Non-equilibrium emission of neutrons in alpha particle induced reactions below 10 MeV/A

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Introduction

Excitation functions (EFs) of alpha induced reactions in the intermediate energy region are of increasing importance for a wide variety of applications e.g medical radioisotope production, radiation and shielding effects in space and technology development of an accelerator driven system for transmutation of nuclear waste or for energy production [1,2]. The information on the excitation function of residual nuclei is also important for verification of different models used to explain the reaction mechanism, optimize the production yield, and estimation of the impurities of radioisotopes simultaneously produced. The production yields of radioisotope can be deduced from the full excitation function of the nuclear process with reasonable accuracy.

^{167}Tm is a candidate radioisotope for both nuclear medicine diagnostics and therapy due to its emitted Auger-electrons, low energy X- and gamma-rays. In the frame of a systematic study of excitation functions for production of medically relevant radioisotopes by charged particle induced reactions on rare earths, the ^{165}Ho(α,2n)^{167}Tm reaction and the ^{165}Ho(α,n)^{168}Tm, ^{165}Ho(α,3n)^{166}Tm, ^{165}Ho(α,4n)^{165}Tm side reactions were measured up to 40 MeV by the stacked foil activation technique followed by offline HPGe gamma-ray spectroscopy. The measured results were compared to the earlier measurements [3 – 5], ALICE-91 code calculations considering equilibrium (EQ) as well as pre– equilibrium (PE) reaction dynamics according to Geometry Dependent Hybrid model (GDH) of Blann and also to the TALYS Code.

Experimental details

The stack foil activation technique was employed for the present measurements. Targets were made from spectroscopically pure holmium of thickness 1.24 mg/cm^2. The stack comprising the target and suitably thick degrader foils of aluminum was irradiated with 40 MeV diffused α –beam at VECC Kolkata (INDIA). The other details about the experiment can be found in our earlier publications [5, 6]. After irradiation the induced γ – activities in each target foil were followed with a HPGe detector of 100 cc active volume coupled to the ORTEC's PC based multichannel analyzer. Energy and efficiency calibration were also done before data analysis. The various channels populated were identified using the decay data adopted from Table of Radioactive Isotopes by Browne and Firestone. The gamma ray spectroscopy software RADWARE was used extensively for analyzing the spectra. The experimentally measured reaction cross-sections were computed using the formulation similar to that in Ref. [5,6]. Proper attention was given for inclusion of various errors that may influence the quality of data. In general these errors are less than 18%.

Model Calculations

The experimentally measured excitation functions for the reactions reported in this report were also calculated theoretically. The theoretical calculations were done using the computer codes ALICE-91 and TALYS. ALICE-91 is based on Weisskopf – Ewing model for compound nucleus decay and hybrid as well as geometry dependent hybrid (GDH) model for the pre equilibrium decay process. This code is capable to predict the excitation functions for pure equilibrium decay as well as with pre-equilibrium decay. The pre-equilibrium decay part of ALICE-91 can account for a large variety of reaction types. In this code besides evaporation of neutrons and protons, clusters such as deuterons and α - particles can be considered.

TALYS is a code which basically simulates all types of nuclear reactions in the energy range of 1 keV–200 MeV. The default optical model potentials (OMP) used in TALYS is the local and global parameterizations for neutrons and protons but we can adjust the parameters on demand. All types of compound nucleus reaction mechanism are included in this code where the calculations are mostly based on the Hauser–Feshbach formalism including width fluctuation corrections (WFC). The multiple pre-equilibrium processes are accomplished by keeping track of all successive particle-hole excitations for either protons or neutrons. An independent treatment of an isomeric state cross-section is the main advantage of this code.

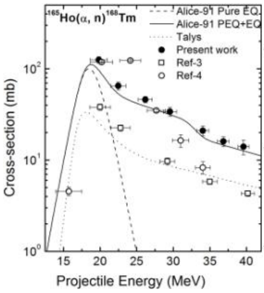

Figure - 1

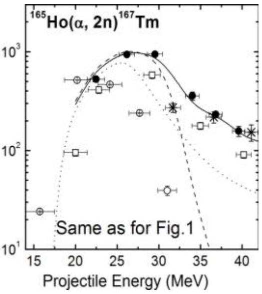

Figure - 2

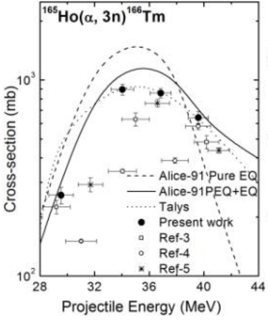

Figure -3

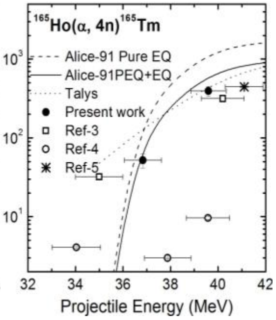

Figure - 4

Results and Discussion

The measured excitation functions with theoretical predictions of ALICE-91 code and TALYS code are shown in figures 1 – 4. The available literature values are also shown in figures. The solid circles show the present measurements. The solid line and the dashed lines show the ALICE-91 prediction with and without inclusion of PE emission. The dotted lines show the TALYS model calculations.

It can be seen that the measured data set is well fitted with the prediction of the code ALICE-91. In general, it is clear from Figs. 1 - 4 that the PE emission is significantly observed in most channels of the present study. Thus, a systematic attempt has been made to estimate the PE contribution at a given energy for a particular reaction channel. The percentage PE contribution deduced from the systematic used in the analysis of the data for different reaction channels are plotted in Fig.5 as a function of the normalized projectile energy (E_α / V_{CB}). It can be seen clearly from Fig.5 that the percentage of the PE contribution is found to increase with normalized projectile energy. Furthermore, the threshold of PE emission for the various reaction channels is found to be different, depending on the corresponding Q-value. However, it may be pointed out that the PE contribution is found to be greater for the channels that consist of fewer PE particle(s), even at smaller projectile energy.

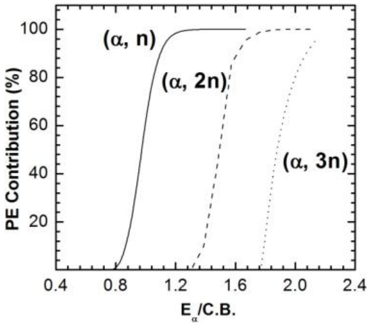

Figure - 5

Acknowledgements:

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