A POSSIBILITY OF PHOTONUCLEAR PRODUCTION OF PLANAR ^{179}Ta SOURCES

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Age-specific reduction of the bone mass (osteoporosis) is one of the most progressing human illness throughout the world. Its diagnostic is based on a measurement of the mineral density of bone mass by radiation absorptiometry technique. In the communication, a possibility to use gamma-sources on the basis of the ^{179}Ta isotope for osteoporosis diagnostics is considered. The isotope can be produced by the ^{181}Ta(γ, 2n)^{179}Ta reaction in a high-energy X-ray radiation field using a target from natural tantalum. Conditions of the ^{179}Ta planar sources production at an electron accelerator were studied. By computer simulation, an optimization of target geometry has been conducted. Yield of target isotope and admixtures have been measured at a bremsstrahlung end-point energy of 40 MeV.

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INTRODUCTION

Osteoporosis is the most widespread metabolic disease of bone system characterised by a loss of its strength in view of decrease of the mineral bone density (MBD). The most known nontraumatic method of the osteoporosis in vivo diagnostics is a measurement of MBD by a technique of radiation absorptiometry. The method is based on a comparison of absorption coefficients of the photons with a specified energy (commonly in the range 30…100 keV) at their transmission through the soft and bone tissues. The method is realised by means of one- or two-photon absorptiometry with the use of gamma sources on the basis of ^{125}J (E_γ =27.5 keV; $T_{1/2}$=60 day) and ^{153}Gd (E_γ ~44 keV and 100 keV; $T_{1/2}$=241 day) isotopes or an X-ray source (see, for example, [1]).

Both isotopes are received by radiochemical extraction from the targets irradiated on a reactor. In case of X-ray radiation, an ultrastable tube with a system of filters forming a spectrum with the two maxima nearly 45 and 80 keV are used [2]. To obtain a 2D-image, the collimated source of γ-radiation and detector are synchronously moved relative to an investigated part of the skeleton situated between them. In view of complexity, such equipment is rather expensive. So it is worthwhile the development of a reactor free technology for production of planar γ-sources with suitable energy of photons and big half-life. On their basis, it is possible designing rather simple systems for osteoporosis diagnostics, e.g., via inspection of peripheral parts of the skeleton. In the work, it is offered to use the ^{179}Ta isotope (Table 1) for production of such sources. It can be generated by the reaction ^{181}Ta(γ, 2n)^{179}Ta having a threshold of 14.2 MeV (Fig. 1).

1. OPTIMIZATION OF SOURCE THICKNESS

Production of γ-sources on the basis of the ^{179}Ta isotope can be realised by irradiation of a tantalum target with the X-ray radiation of an electron accelerator with beam energy E_0 above the reaction threshold. It should be noted that a free range of photons with energy ~20 MeV in tantalum makes ~1 cm [5]. Thus a Ta-target thickness, within which the ^{179}Ta nuclei can be generated, exceeds by two orders of values the free range of the photons emitted by this isotope (see Table 1). It stipulates a necessity of optimisation of the source geometry to provide maximum of the ^{179}Ta activity at minimum of its radiation self-absorption.

Table 1

Ta^{179} radiation spectrum [3]

Line	Photon energy, keV	Free range, mm	Rel. intensity, %
XR l	7.9	0.0036	20.2
XR kα1	54.07	0.1302	21.9
XR kα2	54.61	0.1336	12.6
XR kβ3	62.98	0.1945	2.44
XR kβ1	63.24	0.1966	4.71
XR kβ2	64.94	0.2112	1.61

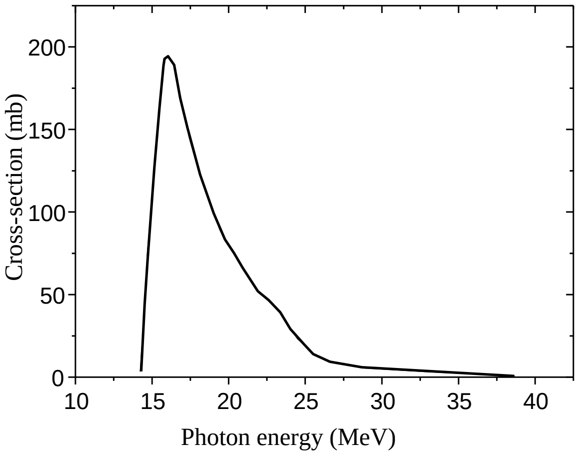

Fig. 1. ^{181}Ta(γ, 2n)^{179}Ta reaction cross-section [4]

An obvious problem solving is the usage a stack of thin foils as a target. In this case, it is possible to receive a set of sources with essentially non-uniform distribution of surface activity corresponding to a profile of the bremsstrahlung photon flux. Other variant, enabling to receive an extended quasi-homogeneous source, is application of a target in the form of a roll with its rotation under activation.

The results of computer simulation of external radiation of thin tantalum plates with evenly distributed ^{179}Ta of identical total activity at different thickness t are shown in Fig. 2.

It is seen that at a thickness $t=1\cdot10^{-6}$ см, the photon self-absorption is practically absent. However, at a given specific activity of ^{179}Ta the intensity of such source will be small. At a thickness $t >1\cdot10^{-2}$ cm, there are only lines with energy ~54 and 64 keV in external radiation, but their intensity considerably decreases in view of self-absorption. Thus one of the features of photonuclear ^{179}Ta technology is ensuring a compromise between the activity of produced source and its area. A key parameter in this choice is the thickness of the produced source t. Namely, at the given volume and general activity of a photonuclear target decreasing t is accompanied by increasing of source area but dropping its activity. Taking into account results of modelling, we have chosen t=0.1 mm.

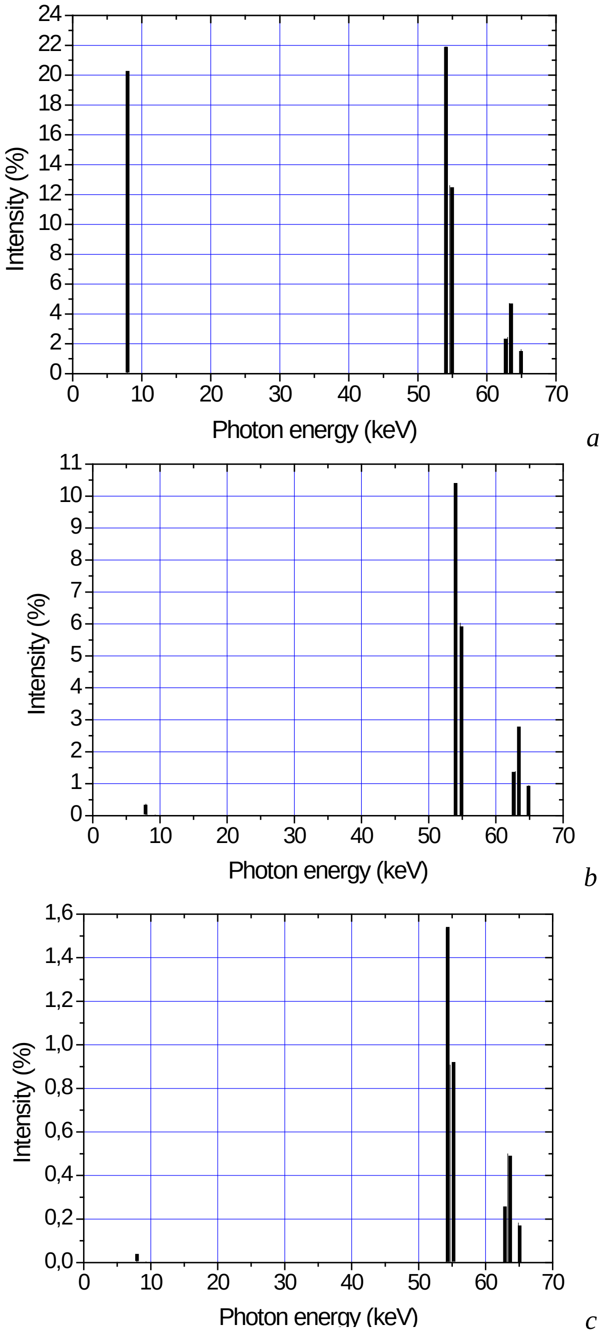

Fig. 2. External radiation of activated Ta plate:
a – t=1·10^{-6} cm; b – t=1·10^{-2} cm; c – t=1·10^{-1} cm

2. OPTIMIZATION OF TARGET GEOMETRY

2.1. It is known that tantalum is widely used as a material for the X-ray converters. Therefore we consider a process of a Ta-target activation by direct acting on it with an electron beam. Thus a considerable part of a beam power is absorbed in the target. So for the ^{179}Ta production at a high-current accelerator the target design should provide its effective cooling, for example, with running water.

Taking into account these considerations, for analysis and optimisation of the conditions of the ^{179}Ta production it is offered a target device which scheme is shown in Fig. 3. It represents a set from n tantalum tubes inserted one into another (n=1, 2…6) – item1. Each tube has a wall thickness of 1 mm. The aperture 2 of internal tube has a diameter of 10 mm. Thus with increasing number n the external diameter of the device will increase proportionally. The central channel of the target as well as the gap 3 of 1 mm thick between the surface of external tube and target casing 4 are filled with cooling water. The casing corresponds a tube from aluminium of 1 mm thick. Such choice of the target geometry allows determine an optimum thickness of the Ta-target by means of a layer-by-layer calculation of the activity and absorbed radiation power.

We consider an electron beam with energy E_0=40 MeV incident on the device surface. The given value of energy seems to be nearly optimal taking into account a yield of the above-threshold X-ray photons as well as a rate of admixture generation. The beam has a diameter of 0.5 cm with uniform distribution of particles within its cross-section. The target is rotated under activation providing in such a way an axially symmetric distribution of the induced ^{179}Ta activity and absorbed radiation power.

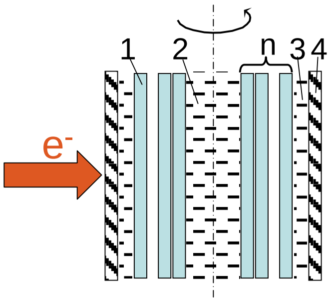

Fig. 3. Diagram of target device (simulation)

2.2. Calculations were carried out by a simulation technique on the basis of a modified PENELOPE-2008 package [6]. The data on the reaction ^{181}Ta(γ, 2n)^{179}Ta cross-section, given in Fig. 1, were used for determining the ^{179}Ta yield. The results of modelling are summarized in Table 2. Their statistical error does not exceed 2 %. The obtained data on the ^{179}Ta yield were reduced to 1 μA of beam current and 1 hour of irradiation run. The data of Table 2 demonstrate that by increasing a thickness of the Ta-target it is possible to increase a total ^{179}Ta yield. However, an average value of linear activity of a received tape-like γ-source thus decreases. An enlargement of its width can be ensured by moving the target under activation along its axis or by application of a scanned electron beam. Last variant seems to be preferable in view of more uniform distribution of a thermal loading on its elements, when the target is activated with a high-power beam.

Table 2

Absorbed radiation power and yield of ^{179}Ta (E_0=40 MeV)

Thickness of Ta-target, mm	1	2	3	4	5	6
Length of ^{179}Ta source (t=0.1 mm), cm	34.5	75.4	122.5	175.8	235.5	301.4
Absorbed radiation power, W/μA:						
Al-casing	0.96	0.84	0.64	0.55	0.52	0.52
water	2.88	3.22	3.13	2.66	2.05	2.05
tantalum	5.52	12.76	18.24	21.63	24.16	26.36
Yield of ^{179}Ta, μCi/μA·hour	0.85	2.7	4.4	6.0	7.3	8.3
Average linear activity of source, nCi/μA·hour·см	24.6	35.8	35.9	34.1	31.0	27.6

3. MEASUREMENT OF ISOTOPE COMPOSITION OF ACTIVATED Ta-TARGET

3.1. For estimating the accuracy of modelling as well as yield of ^{179}Ta and impurities under tantalum activation with the electron beam, an experiment, which scheme is presented in Fig. 4, has been conducted.

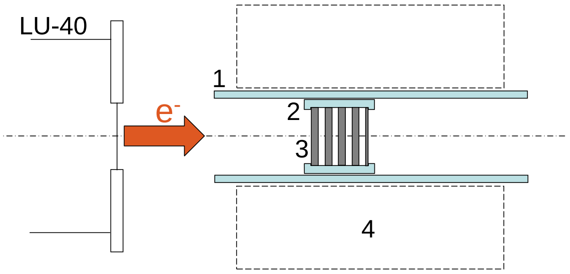

Fig. 4. Scheme of experiment

At the exit of linac LU-40 [7] on the electron beam axis, an aluminium branch pipe 1 of 400 mm length and 54 mm internal diameter was positioned. In the branch pipe centre, a holder 2 was located with a target 3 consisting of five Ta-plates each of 30 mm diameter. The first four plates had a thickness of 1 mm and the fifth of 0.3 mm.

It is known that tantalum, irradiated with electrons, besides X-ray (bremsstrahlung) radiation, generates also a flux of photoneutrons, mainly, due to the ^{181}Ta (γ, n) ^{180m}Ta reaction (see, e.g., [8]). For study of influence of the neutron spectrum on a radionuclide composition of the activated target, in a separate experiment the branch pipe with the target device was positioned in a moderator of neutrons 4 (its detailed description is given in the work [9]).

3.2. In each experiment, the target was irradiated at 40 MeV and 3.85 μA for 2 hours. After cooling during 24 hours for a decay of the short-live isotopes, the thin tantalum plate was directed on a gamma-spectrometry analysis. The measurements were conducted on a station comprising an HPGe-detector (GPD-16195, BSI), an ORTEC 570 amplifier and an ADC-8k-2b analog-to-digital converter with a software An 2.5 (Aspect). The station provides FWHM of 510 eV at 122.1 keV (^{57}Co).

The results of measurements and simulation on the yield of principal radionuclides under tantalum activation with neutron moderator and without it are given in the Table 3.

Table 3

Yield of main isotopes under activation of tantalum with electron beam (E_0=40 MeV)

Isotope	$T_{1/2}$, day	Reaction	Normalized yield, μCi/μA·hour·g		
			Without moderator	With moderator	Simulation
^{179}Ta	665	^{181}Ta(γ, 2n)^{179}Ta	0.091	0.088	0.085
^{182}Ta	114.4	^{181}Ta(n, γ)^{182}Ta	0.004	0.024	-
^{92m}Nb	10.15	^{93}Nb*(γ, n)^{92m}Nb	0.001	0.001	-

* ^{93}Nb is present in natural tantalum as a natural impurity

3.3. As it is seen from the data of the Table 3, the yield of ^{179}Ta does not depend on the neutron spectrum, and the results of modelling and experiment coincide within 7% (that corresponds to an error of the activity measurement). At the same time, the use of neutron moderator is accompanied by the 6 times increase of the ^{182}Ta yield. It is caused by the increase of the ^{181}Ta (n, γ) ^{182}Ta reaction cross-section up to ~20b in the thermal area, as compared with ~100 mb at energy of photoneutrons of~100 keV [10]. In Fig. 5, the spectrum of tantalum activated without moderator, and in Fig. 6 – the low-energy fragments of the spectra for both variants of the target activation are demonstrated.

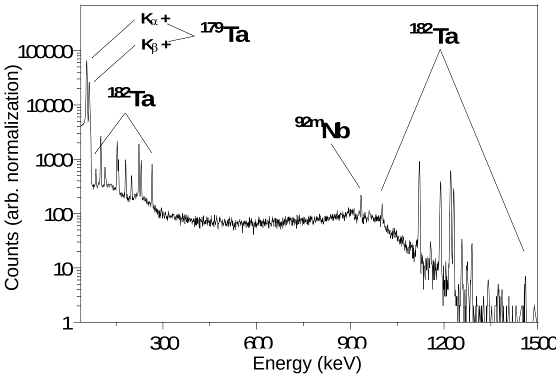

Fig. 5. γ-spectrum of tantalum irradiated without moderator of neutrons

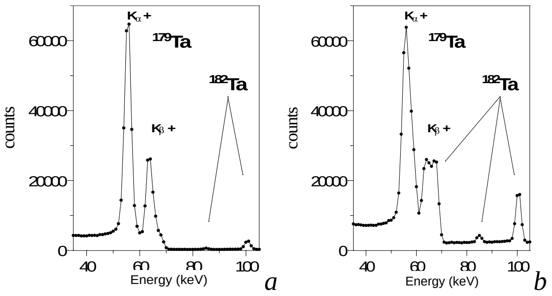

Fig. 6. Spectra of tantalum activated by electron beam (E_0=40 MeV): a – without moderator of neutrons; b – with moderator

CONCLUSIONS

The γ-sources on the basis of ^{179}Ta can be produced at the rather inexpensive and friendly for ecology electron accelerators. In particular, with a beam (40 MeV; 1 mA) it is possible to make for 100 hour run up to 30 planar 10×10 cm sources with activity of ~30 mCi each [11]. An advantage of the offered technology is also application of targets from natural tantalum, which is practically a monoisotope. It delivers from a necessity to use the expensive enriched materials, and also limits a number of channels for impurity generation. Thus the activity of main impurity ^{182}Ta right after EOB does not exceed 5% and decreases further under a service of the γ-source. If it is needed to increase the ^{182}Ta content (e.g., in order to receive a many-photon source), a target activation can be conducted using a moderator of neutrons.

In case of target activation using a high-current beam (>10 A in the bunch), one can expect an increase of the ^{179}Ta and ^{182}Ta yield resulting from excitation of a short-lived isomeric state of ^{181}Ta with energy 6.24 keV having much greater cross-section of reactions [12].

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ВОЗМОЖНОСТЬ ФОТОЯДЕРНОГО ПРОИЗВОДСТВА ПЛАНАРНЫХ ИСТОЧНИКОВ ^{179}Ta

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Возрастное снижение костной массы (остеопороз) является одним из наиболее прогрессирующих видов заболеваний в мире. Его диагностика основана на измерении минеральной плотности костной массы методами лучевой абсорбциометрии. Рассмотрена возможность использования для диагностики остеопороза гамма-источников на основе изотопа ^{179}Ta ($\bar{E}_X$~54 кэВ; $T_{1/2}$=665 дней). Его можно производить в поле высокоэнергетического тормозного излучения по реакции ^{181}Ta(γ, 2n)^{179}Ta в мишени из природного тантала. Исследованы условия получения планарных источников ^{179}Ta на ускорителе электронов. Методом компьютерного моделирования проведена оптимизация геометрии мишенного устройства. Измерены выходы целевого изотопа и примесей при граничной энергии тормозного излучения 40 МэВ.

МОЖЛИВІСТЬ ФОТОЯДЕРНОГО ВИРОБНИЦТВА ПЛАНАРНИХ ДЖЕРЕЛ ^{179}Ta

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Вікове зниження кісткової маси (остеопороз) є одним з найбільш прогресуючих видів захворювань у світі. Його діагностика заснована на вимірюванні мінеральної щільності кісткової маси методами променевої абсорбціометрії. Розглянута можливість використання для діагностики остеопорозу гамма-джерел на основі ізотопу ^{179}Ta (E_X~54 кеВ; $T_{1/2}$=665 днів). Його можна напрацьовувати в полі високоенергетичного гальмівного випромінювання за реакцією ^{181}Ta(γ, 2n)^{179}Ta у мішені з природного танталу. Досліджено умови отримання планарних джерел ^{179}Ta на прискорювачі електронів. Методом комп'ютерного моделювання проведена оптимізація геометрії мішеневого пристрою. Виміряні виходи цільового ізотопу і домішок при граничній енергії гальмівного випромінювання 40 МеВ.