ISBN: 978-3-95450-240-0 ISSN: 2673-5539 doi:10.18429/JACoW-RuPAC2021-MOPSA29

APPLIED RESEARCH STATIONS AND NEW BEAM TRANSFER LINES AT THE NICA ACCELERATOR COMPLEX*

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Abstract

Applied research at the NICA accelerator complex include the following areas that are under construction: single event effects testing on capsulated microchips (energy range of 150-500 MeV/n) at the Irradiation Setup for Components of Radioelectronic Apparature (ISCRA) and on decapsulated microchips (ion energy up to 3,2 MeV/n) at the Station of CHip Irradiation (SOCHI), space radiobiological research and modelling of influence of heavy charged particles on cognitive functions of the brain of small laboratory animals and primates (energy range 500-1000 MeV/n) at the Setup for Investigation of Medical Biological Objects (SIMBO). Description of main systems and beam parameters at the ISCRA, SOCHI and SIMBO applied research stations is presented. The new beam transfer lines from the Nuclotron to ISCRA and SIMBO stations, and from HILAC to SOCHI station are being constructed. Description of the transfer lines layout, the magnets and diagnostic detectors, results of the beam dynamics simulations are described given.

INTRODUCTION

NICA (Nuclotron-based Ion Collider fAcility) is a new accelerator complex being constructed at the Laboratory of High Energy Physics of the Joint Institute for Nuclear Research [1]. Within the framework of the NICA project, it is planned to create three experimental stations for conducting of applied research with long-range ion beams extracted from the Nuclotron, and short-range ion beams extracted from the heavy ion linear accelerator (HILAC) [2].

NEW BEAM LINES IN MEASUREMENT HALL OF VBLHEP JINR

Two new areas are organized within the framework of the NICA applied research program.

* Work supported by grant for young scientists. Unique id 21-102-09
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Special area 1 includes beam channel (Fig. 1) to SOCHI station.

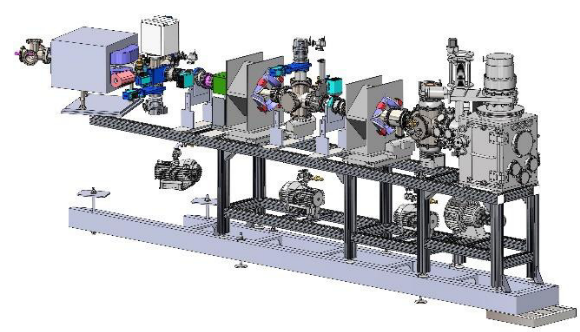

Figure 1: SOCHI beam channel design.

Special area 2 includes two beam channels to SIMBO and ISCRA stations. Beam channels are being developed as part of the JINR-SIGMAPHI collaboration. These channels will be integrated into the existing Nuclotron-to-VP-1 extraction beam line (Fig. 2).

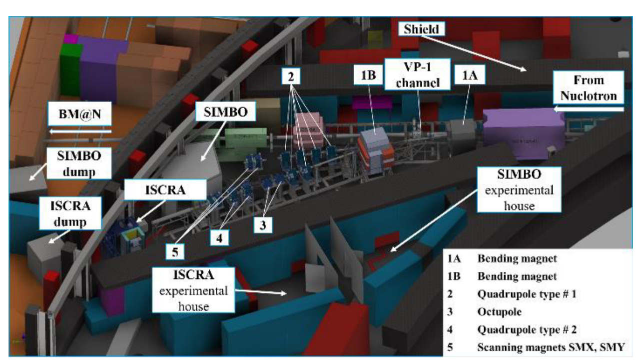

Figure 2: Area 2 infrastructure layout.

BEAM DYNAMICS SIMULATIONS

One of the main conditions required for irradiation of samples is the beam distribution homogeneity at the target area.

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In the SOCHI channel, a 73-mm-wide beam is shaped by quadrupole magnets. The beam envelope in the SOCHI beam line is presented in [3].

In the ISCRA channel two octupole magnets are required to shape the beam profile in the non-scanning mode. The particles distribution on the target was calculated by tracking of 5×10^5 particles in the MAD-X program (Fig. 3).

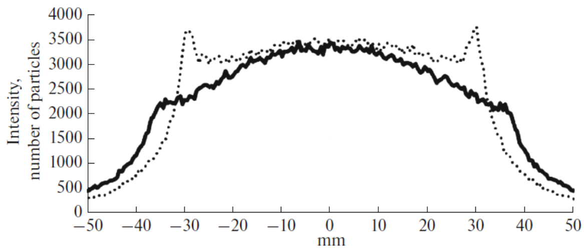

Figure 3: Transverse particle distribution in the horizontal (dotted) and vertical (solid) planes on the target as a function of transverse coordinates.

At the SIMBO station, in addition to quadrupole magnets, a collimator with an adjustable inner diameter from 10 mm to 100 mm will serve to provide a sharp boundary of the irradiation field area in both scanning and non-scanning modes.

MAGNET SYSTEM OF THE NEW BEAM LINES

In addition to the existing dipole magnets that serve to direct the beam from the Nuclotron to the channels [4], the ISCRA and SIMBO channels will be equipped with new scanning magnets, two new families of quadrupoles and new octupole magnets, see Table 1. For the SOCHI channel, two existing quadrupole magnets similar to those in the HILAC-Booster transfer line are used [5].

The detailed technical design of the new magnets has been performed and they are currently under manufacturing at SIGMAPHI. The delivery to JINR is foreseen for summer 2022.

Table 1: Main Requirements on the New Magnet for the ISCRA and SIMBO Channels

Parameter	Scanning SMX/SMY	Quadrupole Type 1	Quadrupole Type 2	8-pole
# magnets	2+2	6	2	2
Gap/bore Ø (mm)	140	108	160	105
Field/Gradient (T, T/m, T/m^3)	±0.8	0.6-5.4	0.2-1.4	1098
L_{eff} (mm)	356±4	492±2	480±2	505±3
Good Field Region (mm)	H×V 60 x 60	Ø 100	Ø 128	Ø 90
Rel. integrated field error $\times10^{-3}$	< ±5	< ±5	< ±5	< ±5
Operating mode	Scanning f=0.5-3 Hz	DC	DC	DC

DETECTORS

Three types of detectors will be used for beam diagnostics in the channels in the Measurement Hall: an offline multiwire proportional ionization chamber (1 pcs. 100×100 mm and 2 pcs. 75×75 mm), scintillation-fiber detector (1 pcs. 100×100 mm and 2 pcs. 75×75 mm) and two systems for online diagnostics (4 scintillation-fiber based detectors 20×20 mm). The offline systems duplicate each other to get more reliable results. The diagnostics and corrector system of the HILAC-Booster channel will be used to control the beam in the SOCHI channel [5]. Beam diagnostics in each of the channels will be in conjunction with the beam diagnostics at the stations.

The ion beam diagnostics and control systems of applied stations should be duplicated by the type of detector. All detectors should be placed on stepper motors that transversely move and withdraw detectors from the beam area. The diagnostics equipment is designed to measure and control such beam characteristics as the ion flux density, ion fluence, ion beam linear energy transfer (LET), mean energy, beam profiles, and absorbed dose [6].

SOCHI APPLIED RESEARCH STATION

The SOCHI station (Fig. 4) is designed to research and tests of promising semiconductor micro- and nanoelectronics products for determination of SEE sensitivity to low energy heavy charged particles at the exit from the HILAC.

Figure 4: General 3D view of the SOCHI station.

Table 2 shows the sufficient ion beam parameters for the planned work.

Table 2: Technical Requirements for the Ion Beams at the SOCHI Station

Ion types	$^{12}C^{4+}$, $^{40}Ar^{8+}$, $^{131}Xe^{22+}$, $^{84}Kr^{14+}$, $^{169}Tm^{21+}$, $^{197}Au^{31+}$, $^{209}Bi^{34+}$
Ion energy at the exit from the HILac, MeV/n	3,2
Ion flux density, particles/(cm^2·s)	10^2..$3\cdot10^5$
Maximum irradiation area, mm	Ø29
Beam diameter, mm	Ø73

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The equipment for the SOCHI station is being developed as part of the JINR-ITEPh collaboration with participation of SPELS/MEPHI, GIRO-PROM, VST.

The diagnostics system is represented by the following detectors: microchannel plates, system for online diagnostics and control of peripheral ion flux density and fluence (four scintillation-fiber detectors based on multichannel photomultiplier), the fast total-absorption scintillation detector with optical readout, a Faraday cup, fast total absorption phosphor screen. The signals from the detectors are integrated into the general data acquisition system.

ISCRA APPLIED RESEARCH STATION

The ISCRA station (Fig. 5) is designed to research and tests of promising semiconductor micro- and nanoelectronics products for determination of SEE sensitivity to high-energy heavy charged particles.

The equipment for the ISCRA station is being developed as part of the JINR-ITEP collaboration with participation of SPELS/MEPHI, GIRO-PROM.

Figure 5: The positioning system of the ISCRA station (left) and energy degrader (right).

Table 3 shows the sufficient parameters of the ion beam for the planned work.

Table 3: Technical Requirements for the Ion Beams at the ISCRA Station

Ion types, energy MeV/n	$^{197}Au^{79+}$	150-350
	$^{131}Xe^{54+}$	150-367
	$^{12}C^{6+}$	150-392
Ion flux density, particles/(cm2·s)	$10^2..3 \cdot 10^5$	
Irradiation area in the scanning mode/nonscanning mode, mm	200x200/Ø29	
Flux uniformity for the maximum irradiation area in the scanning mode/nonscanning mode, %	15/10	

The diagnostics system is represented by the following detectors: ionization chamber 1, proportional wire ionization chamber 2, miniature gas-filled ionization chamber 3, a scintillation-fiber detector, a silicon detector, an online particle flux density meter based on four scintillators (or four silicon detectors), the absolute measurements of the ion flux density can be performed using 0.1-mm-thick plastic foils as offline detectors at specified points.

SIMBO APPLIED RESEARCH STATION

The SIMBO station is designed for radiobiological research to simulate the effects of heavy charged particles of galactic and solar cosmic rays on the cognitive functions of lower primates and small laboratory animals.

The equipment for the SIMBO station is being developed as part of the JINR-VST collaboration.

Table 4 shows the sufficient parameters of the ion beam for the planned work.

Table 4: Technical Requirements for the Ion Beams at the SIMBO Station

Ion types	$^{12}C^{6+}$, $^{40}Ar^{18+}$, $^{56}Fe^{26+}$, $^{84}Kr^{36+}$
Ion energy at the exit from the Nuclotron, MeV/n	500-1000
Ion flux density, particles/(cm^2·s)	$10^3..10^6$
Radiation dose, Gy	1-3
Irradiation area in the scanning mode/nonscanning mode, mm	100x100/Ø10

The diagnostics system is represented by the following detectors: ionization chamber 1, ionization chamber 2, ionization chamber 3, ionization chamber 4, the thin scintillation counter, a diamond semiconductor detector, the system based on four scintillation detectors for online diagnostics and control.

The mounting and commissioning of the SOCHI station are planned for the autumn of 2021, while the ISCRA and SIMBO stations for spring 2022. First beam experiments at the SOCHI station are planned for spring 2022, experiments at the ISCRA and SIMBO stations are start to autumn 2022.

ACKNOWLEDGEMENTS

Work supported by grant for young scientists. Unique ID 21-102-09.

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ISBN: 978-3-95450-240-0 ISSN: 2673-5539 doi:10.18429/JACoW-RuPAC2021-MOPSA29

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