. (5)

The contributions of the neutron flux, fission, and other reactions to the integrated *M* and heat deposition rate are very important. The main contributions to the integrated *M* and heat deposition rate are from the neutron flux, the fission reaction of thorium isotope in ThF₄ and the exothermic ⁶Li(n, α)T reaction of Li₁₇Pb₈₃ molten salt.

3. Numerical Results

In this study, hybrid reactor system have designed by using 79,9% $Li_{17}Pb_{83} + 20\%$ ThF₄ + 0,1% CmO₂ and 79,9% $Li_{17}Pb_{83} + 20\%$ ThF₄ + 0,1% CmO₂ fluids in liquid first wall, blanket and shield zones, ENDF/B-VIII.0 evaluated nuclear data library from 10⁻¹¹ to 20 MeV and V₄Cr₄Ti structural material. Table 2 shows the *TBR*, *M*, heat deposition rate and fission reaction rate in the liquid first wall, blanket and shield regions per fusion source neutron for the selected fluids and ENDF/B-VIII.0 evaluated nuclear data library.

Integrated TBR values calculated in the liquid first wall, blanket and shield regions for 79,9% $Li_{17}Pb_{83}$ + 20% ThF₄ + 0,1% CmO₂ fluids and ENDF/B-VIII.0 evaluated nuclear data library. It was found that *TBR* values calculated for the selected fluids and ENDF/B-VIII.0 evaluated nuclear data library higher than 1.1 the limit value. The *M* value was obtained to be between 1.55 and 1.58 values. This values is greater than 1.2 value desirable of *M*. In the pertinent zones of the reactor, integrated heat deposition rate values for ENDF/B-VIII.0 evaluated nuclear data library $Li_{17}Pb_{83} + 20\%$ ThF₄ + 0,1% AmO₂ and 109.55 W/cm³ for 79,9% $Li_{17}Pb_{83} + 20\%$ ThF₄ + 0,1% AmO₂ and 109.55 W/cm³ for 79,9% $Li_{17}Pb_{83} + 20\%$ ThF₄ + 0,1% CmO₂. The fission reaction rate was calculated in between 1.29.10⁻² and 1.38.10⁻² values.

Table 2. The variation of the TBR, M, heat deposition rate and fission reaction rate for the selected fluids and ENDF/B-VIII.0 evaluated nuclear data library in the liquid first wall, blanket and shield zones.

4. Results and Discussion

In the study the effect of the selected fluids and ENDF/B-VIII.0 evaluated nuclear data library in the designed system on three-dimensional neutronic measurements, such as *TBR*, *M*, heat deposition rate and fission reaction rate, was investigated. It was found that *TBR* values calculated higher than 1.1 the limit value. All *M* values found greater than 1.2 value desirable of *M*. The increase between the minimum and maximum of TBR, *M*, heat deposition rates and fission reaction rate values for the selected fluids and ENDF/B-VIII.0 evaluated nuclear data library was approximately the same. It was found that the greatest contribution to TBR, *M*, heat deposition rates and fission reaction rate values comes from 79,9% $Li_{17}Pb_{83} + 20\%$ ThF₄ + 0,1% CmO₂ fluid.

Acknowledgments

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Μ	1.55	1.58	15 M. Z. Youssef, et al., <i>Fusion</i> <i>Technol.</i> , 1986, 9 , 286.
Heat Deposition Rate (W/cm ³)	105.42	109.55	16 S. Şahin, et al., <i>Energy</i>
Fission Reaction Rate	1.29.10-2	1.38.10-2	Convers. Manage., 2004, 45 , 1497.
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