ON PRODUCTION EFFICIENCY OF MEDICAL & BIOPHYSICAL ISOTOPES USING ELECTRON ACCELERATOR

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INTRODUCTION

The isotopes presenting the main concern for nuclear medicine of Ukraine were selected as object of investigation. Their list and some basic specification are shown in Table 1.

Table 1 The characteristics of isotopes of medical and biophysical application

Isotope	Half-life period, days	Basic decay type	Energy of radiation , MeV	Application	Required intensity of isotope
^{32}P	14.36	e^-	1.71	β-radiometry of neoformation	to 300
^{33}P	25.34	e^-	0.248	spermatogenesis, immunoenzyme analyze	kBq/kg
^{57}Co	270.9	γ	0.122	calibration of γ-chamber	to10^2MBq
^{99m}Tc	0.25	γ	0.140	isotope scanning	10^2... 10^3 MBq
^{181}W	121.2	γ	0.06	enhistotherapy	- « -
^{185}W	75.1	e^-	0.429	- « -	- « -

COMPUTER SIMULATION

The effective production of isotopes using an electron accelerator is possible only by providing the high values of the particle flux. Under the circumstances there is a need of beam scanning within the exit window of the accelerator. That makes also to troubleshoot of a heat rejection from the converter and target device. Therefore, the different versions of a design of converter were investigated as first stage of the technology development. As the criterions of optimization were chosen: maximum conversion coefficient in the range of energy of breaking photos corresponding to photonuclear reactions, capability of an effective heat rejection, as well as maximum absorption of primary electrons in the converter for a decrease of a heat load on the target. The computer simulation was carried out in the 2D-geometry concerning an axis of the electron beam (Fig. 1).

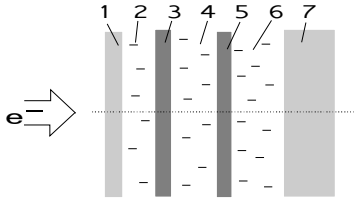

Fig. 1. Conditions of the converter simulations.

It is supposed, that the converter assembly consists of an aluminum case with a thin forward wall **1** and thick back **7**. Inside the case there are two tantalum (tungsten) plates **3, 5** cooled by water layers **2, 4, 6**. The tentative data of calculations and experiment on generation of isotopes have shown that optimum thickness $\mathbf{d_3+d_5}$ in the electron energy range 20...25 MeV makes 2...2.5 mm. Therefore we have limited in calculations by values of 2.4 mm (two plates of 1.2 mm everyone). The thickness $\mathbf{d_1}$ of the forward wall of the case is determined by conditions of providing the mechanical strength at a minimum of energy losses of electrons and is 1.6 mm. The thickness of the water layer $\mathbf{d_2}$ is 3 mm for effective cooling of the converter plates **3, 5.** The back wall of the case is made dwarfed ($\mathbf{d_7}$ = 5 mm) for absorption of electrons passed through converter plates.

The obtained data are listed in Table 2.

Table 2

The data of the computer analysis of the converter

N n/n	E_0, MeV	d, mm	d_4, mm	η	η_{sel}	$E_{conv.}$, MeV	$K_{e.a.}$ %
1	20	0	3	0.317	0.085	11.8	76.1
2	20	0	25	0.324	0.094	13.7	88.5
3	20	3	3	0.297	-	12.3	79.3
4	21	3	25.6	0.268	-	13.7	94.3
5	21	0	5	0.321	0.093	12.0	69.8
6	21	0	10	0.325	0.095	12.5	76.1
7	21	0	15	0.321	0.096	13.0	80.2
8	21	0	20	0.324	0.098	13.4	85.1
9	21	0	25	0.324	0.094	13.7	88.5
10	21	0	28.6	0.330	0.096	13.9	91.3
11	25	3	3	0.350	-	13.0	63.5
12	30	3	3	0.350	-	13.1	51.3

Here η is the total conversion coefficient, η_{sel} is the number of braking photons with energy higher than 9 MeV per on initial electron, E_{con} is the mean energy losses of one electron in the converter, $K_{e.a.}$is the coefficient of electron absorption in converter.

It follows from the table of data analysis, that the introducing of an additional water layer **4** between converter plates **3, 5** insignificantly (7%) reduces an output bremstrahlung flux, though twice improves the conditions for their cooling.

Taking into account the data obtained we have fulfilled calculations of generation of different isotopes for version of the converter made from two tantalum plates separated by 3 mm water layer. It was supposed as well that apart 10 mm behind converter the intimate 10 mm layer from a given material with a natural isotope content is placed as a target. The calculations results in such geometry are listed in Table 3. It represents the data for the specific yield of generation isotope $\mathbf{Y_1}$ (in recalculation per 1 primary electron) and the activity of the isotope **A**, produced per one operating day at a beam current 1 mA, and also a beam power

release in the target **P** at the optimum regime of irradiation (25 MeV). The version of large values E_0 was not esteemed in view of noticeable production

Table 3 The data of the computer analysis of isotope production

Isotope	Reaction	E_0, MeV						P, kW
		15		20		25		
		Y_1	A, MBq	Y_1	A, MBq	Y_1	A, MBq	
	$^{33}S(\gamma,p)^{32}P$	^{32}P	1.14	$4.37*10^{-8}$	19.0	$1.41*10^{-7}$	61.4	2.19
^{33}P	$^{34}S(\gamma,p)^{33}P$	$4.55*10^{-9}$	1.12	$1.60*10^{-7}$	39.4	$6.44*10^{-7}$	15.9	2.19
^{57}Co	$^{58}Ni(\gamma,p)^{57}Co$ $^{58}Ni(\gamma,n) \rightarrow {}^{57}Ni \rightarrow {}^{57}Co$	$1.38*10^{-6}$	31.8	$3.32*10^{-5}$	$7.65*10^{2}$	$9.4*10^{-5}$	$2.16*10^{3}$	4.98
^{99}Mo	$^{100}Mo(\gamma,n)^{99}Mo$	$7.92*10^{-5}$	$1.73*10^{3}$	$4.28*10^{-4}$	$9.36*10^{4}$	$8.54*10^{-4}$	$1.87*10^{5}$	5.18
^{181}W	$^{182}W(\gamma,n)^{181}W$	$1.04*10^{-4}$	$5.36*10^{3}$	$5.03*10^{-4}$	$2.59*10^{4}$	$8.86*10^{-4}$	$4.57*10^{4}$	7.60
^{185}W	$^{186}W(\gamma,n)^{185}W$	$4.08*10^{-5}$	$3.4*10^{3}$	$1.50*10^{-4}$	$1.24*10^{4}$	$2.48*10^{-4}$	$2.06*10^{4}$	7.60

EXPERIMENT

For verification of the results obtained the experiment (Fig.2) was carried out. The converter **3** made in version N10 (see Tab.2) is located at the accelerator LU-20 [1] exit window **1** just behind the beam position sensor **2** [2].

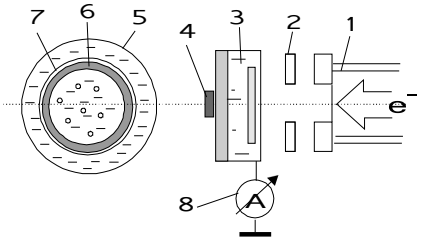

Fig. 2. The scheme of the experiment on ^{57}Co and ^{99}Mo production

The converter **3** has galvanic isolation relative to the ground. That allows one to apply an ampermeter **8** for beam current control during irradiation. On back surface of the converter the assembly of Ni samples of natural isotope content made in the form of tablets with diameter 5 and thickness 2 mm is placed. Behind the converter and symmetrically to beam axis the Mo-target is located. It consists of aluminium case **5** inside which the vessel made from water-resistant graphite **6** is placed. The space between a vessel and case is filled by running water for cooling an molybdenum in aqueous solution NaOH located in vessel. In the given experiment the volume of the solution is 120 ml at the concentration of molybdenum 180 mg/ml. Spacing interval between an axis of the vessel and the back surface of the converter is 90 mm.

The main electron beam parameters during irradiation were:

- a mean current, μA 420
- energy of electrons, MeV - 21

The beam was scanned in a vertical plane (normally to the plane of Fig. 2) with the scanning path length on the forward wall of the converter being equal to 70 mm. After irradiation the Ni and solution (10 ml) samples were studied using **Ge(Li)** detector for definition their activity and γ-spectrum analysis.

The obtained data are shown in the Table 4.

Table 4. The data of the experimental isotope generation

Isotope	Activity, Bq	
	computation	experiment
Co-57	$8*10^{5}$	$1.0*10^{6}$
Mo-99	$2.4*10^{8}$	$3*10^{8}$

SUMMARY

The results obtained demonstrate that using the high-current electron accelerator it is possible to produce a number of isotopes for medicine and biophysics. Though concerning the yield and specific activity of produced isotopes the proposed method is not as effective as the methods using heavy particle accelerators and, especially, reactors, however, it is not accompanied with noticeable quantity of radioactive waste generation. So, for example, manufacturing 1 Ci of Mo-99 with the use of a traditional reactor technology allows one to produce up to 50 Ci of the long-live waste [3]. Besides, the electron accelerator is a preferential radiation source for implementation of other technologies, first of all, sterilization of the ready-made medical forms, γ-activation analysis etc.

The satisfactory agreement of experimental and computer simulation data demonstrates broad capabilities of the latter for optimization of the master schedules of isotope production on electron accelerators and solution accompanying heat-physics problems.

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