ESTIMATION OF Os, Ir, Sc, In ISOTOPE PRODUCTION AT ELECTRON LINEAR ACCELERATORS

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Preliminary data on the production of medical radionuclides ^{47}Sc, ^{114}In, ^{192}Ir and ^{191}Os, ^{191m}Os by the photonuclear method are reported. The targets were irradiated in the bremsstrahlung beam of the NSC KIPT accelerator LU-20 at an accelerated electron energy of 29 MeV and a beam current of 10 μA. The required isotopes were produced in the following channels of nuclear reactions: ^{51}V(γ,α)^{47}Sc; ^{48}Ti(γ,p)^{47}Sc; ^{193}Ir(γ,n)^{192}Ir; ^{192}Os(γ,n)^{191}Os,^{191m}Os; ^{115}In(γ,n)^{114}In. The useful product yields (specific activities) at the end of irradiation, normalized to 1 hour of target irradiation at an average beam current of 1 μA, were obtained.

PACS: 29.17.+w

1. INTRODUCTION

An accumulated wide experience on isotope production and separation has made it possible to substantially extend a range of radionuclides that can be used for nuclear medicine purposes. More stringent requirements on radiation load reduction for both the patients and the clinic personnel play an important part in introduction of new-generation radionuclides into medical practice. At present, there is a world-wide search for new diagnostic and therapeutic isotopes that would have acceptable characteristics, in particular, a high tropic property, and would not involve high-level wastes in their production. A great quantity of radioactive wastes during production of ^{99}Mo → ^{99m}Tc generators [1-3], the problems of their disposal, and the negative attitude of the community to the issues of nuclear reactor operation contribute to a gradual decrease in technetium generator production by the reactor method. A qualitatively different situation appears when considering high-current electron linear accelerators (ELA) as tools for producing radionuclides by the photonuclear method. At present, in Ukraine, there are a number of linear accelerators that have wide ranges of electron energy and beam current [4,5] and can be advantageously used for the purpose. The adaptation of the output units of the accelerators to the tasks of radionuclide production will require substantially lesser expenses than building and putting into operation of 40...100 MeV cyclotrons. Besides, some issues in production of isotopes, particularly, long-lived isotopes and the ones used in medical isotope generators, can be solved simultaneously with other irradiation programs.

2. MATERIALS AND METHODS

The table given below characterizes some promising isotopes, the production of which seems expedient at the ELA [4]. To determine experimentally the levels of activity produced, Os, Ir, Ti, V, Ni, In targets were chosen. Metal samples of In, Ir and Os, as well as Ni of natural composition were used, while Ti and V targets were chosen to produce ^{47}Sc isotopes. This choice of radionuclides was dictated by the possibility of radiochemical separation of the required isotope from the target matrix. Apart from the fact that ^{47}Sc has the 159 keV γ-line that is acceptable for diagnostics, this isotope being the β-radiator holds promise for radioimmunotherapy of tumors [4].

To obtain the data on the radiation field at the location site of each target, the targets were supplied with "check test pieces". The last ones presented thin copper foils that were cut out to repeat the shape of the target; each check test piece was packed together with its respective target. The "total" check test piece had a size knowingly greater than the cross section of the γ-beam in the target-disposed plane.

The Os, V, Ti, In, Ir targets were irradiated at the electron linac LU-20 at accelerated electron energy of 29 MeV. The residual-activity γ-spectra of the samples were measured at the spectrometry bench with the use of the 100 cm^3 Ge(Li) detector [6].

After irradiation, the activity of each check test piece at the moment of irradiation end was measured. The ratio of the activity of an individual check test piece to the activity of the common check test piece is approximately equal to

Table 1. *Characteristics of isotopes produced at the ELA*

No	Isotope	Radiation energy, keV		Half-life	Application
		β-particles	γ-radiation		
1	^{47}Sc	600	159	3.4 days	Radioimmunotherapy
2	^{103}Pd		20.5	16.9 days	Brachytherapy
3	^{111}In		171; 245	2.8 days	Universal
4	^{114m}In	1980	190	49 days	Universal
5	^{180m}Ta		57	9.1 hours	Brachytherapy
6	^{181}W		59	121 days	Brachytherapy
7	^{186}Re	1080	137	90.6 hours	Osteotherapy
8	^{188}Re	2135	155	16.9 hours	Osteotherapy
9	^{191}Os	139	129	15 days	Radiotherapy
10	^{192}Ir	670	316; 468	74 days	Brachytherapy

PROBLEMS OF ATOMIC SCIENCE AND TECHNOLOGY. 2006. № 3.
Series: Nuclear Physics Investigations (47), p.168-170.

the γ-beam utilization factor. The beam utilization factor is quantitatively determined by the ratio of the γ-quantum flux passing through the target section to the total γ-quantum flux passing through the target-disposed plane. According to preliminary estimates, the error of determining the beam utilization factor due to different photonuclear reaction thresholds does not exceed 15%.

3. RESULTS AND DISCUSSION

The gamma-radiation spectra from the Ir target irradiated for 1 hour are presented in Fig.1. Fig.1,a shows the 186 keV, 361 keV, 371 keV, 407 keV, 605 keV γ-lines of ^{190}Ir isotope. The next measurement of the spectrum was performed after a lapse of 150 days (i.e., 2 half-lives of ^{192}Ir isotope). For this period of time the ^{190}Ir isotope decays practically completely, and the radiation spectrum of the target shows only the lines of the ^{192}Ir isotope, as can be seen in Fig.1,b.

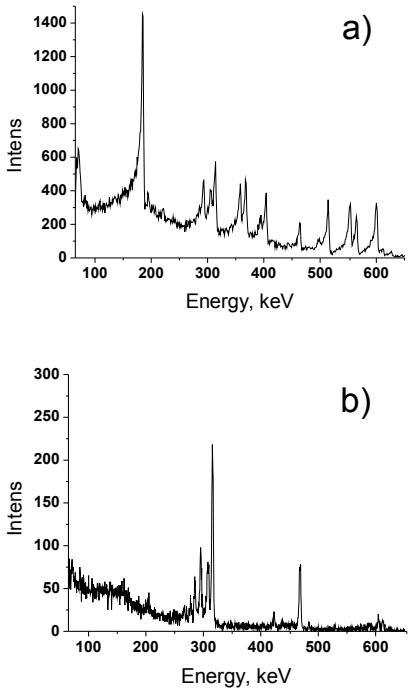

Fig.1. Gamma-radiation spectra of Ir target: 2 days (a) and 150 days (b) after irradiation

The calculations of specific activity of the mentioned nuclides give the following values: $8.7 \cdot 10^5$ Bq/g·μA for ^{192}Ir and $4 \cdot 10^6$ Bq/g·μA for ^{190}Ir.

The isotope ^{47}Sc was produced by means of the following two reactions: ^{48}Ti(γ,p)^{47}Sc and ^{51}V(γ,α) ^{47}Sc. Fig.2 shows the spectra from irradiated titanium and vanadium targets. The two spectra provide a reliable identification of the isotope ^{47}Sc ($T_{1/2}$=3.4 days) by the 159 keV γ-line. The comparison between the spectra from vanadium and tantalum targets suggests the conclusion about a preferential use of the titanium target, since its radiation spectrum has a better purity as compared with the spectrum of irradiated vanadium. Furthermore, the comparison between specific activity values of ^{47}Sc has shown that with the use of the titanium target the specific production of ^{47}Sc is higher than in the vanadium target case. The calculated specific activity values of different radionuclides are given in Table 2.

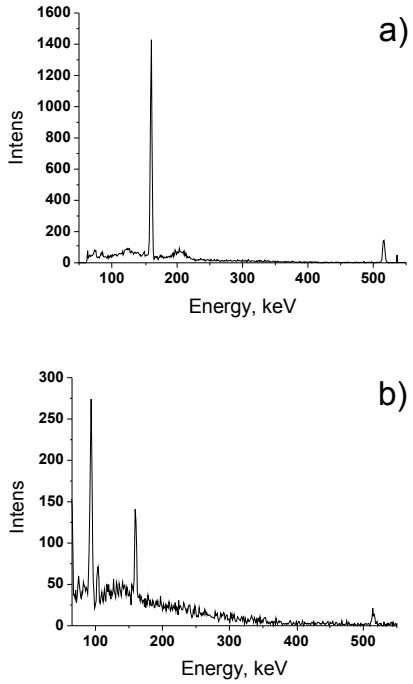

Fig.2. Gamma-radiation spectra of irradiated titanium (a) and vanadium (b) targets

Table 2. *Specific production values of some radionuclides*

No	Reaction	Target mass, g	Initial isotope fraction	Average beam current, μA	Beam utilization factor K	Specific activity Bq/g·μA	Specific activity without K taken into account, Bq/g·μA
	^{192}Os(γ,n)^{191}Os	0.54	0.41	9	0.126	$1.19 \cdot 10^5$	$1.51 \cdot 10^4$
1	^{51}V(γ,α)^{47}Sc	0.14	0.99	9	0.118	$1.90 \cdot 10^5$	$2.24 \cdot 10^4$
	^{115}In(γ,n)^{114}In	0.2	0.96	9	0.816	$1.91 \cdot 10^5$	$1.56 \cdot 10^5$
	^{193}Ir (γ,n)^{192}Ir	0.07	0.615	57	0.155	$8.68 \cdot 10^5$	$1.34 \cdot 10^5$
	^{51}V(γ,α)^{47}Sc	0.14	0.99	57	0.18	$1.27 \cdot 10^5$	$2.28 \cdot 10^4$
2	^{48}Ti(γ,p)^{47}Sc	0.045	0.74	57	0.75	$4.21 \cdot 10^5$	$3.16 \cdot 10^5$
	^{192}Os(γ,n)^{191}Os	0.54	0.41	57	0.126	$1.45 \cdot 10^5$	$1.82 \cdot 10^4$

4. CONCLUSIONS

1. From the analysis of publications it has been established that nuclear medicine tends to turn to radionuclides of new generation, and a list of radionuclides that can be produced at electron linacs has been drawn up (Table 1). Of most interest are the isotopes ^{57}Co, ^{58}Co, ^{47}Sc, ^{114m}In, ^{186}Re, ^{188}Re, ^{191}Os, ^{192}Os, ^{192}Ir, which have intense γ-lines in the energy range used for medical purposes. A possible use of unenriched targets of natural composition is an additional factor in favor of isotope production by the photonuclear method.
2. The value of specific activity produced in irradiated targets is high enough to consider the photonuclear method of isotope production as an alternative to the cyclotron technique.

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ОЦЕНКА НАРАБОТКИ ИЗОТОПОВ Os, Ir, Sc, In НА ЛИНЕЙНЫХ УСКОРИТЕЛЯХ ЭЛЕКТРОНОВ

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Представлены предварительные экспериментальные результаты по наработке медицинских радионуклидов ^{47}Sc, ^{114}In, ^{192}Ir и ^{191}Os, ^{191m}Os фотоядерным методом. Облучение мишеней проводилось на пучке тормозного излучения ускорителя ЛУ-20 ННЦ ХФТИ при энергии ускоренных электронов 29 МэВ и токе пучка 10 мкА. Необходимые изотопы образуются по следующим каналам ядерных реакций ^{51}V(γ,α)^{47}Sc; ^{48}Ti(γ,p)^{47}Sc; ^{193}Ir(γ,n)^{192}Ir; ^{192}Os(γ,n)^{191}Os,^{191m}Os; ^{115}In(γ,n)^{114}In. Измерены значения выхода (удельной активности) полезного продукта на момент окончания облучения, нормированные на 1 час облучения мишеней при величине среднего тока пучка 1 мкА.

ОЦІНКА НАПРАЦЮВАННЯ ІЗОТОПІВ Os, Ir, Sc, In НА ЛІНІЙНИХ ПРИСКОРЮВАЧАХ ЕЛЕКТРОНІВ

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Надано попередні експериментальні результати по напрацюванню медичних радіонуклідів ^{47}Sc, ^{114}In, ^{192}Ir та ^{191}Os, ^{191m}Os фотоядерним методом. Опромінення мішеней проводилось на пучку гальмівного випромінювання прискорювача ЛП-20 ННЦ ХФТІ при енергії прискорених електронів 29 МеВ та струмі пучка 10 мкА. Необхідні ізотопи утворюються за наступними каналами ядерних реакцій ^{51}V(γ,α)^{47}Sc; ^{48}Ti(γ,p)^{47}Sc; ^{193}Ir(γ,n)^{192}Ir; ^{192}Os(γ,n)^{191}Os,^{191m}Os; ^{115}In(γ,n)^{114}In. Виміряні виходи (питомої активності) корисного продукту на момент закінчення опромінення, що нормовано на 1 годину опромінення мішеней при середньому струмі пучка 1 мкА.