New measurement of cross sections of evaporation residues from the ^{nat}Pr + ^{12}C reaction: A comparative study on the production of ^{149}Tb

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Production cross sections of evaporation residues, ^{149}Tb, ^{150}Tb, ^{151}Tb, and ^{149}Gd, are measured using the stacked foil technique followed by off-line γ-spectrometry in ^{12}C-induced reactions on naturally abundant mononuclidic praseodymium target in the 44- to 79-MeV incident energy range. Measured data are interpreted by comparison with previous measurements and theoretical predictions of the nuclear reaction model code PACE4. About 5% and 14% of the theoretical cross sections have been measured for ^{149}Tb and ^{150}Tb, respectively. The new cross sections of ^{149}Tb complement those measured earlier by α spectrometry. Cross sections of ^{151}Tb are comparable to the theory. Cumulative cross sections of ^{149}Gd shed light on the nuclear reaction mechanism. In addition, the discussion shows the feasibility of producing ^{149}Tb in p- and α-induced reactions on gadolinium isotopes.

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I. INTRODUCTION

Due to the short-range and high-linear-energy transfer in tissues, use of α-emitting radionuclides appears more promising than use of β emitters in targeted therapy, where localization of dose becomes important. It is therefore necessary to find more potential radionuclides to make targeted α therapy a standard therapeutic modality. The rationale for selection of potential radionuclides depends on the nuclear properties, methods of production, and complexation behavior with biological molecules. As a consequence, nuclear science has become a major contributor in developing this particular field.

So far, a few α emitters have been found to be suitable for targeted therapy. Due to its short half-life and 3.97-MeV α particle, ^{149}Tb [$T_{1/2} = 4.118$ h; decay mode, ϵ (83.3%) and α (16.7%)] is among the few promising α-emitting radionuclides which are projected for human clinical use [1–3]. This provides impetus to investigate in detail nuclear reactions to produce ^{149}Tb.

Production of proton-rich ^{149}Tb is possible only in accelerators by

(1) light-ion (p, d, α, ^{3}He)–induced reactions on a Gd target;
(2) proton-induced spallation reactions on high-Z material, Ta or W, etc.; and
(3) heavy-ion-induced reactions.

However, a hurdle lies in its production, particularly for applications which demand a significant quantity as well as purity of the radionuclide. Only a few reports are available in the literature that discuss the production of ^{149}Tb [4–6].

Usually, light-ion-induced reactions are preferred to produce clinical radionuclides because of the high yield. However, in the case of ^{149}Tb, light-ion-induced productions suffer from a few shortcomings: (i) the required projectile energy [≈40- to 45-MeV protons (Fig. 4) and 100-MeV α particles (Fig. 5)] is not available in common accelerators, (ii) a suitable enriched Gd target may be required to maintain the purity of ^{149}Tb, and (iii) purification of ^{149}Tb from the bulk target is not an easy task due to the similar chemical properties of lanthanides. A brief discussion of light-ion-induced production of ^{149}Tb has been appended in Sec. IV.

Due to the limited facilities available in the world, production of ^{149}Tb from a 1- to 2-GeV proton-induced spallation reaction followed by an online mass separation technique is also not feasible in practice. In this circumstance, it was assumed that heavy-ion-induced reactions may offer a solution for producing ^{149}Tb radionuclides.

Several heavy-ion reactions may lead to the production of ^{149}Tb either directly or as a decay product of ^{149}Dy. Alexander and Simonoff [4] measured excitation functions using α spectrometry in 12 heavy-ion reactions that produce ^{149}Tb from de-excitation of the compound nucleus of Tb. Eight heavy projectiles—^{10}B, ^{11}B, ^{12}C, ^{14}N, ^{15}N, ^{16}O, ^{18}O, and ^{19}F—were used, in combination with a variety of target isotopes from Ba to Nd, among which ^{141}Pr is the only naturally abundant mononuclidic target. It was found that the peak cross section measured in all target-projectile combinations is a maximum of 7% of the theoretical estimation. This led to the conclusion that compound nuclei having an angular momentum of less than $7.5\pm1.5\hbar$ contribute to these reactions. It is also interesting to note that all the production routes offer comparable peak cross sections of ^{149}Tb, without any added advantage of using enriched targets.

Later Kossakowski *et al.* [5] measured cross sections of evaporation residues from ^{12}C- and ^{14}N-induced reactions in ^{141}Pr and five enriched targets of Sm—^{144}Sm,^{147}Sm,^{150}Sm, ^{152}Sm, and ^{154}Sm—at incident energies of 5 to 10 MeV/A using γ spectrometry, with the aim of understanding the competition among neutron, charged particle, and γ-ray emission as a function of excitation energy, angular momentum, etc. The cross-section data presented for ^{149}Tb from ^{141}Pr(^{12}C,4n)^{149}Tb reaction were 2 orders of magnitude greater with respect to those in [4] and were likely for the high-spin isomeric state, ^{149}Tb^m ($T_{1/2} = 4.16$ min). Among the various target-projectile combination studied in [4] and [5], ^{141}Pr(^{12}C,4n)^{149}Tb

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TABLE I. Nuclear spectrometric data of the radionuclides [12] produced through $^{12}C+^{nat}Pr$ reactions.

Reaction	Product	Spin	$T_{1/2}$	Decay mode	E_γ (keV), I_γ (%)
$^{141}Pr(^{12}C,4n)$	^{149}Tb	$\frac{1}{2}^+$	4.118 h	ϵ, 83.3%; α, 16.7%	**164.98** (26.4), 352.24 (29.4)
$^{141}Pr(^{12}C,4n)$	$^{149}Tb^m$	$\frac{11}{2}^-$	4.16 min	ϵ, 99.98%; α, 0.02%	796.0 (97), 165.0 (7.3)
$^{141}Pr(^{12}C,3n)$	^{150}Tb	2^-	3.48 h	ϵ, 100%; α, <0.05%	**638.050** (72), 496.242 (14.6)
$^{141}Pr(^{12}C,3n)$	$^{150}Tb^m$	9^+	5.8 min	ϵ, 100%	638.050 (100), 650.36 (70)
$^{141}Pr(^{12}C,2n)$	^{151}Tb	$\frac{1}{2}^+$	17.609 h	ϵ, 99.99%; α, 0.0095%	287.357 (28.3), **251.863** (26.3)
$^{141}Pr(^{12}C,2n)$	$^{151}Tb^m$	$\frac{11}{2}^-$	25 s	IT, 93.4%; ϵ, 6.6%	830.50 (3.3), 379.70 (6.3)
$^{141}Pr(^{12}C,p3n)$, $^{149}Tb^m(\epsilon/\beta^+)$	^{149}Gd	$\frac{7}{2}^-$	9.28 d	ϵ, 100%; α, 0.00043%	149.735 (48), **298.634** (28.6)

is the only common reaction found for the comparative study.

No other experiment has been reported till now on the production of ^{149}Tb from this particular target-projectile combination to justify the reported results of [4] and [5] and the ambiguity, if any, lies between them. However, we reported recently the yield of ^{149}Tb and ^{149}Gd under particular experimental condition and suggested the required chemistry for mutual separation of ^{149}Tb and ^{149}Gd from a praseodymium target [7]. ^{149}Tb has a dominating electron capture (83.3%) decay mode and relatively long half-life compared to its high-spin ($\frac{11}{2}^-$) isomeric state, $^{149}Tb^m$, which directly decays to ^{149}Gd ($T_{1/2} = 9.28$ d) via electron capture (99.98%). This situation favors off-line γ-spectrometric investigation of the production of ^{149}Tb along with other residues. We therefore made an attempt to study the excitation functions from the ^{12}C-induced reactions on natural ^{141}Pr target in the 79-44 MeV incident energy range by off-line γ spectrometry. The report provides the idea of visualizing the production of impurity radionuclides along with the desired ^{149}Tb. Reaction cross-section data may also help to reduce certain impurities optimizing the reaction parameters. The definition of *impurity* has been defined in view of nuclear medicine elsewhere in our recent article [8]. We also report a comparative study on the production of ^{149}Tb from p- and α-particle-induced reactions on Gd isotopes using the nuclear reaction model code TALYS [9].

The experimental procedure and of the nuclear model calculations in brief are presented in Secs. II and III, respectively. Section IV discusses the results of the present study and Sec. V concludes the report.

TABLE II. Cross section of radionuclides produced in $^{12}C+^{nat}Pr$ reactions.

E_{lab} (MeV)	Cross section of isotopes (mb)			
	^{149}Tb	^{150}Tb	^{151}Tb	^{149}Gd
61.1	26.6 ± 2.7	33.3 ± 5.	18.1 ± 2.7	166.9 ± 8.3
54.1	2.5 ± 0.2	57.5 ± 8.1	32.7 ± 4.9	7.5 ± 0.4
46.4	–	15.7 ± 2.3	14.6 ± 2.2	–
77.5	3.7 ± 0.4	–	–	489.1 ± 24
71.9	6.1 ± 0.6	–	–	373.0 ± 18.7
65.9	12.2 ± 1.2	8.1 ± 1.2	–	251.4 ± 12.6
59.6	11.9 ± 1.2	25.8 ± 3.9	12.0 ± 1.8	92.1 ± 4.6
52.9	–	36.4 ± 5.5	23.6 ± 3.5	4.7 ± 0.2
61.1	21.9 ± 2.2	34.4 ± 5.1	17.7 ± 2.7	154.2 ± 7.7
54.2	3.2 ± 0.3	50.3 ± 6.8	31.4 ± 4.1	9.3 ± 0.5
46.5	–	17.7 ± 2.7	14.7 ± 2.2	–
75.2	6.8 ± 1.	–	–	593.3 ± 29.
68.9	14.3 ± 2.1	2.7 ± 0.4	–	385.2 ± 19.3
62.1	27.3 ± 4.1	18.1 ± 2.7	10.5 ± 1.6	268.5 ± 13.4
71.2	11.8 ± 1.8	–	–	425.8 ± 21.3
64.5	21.1 ± 3.2	17.0 ± 2.6	10.4 ± 1.6	201.9 ± 10.1
57.5	6.5 ± 1.	22.6 ± 3.4	13.6 ± 2.0	25.3 ± 1.3
50.7	–	10.3 ± 1.5	8.6 ± 1.3	–

II. EXPERIMENTAL PROCEDURE

Nonhygroscopic praseodymium oxide, Pr_6O_{11} (Johnson, Matthey & Co. Ltd.), was used as the target material. Pr_6O_{11} targets of 2.5–3.0 mg/cm^2 thickness were prepared by centrifugation technique on aluminium foil backing 1.5 mg/cm^2 thick. The target assembly was prepared by placing three such Pr_6O_{11} targets each time and was bombarded with ^{12}C beams. A total of six such target stacks were irradiated separately, varying the incident energy, with an overlap between them. The experiment was carried out at the BARC-TIFR Pelletron Accelerator facility, Mumbai, India. The integrated charge was recorded for each irradiation by an electron-suppressed Faraday cup stationed at the back of the target assembly. The projectile energy at a target is the average of the incident and

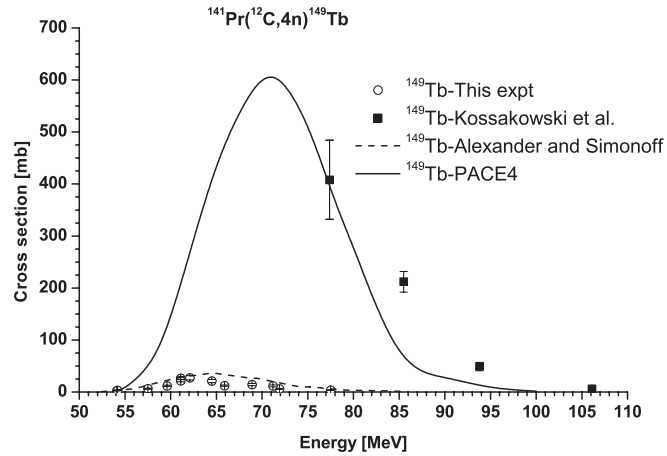

FIG. 1. Comparison of measured cross sections of $^{149}Tb^m$ from $^{12}C+^{nat}Pr$ reaction with those measured by Alexander and Simonoff [4] and Kossakowski *et al.* [5] and calculated from PACE4.

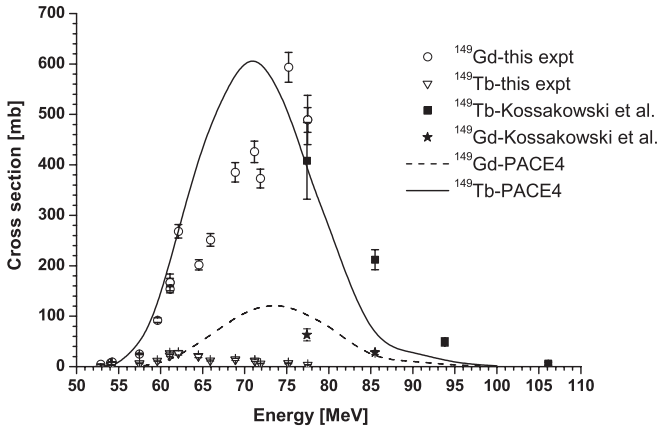

FIG. 2. Comparison of measured cross sections of ^{149}Tb and ^{149}Gd from ^{12}C+^{nat}Pr reaction with those reported by Kossakowski *et al*. [5] and theoretical calculation of PACE4.

outgoing beam energies. Beam energy degradation in the target and the catcher foils has been calculated using Stopping and Range of Ions in Matter (SRIM) [10].

At the end of bombardment (EOB), an off-line γ-spectrometric study was carried out in each foil at a regular time interval up to 7 days using an HPGe detector having a resolution of 2.13 keV at 1332 keV coupled to a PC-based MCA. The background subtracted peak area count corresponding to a particular γ-ray energy is the measure of yield of an evaporation residue. The cross sections of the evaporation residues produced at various incident energies and from different reaction channels were calculated from the standard activation equation. A detail description of the calculation is available elsewhere [11]. The nuclear spectroscopic data used to calculate the production cross sections of the evaporation residue are listed in the Table I [12]. The γ-ray energies in boldface there were used to determine the cross sections of the corresponding residue.

The uncertainties considered in the cross-section measurement are as follows: (i) calibration of the detector, ≈2%; (ii) target thickness, ≈5% atoms/cm^2, and (iii) systematic error in beam current propagated to the cross-section data, ≈10%. Uncertainty in incident beam energy may occur at the successive targets due to energy degradation in the aluminum catchers. However, according to Refs. [13] and [14], the energy straggling is expected to be small even in the case of the lowest incident energy and hence was neglected in this work. In addition, error may occur in the measurement from the counting statistics. The associated error related to the cross-section measurement was determined considering all the factors mentioned and the data are presented up to the 95% confidence level.

III. MODEL CALCULATION

A. PACE4

The fusion-evaporation code PACE4 [15], a modified version of PACE (projection angular momentum coupled evaporation) [16], working in the framework of LISE++ [17] with several new features, was used to calculate the excitation function of residues expected to be produced in ^{12}C-induced reactions on a ^{nat}Pr target. The de-excitation process of the excited nuclei was calculated using the Hauser-Feshbach model. The transmission coefficients for light-particle emission were determined from the optical model potential with default optical model parameters. The code internally decides level densities and masses it needs during de-excitation. The Gilbert-Cameron level density prescription is used in the present work,

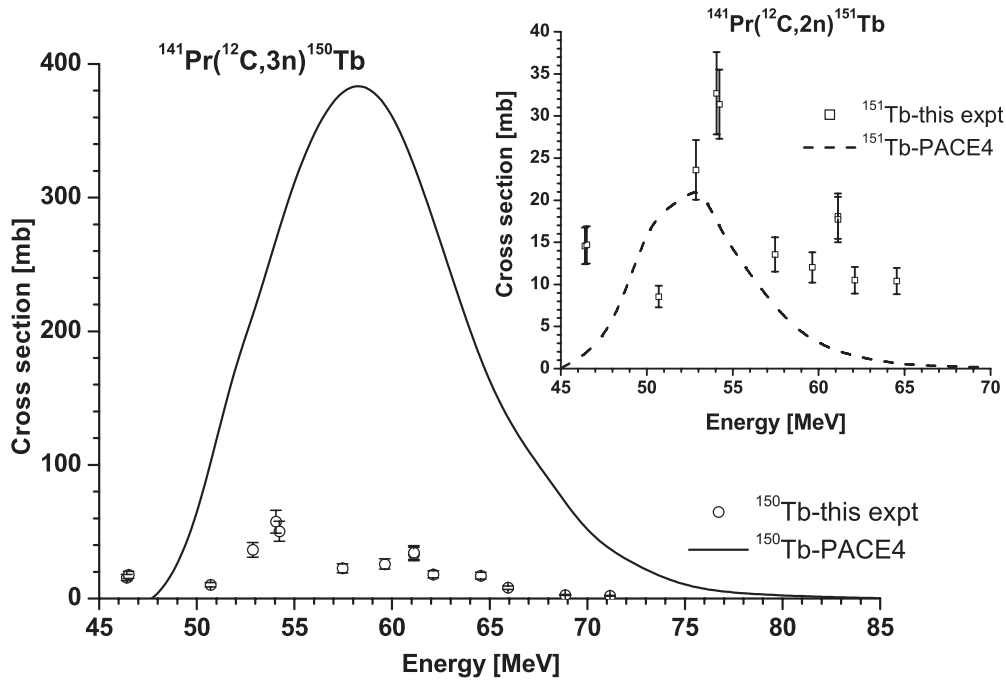

FIG. 3. Measured cross sections of ^{150}Tb and ^{151}Tb from ^{12}C+^{nat}Pr reaction have been compared with theoretical estimation of PACE4.

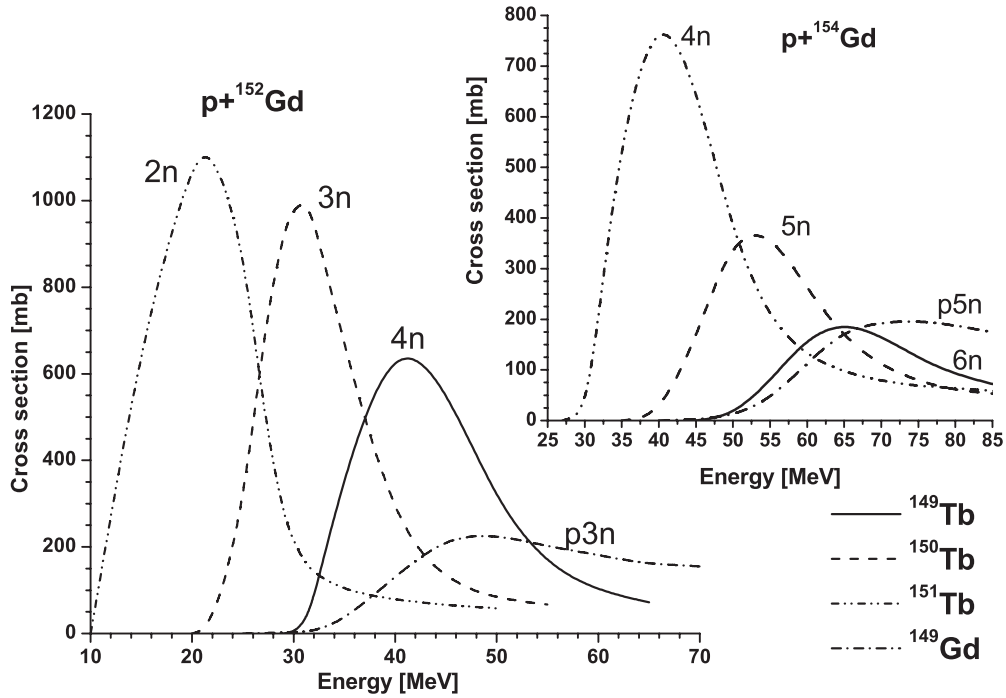

FIG. 4. Theoretical excitation functions of different reaction channels of $p+^{152}$Gd and $p+^{154}$Gd reactions calculated from TALYS.

with a, the level density parameter, $=A/12$ MeV^{-1}. The ratio a_f/a_n is chosen as unity. Fission is considered as a decay mode. The finite-range fission barrier of Sierk has been used. The compound nuclear fusion cross section is determined using the Bass method. The yrast parameter is taken as unity.

B. TALYS

The code TALYS [9] was used to calculate the excitation functions of evaporation residues from p- and α-particle-induced reactions on ^{152}Gd and ^{154}Gd targets. It uses a two-component exciton model to estimate pre-equilibrium emissions, the Hauser-Feshbach formalism for equilibrium emissions, and coupled-channel analysis for direct reaction processes. The level density formulation we have used is a combination of the constant-temperature model of Gilbert and Cameron and the Fermi gas model. In this combination, the total excitation energy range is divided into two regions: the low and high energy regions. The low-energy region goes from 0 MeV to a certain energy up to which the constant-temperature law is valid and the high-energy part starts above that, where the Fermi gas model is used to calculate level densities.

IV. RESULTS AND DISCUSSION

A. ^{12}C-induced reactions

The residual radionuclides produced in the target matrix from ^{12}C+^{141}Pr reaction at different incident energies were identified by analyzing the γ spectra collected at different time intervals after EOB. Decay data clearly indicate the production of ^{149}Tb, ^{150}Tb, ^{151}Tb, and ^{149}Gd radionuclides in the target matrix. Due to the short half-life, no signature of the isomeric states of ^{149}Tb, ^{150}Tb, and ^{151}Tb was observed in the off-line γ spectra. The nuclear reactions involved in producing the evaporation residues are reported in Table I. The measured cross sections of each residue are reported in Table II. Cross-section data were interpreted by comparison with theoretical excitation functions of the residues estimated using the statistical model code PACE4 [15]. The cross sections of ^{149}Tb and ^{150}Tb are found to be a maximum of 5% and 14% of the theoretical estimations, respectively.

Figure 1 compares measured cross sections of ^{149}Tb from ^{12}C+^{141}Pr reaction with those reported by Alexander and Simonoff [4], Kossakowski *et al.* [5], and the theoretical evaluation of PACE4. It is clear that the excitation function of ^{149}Tb measured by off-line γ spectrometry is comparable to that measured earlier using α spectrometry [4]. A maximum cross section of 27.3 ± 4.1 mb was obtained for ^{149}Tb at 62.1 MeV, while the maximum was 36.7 mb at 64.6 MeV in the report of Alexander and Simonoff. It has also been observed that PACE4 expects a peak of the Gaussian at 72-MeV incident energy with an ≈600-mb cross section for ^{149}Tb, while the measured excitation function peaks at around 62-MeV incident energy with a cross section <5% of the theoretical expectation. The cross sections of the ^{141}Pr(^{12}C,4n) reaction channel measured by Kossakowski *et al.* by online γ spectrometry are comparatively very high, 408 mb at 77.4-MeV incident energy, and are commensurate neither with our measurement nor with the measurement by Alexander and Simonoff [4]. The high values were possibly the production cross sections of ^{149}Tb^m, the high-spin $(\frac{11}{2}^-)$ isomer of ^{149}Tb. This observation indicates that the interaction of a ^{12}C projectile with a ^{141}Pr target forms

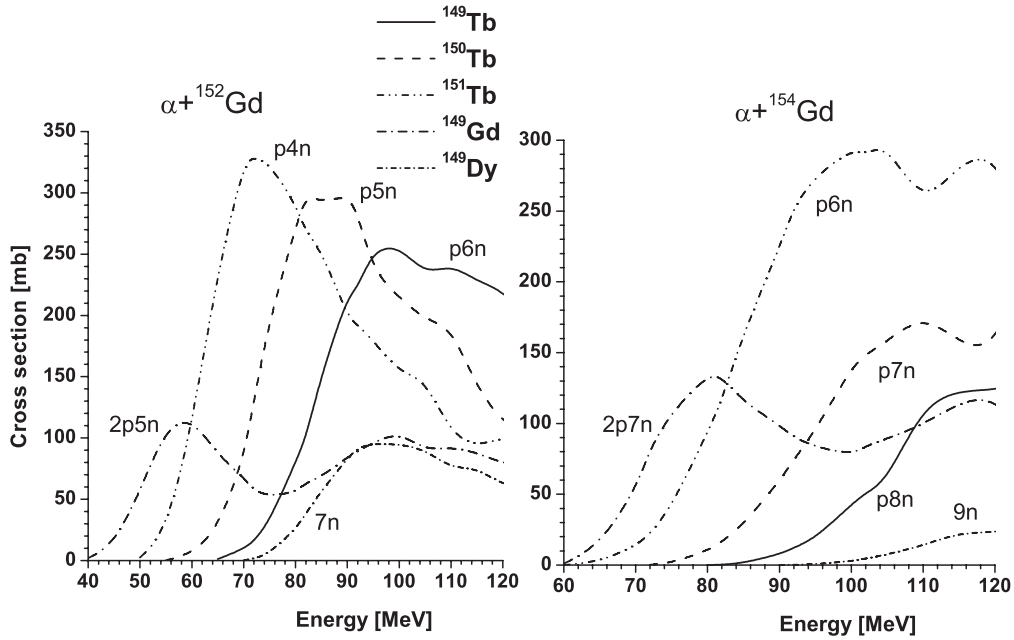

FIG. 5. Theoretical excitation functions of different reaction channels of $\alpha+^{152}$Gd and $\alpha+^{154}$Gd reactions calculated from TALYS.

mostly excited compound-nucleus ^{153}Tb in the high-spin state, which preferentially decays to the short-lived high-spin state ^{149}Tb^m (4.16 min; $\frac{11}{2}^-$). ^{149}Tb^m decays directly to ^{149}Gd via ^{149}Tb$^m(\epsilon/\beta^+)^{149}$Gd reaction. The ^{149}Tb ($\frac{1}{2}^+$) is produced only from low-spin compound nuclei of ^{153}Tb and this gives low cross-section values for ^{149}Tb. Nevertheless, it is noteworthy that two independent measurements of excitation function of ^{149}Tb using α- and γ-spectrometry complement each other, with a confirmation of a low cross-section value of ^{149}Tb.

Figure 2 compares production cross sections of ^{149}Gd with the cross-section values reported by Kossakowski *et al.* [5] for ^{149}Gd and ^{149}Tb and the theoretical excitation functions of ^{149}Gd and ^{149}Tb estimated from PACE4. The ^{149}Gd produced in the target matrix is probably the contribution from (i) direct reaction, ^{141}Pr(^{12}C,p3n)^{149}Gd; and (ii) indirect reactions, ^{141}Pr(^{12}C,4n)^{149}Tb$^m(\epsilon/\beta^+)^{149}$Gd and ^{141}Pr(^{12}C,4n)^{149}Tb$(\epsilon/\beta^+)^{149}$Gd. The cross-section values we report here for ^{149}Gd are the cumulatives of direct and indirect productions. PACE4 estimates a production cross section of maximum 120 mb at 75-MeV incident energy for ^{149}Gd in direct reaction. However, Kossakowski *et al.* measured 63 ± 12 and 28 ± 4 mb cross sections at 77.4 and 85.5 MeV, respectively, in ^{141}Pr(^{12}C,p3n)^{149}Gd reaction. Though only two experimental cross-section values are available for ^{149}Gd, they are either comparable or lower than the theoretical expectation. The cumulative cross sections of ^{149}Gd more or less follow the theoretical excitation function of ^{141}Pr(^{12}C,4n)^{149}Tb, with a little shift in peak energy to 75 MeV. The maximum cross section measured by off-line γ spectrometry for ^{149}Gd is as high as 593 mb at 75.2 MeV, the peak energy of the excitation function calculated for ^{149}Gd from PACE4. Therefore, it may be concluded that the high cross section of ^{149}Gd is due to the huge production of ^{149}Tb^m, which essentially decays to ^{149}Gd. The cross-section values reported by Kossakowski *et al.* for ^{141}Pr(^{12}C,4n)^{149}Tb reaction nicely corroborate with the cumulative cross sections of ^{149}Gd at the higher incident energies, with an overlap of energy at 77.4 MeV. At this particular energy, the cumulative cross section of ^{149}Gd (489 ± 24 mb) is nearly the sum of cross sections of ^{149}Gd (63 ± 12 mb) and ^{149}Tb (408 ± 76 mb) reported by Kossakowski *et al.* [5], whereas only a 3.7 ± 0.4 mb cross section has been measured for low-spin ^{149}Tb. This certainly confirms that the production cross sections of ^{149}Tb reported by Kossakowski *et al.* are the cross sections of ^{149}Tb^m. Analysis of the measured cross-section data confirms that more than 85% of the production of ^{149}Gd comes from the decay of ^{149}Tb^m. Production of ^{149}Tb^m dominates over the incident energy range, though the production of ^{149}Tb is relatively higher below 65-MeV incident energy.

Figure 3 shows a comparison of measured cross sections of ^{150}Tb and ^{151}Tb with those calculated from PACE4. The cross sections of ^{150}Tb are found to be a maximum of 14% of the theoretical estimation. The measured excitation function peaks at 54 MeV, with an average 53.9 ± 7.5 mb cross section for ^{150}Tb. Kossakowski *et al.* measured a 36 ± 13 mb cross section of ^{150}Tb at 77.4 MeV by online γ spectrometry. However, we have observed no production of ^{150}Tb in off-line γ spectrometry above 72 MeV. Like ^{149}Tb, the low cross section of ^{150}Tb may be due to the fact that the excited compound nucleus formed in the high-spin state prefers to produce high-spin isomeric state ^{150}Tb^m (5.8 min; 9^+), which decays to the long-lived α emitter ^{150}Gd (1.8 My). The compound nuclei formed in the low-spin state are only responsible for producing ^{150}Tb (2^-). Measured cross sections of ^{151}Tb are found to be comparable to, but absolute values are higher than, those calculated from PACE4. In the case of the (^{12}C,2n) channel, a similar explanation is applicable regarding production of

$^{151}Tb^{m}$(25 s, $\frac{11}{2}^{-}$), but 93.4% of $^{151}Tb^{m}$ decays to ^{151}Tb via internal conversion. Therefore we have measured the cross sections of ^{151}Tb close to their expected values.

B. Light-ion-induced reactions

Gadolinium has seven naturally abundant isotopes. p- or α-induced reactions on natural Gd will produce a variety of radionuclides and stable isotopes, Tb, Dy, Gd, etc., which are treated as impurities except the desired one. The reaction model code ALICE [18] is well established for investigating light-ion-induced reactions at low incident energies. However, it does not consider direct reaction processes, which are prevalent in the case of high-energy p or α projectiles. Therefore, we have estimated excitation functions of p- and α-particle-induced reactions on ^{152}Gd and ^{154}Gd targets, which are contributing to the production of ^{149}Tb, using the nuclear reaction model code TALYS [9].

Figure 4 shows excitation functions of p-induced reactions on ^{152}Gd and ^{154}Gd targets. In $p+^{152}$Gd reactions, about a 700-mb cross section is expected for ^{149}Tb at 40-MeV incident energy, whereas only a 200-mb cross section is obtained at 65 MeV from $p+^{154}$Gd reaction. In view of the production of ^{149}Tb, a 40- to 45-MeV proton-induced reaction on an enriched ^{152}Gd target is preferred. However, the natural abundance of ^{152}Gd is only 0.2%, which is certainly a disadvantage. Moreover, the required high-energy proton beam is not easy available. It is also demonstrated in Fig. 4 that the possibility of production of impurity isotopes, ^{150}Tb, ^{151}Tb, and ^{149}Gd, along with ^{149}Tb, cannot be ignored irrespective of the targets.

Figure 5 shows the theoretical excitation functions of α-particle-induced reactions on ^{152}Gd and ^{154}Gd targets calculated from the code TALYS. In order to produce ^{149}Tb, a minimum 100-MeV α beam is required if an enriched ^{152}Gd target is used. A 250-mb cross section of ^{149}Tb has been estimated in ^{152}Gd(α, p6n)^{149}Tb reaction. Decay of ^{149}Dy produced via ^{152}Gd(α, 7n) reaction is expected to enhance the production of ^{149}Tb. However, comparable production of impurities (^{150}Tb, ^{151}Tb, ^{149}Gd) is also expected with ^{149}Tb. It is not also reasonable to use ^{154}Gd, as the production cross section of ^{149}Tb is quite low (100 mb) and requires high-energy α particles (120 MeV). Therefore, production of pure ^{149}Tb, located far from the stability zone, is limited by practical constraints even in light-ion reactions.

V. CONCLUSION

This article reports a new measurement of cross sections of evaporation residues produced in ^{12}C-induced reactions on a natural praseodymium target by off-line γ spectrometry. The excitation function of the residues has been measured in the 44- to 79-MeV energy range. Measured cross sections of ^{149}Tb were found to be a maximum of 5% of the theoretical estimation and in corroboration with those determined by Alexander and Simonoff using α spectrometry. The high cumulative cross section measured for ^{149}Gd satisfactorily explains that the nuclear reaction phenomenon takes place during the production of the α-emitter ^{149}Tb in ^{12}C+^{141}Pr reactions. This shows that more than 85% of the cumulative cross section of ^{149}Gd comes from the decay of $^{149}Tb^{m}$. It also reports the first measurement of excitation functions of ^{150}Tb and ^{151}Tb.

This Brief Report on p- and α-induced production of ^{149}Tb on Gd isotopes provides an idea of the cross sections, required projectile energy, and target isotopes. It also reports the practical limitations involved in its production. Though there is enormous interest in the use of the promising α emitter ^{149}Tb in targeted therapy, but its production is a genuine problem. None of the reactions reported here was found to be suitable for the production of ^{149}Tb for clinical applications. Therefore, further investigation is required to find other routes for ^{149}Tb production.

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