Study of ^{12}C induced reaction on ^{89}Y: A signature of preequilibrium emission of neutrons

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Introduction

Investigation of preequilibrium (PEQ) emission of neutrons over compound evaporation in heavy-ion induced reactions on the medium/heavy mass nuclei is a key to understand the dynamics of the excited composite nucleus during the equilibration process and the mechanism of formation of compound nucleus. During the fusion of light-heavy ion projectiles (A $\leq$20), emission of non-evaporated fast neutrons and alpha particles is observed due to the PEQ process and incomplete fusion (ICF) even at the relatively lower energy range ($\sim$ 4-10 MeV/A) [1–4]. Earlier, production cross section of the residues and their recoil range distribution was reported from the ^{12}C+^{89}Y reaction within 5.8 –7.2 MeV/A energy range [1]. Later isomeric cross section ratio and angular momentum distribution of ^{99}Rh produced in the same reaction was reported in the low energy region, within $\sim$ 2.5- 3.7 MeV/A [2].

In the present work, we report the production of ^{98,97,96}Rh from the ^{12}C induced reaction on the ^{nat}Y target within $\sim$3.7- 6.2 MeV/A energy region and the emission of PEQ neutrons in the 3n reaction channel.

Experimental details

The experiment was performed at the BARC-TIFR Pelletron facility, Mumbai, India. The ^{12}C beam was bombarded on a stack of natural yttrium foils of thickness $\sim$ 2 mg/cm^2, backed by the aluminum catcher foils $\sim$ 1.5 mg/cm^2 within 45-75 MeV energy range. Identification of the populated residues was carried out with the help of γ-ray spectrometry using a HPGe detector and GENIE-2K software after the end of the bombardment (EOB) by long time counting. The activity of the residues was calculated at the EOB and the cross sections of the residues were determined using the standard activation formula [3]. The nuclear spectroscopic data of Rh-isotopes produced at different xn-channels is shown in Table I.

TABLE I: Spectroscopic data of Rh-isotopes

Nuclides	$T_{1/2}$	Eγ(keV)[Iγ(%)]	E_{th}(MeV)
^{96}Rh	9.9 min	685.49[95.7]	54.9
		832.57[100]	
^{97}Rh	30.7 min	421.55[75]	42.4
		840.13[12]	
^{98}Rh	8.7 min	652.43[94]	32.6
		745.36[5.3]	

Analysis and results

The measured cross sections of ^{98,97,96}Rh radionuclides populated via xn-channel (x=3,4,5) are presented in Figs.1-3 and are compared with the theoretical model calculations obtained from PACE4 and EMPIRE3.2. The complete fusion cross-section of the interacting nuclei is estimated using simplified coupled channel calculation in EMPIRE, suitable for heavy-ion induced reactions, and one dimensional tunneling model considering the Bass potential in PACE4. Hauser-Feshbach (HF) statistical model is used to estimate the EQ process in both the model codes. The Gilbert Cameron (GC) level density parameter is used in PACE4 while enhanced generalized superfluid model (EGSM) that uses collective excitations of level density,

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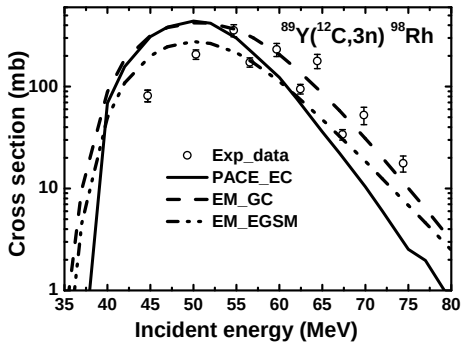

FIG. 1: Comparison of experimental and theoretical cross sections of ^{98}Rh from ^{12}C+^{89}Y reaction

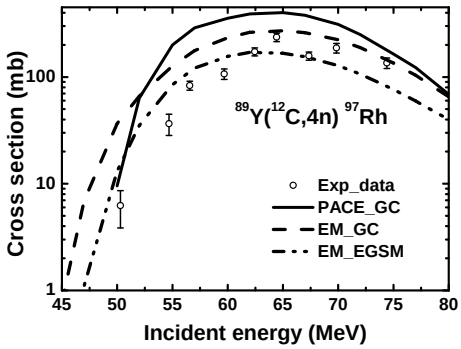

FIG. 2: Same as Fig.1 for ^{97}Rh

and GC level densities with Ignatyuk energy dependent level density parameter are used in the EMPIRE to study EQ emissions. In addition to the EQ process, EMPIRE uses the exciton model to estimate the PEQ emissions.

Fig.1 shows a comparison between the measured excitation function and theoretical model estimations for ^{98}Rh. At low energies, below 50 MeV, the experimental cross section is overpredicted by EMPIRE and PACE4, while high energy tail of the excitation function (∼50-75 MeV) is underpredicted by PACE4, but agrees well with the EMPIRE estimations, indicating clear enhancement in measured cross section values. The observed enhancement of cross sections at the high energy tail could be attributed to the PEQ emission of neutrons. In case of ^{97}Rh, shown in Fig.2, experimental cross sections are grossly reproduced by the EMPIRE above 60 MeV whereas PACE4 overpredicts them. In Fig.3, all the model calculations overpredicts the measured cross sections of ^{96}Rh. It is believed that the residues ^{96}Rh, ^{97}Rh are produced by the compound evaporation mechanism.

Conclusion

Cross sections of the residues produced via xn-reaction channels (n=3,4,5) from the complete fusion of ^{12}C and ^{89}Y within ∼ 3.7- 6.2 MeV/A energy has been reported. Although

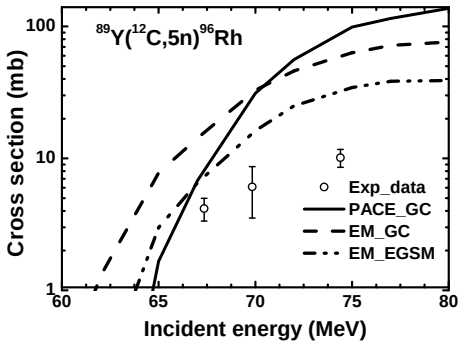

FIG. 3: Same as Fig.1 for ^{96}Rh

EQ process dominates in the energy range considered, a signature of PEQ emission of neutrons has been observed in the $3n$-channel.

Acknowledgments

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