Study on the Production and Yield Measurement of $^{149, 150, 151,152}$Tb from ^{16}O Irradiated Natural Lanthanum Target

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Introduction

The radiolanthanides have various mode of decay properties; viz.; β-particle emitting radionuclides, α-particle emitting radionuclides and Internal conversion or Auger electron emitting radionuclides. Due to this diverse decay characteristics, radiolanthanides have attracted many potential application in the field of nuclear medicine. Short-lived α-emitting radionuclides offer great potential for targeted therapy applications. There is a group of radiolanthanides proposed both for diagnostic and therapeutic purposes [1]. ^{149}Tb (4.118 h, E_α=3967 keV, range=28μm) is among such α-emitting radiolanthanides which has been proposed to be the most promising radiolanthanide for Targeted Alpha Therapy (TAT) [2-3]. Unlike ^{225}Ac, ^{149}Tb does not have daughter alpha emitters in the decay chain, which reduces the dose burden due to the recoil effect during radioactive decay. ^{149}Tb can be considered as a theranostic radionuclide as its positron radiation allows visualizing the distribution of the radiopharmaceutical using PET. To use ^{149}Tb for medical application, it is essential to explore the various production routes. Different production routes for ^{149}Tb are furnished in Table 1 using both light and heavy ion reactions. In principle, there can be direct production of ^{149}Tb and also the indirect production via the decay of ^{149}Dy. Light particle induced nuclear reactions for producing Tb-radioisotopes using Gd-target have significantly higher cross sections compared to heavy ion reactions. But the possible reactions producing specifically ^{149}Tb are very limited. Again, ^{149}Tb has two isomers; viz., ^{149m}Tb (4.16 min., $11/2^-$, 99.98% EC) and ^{149g}Tb (4.12 h, $1/2^+$, 83% EC). Moreover, ^{149g}Tb has got the medical application and ^{149m}Tb does not decay into the ground state.

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Table 1: Different production routes of ^{149}Tb

Serial No.	Reactions	Projectile
1.	^{142}Nd(^{12}C, 5n)^{149}Dy → ^{149}Tb	^{12}C
2.	^{143}Nd(^{12}C, 6n)^{149}Dy → ^{149}Tb	^{12}C
3.	^{152}Gd(p, 4n)^{149}Tb	p
4.	^{139}La(^{16}O, 6n)^{149}Tb	^{16}O
5.	^{141}Pr(^{12}C, 4n)^{149}Tb	^{12}C
6.	^{nat}Ta(p,x)^{149}Tb	p
7.	^{136}Ce(^{16}O, 3n) ^{149}Dy → ^{149}Tb	^{16}O
8.	^{138}Ce(^{16}O,5n)^{149}Dy → ^{149}Tb	^{16}O

So, ^{149g}Tb can be produced only in direct nuclear reactions or as a decay product from ^{149}Dy (indirect reactions). Due to this shielding of ^{149g}Tb formation by its high spin isomer with no IT decay, the indirect route via decay of ^{149}Dy might be preferable for the production of ^{149g}Tb using heavy ion beam [4-5]. However, it is always interesting to investigate the role of input angular momentum on the relative ratio of the yields of the two isomers. In the present work, an effort has been taken up to investigate the relative production yield of ^{149g}Tb by producing ^{149}Tb both via direct and indirect routes. For this, two reactions, viz., ^{139}La(^{16}O, 6n)^{149}Tb and ^{140}Ce(^{16}O, 7n) ^{149}Dy → ^{149}Tb, have been chosen where both the routes can be explored. In present report, the results from the direct reaction will be discussed and the results from the indirect route will be discussed during the symposium.

Experiment

The experiment was performed using 130 MeV ^{16}O beam available at RT Cyclotron, VECC. Both thick and thin ^{nat}La-targets were used. Thick target yields and cross-section measurements were performed respectively with thick (~25 mg/cm^2) La_2O_3 powder and ~200 μg/cm^2 La-targets

electro-deposited on 0.3 mil ultrapure Al-foil. A stack-foil irradiation method was employed for cross-section (CS) measurement with a typical irradiation time of 25 min. The loss of beam energy through targets and catchers as well as the range of the reaction products were calculated by SRIM/TRIM software. The energy resolution of the detector was found to be 1.9 keV at 1332 keV ^{60}Co peak. The energy and efficiency calibrations were performed with standard ^{152}Eu source. The irradiated target was kept at a distance of ~5 cm or more in order to keep the dead time below 5%. The cross section value for a particular radioisotope was calculated from the sum of activities obtained from both target and catcher foils. The product nuclides were identified from their characteristic γ-rays and half-life values determined using offline γ-ray spectrometry.

Results and Discussion

A typical γ-spectrum obtained with 50% HPGe detector shows the decay γ-lines originated from different Tb-isotopes, viz. ^{149}Tb (4.12 h), ^{150}Tb (3.48 h), ^{151}Tb (17.6 h) and ^{152}Tb (17.5 h).

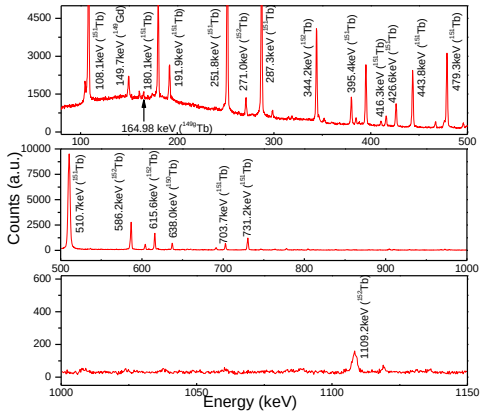

Fig. 1 Singles γ-ray spectrum obtained with HPGe detector

The 165 keV γ-line obtained in the decay γ-spectrum of the irradiated foil can only originate from the decay of ^{149g}Tb (4.12 h) as the high spin isomer ^{149m}Tb (4.16 min) would fully decay before the beginning of the γ-counting after a minimum cooling of 30 min. However, the 149.7 keV γ-line originated from the decay of ^{149}Gd can give the total yield of $^{149(m+g)}$Tb due to the fact that both the isomers EC-decay to ^{149}Gd and the direct production of ^{149}Gd in this route is negligible as predicted by PACE-IV code available in LISE++ software. The incident particle energy corresponding to the maximum yield of ^{149}Tb via ^{139}La(^{16}O, 6n)^{149}Tb route is calculated to be 110 MeV by PACE-IV code and the yield of ^{149}Gd at this energy is <10%. The experimental cross-section values of $^{149(m+g)}$Tb were calculated from the 149.7 keV γ-line and compared with the cross-section values predicted for ^{149}Tb by PACE-IV Code in Fig. 2.

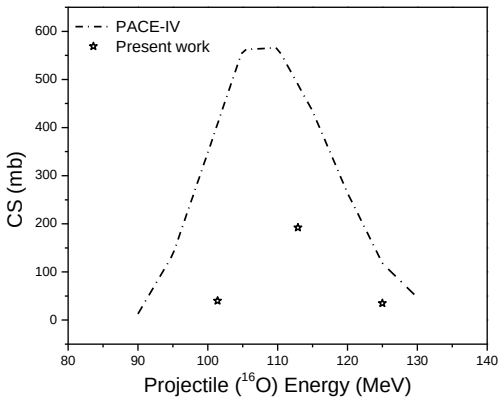

Fig. 2 Excitation function for ^{139}La(^{16}O, 6n)^{149}Tb reaction and comparison with PACE-IV calculation.

The experimental excitation function follows the PACE-IV calculated value.

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