JOINT INSTITUTE
FOR NUCLEAR RESEARCH

FRANK LABORATORY
OF NEUTRON PHYSICS

Experimental Infrastructure of FLNP for Research

Egor Lychagin

Joint Institute for Nuclear Research

The Joint Institute for Nuclear Research

an international intergovernmental organization

15 Member States:

Armenia, Cuba, Kazakhstan, Slovakia

Azerbaijan, DPRK, Mongolia, Uzbekistan

Belarus, Egypt, Romania, Vietnam

Bulgaria, Georgia, Russia

Associate Members:

Germany, Hungary, Italy, Serbia, The Republic of South Africa

JINR comprises 7 Laboratories, each being comparable with a large institute in the scale and scope of investigations performed







Frank Laboratory of Neutron Physics

FLNP staff breakdown (2024):

Total	557
Scientists	202
Engineers and specialists	152
Workers	171
Administrative staff	32

Average age – 48.1 years
Women – 27 %
Doctors – 29 persons
PhD – 108 persons
Foreigners – 96 persons

THREE MAIN SCIENTIFIC DEPARTMENTS of FLNP:

- **Department of nuclear physics** (139 persons)
- **Department of Neutron Investigations of Condensed Matter** (99 persons)
- **Department of Spectrometers Complex IBR-2** (51 persons)

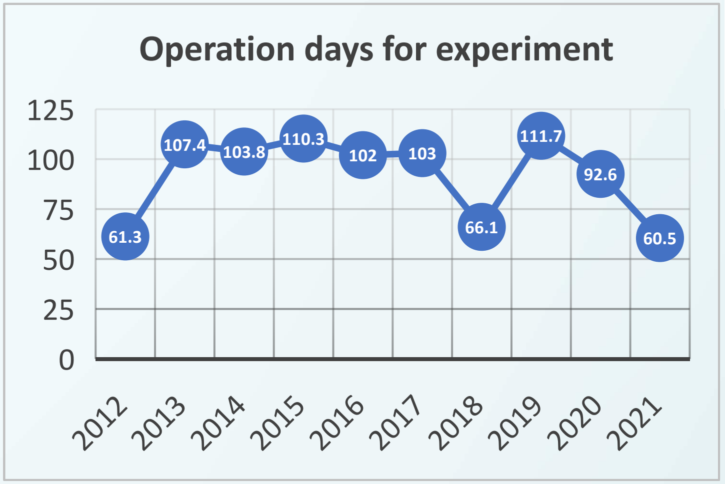
+ Raman spectroscopy sector (10 persons)
+ Sector of a new source and complex of moderators (26 persons**)**

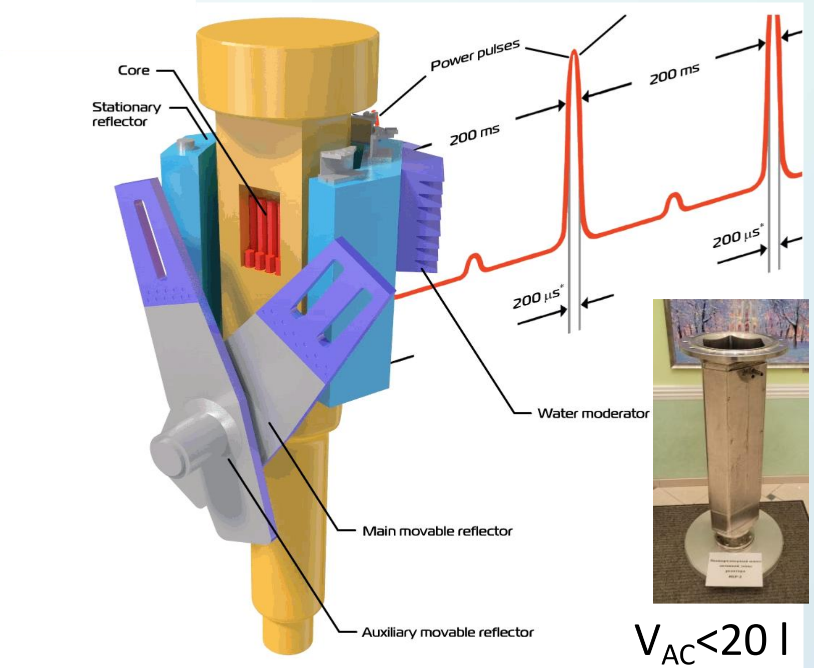
IBR-2 Pulsed Reactor

https://flnp.jinr.int/en-us/main/facilities/ibr-2

Operating since 1984

Deep modernization was carried out in 2006-2010





- October 16, 2021 - February 17, 2025 – reactor **shutdown**
- **Resumption** of operation was done **in March 2025**

Average power, MW	**2**
Fuel	PuO_2
Pulse repetition rate, Hz	**5**
Pulse half-width, µs: fast neutrons thermal neutrons	 200* **340**
Rotation rate, rev/min • Main reflector • Auxiliary reflector	 600 300
Background, %	**7.5**
Thermal neutron flux density from the surface of the moderator • Time average • Burst maximum	 **~10^{13} n/cm^2 s** **~10^{16} n/cm^2 s**

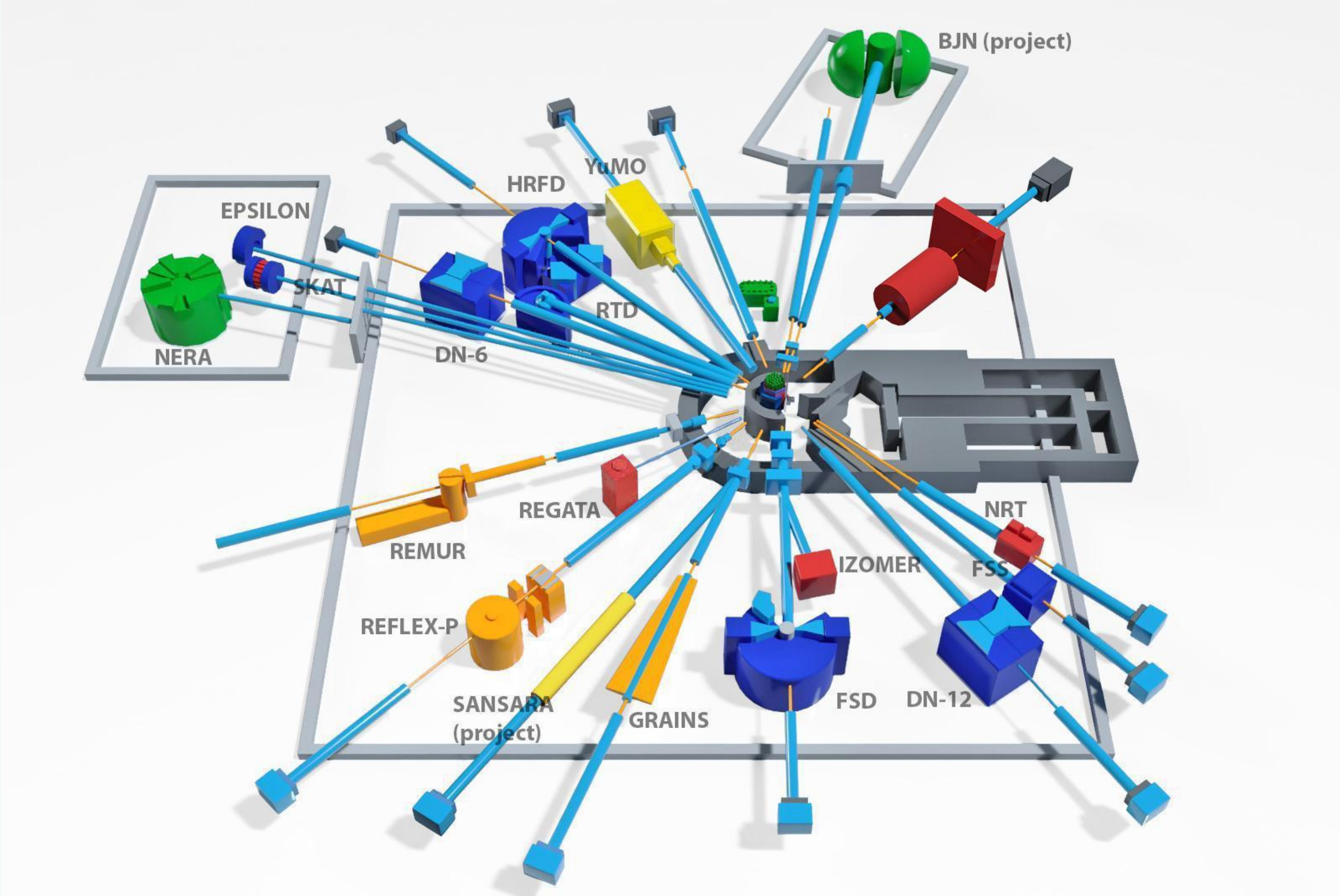
* at reactor power of 2MW

prepared by Dr. D. Chudoba

JOINT INSTITUTE FOR NUCLEAR RESEARCH

FRANK LABORATORY OF NEUTRON PHYSICS

Neutron Instruments



- Length of neutron guides – up to ~30 m in the experimental halls and up to ~100 m in two pavilions.
- Typical neutron flux density on the sample – ~10^6 cm^{-2}s^{1} (up to 4 x 10^7 cm^{-2}s^{1})

14 INSTRUMENTS INCLUDED IN USER PROGRAM

Diffraction:
HRFD
RTD
DN-6
EPSILON
SKAT
DN-12
FSD

Inelastic scattering:
NERA

Small-Angle
YuMo

Reflectometry:
GRAINS
REMUR
REFLEX

NAA:
REGATA

Under construction:

- **SANSARA** – small angle + imaging (2026)
- **BJN** – inelastic scattering (2027)

Parameters of the instruments could be found at https://flnp.jinr.int/en-us/main/facilities/ibr-2

NRT (neutron imaging) is included in the User Program in the second half of 2025

FLNP User Program

Who can apply for beam time?

- Scientists from **any country of the world** can apply for beam time.
- Scientists from member states of JINR get additional financial support.

https://ibr-2.jinr.int

I. Regular access applications

	First round	Second round
Period for proposal submission	September 1 - October 15	March 1 – April 15
Experiments time	1 half-year	2 half-year

https://flnp.jinr.int/en-us/main/your-experiment-at-flnp

Distribution of the beam time

In the FLNP JINR the neutron beam time at the high flux pulsed IBR-2 reactor is distributed between **internal users** (FLNP) and **general science community** (GSC) in the ratio of

- **35%** (internal proposals)
- **55%** (external regular proposals)
- **10%** (external urgent beam time requests)

II. Fast access applications

- NO DEADLINE
- Submission – via FLNP scientific secretary

FLNP User Program

The proposals are evaluated by **Experts Committees** (**technical and scientific**) and beam time for experiments is granted upon possibility of technical implementation and scientific merit of the proposal.

Scientific Experts Committees:

- Nanosystems and Soft Matter (YuMO, GRAINS, REFLEX, REMUR)
- Atomic and Magnetic Structure

  (RTD, DN-6, DN-12, SKAT, EPSILON, FSD, HRFD)
- Lattice and Molecular Dynamics (NERA)
- Neutron Activation Analysis (REGATA)

Detailed information could be found at:

Sidorov N.E., Chudoba D.M., Gorshkova Yu.E., Kochnev P.O., Sadovsky D.A. “User program for the neutron source reactor IBR-2 (FLNP JINR)” Physics of Particles and Nuclei Letters, ISSN 1547-4771, 2024, Vol. 21, No. 3, pp. 553–559.

Neutron scattering in condensed matter physics

https://flnp.jinr.int/en-us/main/science/condensed-matter-physics

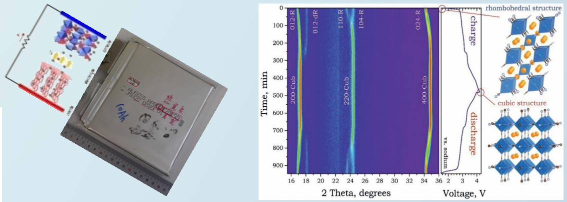
- Search for new properties of crystals, liquids, nanosystems
- Study of materials with new properties promising for engineering, energy, biology and pharmacology
- Study of structure and deformations of materials for solving problems of materials science, archeology, geology
- Study of dynamics (phase transitions, diffusion, changes in magnetic fields) at the microscopic level in molecular crystals, nanostructured materials, biologically active materials, etc.
- Study of cultural heritage objects

https://flnp.jinr.int/images/Books/Main_page/culture_en.pdf

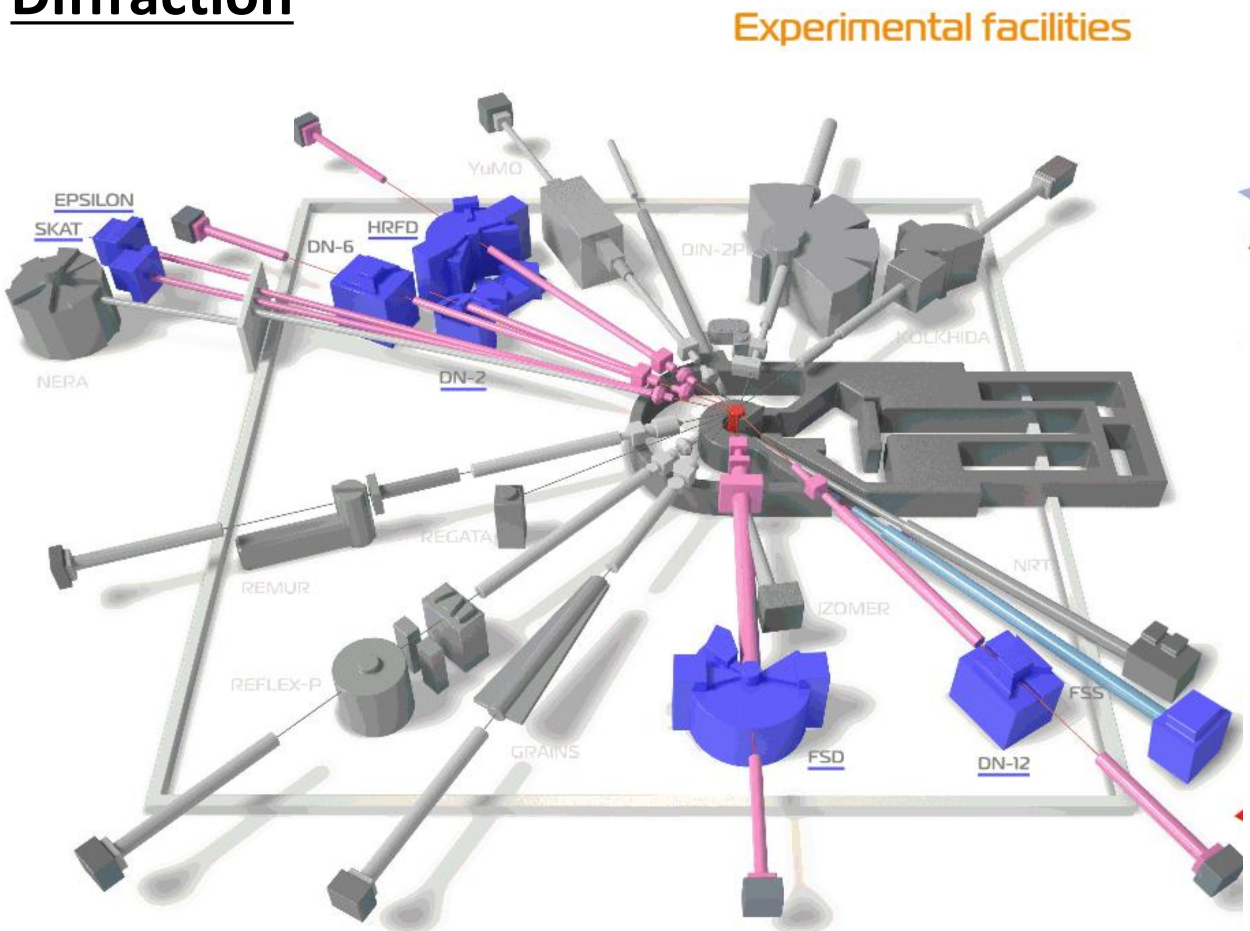
https://flnp.jinr.int/images/Books/Blue_books/LifeSciencesBook.pdf

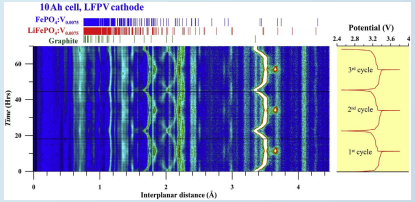
https://flnp.jinr.int/images/box-slider/MaterialsScienceBook.pdf

Neutron scattering in condensed matter physics

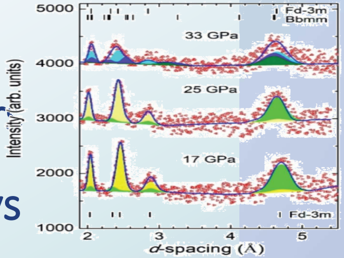


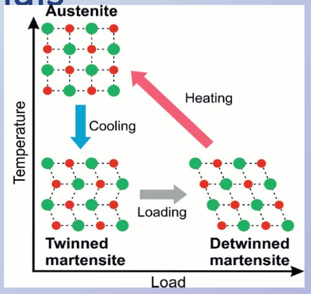
Diffraction





- Crystal and magnetic structure of novel materials under ambient and extreme conditions
- Real-time studies of Li-based accumulator
- Phase transitions of H-based storage alloys
- Crystallographic texture of metals, rocks and biological objects
- Strain measurements in structural materials
- 2D van der Waals magnetic materials





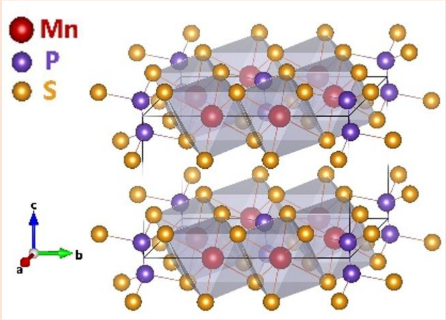
Diffractometers equipped with Fourier choppers to achieve high resolution at short beamlines with long pulse of the reactor

Experimental possibilities of IBR-2 spectrometers complex

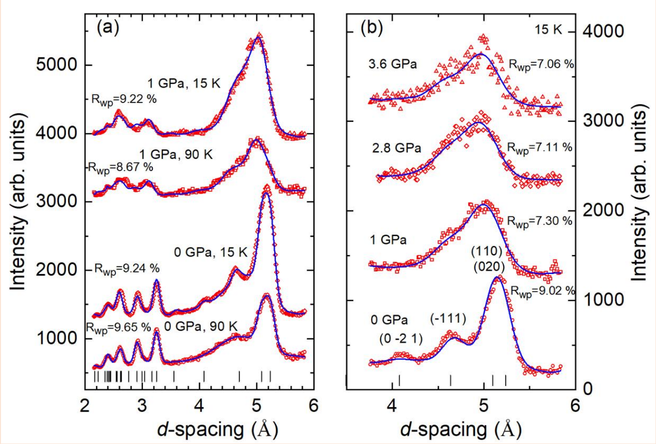
Spectrometer, Instrument	Applications	Basic parameters	Specific features
Neutron diffraction			
HRFD	Investigations of crystalline and magnetic structures of polycrystalline samples, as well as their microstructure under external influences	1) **High resolution mode**: d_{hkl} range – 0.4 - 5 Å, resolution **$\Delta d_{hkl}/d_{hkl} \approx 0.0015$** 2) Medium resolution mode: d_{hkl} range – 0.5 - 14 Å, resolution $\Delta d_{hkl}/d_{hkl} \approx 0.015$ Temperature range: 5 - 1350 K	Sample volume: 0.1÷4 cm^3
RTD	Analysis of crystalline and magnetic structures of materials, investigation of biological samples, kinetics of chemical reactions, structural and magnetic phase transitions **in real time mode**, diffuse scattering in defective crystals	d_{hkl} range: 0.6 – 30 Å, resolution $\Delta d_{hkl}/d_{hkl} \approx 0.01$ Temperature range: 2.5 - 1400 K	Minimum sample volume: polycrystal – 0.3 cm^3, single crystal – 0.1 mm^3. Characteristic spectrum measurement time in real time mode – **from 1 s to 10 min** (depending on sample volume)
DN-6	Determination of parameters of atomic and magnetic structure of functional materials **under ultra-high pressures and low temperatures**	d_{hkl} range: 1.0 – 12 Å, resolution $\Delta d_{hkl}/d_{hkl} \approx 0.025$ Pressure range: 0 - 9 GPa (high-pressure cells with sapphire anvils), 0 - **35 GPa** (high-pressure cells with diamond anvils) Temperature range: **5 - 300 K**	Investigations of microsamples with a volume of about 2-3 mm^3 (high-pressure cells with sapphire anvils), **0.05-0.1 mm^3** (high-pressure cells with diamond anvils)
DN-12	Determination of parameters of atomic and magnetic structure of functional materials **under high pressures and low temperatures**	d_{hkl} range: 1.0 - 12 Å, resolution $\Delta d_{hkl}/d_{hkl} \approx 0.02$ Pressure range: 0 - 5 GPa (high-pressure cells with sapphire anvils) Temperature range: 15-300 K	Investigations of microsamples with a volume of about 2-3 mm^3 (high-pressure cells with sapphire anvils)
FSD	Non-destructive **testing** of internal **mechanical stresses** in industrial products, study of mechanical properties, deformations and microdeformations in crystalline materials	d_{hkl} range: 0.5 - 4 Å, resolution $\Delta d_{hkl}/d_{hkl} \approx 0.0023$ Testing machine LM-29 for *in situ* sample studies under external load (up to **29 kN**) and high temperatures (up to 800°C)	Scanning of residual stresses in bulk samples with a minimum gauge volume of **2x2x2 mm** Linear size of samples – up to **0.3 m**
SKAT	Measurements of **crystallographic texture** in specimens of structural materials, as well as geological and biological samples	d_{hkl} range: 0.7 - 5 Å, resolution $\Delta d_{hkl}/d_{hkl} \approx 0.005$	Sample volume: 8÷**100** cm^3
Epsilon	**Investigation of stresses, strains, and textures** in geological, metallic, and ceramic samples	d_{hkl} range: 0.7 - 6.5 Å, resolution $\Delta d_{hkl}/d_{hkl} \approx 0.004$ Uniaxial compression machine with F_{max} = **100 kN** (150 MPa)	Sample volume: 2÷42 cm^3

Operation of three instruments (HRFD, FSD and EPSILON) for external users is temporarily suspended due to technical reasons.

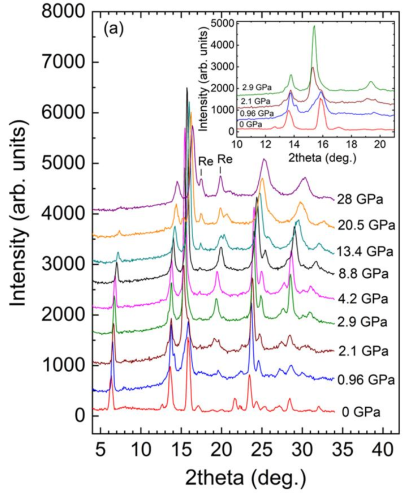
High-Pressure Effects on Structural and Magnetic Properties of van der Waals Antiferromagnet $MnPS_3$



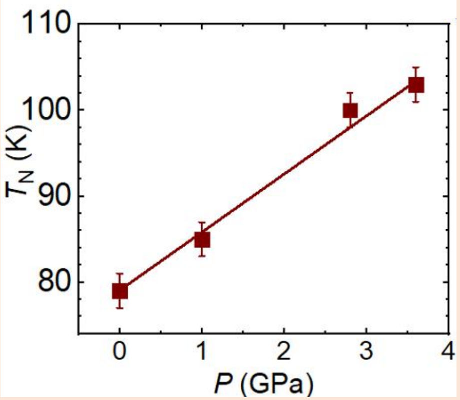
Monoclinic crystal structure of $MnPS_3$



Neutron diffraction patterns of $MnPS_3$ at high pressures and selected temperatures



X-ray diffraction patterns of $MnPS_3$ at high pressures

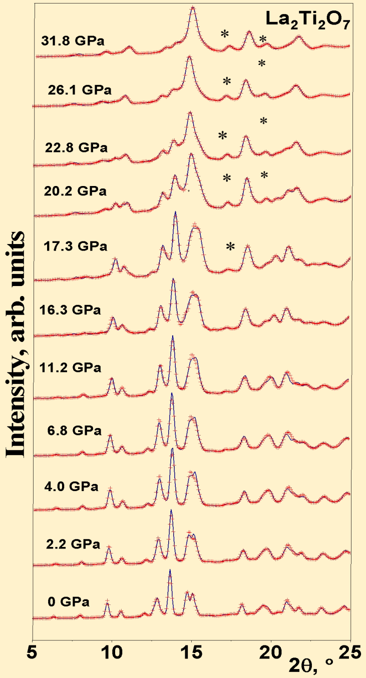


Pressure behavior of the Neel Temperature

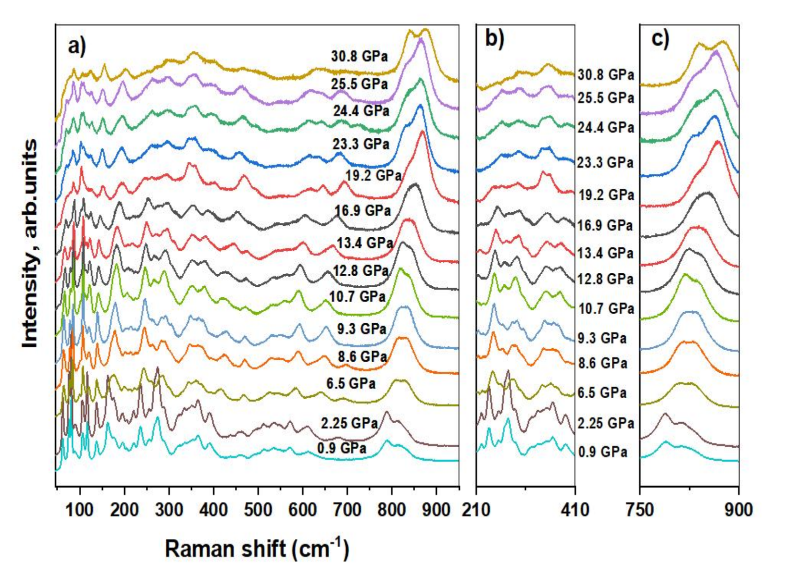
D.P. Kozlenko, O.N. Lis, N.T.Dang et.al, Phys. Rev. Materials 8, 024402 (2024)

Pressure-Induced Ferroelectric – Paraelectric Phase Transition in $R_2Ti_2O_7$ (R=La, Pr, Nd)

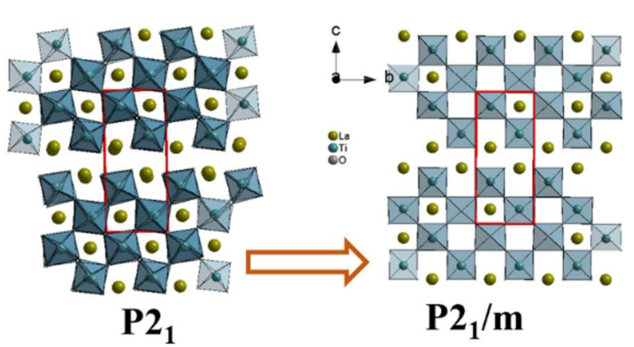
The layered titanates demonstrate one of the highest known ferroelectric Curie temperatures (T_C > 1400 °C) and piezoelectric behavior with high coercive field (Eg > 45 kV/cm)



X-ray diffraction patterns of $La_2Ti_2O_7$ at high pressures



Raman spectra of $La_2Ti_2O_7$ at high pressures

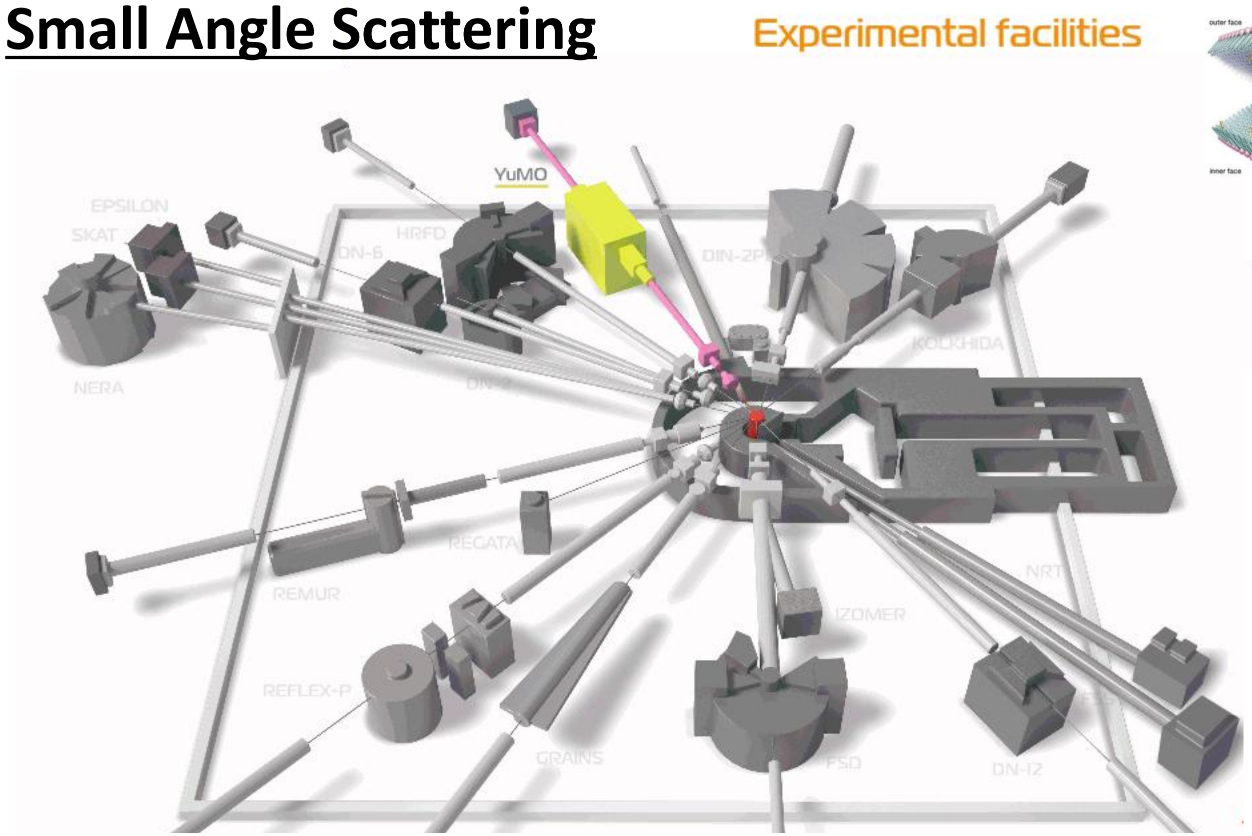


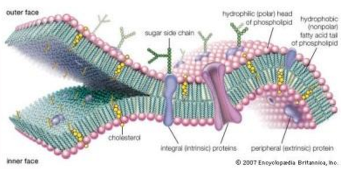
Structural re-arrangement caused by the ferroelectric – paraelectric phase transition in $R_2Ti_2O_7$ at high pressures

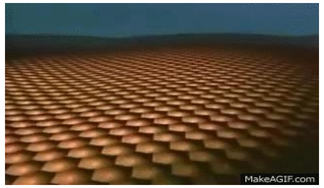
A.G.Asadov, D.P. Kozlenko, S.E. Kichanov, E.V.Lukin et.al, Journal of Alloys and Compounds 1003, 175461 (2024), Solid State Sciences 156, 107676 (2024)

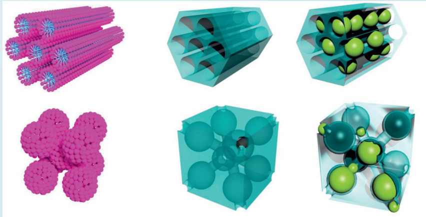
Neutron scattering in condensed matter physics

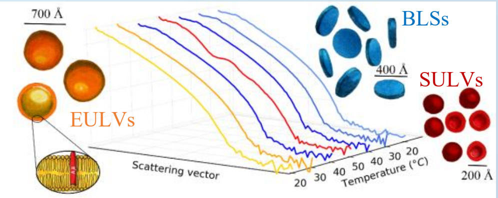
Small Angle Scattering

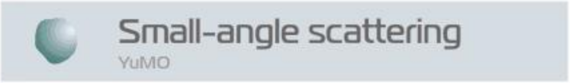












- **Structural organization** and **aggregation** of nanoparticles and **composite systems**
- Interactions of **nanoparticles** with **bio-macromolecules**
- **Nanopores** for magnetic and biomedical applications

Applications	Basic parameters	Specific features
Determination of sizes, shapes, spatial correlations of particles, agglomerates, pores, as well as fractal dimension in nanomaterials, biological objects, polymers, colloidal solutions	Q-range: **7×10^{-3} - 0.5 Å^{-1}** Temperature range: 10-180°C	Characteristic particle size that can be identified: **1-500 nm** Minimum sample volume: **500 µl** Characteristic sample size is up to 1.4 cm in diameter

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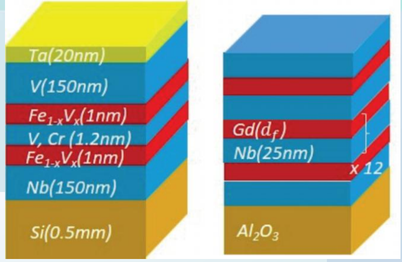
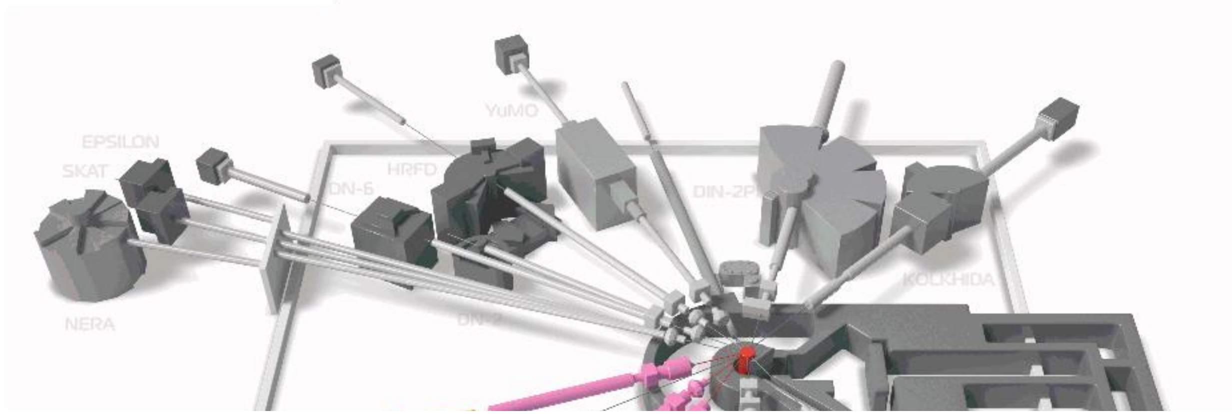
Neutron scattering in condensed matter physics



Reflectometry

Experimental facilities

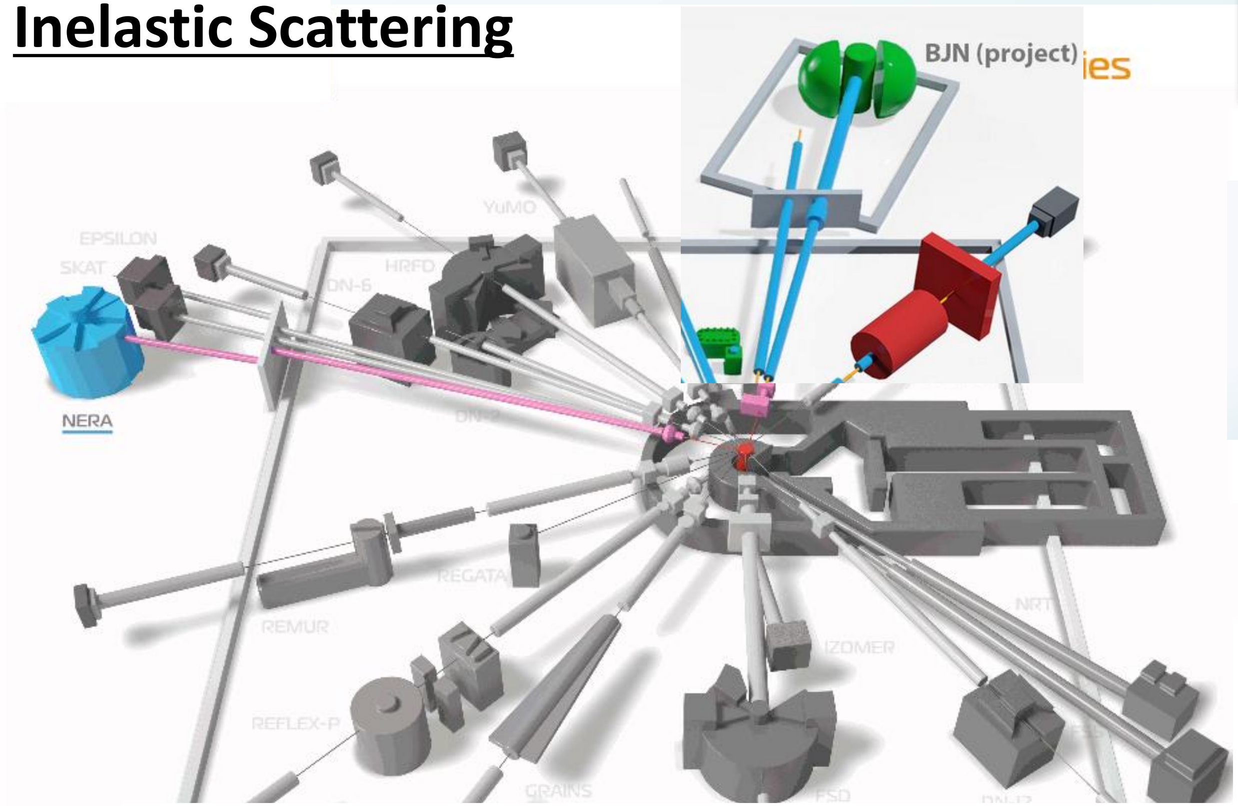


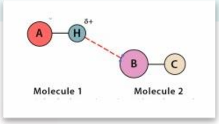
- **Thin films** and surfaces
- **Surface adsorption** of magnetic nanoparticles
- Superconducting and magnetic properties of the **complex layered heterostructures**

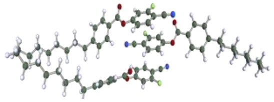
Spectrometer, Instrument	Applications	Basic parameters	Specific features
REMUR	Determination of parameters of magnetic and superconducting heterostructures, nonmetallic thin films	Q-range: 0.001 - 2 nm^{-1}, resolution $\Delta Q/Q \approx 1$ % Temperature range: 1.5 - 300 K Magnetic field on the sample: up to 1.5 T	Minimum surface area of the sample – 5x5 mm^2, thickness of layers accessible for research – **0.5-500 nm**, roughness – ~1 nm
REFLEX	Determination of structural parameters of thin-film nanostructures	Q-range: 0.01 - 1.3 nm^{-1}, resolution $\Delta Q/Q \approx 1 - 15$ % Temperature range: 1.5 - 300 K Magnetic field on the sample: up to 0.5 T	Minimum surface area of the sample – 20x20 mm^2, thickness of layers accessible for research – **2-500 nm**, roughness – ~3 nm
GRAINS	Determination of structural parameters of **interfaces with “soft” and liquid media**	Q-range: 0.05 - 1.0 nm^{-1}, resolution $\Delta Q/Q \approx 5$ %. Temperature range: 10 - 150°C	Minimum surface area of the sample – 5x5 cm, maximum interface thickness – **100 nm**, roughness – up to 5 nm (at a thickness of 100 nm)

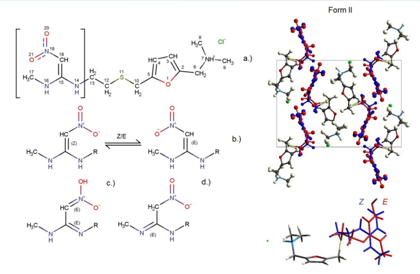
Neutron scattering in condensed matter physics

Inelastic Scattering

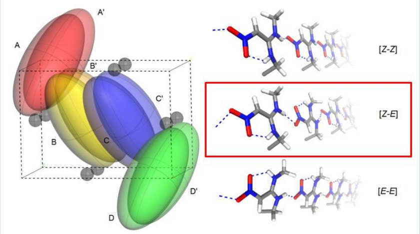


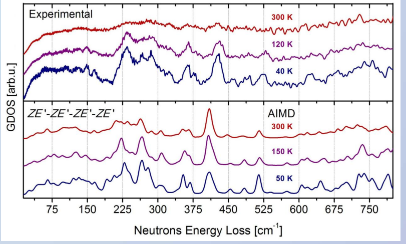


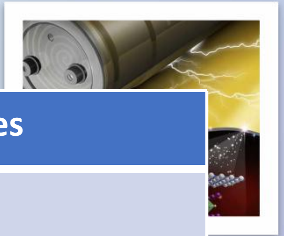




- Molecular structure and **dynamics**
- **Isomeric forms** of drugs
- **Drug delivery systems**



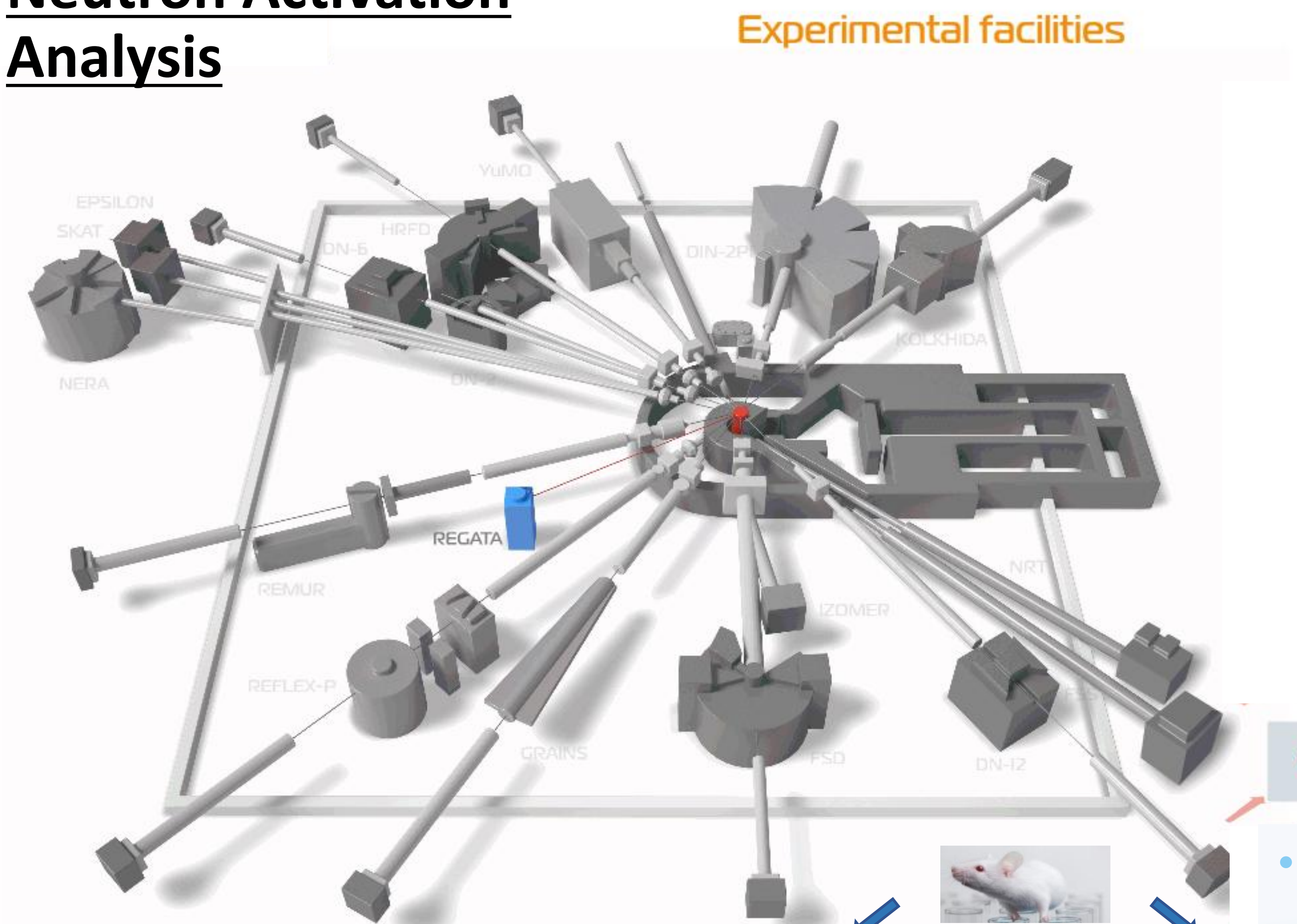


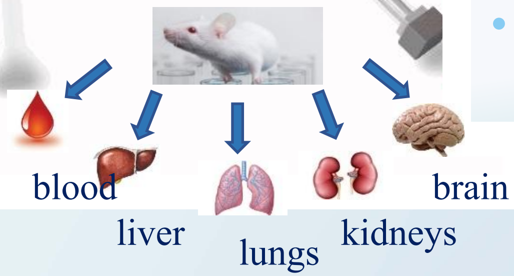


Applications	Basic parameters	Specific features
Investigation of atomic and molecular dynamics of hydrogen-containing compounds, including pharmacological substances, analysis of the effect of phase polymorphism	Energy transfer range: **1 - 160 meV** Resolution $\Delta E/E \approx$ 2- 4% Temperature range: 4 - 300 K	Sample volume is about **4-5 cm^3**

Nuclear analytical method

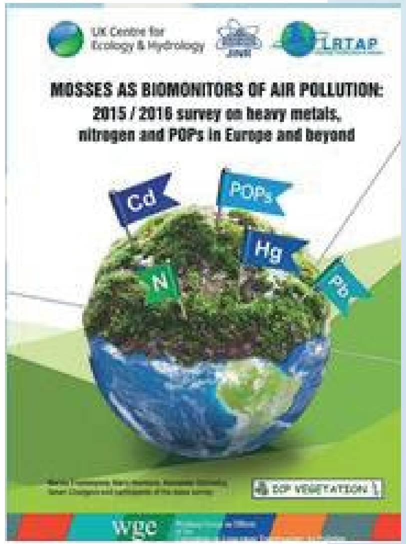
Neutron Activation Analysis

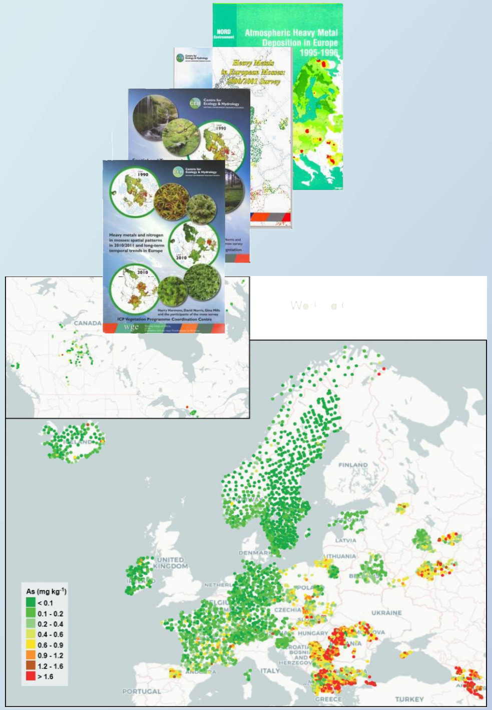


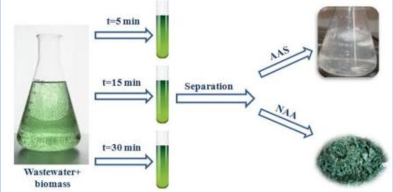


UNECE
United Nations

United Nations Economic
Commission for Europe







Neutron Activation Analysis
REGATA

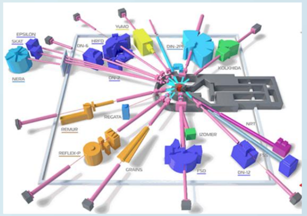
- **Elemental composition analysis** of air, water, and soil or objects of cultural heritage

Development of the biological approach for rare earth elements recovery from wastewater

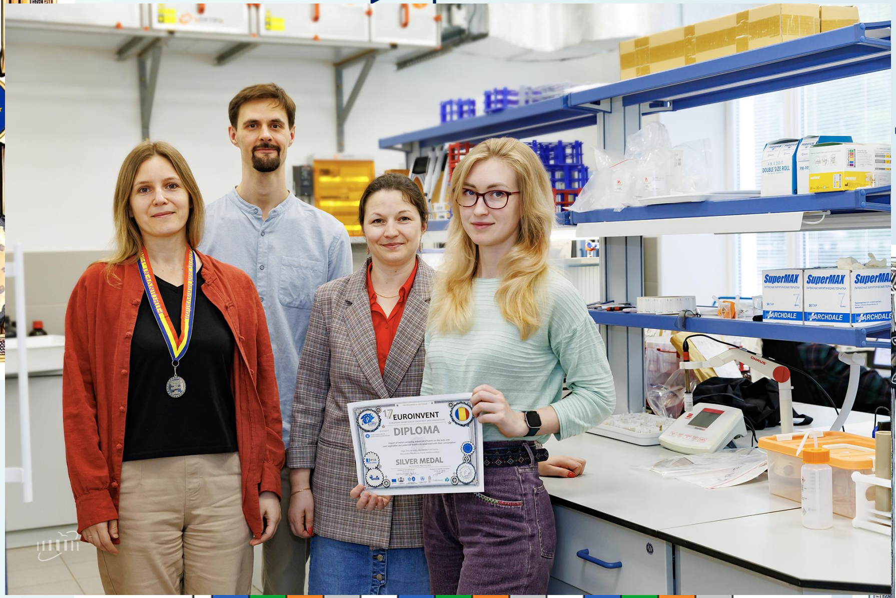
Cultivation for five days

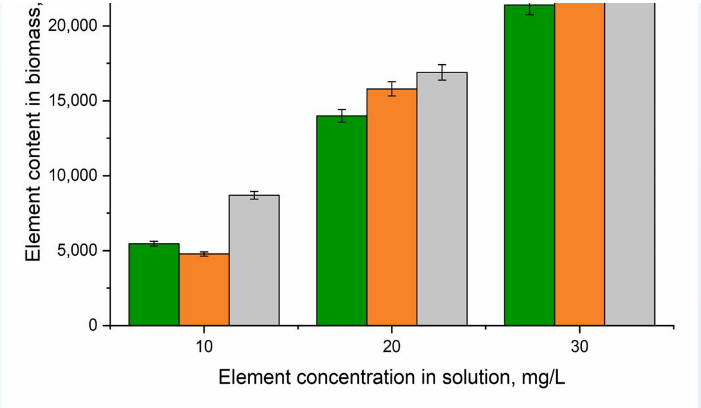
Elemental analysis

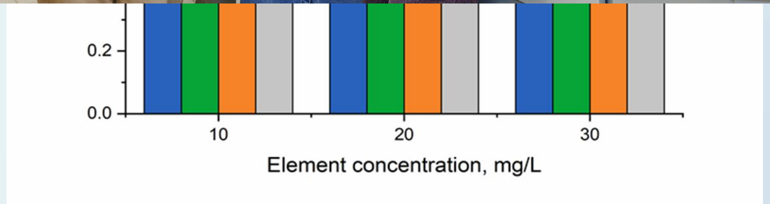
Biomass productivity



Total proteins, carbohydrates, lipids, and malondialdehyde







Uptake of Er, Ho, and Gd by *spirulina* biomass cultivated in a medium supplemented with REEs.

Effects of rare earth elements on spirulina productivity

I. Zinicovscaia et al. Microorganisms, 12, 122. (2024)

FLNP offers a large suite of equipment for comprehensive study of samples by complementary techniques

It includes:

- Xeuss 3.0 X-ray scattering station;
- X-ray Diffractometer EMPYREAN (PANalytical);
- Coherent Anti-Stokes Raman Spectrometer
- Raman spectrometers;
- IR and UV spectrometers;
- RFA;
- ICP-MS
- Chromatography System NGC Quest™ 10 Plus
- AFMs
- …etc.

https://flnp.jinr.int/images/box-slider/Laboratory_Equipment_DNICM_FLNP_JINR_2021.pdf

Main activities in the field of nuclear physics with neutrons:

1. **Investigations of the neutron induced nuclear reactions:**
   - fundamental symmetries;
   - highly excited states of the nuclei;
   - nuclear fission;
   - nuclear data.

2. **Investigations of the fundamental properties of the neutron, ultra-cold neutrons:**
   - tests of quantum mechanics;
   - search for new type of interactions;
   - neutron lifetime measurement.

3. **Applied and methodical research:**
   - neutron activation analysis and others nuclear technics for isotope analysis;
   - neutron in space;
   - Ion beam analysis:
   - IREN developing.

Source of resonance neutrons IREN based at lineal electron accelerator

https://flnp.jinr.int/en-us/main/facilities/iren

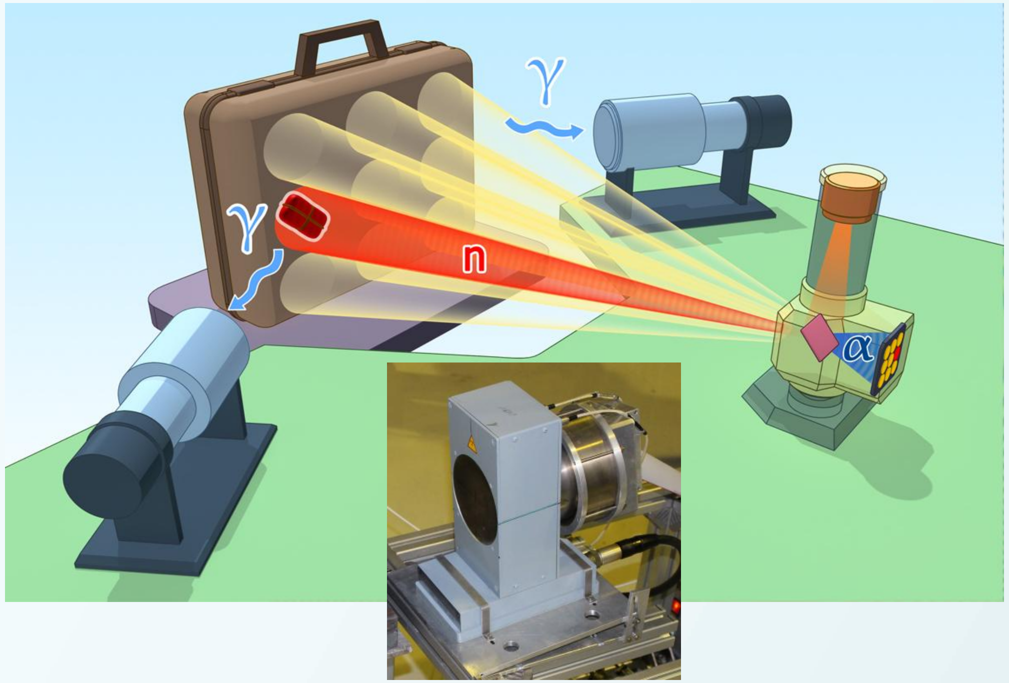
The linear electron accelerator LUE-200 used as a driver for the intense resonance neutron source IREN. The accelerator is positioned vertically. It consists of a pulsed electron gun, an accelerating system, microwave power sources based on 10-cm klystrons with modulators, a focusing-beam transport system, a diagnostics system with a broadband magnetic spectrometer and a vacuum system.

Peak current (A)	3
Repetition rate (Hz)	50
Electron pulse duration (ns)	100
Electron energy (MeV)	110
Beam power (kW)	1.5
Multiplication	1
Neutron intensity (n/s)	$\sim 3 \times 10^{11}$

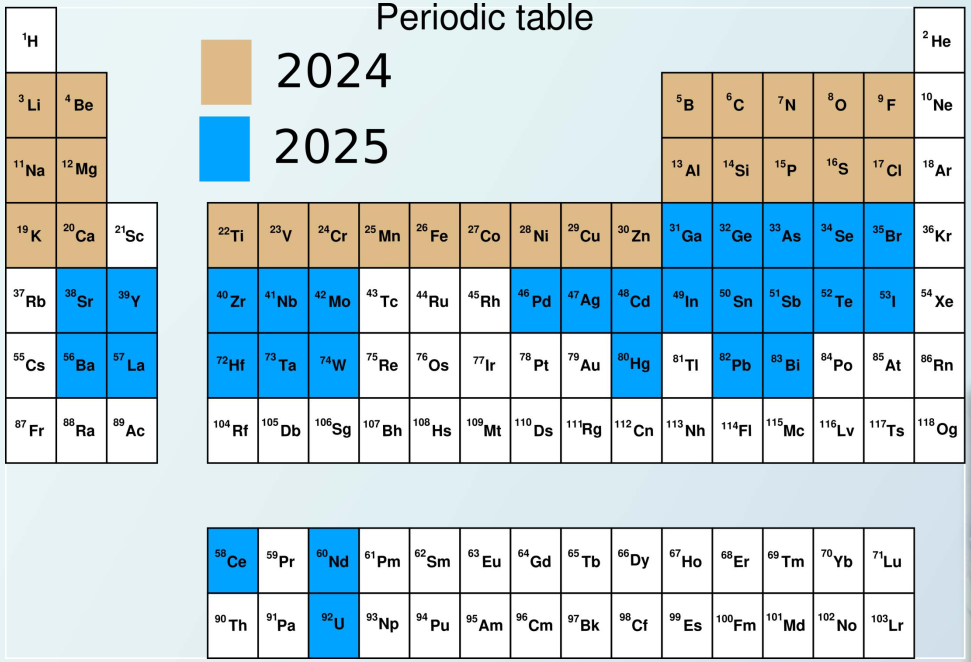
1200 hours/year

D-T generator for tagged neutron technique (TANGRA Project)

https://flnp.jinr.int/en-us/main/facilities/tangra-project-en

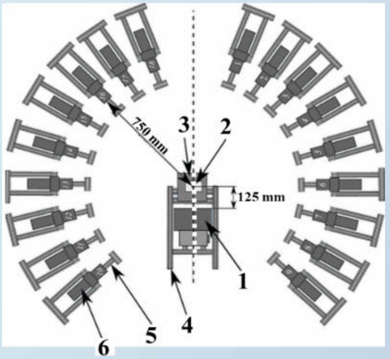


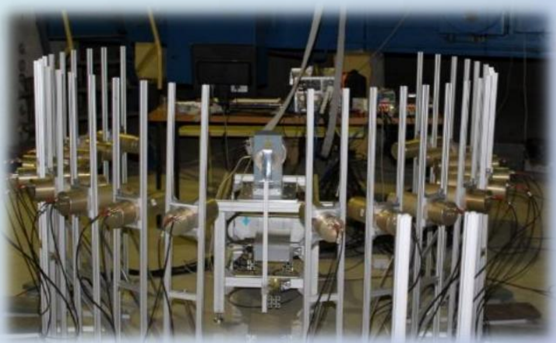
yield up to 10^8 c^{-1}
Set of NaI(Tl) detectors
Set of BGO detectors
Set of LaBr detectors
Set of detectors based on different plastics
HPGe detector

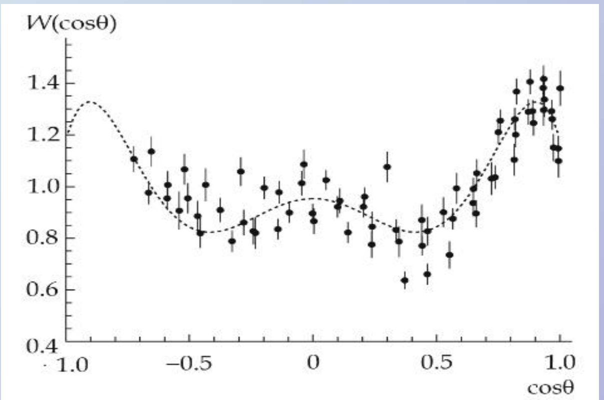


In 2024 γ-ray emission cross sections for light elements was measured: B, C, N, O, F, Na, Mg, Al, Si, P, S, Cl, K, Ca, Ti, V, Cr, Mn, Fe, Co, Ni, Cu, Zn, Sn.

Gamma-spectra and angular distributions of gamma ray have been measured in inelastic neutron scattering reactions for 20 nuclei.

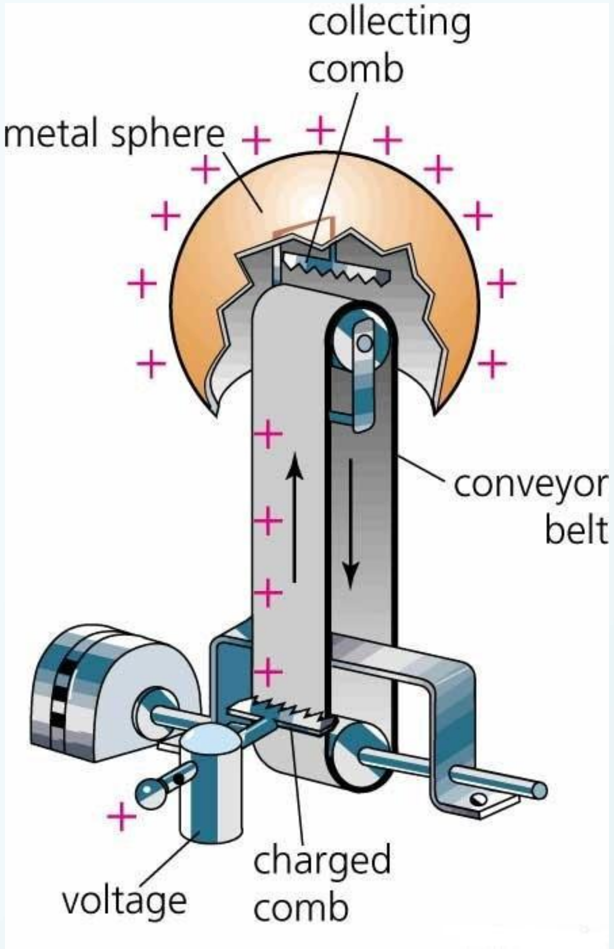






EG-5 *https://flnp.jinr.int/en-us/main/facilities/eg-5*

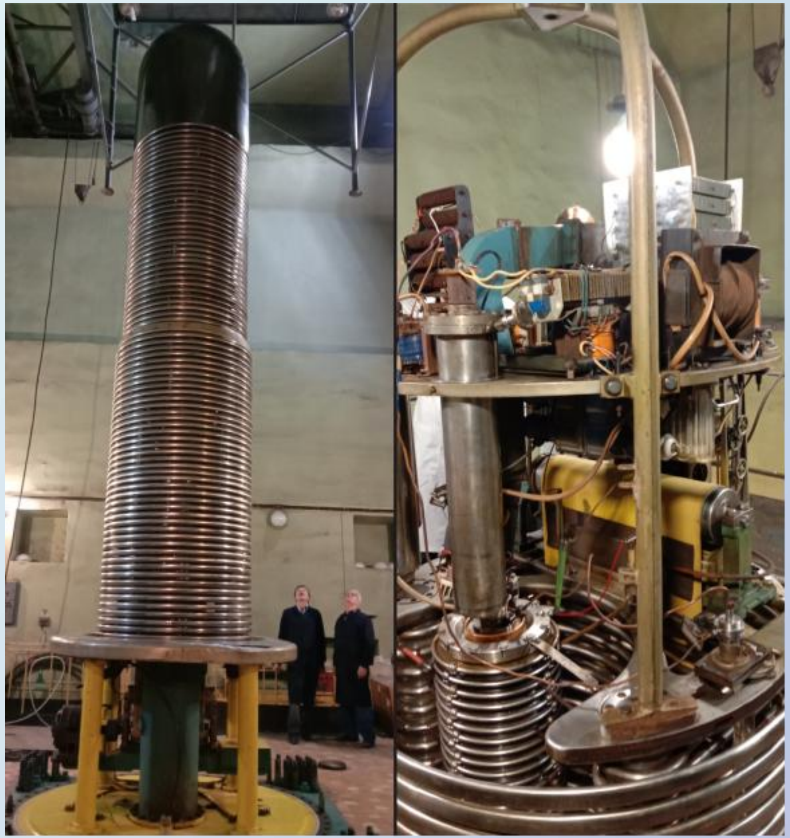
Electrostatic Van de Graaff accelerator, was built in 1965.



<u>The installation remains in demand today.</u>

The characteristics of EG-5 Accelerator:	
Energy region	0.9 – 3.5 MeV
Beam intensity for H +	30 µA
Beam intensity for H e +	10 µA
Energy spread	< 500 eV
Number of beam lines	6

600 hours/year

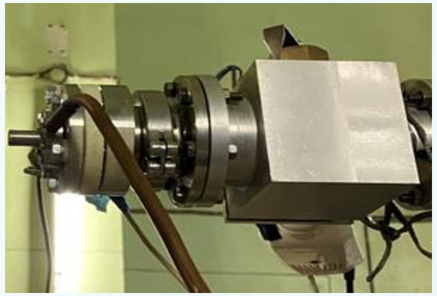


Plan of modernization 2023-2026:

Before modernization	**After modernization**
Terminal voltage - 2,5 MV Beam current – 100nA Ion Energy – 2,5 MeV	Terminal voltage - **4,1 MV** Beam current – **50-100mkA** Ion Energy – **4,1 MeV**

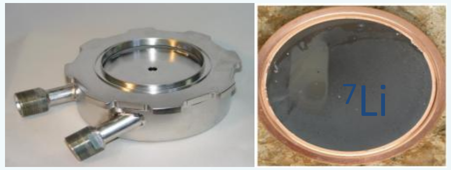
EG-5

Fast neutron reactions



Gas Target D(d,n)^{3}He

- Neutron flux – 5 10^{7} n/s sm^{2}
- Max. neutrons energy - 5,5 ± 0,1 MeV

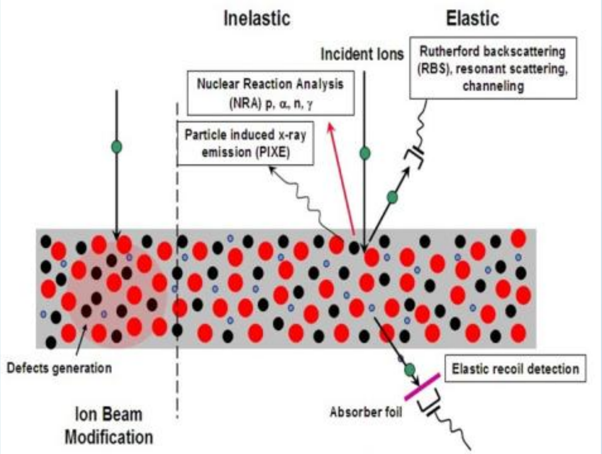


Solid-state target ^{1}H + ^{7}Li - ^{7}Be + n

- Neutrons flux – 5 10^{7} n/s sm^{2}
- Energy region – 20 – 800keV

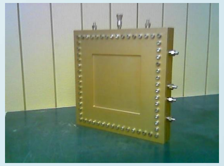
- Quasi-monochromatic neutrons in a wide range of energies

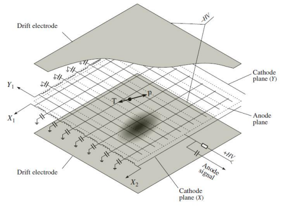
Ion Beam Analysis & complementary methods

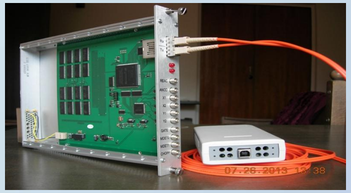


- The elemental composition of multilayer systems, isotopic composition, stoichiometry of films.
- Optical, electronic and electrical properties using complementary methods (ellipsometry voltammetry impedance spectroscopy).

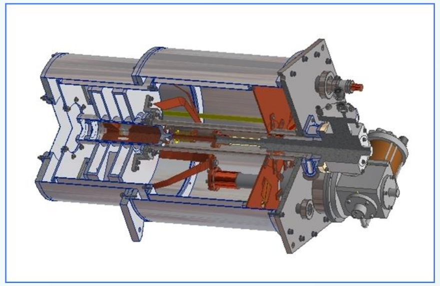
Development of neutron instruments elements :

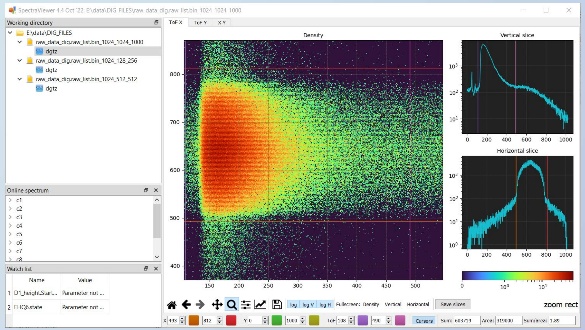




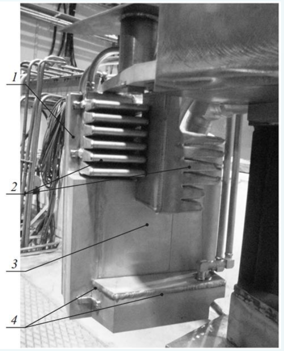


1. **Neutron detectors:**
   - gaseous and scintillator neutron detectors;
   - development of the technology of thin film B_4C coverage;
   - detector electronics.

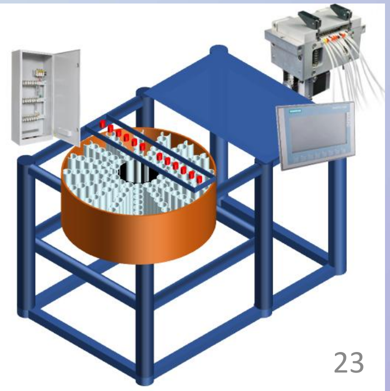




2. **Tools for instrument development and optimization:**
   - simulation of instruments;
   - sample environment systems
   - software.



3. **Developing of cold moderators:**
   - developing of exist moderators' cryogenic system ;
   - developing of methane-based moderator.

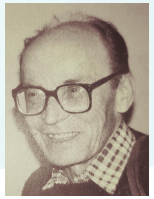


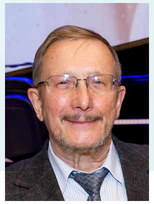
Neutron scattering in condensed matter physics

Inelastic Scattering

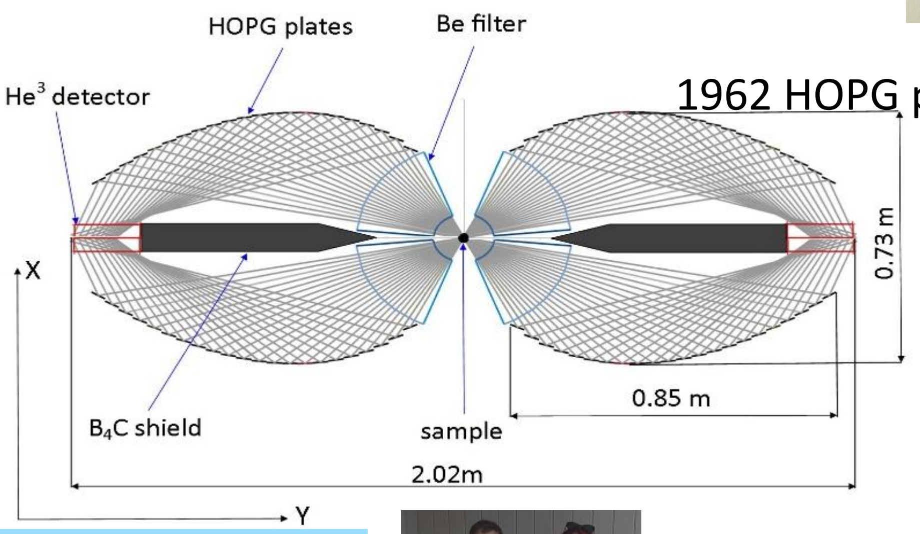
BJN (*Bajorek*-***J****anik*-***N****atkaniec*) spectrometer

New inelastic neutron scattering spectrometer in inverse geometry

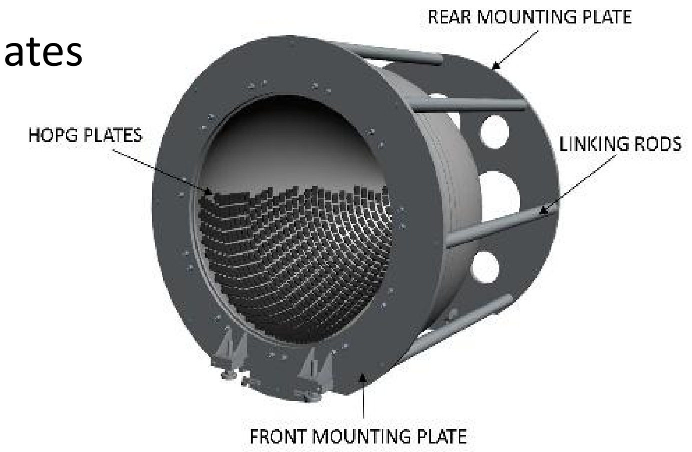


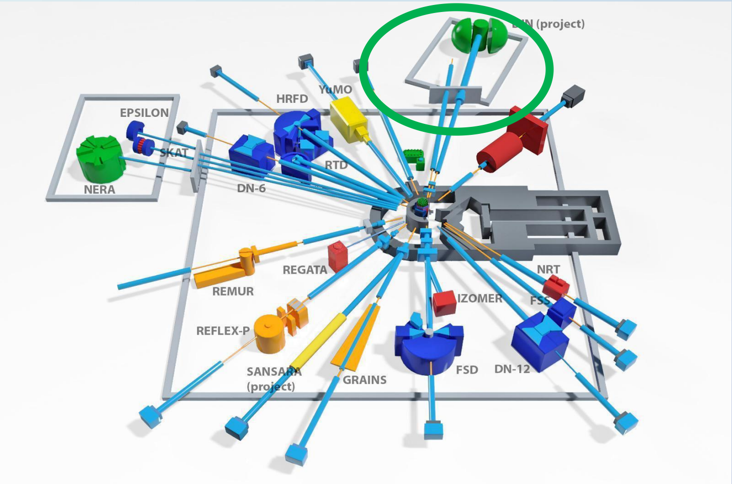


One of the top five in the world



1962 HOPG plates



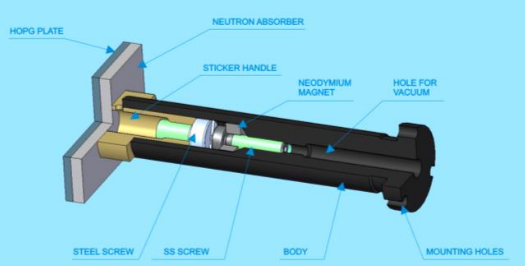


The total **solid angle** coverage of the BJN spectrometer would be **5.8 Sr.**

The overall luminosity of the BJN spectrometer could be enhanced by up to 150 times relative to NERA.

Prototype





https://flnp.jinr.int/en-us/main/facilities/materials/bjn-project

New back scattering detector

New large aperture ZnS scintillator detector system covering scattering angles range 2θ = 133-175°, installed at the HRFD diffractometer.

Ω, sr2
The surface of scintillator S > $10\ m^2$
The approximate length of fibers L=36000 m
Photomultipliers : 216

Experimental site for neutron detector production

Spattering machine for B_4C coverage
Ferry Vatt company, Kazan, Russia
Max. coverage square 400x1200 mm²

Modern equipment and engineer systems

Thank you for attention
and
we invite you to joint research