Production of ^{101}Pd from ^{12}C + ^{93}Nb reaction : A viable route to produce ^{101m}Rh

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Introduction

The study of nuclear reactions has proved huge applications in the medical field through the production of radioisotopes useful in diagnostic as well as therapeutic purposes. Organometallic compounds of Rh, e.g., [RhacacCOD]^0, *mer*-[Rh$(NH_3)_3Cl_3$] [1, 2] have emerged as promising candidates for antitumor drugs. It is due to their action against Ehrlich ascites carcinoma, lung metastatic tumors, etc. [1]. In several of these compounds, currently used as chemotherapeutic agents, the Rh radioisotopes attached to the compounds may act as radiolabels. Interestingly, ^{101m}Rh (4.34 d) is useful as a radiolabel due to its decay properties. It decays into ^{101}Ru by 92.8% electron capture (EC). The auger and Coster–Kronig electrons [3] make ^{101m}Rh of specific interest for being investigated for radiotherapy as well. Further emission of low energy 306.86 keV (81%) γ–ray makes it suitable for imaging purposes.

Various production routes of ^{101}Pd, a precursor of ^{101m}Rh, have been studied, including proton, α-particle, and heavy-ion irradiation [4, 5, 6]. We report the indirect production of ^{101m}Rh from ^{101}Pd through ^{12}C+^{93}Nb reaction. Further chemical separation of ^{101}Pd from the target matrix is required for its medical usage.

Experimental details

The experiment was conducted at the BARC-TIFR Pelletron facility, Mumbai, India. A beam of ^{12}C with an energy up to 77 MeV impinged upon the stack of ^{93}Nb target and ^{27}Al catcher foils placed alternatively. The thicknesses of ^{93}Nb and ^{27}Al were between 1.3 – 3.0 mg/cm^2 and 1.5 – 1.8 mg/cm^2, respectively. The range of the degraded energy (calculated through SRIM software) in the center of targets was 39.5 – 75.9 MeV, while the Coulomb barrier was 37.7 MeV. After the end of bombardment (EOB), the irradiated target foils were placed in front of the pre-calibrated HPGe detector to identify the evaporation residues (ERs) through γ–spectroscopy. The spectra were analyzed by GENIE-2K software, and the measured counts were used to estimate the yield of ERs.

Results and discussion

An energy threshold, E_{th} = 37.6 MeV, is required for the production of ^{101}Pd from the compound nucleus (CN) ^{105}Ag* through the route ^{93}Nb(^{12}C, $p3n$). Additionally, short-lived ^{101}Ag (11.1 min) also decays to ^{101}Pd (8.47 h) through EC (100%). Similarly, ^{101}Pd further decays to ^{101m}Rh (4.34 d) through EC (100%). Hence, both ^{101}Pd and ^{101m}Rh can be formed in a cumulative manner, i.e., independently through the de-excitation of CN as well as through the decay of its higher charge isobars.

Fig. 1 shows the theoretically calculated cross sections at the above barrier energies using statistical model code EMPIRE-3.2.2 with enhanced generalized superfluid model (EGSM) level density. It can be observed that the energy beyond 46 MeV is favorable for the independent production of the desired radionuclides (wine color lines). ^{101}Pd reaches

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its peak production of 456 mb at 68 MeV, while we observe some contamination from other isotopes of Pd, i.e., ^{102}Pd and ^{100}Pd. ^{102}Ag (12.9 min) also decays to ^{102}Pd (stable). However, to minimize the isotopic contamination in ^{101}Pd, we have to carefully choose the energy range accompanied by its immediate chemical separation method [6] from the target matrix to reduce ^{100}Pd (3.63 d) accumulation.

Fig. 2 depicts the experimentally measured cross section of ^{101m}Rh (cumulative) and the derived independent cross section of ^{101}Pd and ^{101m}Rh. Theoretical predictions are satisfying the data quite well. A huge enhancement of $\approx 300 - 650$ mb cross section in ^{101m}Rh from the decay of ^{101}Pd can be seen between 58 – 76 MeV. We had estimated the theoretical yield of ^{101}Pd produced by irradiating 1 mg/cm^2 target with $^{12}C^{6+}$ beam for 1 h, where 1μA beam current was considered. It came out to be a maximum of 67 MBq/C at 68 MeV. Nearly the same experimental yield has been attained at 68.2 MeV for 1 mg/cm^2 target irradiated with $^{12}C^{6+}$ for 3.9 h resulting in the integral charge of 907.1 μC. The theoretical estimate of thick target yield (TTY) gives the value of 531 MBq/C for 15 mg/cm^2 thick target to achieve the energy degradation from 77 – 47 MeV. Provided that the efficient chemical separation of ^{101}Pd can be done from the target matrix, this reaction can be seen as a viable route to the production of ^{101m}Rh.

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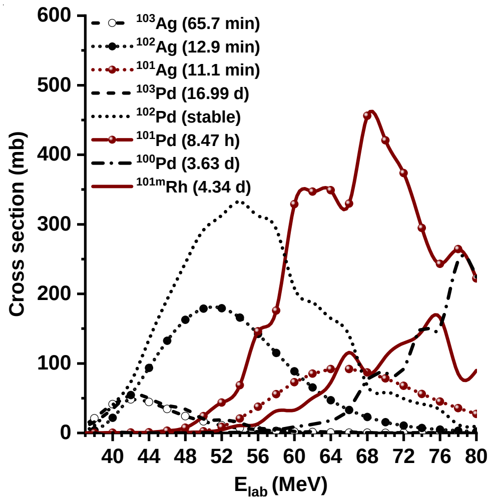

FIG. 1: Cross section predicted by EMPIRE code for the residues of interest.

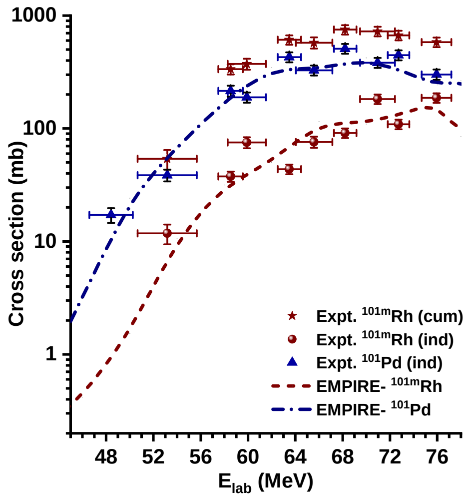

FIG. 2: Comparison of experimental and theoretical cross sections of ^{101}Pd and ^{101m}Rh.

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