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PRODUCING TWO-PHOTON PLANAR SOURCES AT AN ELECTRON ACCELERATOR

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Abstract

Gamma-sources with two-energy spectrum are used in industrial and medical diagnostics for quantitative introscopy (absorptiometry). Commonly, such sources are obtained by a reactor technology (^{153}Gd) or using an ultrastable X-ray tube with properly shaped spectrum of radiation. We suggested utilize the ^{179}Ta isotope (E_x~55 keV, $\tau_{1/2}$=665 days) in combination with ^{57}Co (E_γ=122 keV, $\tau_{1/2}$=273 days). A soft technology for producing the planar sealed ^{179}Ta/^{57}Co sources at an electron accelerator by X-ray irradiation of a target from natural tantalum and nickel was developed. The isotope yield and absorbed power of radiation in the target device vs electron beam energy were calculated using a modified transport code PENELOPE-2008. The results of the experiment conducted to determine the yields of the target isotopes and by-products are in good agreement with the simulation data.

INTRODUCTION

A multiphoton absorptiometry technique is widely used in medicine, industry, inspection checkup, etc. (see, e.g., [1,2]). So in medicine, the γ-sources on basis of the ^{125}J (E_γ= 27.5 keV, $\tau_{1/2}$=60 days) and ^{153}Gd (E_γ= 44 keV and 100 keV, $\tau_{1/2}$=241 days) isotopes are applied for diagnostics of osteoporosis (the most widespread age-related illness of the bone system). Both the isotopes are produced by radiochemical separation from the targets irradiated on a reactor [3]. A period of the target exposure makes from 300 hours (^{125}J) to 2 months (^{153}Gd).

Last two decades, a method of dual absorptiometry using the X-ray tubes with a specially shaped two-component spectrum (the DEXA technique) is actively used also [4]. To obtain a 2D-image, a source of radiation and a detector are synchronously moved relative to an object situated between them. In view of sophistication, such equipment is rather expensive.

In the communication, a soft method for manufacturing the planar one- and two-photon sources on basis of the ^{179}Ta (E_X~55 keV, $\tau_{1/2}$=665 days) and ^{57}Co (E_γ~ 122 keV, $\tau_{1/2}$=271 days) isotopes with the use of an inexpensive electron accelerator is offered.

BASIC REACTIONS

^{179}Ta is produced by the reaction ^{181}Ta(γ,2n)^{179}Ta. It can be realised in a target from natural tantalum (the ^{181}Ta abundance is 99.99 %) exposed to X-ray with energy of photons above the threshold of the reaction (14.2 MeV - see Fig. 1).

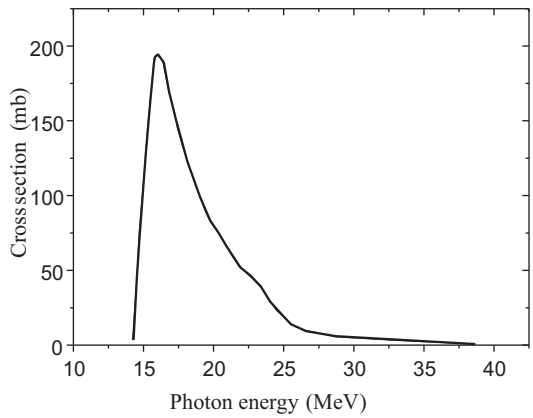

Figure 1: Cross section of the ^{181}Ta(γ,2n)^{179}Ta reaction [5].

^{57}Co can be manufactured on ^{58}Ni in a target from natural nickel (the ^{58}Ni abundance is 68.27 %) simultaneously via two channels (see Fig.2)

^{58}Ni(γ,p)^{57}Co,

$^{58}\mathrm{Ni}(\gamma,\mathrm{n})^{57}\mathrm{Ni} \xrightarrow[\tau_{1/2}=35.6h]{\beta^+} {}^{57}\mathrm{Co}$.

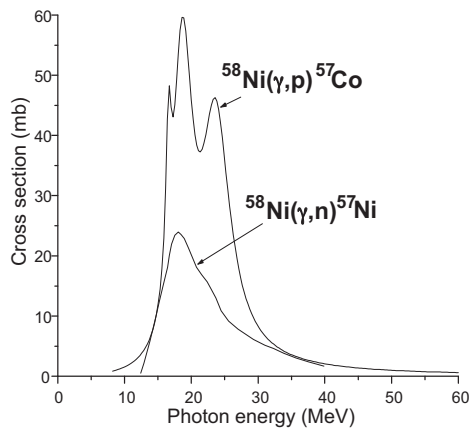

Figure 2: Cross sections of the ^{57}Co production [5].

For photonuclear production of isotopes, an electron beam should be preliminary transformed into a flux of the X-ray (bremsstrahlung) photons. This process can be materialized both in a special intermediate converting target and in an isotope target directly. By the end of the exposure period *t*, its activity $A(t)$ subject to the decay of the new nuclei during irradiation can be presented in the form

$$A(t) = \lambda y \frac{I_0}{e} \cdot t \cdot D(\lambda t), \quad (1)$$

where y is the yield of the new nuclei reduced to one electron of the primary beam, λ is the decay constant, $D(\lambda t)$ is the factor of the target deactivation, I_0 is the

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average beam current,

$$D(\lambda t) = \frac{1-\exp(-\lambda t)}{\lambda t}. \quad (2)$$

In case of a channel with the formation of an intermediate nucleus (^{57}Ni), its contribution $A'(t)$ to the activity of the target isotope can be determined from the expression

$$A'(t) = \lambda y' \frac{I_0}{e} t \frac{\lambda'}{\lambda' - \lambda}\left[D(\lambda t) - D(\lambda' t)\right], \quad (3)$$

where y' is the normalized yield of the intermediary, λ' is its decay constant.

It follows from the formulas (1) - (3), that at a period of the nickel activation t>>35.6 h, the contribution of the ^{58}Ni (γ,n) ^{57}Ni→^{57}Co channel in the total yield of ^{57}Co amounts up to 24 %.

SIMULATION AND BENCHMARKING

The photonuclear yield of the target isotopes and principal impurities, and also the absorbed radiation power in the elements of a target device depending on electron energy were determined by a simulation technique on basis of a modified transport code PENELOPE-2008 [6, 7]. For a check of accuracy of the simulation, an activation of two stacked foils from tantalum and nickel (each of 0.1 mm thick) by X-ray radiation with end-point energy of 40 MeV during 2 hours has been conducted. The major activity of tantalum after irradiation is caused by ^{180}Ta ($\tau_{1/2}$=8.15 h), which is produced in the reaction ^{181}Ta (γ,n) ^{180}Ta and decays quickly (see Table 1).

Table 1: Isotope Yields in the Experimental Target After EOB (kBq/μA·h)

Isotope	^{179}Ta	^{180}Ta	^{57}Co	^{57}Ni
Simul.	1.11	$6.06\cdot10^3$	1.92	154
Exper.	1.08	$6.16\cdot10^3$	2.16	126

In Figs. 3 and 4, the spectra of the activated foils after their cooling are shown.

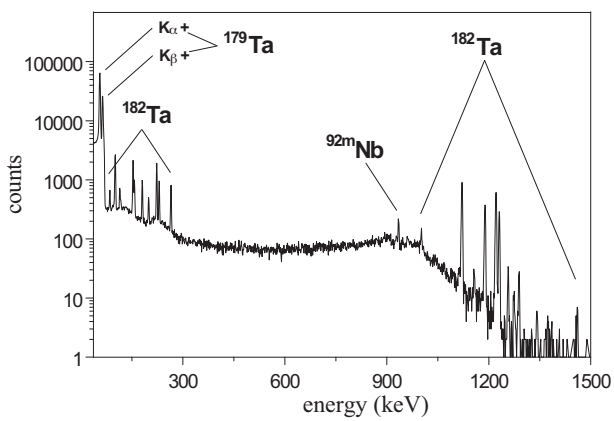

Figure 3: γ-spectrum of activated Ta (33 days after EOB).

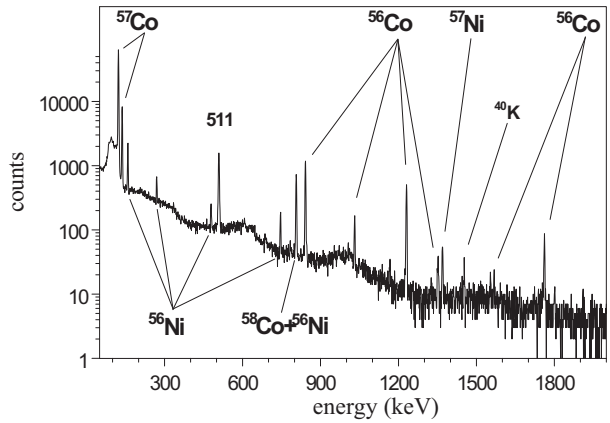

Figure 4: γ-spectrum of activated Ni (17 days after EOB).

Figure 5 demonstrates a low-energy part of the spectrum of a γ-source received by stacking the both foils. It is seen, that the two bands close to 55 and 122 keV dominate.

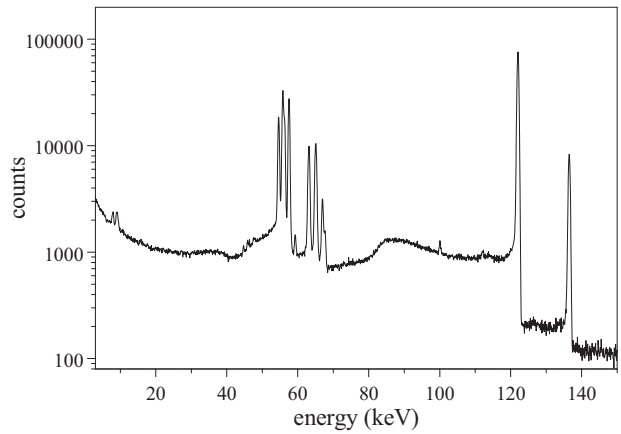

Figure 5: Low-energy part of the spectrum of the combined ^{179}Ta/^{57}Co source.

OPTIMIZATION OF PRODUCTION TARGET

In the spectrum of the X-ray radiation of ^{179}Ta, the lines 7.9 keV (20.2 %), 54.07 keV (21.9 %) and 54.61 keV (12.6 %) determine the major intensity [8]. For the two last, the free range of the photons in tantalum is ~0.1 mm. On the other hand, the range of the bremsstrahlung photons with energy exceeding the reaction threshold makes ~1 cm. Thus the ^{179}Ta nuclei can be effectively generated within a target thickness that is by two orders of value higher than the characteristic thickness of a layer of the self-absorption of photons which this isotope irradiates. Therefore, an obvious option of the structure of a production target is a stack of thin foils. Other variant enabling to receive an extended quasi-homogeneous γ –source, is a structure of a target in the form of a roll with its rotation under activation with an electron beam [9].

The calculations conducted have shown that it is a possibility to increase the total ^{179}Ta yield by increasing the thickness of a wall of the roll. However, an average value of the linear activity of a tape-like γ-source received

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in such a way will decrease. So the linear activity reaches its maximum at a thickness of the wall of 2÷3 mm [10]. Considering also the self-absorption of photons, a thickness of the tape of 0.1 mm is close to the optimum value. In this case, the line with energy 7.9 keV is practically absorbed.

In Fig. 6, the variant of a target device for co-production of the ^{179}Ta and ^{57}Co sources is given. It consists of a casing 1 with the enclosed isotope target 2 as a two-layer cylinder by an external diameter of 2.35 cm and a central passage 3 for cooling water of 0.98 cm in diameter. The roll of the tantalum tape forms the external layer of the target. In this region, both a conversion of the electron beam into bremsstralung and the ^{179}Ta manufacturing take place. An inner layer of the target of 1.80 cm in diameter is formed with a nickel tape of 0.1 mm thick, in which ^{57}Co is produced. The casing from aluminium has an entrance window 4 (Ti, 50 μm) for electron beam passage. Between the target and the casing, there is a 1 mm gap for cooling water. For uniform distribution of the generated activity and absorbed radiation power, the electron beam is scanned along the axis of the target with its simultaneous rotation.

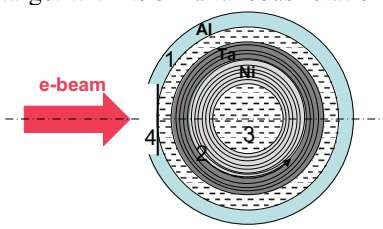

Figure 6: Schematics of the target device for producing the ^{179}Ta/^{57}Co planar sources.

The simulation results on the absorbed radiation power and isotope yields vs electron energy in the offered target device are shown in the Tables 2, 3.

Table 2: Absorbed Power in the Target Device (W/μ A)

Element	Electron energy, MeV			
	30	40	50	60
Water	0.45	0.78	1.01	1.17
Ta	17.61	20.96	22.20	24.78
Ni	8.97	11.96	15.20	17.70

Table 3: Isotope Yields in the Production Target (MBq/μA·h)

Reaction	Electron energy, MeV			
	30	40	50	60
^{181}Ta(γ,2n)^{179}Ta	0.10	0.15	0.18	0.21
^{58}Ni(γ,p)^{57}Co	0.19	0.33	0.44	0.52
^{58}Ni(γ,n)^{57}Ni	15.13	26.66	35.40	42.02
^{181}Ta(γ,n)^{180}Ta	791.8	1048.5	1257.2	1439.1

The developed target device and its activation regime provide the manufacturing of the tape-like ^{179}Ta and ^{57}Co sources of identical length (180 cm) at a maximum yield of the target isotopes and minimum self-absorption of their radiation.

CONCLUSIONS

The offered rector-free technique enables producing the sealed planar γ-sources of any-size for one- and two-photon absorptiometry without the procedures of wet radiochemistry. On basis of such sources and planar detectors of radiation, it is possible to design the simple systems for diagnostics of osteoporosis, rheumatoid, and also devices for two-photon peripheral quantitative computer tomography (pQCT).

In Table 4, the data on the efficiency of various methods of the isotope manufacturing for absorptiometry are summarized. It is seen that from viewpoint of productivity, the photonuclear technology is competitive also. For instance, in such a way it is possible to produce simultaneously up to 18 the ^{179}Ta planar sources with activity ~1 GBq and the same quantity of the ^{57}Co sources with activity ~2.2 GBq measuring 10x10 cm each at an electron accelerator with the routine parameters (40 MeV; 250 μA) during a 500 h run. The yield of the long-lived impurities at EOB in tantalum does not exceed of 5 %, and in nickel of 16 % from the activity of the target isotopes.

Table 4: Capacity of the Isotope Production Techniques (100h run)

Isotope	Installation	Parameters	Yield, GBq
^{125}J	Reactor	$5\cdot10^{13}$n/cm^{2}s	14
^{153}Gd	Reactor	$6\cdot10^{13}$n/cm^{2}s	0.13
^{179}Ta	Electron Linac	40MeV; 250μA	3.7
^{57}Co			8.2

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