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(n,p), (n,2n), (n,d), and (n,α) cross-section calculations of ^{16}O with 0-40 MeV energy neutrons

Omer Faruk Ozdemir[a] , Ali Arasoglu

Yüzüncü Yıl University, Science Faculty, Physics Department, 65080, Van, Turkey

Abstract. Oxygen is one of the elements which interacts with emitted neutrons after fission reactions. Oxygen exists abundantly both in nuclear fuel (UO_2) and moderators (H_2O). Nuclear reactions of oxygen with neutrons are important in terms of stability of nuclear fuel and neutron economy. In this study, equilibrium and pre-equilibrium models have been used to calculate (n,p), (n,d), (n,2n) and (n,α) nuclear reaction cross-sections of ^{16}O. In these calculations, neutron incident energy has been taken up to 40 MeV. Hybrid and Standard Weisskopf-Ewing Models in ALICE-2011 program, Weisskopf-Ewing and Full Exciton Models in PCROSS program, and Cascade Exciton Model in CEM03.01 program have been utilized. The calculated results have been compared with experimental and theroretical cross-section data which are obtained from libraries of EXFOR and ENDF/B VII.1.

1 Introduction

The most important part of nuclear power reactor is reactor core. At core, fission reactions take place and thermal energy was produced. Also at pressurized water reactors, it can reach to high temperatures. Physical stability of nuclear fuel and economy of neutron are effect to security of core region.

Chain fission reactions was constituted by spontaneous neutrons emitted during the fission and delayed neutrons emitted after the fission. The stability, security and power of the reactors can be determined by chain fission reactions [1,2].

Generally UO_2 is used as a fuel in nuclear power reactor. In addition to UO_2, MOX (UO_2+PuO_2, Mixed Oxide Fuel) and DUPIC (Direct Use of Spent PWR Fuel In CANDU Reactors) can be used as a fuel. Neutron emitted after fission in nuclear reactor interact different elements in structural materials and one of these elements is oxygen [3-6]. Oxygen exist both in fuel (UO_2 and PuO_2) and moderator (H_2O). For stability of nuclear fuel and neutron economy, reactions between neutron and oxygen are very important [7].

In this study, equilibrium and pre-equilibrium models have been used to calculate (n,p), (n,d), (n,2n) and (n, α) nuclear reaction cross-sections of ^{16}O. In these calculations, neutron incident energy has been taken up to 40 MeV. Hybrid and Standard Weisskopf-Ewing Models in ALICE-2011 program, Weisskopf-Ewing and Full Exciton Models in PCROSS program and Cascade Exciton Model in CEM03.01 program have been utilized [10-12]. The calculated results have been compared with experimental and theoretical cross-section data which are obtained from libraries of EXFOR and ENDF/B VII.1.

2 Calculations of nuclear reactions

In Weisskopf Ewing Model; projectile particle was absorbed by target nucleus. Without emitting particles, compound nucleus reach the equilibrium state. This model can be used to explain this case [8]. In this model, reaction cross section is given as following;

$$\sigma(a,b) = \sigma_a(\varepsilon)\eta_b(E) \tag{1}$$

In this formula, ε is the incident energy of particle and $\sigma_a(\varepsilon)$ is the cross section for the formation of a compound state. Particle emitting probability of compound nucleus η_b is independent from how the compound nucleus was formed and given as [9];

$$\eta_b = \frac{\Gamma_b}{\sum_{b'}\Gamma_{b'}} \tag{2}$$

Γ_b is the emission probability per time for the particle b and given as:

$$\Gamma_b = \frac{2s_b+1}{\pi^2\hbar^2}\mu_b \int d\varepsilon\, \sigma_b^{inv}(\varepsilon)\,\varepsilon \frac{\omega_1(U)}{\omega_1(E)} \tag{3}$$

In equilibrium, the probability of emitting particle is given as following:

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[a] *Corresponding author: o.f.ozdemir@gmail.com*

$$W_b(\varepsilon) \propto (2s_b+1)\,\mu_b\,\varepsilon\,\sigma_b^{inv}(\varepsilon)\frac{\omega_1(U)}{\omega_1(E)} \tag{4}$$

where s_b is spin, μ_b is reduced mass, ε is energy of emitted particle, σ_b^{inv} is the inverse reaction cross section, $\omega_1(U)$ is the nuclear level density of the nucleus, $\omega_1(E)$ is the nuclear level density of the nucleus emitting b particle, U is the excitation energy of residual nucleus and E is the excitation energy of the emitting nucleus [10].

According to the Griffin Exciton Model, nuclear potential is consisted by one particle states with evenly-spaces. System was excited after interaction between nucleus and projected particle. Therefore, system will be unstable due to given energy.

One particle one hole (exciton) will occur when projectile particle enters target nucleus. After interactions between projectile and system, there will be more excitons. When system has sufficient excitons, system get stable with pairing effect. Exciton Model suggests that it is possible to emit particle during the any steps of excitation process or any steps of such process that system becomes stable. In this model, pre-equilibrium and equilibrium emission spectra equation is given below:

$$\frac{d\sigma_{ab}}{d\varepsilon_b}(\varepsilon_b) = \sigma_{ab}^{r}(E_{inc})\,D_{ab}(E_{inc})\sum_n W_b(E,n,\varepsilon_b)\;\tau_n \tag{5}$$

where, $\sigma_{ab}^{r}(E_{inc})$ is the cross section of reaction (a,b); $W_b(E,n,\varepsilon_b)$ is the probability of emission of b particle with energy ε_b from a state with n excitons and excitation energy E of the compound nucleus; τ_n the solution of the master equation for a state with n excitons; $D_{ab}(E_{inc})$ is a coefficient about particle emission by direct interactions [11].

Another model is named as Cascade Exciton Model. This model occurs in three steps; Intra Nuclear Cascade (INC), Pre-equilibrium and Equilibrium stages. In general, these three steps contribute values obtained as experimentally.

3 Results and discussions

In this study, pre-equilibrium and equilibrium models were used to calculate (n,p), (n,d), (n,2n) and (n,α) nuclear reaction cross-sections of ^{16}O with the incident neutron energies up to 40 MeV. For the pre-equilibrium effects Full Exciton Model (FEM) and Cascade Exciton Model (CEM), for the equilibrium effects Weisskopf Ewing Model have been used. Equilibrium model calculations have been prepared by using PCROSS and ALICE-2011 computer codes. FEM and CEM calculations have been performed by PCROSS and CEM03.01 computer codes, respectively. The results of comparisons between cross section calculations of this study, experimental data and evaluated ones taken from literature are as following:

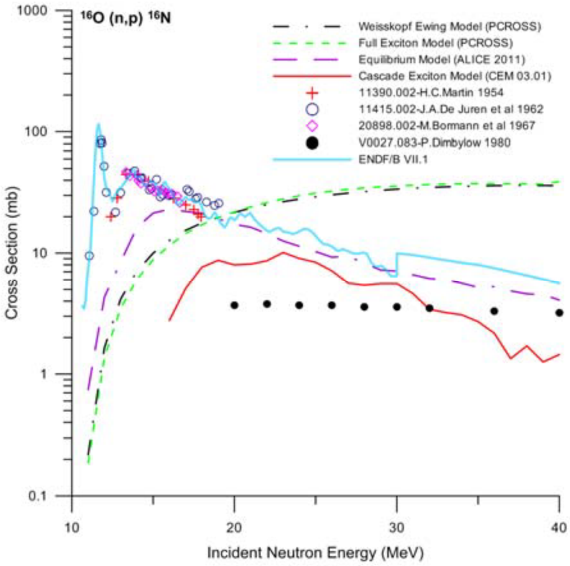

Figure 1. Comparison of cross section calculations of ^{16}O(n,p)^{16}N reaction between given nuclear reaction models, experimental data and evaluated data library [13,14].

In (n,p) reaction calculations (Fig.1); although reaction models produce smaller results than those of experimental and evaluated data up to 15 MeV, in 15-20 MeV region results are in agreement, while in higher energies calculations of ALICE-2011 program and CEM03.01 programs are in good agreement with experimental data and evaluated results.

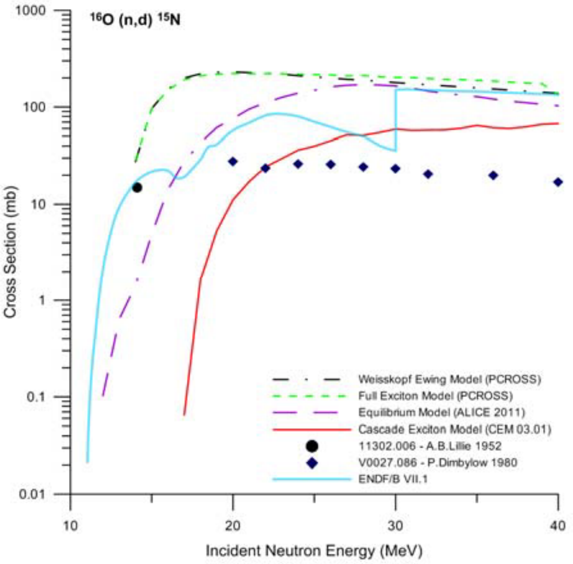

Figure 2. Comparison of cross section calculations of ^{16}O(n,d)^{15}N reaction between given nuclear reaction models, experimental data and evaluated data library [13,14].

As in seen in Fig. 2; Standard WE model is in agreement with experimental data and evaluated results up to 15 MeV for (n,d) calculations. At high energies, the model calculation results are in agreement with evaluated data but greater than experimental data.

Results of calculations of reaction models for (n,2n) reaction are in agreement with experimental data and evaluated results.

In (n,α) reaction calculations, results of all models are in agreement with experimental data and evaluated results up to 20 MeV incident energy. Results gathered from CEM03.01 and ALICE-2011, which utilizes standard WE model, are in good agreement with experimental and evaluated data at high energies.

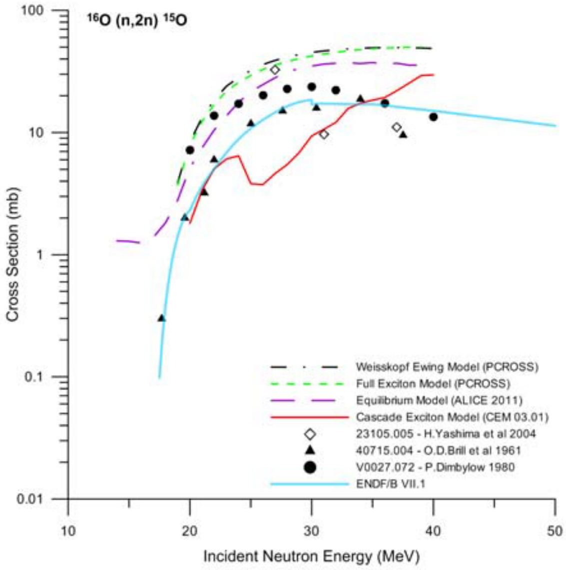

Figure 3. Comparison of cross section calculations of $^{16}O(n,2n)^{15}O$ reaction between given nuclear reaction models, experimental data and evaluated data library [13,14].

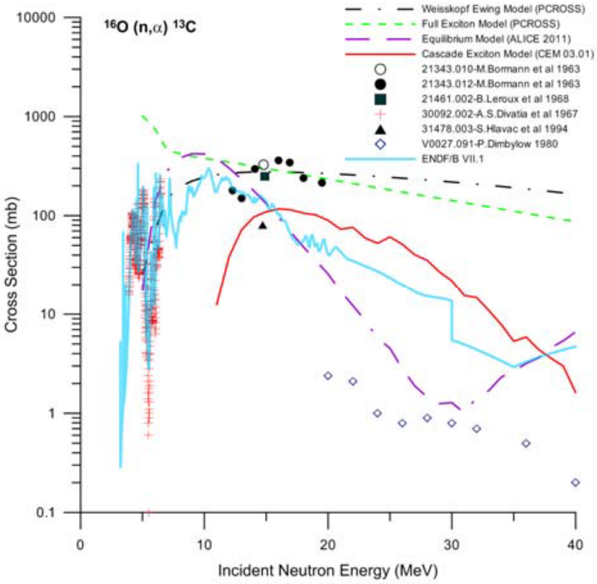

Figure 4. Comparison of cross section calculations of $^{16}O(n,\alpha)^{13}C$ reaction between given nuclear reaction models, experimental data and evaluated data library [13,14].

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