ACCELERATING OF INTENSE BEAMS OF LIGHT IONS AT THE MILAC

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Multicharged ion linear accelerator (MILAC) can be used for effective radionuclide production at NSC KIPT. Currently it is used at short time due to financial difficulties. Basic characteristics of the MILAC are given in Table 1 [1, 2].

Table 1

Parameters of the MILAC

	POS-15	POS-4	main section
Input energy of ions, keV/u	33.3	18.75	975
Output energy of ions, keV/u	975	975	8500
Mass-to-charge ratio, A/q	15	4	5
Operating frequency, MHz	47.2	47.2	47.2
Electric field in gaps, MV/m	91	90	93
Length of accelerating structure, m	4.0	1.2	11.2
Number of drift tubes	46	14	40
Aperture of drift tubes, mm	15-24	16-28	30
Synchr. phase of the bunching regions, deg.	-16	-40	-30
Synchr. phase of the focusing regions, deg.		45	
Number of bunching regions		4	
Number of focusing regions		3	
Acceleration rate, MeV/m	3.5	3	3.3
Longitudinal capture, deg.	48	120	90
Longitudinal acceptance, π·(keV/u)mrad		2440	
Radial acceptance, mm mrad		3100	
Normalized radial acceptance, π mm mrad		2.4	
Duty factor %	0.1	2.5	0.1
Pulse RF power kW	400	2400	300

This accelerator contains two parts: prestripping section (PSS), poststripping main section (MS) designed for energy 0.975 MeV/u and 8.5 MeV/u, respectively. General view of the MILAC is shown in Fig.1.

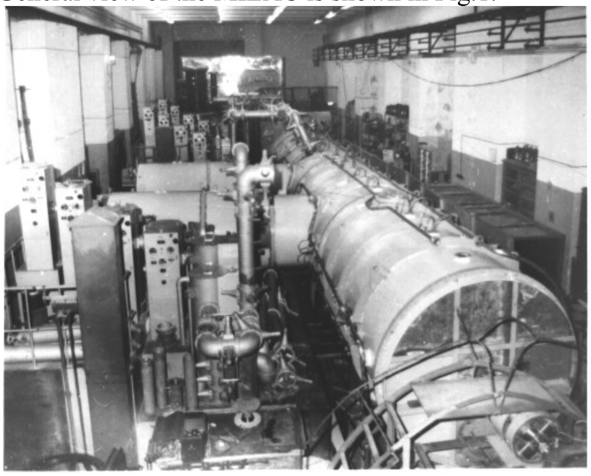

Fig.1. General view of the MILAC.

Effective production of radionuclides can be established in NSC KIPT on the basis of the existing 8.5 MeV/u heavy ion accelerator. For this purpose its upgrading is necessary. Existing prestripper of the linear accelerator of multi-charged ions (MILAC) is designed for accelerating heavy ions with a mass-to-charge ratio A/q≤15. At the same time, it can not accelerate very light ions (p, d, ^{3}He, ^{4}He). Therefore, a new small cavity for only accelerating of these particles from the energy of 37.5 keV/n to the energy of 1MeV/u is designed for the average beam current to 1mA might be built next to the existing prestripper. Such beam (after stripping of $^4He^+$ to $^4He^{2+}$) will be admitted to the existing poststripper by the parallel shift, and will be accelerated to 8.5 MeV/u. Hence, there are no principle limitations for acceleration of protons to the total energy of 8.5 MeV/u, deuterons to 17 MeV, ^{3}He to 26 MeV and ^{4}He to 34 MeV. At the same time, decrease of designed for prestripper A/q from 5 to 1 (for protons) or 2 (for deuterium and helium) will allow the poststripper operation in the facilitated mode of RF-power. Currently, for proton acceleration the energy consumption will be 25 times less, and for deuterium and helium 6.25 times less than the RF-power present level. This will allow to increase considerably the duty factor (pulse frequency and length) that will provide a possibility to obtain average proton beam currents up to 1 mA, and for deuterium and helium ions - close to 0.5mA. Such intensity is not achieved at any known accelerator operating for the radionuclide production.

In nowadays nuclear medicine used are more than 50 radionuclides with the half-life from several minutes to several years obtained at accelerators for research, diagnostics and treatment. Among them there are ultra short-lived isotopes ^{11}Ñ, ^{13}N, ^{15}O, ^{18}F, some of gamma-emitter ^{123}I, ^{211}Tl, ^{67}Ga, ^{111}In, radionuclide generator ^{81}Rb/^{81m}Kr, ^{82}Sr/^{82}Rb, ^{99}Mo/^{99m}Tc and others. The ^{99}Mo can be obtained both at reactors, and at accelerators. Among the most promising there are ^{26}Al, ^{52}Fe, ^{67}Cu, ^{75,77}Br, ^{97}Ru, ^{211}At, ^{237}Pu and others. At various nuclear centers the programs of production of radionuclides on basis of accelerators are developed.

Information about accelerators set at different centers, their parameters, and consumption for radionyclides producing is available from transactions of international conferences on application of accelerators [3,4,5]. The recent data analysis shows that the feasibility of accelerators for applied problems continually increases.

The basis of commercial production of radionuclides over a wide range is cyclotrons of two types; baby cyclotrons (E≤20 MeV) and high-intensity compact cyclotron (E≤42 MeV). The ntensity of accelerated ion beam of protons, deuterons or alpha-particles is close to 200 μA. The electrostatic accelerator of protons and deuterons with energy of 3.7 MeV and current of 750 μA designed in USA for ultra short-lived radionuclides obtaining in curie amounts is known too.[6].

The radionuclides are need in the Ukraine to perform diagnostics and treatment of oncologic diseases. At the present time a rise of the thyroid gland and blood cancer rate, especially in children, is observed. There are 27 oncologic departments in 27 region hospitals. Besides, there are 27 special-purpose oncologic hospitals. As one can see, the need in radionuclides for diagnostics and treatment is great. At the present time the Ukraine only purchases the ^{131}I nuclide. There is not production of radionuclides in the Ukraine, though it is planned to obtain them at the cyclotrons U-120 and U-340 at the Institute of Nuclear Research (Kyiv). The cyclotrons are not operating now because of the financial problems. Even in the case of their putting into operation the cyclotrons won't be able to serve the demand of the Ukraine in the radionuclides.

Now at the NSC KIPT the production of radionuclides based on photonuclear reactions is established. The electron accelerator for the energy in the range of 30-40MeV is used for this purpose. However, the cross-section of nuclear reactions for light incident ions is considerably lower than that of heavy particles.

Some modernization of MILAC heavy ion accelerator will give a possibility to produce a large number of radionuclides for medicine.

Most of them will be obtained with ^{4}Iå ion beam which intensity at the output of the MILAC will be equal 0.5 mA. The total ion energy being 34 MeV, the considerable beam current and the highest reaction section for these particles will give a possibility to obtain radionuclides in Curie amounts.

At present, ^{99m}Tc is of the greatest commercial interest. It is produced mainly by irradiation of ^{98}Mo target with thermal neutrons at the reactor with subsequent β-decay with half-life period 65hours. At the same time, ^{99m}Tc has relatively small half-life period (about 6 hours) with γ-irradiation. ^{99m}Tc can be produced also with the use of protons accelerated to 15 MeV from the ^{10}Mo(p, 2n) ^{99m}Tc.

^{103}Pd is most generally used in nuclear medicine. It is produced at accelerators from the ^{100}Ru(α, n) ^{103}Pd reaction where the α-particle energy is 15-20MeV. The cost of 1μCi is $8. With the beam current 100μA yield of ^{103}Pd will be 1Ci is obtained in 16 hour exposition.

^{201}Tl is of the particular interest due to γ-irradiator using for cardiac diagnostics. It is produced from ^{203}Hg(p, 3n)^{201}Tl reaction with proton energy 22-30 MeV. The half-life time is 73 hours. In addition to mentioned above radionuclides ^{67}Ga, ^{81m}Cr, ^{89}Sr, ^{138}Xe, ^{131}I, ^{123}I, ^{125}I and ^{198}Au and several super short-lived radionuclides are extensively used at the positron emission tomograph, ^{11}C, ^{13}N, ^{15}O, and, in particular, ^{18}F are of the commercial interest. Due to the short life-time they can be used for diagnostics of diseases in the immediate vicinity of the accelerator.

Among the most promising radionuclides, which would be produced at the MILAC are ^{58m}Co, ^{103m}Ru, ^{119}Sb, ^{161}Ho, ^{189m}Os, ^{90}Y, ^{111}In. Their transition to the ground level occurs due to e-capture with radiation of low-energy Auger-electrons. When introduced to malignant cells this radionuclide causes their destruction without damaging nearby Development of a new prestripping section (PSS-4) capable to accelerate light ions with the beam current of 0.5-1 mA is not a complicated problem in principle. The RF-power supply system available at the MILAC accelerator is capable to provide the beam duty-factor of 2.5%. The pulse current of 20-40 mA may be achieved with the use of the principle of alternating–phase focusing with the beam moving center. This principle is outlined in [7, 8]. Calculations of the accelerating structure of the PSS-4 and beam dynamics were fulfilled. Parameters of the accelerating structure are given in the Table. In the course of optimization of the radial-phase stability in the accelerating structure of the interdigital type excited at H_{111}-wave a version of an accelerator being cheap, simple in construction and adequate in power demands was developed.

The PSS-4 accelerating structure is designed for acceleration of ions with A/q ratio =4 from 18.75 to 975 keV/n. The operating frequency is 47.25 Hz, as in the main section. The length of accelerating structure is about 1.2m for the field 9MeV/m in the gaps between drift tubes. In the cavity of 100 cm in diameter there are 17 drift tubes mounted on rods with interdigital configuration. Four bunching and three focusing sections provide the normalized radial acceptance of 2π mm·mrad and longitudinal beam capture of 120^{o}.

The separatrix and bunch phase picture at the PSS-4 output is given in Fig.2 and 3, respectively. Radial trajectories of particles with input parameters (r = 1, 2, 3 and 4 mm, r′ = 6, -3, 0, +3 and +6 mrad) along bunching and focusing sections are given in Fig.4, and the total radial acceptance of PSS-4 is given in Fig.5. The obtained radial and phase characteristics of the beam at the PSS-4 output provides a possibility to capture it to strong-focusing channel of the main MILAC section.

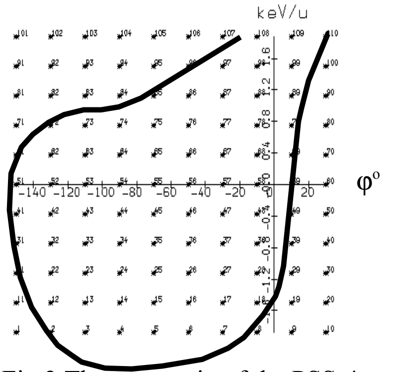

Fig.2 The separatrix of the PSS-4.

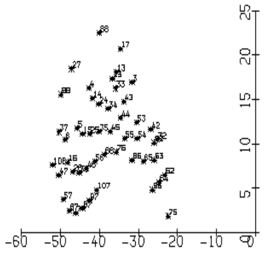

Fig.3. Bunch phase picture at the PSS-4 output.

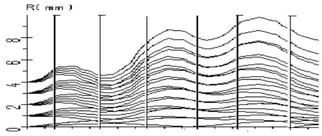

Fig.4. Radial trajectories of particles along bunching and focusing regionsPSS-4.

mm / mrad	-8	-7	-6	-5	-4	-3	-2	-1	0	1	2	3	4	5	6	7	8
54		**0**	**0**	**0**	**0**												
48	**0**	**0**	**0**	**0**	**0**	**0**	**0**										
42	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**									
36	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**								
30		**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**							
24		**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**						
18		**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**					
12			**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**		**0**		
6			**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**			
0			**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**		
-6				**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**		
-12			**0**		**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**		
-18						**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	
-24							**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	
-30								**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	
-36										**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
-42										**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
-48											**0**	**0**	**0**	**0**	**0**	**0**	**0**
-54													**0**	**0**	**0**	**0**	**0**

Fig.5. Radial acceptance of PSS-4.

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