USE OF ACCELERATORS IN GEOLOGY, MEDICINE, ISOTOPES PRODUCTION AND ATOMIC POWER ENERGETICS

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Some examples of using of nuclear-physical methods in contiguous domains are presented.
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1. ANALYSIS OF NOBLE METALS

Use of powerful accelerators for analysis of noble metals in ores allows performing mass analysis on representative trials with a threshold of detectability 0.03 - 1 g/t without preliminary concentration. Herewith one realizes high technical-and-economic characteristics (for example, cost of element determination is in 2-3 times lower than for the assay). A peculiarity of the method offered is the use of directed activity with large (more than 5 days) half-life, that allows to obtain a threshold of detectability of about 0,3 g/t for Ir, Au, Ru, Rh. Oxides and silicates Al, Fe, Ca, Na, I, Mg make up almost 99 % of ores of the earth-crust. On isotopes of these metals, and also O and Si only activities with decay periods less 2 days are induced. Activities on Al and Na have more long half-life (7.38 10^5 and 2.6 year, respectively) and are characterized by a low cross-section of (γ,n)-reactions. The authors have studied the samples of ores from diverse Ukraine's deposits. Irradiation was performed by bremsstrahlung radiation of electrons with energy of 16-25 MeV. A mean electron current was from 100 to 1 mA, irradiation time from 1 hour to several days. The counts of bremsstrahlung radiation absorption in samples under investigation was carried out by irradiation of standards with a known amount of the element being determined and consequent measuring the sought activity in them. The gamma-radiation registration was conducted with a Ge(Li)-detector having an energy resolution of 1,9 keV on the 1333 keV line.

To decrease the background radiation a detector was placed in the leaden container with a shielding thickness of 5 cm, that allowed to decrease a background in the range of 100-500 keV approximately in 5 times.

An element ore composition was determined after mathematical processing of spectra obtained. To do this at first the smoothing of apparatus spectra by Laplace-Gauss filter was made with taking into account the prior information on the width of peaks registered [1]. Hereinafter, using the fast algorithms to solute the set of linear equations for concentrations to be determined with addition of background value by the minimization method, we calculated the search content. For calibration we used the standard spectra from samples with a known content of elements analyzed. A typical spectrum of induced activity of the ore sample is shown in Fig. 1. For Au analysis the activity of ^{196}Au ($T_{1/2}$=6.8 days) was used by measuring gamma-lines with energy of 426, 355.7 and 333 keV. The high cross-section of the ^{197}Au(γ,n)^{196}Au reaction allows to achieve a threshold of detectability 0,03-0,1 g/t for majority of ores excluding manganese. Industrial manganese content in ores (more than 10%) lowers a threshold of detectability of gold to 1-1,5 g/t (due to the intensive ^{54}Mn line with E = 834.8 keV).

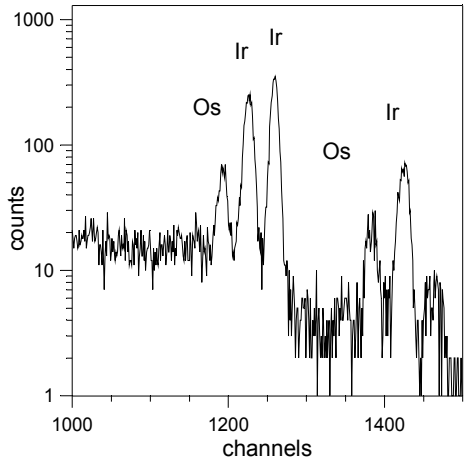

Fig. 1. *Spectrum of a sample from ores with Os*

Determining of the Ir content was conducted by registration of the activity of ^{190}Ir ($T_{1/2}$=12.1 day) and ^{192}Ir ($T_{1/2}$=74 days). For analytic determining Ir as a result of the higher intensity of decay a more preferable is ^{190}Ir (analytic line with E=371, 407, 518, 558, 568, 605 keV). In the case of high background radiation loading and interference from other elements it is possible to use the ^{192}Ir activity (analytic lines of 308, 316, 468 keV). Then a threshold of detectability for above mentioned irradiation conditions on ^{190}Ir is 0.5 g/t.

Determination of Ru content was realized using the induced activity of ^{103}Ru ($T_{1/2}$=207 days). The radiation with E=497 and 610 keV was detected. A threshold of detectability in this case is 0.8 g/t. When using the activity of isotope ^{103}Ru one should take into account the interference from ^{131}Ba (gamma-radiation with an energy of 496.2 keV). In spite of a low Ba content in Ukraine's ores and low abundance of ^{132}Ba, that is 0.097 %, the activity from Ru and Ba has the comparable values. Therefore for a reliable analysis we had to measure the activities of ^{131}Ba and ^{103}Ru in time with consequent numeral account of ^{131}Ba in 497 keV line intensity.

The Rh content was measured by registration of induced activity of isotope ^{102}Rh ($T_{1/2}$ =207 days). The gamma-line with an energy of 475, 557, 628, 1103 keV was detected. A threshold of detectability was 1.8 g/t for given irradiation conditions.

The Os content was measured using the activity of ^{191}Os ($T_{1/2}$=15.4 days). The radiation with energy of 129.4 keV was registered. Due to the interference from thorium-232, which always exists in surrounding constructions, a threshold of detectability is 2-8 g/t. A similar threshold of detectability is realized also in the case of using the reaction ^{196}Os(γ,n)^{195}Os and measuring the activity of ^{195}Os ($T_{1/2}$=94 days). (It is the most intensive 646.1 keV gamma-radiation line.)

On Pt induced is the activity in the reaction ^{195}Pt(γ, γ')^{195m}Pt, that allows to determine the Pt content at a level of 0.3 g/t.

So, at powerful linear accelerators of NSC KIPT we realized the gamma-activation analysis of simultaneous determining the group of noble metals in representative trials of ores with a threshold of detectability 0,03-3 g/t of a high economic effectiveness, that is particularly necessary when testing ores with noble metals at deposits under mining or introduced in production [2-6]. Advantage of the method described consists also in determining noble metals as well as elements-indicators (As, Tl and others).

2. RESEARCH OF DIFFUSION OF ACTINIDES IN GRANITES

Working out the schemes for reliable disposal of NPP radioactive waste in geological structures is an important factor of atomic energetic development in Ukraine. Use of powerful electron accelerators allows deciding successfully the problems concerning the choice of the area for RAW storage placing.

Study of diffusion with RAW imitators was carried out as follows: a Yb_2O_3 standard was irradiated by bremsstrahlung radiation from 22 MeV linear electron accelerator (LEA). During irradiation observed was the activation of isotopes Yb: ^{175}Yb ($T_{1/2}$=4.2 days), the most intensive line 396 keV and ^{169}Yb ($T_{1/2}$=30.7 days), the most intensive lines 198 keV and 177 keV.

The weighed amount of Yb oxide (Yb_2O_3) in irradiated granite was 100 mg. The extracted Yb oxide was dissolved in 0,2 ml of concentrated HCl and reduced with deionized water to pH=1.8. The obtained $YbCl_3$ volume of 40 ml was placed in a heat-resistant retort with a reverse cooler. Heating of the solution was performed in the water bath during 32 hours. After this the granite standards were washed with distilled water during 24 hours and dried out in a drying cabinet at 60°C. Skimming of layers from standards was conducted by the methods of precision grinding. The layer thickness of 1 μm was sufficient to study the diffusion in the standard. To avoid losses of skimmed layers we performed wet grinding with the use of filtering and parchment liners. The thickness of skimmed layers was from 2 to 100 μm, that made it possible to judge more exactly and reliably on the diffusion profile. The skimmed layers were packed and after their activity was measured with the Ge(Li)-detector.

Measuring of the Yb radiation intensity was carried out during 20-30 min. Analysis of spectra was performed by standard programs of gamma-radiation spectrum processing. The typical activity spectra of ^{169}Yb are shown in Fig. 2. The thickness of the skimmed layer was 50 μm, therefore the gamma-lines from the granite matrix: 881 keV (^{84}Rb), 1297 keV (^{47}Ca) and others are well displayed.

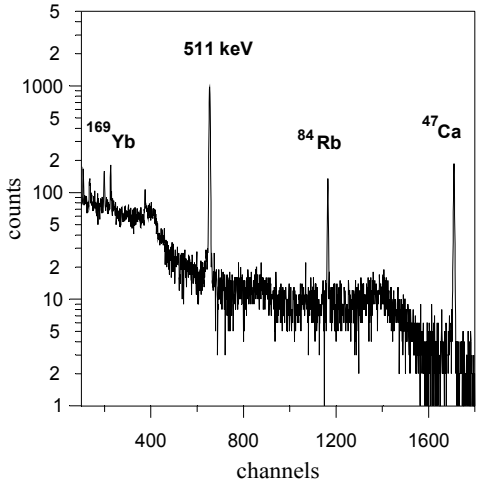

Fig. 2. *Typical granite spectrum of the granite layer activity (d = 50 μm, 3 Grad)*

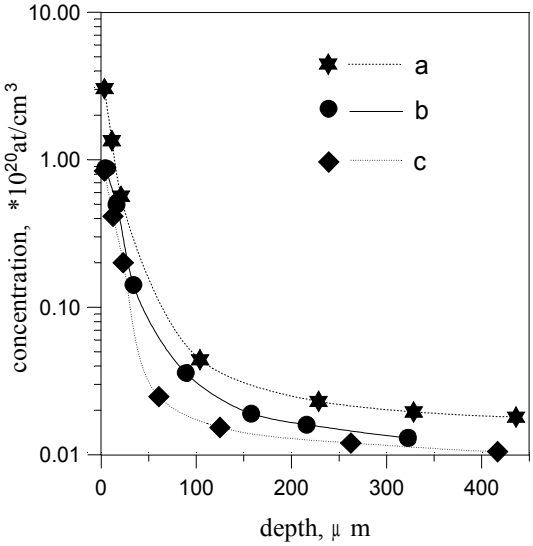

Fig. 3. *Concentration of ^{169}Yb in some granite standards (b - initial with pegmatite structure, c - initial uniformly grained, a - after irradiation with a dose of 3 Grad)*

The calibration measurements of radiation intensities enabled one to calculate the Yb concentration in granite. Its maximum value at the surface of the standard irradiated by a dose 3 Grad was $3*10^{20}$at/cm^3.

The results of measuring Yb profiles in granites for mentioned above conditions are given in Fig. 3. Visible are two typical ranges of values: 0 to 60 and 60 to 500 μ m. The first range conforms to diffusion into crystallites, which are in the composition of plagioclases. It should be note, that in the sample, exposed to irradiation to 3 Grad, the concentration dependence of Yb diffusion differs essentially from the analogous dependence for sample, not exposed to irradiation. The char-

acter of the curve for sample 3, corresponds to the diffusion along the grain boundary (in our case, evidently, by cracks, chips etc., which are detected by mineral - petrographic analysis). Note, that during irradiation cracking of feldspar crystals takes place. Analysis of samples 7 and 8 also shows diffusion through mentioned above defects; at the same time the volume diffusion into grains (crystallites) is observed. The values of the diffusion coefficient in the first range are $3.2*10^{-11}$ (for 3), $1.4*10^{-11}$ (for 7) $1.09*10^{-11}$ (for 8).

In the range of 60-500 μm the concentration dependencies for all sample have a similar character, and only the concentration values differ. In coordinates $x^{6/5}$ they have a linear character. This confirms the dominance of diffusion in this area along the grain boundaries. And values of diffusion coefficients $2.2*10^{-8}$ (for 3), $6*10^{-9}$ (for 7) and $4.8*10^{-9}$ (for 8) cm^2/c justify this fact. For the irradiated sample the diffusion along the grain boundaries exceeds in 1500 times the diffusion in crystals. Note, that in the irradiated standard the diffusion coefficient is higher as for crystals (grain modification), as well as for grain-boundary diffusion (probably, as petrographic analysis shows, this is conditioned by space of Na, Ca, K, Si). Probably in this case not classic diffusion on grain boundary is realized, but the diffusion with discontinuous Yb precipitation. In this connection the creation of artificial matrices should be done with providing the decrease of the grain-boundary mobility of Na, Ca, K and creation of conditions for suppressing the mentioned above processes at granite crystal boundaries.

Like to the man-caused effect on granites, under irradiation the most essential role is played by the proc esses, which lead to formation of ions H^+, OH^-, CO_3^{2-}, Na^+, Ca^{2+} and their complex influence on the processes of boundary modifications, melting of cracks, diverse precipitations and, as a result, have influence on the RAW mass transfer.

3. ANALYSIS OF THE ELEMENT COMPOSITION OF CONSTRUCTION AND OTHER MATERIALS OF CHNPP 4 UNIT

Using the methods of nuclear-physical, crystal-optical analyses and infrared spectroscopy (IR spectroscopy) the study was conducted on a phase composition and structural transformation of core samples, selected when boring the cement wall of ChNPP 4 Unit.

A typical concrete standards spectrum after irradiation on electronic accelerator brought on Fig. 4. After activation of the concrete core on powerful electron accelerator the concentrations of I, Ca, Ce, Mn, Sr, Cs, Na, Rb, Zr, Ni, Pb and other elements for diverse bedding depths were determined.

4. NUCLEAR-PHYSICAL METHODS FOR ANALYSES OF IODINE FILTERS IN THE PROCESS OF NPP OPERATION

Use of powerful electron accelerators for analysis of element composition of iodine filters enables one to work out successfully the problem of their regeneration and further use in the systems of NPP throwaway cleaning.

In the present research the macro- and microelement composition of NPP iodine filters after decommissioning was determined. For this the iodine filter was opened with a special sampler and the coal samples in three positions were taken. The coal cores taken from diverse depths were packed up by 5, 6, 7 g.

Absolute values of element content were determined relatively to samples, which were irradiated together with the samples under study. We measured the activities of isotopes obtained in reactions: $^{55}Mn(n,\gamma)^{56}Mn$,

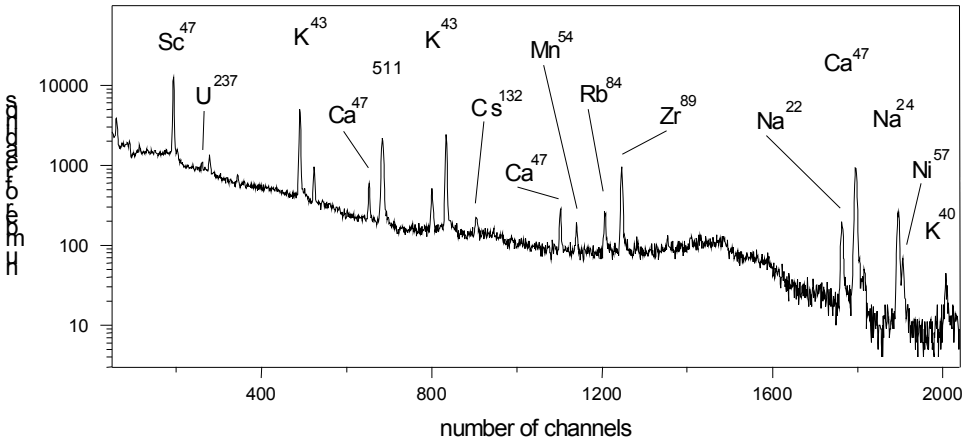

Fig. 4. *Gamma spectrum of the sample 133 after irradiation at LEA during 41 hours*

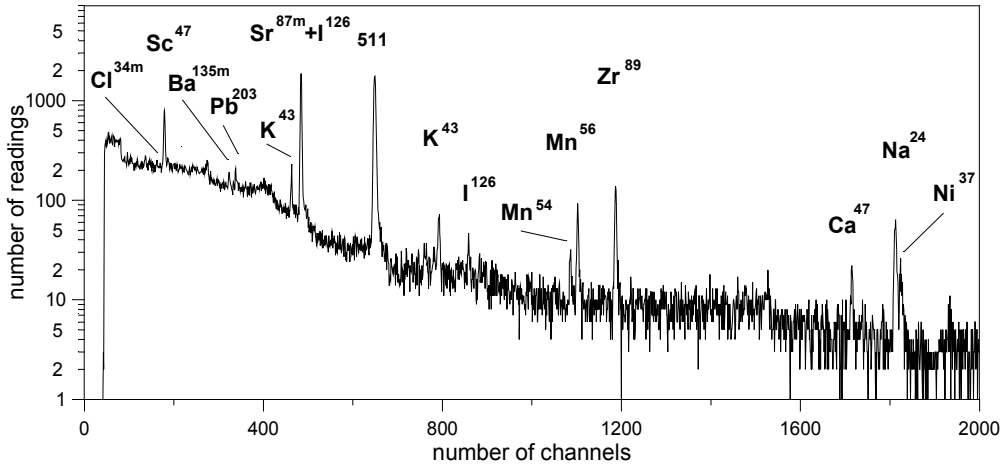

Fig. 5. *Typical spectrum of coal filter activity after irradiation at the electron accelerator*

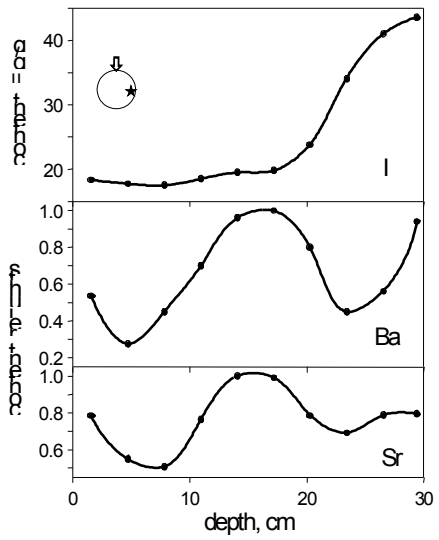

Fig. 6. *Content of a number of elements depending on the filter depth*

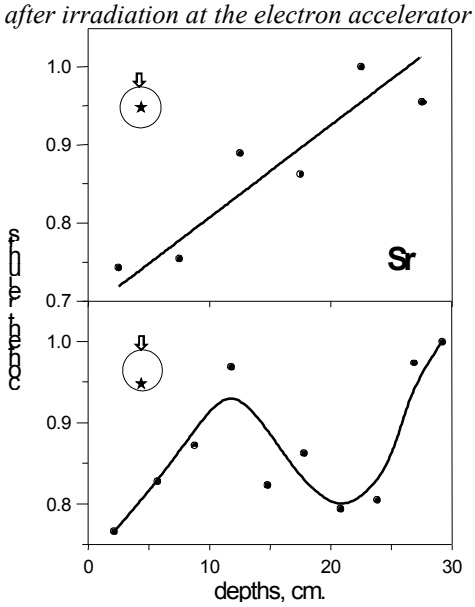

Fig. 7. *Sr content depending on the filter depth in centre and at periphery*

$^{127}I(\gamma,n)^{126}I$, $^{35}Cl(\gamma,n)^{35m}Cl$, $^{90}Zr(\gamma,n)^{89}Zr$, $^{88}Sr(\gamma,n)^{87m}Sr$, $^{48}Ca(\gamma,n)^{47}Ca \rightarrow {}^{47}Sc$, $^{44}Ca(\gamma,p)^{43}K$, $^{23}Na(n,\gamma)^{24}Na$, $^{140}Ce(\gamma,n)^{139}Ce$, $^{204}Pb(\gamma,n)^{203}Pb$. A typical spectrum of induced activity is shown in Fig. 5. The content of measured elements in dependence on the depth of a core, taken at the filter periphery, is given in Fig. 6. In the given position a turbulent behavior of the airflow was not observed. In Fig. 7 given is the strontium content depending on the depth for two cores: in center (turbulent behavior of the air flow) and at periphery (from one side, where laminar air flow behavior is observed).

From Fig. 6 it can be seen, that the ^{127}I content decreases with the core depth. Note the typical distribution on depth by concentration of Ba, Sr, Zr, Ca. Peculiarity of their distribution is a maximum at 15 cm. The most considerable concentration increasing is observed for barium that is related to his high reaction capability. It is known, that Ba makes lightly oxides and nitrides. Also, it is capable to form lightly iodates ($Ba(IO_3)_2$) and iodide (BaI_2).

The maximum concentration of above-mentioned elements in the filter middle, presumably, are conditioned by the influence of vapors of NO_2, ClO, $ClONO_2$ (chlorine nitrate), which are formed in air under radiation [7]. Radiation effect leads also to formation of acetic acid from methane, being contained in air (oxidation of CH_4 with hydroxyl (OH) $\rightarrow CH_3 + O_2 \rightarrow CH_3O_2 + HO_2 \rightarrow CH_3OOH$). Acetic acid interacts with elements of the second group intensively. Nitrates, nitrides, hypoclorides, barium acetates and strontium or their complex compounds being formed can easy move on the filter, and as a result the dynamic distribution of these elements with a maximum in depth of 15 cm takes place.

A practically permanent concentration of Mn, Ni, Na, Ce, Pb on the core depth is observed. Note, that PbI_2 is one of the very steady iodine compounds. An insignificant entering of aerosols from the near- reactor space into iodine filters can hamper their reliable exploitation. A typical spectrum of aerosols, deposited on the iodine filter grid, is represented in Fig. 8. It is obvious, that the presence of ^{137}Cs, ^{60}Co, ^{110m}Ag, ^{54}Mn conforms to the typical composition of radioactive aerosols for the reactor being in operation.

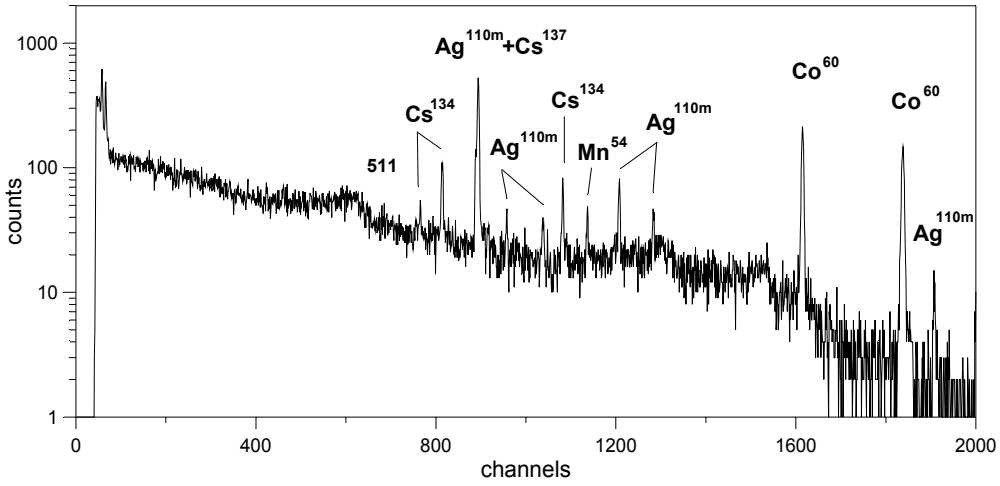

Fig. 8. *Typical activity spectrum on the filter grid*

5. USE OF ELECTROSTATIC ACCELERATORS IN RELATED FIELDS

The electrostatic accelerators of NSC KIPT are used for solving the problems in the field of ecology and medicine [1,6,8]. Depending on the problem being solved one uses diverse nuclear-physical methods: Rutherford backscattering (RBS), promt radiation of nuclear reactions (PRNR) and X-ray radiation (XRR) excited by protons or multicharged ions of N and O. The given methods possess the most acceptable technical and economic characteristics when determining the element composition and impurity atom distributions in the sample depth. Choosing the energy and type of accelerated particles; one can control the threshold of detectability for definite groups of elements.

X-ray radiation was registered with a spectrometer on base of a Si(Li)-detector with an energy resolution of 220 eV on the 5,9 keV line. An element composition of biological samples was determined after mathematical processing of spectra obtained. Herewith, for calibration the standard spectra from the samples with a known content of elements being analyzed were used.

During element analysis a special attention was paid to the sample preparation that allows one to broader the possibilities of nuclear-physical methods used. To achieve at acceptable technical and economic characteristics, where possible, the sample in a natural form (hairs, nails, teeth, filters etc.) were used. To avoid the sample destruction in the process of measurements, a complex of actions on decreasing the current density of ions used and optimization of the X-ray spectrometer position were undertaken. The current density was 10 nA/cm^2 for AFA filters and hairs. The dose was 3-5 μCoul. A threshold of detectability depends on the atomic element number, e.g. for iron it is 10^{-7} g/g. If during measuring the required threshold of detectability (mainly for toxic elements: Hg, As, Cd, Pb) was not reached then the concentrating took place. More frequently it is the decomposition of the sample and mercury deposition in the form of clorides, lead - as sulphates, cadmium - as sulphides. When it was necessary to measure the content of elements with a threshold of detectability of 10^{-10} g/g one conducted the sample decomposition with consequent electrolytic concentrating the element on the plate from graphite or other material.

When analyzing the liquid samples (blood, serum, plasma) the dry and wet aching was performed. The formed mineralized the carrier was deposited layer by layer onto the plate. The calibration curves were obtained by the method of additions during the target preparation.

Analysis of light elements (Na, F, C, N, Li, B, Mg, Al) was conducted with the use of PRNR. In this case γ-radiation, more rarely - charged particles and neutrons were detected. For example, when using the reaction $^{19}F(p,\alpha\gamma)^{16}O$ a threshold of detectability of fluorine in teeth (this object allows a rather high intensity and proton dose) was 10^{-7} g/g. For nitrogen being a basic element in the protein composition, a threshold of detectability limit was at a level of 10^{-5} g/g in the reaction $^{15}F(p,\alpha\gamma)^{12}C$. The lower thresholds of detectability of 10^{-5} g/g were obtained for B, Be, Na and for C, Li, Mg, Al it was by two order higher, 10^{-4} g/g.

An essential property of nuclear reactions is a possibility to study the element distribution in biological samples in depth that is important diagnostics of some diseases.

In the present given are the results of studying the effects of general and specific contaminations on evolution and propagation of some cancer diseases (cancer light, skin cancer).

In technological processes of many operating enterprises one uses a raw materials containing toxic elements. A toxicity of the element is conditioned by its chemical nature, amount and composition of the compound, in which it is, as well as by the method of entering in the organism, and depends on the age, sex and individual peculiarities of the organism.

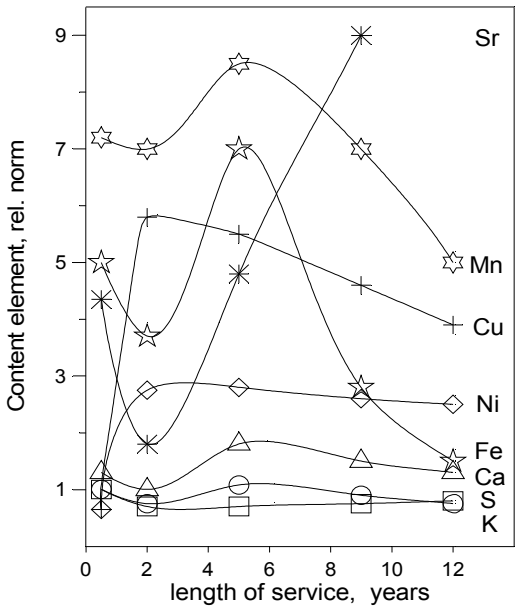

Fig. 9. *Element content in hairs of workers working in harmful conditions vs the length of service*

Man illnesses, caused by the presence of toxic elements in air of the working zone, in raw materials, ready production, and consequently, in biological objects (hairs, nails, teeth, blood), in most cases are complicated by falling the activity of immune system. For example, it was established, that in first years (1-3) of workings at enterprises with harmful labour conditions a number of diseases of viral, bacterial and other etiology (mycosis, herpes, frequent respiratory diseases, flu) is observed in 42-60 % of workers, in consequent years one marks their smooth diminution. To 3-5 years a number of dynamic diseases increase to 10-15 %, to 5-6 yeas it decreases, and to 9-10 years it increases to 25 %. Such "undulating" character of a number of diseases is in correlation with content of some elements in hairs of persons working in harmful labour conditions. In Fig. 9 represented are the elements in hairs of workers depending on the length of service. The content of such elements as Zn, K, S, Ca during the observation period from one to ten years does not reveal significant deviation of these elements from the sample. The content of Mn, Fe, Cu, Ni has two maxims for years of servicing with a tendency to lower after 10-years length of service. The content of Sr in hairs rises in the first year of working, decreases during the second year and monotonously grows in consequent years. The above-mentioned "undulating" character of dependencies, presumably, can testify of the degree of workers' adaptation to harmful labour conditions. A similar dependence is not observed for workers the activity of which is not connected with harmful labour conditions. It should be also noted, that the percentage of morbidity by infectiously allergic forms is higher for men than for women. Changes in the immunological status of workers and in the content of microelements at first bear a unspecific character. However, development of a subsequent immunodeficit and lack of organism's adaptation reaction on the influence of harmful production factors leads to beginning of a chronic form of morbidity (psoriasis, bronchial asthma), to disability and to development of cancer diseases. A statistics shows a high rate of the death from cancer diseases for people, retired on a pension after work in harmful labour conditions.

Analysis of results on the element content in raw materials, ready production and in air of the working zone testified the accordance of these values to maximum permissible concentrations. Undoubtedly, this fact considerably complicates conducting the disease-prevention service and justifies the necessity of developing individual measures for everyone of working persons.

The mathematical processing (correlation and regression analysis, function of distribution density probability) of dependencies of general and specific contaminations for 14 regions of Ukraine on propagation of cancer diseases (cancer light, skin cancer out etc.) has shown, that actually there is not distinct linear dependence between the degree of contamination in that or another domain and the degree of cancer disease propagation. The character of these dependencies is more complicated, having also "undulating" nature, depending on the sex, age, mechanisms of organism adaptation etc.

So, the use of electrostatic accelerators for analysis of element composition of biological objects and objects of environment can be an effective control means, and also provides a high-productivity due to many-element factor, exactnesses and measuring sensitiveness.

6. DEVELOPMENTS AND USE OF DIRECT NUCLEAR- PHYSICAL METHODS

To realize these opportunities the specialists of KIPT developed the methods, devised, constructed and put in service the installation with a goniometer having three degrees of freedom. They provided a possibility for simultaneous registration of nuclear reaction radiation, backscattering particles and characteristic X-ray radiation, excited with accelerated particles. There were relized: automatic mode of angular crystal orientation relatively to the bunch pulse; search and identification of crystallographic directions, plane-parallel shift of targets relatively to the point of beam impinging the target; angular scanning; and registration of radiation yields with spectrometers.

The goal of the works was studying the structure, composition and properties of ion-doped monocrystalline single-element and binary quasi-conductors, magnetic materials, many-component compounds (including HTSC) and model structural metals.

The results of these works served, in particular, as a base for development of a technology of infrared radiation devices (IR-devices). It is shown, that such devices can be made on the base of antimonide india doped with Be ions. The technology of basic structures of such devices is optimized. In Fig. 10 shown is the dependence of aγ-quantum yield of the reaction $^{9}Be(\alpha,n\gamma)^{12}C$,

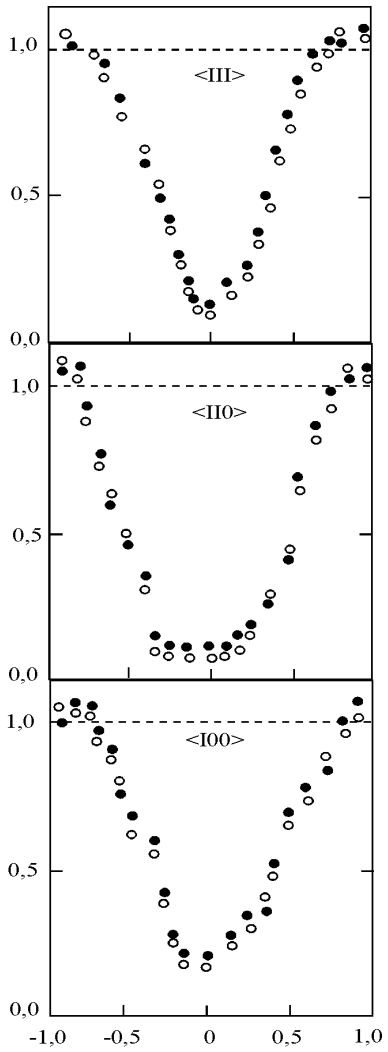

***Fig. 10**. Results of anglular scanning within main crystal axes of InSb, ion-doped Be, (•) - γ-quantum yield from the reaction $^{9}Be(\alpha,n`\gamma)^{12}C$, (○) - backscattered α-particles. Dose of Be ions is $6\cdot10^{14}$ $cm^{-2,}$ energy is 100 keV*

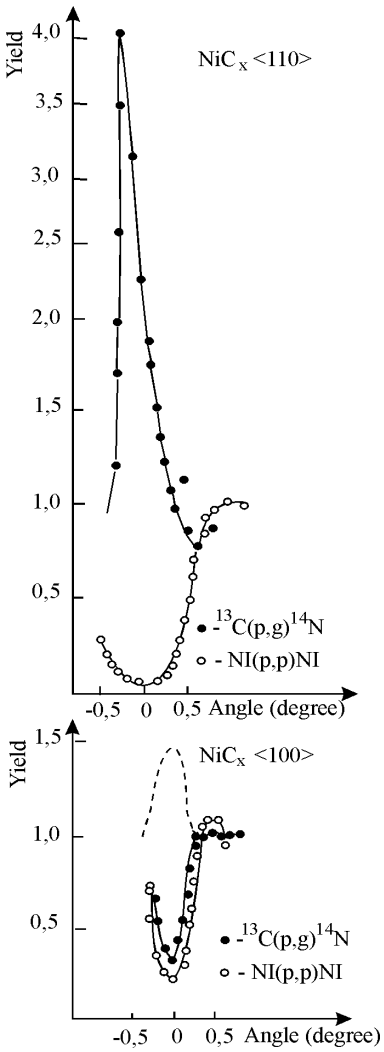

***Fig. 11.** Dependence of gamma-quantum yield from the reaction $^{13}C(p,\gamma)^{14}N$ and of back-scattered protons from the crystal Ni + 0,3 at.% ^{13}C by anglular scanning in vicinity of crystallographic axis <110> and plane (100)*

and backscattered α-particles from InSb crystal, doped with Be ions. Although, Be ion dose in this case exceeds by two order of magnitude the optimum dose, the radiation damages of a doped crystal are insignificant, as follows from these data. The γ-quantum yield from the reaction in a minimum of angular dependence is close to the yield of backscattered α-particles and the width at half-height of a hole of γ-quanta is the same as for α-particles. This means, that even in this case practically all the introduced Be atoms even in this case practically all the introduced Be atoms are electrically active.

Promising is the use of accelerators and nuclear methods for studying the structure and properties of metal oxide compounds junctions and, first of all, high-temperature superconductors (HTSC). To optimize the technology of crystals $La_{2-x}Sr_xCuO_4$ and $Nd_{2-x}Ce_xCuO_4$ a cycle of works was conducted. It is shown, that the oxygen sub lattice is disordered by 20 % relatively to sub lattices of Cu and La. A distinction in the amplitude of oscillation of atoms O1 and O2 was observed. It is established, that the rate of radiation destruction of the oxygen sub lattice is higher, than in cation sub lattices. The localization of implanted atoms of lithium and boron in $La_{2-x}Sr_xCuO_4$ is determined.

Application of nuclear methods and accelerators for study of properties ferrite-metal oxide compounds (used in magneto-optics and calculation technique - ferrite-garnet films) and in quantum electronics (ticor), essentially, only begins. It is shown, that Tl^{4+} and Tl^{3+}in the ticor lattice are disposed in tetrahedral interstitial site and interstitial site, respectively, displaced relatively to the aluminum sub lattice along direction <0001>. A position of implanted atoms of B and N in the lattice of ferrite-garnet films is determined, a type of defects and relation between the profile of radiation defects and interstitial atoms are defined, and other problems are solved, too.

Table 1. *Data of computer modeling obtained of isotopes on electrons accelerator*

Isotope	Reaction	Yield, Ci/mA(day)	kw/mA
^{57}Co	^{58}Ni(γ,p)^{57}Co, ^{58}Ni(γ,n)^{57}Ni→^{57}Co	5.8*10^{-2}	4.98
^{99}Mo	^{100}Mo(γ,n) ^{99}Mo	5.05	5.18
^{181}W	^{182}W(γ,n)^{181}W	1.24	7.60
^{185}W	^{186}W(γ,n)^{185}W	0.56	7.60

For study of peculiarities of particle channeling the specialists of KIPT offered an approach, based on the use of nuclear reaction resonances. Nuclear reactions, besides other advantages, allow studying both domains adjacent to atomic chains or to planes, and a central domain of the channel. Application of reactions with narrow resonance allowed one to study a fine structure of anomalous high radiation yields in channeling. A new method for determination of bremstrahlung energy losses of hyperchanneled particles is suggested. In Fig. 11 shown is the angular dependence of the gamma-quanta of the reaction ^{13}C(p,γ)^{14}N from the Ni crystal, containing the dissolved atoms of isotope ^{13}C and protons scattered on nuclei of Ni atoms. From these data is follows, that the C atoms in Ni crystals are disposed in octahedral interstitial sites.

7. METHODS AND TECHNOLOGIES OF ISOTOPE PRODUCTION FOR MEDICINE AT AN ELECTRON ACCELERATOR

A possibility in principle to generate isotopes for nuclear medicine in photonuclear reactions under influence of high-energy bremsstrahlung radiation produced by the electron accelerator is known for a long time. At the same time, their realizations become possible only with creation of powerful accelerators [9] and with development of required technologies [10].

Computer simulation. For analysis of efficiency of diverse isotope production, and also determining the radiation and thermal loading on the target one have developed the methods of computer simulation of the processes of interaction of accelerated electrons and bremsstrahlung-produced photons with elements of the target device [11]. Hence, the data on isotope yields in dependence on the initial electron energy and bremsstrahlung converter composition were obtained. So, in Table 1 are given the results of calculation of a daily isotope production (25 MeV, 1 mA) with using the target of natural isotope composition 10 mm in thickness.

Technology.

99Mo is a parent isotope ^{99m}Tc, providing a basic volume of analyses by the method gamma-scintigrapgy. To produce ^{99}Mo at the electron accelerator one studied two types of targets: solid (composed of a set of plates from natural Mo cooled with water) and liquid (base on a Mo solution in water solution NaOH [11]).

^{57}Co. As it is known, in Ukraine the own production of topographic gamma-chambers is arranged. For setting up and calibration of their measuring line an isotope source with radiation close to ^{99m}Tc, but with large half-life period is required. The most suitable was ^{57}Co. The Conditions of chamber calibration determine the basic requirements to the source: activity of ≈μCi and no uniformity of distribution of an exposure dose power within the working area of the chamber (400 mm in diameter) no more than 1 % with meeting the requirements of Ukraine's radiation safety standards URSS -97 as for radiation levels outside the shielding unit of the source.)

To this end we have conducted a pilot production of ^{57}Co sources. So, at the accelerator LA-20 a target was established comprising a converter of bremsstrahlung radiation in the form of two elongated plates from Ta of 1.2 mm thickness each and plates from nickel of 1.5 mm thickness and dimension 28×84 mm^2, placed immediately behind the converter. The plate, in its turn, was composed of three easy separable parts of dimension 28 ×28 mm^2. Irradiation was carried out during 100 hours at a mean value of a beam current 530 μA, pulse current 670 mA and mean value of electron energy E=28 MeV.

After exposition during 20 days (for decay of short-lived "background" isotopes) we conducted the spectrometric study of a prototype of the ^{57}Co source (plates of 28x28 mm) obtained. Its activity was 2 mCi at a total activity of background radionuclides no more than 1%.

^{181}W and ^{185}W. Production of these isotopes is supposed to be made mainly in the solid target version with continuous cooling by circulating water.

Metrological maintenance. One of basic conditions to ensure the effective and safe technology of isotope production is providing monitoring of accelerator radiation parameters and output isotope production. On the base of PC specialized system for control of bremsstrahlung radiation [12] and target activity and device for analysis of its isotope composition were developed.

Considerable possibilities of a linear electron accelerator can be realized by making isotopes for braphytherapy. In this case the samples with a high specific activity are required. The original methods of creation of high-intense γ-radiation in small volumes, developed at R&D Complex "Accelerator", allow one to produce ^{103}Pd with a specific activity of 1.5 mCi an samples of 6 mg weight. For this the reactions: ^{104}Pd(γ ,n)^{103}Pd, ($T_{1/2}$=16.9 days, Q=–10,0 MeV) are used. The abundance of ^{104}Pd is 11.4 %. The isotope ^{103}Pd is promising for prostate cure. A Pd sample with a wall thickness of 40 μm, diameter of 0.8 mm and length of 4.5 mm has weight 5.45 mg. The use a bremsstrahlung radiation beam up to attenuation in e times (μ =0,0411 cm^2/g for Pd)(one can irradiate 3300 such

samples filled with pyrocarbon (4460 are empty). The use of a moving target will allow one to obtain the activity of one samples of 110-120 MBk for an irradiation time of 34 days). After radiation cooling during 26 days a final activity of ^{103}Pd will be 1 mCi.. The activity of ^{101m}Rh in this case will be 0,1 % of the activity of ^{103}Pd.

8. PRODUCTION OF SHORT-LIVED RADIONUCLIDES

Most of radionuclides means for medical diagnostics (≈ 80 %) is pharmaceuticals based on ^{99m}Tc. However, a rather essential (and even determining in a number of cases) role in diagnostics of a various kind of diseases is assigned to pharmaceuticals tagged by radionuclides as ^{11}C, ^{13}N, ^{15}0, ^{18}F. These positron-active radionuclides are widely used all over the world as sources of annihilation gamma-radiation with the energy of 511 keV in positron-emission tomographs (PET). In connection with growing interest to the PET-technique and efforts undertaken for creation of a tomograph in NSC KIPT, it is expedient to study capabilities of production of short-lived radionuclides on the available electron linacs of NSC KIPT.

The investigation are undertaken with the purpose of obtaining the experimental data about the values of specific activity of short-lived radionuclides on particular targets in the operating 25 MeV linear accelerator of electrons "EPOS" with the beam power 10-20 kW.

Experiments were performed to determine the specific activities (Bq/g·μA) of ^{11}C, ^{13}N, ^{15}0, ^{18}F radionuclides of medical purpose for PET (positron-emission topography) which are realized under conditions of the electron linear accelerator LU-20 "EPOS" with power ≅ 20 kW. For this the following substances were used as targets: water (in glass capsules of 2 cm^2 for medical purpose), powders of boron acid H_3BO_3 and boron nitride BN, films of fluoroplastic C_2F_4, and polyethylene $(C_2H_2)_n$,. The powders were packed in containers from aluminum of 0.1 mm thick and 20 mm diameter. The films of fluoroplastic and polyethylene were in the form of disks of 16 mm diameter and manufactured from the tape of 0.2 mm thick. The samples were weighted with the analytical balance to the nearest ± 5mg; the reference density values for materials being irradiated have been used. The target-samples prepared were mounted in the assembly with dimensions 25×40 mm^2, which was placed onto the electron beam directly behind the lead converter of 2 mm thick. Especially for these works on the accelerator the following radiation conditions were created: electron energy – 25 MeV; average current – 400 μA; area of beam under scanning - 80×300 mm^2; irradiation time – 10 min.

The specific activity was determined on the measuring spectrometric bench for the counting rate (pulse/sec) of irradiated samples having the known chemical composition and weight and the known density of accelerated electron current.

Spectrometric bench is equipped with a Ge(Li)-detector, electronics in CAMAC standard and computer IBM PC Pentium-133. The measured activity values were corrected for the detector efficiency in the given measurement geometry and for the dead time. After processing of all experimentally obtained spectra the decay curve was plotted over the values of counting sum under the photoabsorption peak (with taking into account the background). By the use of the program REGRESS the experimental data were fitted by the curve of the form $A_1=A\cdot\exp(-\lambda t)$, where λ is the decay constant, t is the time from the irradiation stopping, A - measured activity on moment t, A_1.- is the activity in a moment of irradiation stopping. Besides, the measurement errors were calculated with regard to the main factors. Specific activity is:

$$A_0 = \frac{A_1}{\eta \cdot m \cdot S \cdot J \cdot k}$$

(Bq/g μA), where *m* and *S* are mass and area of the sample, J is the mean current density' on the converter (μA/cm^2), η is the detector efficiency with taking into account the solid angle, k is the multiplicity- coefficient of γ-quanta, A_1 is the activity of the sample in a moment of irradiation stopping. Under irradiation condition note above the position-emitting radionuclides ^{11}C, ^{13}N, ^{15}0, ^{18}F with specific activity (in Bq/g·μA) $1.9\cdot10^7$; $1.67\cdot10^6$; $2.5\cdot10^6$; $I.7\cdot IO^6$ respectively are obtained.

A comparison between the experimental data on production of isotopes ^{11}C, ^{13}N, ^{15}0, ^{18}F and calculation results of other authors was done. This comparison shows that the experimental values of specific activities of ^{11}C, ^{13}N, ^{15}O are in satisfactory agreement with calculation data of Mac Gregor and Lutz.

However, the distinctions between calculated and measured activity- values can be explained by differences in the irradiation geometry for different authors as well as by uncertainties in the bremsstrahlung spectrum.

The observed exceeding (approximately by a factor of 5) of the experimental value of radionuclide ^{18}F production as compared to the calculated one is related to the contribution of the process of production from neutrons according to the reaction ^{19}F(n,2n)^{18}F that can take place under conditions of the "EPOS" accelerator.

In Table 2 the comparative data on production ^{15}O in various accelerators of electrons are given. One can see that the production of ^{15}O on the accelerator "EPOS" in 200 cm^3 of a water for 10 minutes of irradiation is 26 times more, than is required (5 mCi) for examination of one patient.

The data are shown that 25 MeV electron linac with power of the beam about 20 kW able to meet competition with cyclotron in short-lived isotopes for PET and ^{99m}Tc production. Additional advantages of the electron linac application for medical radionuclides production is its comparability with other traditional accelerators programs such as sterilization, activation analysis, radiation modification of polymers and semiconductors etc. A rather low cost of the electron accelerator with the beam power ≈ 20 kW creates some additional perspectives. It allows one to use an "electron linac" not only as a tool for production of short-lived radionuclides for diagnostics in a combination with PET, but also for sterilization, gamma-therapy, and for creation of a multi-purpose source of neutrons with a flow of ≈10^{13} n/s. thus expanding both scientific and applied capabilities of radiation technology.

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Table 2

Source of information	Linac "Fakel" Kurchatov IAE, Moscow	Linac-30 MeV Center of Nuclear Medicine. USA. Cincinnati	Linac "EPOS" NSC KIPT, Kharkov
Conditions ofirradiation	E_0=30 MeV I_{av}=l00 μA T_{irr}=7 min V=200 cm^3	E_0=26 MeV I_{av}=l00 μA T_{irr}=4 min V=500 cm^3 6×18 cm	E_0=25 MeV I_{av}=l00 μA T_{irr}=10 min V=200 cm^3
Integral activity ina moment of the end of irradiation	700 mCi	184 mCi	130 mCi (recalculation to 1 cm^3)

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