The relative position of the accelerating electrodes and spiral sectors is shown on Fig.3. The first calculations have shown, that for Z-focusing on first turns more preferable dee with angular extent of 90° instead of 60°. The necessary isochronous magnetic field is submitted on Fig.2. The range of phases acceptable for acceleration makes 40° and has been determined basically by conditions of Z-movement. The central phase of a range is determined by a maximum energy gain after 60 revolutions. On Fig.4 the particle energy for an optimum phase of acceleration on during of 60 revolutions is submitted. Linear low of energy increase confirms an isohronism of a chosen magnetic field. On Fig.5 uncentring of orbits on dependence of the turns number is submitted. According to a presented data, the centre of curvature coincides a centre of a magnetic field with accuracy of 10 mm at $N = 60$ turns $E = 14$ MeV and $R = 400$ mm. Z-movement of a particle with a optimum phase of acceleration is submitted on Fig.6. In the present report the first preliminary data on particles dynamics in the central region of isohronous cyclotron GIC are presented. The further progress is connected to refinement of electrical field distribution on first turns and introduction of a corresponding corrections in the program.

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LOW ENERGY ACCELERATORS OF PNPI AND THEIR USING IN SCIENTIFIC AND APPLIED RESEARCHES

V. M. Lebedev, V. A. Smolin, B. B. Tokarev

There are some working accelerators in the PNPI: electrostatic accelerator (ESA) [1] and neutron generator (NG)[2]. The machines of such a type are used widely both in scientific and in applied investigations [3]. The researche works in the fields of solid state physics, radiation physics, radiobiology, element analysis of the matter are been leading in these accelerators. The base parameters of the accelerators are given in the tables 1, 2. Their opportunities have been broadened during the last years: in ESA deuterium and electron beams have been developed, in NG fast air-powered target transportation has been made.

The ESA is shown draftly in Fig.1. The ion tract with the length 15 m has ion-optical elements, beam control devices and analyzing magnet that makes it possible to form and to lead to the target ion beam with desired size and intensity as well as to stabilize its energy [1].

Table 1

ESA parameters

accelerating particles	p,d,e^-
partical energy	(0.3 - 1.8) MeV
energy stability $\delta E/E$:	
for p and d	10^{-4}
for e^-	10^{-2}
beam intensity on the target:	
for p and d	from 1 nA to 30 μA
for e^-	from 1 nA to 150 μA
beam diameter on the target:	
for p and d	(1 - 8) mm
for e^-	10 mm
vacuum	10^{-6} Torr

Table 2

NG parameters

type reaction	T(d,n)^{4}He
neutron yield (E_n =14.2 MeV)	$\leq 2 \cdot 10^{12} s^{-1}$
neutron flux	$\leq 10^{11}$ n/cm$^2 \cdot$ s
time of double degradation of neutron yield	2 h
deuteron energy	160 keV
deuteron current	$\leq$ 20 mA
beam diameter on target	(10-20)mm
radioactivity of the tritium target	$\leq$ 150 Ci
rotation velocity of target	1000 min^{-1}
power on target	$\leq$ 4 kW
vacuum	10^{-6} Torr
transportation time of irradiated targets	1.5 s

The scheme of the NG is shown in Fig.2. 14 MeV monoenergetic neutrons are obtained in the T(d,n)^{4}He reaction by irradiating tritium target 160 keV accelerated deuterons. The heat on the target (in our case 4kW/cm^2) is taken off with the help of the rotating vacuum tightening up, as in most modern generators. The speed of the rotating target is 1000 min^{-1} [2].

The vacuum in the accelerators is free of oil and is made by means of sputter-ion pumps.

The main parameters of the described accelerators – energy stability of ESA $\Delta E/E = 10^{-4}$ and neutron yields of NG $2 \cdot 10^{12}$ n/s correspond the modern level of the devices [4].

On the base of such a type accelerators the nondestructive nuclear-physical methods of element matter analysis were developed and applied in PNPI. These methods were ion roentgenspectral analysis (PIXE), nuclear reactions (NR), rutherford back scattering (RBS), neutron-activation analysis (NAA) including short-lived nuclei.

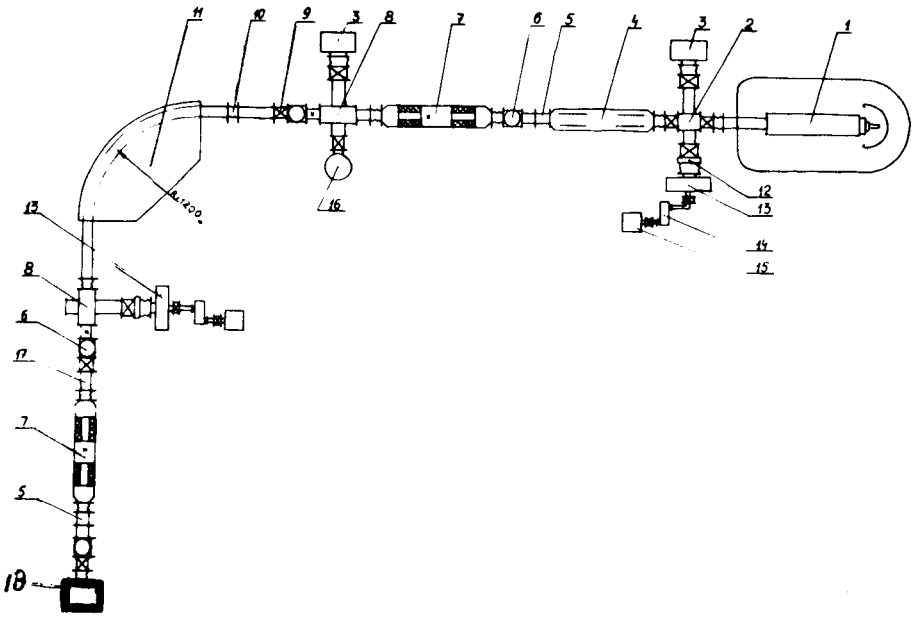

Fig.1. General scheme of the ESA:
1 — accelerating tube and high pressure tank; *2* — vacuum system; *3,13,15,16* — pumps; *4* — electrocorrector; *5* — slit device; *6* — beam control devices; *7* — electromagnetic quadrupole lens; *8* — vacuum system; *9* — vacuum valve; *10* — vacuum connector; *11* — magnet; *12,14* — liquid nitrogen traps; *17* — tube; *18* — camera

The experimental installation for elemental analysis consists of the target chamber, Si(Li)- and crystal-diffraction spectrometers for X-rays, planar Si-detectors for ions and Ge(Li)-spectrometer for gamma-rays. Spectra from the detectors are measured with CAMAC electronics and are stored on a computer.

The detailed describtion of these methods, their analytical characteristics for solving problems are pointed in [5–7].

The PIXE, the NR and the RBS methods have a high precision and sensitivity. Adding to each other, they make it possible to determine elements from Li to U. The synthesis of these methods in the single installation gives an opportunity to receive the detailed information about the structure and compound of the investigating samples in one experiment.

These methods were used for the investigation of the element depth distribution in surface layers of the different materials such as fluorine-contained glasses [8], manylayers HTSC-structures [9], semiconductive films of InP [10] and etc.

In separate cases the association of the possibilities ESA and NG gives an opportunity to receive the information about the content of element both in surface layer and in sample volume.

For the first time it was realyzed in the case of the precision content determination of oxygen in the HTSC ceramics [7].

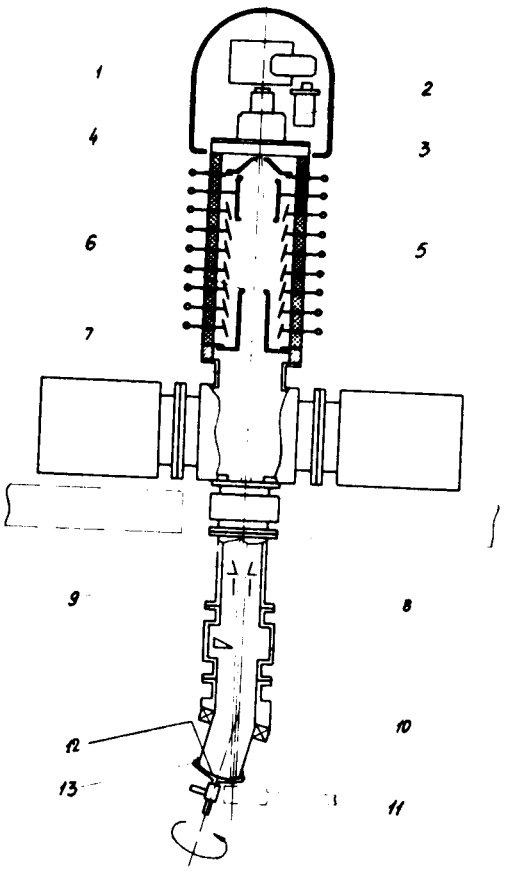

Fig.2. Scheme of the NG: *1* — ion source; *2* — palladium filter; *3,4* — extracting and focusing electrodes; *5* — accelerating tube; *6* — accelerating electrode; *7* — vacuum chamber with pumps; *8* — vacuum valve; *9* — limiting diaphragm; *10* — beam interrupter; *11* — rotating vacuum connector; *12* — target; *13* — target cooling system

The radiobiology works [11] and the works concerning radiative semyconductive physics [12] were made on the accelerators beams. The precision, the sensitivity and the resolution over the depth of the developed methods correspond to a modern level. These methods are applied in investigations of new and superpure materials, in high technologies, in semiconductive technique and etc.

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NUCLEAR MICROANALYSIS AT PNPI ELECTROSTATIC ACCELERATOR

V. M. Lebedev, V. A. Smolin

The light ione beams have been used widely for microanalysis of solids by means of nuclear physics techniques: proton indused X-ray emission [PIXE], nuclear reaction analysis [NR] and Rutherford backscattering spectrometry [RBS]. Element composition of the bulk materials, the structure of the films and the outer layers of the solid, concentration profiles are generally considered in microanalysis of solids. The RBS and NR methods have been used for investigation of interactions of layers in multilayer multielement structures. Also detection of trace elements is actual too.

The experimental installation for element analysis was designed at PNPI electrostatic accelerator. It consists of the target chamber, Si(Li)- and crystal-diffraction spectrometers for X-rays [1], planar Si detectors for ions [2] and Ge(Li)-spectrometer for γ-rays. Spectra from the detectors are collected with CAMAC electronics and stored on MERA-60 and SM-1425 computers. The parameters of the experimental installation are given in Table 1.

The nuclear physics techniques are undestructive, highsensitive and precise. However the possibilities of the PIXE, RBS and NR methods for detection of elements with low and high atomic numbers and for measurement of their contents in the sample are different. The RBS is more sensitive to heavy elements (with atomic number Z greater then 30). In favorable cases 10^{12} at/sm^2 can be detected. In spite of the lower sensitivity for high Z elements the PIXE can give better element resolution then RBS. Nuclear reactions are ideal for the detection of low Z ($Z < 16$) impurities and hence complement RBS and PIXE. The RBS and NR techniques can give depth distribution of elements in a sample.

The simultaneous usage of these methods allows to obtaine detail and precise information on element composition from one experiment. Analytical characteristics of nuclear technigues are given in Table 2.