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Some Medical Radionuclides Production by C18/18 Cyclotron

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Abstract. The possibility of ^{55}Co and ^{124}Sb radioisotopes production by CYCLONE C18/18 is discussed. Using ^{55}Co in Positron Emission Tomography (PET) visualization seems attractive, and ^{124}Sb can be used in Intra Vascular Brachytherapy (IVBT). Calculations by TALYS 1.6 code are performed for ^{58}Ni(p,α)^{55}Co and ^{124}Sn(p, n)^{124}Sb reactions and the obtained data are compared with the experimental ones from EXFOR data base.

Keywords: medical radioisotope, cyclotron, activation method, excitation function

Currently numerous radioactive isotopes come into wide use in medicine for diagnosis of various diseases, as well as in therapy and the demand for various radioisotopes is very big.

The CYCLONE C18/18, which soon will soon be operated in Yerevan (Armenia), is a cyclotron intended to the production of isotopes for Positron Emission Tomography (PET), more specifically, ^{18}F for the production of fluorodeoxyglucose (^{18}FDG). Though, it's also possible to use this cyclotron for production of the large number of isotopes useful in medicine and industry.

Let us discuss the probability of production of some medical radionuclides by CYCLONE C18/18.

Production of ^{55}Co isotope. Several studies have shown the feasibility of ^{55}Co isotopes in imaging of neuronal damage in stroke, multiple sclerosis, cerebral tumors and trauma ($T_{1/2}$ = 17.53 h, 69.6% positron decay). In accelerator based production ^{55}Co can be obtained in ^{58}Ni(p,α)^{55}Co reaction.

The excitation function of ^{58}Ni(p,α)^{55}Co reaction is presented on Fig. 1. The experimental data are taken form EXFOR database [1]. The data are scattered (at the maximum of the excitation function the data are different twice) and therefore need to be elaborated.

We performed calculations by TALYS 1.6 software [2] for energy from threshold to 50 MeV. The result is presented on Fig. 1. As one can see, the calculated curve well coincides with data of [10, 11, 12].

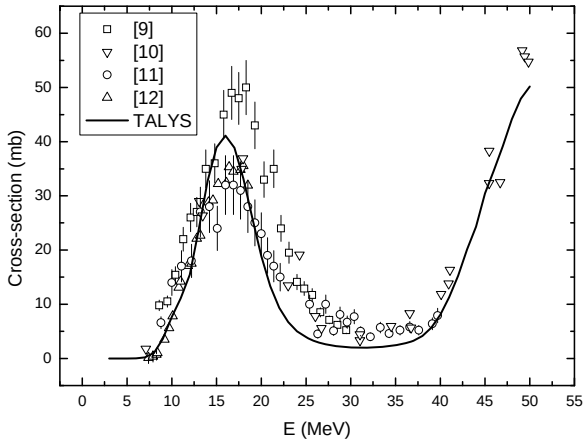

Fig. 1. Excitation function for ^{58}Ni(p, α)^{55}Co reaction.

We plan to obtain the excitation function of ^{58}Ni(p,α)^{55}Co reaction experimentally. For this purpose, the stacked-foil target method [3] is usually used. Stacked-foil technique supposes that the stack of several foils (typical value is 5–20) is used to measure the experimental excitation function of a nuclear reaction at a single irradiation. In our case, the set of the target consists of 10 identical target-foils of ^{58}Ni. Target-foils are located between the monitor-foils and energy degrader-foils. The Cu foils are chosen as the monitor, and the Al foils are used as the degrader. Al foils catch the ejected product nuclides from the preceding target-foils ("catcher foil" does not produce any radioactive product by the proton at the used energy range). So, a pair of foils (target + catcher) contains all of the produced radioactive isotopes from the ^{58}Ni target. Less than 1% of the residual nuclei can be detected in the catcher foil [4]. A scheme of the target set is presented in Fig.2.

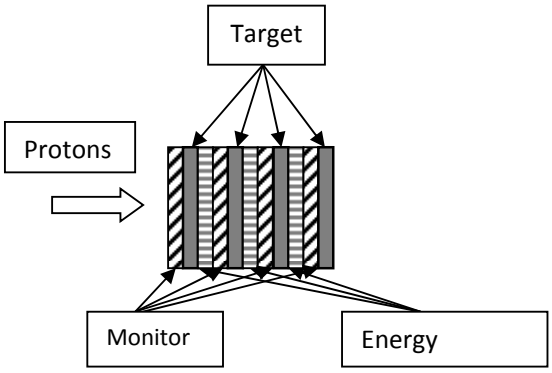

Fig. 2. Scheme of the target sets for obtainment of excitation function of ^{58}Ni(p,α)^{55}Co reaction by stacked-foil target method.

The overall thickness of the stack was calculated by SRIM (The Stopping and Range of Ions in Matter) software [16]. It is necessary to reduce the beam energy to zero at the last foil. The set of foils must be pressed together to avoid air gaps between the foils, which might influence on the particle stopping.

The first monitor-foil is located at the front position for estimation of the initial beam flux. The cross-sections of monitor reactions ^{63}Cu(p, $2n$) ^{62}Zn and ^{65}Cu (p ,n)^{65}Zn are given in [5]. After the irradiation, the stack is disassembled into Ni –Al pairs. The induced activity in the targets is measured by HPGe-detector to determine the cross-section curve.

The cross sections of the investigating reactions are calculated by the equation (1)

$$\sigma(E) = \Delta N \lambda / \left(N_p N_{nuc} k \varepsilon \eta \left(1 - e^{-\lambda t_1}\right) e^{-\lambda t_2} \left(1 - e^{-\lambda t_3}\right)\right), \qquad (1)$$

where ΔN is the number of events under the photopeak measured by the detector during the time t_3 (h), λ is the decay constant, N_p is the number of beam protons (1/hour), N_{nuc} is the number of target nuclei (1/cm^2), k is coefficient of absorption of gamma rays in the target, air and detector's cup, ε is the detector efficiency, η is the partial intensity of the product's gamma line, t_1 (h) is the duration of irradiation, t_2 (h) is the time between irradiation and measurement.

Characteristics of residual nuclei formed in discussed proton-nucleus reactions are presented in Table 1.

Table 1. Characteristics of residual nuclei formed in proton-nucleus reactions

Nuclear product	$T_{1/2}$	Eγ (keV)	I (%)	Type of reactions	Threshold (keV)
$^{55}_{27}Co$	17.53 h	931.3 477.2 1408.4	75 20.2 16.88	^{58}Ni(p,α)^{55}Co	1358.054
$^{65}_{30}Zn$	244.26 d	1115.546	50.6	^{65}Cu(p,n)^{65}Zn	2167.12
$^{62}_{30}Zn$	9.186 h	596.56 548.35	26 15.3	^{63}Cu(p, 2n)^{62}Zn	13477.832
$^{62}_{29}Cu$	9.74 m	1172.9 875.68	0.34 0.15	^{63}Cu(p, pn)^{62}Cu	11037.582

Production of ^{124}Sb isotope. Isotope **^{124}Sb** (I^p =3$^-$) can be used in intravascular brachytherapy (IVBT). It is well known that the restenosis often occur after angioplasty or stent implantation in the patient vessel. Radiation may be used to prevent recurrent restenosis. High energy β-particles (1-2 MeV and more) and low energy γ-rays (20-300 keV) are ideal for that purpose. As the radiation source the following radioisotopes are used: ^{32}P, ^{192}Ir and ^{90}Sr/^{90}Y. All this radionuclides are produced in nuclear reactor. Recently the **^{124g}Sb** radioisotope was offered to use in IVBT [6, 7]. ^{124g}Sb radiates β- particles and γ- rays characteristics of which are present in Tab. 2. High energy β-particles emitted by ^{124g}Sb and long half-life period of this isotope provides prevention of restenosis.

According to the experimental data taken from EXFOR data base the cross-section of the reaction ^{124}Sn(*p, n*)^{124g}Sb is maximal at the energy range 8-10 MeV. However, different authors take various data at this energy range (see Fig. 3). We plan to irradiate ^{124}Sn target at energy range 8-10 MeV and obtain the cross-section of the reaction using induced activity method. The CYCLONE C18/18 provides 18 MeV protons. In the experimental hall proton beam energy is 16.3 MeV because of the output window. For having lower energy (10 MeV) aluminum degrader is located before ^{124}Sn target. The thickness of the degrader was calculated using SRIM software. Thin foil of Cu is located after degrader as a monitor and then the ^{124}Sn target is located. The number of protons in the beam is obtained by the well-known cross-sections of monitor reactions [5].

We calculated cross-sections of ^{124}Sn(*p, n*)^{124}Sb reaction by TALYS 1.6 for energy from threshold to 50 MeV and compared obtained data with the existing experimental data taken from EXFOR (see Fig. 3).

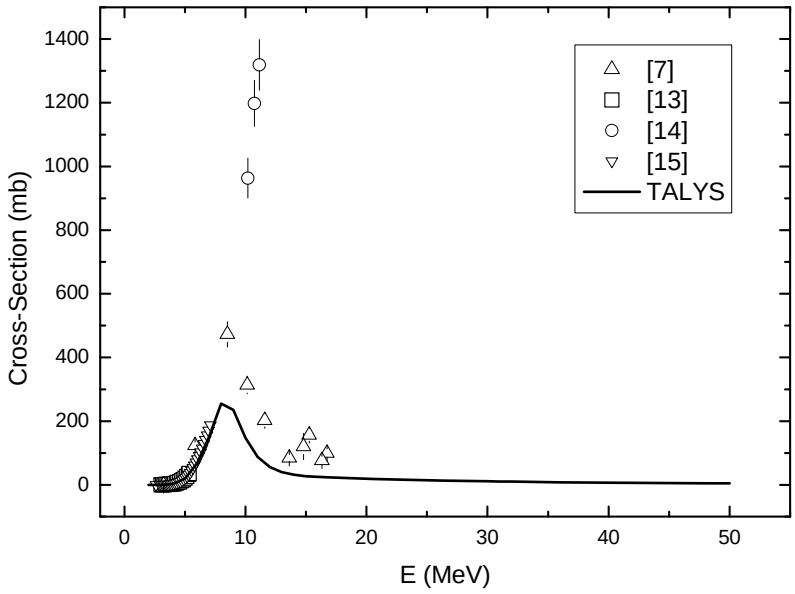

Fig. 3. Excitation function for ^{124}Sn(p, n)^{124}Sb reaction.

As one can see, the calculated data are significantly lower than experimental ones. Earlier we noticed [9] that for nuclei, which have high-spin yrast lines in the level scheme of ^{124}Sb nucleus, the TALYS data do not agree with the experimental ones for high-spin isomeric state. Nucleus ^{124}Sb has yrast states [8]. So it is interesting to compare calculated and experimental data for this nucleus and check if the yrast-lines have an influence on ^{124m1}Sb high-state (8^-, $T_{1/2}$ = 20 min) cross-section. For investigation of ^{124m}Sb isotope, we plan to irradiate the ^{124}Sn target for a short time, measure the γ-spectra and calculate cross-section of ^{124m}Sb isotope. The characteristics of ^{124g,124m,124m1}Sb isotopes are presented in Tab. 2

Table 2. Characteristics of ^{124g,124m,124m1}Sb radioisotopes.

Radioisotope	I^p	$T_{1/2}$	E_γ, keV (Iγ, %)	E_β, keV (I_β, %)	Decay mode
$^{124g}_{51}Sb_{73}$	3^-	60.2 d	602.73 (97.8%) 1690.98 (47.3 %)	210.81 (8.86%) 610.78 (51.9%) 865.2 (3.87%) 946.6 (2.03%) 1578.98 (4.8%) 2301.8 (22.3%)	β^- (100%)
$^{124m1}_{51}Sb_{73}$	8^-	20.2 min	–	–	IT (100%)
$^{124m2}_{51}Sb_{73}$	5^+	93 sec	498.3 (25%) 645.85 (25%) 602.73 (25%)	565.59(0.5%) 1168.39(25%) 1666.78(1.35)	β^-(25%) IT(75%)

The results of the work allow us to suggest ^{124}Sb in IVBT application to cover the stent by the radioactive ^{124}Sb isotopes. It is also possible to cover the stent by stable ^{124}Sn and then irradiate it with proton beam. The thickness of the coating, beam flux and irradiation time must be chosen precisely for obtaining necessary therapeutic activity. After "cooling", the stent can be implanted in the patient vessel. After irradiation, the nuclear reaction leading to radioisotope production can occur in the stent material. It is necessary to take into account when we choose the material of stent.

The significant number of heart vessel disease patients in the world and especially in our country indicates the necessity of thinking about that problem and we think that covering the stents with necessary amount of ^{124g}Sb isotope to prevent restenosis is a good idea.

References

[1]. https://www-nds.iaea.org/exfor/exfor.htm
[2]. http://www.talys.eu/
[3]. F. Ditroi. Nucl. Instr. Meth. in Phys. Res. B 188, 115 (2002).
[4]. A. R. Balabekyan, A.S. Danagulyan *et al*., Physics of Atomic Nuclei, 70 (11), 1889 (2007).
[5]. P. Kopecky. Applied Radiation and Isotopes Vol. **36**, Issue.8, p.657-661, (1985).
[6]. H. A. Rowland, Trans R Soc Trop Med Hyg.; 62(5): 6 32-46 (1968).
[7]. E. K. Elmaghraby, S. A. Said, F. I. Asfour, Appl. Rad. Isotopes 67, 147 (2009).
[8]. T. Fenyes *et al*., Acta Physics Hungariea 71, 239.(1992).
[9]. V. N. Levkovskij, Act. Cs. By Protons and Alphas, Moscow 1991, (1991), USSR
[10]. G.A. Brinkman, J. Helmer, L. Lindner, Radiochemical and Radioanalytical Letters, Vol.28, p.9 (1977).
[11]. H. A. Ewart, M. Blann, Priv. Comm: Ewart (1964).
[12]. S. Kaufman, Physical Review, Vol.117, p.1532 (1960).
[13]. C. H. Johnson, R. L.Kernell, Physical Review, Part C, Nuclear Physics, Vol.2, p.639 (1970).
[14]. B.V. Zhuravlev, A.A. Lychagin, N.N. Titarenko, Physics of Atomic Nuclei, Vol.69, p.363 (2006).
[15]. C.H. Johnson, J.K. Bair, C.M. Jones, S.K. Penny, D.W. Smith, Physical Review, Part C, Nuclear Physics, Vol.15, p.196 (1977).
[16]. http://www.srim.org/