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YIELD OF Be-7 PRODUCED ON THE NUCLEAR REACTOR BY SECONDARY CHARGED PARTICLE INDUCED NUCLEAR REACTIONS

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The yields of the radionuclide ^{7}Be produced in a nuclear reactor by secondary nuclear reactions induced by recoil protons and deuterons on Li and B – ^{7}Li(p, n) + ^{10}B(p, α) + ^{11}B(p, α n) + ^{6}Li(d,n) +^{7}Li(d,2n)+ ^{10}B(p, α) +^{10}B(d, α n) + ^{11}B(d, α 2n) were investigated. The powder specimens LiOH and H_3BO_3 fixed in some hydrogen – containing viscous liquid materials and placed in quartz ampoules were irradiated in the nuclear reactor. The number of ^{7}Be nuclei accumulated in the targets was measured by counting the γ-rays from ^{7}Be using a REGE detector of company CANBERRA. The yield of ^{7}Be produced by group nuclear reactions with lithium was 181.5 ± 27.2 kBq/g.h, while that produced by group nuclear reactions with boron was 58.8 ± 8.54 kBq/g.h. The results obtained by using the nuclear reactor are compared with the compiled data obtained with application of the cyclotron.

Keywords: *neutron elastic and inelastic back scattering, charged particle nuclear reaction, recoil protons and deuterons, activation analysis, isotope production, yield of radionuclide*

INTRODUCTION

In development of nuclear methods for the analysis of lithium and boron, for their use in modern nuclear energy installations and for production of the radionuclide ^{7}Be ($T_{1/2}$=53.3 d), a detailed knowledge is required on the radioactivity of ^{7}Be accumulated in the targets. As it is known, the yield of a radionuclide is an important physical value defining an amount of radioactive atoms in irradiated samples [1].

At low and middle particle energy the radionuclide ^{7}Be is mainly formed from lithium and boron as a result of nuclear reactions given in Table 1. their Q-values are also given. Therefore, in many cases charged particle accelerators are used to study the ways of radionuclide formation. With the purpose of using the cyclotron in activation analysis we have researched the possibility of he radionuclide formation by irradiation of the targets with charged particles accelerated in the cyclotron U-150 INP AS RUz) [2-4]. ^{7}Be production in Li(d,n) and Be(d,n) reactions for 25 and 40 MeV deuterons was also measured [5]. Its formation in proton, 3He and α-particle induced reaction on many other light nuclei has also been investigated [6-8].

The other way of 7Be production could be the use of recoil protons and deuterons produced in a nuclear reactor as a result of (n, p) or (n,d) inelastic and elastic scattering interaction of fast neutrons with nuclei of hydrogen [9]. We have not found literary sources denoted to the study of such ways of the production and using of nuclear reactions excited with recoil protons + deuterons.

This paper presents the experimental results on the production of, ^{7}Be, by means of the recoil protons and deuterons on natural lithium and boron in a nuclear reactor.

DEFINTION

The yield of a radionuclide is defined by the expression:

$$Y = \frac{A_0}{m\left(\dfrac{1-e^{-\lambda t_{обл}}}{\lambda}\right)} \tag{1}$$

where,
Y- yield of radionuclide;
m- mass of irradiated chemical element;
$t_{обл}$ - irradiation time;
A_0 - initial activity of radionuclide (when $t_{cool} = o$);
λ - the decay constant;
Radioactivity of ^{7}Be brought about the mass unit of irradiated sample:

$$A = \frac{A_0}{m_x} = \left(\frac{N_\gamma e^{-\lambda t_{cool}}}{t_{det}\varsigma\omega I_\gamma}\right)\Big/ m_x \tag{2}$$

where,
N_γ - number of detected impulses;
t_{det}- detection time;
ς - geometric factor of detection;
ω - detection efficiency;

I_γ- intensity of γ-quant;

t_{cool}- cooling time;
m_x- sample mass;

EXPERIMENTAL

The radionuclide ^{7}Be possesses with suitable for measurement the half-life $T_{1/2}$=53.61 d and energy of the emitted gamma-quantum E_γ = 477.5keV, I_γ=10.3 %.

For the sample preparation we fixed the powders of LiOH and H_3BO_3 in some hydrogen - containing organic compounds - polystyrene, polyfoam or epoxy, while using the epoxy, it was conducted as follows. The resin was dispersed in solvent in the proportion 5:1.Weight of "proton -creating" material must be 3-4 times more weight of investigated sample. Since weight of sample was 30-50 mg we took 200-300 mg of this viscous mixture and fixed it with the investigated sample. The prepared sample was filled in Petri cup and left to dry during a full day. The dried sample turned into a flexible film which was packed in polyethylene bags for irradiation. We took three samples of 30-50 mg weight each. The sample placed in a quartz ampoule of 20 mm diameter was sealed and placed in an Al-container.

We irradiated the samples in neutron flux during 20 hours. The flux density of thermal neutrons was $7.10^{13}cm^{-2}\cdot s^{-1}$. The cooling time of irradiated samples was changed from 2 up to 7 days. The cooled samples were carried from "hot cameras" in boxes for unpacking samples, where quartz ampoules were split and samples were placed in separate polyethylene bags for measurement of radioactivity.

The radioactivity of irradiated samples was measured with the semiconductor detector REGE of company CANBERRA. Time of the measurement was changed from 200 up to 1000 and more seconds, depending on the value of radioactivity. The radioactivity of ^{7}Be was measured using a stand installed at different distances from the surface of the detector. The activity of ^{7}Be was determined using the photo peaks of energy Eγ=477.5 keV. In the γ- quantum spectrum besides the photo lines of ^{7}Be the photo lines of other radionuclides produced from the impurity elements as result of capture reactions of the thermal neutron interactions were also observed.

DISCUSSION OF RESULTS

In Tables 1 and 2 the experimental results obtained in our study are presented. It is seen that the yield of ^{7}Be produced in lithium and boron is 181.5 ± 27.2 and 58.8 ± 8.54 kBq/g.h, respectively.

To estimate the advantage or disadvantage of the proposed method in contrast to the cyclotron method of the radionuclide production a comparison of the yields values of ^{7}Be produced by both methods is necessary. It is very difficult to conduct such a comparison, since due to small penetration ability of charged particles into targets in the case of the cyclotron the notion of "irradiation of thick targets (when range of the charged particle is less than target's thickness)" is used. However, we tried to conduct the comparison for a certain acceptable condition of activations. For this purpose we have compared the data obtained using a cyclotron with results obtained in this study. Our data for the cyclotron were compiled in [1-4]. Nuclear data for the two means of radionuclide production are listed in Table 3.

Table 1. Experimental results for the radionuclide ^{7}Be produced on irradiation lithium with neutrons.

Sample number	T_{cool},Days				$\frac{N_\gamma e^{-\lambda t_{cool}}}{t_{det}\omega\varsigma}$ γ - quant/s	A_0, kBq	A, kBq/g	Y, kBq/g.h
	17	39	66	95				
		N_γ / t_{det}, imp/s						
1	3.126	2.274	2.389	0.996	4.18	2.04	214.6	213.6
2	4.029	2.558	1.822	1.421	5.60	2.72	192.2	191.2
3	3.255	2.517	1.716	1.080	4.10	2.03	141.7	140.7
Average	3.47 ± 0.37	2.45 ± 0.51	1.98 ± 0.28	1.17 ± 0.17	4.62 ± 0.62	2.23 ± 0.29	182.5 ± 27.2	181.5 ± 27.2

Table 2. Experimental results for the radionuclide ^{7}Be accumulated in irradiated boron samples

Sample number	T_{cool},Days				$\frac{N_\gamma e^{-\lambda t_{cool}}}{t_{det}\omega\varsigma}$ γ - quant/s	A_0 kBq	A, kBq/g	Y, kBq/g.h
	10	38	66	95				
	N_γ / t_{det}, imp/s							
1	0.92	0.82	0.64	0.30	0.98	475.7	60.2	60.1
2	1.00	0.71	0.51	0.26	1.20	582.5	68.4	68.3
3	0.77	0.55	0.31	0.16	0.87	427.2	48.1	48.0
Average	0.90 ±0.08	0.69 ±0.09	0.49 ±0.12	0.24 ±0.06	1.01±0.12	495.1 ±5.82	58.9 ±8.64	58.8 ±8.54

Table 3. Values of the ^{7}Be yield from two methods of radionuclide production

Radionuclide production method	Nuclear reactor	Cyclotron E_p = 6 MeV	
	Y, kBq/(g.h)	Y, kBq/(μA.h)	Range R, g/cm^2 [1]
Li → ^{7}Be	181.5	3260	0.0569
B → ^{7}Be	58.8	470	0.0580

Now, we shall expect that for choice of the comparable conditions of activation the thick targets consisting only of lithium and boron are irradiated in the cyclotron by protons with Ep=6 MeV. This energy of the protons is comparable with the energy of the recoil protons produced as result of back scattering of fast neutrons from a nuclear reaction on hydrogen. As it is well known, in an accelerator the targets are usually irradiated through collimators of 3-10 mm diameter. Consequently, the area of irradiated surface of the targets does not exceed 0.8 cm^2. For the case, when current of the charged particles through collimator of 1 cm diameter is 1 μA, the activated masses of lithium and boron are 45.5 and 46.4 mg, respectively.

To estimate the yield of radionuclide under choice condition of activation in the cyclotron we used the following expression:

$$Y = \frac{Y_{tab} I_p}{RS} \tag{3}$$

where, Y_{tab}-the tabulated yield value for the cyclotron protons; I_p-Current of protons; R-Range of protons in target; S-Area of irradiated surface of target;

To find the ration of the values of the yield of radionuclide produced by two methods of activation we used the following expression:

$$k = \frac{Y(\text{reactor})}{Y(\text{cyclotron})} \tag{4}$$

The values of k under chosen the condition of activation (t_{irr}=1 h, m=1 g and E_p=6 MeV) for lithium and boron are 1.24 and 2.70, accordingly. Consequently, under irradiation of lithium and boron in a nuclear reactor the yield of radionuclide is well above, (for instance, for boron 2.7 times) than the yield of the radionuclide produced in the cyclotron.

Table 4. The comparable characteristics of two methods of radionuclide formation

Devices	Advantages	Disadvantages
Cyclotron	1) Production of radionuclide without carrier with comparatively small background radioactivity from impurity elements 2) Yield of radionuclide is high	1) Relatively high cost of irradiation time on accelerator
Reactor	1) Simplicity of irradiation of targets 2) Low cost of high active radionuclide production 3) Irradiation of targets with comparatively high mass is possible	1) High background activity of radio nuclides from impurity elements due to capture reactions of thermal neutrons 2) There is need to use an additional compound for the generating of flow of charged particles

However, when the cooled and revolving targets are used, the flow of charged particles to targets can be high enough (several tens μA). So, at more high current and energy of the particles the value of radionuclide yield can rise by two and more orders of magnitude than this is shown in Table 3.

We shall consider the advantage and disadvantage of the methods of the radionuclide formation with using of the nuclear reactor and cyclotron. In Table 4the comparable characteristics of two methods of radionuclide formation are presented.

It is seen the reactor method of the radionuclide formation is relatively simple and lower in cost but it contains lot of impurities. Moreover, it is possible to irradiate large amount of material in a nuclear rector, which allows reaching a high radionuclide yield.

CONCLUSION

1) The yields of the radionuclide ^{7}Be produced in a nuclear reactor by secondary nuclear reactions exited with recoil protons + deuterons on Li and B were measured. They were found to be 181.5 ± 27.2 kBq/g.h for lithium and 58.8 ± 8.54 kBq/g.h for boron.

2) The results obtained using the nuclear reactor are compared with ones obtained with application of the cyclotron. The reactor method of radionuclide formation compared with the cyclotron method takes advantage, due to the possibility for the achievement of the high radionuclide yield as a result of the irradiating relatively large amount of the target material.

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خرج نويدات بريليوم-٧ الناتجة في المفاعل النووي بواسطة التفاعلات النووية بإستخدام الجسيمات المشحونة الثانوية

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معهد الفيزياء النووية التابع لأكاديمية العلوم الأزبيكية ، أولج بك ، طشقند، ١٠٠٢١٤ ، أزبكستان

تم دراسة خرج نويدات البريليوم-٧ المشعة الناتجة في مفاعل نووي والمستحثة بواسطة البروتونات المرتدة والديوترونات علي أهداف ليثيوم وبريليوم. تم قياس عدد نويدات بريليوم-٧ المتجمعة في الأهداف وذلك بدلالة أشعة جاما الناتجة من بريليوم-٧. تم مقارنة النتائج التي تم الحصول عليها بواسطة المفاعل النووي مع النتائج المجمعة بإستخدام السيكلترون.