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NEW NUCLOTRON BEAM LINES AND STATIONS FOR APPLIED RESEARCHES

E. Syresin, A. Baldin, A. Butenko, G. Filatov, A. Slivin, G. Timoshenko, G. Trubnikov, A. Tuzikov, Joint Institute for Nuclear Research, Dubna, Russia

M. Kats, T. Kulevoy, D. Liakin, Y. Titarenko, Institute for Theoretical and Experimental Physics of National Research Centre, Kurchatov Institute, Moscow, Russia

D. Bobrovskiy, A. Chumakov, National Research Nuclear University, Moscow Engineering Physics Institute, Moscow, Russia.

Abstract

New beamlines for applied researches on the Nuclotron are under development within the framework of implementation of the NICA accelerator facility. Ion beams with energies of 150-800 MeV/n extracted from the Nuclotron will be used for radiobiological researches and modeling of cosmic rays interactions with microchips. Equipment of two experimental stations is under development by the JINR-ITEP-MEPhi collaboration for these applied researches. Ion beams with the energy of 3.2 MeV/n extracted from the heavy ion linac HILAc will also be used for irradiation and testing of microchips. The specialized channel will be reconstructed for investigations in the field of relativistic nuclear power at light ion energies of 0.3-4.5 GeV/n. Three new experimental areas are organized for applied physics researches within the framework of implementation of the NICA accelerator facility.

APPLIED RESEARCHES AT NICA

The NICA accelerator complex [1] is under construction and commissioning at JINR. NICA experiments will be aimed at searching for the mixed phase of baryonic matter and investigations of nucleon/particle spin.

Three new areas are organized for applied researches within the of NICA project. Special area-1 will be developed for investigations of radiation damages in microelectronics based on a heavy ion linac (HILAc). Heavy ions with the energy of 3.2 MeV/u will be used for irradiation of decapsulation microchips. Area-2 is created for Nuclotron extracted beams at medium energies of 150-800 MeV/u [2]. Two stations are under development for radiobiological researches and tests of microelectronis that suffered radiation damage by heavy ions. The new Nuclotron transport beamlines will be created for these stations. Special area-3 will be constructed for relativistic nuclear power and utilization of radioactive waste [3] at light ion energy 0.3-4.5 GeV/n.

CHIP IRRADIATION BY LOW ENERGY IONS

Within the framework of the NICA project, the SOCIT station is created for chip irradiation by short-range ions extracted from the HILAc at the energy of 3.2 MeV/n. The HILAc-Booster beamline (Figure 1) will be used for beam transportation to SOCIT. A dipole magnet will be installed in the middle of this channel to deflect the ion beams to SOCIT (Figure 2).

Figure 1: The HILAc-booster beamline.

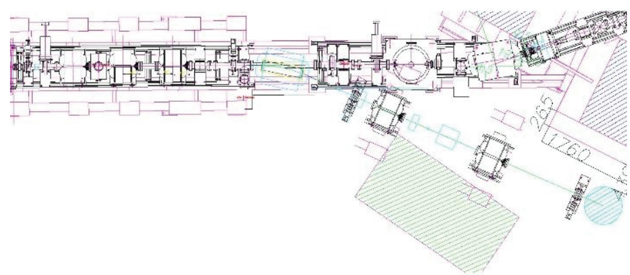

Figure 2: The sketch of the HILAc-SOCIT applied research beamline.

The ion energy after the HILAc is insufficient to pass through the microchip-surrounded capsule. Therefore, the chip decapsulation will be done before its irradiation. The $^{197}Au^{79+}$ ions provide the linear energy transfer (LET) of 95 MeV×cm^2/mg in the silicon chip at the energy of 3.2 MeV/n. The maximum ionization dose rate during one HILAc beam pulse should be less than 10^6 rad/s in the silicon chip. This requires to reduction of the beam current from milliamperes after the HILAc to several tenth of nanoamperes at the chip irradiation. A diaphragm with several holes of 20 μm in diameter will be installed in front of the triplet of quadrupoles in the HILAc-Booster channel to reduce the beam current by five orders of magnitude. The HILAc-SOCIT channel optics involves a triplet of quadrupole lenses, a dipole magnet, and two quadrupole lenses. It permits formation of the round-shaped ion beam

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with the FWHM size of 70 mm on the irradiation target (Figure 3). The beam inhomogeneity is less than 10% at the chip target size of 30 mm.

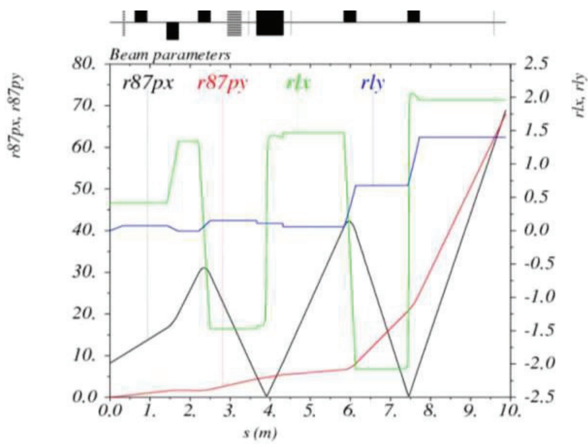

Figure 3: Dependences of horizontal and vertical beam sizes (95% of particles) on the beamline longitudinal coordinate.

The vacuum pressure in the SOCIT will be less than 10^{-5} Torr and 3 orders of magnitude higher than the pressure of 10^{-8} Torr in the HILAc-Booster channel. The HILAc-SOCIT channel should be designed to allow differential pumping in the area behind the dipole-deflecting magnet and prevent heavy gases like CO and H_2O leaving SOCIT and penetrating to the HILAc-Booster channel. To solve these problems, a cryogenic trap, a pulsed diaphragm crossing vacuum chamber and pumps will be installed in this applied channel behind the deflection dipole magnet.

The beam diagnostics will operate in the "tuning" and "irradiation" modes. The diagnostic equipment is designed to measure the following beam characteristics: the ion flux density, the flux, the fluence and the beam profiles.

NEW NUCLOTRON BEAMLINES

Area-2 is under development for applied researches with the extracted Nuclotron beams with medium energies of 150 -800 MeV/u. The old part of the Nuclotron channel consists of the septum, the Lambertson magnet, the triplet of quadrupole lenses, the duplet of lenses, and the vertical deflection dipole magnet. Two new beamlines will be constructed for radiobiological researches and chip irradiations. The new part of each channel involves an SP-94 dipole magnet, two doublets of quadrupole lenses, and a pair of scanning magnets (Figure 4). Two deflection dipole magnets SP-94 are used for beam transportation to both stations. The maximal magnetic field in these magnets is 1.5 T (Figure 5), and the length of the magnets is about 1.3 m. The scanning vertical and horizontal magnets serve to from a uniform dose distribution with a large target area of 200×200 mm. The horizontal and vertical beam sizes are shown in Figure 6.

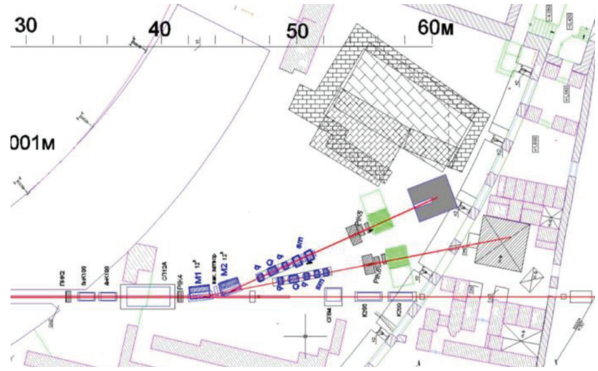

Figure 4: The new Nuclotron beamlines applied for radiobiological researches and chip irradiations.

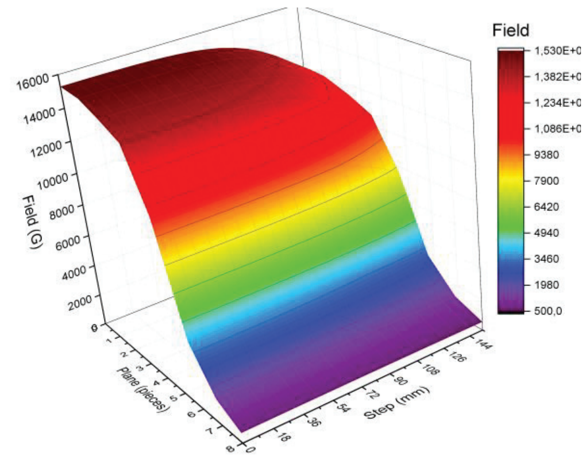

Figure 5: 3D map of the magnetic field for the SP-94 dipole magnet used in the new Nuclotron applied beamlines.

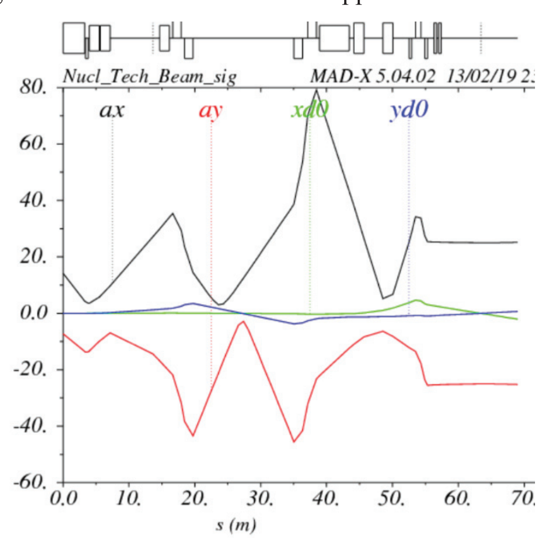

Figure 6: Dependence of the horizontal and vertical beam sizes (95% of particles) on the longitudinal coordinate of the Nuclotron beamline.

Heavy ion beams extracted from the Nuclotron will be used for irradiation of capsulated chips. The ions like $^{131}Xe^{54+}$ and $^{197}Au^{79+}$ at the energy of 150-200 MeV/u are decelerated in the surrounded microchip capsule to the energy of 5-10 MeV/u corresponding to the Bragg peak.

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The LET is 60-70 MeV×cm^2/mg for $^{197}Au^{79}$ ions in the Si chip for this energy. A reduction of LET (Figure 7) at capsulated chip irradiation results from the straggling effect at the ion energy degradation in the chip capsule. The second problem in capsulated chip irradiation is related to production of secondary particles in its capsule (Figure 8).

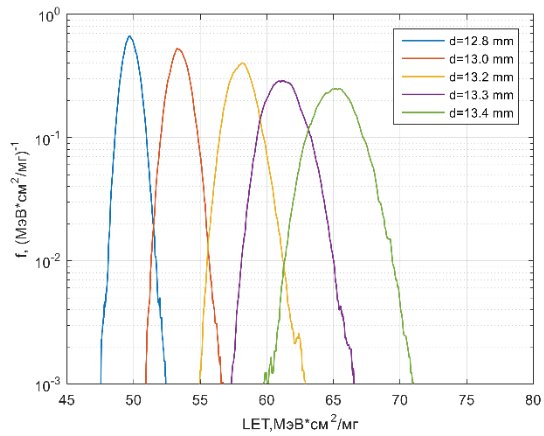

Figure 7: Spectrum of LET in the Si chip for 197Au79+ ions at the initial energy of 250 MeV/u after their deceleration in the polyethylene degraders of different thickness.

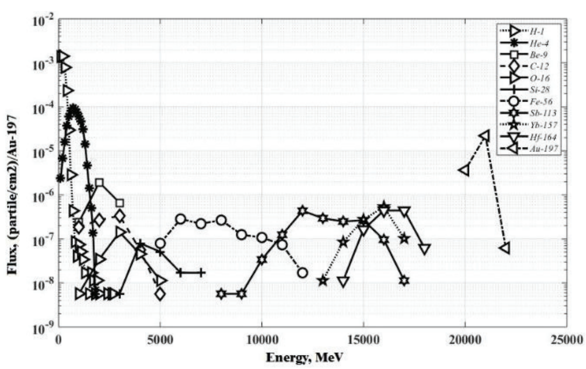

Figure 8: Spectrum of secondary particles at the ion energy degradation in the chip capsule.

Beam diagnostics will operate in the “tuning” and “irradiation” modes. The diagnostics provides measurements of the following parameters at the chip irradiation: the ion beam profiles, the primary ion fluence, the primary ion density flux, the secondary particle density flux and the radiation dose.

The accelerator-based researches in radiobiology are important for improving radiotherapy and ensuring protection in cosmic space. Heavy ions extracted from the Nuclotron at the energy of 0.5-0.8 GeV/u are a tool for modeling biological action of cosmic space radiation. Heavy charged particles from Galaxy are the most dangerous type of cosmic radiation. The more probable energy of the the galactic bare nuclei corresponds to 0.5-0.8 GeV/n. Exposure to the galactic heavy ions may cause incidence of cancer and formation of genetic and structural mutations, violation of visual functions, lesions of retina, and incidence of a cataract. Different ion beams extracted from the Nuclotron can be used for producing a typical dose of one Gy required for radiobiological researches.

The equipment of the radiobiological station permits ion irradiation of biological samples and animals like rats and monkeys. A uniform dose distribution will be formed in the target with the maximal size of 100×100 mm and depth of 100 mm. Scanning magnets are used for this dose formation. The diagnostic system is used for measuring of the ion flux, the horizontal and vertical profiles and controlling the beam position relative to the target optical axes, dose space distribution and received dose.

The specialized channel will be reconstructed for relativistic nuclear power and ADS. Instead of proton beams, light ion beams with the energy of 0.3-4.5 GeV/n are planned to be used for ADS the research program on the Nuclotron. Light ions extracted from the Nuclotron have a short path in the target, which reduces the probability of inelastic nuclear interactions and the required beam power for ADS.

Reconstruction of the channel for nuclear power includes the construction of new beamline equipment, construction of radiation protection shielding in the target area, development of a new diagnostic system as for both monitoring of the beam parameters and measurements of the target temperature fields and space distribution of neutrons inside and outside of the target.

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