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BEAM LINES AND STATIONS FOR APPLIED RESEARCH BASED ON ION BEAMS EXTRACTED FROM NUCLOTRON

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Abstract

New beamlines and irradiation stations of the Nuclotron-based Ion Collider fAcility (NICA) are currently under construction at JINR. These facilities for applied research will provide testing on capsulated microchips (ion energy range of 150-500 MeV/n) at the Irradiation Setup for Components of Radioelectronic Apparatus (ISCRA) and space radiobiological research (ion energy range 400-1100 MeV/n) at the Setup for Investigation of Medical Biological Objects (SIMBO). In this note, the technical details of the SIMBO and ISCRA stations and their beamlines are described and discussed.

INTRODUCTION

The NICA (Nuclotron-based Ion Collider fAcility) project is a new acceleration and storage complex that is currently under construction at JINR [1]. The project includes both fundamental and applied research.

Beams of ions from the Nuclotron accelerator will be used to simulate cosmic rays within applied research at NICA. The applied research assumes construction of new stations and beam lines to irradiate targets. These setups with special equipment help assess the risks of space radiation to human and equipment during space trips.

In this note SIMBO and ISCRA stations, their beamlines technical details are described and discussed [2-4].

PURPOSES

Safety space exploration requires studies of risks of cosmic radiation. Space equipment and biological samples can be irradiated by simulated cosmic rays on the Earth before a space mission. Existing and new setups in frame of the NICA applied research program will be used for these aims.

So, risks of cosmic radiation posed to space missions due to galactic cosmic rays can be simulated and studied on the Earth at NICA.

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For these purposes ion beams extracted from the Nuclotron with varying species types and energies (Table 1) and equipment of SIMBO and ISCRA setups with different irradiation forming and measurement methods help to determine and measure radiation influence on the biological and electronics targets.

Table 1: Parametres of Ion Beams Extracted From the Nuclotron for SIMBO and ISCRA

Parameter	SIMBO	ISCRA
Ion type	$^{12}C^{6+}$, $^{40}Ar^{18+}$, $^{56}Fe^{26+}$, $^{84}Kr^{36+}$, $^{131}Xe^{54+}$, $^{197}Au^{79}$	
Ion energy, Mev/nucleon	400-1100	150-500
Extracted beam intensity, ion/spill	10^6-3×10^9	3×10^4-10^8
Beam emittances (95%), $\varepsilon_x/\varepsilon_y$, π·mm·mrad	3-10/8-15	5-17/13-25
Spill time, sec	2-20	

BEAM LINES

New beam lines will be constructed and integrated into the existing VP-1 transfer line, to transport the beams from Nuclotron to SIMBO and ISCRA stations. The SIMBO and ISCRA beam lines are 17 m and 22 m long respectively include two existing dipole magnets SP-94, which bend the ion beams to its station (Fig.1).

The scanning and non-scanning operating modes will be used to provide different beam spot sizes at the station targets. The SIMBO and ISCRA stations can operate in both modes. The parameters of the magnets and their positions in the transfer lines were defined by beam dynamics simulation using the MAD-X code [3, 5]. One of the main requirements at sample irradiation is the homogeneity of the beam distribution at the target area.

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The beam parameters are adjusted by four quadrupole magnets in the VP-1 transfer line. Also, each SIMBO and ISCRA beam lines includes four additional quadrupoles to form beams at the stations.

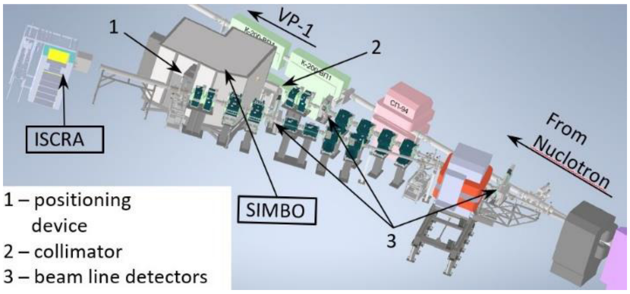

Figure 1: The 3D model of the beam transfer lines and stations in the Measurement Pavilion.

In the non-scanning mode, a target irradiation uniformity cannot be achieved by only quadrupole magnets due to a short quadrupole-to-target distance, restricted by the overall ISCRA transfer line length. To overcome this issue, two octupole magnets will be used in addition to quadrupoles.

SIMBO Collimator

A sharp boundary of different irradiation field areas is required for SIMBO targets. A 500-mm-long movable beam limiting collimator (Fig. 2 (left)) with a set of inserts with various inner diameters will be used to meet this requirement.

In the non-scanning mode, inserts have cylindrical profiles with diameters from 10 mm to 50 mm.

In the scanning mode, two scanning magnets form a deflected cylindrical beam. Therefore, conical-shaped insert with the entrance and exit hole diameters of 30 mm and 42 mm respectively will be used for scanning beams.

Beam Lines Detectors

The beam diagnostics includes measurements of the following irradiation parameters: the ion beam profiles, the primary ion fluence and the primary ion density flux. To control and setting of the beam parameters in the stations there will be used offline and online detectors. Offline detectors include two duplicate types of detectors to provide comparison between obtained results. An ionization chamber (IC) and a scintillating fiber-based beam position monitor (SFM) will be used as the offline detectors. An assembly based on the movable motors with four sensors will be used as an online detector (OD), which measures the beam halo.

To measure the beam parameters after the dipole magnets in transfer beam lines, three ICs and three SFMs will be placed at the beginning of the common part of the transfer lines and after the second dipole magnet. Two ODs are placed in the common part and in the ISCRA beam line. All three detectors are assembled in one unit (Fig. 2 (right)).

The IC detectors with an acquisition rate of 1 Hz should register Au and C ions at the energy range of 150-1100 MeV/nucleon. The 1 Hz requirement will allow working without essential signal saturation.

A required the minimum flux density (ions/(cm^2·s)) depends on the type and signal noise of the electrometer. The Pyramid electrometer I128 was chosen for our measurements.

The SFM sensor radiation hardness lifetime should not be less than 300 hours with maximum degradation of 10% at the beam parameters given in Table 1.

To overcome these issues the detectors will be only used during the setting mode at the low ion intensity of 1.7×10^3ions/cm^2/s for Au ions at an energy of 150 MeV/n.

The advantage of the SFM detector as compared to the coordinate strip IC, is that it gives information directly about the distribution of particles in the beam in the transverse plane, whereas the IC shows only the convolution (sum) of the beam ions along the strips, which does not allow to obtain the real beam transverse dimensions.

The SIMBO and ISCRA beam lines are currently being produced by the SIGMAPHI–JINR collaboration.

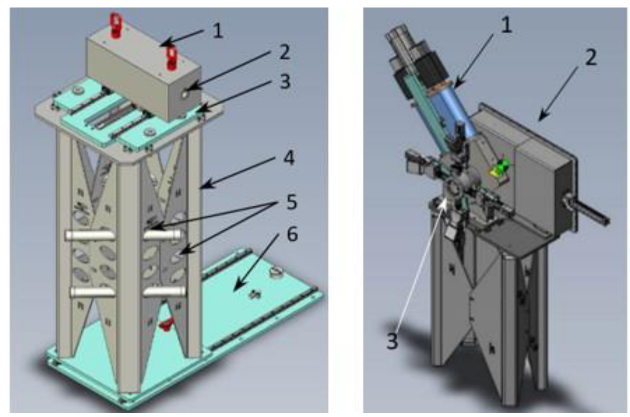

Figure 2: The 3D model of the SIMBO collimator (left) and beam line assembled diagnostics (right). Left: 1 – the movable collimator body, 2 – the hole for inserts, 3 – the movable platform, 4 –the stand, 5 – inserts and place for them, 6 – the base plate. Right: 1 – SFM, 2 – IC, 3 – OD.

STATIONS

The equipment of the SIMBO and ISCRA stations was constructed. Beam diagnostics in each transfer line will be in conjunction with the beam diagnostics at the stations. The diagnostics systems of the stations are discussed in [4].

SIMBO Station

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

The scintillation-fiber detector № 1 is used to measure ion flux density and beam profiles in the non-scanning mode during beam adjustment before the experiment.

Ionization chamber № 2 based on the IC64-16 strip ionization chamber (Pyramid Technical Consultants, Inc) duplicates detector № 1 and solves similar problems (Fig. 3 (left)).

Ionization chamber № 3, a slanted multi-section dosimetric ionization chamber with column recombination suppression, is used to determine the absorbed dose.

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Ionization chamber № 4 based on a model QIC-2S (Pyramid Technical Consultants, Inc) four-channel ionization chamber is used as a local dose detector (Fig. 3 (right)).

The system for online diagnostics and control of the peripheral ion flux density is based on four scintillation detectors.

A diamond semiconductor detector of the local dose and average ion energy will be installed at the positioning system.

A thin scintillation counter is used for the measurement of impurities in a beam of non-target ions.

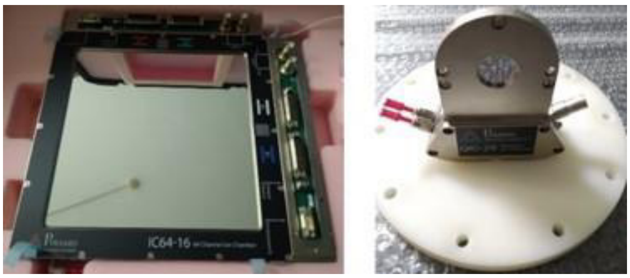

Figure 3: SIMBO detectors. Ionization chamber № 2 (left), ionization chamber № 4 (right).

ISCRA Station

The ISCRA station is constructed to research and tests of promising semiconductor micro- and nanoelectronics products for determination of SEE (single event effect) sensitivity to high-energy heavy charged particles.

Ionization chamber № 1 (128×128 mm) is used to control primary beam parameters in front of the degrader during beam adjustment before the experiment.

Ionization chamber № 2 (256×256 mm) is used to measure the ion flux density of the secondary beam in the target area during beam adjustment before the experiment (Fig. 4 (left)).

Ionization chamber № 3 (10×10 mm) (miniature gas-filled ionization chamber) is used to measure the LET (linear energy transfer) in the target area during experiment in the ion energy range of 3-350 MeV/n; and the LET measurement range is 5-80 MeV·cm^2/mg (Fig. 4 (right)).

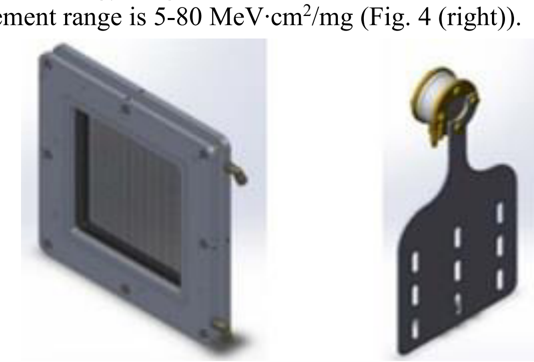

Figure 4: ISCRA detectors. Ionization chamber № 2 (left), ionization chamber № 3 (right).

A silicon detector (the set of 6 pcs 10×10 mm 300 µm–thick detectors) is used to control and measure the LET of ions in the target area.

A particle flux density detector based on four scintillators (or four silicon sensors) is used to control the ion flux density in the peripheral area of the ion beam in real-time.

A 80×80 mm scintillation-fiber detector is used to measure the ion flux density and beam profile during beam adjustment before the experiment.

The equipment for the SIMBO station is being developed as part of the JINR-VST and JINR- Ostec Enterprise collaborations. The positioning device for irradiated objects for the SIMBO station is presented in Fig. 5 (left).

The equipment for the ISCRA station is being developed as part of the JINR-ITEP collaboration with the participation of SPELS/MEPHI and GIRO-PROM. The positioning system of the ISCRA station is presented in Fig. 5 (right).

Figure 5: The positioning device for irradiated objects for SIMBO station (left) and the positioning system of the ISCRA station (right).

CONCLUSION

The installation and commissioning of the ISCRA and SIMBO infrastructure, beam lines and stations are planned for summer-autumn 2022. The first beam experiments are planned to start in 2023.

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