Activation cross sections of ^{66,67,68}Ga and ^{68,69}Ge produced in alpha-induced reactions on natural Zn up to 30 MeV

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Introduction

Medium energy light charged particles induced reactions from cyclotrons are used to study medicinally and technologically important radionuclides [1,2]. Activation cross sections and thick target yields are measured for optimized production of medicinally important radionuclides using alpha beams from K130 cyclotron at VECC, Kolkata [1-3]. In continuation of our work in this direction, we report the production cross section and thick target yield measurements of ^{66,67,68}Ga and ^{68,69}Ge produced via ^{nat}Zn(α,x) reactions up to 30 MeV.

The three medicinally important radioisotopes, ^{66,67,68}Ga, could be produced via ^{nat}Zn(α,x) reactions [2]. To optimize the production of isotope of interest with minimum contamination from others, accurate cross section data are required. The excitation functions of these reactions have maximum cross sections at ~30 MeV for ^{66}Ga, ~18 MeV for ^{67}Ga and ~30 MeV for ^{68}Ge/^{68}Ga [2]. The experimental activation cross section data are relatively scarce around these energies and therefore the cross sections are measured in the lower energy range up to 30 MeV [2,4].

In this work, the production cross sections of ^{66,67,68}Ga, ^{68,69}Ge and ^{65}Zn via ^{nat}Zn(α,x) reactions have been measured. Excitation functions of all the produced radioisotopes are measured using high-resolution gamma ray spectrometry. Thick target integral yields will be deduced from the measured cross section data and the results will be compared with earlier reported literature data and theoretical data from TENDL-2023 based on TALYS-2.0 code [5].

Experimental

The experiment was performed using 30 MeV alpha beams from K130 cyclotron at VECC, Kolkata. The targets were high purity Zn foils of 10 μm thickness. Irradiations were performed using standard stacked foil activation method [1-5]. Different stacks were prepared for irradiation to cover the energy range from 30 MeV down to their respective thresholds energies. The stacks were irradiated with 30 MeV initial alpha beams of ~150-200 nA current for ~30 minutes. After irradiation, each target was packed in a small polythene pouch. They were counted multiple times using a 50 % relative efficiency HPGe detector of 1.8 keV energy resolution at 1.3 MeV of ^{60}Co. Energy and efficiency calibration of the detector was done using standard ^{152}Eu source.

Results and discussion

^{66,67,68}Ga, ^{68,69}Ge, and ^{65}Zn were identified in the irradiated Zn foils from their characteristics gamma rays in the studied energy range. A typical gamma ray spectrum of the 29.5 MeV alpha irradiated ^{nat}Zn target is shown in Fig. 1.

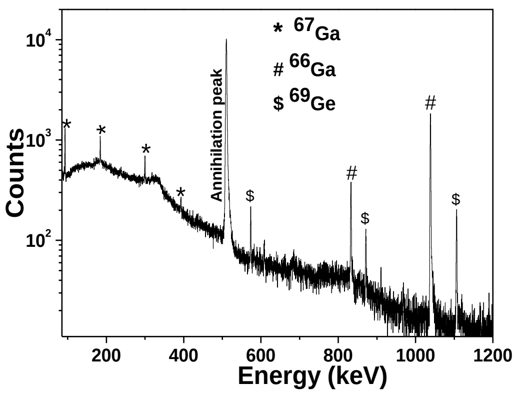

Fig. 1 Gamma ray spectrum of 29.5 MeV alpha beam irradiated ^{nat}Zn target acquired for 900 s after 25.7 h cooling time. Origin of the gamma rays are marked in the spectrum.

Nuclear spectroscopic data of the studied radionuclides are given in Table 1 [2,4].

Table 1: Nuclear spectroscopic data of the studied radionuclides

Nuclides	$T_{1/2}$	Decay Mode (%)	E_γ (keV)	I_γ (%)
^{66}Ga	9.49 (3) h	EC + β^+ (100)	1039.220	37.0
^{67}Ga	3.2617(5) d	EC (100)	300.217	16.64
^{68}Ga	67.71 (8) m	EC + β^+ (100)	1077.34	3.22
^{68}Ge	270.95(16)d	EC (100)	--	--
^{69}Ge	39.05 (10) h	EC + β^+ (100)	1106.77	36
^{65}Zn	243.93(9) d	EC + β^+ (100)	1115.539	50.04

Natural Zn contains five isotopes: ^{64}Zn (48.63%), ^{66}Zn (27.90%), ^{67}Zn (4.10%), ^{68}Zn (18.75%) and ^{70}Zn (0.62%). The reactions that are contributing to the production of these radioisotopes are given in Table 2 [2,4].

Table 2: Contributing nuclear reactions of the produced radionuclides from ^{nat}Zn(α,x)

Nuclides	Contributing reactions (with E_{th} in MeV)
^{66}Ga	^{64}Zn(α,d) (13.8), ^{66}Zn(α,tn) (27.3), ^{66}Ge (2.26 h) decay
^{67}Ga	^{64}Zn(α,p) (4.2), ^{66}Zn(α,t) (15.4) ^{67}Zn(α,tn) (22.9), ^{67}Ge (18.9 m) decay
^{68}Ga	^{66}Zn(α,pn) (15.5), ^{67}Zn(α,p2n) (22.9) ^{68}Ge decay (EC)
^{68}Ge	^{64}Zn(α,γ), ^{66}Zn(α,2n) (16.6)
^{69}Ge	^{66}Zn(α,n) (7.9), ^{67}Zn(α,2n) (15.4), ^{68}Zn(α,3n) (16.2), ^{69m}Ge (~μs) decay
^{65}Zn	^{64}Zn(α,2pn) (21.6), ^{65}Ga (15.2 m) decay

Activation cross sections of ^{nat}Zn(α,x) ^{66,67,68}Ga, ^{68,69}Ge, and ^{65}Zn reactions are measured using the standard activation equation using their intense gamma-rays. The applications of these radionuclides depend on their decay characteristics. ^{68}Ga ($T_{1/2}$ = 67.71 min) is useful for PET imaging, whereas ^{67}Ga ($T_{1/2}$ = 3.2617 days) is used in SPECT imaging. ^{66}Ga ($T_{1/2}$ = 9.49 h), is used as a tracer to study time taking biological processes. ^{68}Ga can be produced directly as well as EC decay (100%) of ^{68}Ge ($T_{1/2}$ = 67.71 min). Due to the short half-life of ^{68}Ga ($T_{1/2}$ = 67.71 min), its production via ^{68}Ge/^{68}Ga generator is more effective in practical purposes where in-house medical cyclotron facilities are unavailable. Alpha induced reactions on Zn produce ^{68}Ga directly, and via decay of ^{68}Ge to ^{68}Ga as given in Table 2.

Conclusion

Production cross sections of the ^{66,67,68}Ga, ^{68,69}Ge, and ^{65}Zn radionuclides produced from ^{nat}Zn(α,x) reactions were measured from 30 MeV down to their respective threshold energies using standard stacked foil activation method in order to optimize the production of medicinally important radionuclide of interest (^{66,67,68}Ga). There are only few measurements available in literature for these radionuclides in the lower energy region. The present study aimed to get new activation cross section data for these radionuclides to calculate their integral yields and optimize the production process using low energy alpha beams.

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