Research Article

Evaluating Cross Sections of Gallium Isotopes Production Using proton and deuteron Irradiation

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Abstract

In the present work, the production of the cross sections of three Gallium isotopes: ${}^{66}_{31}Ga_{35}$ ($t_{1/2}$ = 9.4h, β^+ = 4.2MeV), ${}^{67}_{31}Ga_{36}$ ($t_{1/2}$=3.2617d, EC=100%) and ${}^{68}_{31}Ga_{37}$ ($t_{1/2}$ = 68min, $I\beta^+$ = 89%) have been discussed. The Gallium isotopes have important applications in nuclear medicine, particularly in Positron Emission Tomography (PET), Single Photon Emission Tomography (SPET) imaging technique and used in tumors diagnosing. The production of irradiant ${}^{66}Ga$, ${}^{67}Ga$ and ${}^{68}Ga$ is made by irradiation of an enriched Zinc target using proton and deuteron charged particles. Utilizing high cyclotron yield and low radionuclide impurities, the optimum cyclotron energy range has been chosen for the production of Gallium isotopes. The cross sections of (p,xn), (p,γ) and (d,xn) reactions for the production of Gallium isotopes have been evaluated depending upon the empirical data taken from EXFOR library, which is belonging to the International Atomic Energy Agency (IAEA). Also the yield for each reaction has been evaluated.

Keywords: cross sections, Gallium Isotopes, optimized energy range

الخلاصة

في العمل الحالي، تم مناقشة انتاج المقاطع العرضية لثلاث نظائر لعنصر الكاليوم: 〖t〗_(1⁄2)=9.4h) و,β^+=4.2MeV), (〖t〗_(1⁄2)=3.2617d, EC=100%) (〖t〗_(1⁄2)=68min, 〖Iβ〗^+=89%). نظائر الكاليوم لها تطبيقات مهمة في مجال الطب النووي وعلى وجه الخصوص استخدامها في تقنية التصوير المقطعي بالانبعاث البوزتروني (PET) والتصوير المقطعي بأنبعاث فوتون منفرد (SPET),واستخدامها في تشخيص الاورام. يتم انتاج نظائر الكاليوم المشعة بتشعيع هدف الزنك المخصب بأستخدام الجسيمات المشحونة من البروتونات والديتريونات باستخدام أعلى انتاجية للمعجل واقل نسبة شوائب للنظائر المشعة، تم تحديد افضل مدى طاقة للمعجل لانتاج نظائر الكاليوم. تم تقييم المقاطع العرضية لتفاعلات (p,γ)، (p,xn) و(d,xn)لأنتاج نظائر الكاليوم المشع أعتمادا على القيم العملية المتوفرة في مكتبة (EXFOR)التابعة لوكالة الطاقة الذرية الدولية(IAEA) . كذالك تم حساب الانتاجية لكل تفاعل.

Introduction

The radioisotopes have a significant importance in the field of nuclear medicine, specifically in diagnostic imaging including Single Photon Emission Computed Tomography (SPECT) and Positron Emission Tomography (PET), and in the field of nuclear medical therapy. These radioisotopes are produced using reactors through nuclear reactions or accelerators through bombardment reactions using charged particle such as protons, deuterons and alpha particles [1]. The three radioisotopes of Gallium (${}^{66}Ga$, ${}^{67}Ga$ and ${}^{68}Ga$) have a great importance in nuclear medicine, especially in PET scan and in radiotherapy by attaching them with monoclonal antibodies to detect tumors locations, and in investigation of different diseases [2]. Gallium-66 ($t_{1/2}$ =9.49h, Eγ= 833.5, 1039.3keV, β^+: 56.5%, $E_{max\beta^+}$: 4.153MeV; EC: 43.5%), has an intermediate half-life make it suitable for PET imaging of bioprocesses with intermediate to slow target tissue uptake [3]. The Gallium-67 ($t_{1/2}$=3.2617d; EC=100%), is widely used in medical applications due to its ability to emit several Auger electrons with energies (7–8) keV. These electrons may reach the investigated cell nucleus from the cell surface or from cytoplasm; hence it is effective in single cell killing. Gallium-67 emits rays with energies ranged from 91 to 394keV, which is suitable to be detected by gamma cameras [4]. for single photon imaging in PET scan [5]. Ga-68 ($t_{1/2}$= 68min, β^+: 89.1%; EC: 10.9%) has distinctive characteristics that made it used in PET scan imaging and in tumor diagnosing[6]. The aim of the present work is to evaluate the experimental data of nuclear reactions induced by proton and deuteron particles on enriched Zn target and selected optimization energy range for the production of ^{66}Ga, ^{67}Ga and ^{68}Ga with small and/or medium-sized cyclotrons less than 30MeV and improve efforts in this field of production.

Materials and Methods

Cross Sections Calculations

The experimental data play an important role in the evaluation of nuclear reaction cross sections. Table (1), shows the experimental data that have been published in (EXFOR) library, which belongs to the International Atomic Energy Agency (IAEA) for proton and deuteron induced reactions specific for Zn target [7]. The empirical data that obtained by different authors listed in table (1) are not identical. In the present work the evaluations was made by including a careful analysis for these data by recalculating the energy in steps of the interval (0.01MeV) and the calculated cross sections were plotted using Matlab-8 programming language as shown in Figures (1→5).

Yield of Calculated Products

The yield of a nuclear reaction can be defined as the ratio of the number of the nucleus formed in a nuclear reaction to the number of the bombarding particles hitting the target. The yield production of nuclei for any energy, E can be expressed as a function of the cross section as [8]:

$$Yield = I(\phi\ n)\ H\ \left(1-e^{-\lambda t}\right)\int_{E_{out}}^{E_{in}}\sigma(E)\left(-\frac{dE}{dx}\right)^{-1}$$

Where: Y is the activity in (Bq) of the product nuclei. I: current of projectile in (μA). ϕ : the flux is ~10^{12} to $10^{14}\ n/cm^2\cdot s$. n: umber of atoms per unit volume (N/A).N: Avogadro's number. A: the mass number of the target in (amu). H: isotopic abundance (or enrichment) of the target. λ : The decay constant of the product= $(\frac{0.693}{t_{1/2}})$ in (h^{-1}) . t: time of irradiation in (h). $\frac{-dE}{dx}$: the stopping power, $\sigma(E)$: Cross section at energy E in (mb).

Results and Discussion

Gallium radioisotopes $^{66}_{31}Ga_{35}$ ($t_{1/2}$ = 9.4h), $^{67}_{31}Ga_{36}$ ($t_{1/2}$ = 78h) and $^{68}_{31}Ga_{37}$ ($t_{1/2}$ = 68min) are commonly used for diagnostic studies using (PET) and (SPET), it can be produced *v*ia various reactions induced by charged particle as shown in Table 1.

There are three routes for the accelerator production of $^{66}_{31}Ga_{35}$ by proton projectile *v*ia $^{66}_{30}Zn_{36}(p,n)^{66}_{31}Ga_{35}$, and $^{67}_{30}Zn_{37}(p,2n)^{66}_{31}Ga_{35}$ reactions as shown in Figures (1-a), and (2-a) respectively; also by deuteron bombardment *v*ia $^{66}_{30}Zn_{36}(d,2n)^{66}_{31}Ga_{35}$ reaction as shown in (4-a).comparing the three reactions mentioned above, the optimum reaction to produce ^{66}Ga is $^{66}_{30}Zn_{36}(p,n)^{66}_{31}Ga_{35}$ reaction with a production yield equals to 7.4*MBq (mCi)/μAh* (Figure 6), high cross section (700mb), at area of optimum energy range $E_p=(8\rightarrow 14)MeV$, and with no impurities. The obtained value is in a good agreement with the value obtained from ref. [2], with $E_p=(6\rightarrow 15)MeV$ because of the highly isotopic abundance (27.9%) [9] of ^{66}Zn in a natural Zinc matrix target. The yields of $^{67}_{30}Zn_{37}(p,2n)^{66}_{31}Ga_{35}$ and $^{66}_{30}Zn_{36}(d,2n)^{66}_{31}Ga_{35}$ reactions are 0.093*MBq mCi)/μAh* and 3.97*MBq(mCi)/μAh* with optimum energy range $E_p=(5\rightarrow 15)MeV$ and $E_p=(10\rightarrow 15)$ MeV respectively.

The optimum production of ^{68}Ga is *via* $^{68}_{30}Zn_{38}(p,n)^{68}_{31}Ga_{37}$ reaction with a yield of 30.34MBq (mCi)/μAh (Figure 8), high cross section (1060mb), optimum energy range $E_p=(8\rightarrow 12)MeV$, and with a minimum impurity 0.002% of ^{67}Ga. This value is agree with value obtained from ref. [6] with

$E_p = (4 \rightarrow 13)MeV$ because of the highly isotopic abundance of ${}^{68}Zn$ (27.9%) compared with ${}^{67}Zn$ (4.1%) [9] in a natural Zinc matrix target. The results of the optimum energy range is less than 30MeV, hence the data obtained in the present work has a good agreement with some calculations made by researches. At which Gallium isotopes could conveniently yield at cyclotron energy for a medium *via* proton irradiation on natural Zinc target. However, calculations in the recent practical data of cross sections *via* deuteron irradiation on natural Zinc might be added a new production route for radio Gallium isotopes [4].

Conclusions

The accelerators production of Gallium radioisotopes has suitable physical properties, since it have intermediate or short half-life, so it is widely used in medical applications in imaging techniques and radiotherapy. In the present work, the evaluation of cross sections for the reactions induced by proton and deuteron particles give a good agreement with experimental calculations taken from IAEA which done by different authors. The high enrichment target is used to reduce the radio impurities due to the activation of impurities, but this radio impurity does not disappear. These impurities can be removed only by using enriched target and/or by a careful selection of the effectively charged particle energy range in the target. From the results, we concluded the optimum reactions to product ${}^{66}Ga$, ${}^{67}Ga$ and ${}^{68}Ga$ from ${}^{66}_{30}Zn_{36}(p,n){}^{66}_{31}Ga_{35}$, ${}^{68}_{30}Zn_{38}(p,2n){}^{67}_{31}Ga_{36}$, ${}^{68}_{30}Zn_{38}(p,n){}^{68}_{31}Ga_{37}$ and ${}^{68}_{30}Zn_{38}(d,2n){}^{68}_{31}Ga_{37}$ reactions respectively. Another reactions are not desirable to product ${}^{66}Ga$, ${}^{67}Ga$ and ${}^{68}Ga$, because of minimum product yield and the production of isotopic impurities appear in reaction process. We found from the results that Gallium-68 is the best isotope to be used in medical application because it have a short half-life and high cross sections.

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