Journal of Physical Chemistry and Functional Materials (JPCFM)

journal homepage: http://dergipark.gov.tr/jphcfum

Received: 23 July 2018 Accepted: 31 July 2018 Research Article

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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 V_4Cr_4Ti Ferritic steel structural material and the molten salt-heavy metal mixture 79,9% $Li_{17}Pb_{83}$ + 20% ThF_4 + 0,1% AmO_2 and 79,9% $Li_{17}Pb_{83}$ + 20% ThF_4 + 0,1% CmO_2, 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. Three-dimensional 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.

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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/m^2 and fusion power 4000 MW.

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

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

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

[a] 80% SS316LN, 20% H_2O

[b] 60% V_4Cr_4Ti, 40% (79,9% $Li_{17}Pb_{83}$ + 20% ThF_4 + 0,1% AmO_2, 79,9% $Li_{17}Pb_{83}$ + 20% ThF_4 + 0,1% CmO_2)

[c] 100% V_4Cr_4Ti

[d] 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

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 $^{6}Li(n,\alpha)T$ reaction is produced with thermal neutrons, and the $^{7}Li(n,\alpha n^{/})T$ 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:

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

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

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

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:

$$M=[(200x(\Phi\ .\ \Sigma_f)+4.784xT_6-2.467xT_7)\ /14.1]\ +1 \qquad (4)$$

$$(\Phi\ .\ \Sigma_f) = \iint \Phi\ .\ \Sigma_f\, dE\ dV, \text{ total fission rate.} \qquad (5)$$

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 ThF_4 and the exothermic $^6Li(n,\alpha)T$ reaction of $Li_{17}Pb_{83}$ molten salt.

3. Numerical Results

In this study, hybrid reactor system have designed by using 79,9% $Li_{17}Pb_{83}$ + 20% ThF_4 + 0,1% CmO_2 and 79,9% $Li_{17}Pb_{83}$ + 20% ThF_4 + 0,1% CmO_2 fluids in liquid first wall, blanket and shield zones, ENDF/B-VIII.0 evaluated nuclear data library from 10^{-11} to 20 MeV and V_4Cr_4Ti 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% ThF_4 + 0,1% AmO_2 and 79,9% $Li_{17}Pb_{83}$ + 20% ThF_4 + 0,1% CmO_2 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 are 105.42 W/cm^3 for 79,9% $Li_{17}Pb_{83}$ + 20% ThF_4 + 0,1% AmO_2 and 109.55 W/cm^3 for 79,9% $Li_{17}Pb_{83}$ + 20% ThF_4 + 0,1% CmO_2. 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% ThF_4 + 0,1% CmO_2 fluid.

Acknowledgments

This work was supported by İnönü University Research fund with the project number FYL-2018-1038.

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	AmO_2	**CmO_2**
TBR	1.796	1.883
M	1.55	1.58
Heat Deposition Rate (W/cm^3)	105.42	109.55
Fission Reaction Rate	$1.29.10^{-2}$	$1.38.10^{-2}$