Pre-Equilibrium Contribution in Alpha-Induced Reactions on ^{nat}Sb

Pankaj K. Giri[1],* A. Sharma[1], K. Basu[1], S. S. Ghugre[1], S. Dasgupta[2], J. Datta[2], G. Mukherjee[3,4], S. Bhattacharyya[3,4], and R. Raut[1†]
[1]*UGC-DAE CSR, Kolkata Centre, Kolkata 700106, INDIA*
[2]*Analytical Chemistry Division (BARC), VECC, Kolkata-700064, INDIA*
[3]*Physics Group, Variable Energy Cyclotron Centre, Kolkata 700064, India and*
[4]*Homi Bhabha National Institute, Anushaktinagar, Mumbai 400094, India*

Introduction

Pre-equilibrium reactions occur in time scales between the direct reactions and the compound nucleus fusion, and are of much pertinence towards a complete understanding of the nuclear reaction dynamics. There have been different models for representing the particular mechanism and its cross section but, as it shall be illustrated in the present study, there is a need for improving upon the theory in the light of updated experimental data.

Alpha-induced reactions have gained interest due to their broad applications in nuclear astrophysics, medicine, and radioisotope production. These reactions are important not only for understanding stellar nucleosynthesis [e.g. ^{151}Eu(α,γ)^{155}Tb] but also for producing radioisotopes used in diagnostic imaging [e.g. ^{144}Sm(α,n)^{147}Gd] and targeted radiotherapy [e.g. ^{209}Bi(α,2n)^{211}At], thus extending the scope of nuclear research to societal applications.

This work is based on investigating α induced reactions on Sb (Z=51) isotopes towards probing the contribution of the pre-equilibrium mechanisms to the resulting yields. By analyzing alpha-induced reactions on ^{nat}Sb and comparing the experimental data with theoretical predictions, this work aims to bring out the credibility of the relevant models and indicate the need for refinements therein.

*Electronic address: pankajcuj@gmail.com
†Electronic address: rajarshi.raut@gmail.com

Experimental Setup

The natural Cu-Sb stack foils were irradiated with an alpha beam, ranging from 40 to 51 MeV, at the 0^o beam line of the K130 Room Temperature Cyclotron (RTC) in VECC, Kolkata, India. The beam current was approximately $\sim$ 50 nA, and each stack was irradiated for around 2 hours to achieve the required activity buildup of interested radioisotopes. Post-irradiation, the foils were counted to detect decay gamma-ray activity using a 40% single crystal HPGe detector that was calibrated and characterized with standard sources ^{152}Eu and ^{133}Ba. A typical gamma spectrum of a Cu-Sb foil stack, irradiated at 44 MeV, is shown in Fig. 1.

The beam flux incident on the foil stack was extracted using the cross sections of the monitor reaction ^{nat}Cu(α,x)^{67}Ga As depicted in Fig. 2, the experimental results for the same closely match the IAEA-recommended values [2], confirming the accuracy and reliability of the parameters used in exploring the α + ^{nat}Sb system.

Results and Discussion

Eight evaporation residues (ERs) were produced from alpha-induced reactions on ^{nat}Sb under the present experimental conditions. These residues were identified via gamma-ray detection from calibrated spectra, followed by decay curve analysis. The TALYS 2.0 code was used to explore equilibrium and pre-equilibrium effects, comparing experimental results with theoretical cross-sections. The ^{nat}Cu(α, x)^{122}Sb reaction, shown in Fig. 3, reveals a significant deviation when only equilibrium models are considered, but improved overlap with the cross-section data when pre-

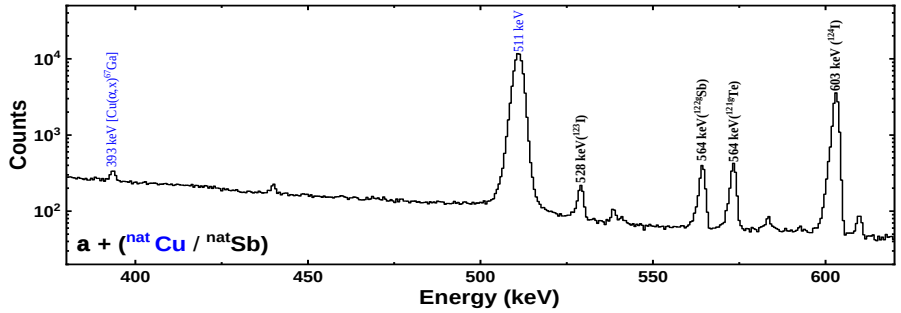

FIG. 1: Calibrated γ-spectrum from α energy 44 MeV irradiation of natural Cu and Sb foils.

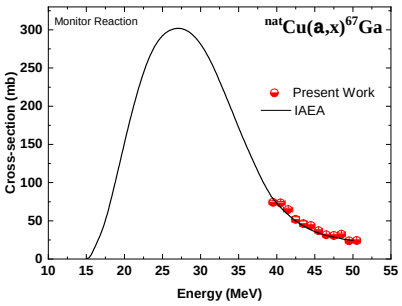

FIG. 2: Monitor reaction ^{nat}Cu(α, x)^{67}Ga [1] overlap with IAEA recommended data [2] for the present experimental conditions.

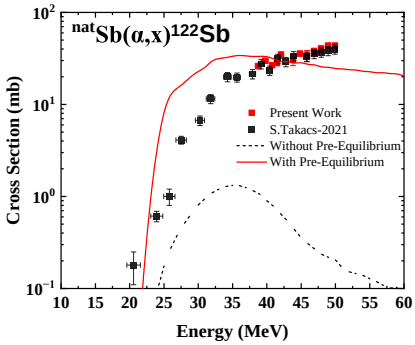

FIG. 3: Excitation function plot of ^{nat}Cu(α, x)^{122}Sb with literature data [3].TALYS code estimated without Pre-equilibrium (doted line) and with Pre-equilibrium mode (solid line)

.

equilibrium effects are included. Models like Avrigeanu's [4] OMP and the Brink-Axel Lorentzian GSF accurately matched the experimental data, along with the Constant Temperature + Fermi Gas Model (CTM) and exciton-based pre-equilibrium modeling.

Conclusion

This study underscores the importance of pre-equilibrium processes in alpha-induced reactions on ^{nat}Sb, especially owing to its significance at beam energy $\geq$10 MeV/nucleon. The results provide a strong basis for further research into nuclear reactions with applications in nuclear astrophysics and theranostics. Further and detailed illustrations of the results that are currently being finalized shall be presented in the Symposium.

Acknowledgments

This work has been carried out under SERB (DST) Project No. CRG/2021/001011.

References

[1] Pankaj K. Giri et al., J Radioanal Nucl. Chem. (2024). https://doi.org/10.1007/s10967-024-09545-z.

[2] IAEA recommended data set for ^{nat}Cu(α,x)^{67}Ga reaction channel; https://www-nds.iaea.org/medical/medical-2020-05/cua67ga0.html.

[3] S. Takacs et al., Nucl. Instrum. Methos Phys. Res. B **505**, 24 (2021).

[4] V. Avrigeanu at. al., Phys. Rev. C **90**, 044612 (2014).