Analysis of residual cross section from ^{11}B-induced reaction on Zr

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Introduction

Over the years, extensive research has been conducted on fusion reactions involving both tightly and weakly bound heavy projectiles on medium and heavy targets [1, 2]. An in-depth study of theoretical and experimental aspects has been dedicated to it. Important mechanisms in those studies, such as complete fusion (CF) and incomplete fusion (ICF), where the projectile either fully or partially fuses with the target nucleus, remain areas of ongoing investigation. Pre-equilibrium (PEQ) emission, where particles are emitted before the system reaches a fully equilibrated state, adds further complexity to reaction dynamics [3]. Deep inelastic scattering, which involves the exchange of significant momentum and energy between the projectile and target, and quasifission, a process similar to fission but occurring before forming a compound nucleus, also challenges our current models. Moreover, nucleon transfer still needs to be understood, particularly near Coulomb barrier energies, where quantum tunneling effects dominate.

This work advances the understanding of nuclear reaction mechanisms in synthesizing different radioisotopes. In order to estimate reaction cross sections, it is important to evaluate the predictive accuracy of reaction codes, particularly considering their most recent modifications [4]. In this work, we have reported the residual cross sections from the ^{11}B-induced reaction on the natural Zr target within 37-63 MeV energy range and analyzed the corresponding fusion behavior.

Experimental details

In this experiment, we utilized a beam of ^{11}B$^{+4,+5}$ ions delivered by the Pelletron accelerator at BARC-TIFR, Mumbai. The experimental setup featured self-supported thin Zr foils (99.99% pure) with a 1.4 mg/cm^2 thickness, complemented by Al backing foils with a 1.8 mg/cm^2 thickness, forming the target matrix. After irradiation, we measured residual activity with a pre-calibrated high-purity germanium (HPGe) detector with an energy resolution of $\leq$ 2.0 keV at 1332 keV from ^{60}Co. Using GENIE2k software and a multichannel analyzer, we measured the γ spectra. By examining the γ-ray spectra, we determined the reaction residues based on their distinct decay patterns and γ-rays.

Results and discussion

Production of 13 radionuclides, ^{101m,100,99m,98,97}Rh, ^{97}Ru, ^{99m,96,95,94}Tc, ^{93m}Mo, and ^{97,96}Nb, resulting from the fusion of ^{11}B with the ^{nat}Zr target within 37-63 MeV energy range via xn, pxn, αxn, αpxn and $2\alpha xn$ channels, has been confirmed by the time-resolved γ-ray spectra. We have compared the measured excitation functions (EFs) of the residues with the theoretical predictions from EMPIRE-3.2.2 [5] in order to understand the underlying reaction dynamics. EMPIRE uses the exciton model to describe the PEQ process and applies the Hauser-Fesbach formalism for compound nucleus (CF) formation. In our study, we have employed the EMPIRE code with three different level density models: EGSM (Enhanced Generalized Superfluid Model), GSM (Generalized Superfluid Model), and GC (Gilbert-Cameron). These models incorporate the Ignatyuk energy-dependent parameter, which accommodates the shell effects as the excitation energy increases and considers the collective excitation effects on level density. Among the three, EGSM is especially useful for studying heavy ion fusion reactions because it offers a more accurate

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description of angular momentum.

For the xn-channel residues ^{100}Rh and ^{99m}Rh, the EGSM model accurately reproduces the experimentally observed EFs. In contrast, the GC model consistently overestimates the EFs across the entire energy range, while the GSM model shows overestimation at lower energies but tends to underpredict the higher energy.

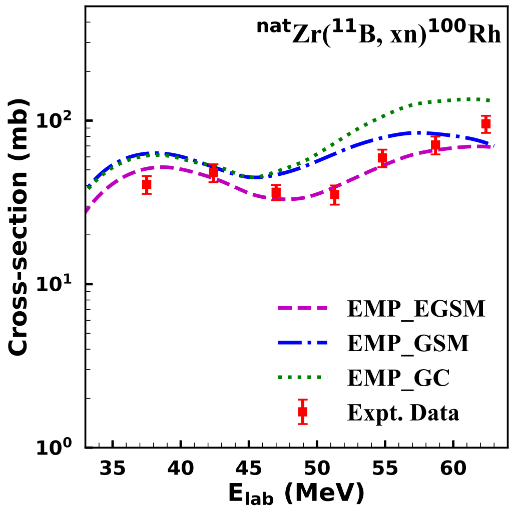

FIG. 1: A comparison between the measured excitation function of ^{100}Rh produced via the xn channel and theoretical predictions from EMPIRE.

In this abstract, we have focused on the xn channel residues. The measured EFs of ^{100}Rh (20.8 h) and ^{99m}Rh (4.7 h) are compared with the predictions from EMPIRE-3.2.2, employing various nuclear-level density models, as shown in Figure 1 and Figure 2. The figures show a good agreement with the EMPIRE model, particularly with the EGSM level density. This gives insight into the fundamental process of nuclear reactions and highlights the role of compound nucleus formation.

Further analysis is ongoing to understand the effect of different entrance channel parameters on fusion dynamics and to determine if there are any ICF signatures in the radioisotope production through the αxn channel

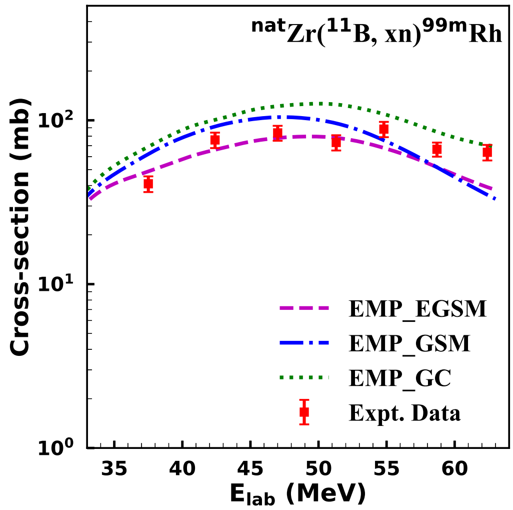

FIG. 2: Same as Figure 1, but for ^{99m}Rh.

(breakup threshold of ^{11}B = 8.6 MeV), as it has been already reported in the literature for other strongly bound nuclei, ^{12}C and ^{14}N with α-breakup thresholds of 7.6 MeV and 11.6 MeV, respectively. More details will be presented during the conference.

Acknowledgment

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