Status of ARIADNA Collaboration for applied research at NICA facility

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NICA MEGA-SCIENCE PROJECT

NICA

Nuclotron-based
Ion Collider fAcility

ENG | RUS

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NICA Physics | NICA Complex | Megaproject | Education | Innovation | Media & Events | Contacts | Review Committee

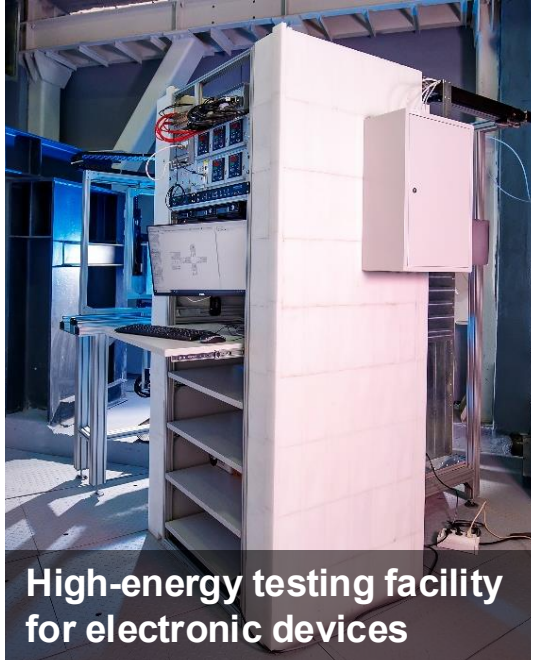
NICA (**N**uclotron based **I**on **C**ollider f**A**cility) is a new accelerator complex designed at the Joint Institute for Nuclear Research to study properties of dense baryonic matter.

Besides fundamental physics issues, the NICA complex provides the dedicated infrastructure for applied research with accelerated ion beams.

Low-energy testing facility for electronic devices

ARIADNA

INFRASTRUCTURE FOR APPLIED RESEARCH AT NICA FACILITY



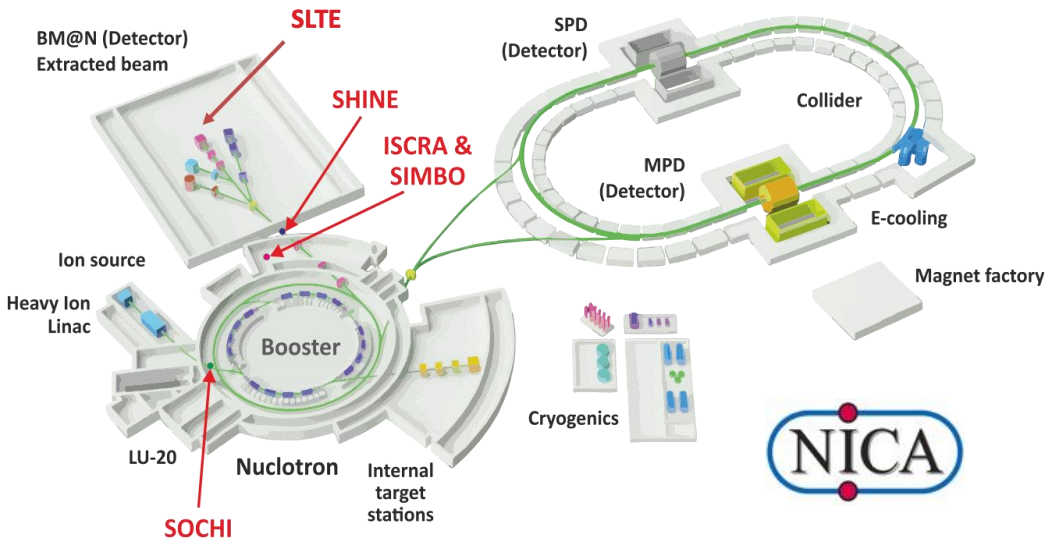
High-energy testing facility for electronic devices

Target station for biological samples

ARIADNA beamlines

Target station for long-term irradiation

Sample preparation room



ARIADNA INFRASTRUCTURE

ARIADNA collaboration

Applied Research Infrastructure for Advanced Developments at NICA fAcility includes:

(1) Beamlines with magnetic optics, power supplies, beam diagnostics systems, etc.

(2) Experimental zones equipped with target stations for users.

(3) Supporting user infrastructure including areas for deployment of user's equipment, for sample preparation and post-irradiation express analyses.

Low-energy ion beams available at HILAC	Intermediate-energy ion beams available at Nuclotron	High-energy ion beams available at Nuclotron
3.2 MeV/nucleon	150-1000 MeV/nucleon	up to 4.5 GeV/nucleon

Life sciences, Materials science, Radiation damage to microelectronics, Nuclear technology applications

Protons and ions with Z = 2 to 92

Irradiation of decapsulated microcircuits and solid materials with 3.2 MeV/nucleon ions.

Ions: $^{12}C^{6+}$, $^{40}Ar^{18+}$, $^{56}Fe^{26+}$, $^{84}Kr^{36+}$, $^{131}Xe^{54+}$, $^{197}Au^{79}$

Irradiation of capsulated microcircuits with 150-350 MeV/nucleon ions. Ions like $^{197}Au^{79+}$ are decelerated in the capsule to 5-10 MeV/nucleon.

500-1000 MeV/nucleon ions be available at the target station for biological sample irradiation.

Ions: $^{1}H^{1+}$, $^{2}D^{1+}$, $^{12}C^{6+}$, $^{40}Ar^{18+}$, $^{7}Li^{3+}$

Target station will be equipped with targets from C to Pb and with the systems of beam and target diagnostics, positioning, thermometry, synchronization, radiation control, and data acquisition.

ARIADNA COLLABORATION

Established in **2022**

30 cooperating organizations

202 participants

7 countries

Applied Nuclear Technologies

- Institute of Nuclear Problems, BSU (Belarus)
- Institute of Nuclear Physics (Kazakhstan)
- Institute of Nuclear Physics, AS RUz (Uzbekistan)

Radiation Materials Science Radiation Testing of Electronics

- Research Institute of Nuclear Physics, MSU (Russia)
- National Research Nuclear University MEPhI (Russia)
- Institute of Nuclear Physics, AS RUz (Uzbekistan)
- CANDLE SRI (Armenia)
- Alikhanyan National Science Laboratory (Armenia)
- Research Center of Chemical Physics, RAS (Russia)
- University of Electronic Technology (Russia)
- Institute of General and Inorganic Chemistry (Russia)
- Joint Institute of High Temperatures (Russia)
- North Ossetian State University (Russia)
- LLC “PROTON” (Zelenograd, Russia)
- LLC “SOL-Instruments” (Belarus)
- LLC “Quantum R” (Russia)
- LLC “S-Innovations” (Russia)

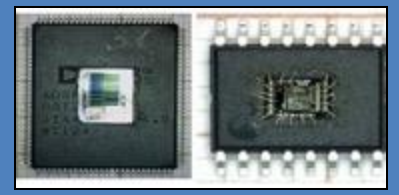
Life Sciences

Radiation Biophysics, Radiobiology, Improving ion therapy planning, etc.

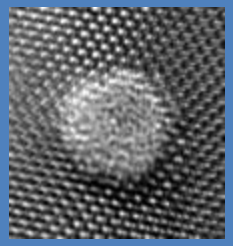
- Institute of Biomedical Problems, RAS (Russia)
- Burnasyan Federal Medical Biophysical Center (Russia)
- National Research Nuclear University MEPhI (Russia)
- St.-Petersburg State Univercity (Russia)
- RUDN University (Russia)
- Moscow Institute of Physics and Technology (Russia)
- Tsyb Medical Radiological Research Centre (Russia)
- Institute of Theoretical & Experimental Biophysics (Russia)
- CANDLE SRI (Armenia)
- Yerevan State University (Armenia)
- Institute of Molecular Biology (Armenia)
- iThemba LABS (South Africa)
- University of Zululand (South Africa)
- Instituto Nacional de Cancerología – INCan (Mexico)

PILLARS OF APPLIED RESEARCH WITH NICA BEAMS

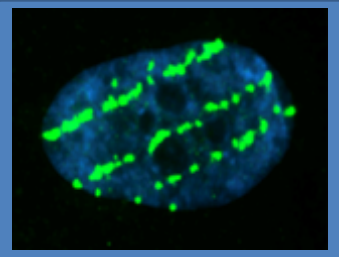
Radiation effects in microelectronics



Radiation protection on Earth and in space

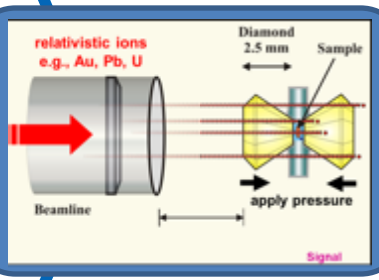


Materials research with ion beams



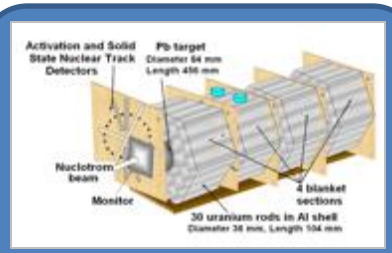
Radiation biophysics and radiobiology

NICA

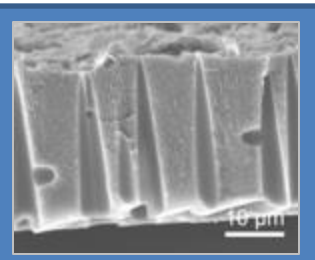


Materials in extreme radiation dose conditions

Radiation therapy-related research



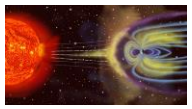
Novel technologies for accelerator-driven systems (ADS)



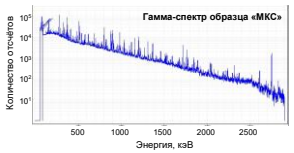
WORK PACKAGE FOR RADIATION SAFETY IN SPACE

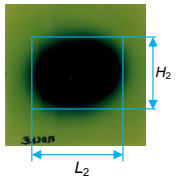
(COMBINED EFFECTS, PHARMACOLOGICAL PROTECTION, RADIATION-PROTECTIVE MATERIALS)

Study of combined effect of space flight factors on biological objects. Development of pharmacological protective measures. Improvement of standard means of spacecraft radiation protection

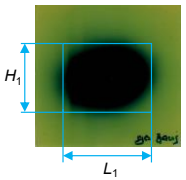


Study of radiation modification of composite materials with NICA high-energy ion beams





Study of radiation-protective properties of existing and novel composite materials

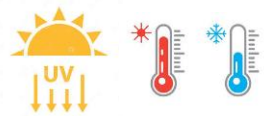


Project of Russian Orbital Service Station (ROSS)

Composite materials for spacecraft walls

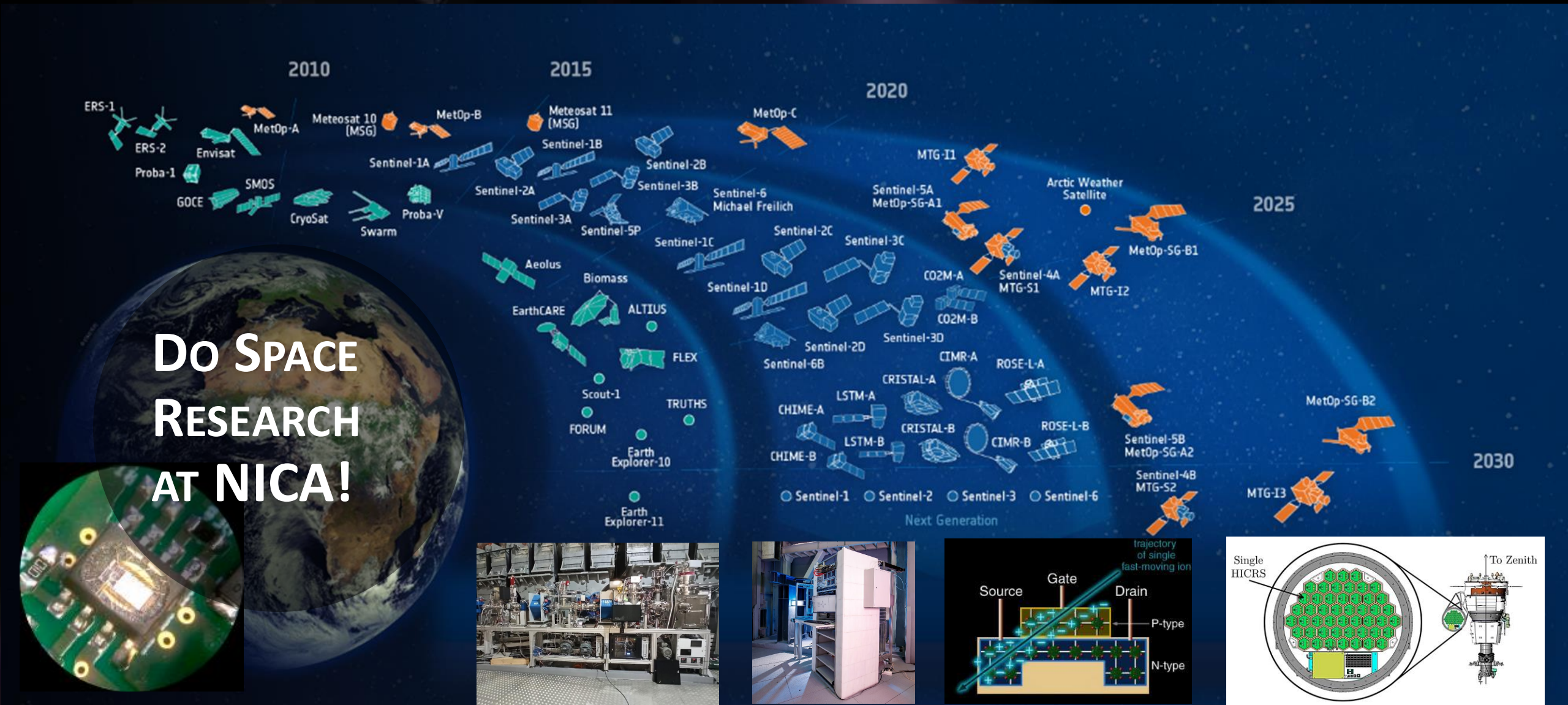
Structural, chemical and physical methods of testing

Comparative studies under the influence of other types of ionizing radiation



Combined effects of radiation and non-radiation factors of space flight on materials

Work package for development and testing of space instruments (Microelectronics and detectors)



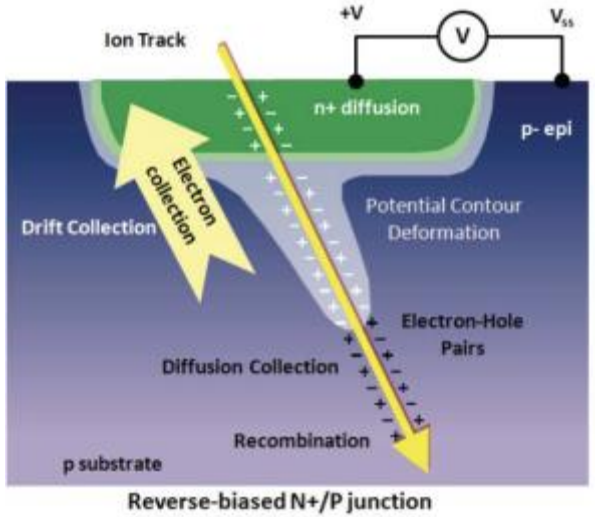
Do Space Research at NICA!

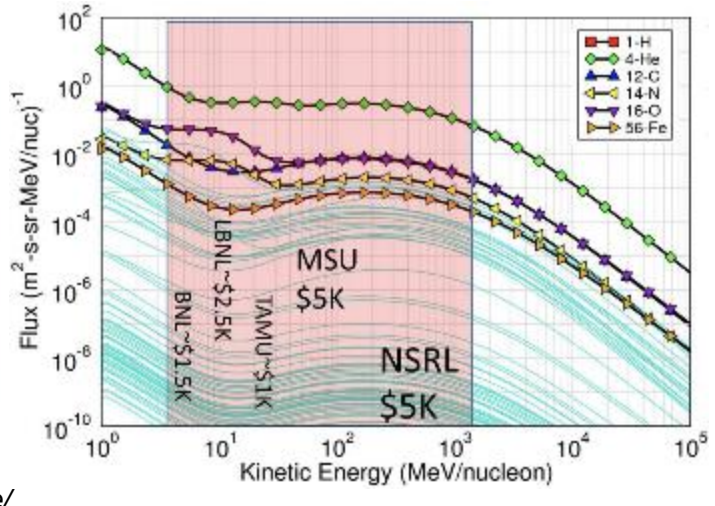
RADIATION TESTING OF ELECTRONICS WITH HIGH-ENERGY ION BEAMS

Two types of radiation effects

- Cumulative (dose) effects result from long-term exposure to radiation environment
- Single-Event Effects (SEE) occur promptly due to a **single particle** strike

Recent studies: 25-50% of spacecraft anomalies due to SEE (depends on spacecraft orbits)





/R.C. Baumann, 2013 NSREC Short Course/

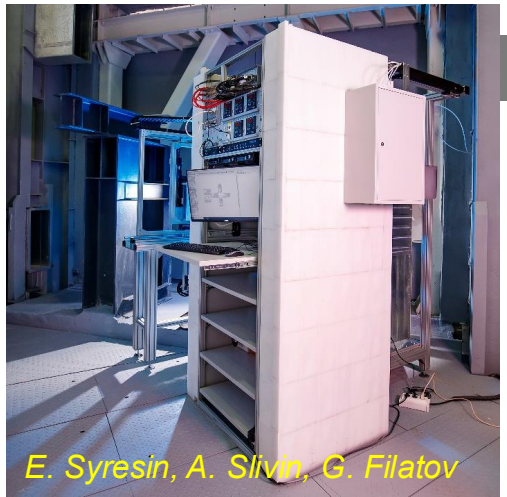
Increasing integration poses problems for SEE testing with low-energy beams

- Multiple die stacked together in packages.
- Behavior may differs if dis-assembled, tested separately.
- Packages now intrinsic to part performance.
- Dis-assembly may compromise timing, thermal and structural characteristics—especially if thinning required.

SEE Frontiers:

1. Technology Frontier
2. Low-Energy Frontier
3. **High-Energy Frontier – relevant to facilities like NICA**

- Ideally, prefer test with ions' characteristic relevant to space
- GCR ions fairly flat out to >2 GeV/nucleon (min. ionizing)
- Difficult and expensive to achieve at accelerators



ISCRA

NICA

SLTE

WORK PACKAGE FOR RADIATION BIOPHYSICS

ARIADNA beamlines

KEY COMPETENCIES

• **Structural and functional studies of proteins after irradiation**, including those significant for medicine or biotechnology. Application of X-ray structural analysis, X-ray and neutron small-angle scattering and electron microscopy.

• Structural and functional studies of **membrane proteins and their complexes,** including photoactive retinal proteins and G-protein coupled receptors (GPCRs).

• **Genetic engineering:** introducing mutations, developing chimeric constructs, genetic engineering for expression in bacteria, yeast, LEXSY eukaryotes, mammalian cells, human cells.

• **Protein expression** in various expression systems and **purification** (IMAC, SEC, etc.)

• **Optogenetic tools** for controlling cellular responses to heavy ion irradiation.

nature
Science
PNAS
nature COMMUNICATIONS
SciAdv AAAS
JACS JOURNAL OF THE AMERICAN CHEMICAL SOCIETY
Angewandte Chemie
nature chemical biology
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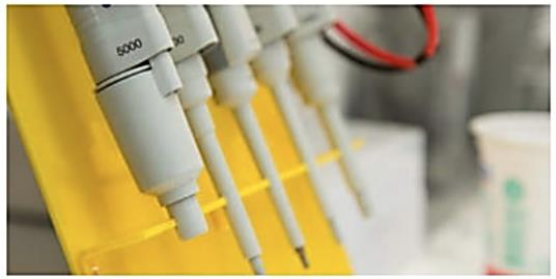
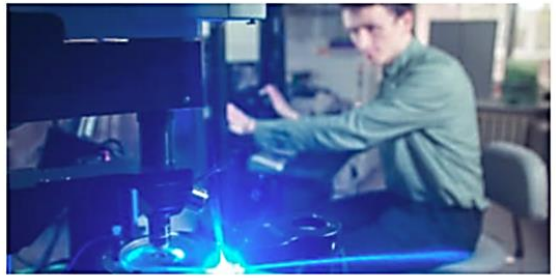
CHEMICAL REVIEWS



PLATFORM FOR PROTEIN EXPRESSION AND PURIFICATION

MODERN SUPER-RESOLUTION MICROSCOPY

HIGH-THROUGHPUT PROTEIN CRYSTALLIZATION PLATFORM



OPTOGENETICS, PATCH-CLAMP AND FLASH PHOTOLYSIS STUDIES

PROTEIN CRYSTALLOGRAPHY AND X-RAY SCATTERING

MEMBRANE PROTEIN FUNCTIONAL ASSAYS

МФТИ

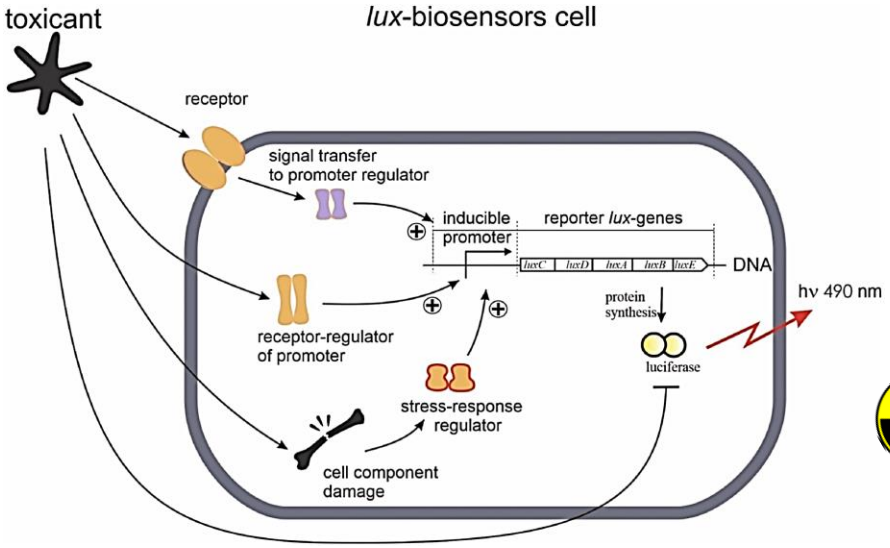
RESEARCH EQUIPMENT OF COLLABORATING ORGANIZATIONS

STUDY OF ION BEAM INTERACTION WITH LIVING SYSTEMS AT CELLULAR AND ATOMIC LEVELS

ARIADNA collaboration

RADIATION DAMAGE AT THE LEVEL OF CELLULAR BIOSENSORS

Objects: whole-cell lux-biosensors A set of lux-biosensors using inducible promoters: PoxyS, PsoxS, PalkA, Pdps

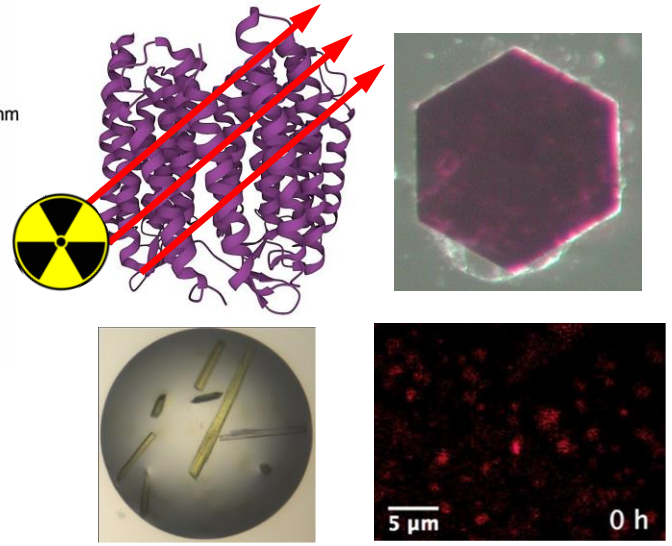


Reacting on damage to cell components (DNA, proteins, membranes, the appearance of reactive oxygen species), biosensors respond by increasing the expression of lux genes, which leads to an increase in cell luminescence.

ION TRACKS IN MEMBRANE PROTEIN CRYSTALS

Objects: crystals of retinal membrane proteins.

Tasks: study of damage to protein molecules, changes in the absorption spectrum of retinal using fluorescence and electron microscopy.

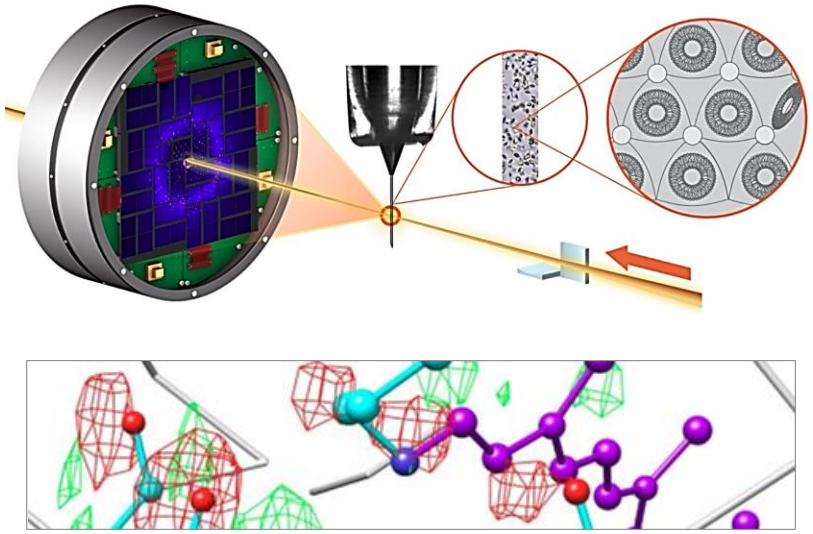


BACTERIORHODOPSIN (BR)
LIGHT-DRIVEN PROTON PUMP

RADIATION DAMAGE TO BIOMOLECULAR CRYSTALS

Objects: membrane proteins that form highly ordered crystals (bacteriorhodopsin, lysozyme, cytochromes, flavin-binding proteins, etc.).

Tasks: study of structural changes after exposure to accelerated high-energy ions using X-ray structural analysis and cryoelectron microscopy, interpretation of structural changes.

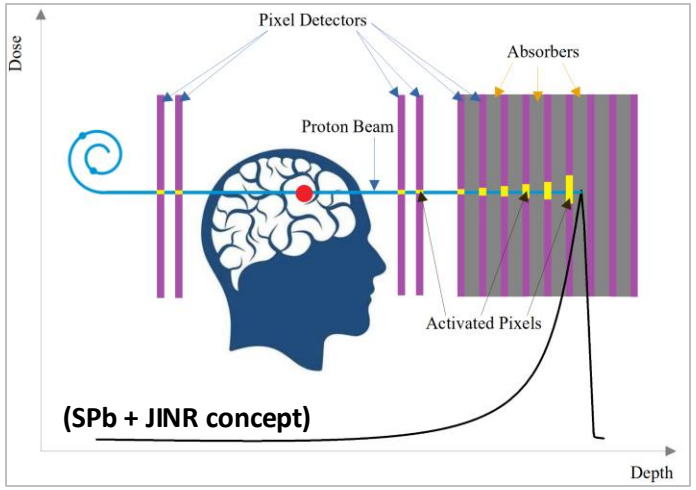


МФТИ ИТЭБ РАН

PROTON AND ION TOMOGRAPHY

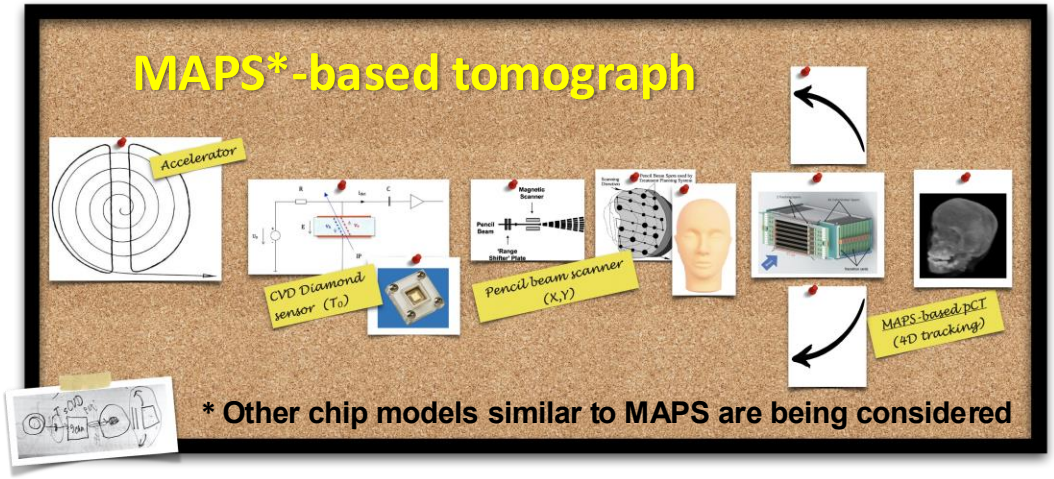
Typically, X-ray imaging is used to plan proton and ion therapy sessions. The data is then recalculated for proton or heavy ion irradiation, respectively. The conversion process results in an uncertainty of ~2.0-7.4% in predicting the penetrating depth of protons and heavy ions.

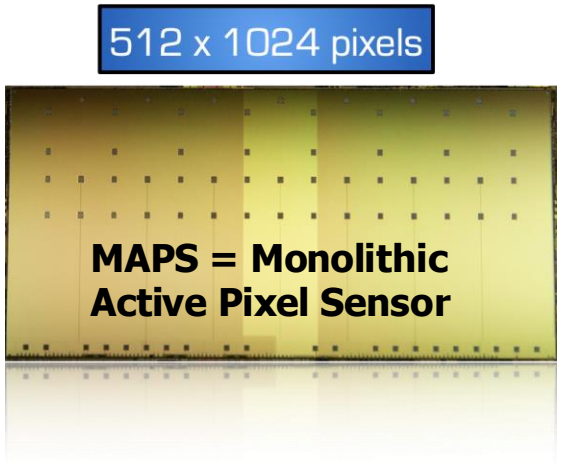
Proton tomographyy detector



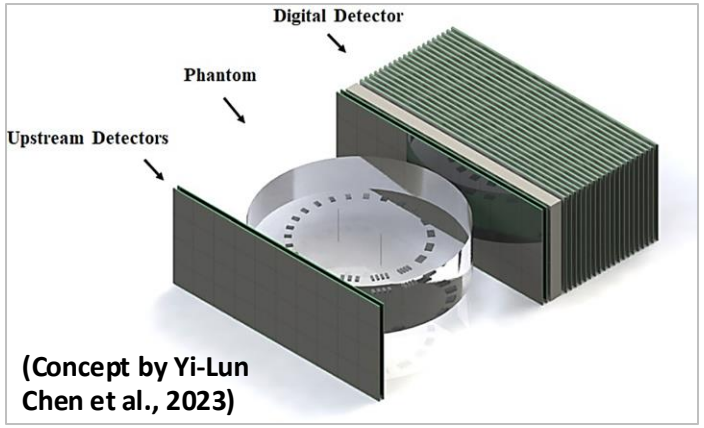
Report by V. Petrov at NUCLEUS 2025

48 planes,
9 x 18 MAPS chips or analogous.
7776 in total

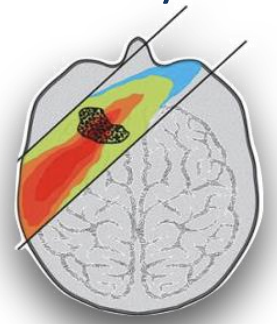




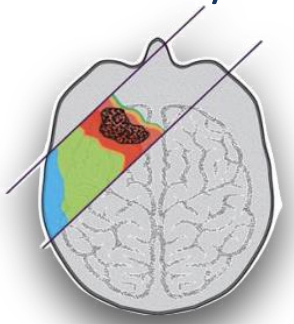
Ion (^{12}C) tomography detector

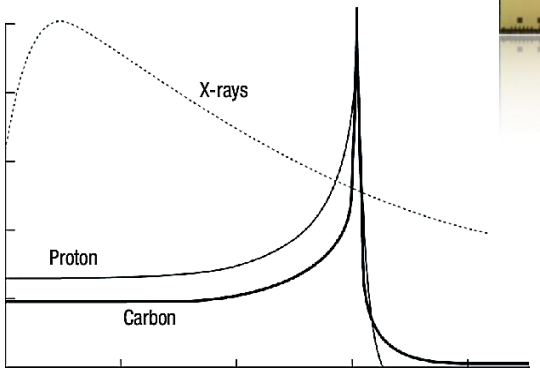


X-rays



Protons/ions



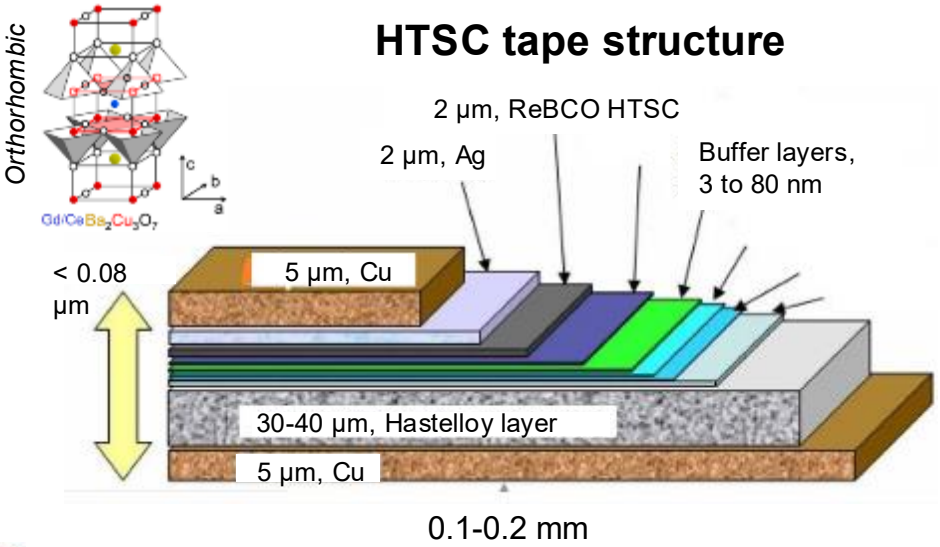


- Improved treatment planning performance for proton and ion therapy through diagnostic and therapeutic method alignment.
- Reduction of uncertainty to 0.3–1.0%.

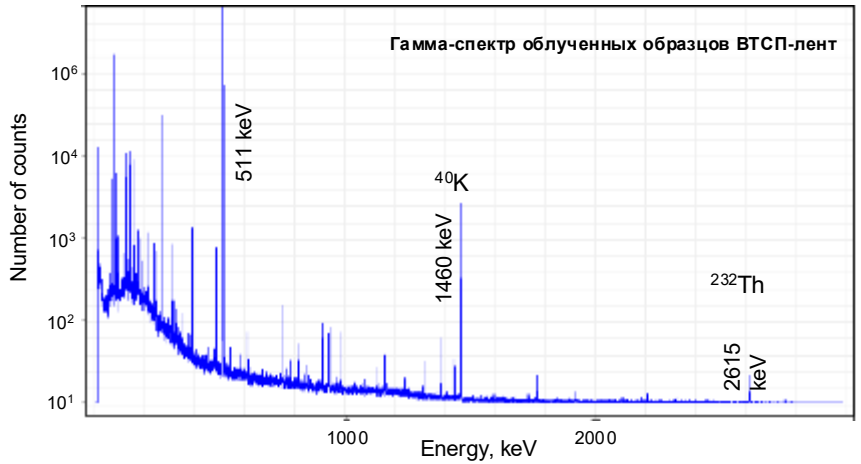
Work package for Materials Science:

Improving properties of high-temperature superconducting

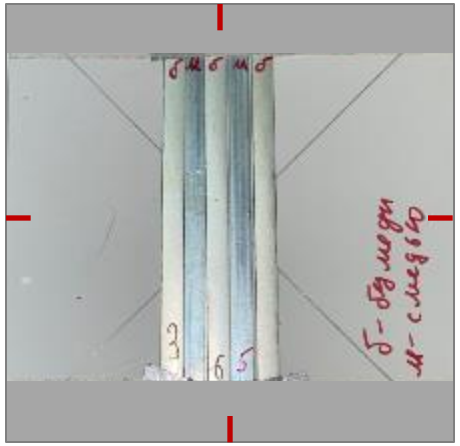
- Development of methods for increasing the critical current of high-temperature superconductors (HTSC) by means of radiation modification (induction of pinning centers in the bulk of the superconductor).
- Comparative analysis of the critical current values upon irradiation of HTSC tapes with $^{124}Xe^{54+}$ ions of 3.8 GeV/nucleon and protons of 660 MeV.
- Estimation of the stability of the effect of increasing the critical current in an irradiated superconductor.
- Development of equipment prototypes based on radiation-modified HTSC tapes and their testing.

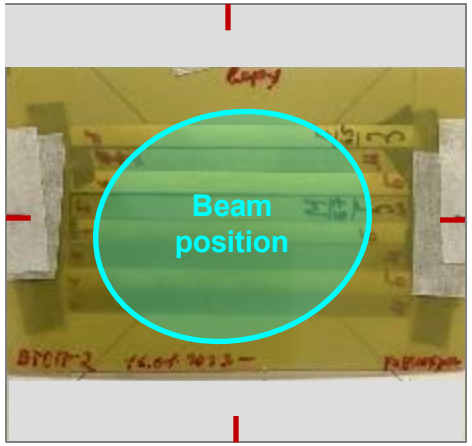


Methods for measuring current-voltage characteristics, Hall coefficient, magnetoresistance, thermo-EMF coefficient, thermal conductivity coefficient, magnetic moment in the temperature range of 1.7–300 K and magnetic fields up to 8 T.



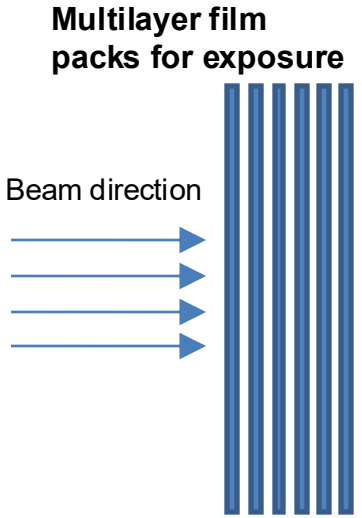
Irradiation of vertically and horizontally arranged HTSC tapes with and without copper content

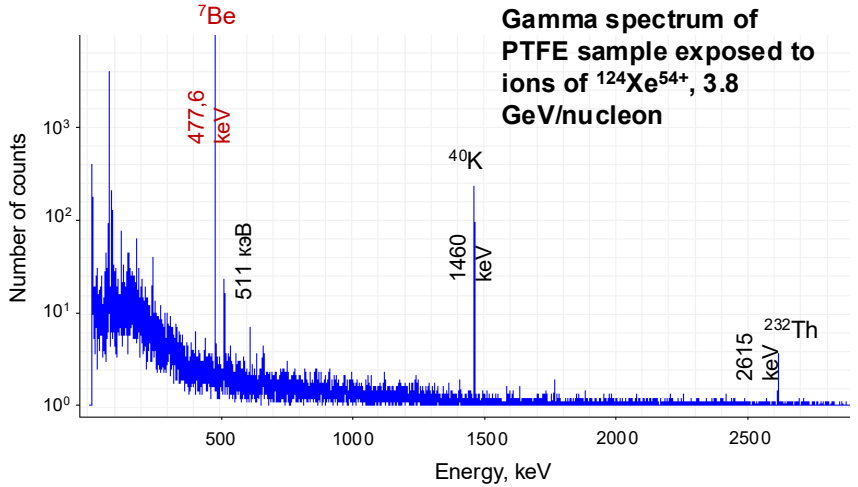


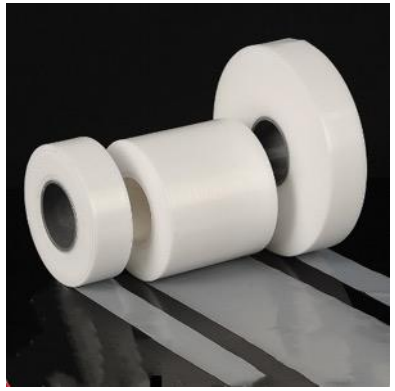


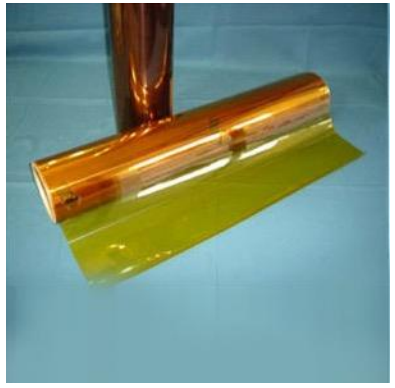
RADIATION MODIFICATION OF POLYTETRAFLUOROETHYLENE (PTFE), POLYETHYLENE TEREPHTHALATE (PET), POLYETHYLENE (PE) AND POLYIMIDE (PI) FILMS

- Study of the processes of amorphization and recrystallization of polymers and nanocomposite materials.
- Investigation of regularities of radiation-chemical damages in PTFE, PET, PE and PI films.
- Establishment of regularities in radiolysis of condensed matter under the exposure to ion beams with energies of several GeV/nucleon.
- Development of ion-track technologies with "thick" targets and multilayer materials.









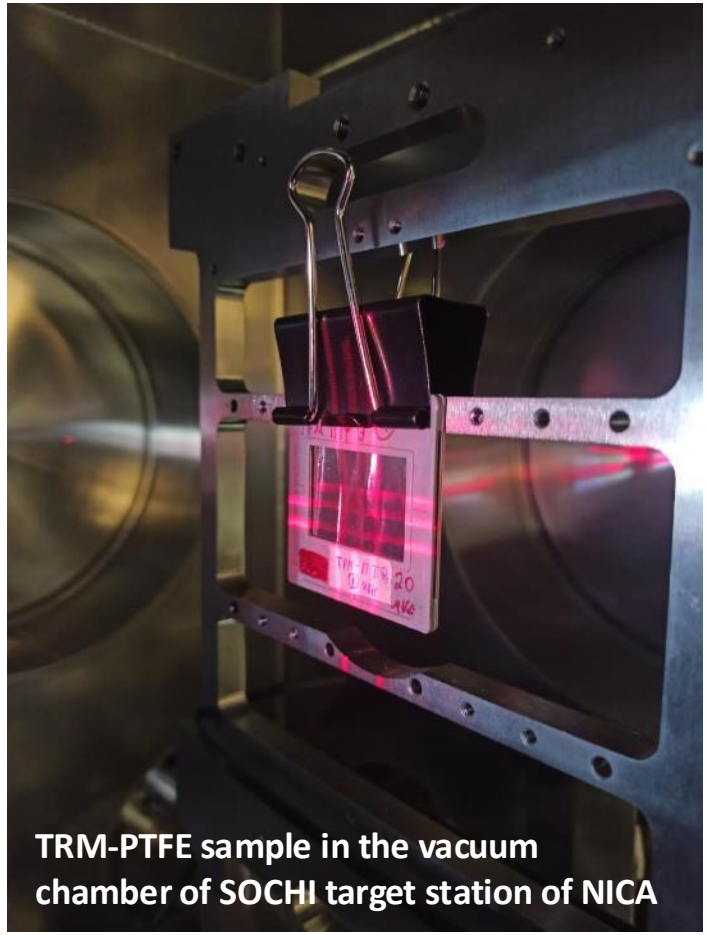

PTFE, PET, PE and PI films of 12, 20, 40, 50, 80 μm thick

Research methods: scanning and transmission electron microscopy, X-ray phase analysis, X-ray photoelectron spectroscopy and X-ray energy-dispersive elemental analysis, atomic force microscopy and low-temperature nitrogen sorption, wettability with respect to water and heptane, optical and infrared spectroscopy, infrared spectroscopy of frustrated total internal reflection, diffuse spectroscopy and specular reflection, laser Doppler strainmetry.

METHOD OF MANUFACTURING A REFLECTOR BASED ON RADIATION-MODIFIED OPTICAL PROPERTIES OF POLYTETRAFLUOROETHYLENE

- In collaboration with Federal Research Center for Chemical Physics RAS, the materials science research was performed on the optical properties of thermoradiation-modified polytetrafluoroethylene (TRM-PTFE) films irradiated with 3.2 MeV/nucleon xenon ions at NICA.
- Radiation-induced modifications in the TRM-PTFE spectra were observed, including the emergence of several absorption peaks at 206, 374, 476, 578 nm, which may be associated with radiolysis products. For the first time, the radiation-induced interference was detected, which potentially caused by the overlapping latent tracks of 3.2 MeV/nucleon xenon ions.
- Based on these findings, **a method for manufacturing a reflector using TRM-PTFE was suggested**, which is patented by a joint team (patent # 2820796).

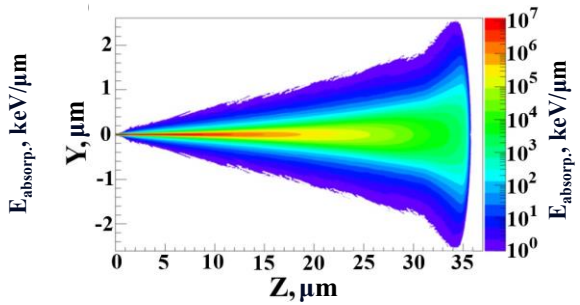
TRM-PTFE samples



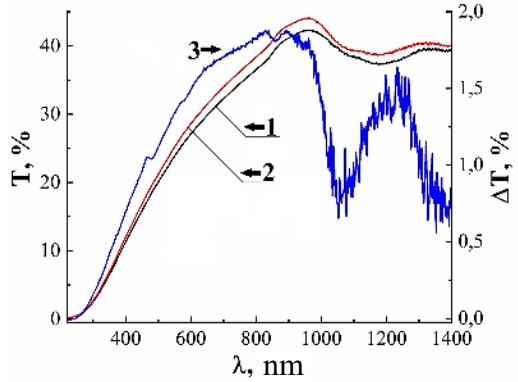
Patent # 2820796

Authors:
A.S. Smolyansky, O.V. Belov, D.P. Kiriukhin, P.P. Kush, S.M. Ryndia, K.S. Polunin, O.A. Koshkina, L.I. Trakhtenberg

Patent Holders:
FRC CP RAS (Moscow), JINR (Dubna), FRC PKhP and MCh RAS (Chernogolovka), NRNU MEPhI (Moscow)



2D distribution of the absorbed energy released in a PTFE sample irradiated with 3.2 MeV/nucleon xenon ions, calculated using the Geant4 toolkit.



Transmission spectra of 100 μm thick TRM-PTFE films: 1 – non-irradiated polymer; 2 – irradiation with xenon ions (fluence value is $1.08 \cdot 10^8$ particles); 3 – difference spectrum. Dashed lines indicate components of the triplet absorption band (374, 476, 508 nm). Arrows and inscriptions indicate maxima and minima of the interference pattern.

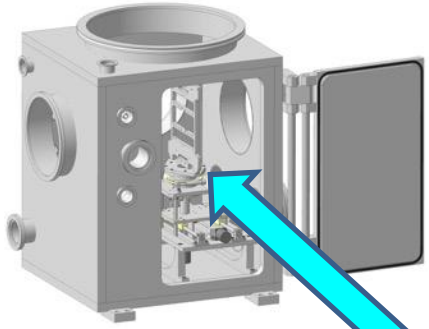
REAL-TIME CHARACTERIZATION OF RADIATION DAMAGE TO (NANO)MATERIALS WITH SCANNING PROBE MICROSCOPY

Development of systems for real-time investigation of surface radiation defects during irradiation using scanning probe microscopy methods

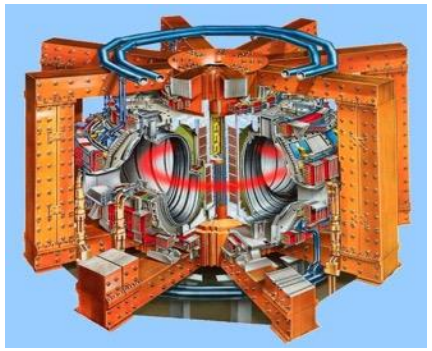
The scanning head of a microscope can operate both in an air and in vacuum conditions; it is highly resistant to radiation.

Experience of operating the microscope scanning head in extreme conditions:
- on the inner wall of the TOKAMAK,
- in open space conditions.

“SMM-2000-REM”

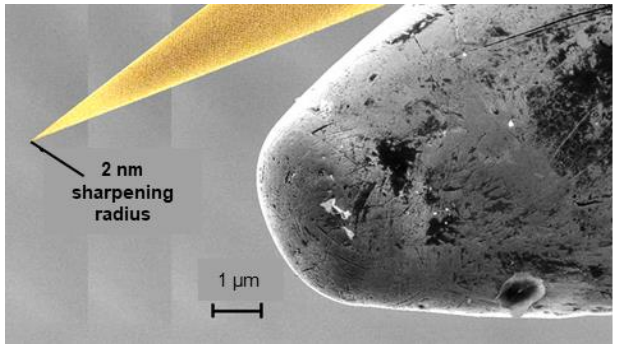


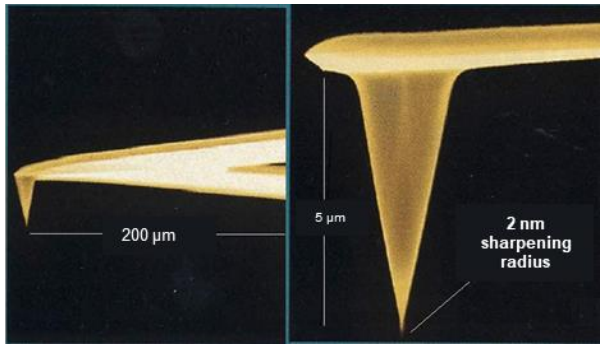
Vacuum chamber of SOCHI facility at NICA



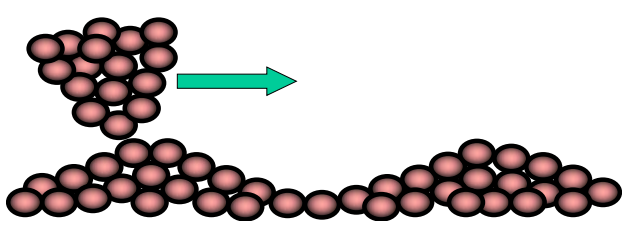
Probe microscope head manufactured by JSC Proton Plant and MIET

Scanning probe microscopy

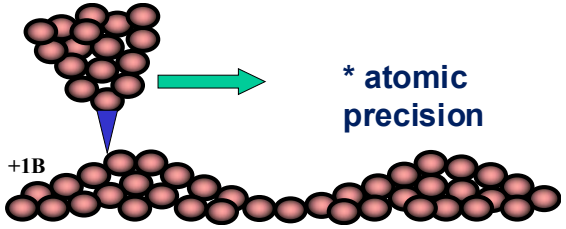




A needle moves along the relief and takes a profile

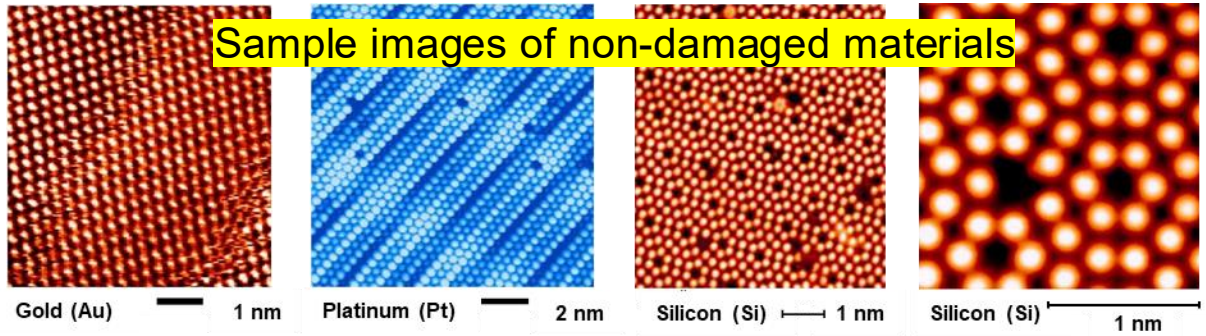


Atomic force microscopy



Scanning tunnelling microscopy

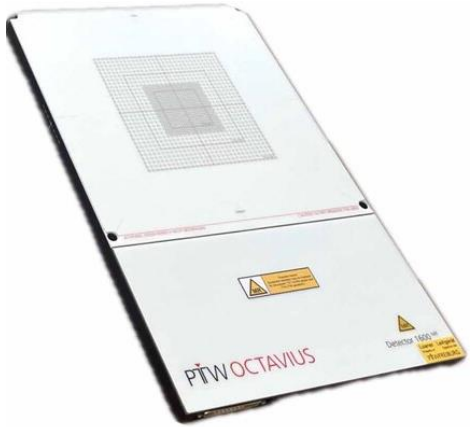
Sample images of non-damaged materials



DETECTOR TECHNOLOGY. DOSIMETRY AND MICRODOSIMETRY WITH HIGH-ENERGY ACCELERATED ION BEAMS

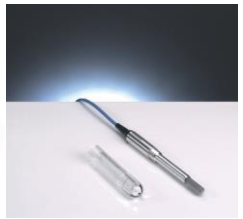
Development of experimental techniques at ARIADNA target stations requires equipping them with various sample environment systems, as well as improving existing detector systems for high-energy beam diagnostics

DOSIMETRY COMPLEX BASED ON ION CHAMBER MATRIX



OCTAVIUS Detector 1600 XDR

Dosimeter (electrometer)
PTW Unidos Webline



Reference ion chambers

The OCTAVIUS Detector 1600XDR is a high resolution ion chamber matrix for quality control of irradiation and dose measurements with protons or heavy ions.

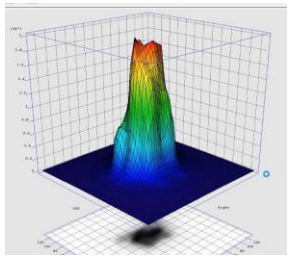
- **1521 ion chambers, providing a maximum field size of 15 x 15 cm²**
- **2.5 mm x 2.5 mm x 2 mm in size and the center-to-center spacing is 2.5 mm in the central area of 6.5 x 6.5 cm2 and 5 mm in the area surrounding it.**
- **100% field coverage in the central region.**
- **Read out cycles of 100 ms provide the basis for real-time analysis of beam profiles.**

Activities in the field:

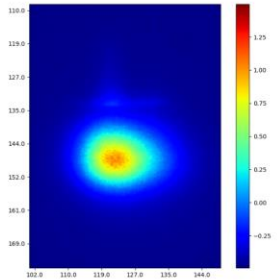
– Development of detector systems used in diagnostics of high-energy ion beams.

– Development of readout equipment for detector systems.

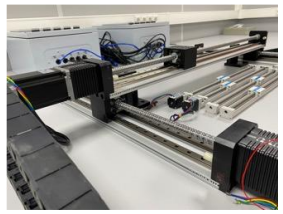
– Development of precise mechanic systems for sample positioning.



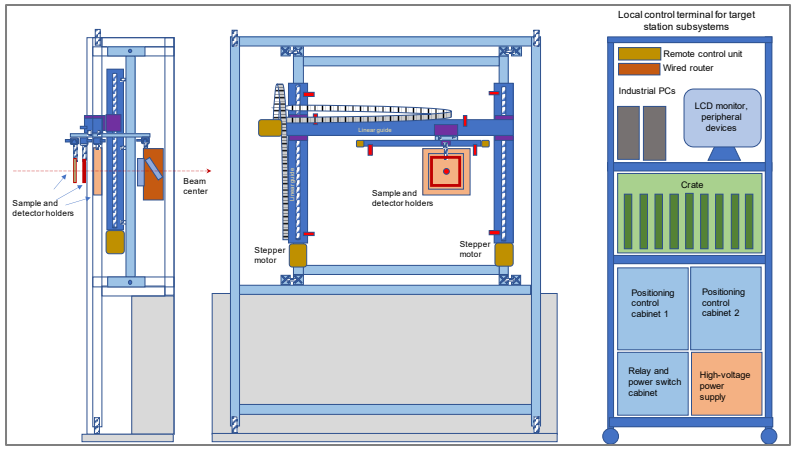
3D-map
of irradiation



Radiation dose
distribution map



ARIADNA Long-Term Exposure station
behind the BM@N facility



THANK YOU FOR YOUR ATTENTION!