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PRODUCTION OF ^{61}Cu BY α- AND ^{3}He BOMBARDMENTS ON COBALT TARGET

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For the production of ^{61}Cu for medical use, natural cobalt was bombarded with α or ^{3}He particles up to 40 MeV. The best bombardment conditions were determined on detailed examination of the excitation curves and thick-target yield curves for ^{61}Cu and the by-product nuclides. 6 mCi/μAh of ^{61}Cu could be obtained by bombardment with 40 MeV α particle and separated by anion exchange method with high radiochemical purity in carrier-free state.

1. Introduction

As radioisotopes of copper interested in nuclear medicine, ^{64}Cu(12.8h, β^-38%, β^+19%, EC43%) is widely applied which is produced by the reaction of either ^{63}Cu(n,γ)[1] or ^{64}Zn(n,p)[2]. However the absorbed dose for the patient is undesirably high due to the emission of β^- and β^+ rays in addition to γ ray of 1.34 MeV. On the other hand ^{61}Cu(3.32h) is in advantage in the sense that its γ ray energy of 0.284 MeV is suitable for scintiscanning and that its effective half life 0.138d[3], in contrast to 0.53d[3] of ^{64}Cu, can definitly reduce the absorbed dose for the organs and tissues.

So far ^{61}Cu has been produced by the following reactions :(p,n) on ^{61}Ni[4] or (p,2n) on ^{62}Ni[5], (p,p4n) on ^{65}Cu[6], (p,pxn) reaction on Cu[7], (^{3}He, αn) reaction on ^{63}Cu[8] and (d,αn) on ^{64}Zn[9]. In this study cobalt target was bombarded with α or ^{3}He particles to construct the excitation curves for both ^{61}Cu and the by-product nuclides. The best bombardment conditions were determined on detailed examination of these curves and of the resulting thick-target yield curves.

As the results, 6 mCi/μAh of ^{61}Cu could be obtained by bombarding cobalt metal target of 183 mg/cm^2 with 40 MeV α particles. The tracer experiment has revealed that ^{61}Cu in a carrier-free state can be obtained free from the by-product nuclides, ^{57}Co, ^{58}Co and the target cobalt with the aid of anion exchange resin method[10] in the period as short as 150 minutes.

2. Experimental

2-1. Preparation of target

A foil of cobalt metal was electrodeposited on copper sheet (electrolytic grade) of 35 μ thickness working as the cathode for platinum wire anode in cobalt sulfate solution in a cell of 35 ml. The cobalt foil was carefully removed from the substrate, washed, dried and then weighed. Ten to fifteen of foils were stacked together for constructing the excitation curves and were fixed to a target holder of the cyclotron.

2-2. Bombardment and measurement of activity

Bombardment was performed under various conditions with α or ^{3}He particles of energy up to 40 MeV at beam current 0.5 to 1.5 μA for 30 to 90 minutes. The width of the incident beam on the target (30 mm dia.) was adjusted to 10 x 10 mm with the aid of a slit placed close to the beam port. The energy of photo peaks of γ spectrum was determined by a Ge(Li) detector with multi-channel pulse hight analyzer. The amount of each nuclide produced at the end of bombardment (E.O.B) was determined by the usually approved way.

2-3. Excitation curves and thick-target yield curves

The excitation curve and thick-target yield curve of each nuclear reaction were obtained from the activity of the corresponding nuclide at E.O.B. according to the usual procedures.

In case of α bombardment ^{61}Cu was produced by (α,2n) reaction on natural cobalt (mononuclidic ^{59}Co). The maximum cross section of the reaction was found 340 mb at 25 MeV, decreasing therefrom in the range 25-35 MeV as

shown in Fig. 1. This is due to the occurence of a competing reaction $^{59}Co(\alpha,3n)\ ^{60}Cu$ with threshold energy of 27.4 MeV. The thick-target yield of ^{61}Cu production was 6 mCi/μAh at 40 MeV α bombardment on cobalt as shown in Fig. 1. In addition to ^{61}Cu, α bombardment on cobalt may produce such by-product nuclides as $^{59}Co(\alpha,n)\ ^{62}Cu$(Eth:5.41 MeV), $^{59}Co(\alpha,3n)\ ^{60}Cu$(Eth:27.41 MeV), $^{59}Co(\alpha,\alpha n)\ ^{58}Co$(Eth:11.17 MeV) and $^{59}Co(\alpha,\alpha 2n)\ ^{57}Co$ (Eth:20.33 MeV). These reactions were assumed to have occured in consideration of their threshold energies and the energy of α bombardment, 40 MeV. The excitation curves and thick target-yield curves for these reactions will be reported in detail elesewhere.

Among the above listed by-products, the activity of ^{60}Cu (23.4m) and ^{62}Cu(9.76m) should decay out during the cooling time of 4 hours. But ^{57}Co(270d) and ^{58}Co(71.3d), produced at the rates of 65 and 16.8 μCi/μAh respectively by 40 MeV bombardment should still be present due to longer half-lives.Therefore it is necessary to separate ^{61}Cu in a carrier-free state from these nuclides as well as from inactive target cobalt.

On the other hand in case of ^3He bombardment, the $(^3He,n)$ reaction on ^{59}Co has a low Q value of +6.61MeV, but the maximum cross section is as low as 6mb at 35 MeV. Accordingly the thick-target yield is also small, 110 μCi/μAh at 40 MeV. This is probably due to the reason that ^3He particles which overcome the coulomb barrier of 9.72 MeV in this reaction simultaneously induces the following competing reactions having larger cross sections than that of $(^3He,n)$ reaction, $^{59}Co(^3He,\alpha)\ ^{58}Co$, $^{59}Co(^3He,\alpha n)\ ^{57}Co$ and $^{59}Co(^3He,\alpha 2n)\ ^{56}Co$. The maximum cross sections of these reactions in this order were found as large as 300, 75 and 63 mb respectively under 40 MeV of ^3He particles bombardment. Accordingly, from the stand point of ^{61}Cu production, the maximum cross section of the α reaction is 61 times as large and thick target yield is 63 times as large compared with those of ^3He reactions.

In consideration of the dose of ^{64}Cu applied to brain scanning or diagnosis of Willson's disease being about 2mCi to 200 μCi per inspection, the production rate of ^{61}Cu by α bombardment is highly promissing to provide enough amount of the tracer in place of ^{64}Cu for medical use.

2-4. Chemical separation by anion exchange resin

As the radiochemical separation method, the co-precipitation, solvent extraction and anion exchange resin methods were examined to separate ^{61}Cu free from such by-product nuclides as ^{58}Co, ^{57}Co, ^{62}Ni and unreacted target cobalt. It turned out that the anion exchange method on chlorocomplex ions of cobalt and copper provided an excellent result in carrier-free separation of ^{61}Cu in a relatively short experimental period with high radiochemical purity.

The target of about 150 mg was dissolved in a mixture of 2 ml of 4N HNO_3 and a few ml of 6N HCl with the addition of a drop of bromine to oxidize copper ions.The resulting solution was heated to nearly dryness to remove the excess HNO_3 and Br_2. It was then dissolved with 25 ml of 8N HCl to transfer Co^{2+} and Cu^{2+} into chlorocomplexes, which was charged to the column of anion exchange resin (Dowex 1-X8, 200-250 mesh, 0.5 cm^2 x 15cm) treated beforehand into chloride form.

In the range of 0.1N < HCl < 12N, Ni^{2+} ion clearly passed through the column without being adsorbed onto the resin[10]. Then cobalt fraction was eluted at a rate of 0.5 ml/min with 25 ml of 4N HCl as shown in Fig. 3. The eluate of 2 ml aliquot were subjected to γ ray measurement with a NaI(Tl) well-type scintillation counter. This fraction contains unreacted cobalt (150 mg) and ^{58}Co and ^{57}Co resulting from $(\alpha,\alpha n)$ and $(\alpha,\alpha 2n)$ reactions.

Then ^{61}Cu was eluted with 50 ml of 2N HCl. As shown in Fig. 4, ^{61}Cu eluted in the first 20 ml aliquot of the eluting agent. Measurement of the eluate with a Ge(Li) detector for 20 minutes revealed the absence of other radionuclides, indicating the attainment of a high radiochemical purity. This is due to the fact that ^{62}Cu(9.76m) and ^{60}Cu(23.4m) decayed out into stable ^{62}Ni and ^{60}Ni respectively at the measurement in 4 hours after the bombardment. The radiochemical yield of the separation process for ^{61}Cu was 95%, according to the tracer test performed with ^{64}Cu.

3. Comparison of ^{61}Cu with the other copper isotopes

Among the eleven radioisotopes of copper, only ^{61}Cu(3.32h), ^{64}Cu(12.8h) and ^{67}Cu(61.7h) could be useful for biological and medical applications from the aspects of half-life and energy. The absorbed dose to the various organs and tissues was calculated according to ICRP method[3] for a hypothetical case of oral administration of 1 μCi of each radioisotope (Table I). The absorbed dose estimated was the smallest for ^{61}Cu, larger for ^{64}Cu, increasing up to about 5 times

Table I. Estimated absorbed doses to various organs and tissues from orally administered 1 μCi of ^{61}Cu, ^{64}Cu and ^{67}Cu.

Organs	Mass (gm).	^{61}Cu		^{64}Cu		^{67}Cu	
		Effective energy (MeV)	Absorbed dose ($\times10^{-3}$mrem)	Effective energy (MeV)	Absorbed dose ($\times10^{-3}$mrem)	Effective energy (MeV)	Absorbed dose ($\times10^{-3}$mrem)
Total body	7×10^4	0.796	16.28	0.241	18.81	0.213	108.6
Spleen	150	0.505	3.44	0.162	4.22	0.177	30.0
Kidney	300	0.505	8.60	0.162	10.57	0.177	75.0
Liver	1.7×10^3	0.555	3.35	0.176	4.06	0.183	27.5
Heart	300	0.505	2.58	0.162	3.17	0.177	22.6
Brain	1.5×10^3	0.630	6.44	0.196	7.65	0.196	49.9

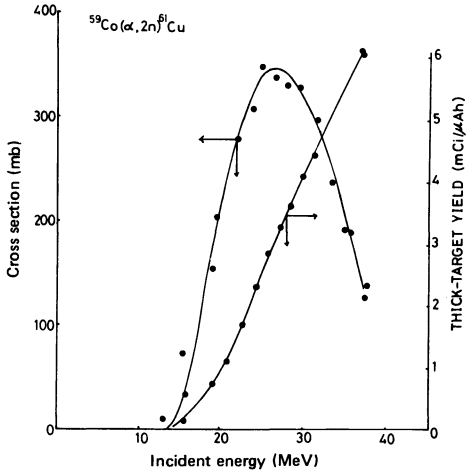

Fig. 1. Excitation curve and thick-target yield curve for ^{61}Cu from (Co + α) reaction.

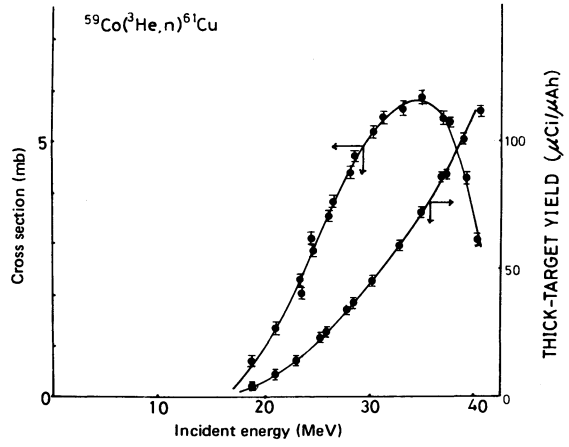

Fig. 2. Excitation curve and thick-target yield curve for ^{61}Cu from (Co + ^{3}He) reaction.

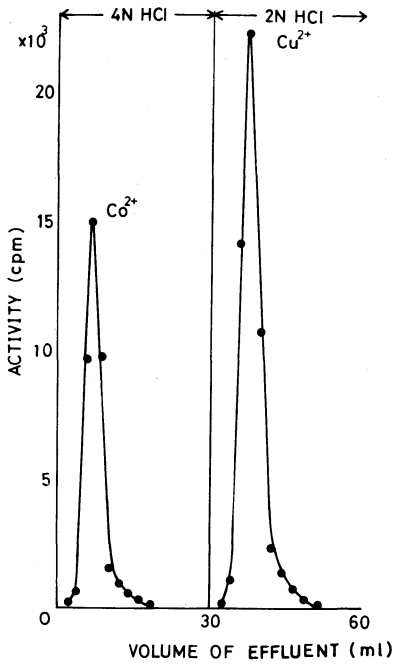

Fig. 3. An elution curves of Co^{2+} and Cu^{2+}.
Dowex 1-X8, 100–200 mesh 0.5 cm^2 x 15 cm, flow rate; 0.5 ml/min.

for ^{67}Cu. Though ^{64}Cu produced by $^{63}Cu(n, \gamma)$ is not in carrier-free state, its specific activity can be improved to 20-50 mCi/mg Cu by Szilard-Chalmers' reaction with Cu-phthalocyanine target[11-14]. Or it could be made carrier-free by $^{64}Zn(n, p)^{64}Cu$[2]. But still ^{64}Cu is not adequate to be used in vivo because of its high dose and lackness in suitable γ rays for scanning (100-250 KeV).

Production of ^{67}Cu has been reported by the reaction of $^{64}Ni(\alpha, p)^{67}Cu$ using an enriched ^{64}Ni target[15] or by $^{68}Zn(\gamma, p)^{67}Cu$ with a linear accelerator of the amount 5 mCi[16]. But it still contains about 1% of ^{64}Cu at use even 50 hours after E.O.B. Besides it is a β^- emitter with half-life 61.7h and the effective half-life 2.49d. Thus, although it may be useful for relatively long in vitro biochemical experiments but not for in vivo application due to the high absorbed dose.

On the other hand, ^{61}Cu is advantageous to ^{64}Cu and ^{67}Cu at scanning due to the presence of the desirable γ ray (0.284MeV-12%). Since it is a β^+ emitter, it is also suited to positron camera technique. ^{61}Cu is thus the most suitable radioisotope of copper for nuclear medicine. The present experiment has demonstrated that ^{61}Cu can be produced with yield of 95% at 6 mCi/μAh from natural cobalt target of 183 mg/cm^2 thick by bombardment with 40 MeV α particle followed by an anion exchange treatment which can be performed in a short period, 150 min.

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