Research with neutrons at Frank Laboratory of Neutron Physics JINR

Egor Lychagin

Joint Institute for Nuclear Research
The Joint Institute for Nuclear Research
an international intergovernmental organization

16 Member States:
- Armenia
- Cuba
- Kazakhstan
- Russia
- Azerbaijan
- DPRK
- Moldova
- Slovakia
- Belarus
- Egypt
- Mongolia
- Uzbekistan
- Bulgaria
- Georgia
- Romania
- Vietnam

Associate Members:
Germany, Hungary, Italy, The Republic of South Africa, Serbia

JINR comprises 7 Laboratories, each being comparable with a large institute in the scale and scope of investigations performed.
THREE MAIN SCIENTIFIC DEPARTMENTS of FLNP:

- Department of nuclear physics (143 persons)
- Department of Neutron Investigations of Condensed Matter (101 persons)
- Department of Spectrometers Complex IBR-2 (49 persons + 23 persons SNSCM)
- Raman spectroscopy sector (10 persons)
- Sector of new neutron source (24 persons)

FLNP staff breakdown (2023):

<table>
<thead>
<tr>
<th>Category</th>
<th>Count</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td>564</td>
</tr>
<tr>
<td>Scientists</td>
<td>203</td>
</tr>
<tr>
<td>Engineers and specialists</td>
<td>155</td>
</tr>
<tr>
<td>Workers</td>
<td>174</td>
</tr>
<tr>
<td>Administrative staff</td>
<td>32</td>
</tr>
</tbody>
</table>
Pulsed Reactor IBR-2

Operate since 1984

Deep modernization was done at 2006-2010

Operation days for experiment

<table>
<thead>
<tr>
<th></th>
<th></th>
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<th></th>
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<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Days</td>
<td>61.3</td>
<td>110.3</td>
<td>103</td>
<td>110.7</td>
<td>103</td>
<td>111.7</td>
<td>92.6</td>
<td>60.5</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Average power, MW

<table>
<thead>
<tr>
<th></th>
<th>2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuel</td>
<td>PuO₂</td>
</tr>
<tr>
<td>Number of fuel assemblies</td>
<td>69</td>
</tr>
<tr>
<td>Maximum burnup, %</td>
<td>9</td>
</tr>
<tr>
<td>Pulse repetiton rate, Hz</td>
<td>5</td>
</tr>
</tbody>
</table>
| Pulse half-width, µs:
  fast neutrons | 200*        |
  thermal neutrons | 340         |
| Rotation rate, rev/min:
  Main reflector | 600         |
  Auxiliary reflector | 300         |
| MMR and AMR material | Nickel + steel |
| MR service life, hours | 55 000 |
| Background, % | 7.5         |
| Thermal neutron flux density from the surface of the moderator:
  Time average | $\sim10^{13}$ n/cm² s |
  Burst maximum | $\sim10^{16}$ n/cm² s |

* at reactor power 2MW

prepared by Dr. D. Chudoba
Neutron Instruments

13 INSTRUMENTS INCLUDE IN USER PROGRAMM

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

Small-Angle:
- YuMo

Reflectometry:
- GRAINS
- REMUR
- REFLEX

Inelastic scattering:
- NERA
- REGATA

Under construction:
- SANSARA – small angle + imaging (2024)
- BJN – inelastic scattering (2025)

The Instruments parameters could be found at https://flnp.jinr.int/en-us/main/facilities/ibr-2
User meetings are held every two years on the framework of the “Condensed Matter Research at the IBR-2 Reactor” conference traditionally.

The 2024 meeting will be postponed due to a long reactor shutdown.
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.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peak current (A)</td>
<td>3</td>
</tr>
<tr>
<td>Repetition rate (Hz)</td>
<td>50</td>
</tr>
<tr>
<td>Electron pulse duration (ns)</td>
<td>100</td>
</tr>
<tr>
<td>Electron energy (MeV)</td>
<td>110</td>
</tr>
<tr>
<td>Beam power (kW)</td>
<td>0.4</td>
</tr>
<tr>
<td>Multiplication</td>
<td>1</td>
</tr>
<tr>
<td>Neutron intensity (n/s)</td>
<td>(~3\times10^{11})</td>
</tr>
</tbody>
</table>

1200 hours/year

https://flnp.jinr.int/en-us/main/facilities/iren
Electrostatic Van de Graaff accelerator, as one of basic experimental facilities of Frank Laboratory of Neutron Physics was built in 1965.

The installation remains in demand today.

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

600 hours/year

Plan of modernization 2023-2025:

<table>
<thead>
<tr>
<th>Before modernization</th>
<th>After modernization</th>
</tr>
</thead>
<tbody>
<tr>
<td>Terminal voltage - 2,5 MV</td>
<td>Terminal voltage - 4,1 MV</td>
</tr>
<tr>
<td>Beam current – 100nA</td>
<td>Beam current – 50-100mkA</td>
</tr>
<tr>
<td>Ion Energy – 2,5 MeV</td>
<td>Ion Energy – 4,1 MeV</td>
</tr>
</tbody>
</table>
Fast neutron reactions

Gas Target D(d,n)³He
- Neutron flux – \(5 \times 10^7\) n/s sm²
- Max. neutrons energy - 5,5 ± 0,1 MeV

Solid-state target \(^1\text{H} + ^7\text{Li} - ^7\text{Be} + n\)
- Neutrons flux – 5 \(10^7\) pat/s sm²
- 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).
EG-5 activities

1. Scientific collaboration 2023

11 - countries;
23 - institutes;
7 - projects;
23 - cooperation agreements;
3 - industrial partners including major electronics manufacturers (JSC MICRON) and the State Corporation ROSATOM.

2. Industrial Partners 2023

1. JSC Mikron.
2. JSC Angstrem
3. ROSATOM State Corporation

3. Formal performance indicators in 2023

- 39 publications, including Q1 and Q2;
- 20 oral presentations.

Project JINR-Serbia №: Order 373 from 22.05.2023, point 4(5).

ZrO$_2$ – Y$_2$O$_3$ nanoparticle

The best report at the «Alushta 2023» conference
Neutron generators

DT, DD neutron generators of 14, 2.5 MeV neutrons with alfa particle PSD
Neutron yield up to $10^8$ s$^{-1}$

Special DT neutron generator is the base for "TANGRA" (TAgged Neutrons and Gamma RAys) facility used for implementation the tagged neutron method (TNM). The facility serves as for solving the problem in nuclear physics as for applied research.

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

Neutron radioisotope sources

$^{252}$Cf,

$(\alpha,n)$ $^{241}$Am, $^{239}$Pu, $^{238}$Pu

Intensity $10^5$ – $10^7$ s$^{-1}$
Neutron scattering in 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 the 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 sites.

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


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

Neutron scattering in condensed matter physics

Experimental facilities

- Crystal and magnetic structure of novel materials at ambient and extreme conditions
- Real-time studies of Li-based accumulators
- Phase transitions of H-based storage alloys
- Crystallographic texture changes in steel
- Strain measurements in granite samples
Neutron scattering in condensed matter physics

- Crystal and magnetic structure of novel materials at ambient and extreme conditions
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- Strain measurements in granite samples

16 April, Tuesday
103 16:10 Olga Lis
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
Neutron scattering in condensed matter physics

Reflectometry

- Thin films and surfaces
- Surface adsorption of magnetic nanoparticles
- Superconducting and magnetic properties of the complex layered heterostructures
- 2D van der Waals magnetic materials
Neutron scattering in condensed matter physics

Inelastic Scattering

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

Neutron Activation Analysis

Elemental composition analysis of air, water, and soil or the objects of cultural heritage
Nuclear analytical method

Neutron Activation Analysis

**Today:**
12 14:30 Inga Zinicovscaia
16 15:50 Wael Badawy
17 16:10 Alexandra Kravtsova
18 17:00 Otilia Culicov
20 17:40 Yulia Aleksiayenak

**15 April, Monday**
46 12:00 Marina Frontasyeva
48 12:40 Omari Chaligava
49 14:30 Margarita Shvetsova
50 14:50 Konstantin Vergel
52 15:30 Pavel Nekhoroshkov

- **Elemental composition analysis** of air, water, and soil or the objects of cultural heritage
Neutron scattering in condensed matter physics

Neutron Imaging

- **Non-destructive** imaging of the industrial or precious objects
Neutron scattering in condensed matter physics

Neutron Imaging

16 April, Tuesday (radiational effects)
92 Almas Yskakov

- Non-destructive imaging of the industrial or precious objects
The laboratory has accumulated a large amount of equipment for comprehensive examination of samples by additional methods.

**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

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 and very cold neutrons:**
   - tests of quantum mechanics;
   - search for new type of interactions;
   - development of UCN sources.

3. **Applied and methodical research:**
   - neutron activation analysis and others nuclear technics for isotope analysis;
   - neutron in space;
   - Ion beam analysis;
   - IREN developing.
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17 April, Wednesday
148 15:10 Almat Yergashov
149 15:30 Sergey Borzakov
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Today:
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25 15:10 German Kulin
26 15:30 Turlybekuly Kylyshbek
28 16:00 Maxim Zakharov
29 16:15 Alexander Nezvanov
34 18:00 Eduard Sharapov
35 18:10 Aleksander Popov
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**16 April, Tuesday**
- 98 14:30 Nina Simbirtseva
- 101 15:30 Valerii Lobachev

**17 April, Wednesday**
- 148 15:10 Almat Yergashov
- 149 15:30 Sergey Borzakov
Investigation of neutron-induced reactions with charge particles emission

Work is planned to measure cross sections for reactions (n,p), (n,α) on various isotopes.

In 2024, it is planned to measure (n,α) reaction cross sections on gas samples Ar, F, O, Ne at EG-5, FLNP JINR (En=3-5 MeV) and at the tandem accelerator HI-13 CIAE (En=8-11 MeV) using specially constructed ionization chamber.

Cross sections will also be measured for $^{148}$Sm(n,α) at EG-5, FLNP JINR.

It is also planned to conduct test measurements of reactions (n,p), (n,α) on $^6$Li and Cl at the IREN facility.

Developing a proposal for experiments at CSNS (China) is undergoing.


Experimental hall EG-5, FLNP JINR

Experimental hall at IREN facility

New ionization chamber for the IREN facility
Investigation of neutron-induced reactions with charge particles emission

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

Setup for measuring γ-ray emission cross sections consisting of two HPGe detectors (4) and four LaBr detectors (5).
In 2024 it is planned to measure γ-ray emission cross sections for light elements: B, C, N, O, F, Na, Mg, Al, Si, P, S, Cl, K, Ca, Ti, V, Cr, Mn, Fe, Co, Ni, Cu, Zn, Sn.
Construction of a pilot mobile setup for determining the carbon content in soil using the Tagged Neutron Method (in collaboration with LLC “Diamant”).
Study of rare fission modes and prompt neutron emission in nuclear fission

Search for rare and exotic fission modes (quaternary and quinary fission) in thermal neutron induced fission of $^{252}\text{Cf}$, $^{233}\text{U}$ and $^{235}\text{U}$ nuclei.

- **Targets:** $^{235}\text{U}$, $^{237}\text{Np}$, $^{239}\text{Pu}$.
- **Measurements** are planned at IREN resonance neutron source.

Distribution of angles between two $\alpha$ particles from the quaternary fission of $^{252}\text{Cf}$.

Schematic representation of different types of fission processes: binary (a), ternary (b) and “pseudo” quaternary (c) and “true” quaternary (e).
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Frescoes of Moscow Kremlin Cathedral

- Specialist of NAA group of FLNP together with art historians research wall paintings of ancient Russian churches
  - Elemental composition analysis by NAA at IREN and IBR-2, X-ray fluorescence, electron microscopy, infrared and Raman spectrometry
  - Determining the fresco colours in their original reality by physico-chemical studies to be able to restore them
Methodical research:
- Neutron spectrometers;
- Detectors;
- Sample environment;
- Hardware & software;
- Cryogenics;
- Network and computing;
Methodical research:

- Neutron spectrometers;
- Detectors;
- Sample environment;
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- Cryogenics;
- Network and computing;

16 April, Tuesday
119 18:00 Maxim Podlesnyy

17 April, Wednesday
159 15:30 Sabuhi Nuruyev
166 17:10 Constantin Hramco
167 17:20 Sidorova Olga
Development of new neutron source project at FLNP JINR for period beyond 2040

2020 Technical proposal from the general designer (JSC “NIKIET”) for the reactor and 4 options for the AC design (different assembling of fuel rods)

Reactor parameters:

<table>
<thead>
<tr>
<th>Fuel</th>
<th>NpN, NpN+UN (on the periphery)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power</td>
<td>15 MW</td>
</tr>
<tr>
<td>Pulse duration</td>
<td>200 μs</td>
</tr>
<tr>
<td>Repetition rate</td>
<td>10 Hz</td>
</tr>
<tr>
<td>Average flux density on moderator surface</td>
<td>$5 \pm 10 \cdot 10^{13} \text{cm}^{-2}\text{s}^{-1}$</td>
</tr>
</tbody>
</table>

Priority open questions:

- Dynamic stability of the reactor.
- Optimization of the reactor vessel and the reactivity modulator to reduce thermal capacity and deformation.
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<td></td>
</tr>
<tr>
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Thank you for attention