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Calculations of neutron-induced alpha emission double-differential cross section of Flourine at 14.2 MeV

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Abstract. In this preset study, calculations of neutron-induced alpha particle emission double-differential cross section of fluorine (^{19}F) at 14.2 MeV have been calculated by using ALICE and EMPIRE model programs for six different emission angles ranging from 30º to 150º. Calculated results from the Hybrid Monte Carlo pre-equilibrium emission and the full featured Hauser-Feshbach model have been compared with the experimental (EXFOR). The calculated double-differential cross section results using three codes are in good agreement with experimental data.

1 Introduction

Light nuclides (such as FLiBe) are candidate material as an advanced blanket design in fusion reactor. Because these nuclides are usually a complex structure in the nuclear reactions around 14-15MeV neutrons. FLiBe is a molten salt made from a mixture of LiF, BeF, ThF, and UF [1]. Molten salt reactors are a good neutron moderator characterized by the use of fluoride salts as reactor coolant [1,2]. Florine and its compounds have been used widely for the nuclear applications such as processing nuclear fuel [3].

Double differential cross sections are very important for the neutronics design of fusion reactors. Double differential cross sections of charged particles emission reactions excited by 14 MeV incident neutrons is important for evaluation of nuclear heating and material damages in fusion power reactor. Theoretical calculations of double differential cross sections are very important to understand the reaction mechanism and to compare with available experimental data [4-9].

In this work, the theoretical double differential cross sections of alpha particle emission spectra at 30, 45, 60, 90, 110 and 150 degrees have been calculated for an incident neutron energy of 14.2 MeV on ^{19}F(n,xa) reactions. In calculations, three calculation models including EMPIRE-3.2 [10], and HMS-ALICE-2011 [11] were used. These theoretical calculations were done using Hauser-Feshbach statistical model [12], statistical model with compound, pre-equilibrium and direct [13].

2 Results and Discussions

In this study, double differential cross section emission spectra for the ^{19}F(n,xa) fusion materials have been calculated by using the Hybrid Monte Carlo (HMS) for pre-equilibrium emissions at 14.2 MeV incident neutron energy and emission angles ranging from 30º to 150º (30°, 45°, 60°, 90°, 110° and 150°). In calculations, ALICE and EMPIRE computer codes were used. The calculated values of the emitted alpha particles at given angles were compared with experimental data.

The calculated double differential cross section results for ^{19}F(n,xa) reaction were given in Figs. 1-6, respectively. The experimental data for ^{19}F(n,xa) in literature are taken from Kondo et al. [14], Terada et al. [15] with using the EXFOR library [16].

Theoretical double differential cross section calculations at 30° for ^{19}F(n,xa) were given in Fig. 1. In Fig 1, we compared our double differential cross section calculations with the experimental data of Kondo et al. [14]. Theoretical double differential cross section calculations from ALICE code are close agreement with experimental data by Kondo et al. [14] especially at the continuum from 4 to 11 MeV while EMPIRE results are similar with experimental data between 4 and 7 MeV.

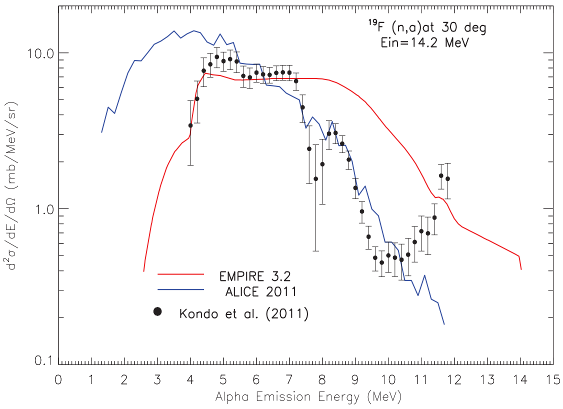

Fig.1. Calculated double differential cross section calculations of alpha particle at 30°.

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Fig. 2 shows two double differential cross section calculations for the alpha emission spectrum at 45° for an incident neutron energy of 14.2 MeV on ^{19}F(n,xa) reaction. Experimental data from Terada et al. [14] are in general agreement with ALICE results.

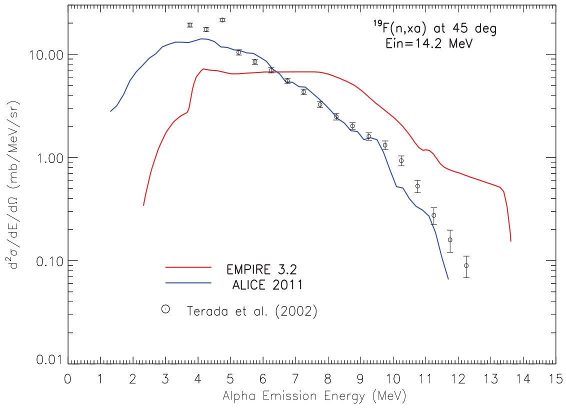

Fig. 2. The same with Fig. 1, but for 45°.

The calculated double differential cross section alpha emission spectra comparing with the experimental data by Terada et al. [15] at emission angle of 60° and for 14.2 MeV incident neutron energy are given in Fig. 3. Similar to the 45°, ALICE results are in general agreement with experimental data especially between 4 MeV and 12 MeV.

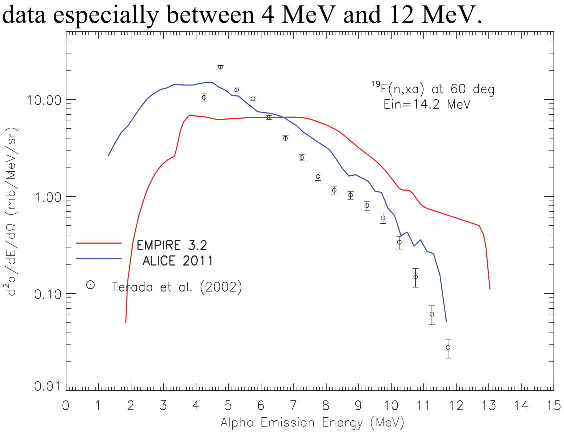

Fig. 3. The same with Fig. 1, but for 60°.

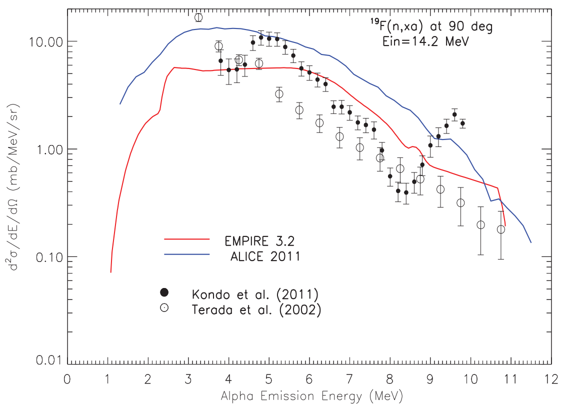

Fig. 4. The same with Fig. 1, but for 110°.

Fig. 4 shows the results of double differential cross section for alpha emitted in reactions of incident neutron energy of14.2 MeV at emission angle of 90° degree for ^{19}F(n,xa) reaction. In Fig. 4, the calculated data for 14.2 MeV neutrons are compared with measurement data by Terada et al. and Kondo et al. [14]. Both theoretical cross section data calculated by EMPIRE-3.2 and ALICE codes from 3 MeV to 11 MeV are approximately close agreement with experimental data.

Fig.5 shows the double differential alpha emission cross sections of fluorine for 14.2 MeV neutrons at angles of 110 degree in comparison with experimental data measured by Terada et al. [15] and Kondo et al. [14]. From Fig. 5, it is seen that there are two peaks of experimental data given by Kondo et al. [14] at 5MeV and 9 MeV. Double differential cross section curves of ALICE and EMPIRE are almost constant throughout the entire alpha emission energy range. The comparison of calculated data from three codes at this incident energy for 110° is in good agreement with experimental data.

Fig. 6 shows the results of double differential cross section for alpha emitted in reactions of an incident neutron energy 14.2 MeV at 150° for ^{19}F(n,xa) reaction. Fig. 6 also shows the comparisons of double differential cross sections among the calculated data and available experimental data by Kondo et al. [14]. Comparing theoretical calculations from ALICE and EMPIRE codes with experimental data, it is seen that experimental data is lower cross section values between 4.5 MeV and 7.5 MeV.

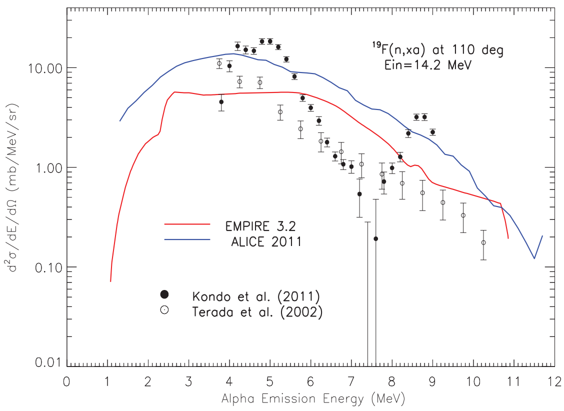

Fig. 5. The same with Fig. 1, but for 90°.

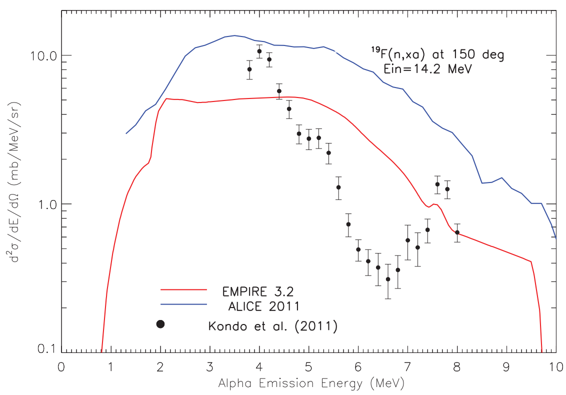

Fig. 6. The same with Fig. 1, but for 150°.

We calculated theoretical energy differential cross section for ^{19}F(n,xa) reaction as seen from Fig. 7. The energy differential cross sections are plotted versus alpha emission energy at 14.2 MeV in Fig. 7. As seen from Fig. 7, total, direct, pre-equilibrium, and compound energy differential cross sections are given. Moreover, experimental energy differential cross section obtained from Terada et al. [15] is plotted to compared with theoretical results. Calculations of dσ/dE predicts that probability of alpha energy are generally emitted from compound nucleus mechanism.

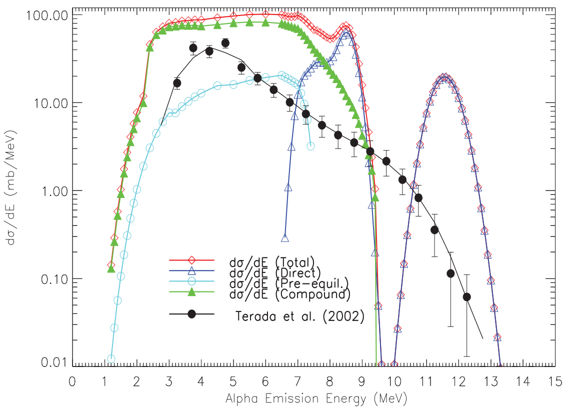

Fig. 7. Theoretical differential energy spectra of emitted alphas from ^{19}F(n,xa) reaction at 14.2 MeV neutrons.

We also obtained angular distributions of the double differential alpha emission cross sections at the incident energies of 0-2, 2-4, 4-6, 6-8, 8-10, and 10-12 MeV at incident energy of 14.2 MeV and then we plotted logarithmic energy values versus angle values from 0 to 180° as seen Fig. 8.

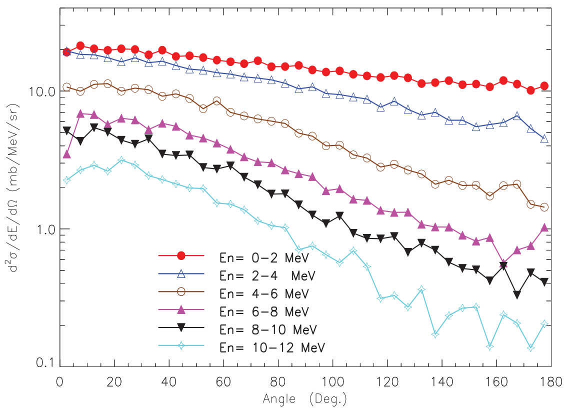

Fig. 8. Angular distributions of emission alpha from from ^{19}F(n,xa) reaction for different energies at incident energy of 14.2 MeV

3 Conclusion

In present work, we used ALICE, EMPIRE model codes to calculate double differential cross sections spectra for the ^{19}F(n,xa) structural fusion materials at 14.2 MeV for different emission angles ranging from 30 to 150 degrees.

Conclusions are briefly summarized as;

- The model calculations provide the good description of the shape and magnitude of double differential cross of alpha emission for selected emission angles except for 150 deg.
- It is clearly seen that there are very good agreements in the energy region less than about alpha emission energy 11 MeV at all emission angles.
- For all angles between 30-150 degrees, alpha emission energy values are seen up to maximum 12 MeV and hence these energy range are decrease while emission angles increase.
- It is also clearly seen that there are very good agreements in the full alpha energy range for all angles.
- For better double differential cross alpha emission further theoretical studies are required.

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