NUCLEAR PHYSICS TECHNIQUE FOR ADJACENT REGIONS

N.P. Dikiy

National Science Center "Kharkov Institute of Physics and Technology", Kharkov, Ukraine

Development of nuclear physics technique at electrostatic accelerates of NSC KIPT are given. These methods allow analysing the elements from hydrogen isotopes to transuranium elements. Using of resonance nuclear reactions are especially effective for interstitial impurity, which essentially influence on properties of constructional materials. It is described using of combined methods. The nuclear-physical data for biology and medicine are given.

PACS: 87.58. Ji

INTRODUCTION

Progress of nuclear physics for thirtieth years of past century was promoted to use of nuclear physics technique on adjacent sciences. Already at 1936 year dysprosium was determined into drugs by means of neutrons activation from source of Ra-Be [1]. A few late Seaborg and Levingood applied cyclotron deuterons for determination of gallium into iron [2]. Note, that even at period of Second World War the nuclear physics technique are used for determination of carbon in steel [3].

Development of nuclear - physical methods in NSC KIPT is related with development in the field of radiation science metallurgy and physics of condensed condition. The absent of alternative methods bring, as rule, to use nuclear physics technique. The nuclear physics techniques are founded on fundamental notions and data about structure of atomic nucleus, cross sections of separate nuclear reactions, schemes of disintegration of radioisotopes, their half-decay periods, radiation energies and etc. Therefore it's allowed to detect atomic nucleus from hydrogen isotopes to transuranium elements. The nuclear physics techniques are characterised by low threshold delectability, high exactness, rightness and results reproducibility, expressive, selectivity, multielementness, locality, analysis process automation possibility, remotability. However these descriptions realise for different measure and domains of their application is variously.

The important advantage of nuclear physics technique are possibility of measure of location atom of crystals grate with exactness 0,01 nm by means of use channelling of charged particles. Also these allow to determination of spatial atoms distributions in surface by resonance nuclear reactions with resolution on depth 1-1,5 nm.

Application of the nuclear physics technique in NSC KIPT is conditioned by presence of charged particle accelerators. Research of structure and composition of superficial layers, grain boundary, ionic-plasma cover are most effectively by means of precise electrostatic accelerators ($\Delta E/E$=0,03%). Such accelerators are characterised by small dispersion of speed-up ions on energy, possibility of smooth energy change, reliability and etc. These properties of electrostatic accelerators for the first time in NSC KIPT were used in work E.V. Inopin, S.P. Tzytko, M.I. Guseva for determination of profiles on depth of silicon, implant in tantalum and copper [4].

The enriched isotope ^{18}O was used for investigation of interaction of oxygen with zirconium by resonance nuclear reaction $^{18}O(p,\alpha)^{15}N$ [5]. Zirconium uses for making of casing of fuel element. Therefore clearing up of oxidation mechanism and oxygen diffusion in zirconium has essential significance for reliable APS exploitation.

NUCLEAR PHYSICS TECHNIQUE OF ADJACENT REGIONS AT ELECTROSTATIC ACCELERATORS OF NSC KIPT

A hydrogen, a nitrogen, an oxygen, a carbon creates with metals of interstitial solutions. Diffusion coefficients of interstitial solutions are much more, than of such of substitutions solutions. Therefore interaction of interstitial atoms with substance is caused of intent attention of physical metallurgy.

HYDROGEN

Hydrogen practically is present in all construction material, has major diffusion mobility even at room temperature and as a rule essentially influences negatively of their mechanical characteristics. So, in a series of cases hydrogen absorption is major factor, which determining of corrosive firmness and wares exploitation time with hydro medium. For some time past this problem supplementary has actuality in connection with profiting of hydrogen for fuel quality. Hydrogen uses as plasticizer for hot deformation of titanic alloys and as strengthen agent for processing by means of hydrogen-phase cold hardening. The structural stability of alloys studies by means of investigation hydrogen also. [6-9]. The determination of hydrogen was raised with of engineering problems of nuclear synthesis.

The reactions $^{1}H(^{15}N,\alpha\gamma)^{12}C$ and $^{1}H(^{19}F,\alpha\gamma)^{16}O$ are used for determination of hydrogen for substance most widely. The method of recoil nucleus is used for determination of hydrogen in surface also. In this case particles beam strike the target and scattering protons, which pass over absorber, register by detector. The elastic scattering particles of primary beam are absorbed and there not register by detector. The high quality of surface is necessary in these methods. The real dimensions of beam, detection apparatus, straggling cause of limitation using corners and lead on the limitations on spatial resolution [10].

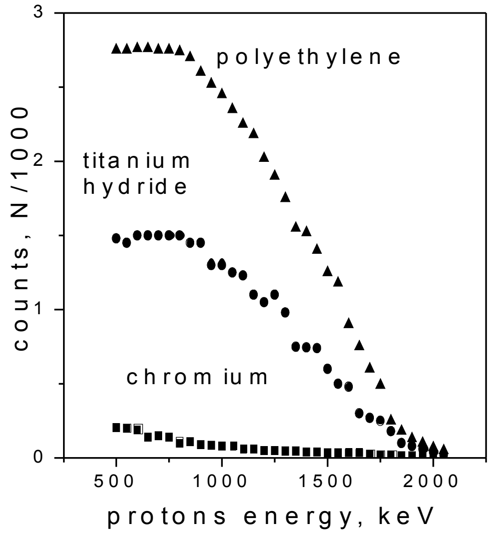

Fig. 1. *Spectrum recoil nucleus from samples Cr, TiN, polyethylene*

The method of determination of content hydrogen by measuring of recoil nucleus, emerging from analyse layer as result of elastic collisions with neutrons, obtained with reaction $^{11}B(\alpha,n)^{14}N$ was realised at ESA-5 of NSC KIPT [11]. The typical recoil nucleus spectrums for chrome samples which obtaining by ionic-plasma deposit, is shown in Fig. 1. A hydrogen threshold delectability was $2\cdot10^{-4}$ mass percent for helium ions current 2 μA and time of measuring 30 minutes.

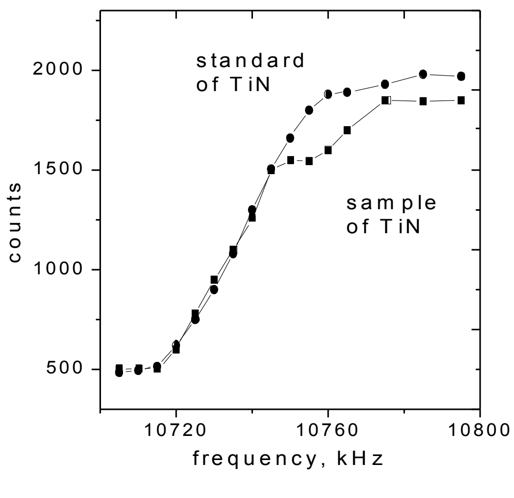

Fig. 2. *Yield of reaction $^{15}N(p,\alpha\gamma)^{12}C$ in neighborhood of resonance at 429 keV*

LIGHT ELEMENTS (BORON, CARBON, OXYGEN, NITROGEN)

Advantages of nuclear physics technique essentially are shown for research of surface of ionic-plasma deposit, implant and oxidise layers and etc. by means of resonance nuclear reactions. The examples of using resonance nuclear reactions $^{15}N(p,\alpha\gamma)^{12}C$ and $^{14}N(\alpha,\gamma)^{18}F$ are shown in Fig. 2,3.

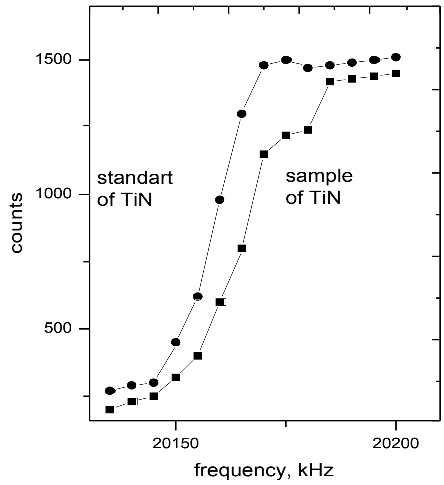

Fig. 3. *Yield of reaction $^{14}N(\alpha,\gamma)^{18}F$ in neighborhood of resonance at 1529 keV*

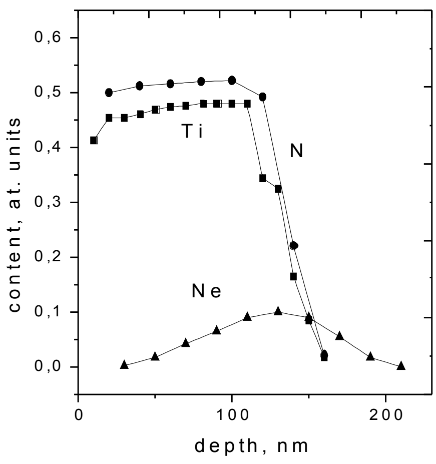

Fig. 4. *Content of neon, nitrogen and titanium in ion-plasma deposit*

The narrow resonance of nuclear reactions at 429 keV and 1529 keV were utilized in this case for an establishment of a new phase Ti_3N_2 of thickness 1-2 nm at surface titanium nitride, exposed to influence of hydrogen plasma.

Resolution on depth for reaction $^{14}N(\alpha,\gamma)^{18}F$ was 1,5 nm [12,13].

Use of the nuclear reaction $^{10}B(\alpha,p\gamma)^{13}C$ allowed setting a mechanism boundary segregation of boron in molybdenum alloys, which applied for cosmic science of materials [14]. The nuclear reaction $^{13}C(\alpha,n)^{16}O$ is effective for study of carbon redistribution in surface steels after impulsive irradiation of electrons. Influence of neon on diffusive mobility for ionic-plasma deposit was studied by means of the nuclear reaction $^{20}Ne(p,\gamma)$ ^{21}Na [15] (Fig.4.).

Content and spatial distributions of carbon of samples was studied by means reactions $^{12}C(p,\gamma)^{13}N$, $^{13}C(p,\gamma)^{14}N$ [16].

Threshold delectability was $2{\cdot}10^{-5}$ % mass by using nuclear reaction $^{19}F(p,\alpha\gamma)^{16}O$. The content of interstitial impurity had been determined by gamma activation analysis with radiochemical separation at NSC KIPT also [17].

ELEMENTS OF MIDDLEWEIGHT

The content and profiles on depth of elements with $A > 20$ usually was studied by radiation capture reactions. In this case the gamma-radiation of reactions was detected of NaI(Tl)- detector or Ge(Li)- detector. The content and profile on depth of substance was studied successfully by radiation capture reactions of isotopes ^{27}Al, ^{30}Si, ^{23}Na, ^{24}Mg, ^{31}P, ^{35}Cl, ^{40}Ar, ^{45}Sc, ^{48}Ni, ^{51}V, ^{52}Cr, ^{54}Mn, ^{56}Fe, ^{58}Ni at NSC KIPT [18-21].

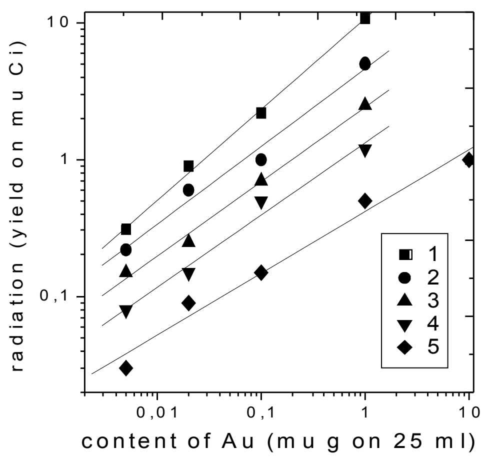

Fig. 5. Dependence of yield of X-rays on gold for various requirements of and cathode, deposition at pH=0.6:

1 - $HCl+HNO_3+CH_3COOH$ U=5.0 V
2 - $HCl+HNO_3+CH_3COOH+SC(NH_2)_2$ U=5.0 V
3 - $HCl+HNO_3+CH_3COOH+SC(NH_2)_2$ U=4.0 V
4 - $HCl+HNO_3+CH_3COOH+SC(NH_2)_2$ U=2.6 V
5 - $HCl+HNO_3+SC(NH_2)_2$ U=1.1 V

The wide possibilities for element analysis realised by method of X-rays, excited by protons, by using Si(Li)-detector [22]. Add, that Si(Li)-detector was made at NSC KIPT from homemade component for the first time in USSR.

EXPERIMENTAL ENGINEERING

Application of nuclear physics technique connects with development methods of radiation detection, use of calculable engineering and etc. The scintillation detectors on base NaI(Tl)- crystals by the size from 40x40 to 100x150 mm, Ge(Li)-detectors, Si(Li)-detectors, CsI(Tl)-thin detectors for recoil protons registration, neutrons detectors on a basis stilbene crystals with electronic scheme rejection of gamma-radiation, the semiconductor detectors E and ΔE of charged particles were applied for registration of various radiation. The coincidences schemes with of time resolution from 10 to 120 ns were applied for gamma activation analysis.

For analysis of spatial distributions were worked up the mathematical processing programs of experimental data, which with high exactness took into account a dispersion of analysed beam on energy and its evolution by means of methods decision no correct problems. The programs of regressive, correlation analyses and finding unknown probability density function was created also.

The data preparation methods by means of Laplace-Gauss filters was realised for gamma-radiation spectrums analysis from Ge(Li)-and Si(Li)-detectors. The exactness was raised from 1,3 to 1,7 times for determination of elements content into samples by use such filter [23].

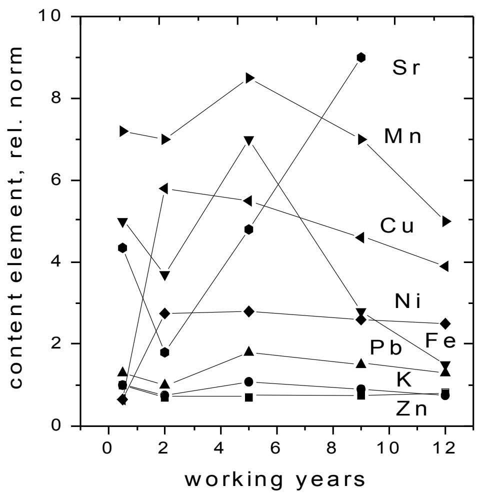

Fig. 6. Content of elements in hair of glass factory workers

The threshold of delectability for elements (toxic elements, noble metals, rare-earth metals, rare metals) was lowering by means of methods of chemical and electrochemical concentrating at NSC KIPT. For example, the method of electrolytic gold sedimentation on substrate from pyrolitic graphite allowed to accord threshold of delectability $2{\cdot}10^{-10}$ g/g [24] (Fig. 5). The method of deposition by electrolysis of biological and environment samples was applied [25].

The important description of nuclear physics methods is multielementness with high relative exactness of elements content. This fact in virtue of further correlation analysis and renewal of probability density function the nuclear data allow to reveal deep dependencies. For example, an influence of conditions of working zone on workers health was determined by using of content essential and toxic elements in their hairs and blood [26] (Fig. 6).

The pathogenesis of different derma tic diseases was studied by means of correlation analysis of content of variable valence elements with free radical peroxide oxidation in blood. The modification of process proliferation and cytodifferentiation is established [27] (Fig. 7).

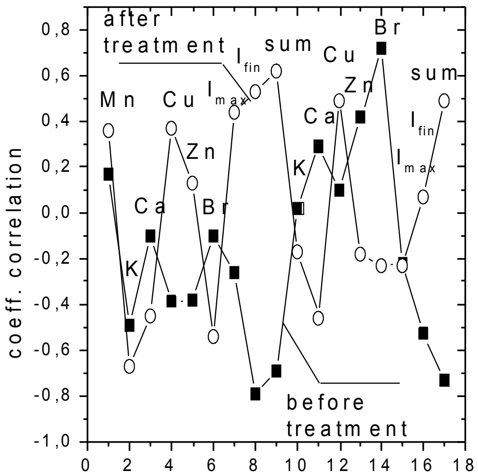

Fig. 7. Correlation coefficients of elements content dependence in serum with value of intensity free radical peroxide oxidation in psoriasis ills before and after treatment. Fe with Mn, K, Ca, Cu, Zn, Br and intensity of I_{max}, I_{fin},sum (1-9), Mn with K ... sum (10-17)

The nuclear physics technique allows determining of isotope ratio $^{44}Ca/^{48}Ca$ in normal and malignant tissues of thyroid gland [28] (Fig. 8).

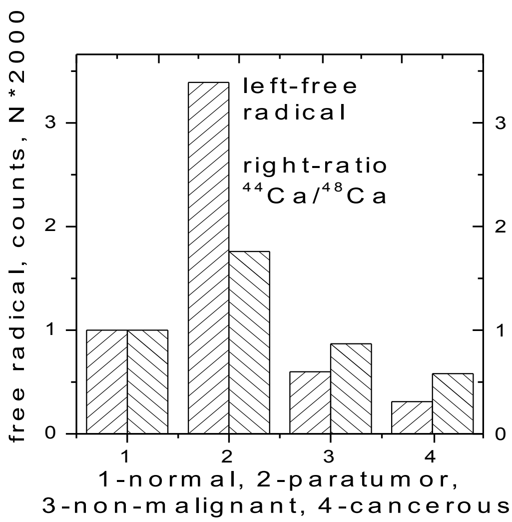

Fig. 8. *Intensity of induced chemo luminescence and isotope ratio $^{44}Ca/^{48}Ca$ for thyroid gland tissue*

The nuclear physics technique successfully is applied for determination of age of rocks. Simultaneous content determination ^{187}Os and ^{187}Re in molybdenite allowed determining age (2,3 billion years) for perspective gold deposits of Ukrainian Crystalline Shield [29].

CONCLUSION

The nuclear physics technique at electrostatic accelerators are powerful research tool of determinate of content and profile on depth of interstitial impurity, which important for nuclear science of materials, electric active impurity into semiconductors, essential and toxic elements in bio- and environment samples, noble elements and rare-earth metals of geology samples. Their allow to study the fundamental questions pathogenesis of malignant cells, to determine Universe age, to study the evolution processes of Sun System.

REFERENCES

1. G.V. Hevesy, H. Levi. in G. Hevesy. *Adventures in Radioisotope Research.* V. I. N. Y.: "Pergamon Press", 1962, p. 47-52.
2. G. Seaborg, J.J Levingood. Artificial radioactivity as a test for minute traces of elements // *J. Amer. Chem.* 1938, v. 60, p. 1784-1789.
3. M. von Ardenne, F.Z. Bernhard. Ein kernphysikalisches es verfahren zur bestimmung gerineer kohlenatoffzustze in eisev // *Phys.* 1944, №122, p. 740-744.
4. M.I. Guseva, E.V. Inopin, S.P. Tsytko. Depth of penetrates and character distribution of implant atoms in isotope target ^{30}Si // *JETF.* 1959, v. 36, is. 1, p. 3-9 (in Russian).
5. N.A. Skakun, A.P. Klucharev, O.N. Kharkov, V.F. Zelensky. Use of nuclear reaction $^{18}O(p,\alpha)^{15}N$ for study oxidation metals // *Atomic energy.* 1971, v. 30, is. 5, p. 456-458 (in Russian).

6. Yu.A. Carpov, I.P. Alimarin. New stage in analytical chemistry of high purity substance // *JACh.* 1979. v. XXXIY, is. 7, p. 1402-1410 (in Russ.).
7. W. Robinson, H. Mudi. Influence of hydrogen, tritium and helium on crack resistance strengthened stainless steel // *Atomic engineering for boundary.* 1988, №3, p. 31-35 (in Russian).
8. M.I. Gyseva, V.G. Stolyarova, E.A. Gorbatov et al. Influence ion helium bombardment on behavior of hydrogen in stainless steel // *Atomic energy.* 1987, v. 76, is. 1, p. 17-20 (in Russian).
9. D.M. Grant, D.L. Cumming, D.A. Blackburn. Hydrogen in 304 steel: diffusion, permeation and surface reaction // *J. Nucl. Mat.* 1987, v. 149, №1, p. 247-251.
10. I.P. Chernov, V.N. Tshadrin, Yu.P. Cherdantsev et al. Nuclear-physical method determination hydrogen in surface layer of substance // *JACh.* 1984, v.XXXIX, is. 3, p. 442-447 (in Russian).
11. N.P. Dikiy. Determination hydrogen of nuclear-physical methods // *Vestnik Kharkov National University, ser.: Physical. Nucleus, particles, fields*, 2001, №522, is. 2(14), p. 53-56 (in Russian).
12. V.S. Voitsenya, Yu.A. Gribanov, N.P. Dikiy, P.N. Zhmurin et. al. Study of erosion of TiN coating in a hydrogen discharge with oscillating electrons // *Jour. of Nucl. Mat.* 1990, v. 176 and 177, p. 886-889.
13. Yu.P. Antufev, N.P. Dikiy, V.D. Zabolotny, A.S. Litvinenko et al. Determination of element composition substance and distribution in depth of impurity atoms by means of use prompt radiation of nuclear reaction // *VANT.* 1990, *ser.: physics of radiation damages and radiation metallurgy*, is. 3(54), p. 96-100 (in Russian).
14. O.A. Belous, N.P. Dikiy, V.I. Minakov, N.A. Skakun, V.I. Trefilov. Use of nuclear reaction for investigation boundary segregation boron in molybdenum alloy // *DAN USSR.* 1980, v.255, №3, p. 562-564 (in Russian).
15. N.P. Dikiy, N.S. Lomino, V.D. Ovcharenko. Using influences neon of formation ion-plasma coating by nuclear-physical methods // *VANT. ser.: physics of radiation damages and radiation metallurgy*, 1998, is. (69), 4(70), p. 141 (in Russian).
16. P.N. Vugov, N.P. Dikiy, S.D. Lavrinenko, A.S. Litvinenko et al. Determination of carbon in niobium and iron by accelerate protons // *VANT. ser. general and nuclear physics*, 1983, is.1(2), p. 50-52 (in Russian).
17. A.F. Gorenko, N.A. Skakun, A.S. Zadvorny, A.P. Klyucharev et al. *VANT. ser.: physics of high energies*, is. (1), 1972, p. 29 (in Russian).
18. Yu.P. Antufev, N.P. Dikiy, V.D. Zabolotny, P.P. Matyash et al. Use reaction $^{40}Ar(p,\gamma)^{41}K$ for study of distribution argon in molybdenum // *Abstracts 36 conf. on nuclear spectroscopy and to structure of atomic nucleus*, Leningrad: "Nauka", 1986, p. 559 (in Russian).
19. N.P. Dikij, A.A. Valter, A.N. Dovbnya, E.P. Medvedeva et al. *Accelerator based techniques for geology and medicine.* Modern Aspects of Analytical Chemistry, 5 Russian-Ukrainian-German analytical symposium, Aachen: Mainz, 1997, p. 189-192.
20. N.P. Dikiy, V.E. Storishko, E.P. Medvedeva, V.I. Borovlev et al. Use electrostatic accelerators for determination noble, rare and rare-earth metals in rocks // *Proc. of 11 conf. on electrostatic accelerators*, Obninsk (Russia): RF SSC FEI, 1996, p. 137-144 (in Russian).
21. Yu.P. Antufev, N.P. Dikiy, V.D. Zabolotny, A.S. Litvinenko et al. Use nuclear reactions for determination impurity of heavy metal in samples environment and food // *Abstracts 41 conf. on nuclear spectroscopy and structure of atomic nucleus*, Leningrad: Nauka, 1991, p. 449 (in Russian).
22. A.G. Strashunsky, G.K. Homyakov, N.A. Skakun, A.P. Klucharev et al. *UFJ.* v. 20, №10, 1975, p. 1606-1609 (in Russian).
23. N.P. Dikiy, E.P. Medvedeva, N.A. Shlyahov, V.D. Zabolotny et al. *Physical analytical complex in medicine. Nuclear-physical methods. Statistical handling. Computer diagnostics*. Preprint KFTI, 94-13, Kharkov, 1994, 17 p. (in Russian).
24. N.P. Dikiy, A.N. Dovbnya, A.A. Valter, V.E. Storishko, E.P. Medvedeva et al. Gamma activation analyses noble metals in rocks // *Mineralogical journal.* 1995, v. 17, №6, p. 85-89 (in Russian).
25. N.P. Dikiy, V.E. Storishko, E.P. Medvedeva, N.A. Shlyahov et al. Use nuclear-physical methods for investigation function diseases // *Proc. of 11 of conf. on electrostatic accelerators*, Obninsk (Russia): RF SSC FEI, 1996, p. 145-152 (in Russian).
26. N.P. Dikiy, E.P. Medvedeva, Ya.F. Kutasevich, I.I. Mavrov et al. Analytical accelerator-spectrometer complex in system analyze of production glass // *Abstracts 44 conf. on nuclear spectroscopy and structure of atomic nucleus.* S.-Pet.: "Nauka", 1994, p .352 (in Russian).
27. V.P. Starenky, L.I. Simonova, N.P. Dikiy, E.P. Medvedeva et al. Interdependence change biophysical and biochemical parameters peroxide oxidation lipids in cancer lung patient in process radiotherapy // *Proceeding conf. "Actual oncology problems and medical radiology"*, Minsk: MPH Rep. Byelorussia, 1996, p. 224-232 (in Russian).
28. N.P. Dikiy, A.N. Dovbnya, N.V. Krasnoselsky, E.P. Medvedeva et al. Determination of isotope ratio calcium by gamma activation analysis and free radical oxidation of lipids in normal and cancerous tissues of thyroid gland // *VANT, ser.: nuclear-physical researches.* 2000, is. 2(36), p. 54-57.

29. N.P. Dikiy, Yu.V. Lyashko, E.P. Medvedeva, I.D. Fedorets. Nuclear-physical methods of determination age uranium rocks // *Abstracts 51 inter. conf. on nuclear spectroscopy and structure of atomic nucleus*, Sarov (Russia): RFNC-VNIIEF, 2001, p. 243 (in Russian).