Experimental study on the production of Pd-radionuclides in ^{11}B+ ^{93}Nb reaction

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Introduction

Study of heavy-ion induced reactions on intermediate or heavy mass targets is necessary to understand the pre-equilibrium (PEQ) emissions, complete and incomplete fusion reactions, nucleon transfer processes etc. In heavy-ion induced reactions, PEQ emission of neutrons are observed at relatively low projectile energy (4-10 MeV/A). PEQ emissions in ^{12}C- and ^{16}O-induced reactions on intermediate/heavy mass targets like ^{128}Te, ^{159}Tb, ^{197}Au, ^{64}Ni etc. in 4-10 MeV/A energy range were reported in [1–3]. However heavy-ion induced reaction data near the barrier is still rare in order to develop sophisticated formalism for PEQ reactions in 4-10 MeV/A, low energy range.

For the first time, production of ^{101,100,99}Pd radionuclides via neutron channels is reported in ^{11}B induced reaction on natural niobium (^{93}Nb) target in 3-5 MeV/A. Although ^{101m,100,99}Rh, ^{97}Ru radionuclides have also been identified, but this report is focused on the production of Pd-isotopes.

Experiment

The experiment was carried out at the BARC TIFR pelletron facility, Mumbai, India. The $^{11}B^{5+}$ beam of various energy was allowed to incident on the ^{93}Nb foils of thicknesses 2 and 1.84 mg/cm^2, respectively, with the backing of aluminium foils of 1.5 mg/cm^2 thickness. Al foils served the purpose of a catcher as well as energy degrader. After the end of bombardment (EOB), target ^{93}Nb and its backing catcher-Al foils were analysed collectively with the help of a Falcon 5000 HPGe-based detector coupled with a tablet PC operating with GENIE-2K software (Canberra). Standard activation formula was used to calculate the cross-sections of each evaporation residues produced in each target foil at various energies.

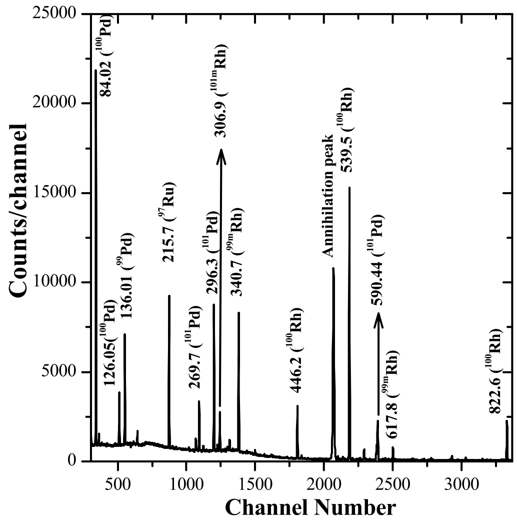

FIG. 1: The γ-ray spectrum of the 51 MeV ^{11}B irradiated ^{93}Nb foil after 38 minute of EOB

TABLE I: Spectroscopic data of the residual radionuclides.

Radionuclides	$T_{1/2}$	Eγ(keV)(Iγ(%))	E_{th}(MeV)
^{101}Pd	8.47 h	296.29(19.0)	19.4
		590.44(12.1)	
^{100}Pd	3.63 d	84.02(52.0)	28.6
		126.05(7.8)	
^{99}Pd	21.4 m	136.01(73.0)	41.0
		263.60(15.2)	

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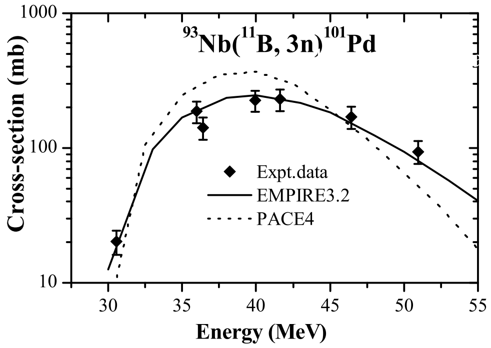

FIG. 2: Measured excitation function of ^{101}Pd was compared with EMPIRE3.2 and PACE4 calculation.

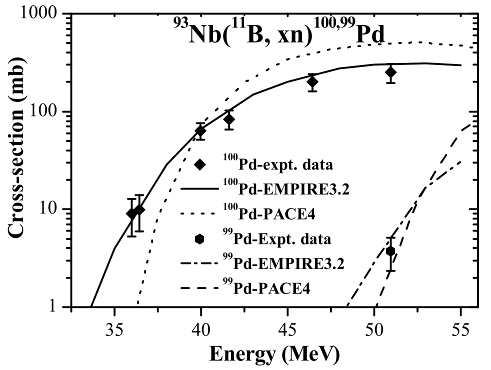

FIG. 3: Measured excitation function of ^{100}Pd, ^{99}Pd compared with EMPIRE3.2 and PACE4 calculation.

Results and discussion

Fig 1 shows the characteristic γ-ray peaks of all the residues produced at 51 MeV incident energy. Spectroscopic data are tabulated in Table I. To investigate the reaction mechanisms involved in this system, theoretical estimations of PACE4 and EMPIRE3.2 were done. The code PACE4 considers the Hauser-Feshbach (HF) model with Gilbert Cameron level density for the compound nuclear process. While EMPIRE3.2 uses exciton model for PEQ emission of particles along with HF model for compound process and uses enhanced generalized superfluid model (EGSM) for level density. Measured cross-sections of ^{101}Pd and ^{100,99}Pd at different incident energies are plotted and compared with theoretical data, shown in Fig 2 and Fig 3, respectively. It is clear that EMPIRE3.2 calculations reproduce the measured data quite well within statistical errors compared to PACE4. This indicates that EGSM level density is a better approach than Gilbert Cameron level density, used in PACE4, to explain the measured data.

As seen in Fig 2, EMPIRE3.2 predicts PEQ emission of neutrons in high energy tail of the excitation function, when compared with PACE4 results and experimental value at 51 MeV supports the EMPIRE3.2 estimations and indicating the PEQ emission of neutrons in 3n channel. Hence, one PEQ and two equilibium neutron emission might be the possible route of production of higher cross-section in 3n channel. Overall, compound reaction mechanism is dominant process over the energy range studied.

Conclusion

This study indicates the compound reaction mechanism is a dominant process in ^{11}B + ^{93}Nb system upto 5 MeV/A energy. In addition, signature of PEQ emission of neutrons is also observed in 3n channel around 5 MeV/A. The EGSM level density reproduces the experimental data better compared to the Gilbert Cameron level density.

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