PRODUCTION OF MEDICAL ISOTOPES AT ELECTRON ACCELERATORS

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A brief summary of the production medical isotopes by powerful linac electron accelerator is presented.
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The majority of medical isotopes are produced on high-power reactors and cyclotrons. The problems of a radiation waste and negative public opinion resulted in decrease of reactor quantity in the world [1,2]. Despite of wide opportunities of reactors and cyclotrons the deficit of some isotopes is observed. For example it is ^{89}Sr, ^{188}Re, ^{103}Pd. The isotopes, which were applied earlier, are extensively used again. The radiobioconjugates are investigated for injection of isotopes in cancer cells [3].

This paper is purposed to the medical isotope production with the use of bremsstrahlung, photoneutrons at a high-power electron accelerator of NSC KIPT. The radiochemical or physical separation isotopes are used if it is necessary. In the last few years at R&D "Accelerator" the activity on upgrading the linear electron accelerator [4] is conducted. Now the accelerator operates at the energy 25-27 MeV and current up to 1 mA. These parameters of the accelerator have been used to estimate the yield of isotopes considered below.

For the last two years the technology of the ^{99m}Tc isotope most widespread in the medical practice was developed [5]. The accelerator is capable to produce up to 4 Ci of a parent ^{99}Mo isotope in one day. For production of this isotope the nuclear reactions [6,7] can be used:

^{100}Mo(γ, n) ^{99}Mo ($T_{1/2}$ = 66.02 hrs),

^{98}Mo(n,γ) ^{99}Mo ($T_{1/2}$ = 66.02 hrs).

The distinctive feature of such a method is the use of molybdenum with natural isotope composition (the abundance of ^{100}Mo is 9.63 %, ^{98}Mo - 24.13 %) and two channels of production ^{99}Mo. To use this isotope the technology of electrolytic deposition of ^{99m}Tc on a carbon substrate with subsequent dissolving ^{99m}Tc to technetium acid solution was developed. Now the works on development of a new technology of ^{99m}Tc mass production and distribution of this isotope for the use in medical establishments of the East region of Ukraine are conducted.

Taking into account the world tendencies, the physical principles of producing radioisotopes are developed. ^{43}K ($T_{1/2}$ = 22.3 hrs) being used in cardiology can be effectively generated at the linac. The most intensive gamma radiation ^{43}K has the energy 372 keV. One can use the reaction [8]:

^{44}Ca(γ,p)^{43}K (Q = –12.3 MeV).

The reaction cross section on the gamma radiation withE= 20 MeV practically is compared with the (γ,n) - reaction. It allows one even for abundance of the ^{44}Ca 2.08 % isotope to produce in one day about 10 GBk of this isotope and to realise diagnostics of cardiac diseases for 100 patients. As compared with ^{201}Tl ($T_{1/2}$ = 73.1 hrs) this isotope has radiation loading on the patient organism approximately three times smaller [9]. The reaction ^{42}Ca(n,p)^{42}K ($T_{1/2}$ =12.5 hrs) has a cross section on nuclear fission neutrons equal to 2.6 mb and its contribution to the activity of kalium will be insignificant [10].

Production of isotope for cardiology and positron emission tomography (PET) simultaneously is possible with the use of nuclear reactions:

^{84}Sr(γ,2n) ^{82}Sr, (Q = –20.76 MeV).

^{82}Sr has the half-life period of 25.0 day's [11] and is decaying to ^{82}Sr, which has the half-life period of 1.25 minutes. The basic characteristic of this generator is the small radiation loading on the patient. The abundance of ^{82}Sr isotope is only 0.54 % therefore the expected yield of ^{82}Sr on strontium of a natural isotope composition will be 0.1 GBk per day. But even this will allow fulfill up to 1000 analyses. Therefore there is cost effectiveness of ^{82}Sr production. It also can be used in cardiac therapy. The nuclear reaction depressing the quality of this generator is:

^{84}Sr(γ,n) ^{83}Sr, ($T_{1/2}$ = 32.4 hrs).

^{83}Sr decays to ^{83}Rb ($T_{1/2}$ = 86,2 day). Therefore after the complete decay of ^{83}Sr (about 6 days) from the irradiated target ^{83}Rb will be released and further the generator will be ready to use ^{82}Rb.

Significantly best production conditions are realized by manufacturing the generator of ^{68}Ga. For this purpose the following nuclear reaction can be used:

^{70}Ge(γ,2n)^{68}Ge, ($T_{1/2}$ = 287 days, Q = –20 MeV)

→ ^{68}Ga, ($T_{1/2}$ = 68 min.)

The abundance of ^{70}Ge is 20.5 %; therefore the yield of ^{68}Ge isotope is about 0.3 GBk per day [11]. ^{68}Ga has a low value of half-life period therefore the activity obtained for one day will allow fulfilling up to 4000 analyses and its cost effectiveness is high. ^{68}Ga can be used for diagnostics of malignant tissues that allows one to maintain a high frequency of its application.

A promising generator ^{42}K can be obtained by nuclear reactions:

$^{46}Ca(\gamma,\alpha)^{42}Ar$, ($T_{1/2}$ = 32.9 years, Q = −11.1 MeV)
→ ^{42}K ($T_{1/2}$ = 12.36 hrs).

The abundance of ^{46}Ca is only 0.004 % and, consequently, the production of a natural isotope composition on calcium is meaningless. The use of enriched ^{46}Ca isotope allows producing with a rather high efficiency, i.e. 6 MBk of ^{42}Ar per day.

The production of ^{111}Sn can be realized by nuclear reactions:

$^{112}Sn(\gamma,n)^{111}Sn$ ($+^{111m}Sn$), ($T_{1/2}$ = 35.3 min (7,7 min)
Q = −10.8 MeV)→ ^{111}In ($T_{1/2}$ = 2.8 days).

Simultaneously on tin of a natural isotope composition the generator ^{113}In is implemented by nuclear reactions:

$^{114}Sn(\gamma,n)^{113}Sn$, ($T_{1/2}$= 115,2 days) Q= −10,3 MeV)
→ ^{113m}In ($T_{1/2}$ = 99,4 min).

The abundance of ^{112}Sn, ^{114}Sn is 0.95, 0.65 %, respectively, and productivity on tin of a natural isotope composition will be 15 GBk for ^{111}In and 0.3 GBk for parent isotope ^{113m}Sn per day.

Production of ^{45}Ca (pure emitter of β-particles) for treatment of bones cancer is possible with the use of nuclear reactions [11]:

$^{45}Sc(n,p)^{45}Ca$, ($T_{1/2}$ = 163.8 days, Q = +0.53 MeV).

It is well known that the linac can be a neutron source [13-15]. The neutron intensity for the energy 30 MeV is approximately 10^{12} per kW of the electron beam power. In our case it is possible to achieve the activity of ^{45}Ca 0.3 GBk per day. It is enough for treatment of 10 patients, and the cost of one dose is 3-5 times less than for treatment by ^{89}Sr drugs. Note, that at the accelerator one can produce also ^{89}Sr using the nuclear reactions [11] :

$^{89}Y(n,p)^{89}Sr$, ($T_{1/2}$ = 50.5 days, Q = −0.72 MeV),
$^{92}Zr(n,\alpha)^{89}Sr$, ($T_{1/2}$ = 50.5 days, Q = +3.39 MeV),

but, in this case, the cost of manufacturing the activity unity will be approximately 10 times more, than for ^{45}Ca (the abundance of ^{89}Y and ^{92}Zr is 100 and 17.11 %, respectively).

In this sense the production of the ^{87m}Sr generator for diagnostics of cancer deserves attention. There one can use the nuclear reactions [11]:

$^{89}Y(\gamma,2n)^{87}Y$, ($T_{1/2}$ = 80.3 hrs, Q = −20.8 MeV)
→ ^{87m}Sr ($T_{1/2}$ = 2.8 hrs).

The estimation of ^{87}Y yield for 30 MeV electrons makes 30 GBk per day. It enables significant reducing the cost price of the analysis for diagnostics of bones cancer, a well as the radiation loading onto the patient in comparison with the use of ^{85}Sr hundreds times as large.

At the linac the production of $^{123,125}I$ is possible by the reactions:

$^{126}Xe(\gamma,n)^{125}Xe$, ($T_{1/2}$ = 17 hrs, Q = −10.12 MeV)
→ ^{125}I ($T_{1/2}$ = 59.9 days)
$^{124}Xe(\gamma,n)^{123}Xe$, ($T_{1/2}$ = 2,08 hrs, Q = −10.2 MeV)
→ ^{123}I ($T_{1/2}$ = 13.3 hrs).

The abundance of ^{124}Xe, ^{126}Xe isotopes is 0.096 and 0.09 %, respectively. The estimation of ^{123}I, ^{125}I productivity gives 0.1 and 12 GBk per day, respectively. But ^{123}I has considerably best parameters for diagnostics of the thyroid gland (reducing the radiation loading, best conditions for radiation detecting). The ^{125}I has a wide application for scientific (for example, for studying the activity of Auger electrons on the cancer cell) and radioimmune examinations. Therefore, their production in Ukraine shows an impressive promise.

The great opportunities of the linac can be also implemented by manufacturing isotopes for brachytherapy. In this case the samples with a high specific activity are necessary. The original methods of making γ-radiation of high intensity in small volumes, developed at R&D "Accelerator", allow to gain ^{103}Pd, ^{181}W with 1.5 mCi specific activity for samples of 6 mg in weight. For this purpose the following nuclear reactions [11] can be used:

$^{104}Pd(\gamma,n)^{103}Pd$, ($T_{1/2}$ = 16.9 days, Q = −10.0 MeV)
$^{182}W(\gamma,n)^{181}W$, ($T_{1/2}$ = 121.2 days, Q = −8.1 MeV).

The abundance of ^{104}Pd, ^{182}W is 11.4 % and 26,3 %, respectively. ^{103}Pd is promising for brachytherapy of prostate cancer, and ^{181}W for brachytherapy of a wide application (radiation source, small-sized devices for determination of element composition in geology, agriculture, engineering on the base of CdTe(Zn) crystals*)*. For this purpose ^{180m}Ta is suitable produced by the reaction:

$^{181}Ta(\gamma,n)^{180m}Ta$, ($T_{1/2}$ = 8,1 hrs, Q = −8.5 MeV).

The abundance of ^{181}Ta is 99,99%.

For brachytherapy one can use also ^{91m}Nb produced by the nuclear reaction:

$^{92}Mo(\gamma,n)^{91}Mo$, ($T_{1/2}$ = 15.5 min, Q = −12.7 MeV)
→ ^{91m}Nb, ($T_{1/2}$ = 62 days).

The basic radiation loading of ^{91m}Nb is performed at the expense X-rays and Auger electrons (radiation level for 1204.5 and 104 MeV is 3 and 0.5 %, respectively). ^{91m}Nb also can be used for treatment of lymph tumour [16]. The expected productivity of ^{91m}Nb on molybdenum of a natural isotope composition will make 0.7 GBk per day.

The methods of concentrating the gamma radiation allow to producing model isotope sources for calibration of gamma chambers and defectoscopy of $^{57,58}Co$ with a cost effectiveness at a level of foreign firms. For this one can use nuclear reactions:

$^{58}Ni(\gamma,n)^{57}Ni$, ($T_{1/2}$ = 36.8 days, Q = −12.2 MeV)
→ ^{57}Co ($T_{1/2}$ = 290.7 days).
$^{59}Co(\gamma,n)^{58}Co$, ($T_{1/2}$= 70.78 days, Q=−10.5 MeV).

^{58}Co is used for studying the lifetime of positrons in condensed medium also. This method is effectively applied to the study of radiation defects in materials of nuclear power engineering. ^{58}Co for medicine application can be produced by the nuclear reactions:

$^{58}Ni(n,p)^{58}Co$, ($T_{1/2}$= 70.78 days, Q=+0.39 MeV).

The abundance of ^{58}Ni is 67.8 % and the expected yield of ^{58}Co will make 2.4 GBk per day (cross-section for 6 MeV neutrons is 650 mb). Moreover, on the γ-radiation beam the production of ^{57}Co and on the photoneutron beam the production of ^{58}Co will be realized simultaneously.

Promising is the production of the ^{188}W generator at the linac. For this purpose the following nuclear reactions can be used:

$^{192}Os(\gamma,\alpha)^{188}W$, ($T_{1/2}$ = 69.4 days, Q=+0.36 MeV)
→ ^{188}Re, ($T_{1/2}$ = 16.98 hrs).

The abundance of ^{192}Os is 41%. The activity, which is achieved in this case, will be 50 MBk per day. It allows conducting diagnostics for ~200 patients and the cost price of one analysis is little higher than that in the case of other isotopes. But potentialities of this isotope for diagnostics are much wider, than traditional.

The production of ^{186}Re isotope merits attention too. For this one can use the reaction:

^{187}Re(γ,n)^{186}Re, ($T_{1/2}$ = 90.6 hrs, Q=–7.37 MeV).

It is possible to produce up to 3200 GBk ^{186}Re per day. But its use for diagnostics or treatment is limited by risk of accumulating its activity with taking into account the inactive isotope (activity of 1 mg rhenium of a natural isotope composition is 150 GBk of ^{186}Re). ^{186}Re can be used for treatment (β-particle with a maximal energy of 1.07 MeV) as well as for diagnostics. The inappreciable activity of ^{184}Re also will be present, but without β-activity, that is important for the use of ^{186}Re for treatment. Production of isotopes of rhenium does not pollute environment as against use ^{99m}Tc (^{99}Tc ($T_{1/2}$ = 2.13.10^5 years) [17,18].

The production of ^{186}Re is possible by reaction

^{187}Os(γ,p)^{186}Re, ($T_{1/2}$= 90,6 hrs, Q =–6,587 MeV)

also. The Ukrainian molybdenum ore contain of trace element Re which decay on ^{187}Os. Therefore the production molybdenum is accompanied by extraction of ^{187}Os. The cross section is nearly 1 mb. Therefore per day it is possible to produce 2 GBk ^{186}Re.

The production of isotopes at the linac can compete also in the traditional field of use of reactors and cyclotrons. For example, the production of ^{32}P with the use of the nuclear reaction:

^{32}S(n,p)^{32}P, ($T_{1/2}$ = 14.36 days, Q = +0.96 MeV)

allows producing about 12 GBk of ^{32}P per day. Simultaneously on sulphur of natural isotope composition the nuclear reactions:

^{34}S(γ,p)^{33}P, ($T_{1/2}$ = 25.34 days, Q=–10.88 MeV),

^{33}S(γ,p)^{32}P, ($T_{1/2}$ = 14.36 days, Q=–9.57 MeV)

will be realized but with significantly lower yield, than in (n,p) - reaction. The abundance of sulphur isotopes is 95, 0,75, 4,2 % for ^{32}S, ^{33}S, ^{34}S, respectively.

Also by means of the (n,p)–reaction ^{64}Cu can be produced for using in the positron emission tomography:

^{64}Zn(n,p)^{64}Cu, ($T_{1/2}$ = 12,7 years, Q = +0,21 MeV).

The abundance of ^{64}Zn is 48,6 % and the expected productivity of ^{64}Cu will make 70 GBk per day (cross section for neutrons of nuclear fission is 30 mb).

Production of isotopes ^{11}C, ^{13}N, ^{15}O, ^{18}F for the positron emission tomography is possible at high-power electron accelerator also. In our opinion attention should be given to the nuclear reactions [11,15]:

^{20}Ne(γ,np)^{18}F, ($T_{1/2}$ = 109.8 min, Q= –23.27 MeV),

^{20}Ne(γ,2n)^{18}Ne, ($T_{1/2}$ = 1,6 s , Q = –28.5 MeV)

→ ^{18}F ($T_{1/2}$ = 109.8 min).

The estimation of the ^{18}F yield for 30 MeV gives 10 GBk per hour that allows to conducting diagnostics on ten positron-emission tomographs simultaneously.

Parameters of isotopes produced at electron linear accelerator.

N	Isotope	$T_{1/2}$	Energy, keV (intensity, %)		Possible use
			β-particle	γ-radiation	
1	^{18}F	109.8 min	649(97)	511(193)	PET
2	^{32}P	14.3 days	1709(100)		Osteotherapy
3	^{33}P	25 days	248(100)		Osteotherapy
4	^{42}K	12.4 hrs	3520(82)	1524,7(18)	Myocardial therapy
5	^{43}K	22.6 hrs	830(83)	372/ 617(90/72)	Myocardial therapy
6	^{45}Ca	164 days	257(100)		Bone-pain therapy
7	^{57}Co	267 days		122(85)	Calibration γ-chamber
8	^{58}Co	70.8 days	474(15)	811/ 511(81/30)	Defectoscopy
9	^{58m}Co	9.15 hrs	Auger electron		Radiobioconjugate
10	^{64}Cu	12.7 hrs	573(38)	511(37)	PET
11	^{68}Ga	68 min	1940(96)	511(178)	PET
12	^{73}As	80.3 days	Auger electron		Radiobioconjugate
13	^{82}Rb	1.25 min	3500(100)	511(189)	Myocardial therapy
14	^{87m}Sr	2.8 hrs		388(84)	Osteotherapy, diagnostics
15	^{89}Sr	50.5 days	1463(100)		Bone-pain therapy
16		62 days		KX17(46); 1204,5(3)	Radiobioconjugate
17		6.02 hrs		140,5(89,6)	Universal
18	^{103m}Rh	56.1 min	Auger electron		Radiobioconjugate
19	^{103}Pd	16.9 days		KX20,5(77)	Brachytherapy
20	^{111}In	2.8 days		171(91)/245(94)	Universal
21	^{113m}In	99.4 min		392(64)	Universal
22	^{119}Sb	38 hrs	Auger electron		Radiobioconjugate
23	^{123}I	13.3 hrs		159(83)	Radiobioconjugate
24	^{125}I	59.9 days		KX28(139)	Radioimmunotherapy
25	^{180m}Ta	8.1 hrs		KX57(73)	Brachytherapy
26	^{181}W	121 days		KX59(65)	Brachytherapy
27	^{186}Re	90.6 hrs	1080(92)	137(9,2)	Osteotherapy, universal
28	^{188}Re	16.9 hrs	2135(78)	155(15)	Osteotherapy, universal
29	^{195m}Pt	4.02 days	Auger electron	99(11)	Radiobioconjugate

In particular, it is necessary to note the possibility of isotope production for intranuclear irradiation of cancer cells with Auger electrons: ^{58m}Co, ^{73}As, ^{103m}Rh, ^{119}Sb, ^{195m}Pt. It is well known that efficiency of Auger electron action in the nucleus of a cell is hundreds times higher than that for irradiation with electrons or gamma quanta of a high energy. To use these isotopes the carriers are developed. The carriers will allow transporting isotopes in the nucleus of a cell [3]. The high yield of ^{58m}Co (5,6 GBk per hour) is achieved by the nuclear reactions:

^{58}Ni(n,p)^{58m}Co, ($T_{1/2}$ = 9.15 hrs, Q=+0.39 MeV).

The considerable yield of isotopes is achieved by means of the following nuclear reactions:

^{120}Te(γ,n)^{119}Te, ($T_{1/2}$ = 4.7 days, Q= −10.29 MeV)
→ ^{119}Sb ($T_{1/2}$ = 38.1 hrs);
^{104}Pd(γ,n)^{103}Pd, ($T_{1/2}$ = 16.9 days, Q= −10.0 MeV)
→ ^{103m}Rh ($T_{1/2}$ = 56.1 min);
^{74}Se(γ,n)^{73}Se, ($T_{1/2}$ = 7.15 hrs, Q= −12.08 MeV)
→ ^{73}As ($T_{1/2}$ = 80.3 days).

Production of ^{73}As is very important for treatment of metastases in bones. Bone-pain palliation therapy may be indicated in about 50000 cancer patients in Ukraine alone. Unlike other isotopes, which can be used for this purpose, ^{73}As does not damage the marrow. ^{73}As can be used also for brachytherapy. Its properties in particular are exhibited for treatment of tumours of a small size. The layer of half weakening of radiation for ^{73}As is 1,3 mm, that allows to use it for brachytherapy of tumours by the size down to 3-5 mm.

Last years the platinum complex compound attracted increased attention of oncologists [19]. The classical representative of this group (cisplatin) has widely come into the practice of malignant neoformation treatment. It is known that cisplatin and the similar preparations are being incorporated into a nucleus of the cancerous cell during chemotherapy, inhibit the embedding of the predecessors into macromolecule DNA and RNA. It is proposed for cancerous cell destruction to use the high linear energy transfer (LET) effect of electrons that appeared decays of isotopes. The radioactive isotope ^{195m}Pt produced by using bremsstrahlung:

^{195}Pt(γ,γ′)^{195m}Pt, ($T_{1/2}$ = 4 days, Q = −0.259 MeV);
^{196}Pt(γ,n)^{195m}Pt, ($T_{1/2}$ = 4 days, Q = −8.18 MeV);
^{199}Hg(γ,α)^{195m}Pt, ($T_{1/2}$ = 4 days, Q = 0.561 MeV);
^{196}Pt(γ,p)^{195m}Ir→^{195m}Pt, ($T_{1/2}$=4 days, Q=−8.37 MeV);
^{197}Au(γ,np)^{195m}Pt, ($T_{1/2}$ = 4 days, Q = −13.977 MeV).

The yield of ^{195m}Pt is low but advantage is high. The abundance ratio of isotopes ^{195,196}Pt, ^{199}Hg, ^{197}Au are 33.8, 25.2, 16.8, 100%, respectively. The cross section is smaller 0.1 mb for these nuclear reactions. Therefore per day it is possible to produce 0.5 GBk of ^{195m}Pt.

So, the high-power electron accelerator of NSC KIPT is capable to produce practically all of isotopes for nuclear medicine without environmental pollution and with high cost efectiveness. In particular the advantage can be realized for complex production of many isotopes.

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REFERENCES

1. N.V Kurenkov, Yu.N. Shubin. Radionuclides in nuclear medicine // *Radiology and radiation safety*. 1996, No 5, p.54-63 (in Russian).

2. *Nuclear Research Reactors in the World.* December 1997, 120 p., ISBN 92-0-100298-X.

3. S.C. Srivastava. Is Life after Technetium: What is the Potential for Developing New Broad-Based Radionuclides?//*Sem. in N. Med.* 1996, v. 26, No 2, p. 119.

4. A.N. Dovbnya, A.M. Aizatsky, Yu.D. Tur. et al. Modern state and perspective of development linac for fundamental research in Ukraine // *Ukraine Jour. Phys*. 1995, v. 40, No 9, p. 909-912 (in Russian).

5. R.G. Bennett et al. A system of ^{99m}Tc production based on distributed electron accelerators and thermal separation//*Nucl. Techn.* 1999, v. 126, p. 102-121.

6. A.N. Dovbnya, N.P. Dikiy, N.I. Pilipenko et al. The new technology of obtaining ^{99m}Tc // *Ukraine Jour. Radiology.* 1999, v. 7, N1, p.23-24, (in Rus.).

7. V.L. Uvarov, N.P. Dikiy, A.N. Dovbnya et al. Bull. Accelerator`s Prod of Technetium-99m for nuclear medicine // *Of APS.* 1997, v.42, No.3 (PAC`97, 12-16 May 1997, Vancouver, B.C. Canada) p. 1338.

8. J.C. Hafele, F.W. Bingham, J.S. Allen. Proton Capture Radiation from ^{40}Ca in the Region of the Giant Resonance // *Phys. Rev*. 1964, v. 135B, p. 365-370.

9. N.I. Pilipenko, V.G. Nesterov. Radionuclides research in cardiology // *Ukraine Jour. Radiology.* 1997, v. 5, N1, p. 95-100 (in Russian).

10. *Phys. magnitudes: Handbook.* Energatomizdat. 1991, 1232 p.; B.S. Djelepov, L.K. Peker *Scheme of decay of rad. nuclei*. M.: "Nauka", 1966, 750 p. (in Rus.).

11. *Handbook on Nuclear Activation Cross-Sections*, Tech. Rep. Ser. No.156, IAEA, Vienna, 1974, 560 p.

12. A.I. Lepestkin et al. Energy distribution of photoneutrons heavy nucleus at E_{max}=28,5 MeV // *Nucl. Phys.* 1985, v. 42, N4, p. 801-808 (in Russian).

13. N.A. Vlasov. *Neutrons.* M.: "Atomizdat", 1971, 552 p.

14. I.V. Gordeevmet al. *Nuclear-physics constants.* M., Atompizdat, 1963, 508 p. (in Russian).

15. V.G. Nedorezov, Yu.N. Ranyuk. *Photofission behind giant resonance*. Kyiv: "Naukova Dumka". 1989, 192 p. (in Russian).

16. Yu.I. Moskalev. *Radiobiology incorporated radionuclides*. M.: "Energoatomizdat", 1989, 112 p. (in R.).
17. K.P. Makhon'ko et al. // *Atomic energy.* 1996, v. 81, N3, 220 p. (in Russian).
18. S. Uchida et al. Separation method for determ. of Tc-99 in environmental water by ICP-MS// *Radioactivity and Radiochemistry.* 1999, v. 10, No 2, p. 23-28.
19. M. Takaharap et al. Crystal structure of double-strander DNA containing the major adduct of the anticancer drug cisplatin // *Nature.* 1995. v. 377, p. 649-652.