# Review report on scientific activities and infrastructure of FLNP

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*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**







Frank Laboratory of Neutron Physics

# FLNP staff breakdown (2023):

| Total | 564 |
|---|---|
| Scientists | 203 |
| Engineers and specialists | 155 |
| Workers | 174 |
| Administrative staff | 32 |

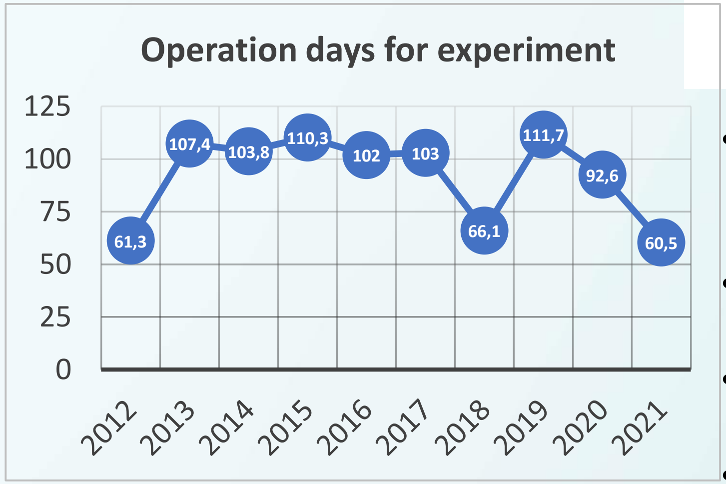
## THREE MAIN SCIENTIFIC DEPARTMENTS OF FLNP:

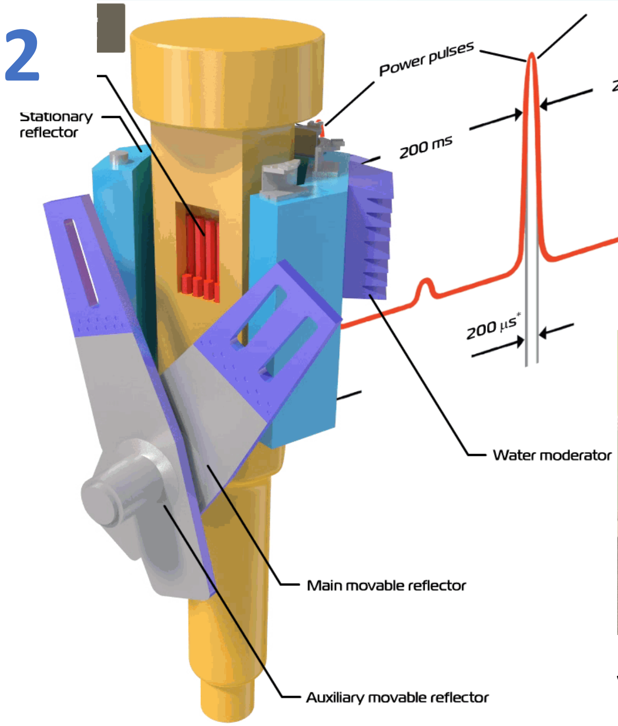
- **Department of nuclear physics** (143 persons)
- **Department of Neutron Investigations of Condensed Matter** (101 persons)
- **Department of Spectrometers Complex IBR-2** (49 persons+23 persons SNSCM)
- **Raman spectroscopy sector** (10 persons)
- **Sector of new neutron source** (24 persons)

# Pulsed Reactor IBR-2

Operate since 1984


Deep modernization
was done at 2006-2010



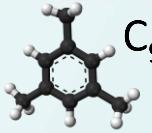

$V_{AC}$<20 l

- October 16, 2021, reactor **shutdown** due to leakage in the secondary cooling circuit air heat exchanger (HE).
- New license for operation till Apr 1 2032 obtained at Apr 24 2024.
- The air heat exchangers are now being replaced with new ones.
- Resumption of work is planned for the 4th quarter of 2024.

| **Average power, MW** | **2** |
|---|---|
| Fuel | $PuO_2$ |
| Number of fuel assemblies | 69 |
| Maximum burnup, % | 9 |
| Pulse repetiton rate, Hz | **5** |
| Pulse half-width, μs:<br>fast neutrons<br>thermal neutrons | <br>200*<br>**340** |
| Rotation rate, rev/min<br>• Main reflector<br>• Auxiliary reflector | <br>600<br>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<br>• Time average<br>• Burst maximum | <br><br>**~$10^{13}$ n/cm² s**<br>**~$10^{16}$ n/cm² s** |

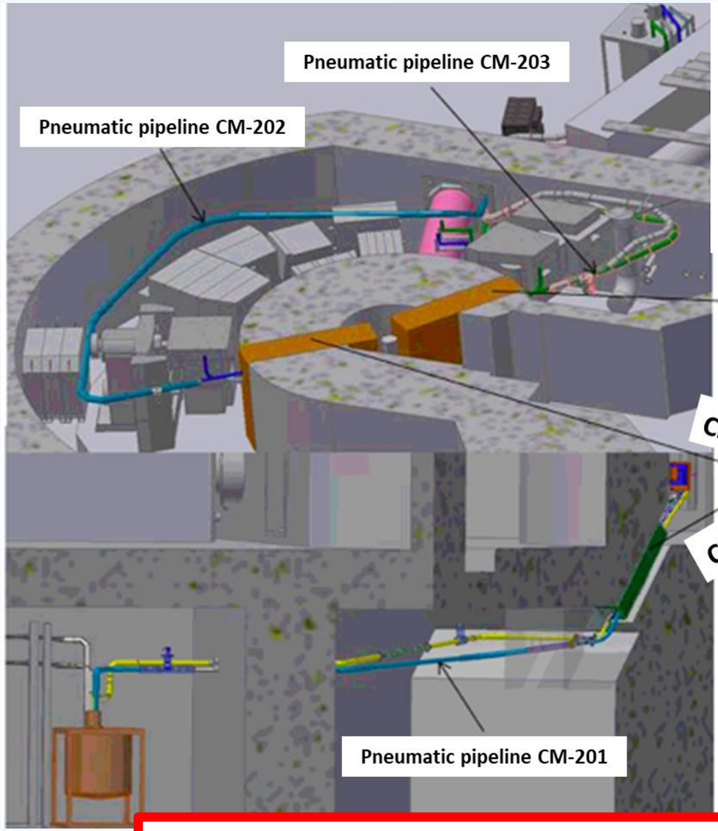
* at reactor power 2MW

# A system of cold moderators at IBR-2

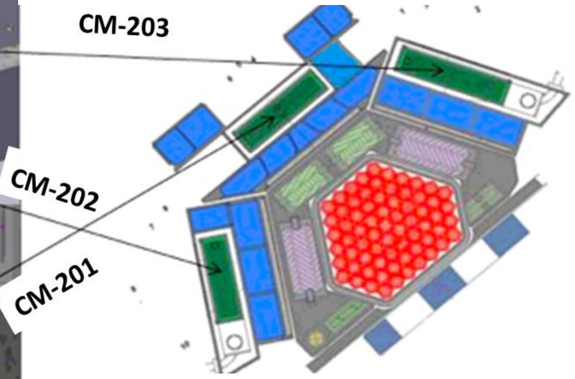


$C_9H_{12}$

Mix of the aromatic hydrocarbons (mesitylene and m-xylene)

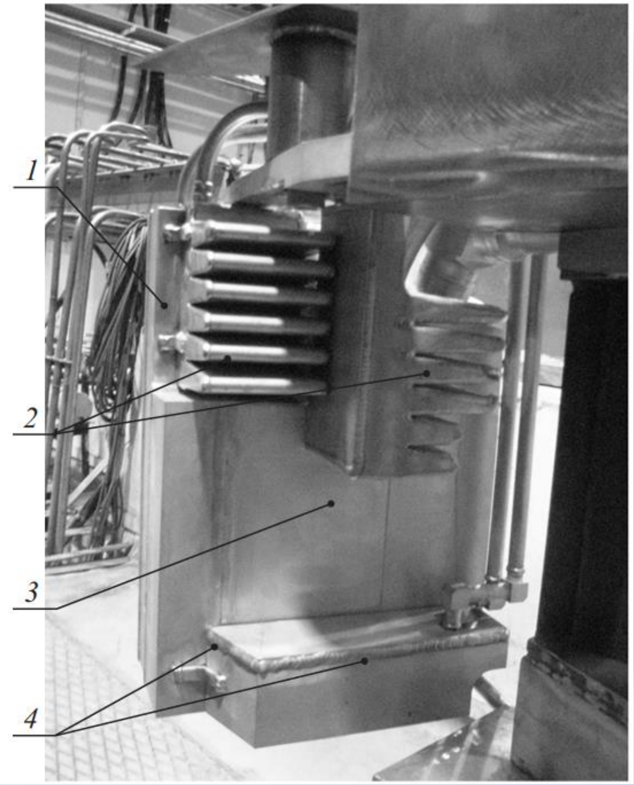



After modernization, the reactor was equipped with two cryogenic moderators step by step.




- Moderators CM-202, CM-203 are in the same plane.
- Shielding and maintenance room for the CM-201 moderator are located

CM202




Equipment of KGU 1800

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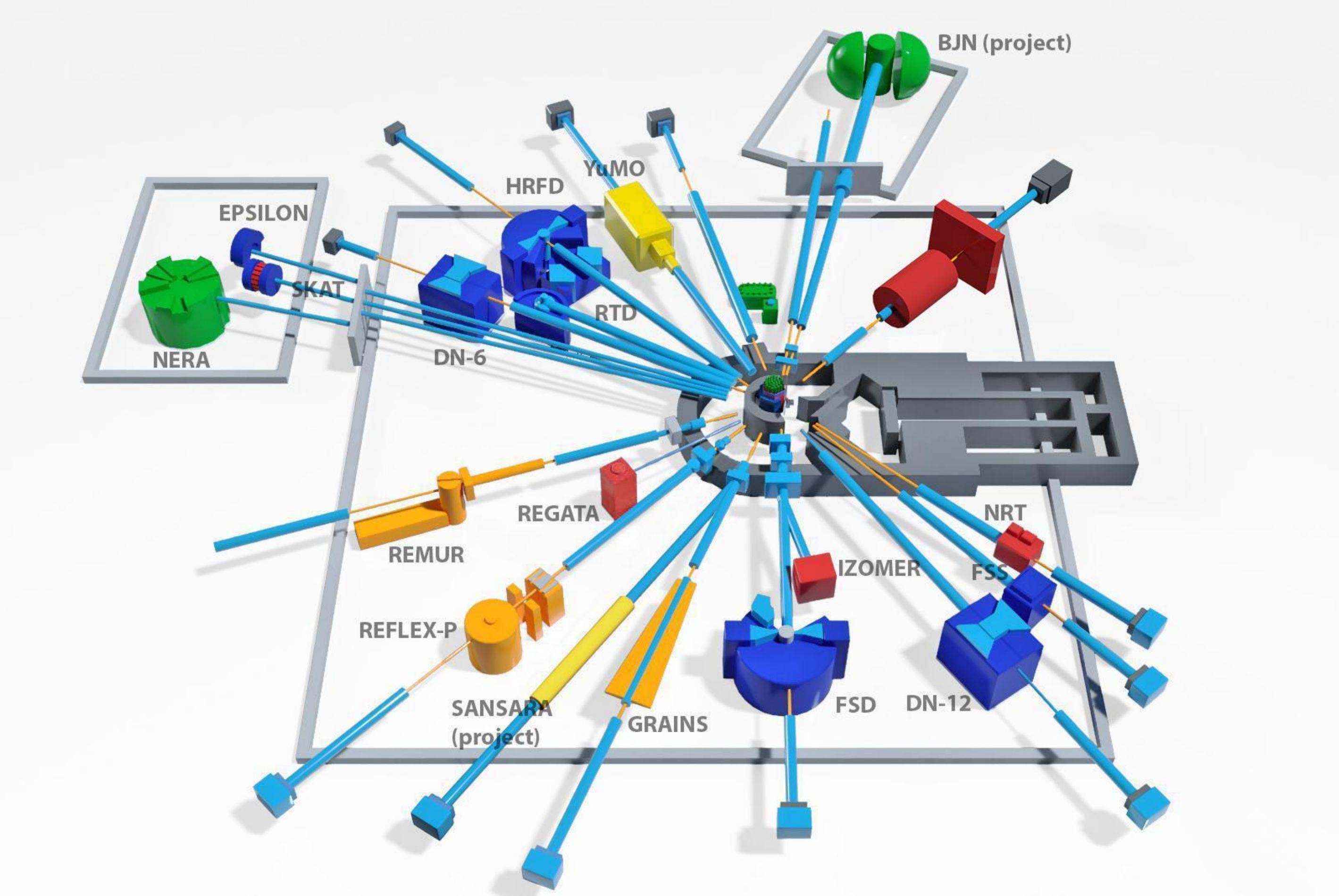
**Tomorrow:**

1. *Sergey Kulikov* Development of cold neutron moderators at FLNP
2. *Maxim Bulavin* Technological systems of pelletized cold neutron moderators based on hydrocarbons

surface
ost-
moderators.

# Neutron Instruments




- Neutron guides length up to ~30 m in the experimental halls and up to ~100 m in two pavilions.
- The typical neutron flux density on a sample is ~$10^6$ $cm^{-2}s^{1}$ (up to $4 \times 10^7$ $cm^{-2}s^{1}$)

## 13 INSTRUMENTS INCLUDE IN USER PROGRAMM

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

Small-Aangle
YuMo

**Reflectometry:**
GRAINS
REMUR
REFLEX

**Inelastic scattering:**
NERA

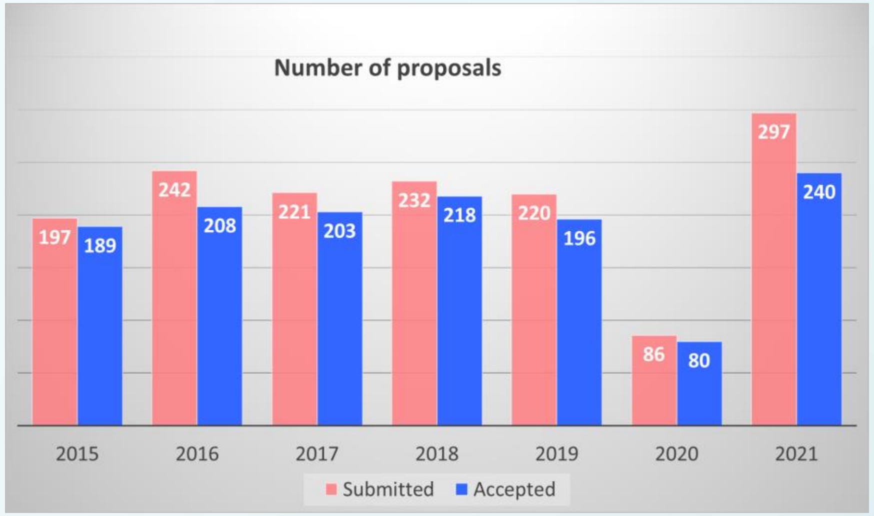
**NAA:**
REGATA

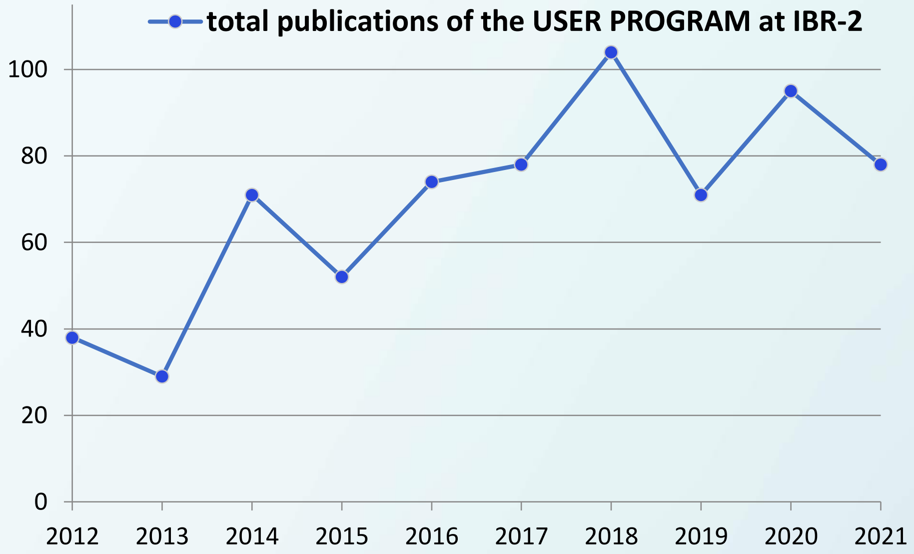
**Under construction:**
- **SANSARA** – small angle + imaging (2024)
- **BJN** – inelastic scattering (2025)

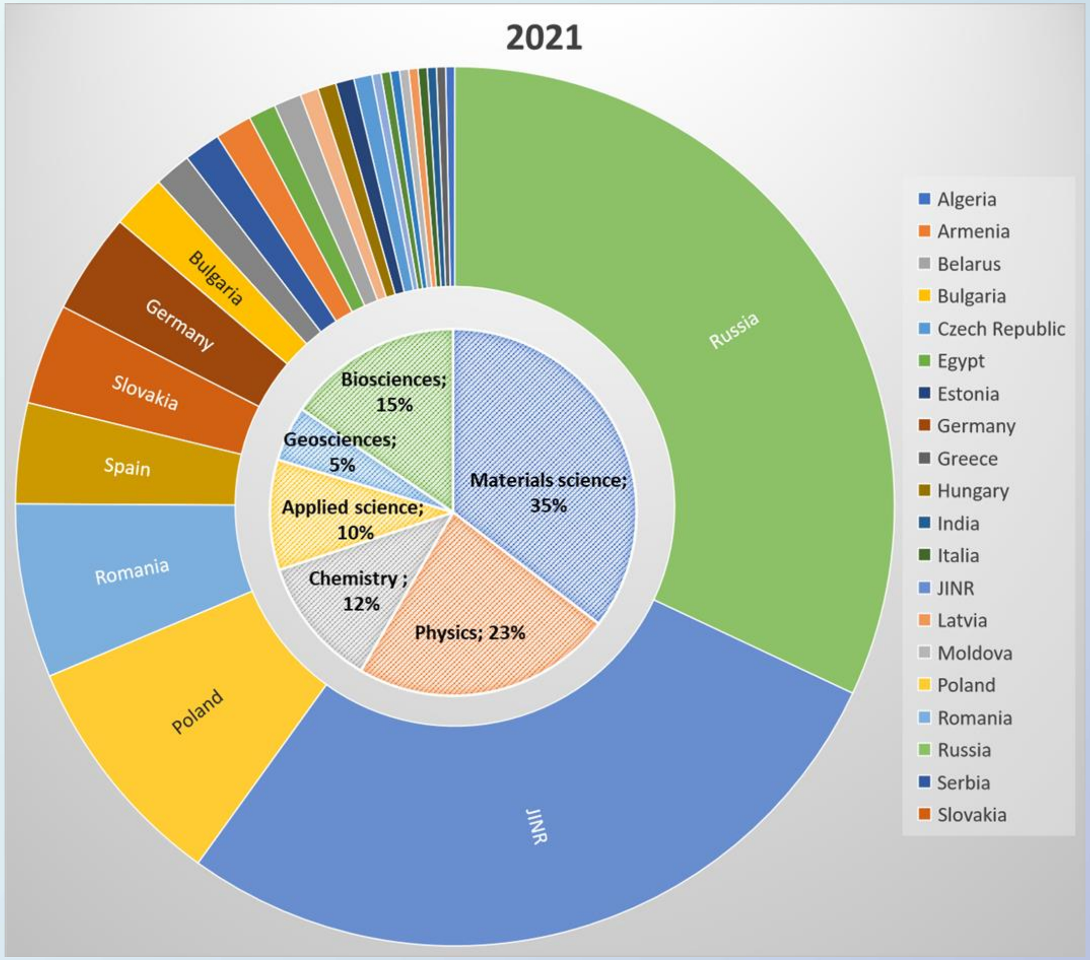
***The Instruments parameters could be found at https://flnp.jinr.int/en-us/main/facilities/ibr-2***

# IBR-2 User Club website: https://ibr-2.jinr.ru/

| Year | Registered users |
|---|---|
| 2020 | 269 |
| 2021 | 147 |
| 2022 | 3 |
| 2023 | 5 |
| **Total:** | **424** |




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.

# Source of resonance neutrons IREN based at lineal electron accelerator

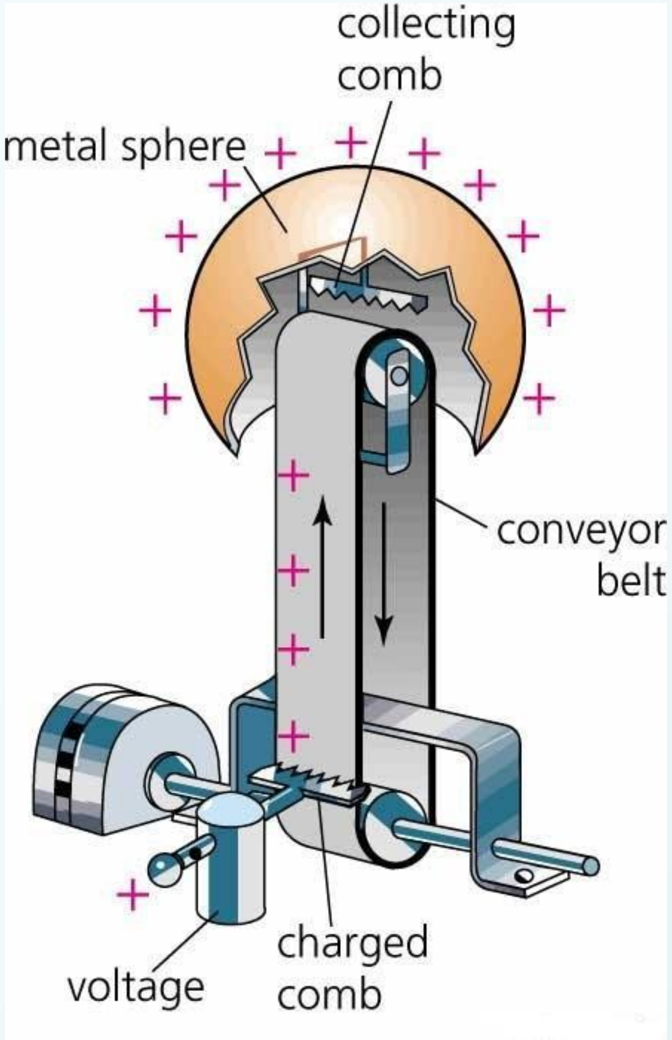
The linear electron accelerator LUE-200 used as a driver for the intense resonance neutron source IREN. The accelerator is positioned vertically. It consists of a pulsed electron gun, an accelerating system, microwave power sources based on 10-cm klystrons with modulators, a focusing-beam transport system, 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) | 0.4 |
| Multiplication | 1 |
| Neutron intensity (n/s) | ~$3x10^{11}$ |

**1200 hours/year**

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

# EG-5




**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

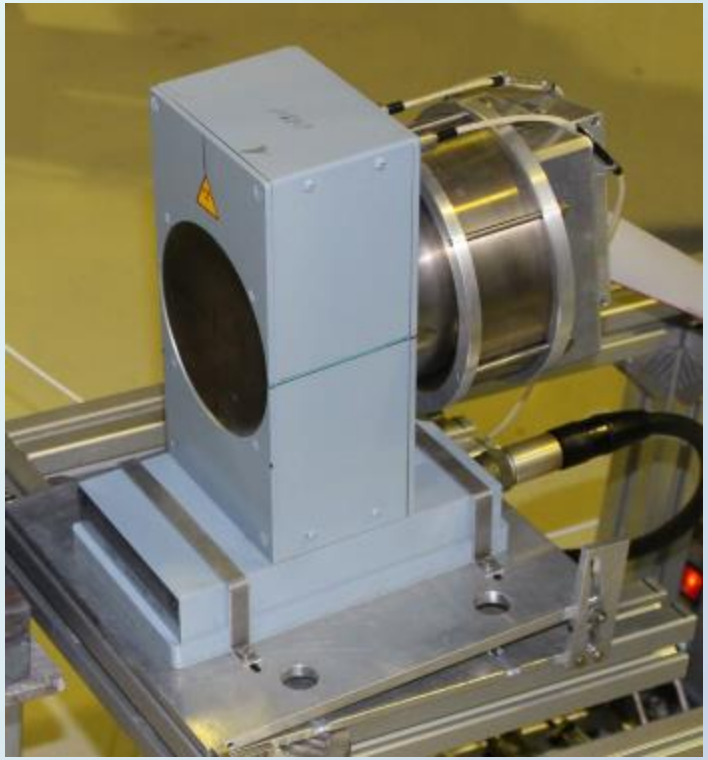
**600 hours/year**

Plan of modernization 2023-2025:

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

# 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

**$^{252}Cf$,**
**(α,n) $^{241}Am$, $^{239}Pu$, $^{238}Pu$**
**Intensity $10^5$ – $10^7$ $s^{-1}$**

# Neutron scattering in condensed matter physics

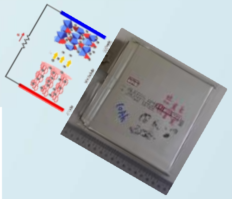
- Search for new properties of crystals, liquids, nanosystems.
- Study of materials with new properties promising for engineering, energy, biology and pharmacology
- Study of the structure and deformations of materials for solving problems of materials science, archeology, geology
- Study of dynamics (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

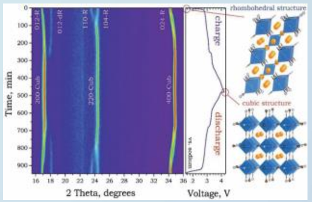

https://flnp.jinr.int/images/Books/Main_page/culture_en.pdf


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


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

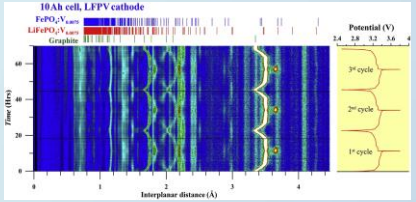
# Neutron scattering in condensed matter physics

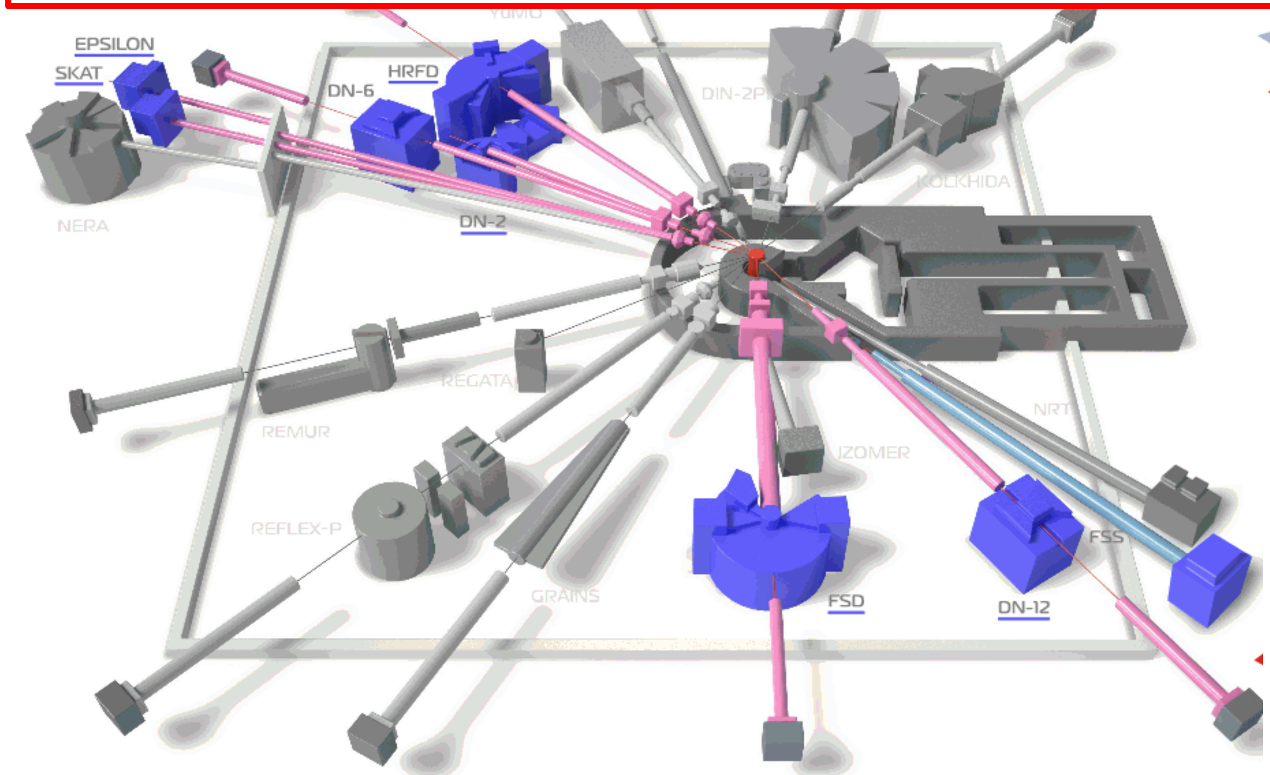





Today:

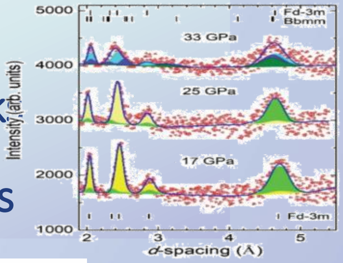
1. *Sergey Sumnikov* Fourier and Real Time Diffractometry at the IBR-2 and Science
2. *Sergey Kichanov* High Pressure Diffraction and Imaging at the IBR-2 and Science



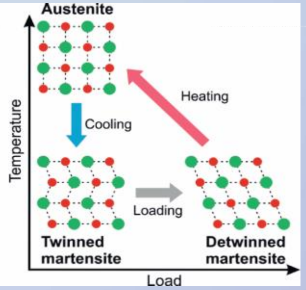





- Crystal and magnetic structure of novel materials at ambient and extreme conditions
- Real-time studies of Li-based accumulators
- Phase transitions of H-based storage alloys
- Crystallographic texture of metalls and rock
- Strain measurements in structural materials

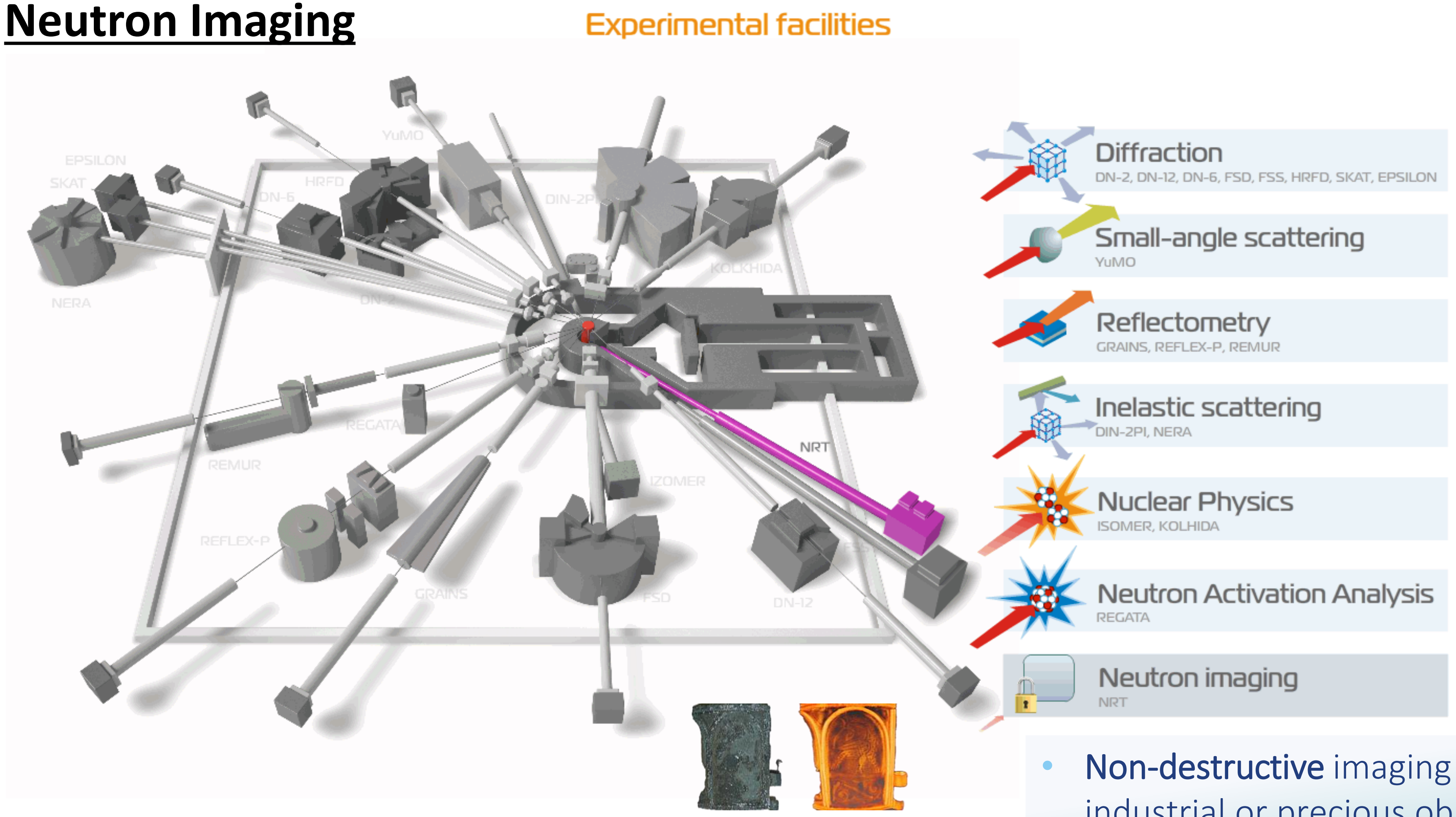


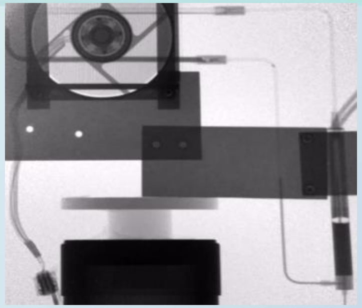

Some diffractometers equipped by Fourier choppers to achieve high resolution at short beamlines with long pulse of the reactor.

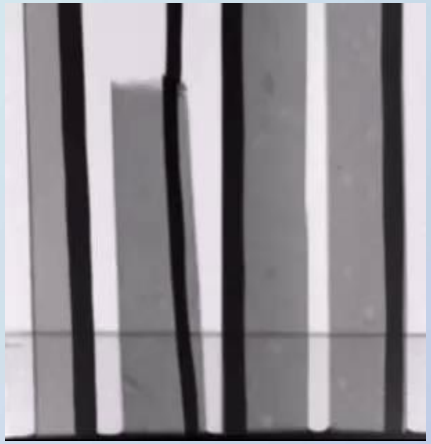


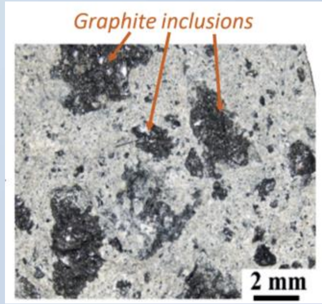
# Neutron scattering in condensed matter physics

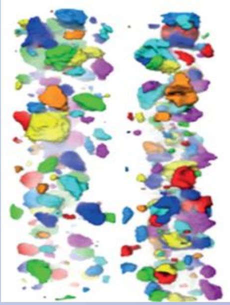
## Neutron Imaging



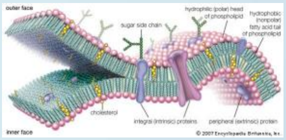




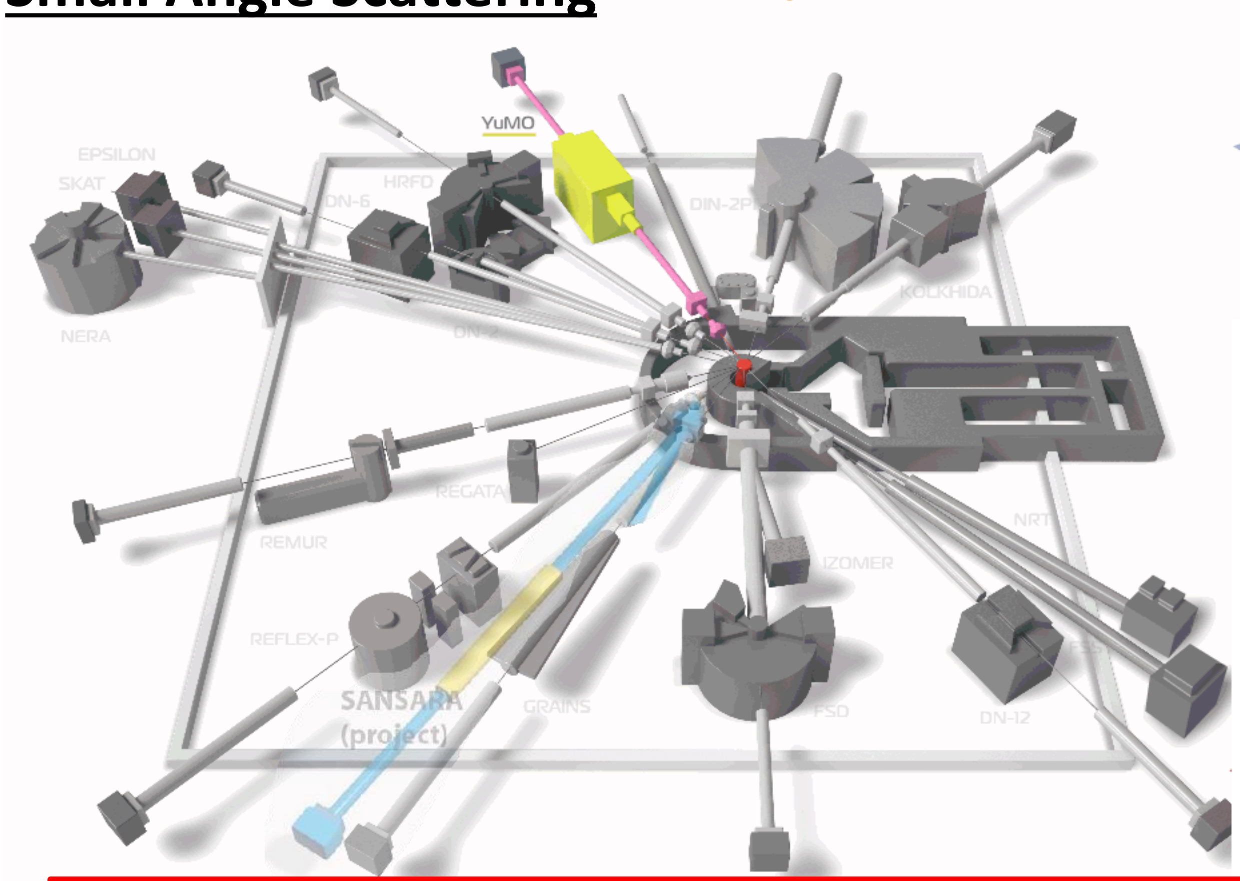
- **Non-destructive** imaging of the industrial or precious objects

# Neutron scattering in condensed matter physics

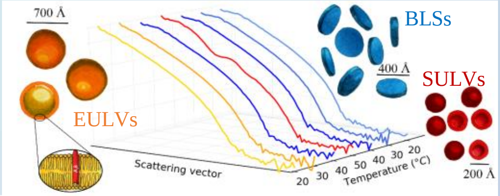


## Small Angle Scattering

Experimental facilities







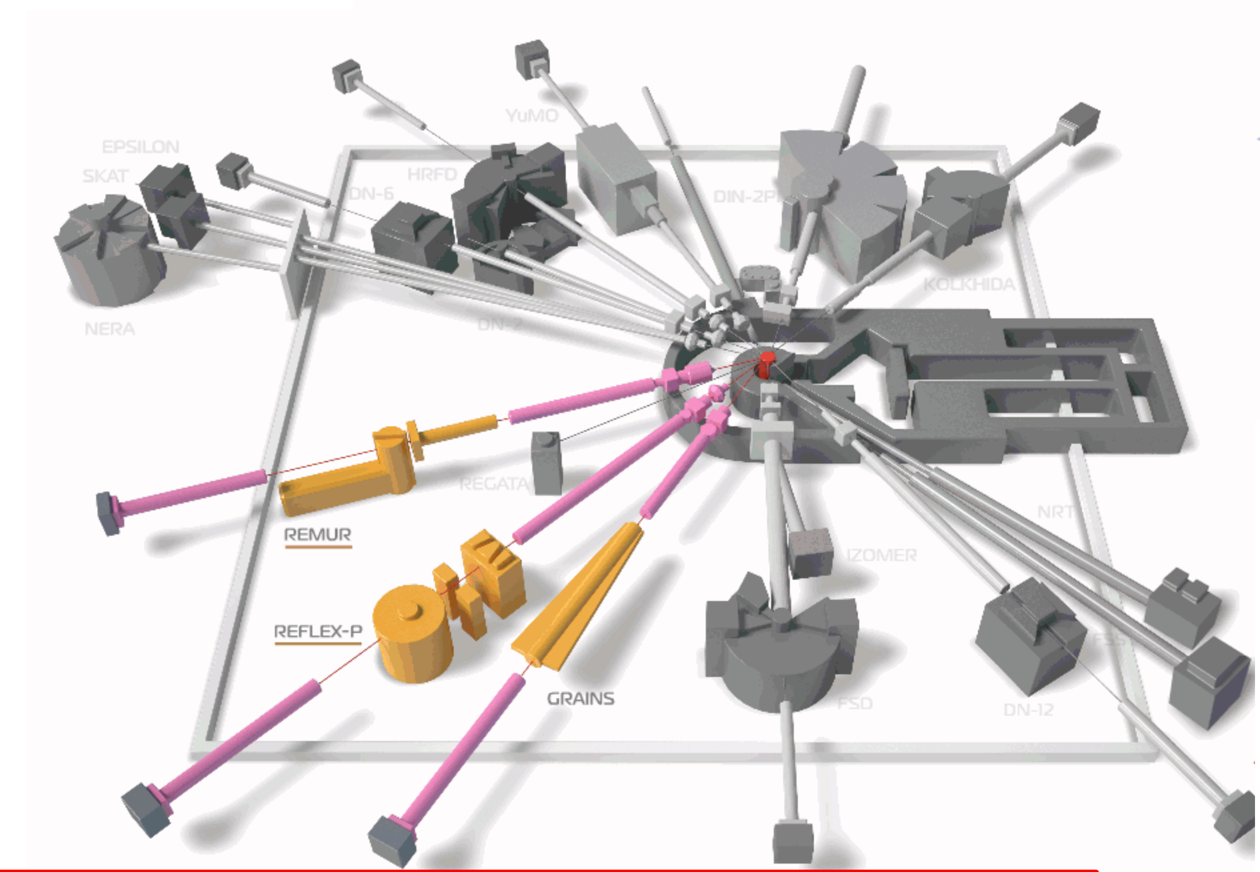

- **Structural organization** and **aggregation** of nanoparticles and **composite systems**
- Interactions of **nanoparticles** with **bio-macromolecules**
- **Nanopores** for magnetic and biomedical applications

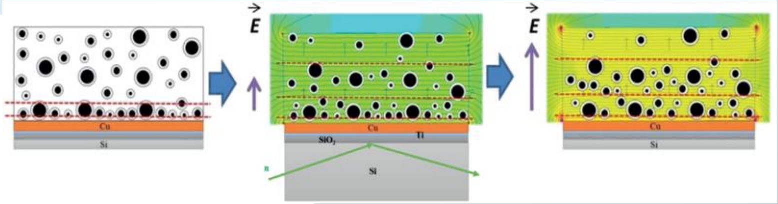
Today:
*Oleksandr Ivankov* Small Angle Neutron Scattering at the IBR-2 and Science

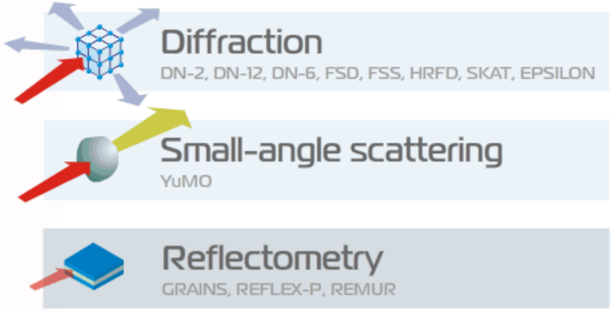
# Neutron scattering in condensed matter physics

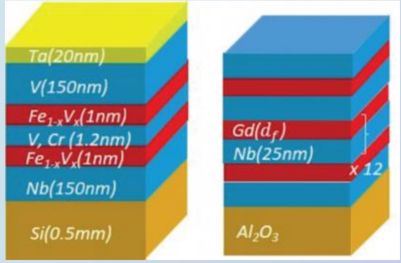
## Reflectometry

Experimental facilities





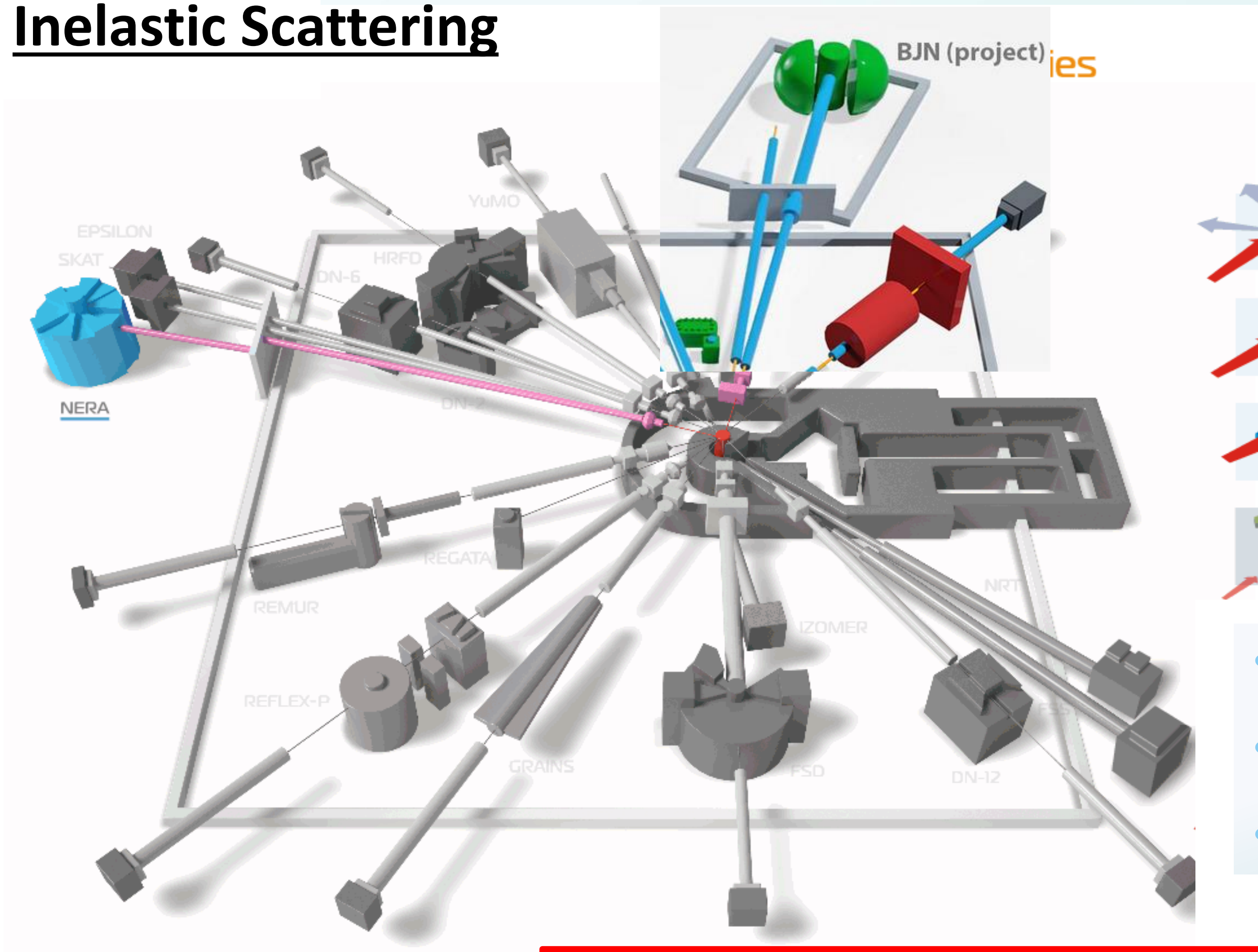

- **Thin films** and surfaces
- **Surface adsorption** of magnetic nanoparticles
- Superconducting and magnetic properties of the **complex layered heterostructures**
- **2D** van der Waals **magnetic materials**

Today:

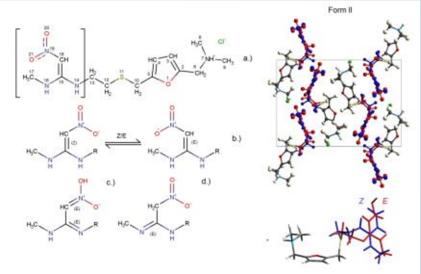
1. *Mikhail Avdeev* Reflectometry at the IBR-2 and Science

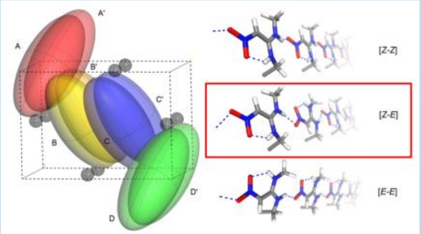
# Neutron scattering in condensed matter physics

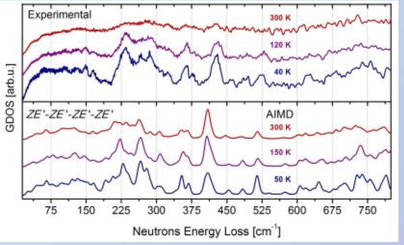
## Inelastic Scattering



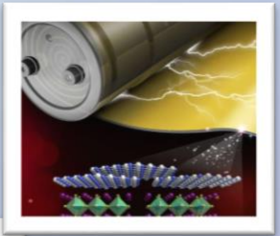


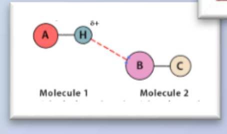


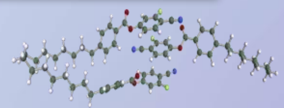





- Molecular structure and **dynamics**
- **Isomeric forms** of drugs
- **Drug delivery systems**





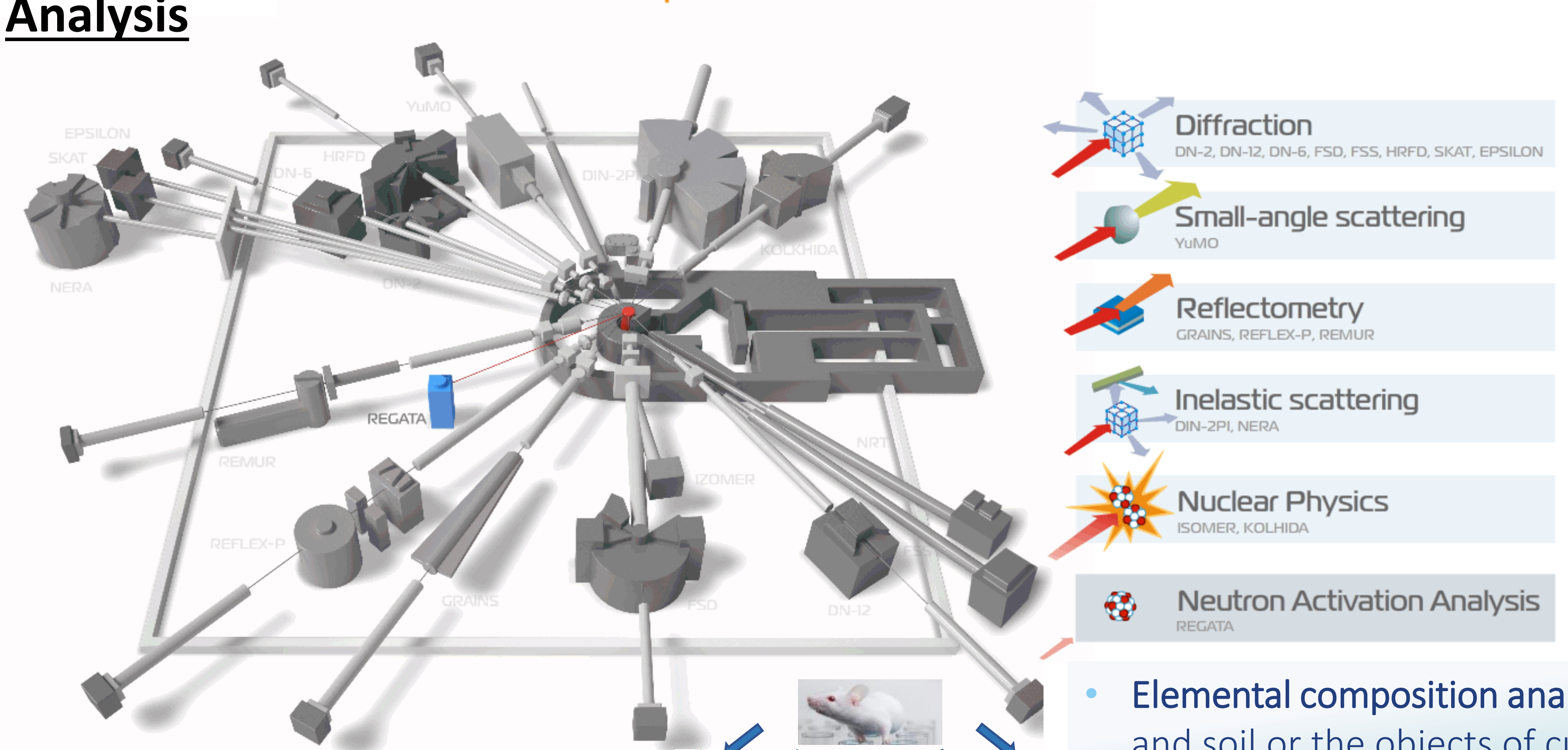



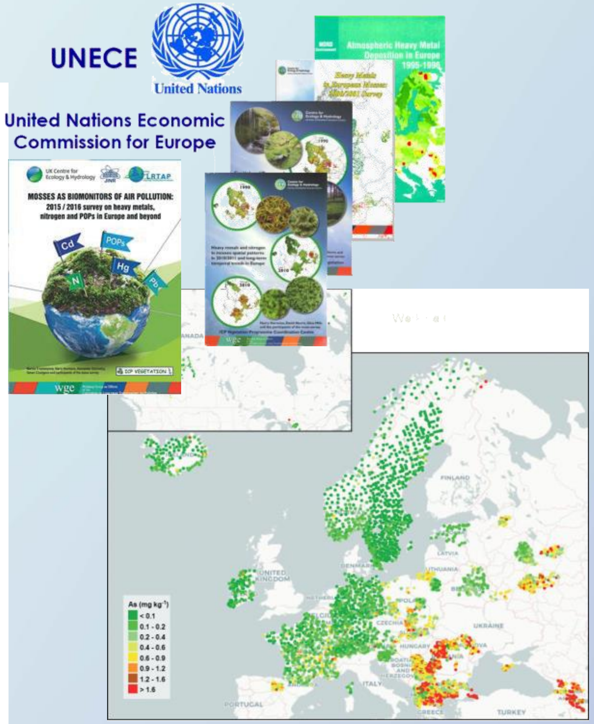
Today:
1. *Dorota Chudoba* Inelastic neutron spectrometer

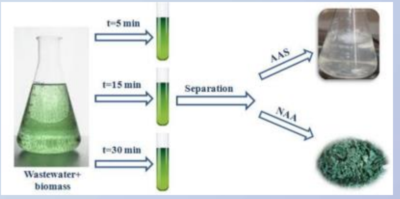
# Nuclear analytical method

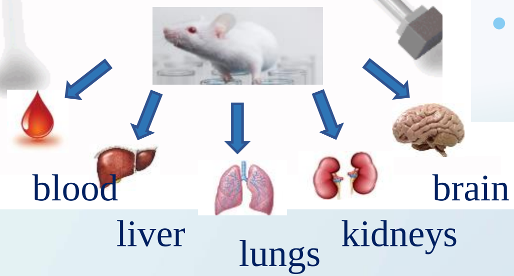
## Neutron Activation Analysis

Experimental facilities




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

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 ac… …hysics

Today:
*Yuri Kopach* Nuclear physics investigations at FLNP

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:**

Day after tomorrow:
1. *German Kulin* UCN source with pulsed accumulation of neutrons in a trap
2. *Alexander Frank* Some problems of long-wave neutrons optics

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

# Investigation of neutron-induced reactions with charge particles emission

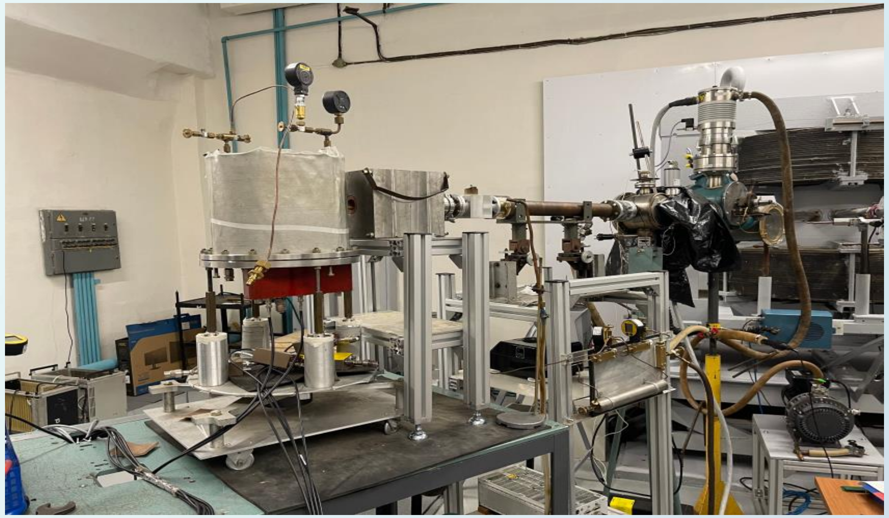
Work is planned to measure cross sections for reactions (n,p), (n,α) on various isotopes.

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.

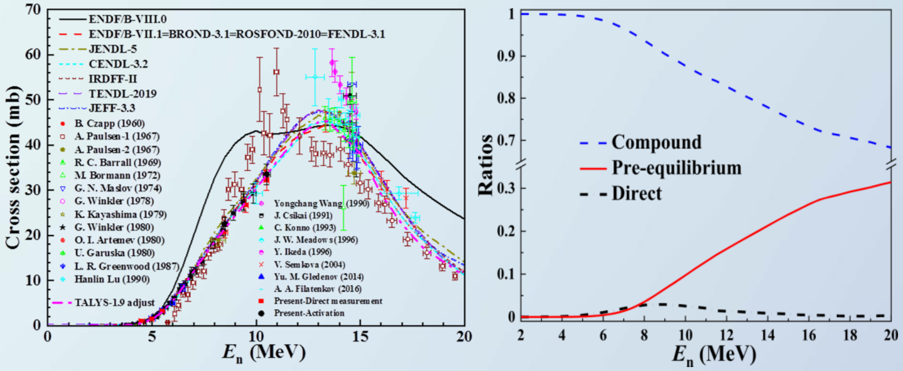
It is also planned to conduct test measurements of reactions (n,p), (n,α) on $^{6}$Li and Cl at the IREN facility.

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



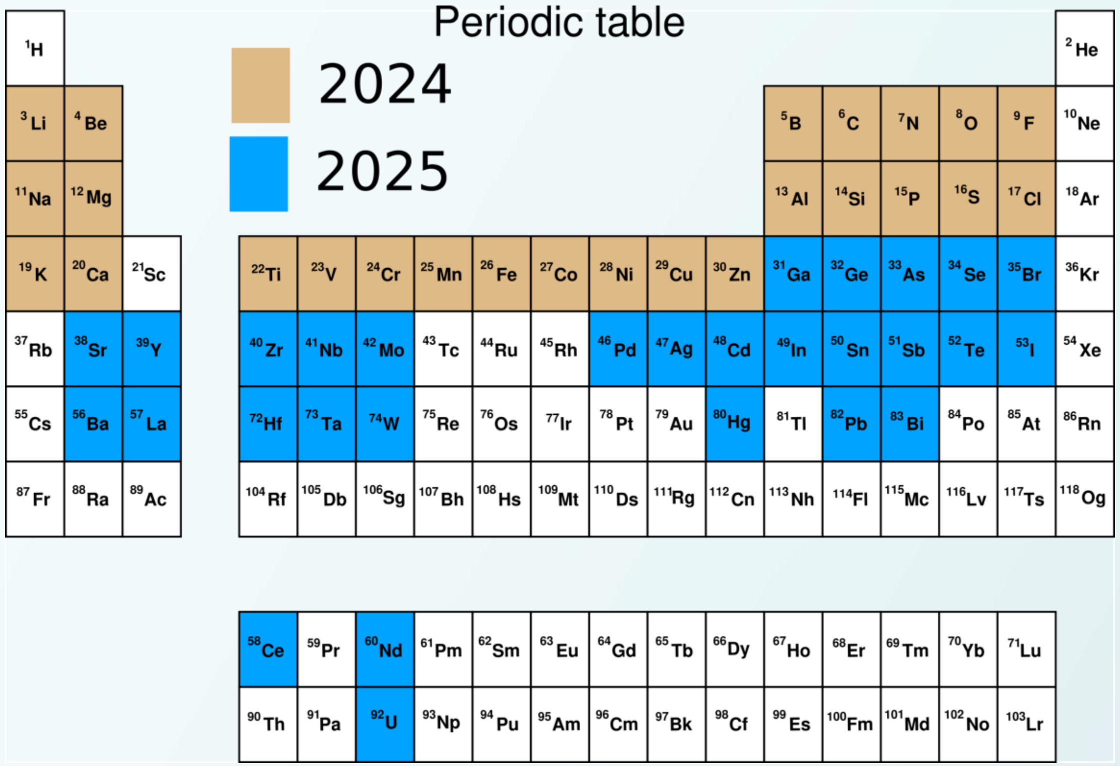
Experimental hall EG-5, FLNP JINR

Experimental hall at IREN facility

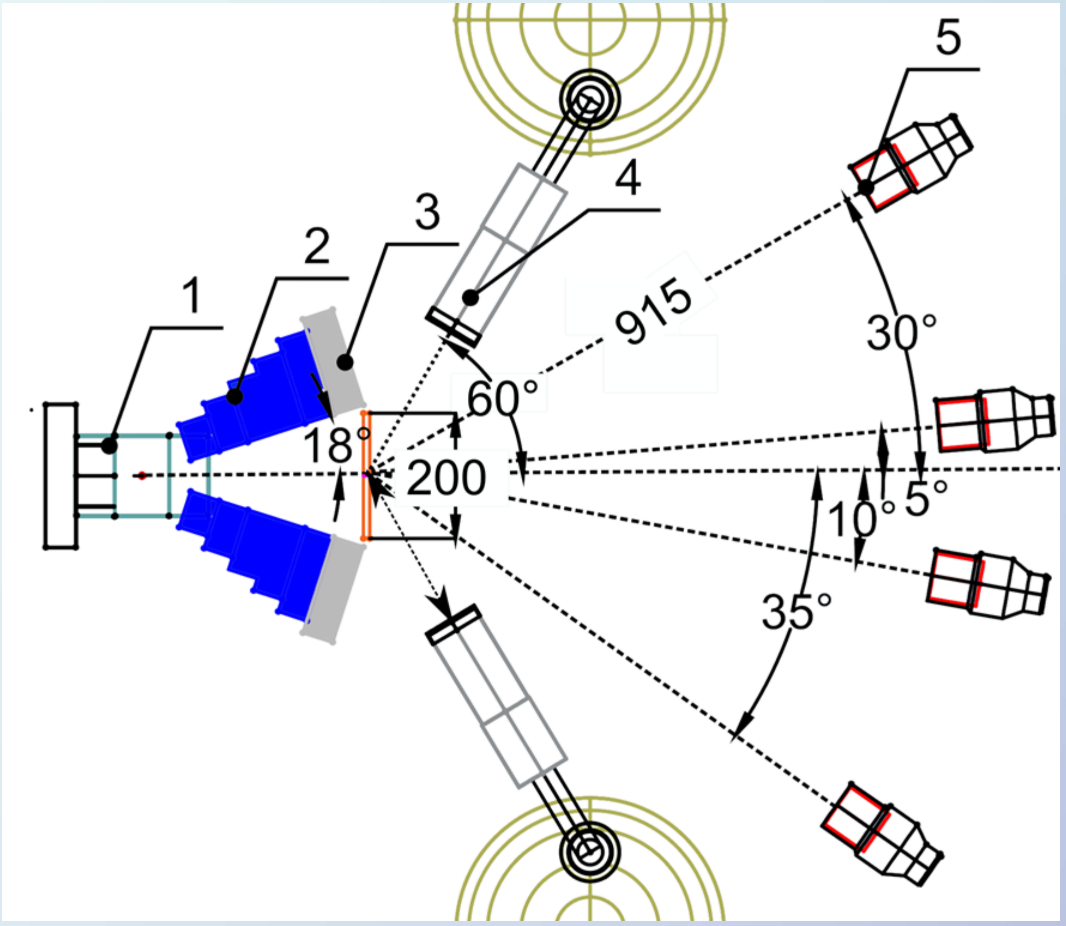



*Yu M Gledenov et.al «63Cu(n, α)60Co cross sections in the MeV region»*
*J. Phys. G: Nucl. Part. Phys., Vol. 50, (2023)*
*DOI 10.1088/13616471/acb960*

New ionization chamber for the IREN faclilty

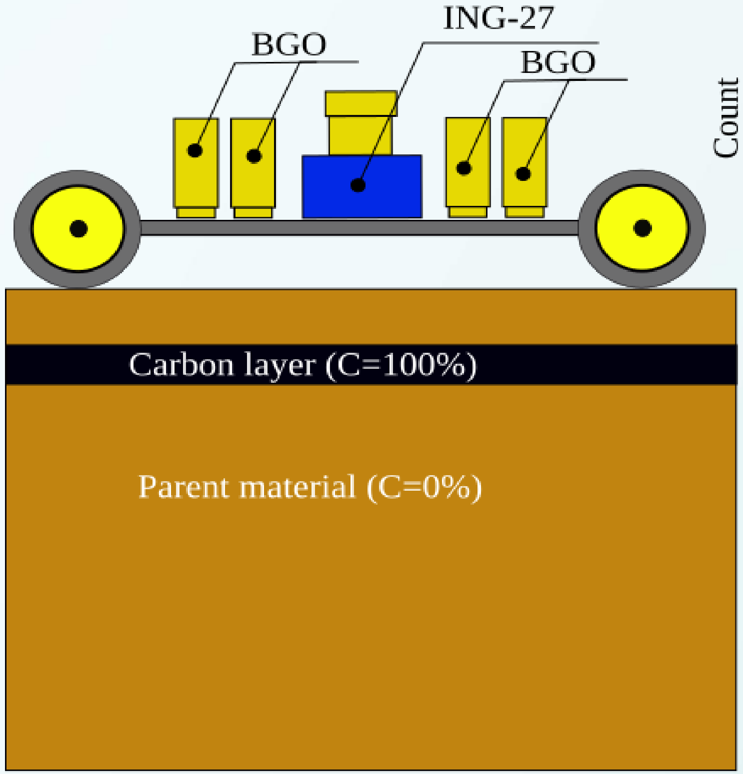


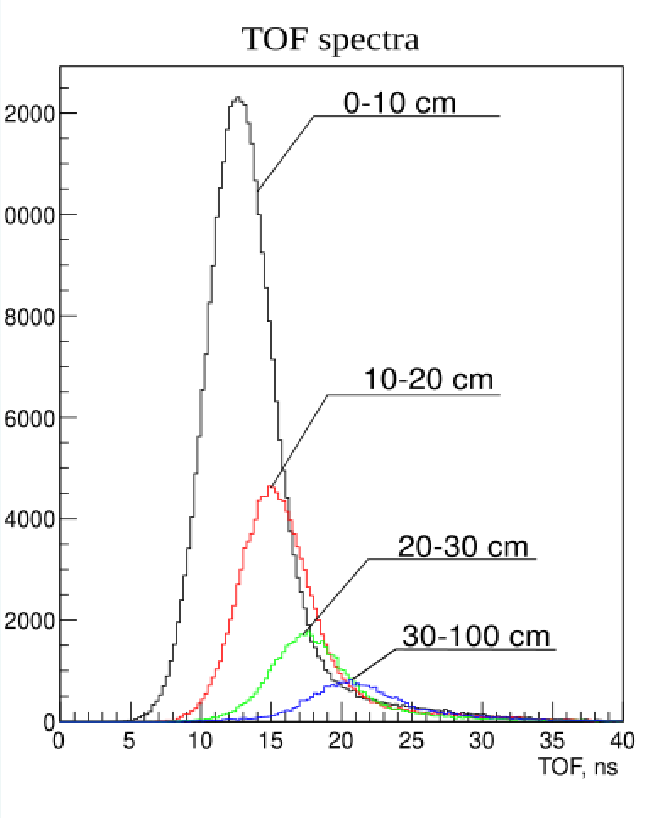

Setup for measuring γ-ray emission cross sections consisting of two HPGe detectors (4) and four LaBr detectors (5).

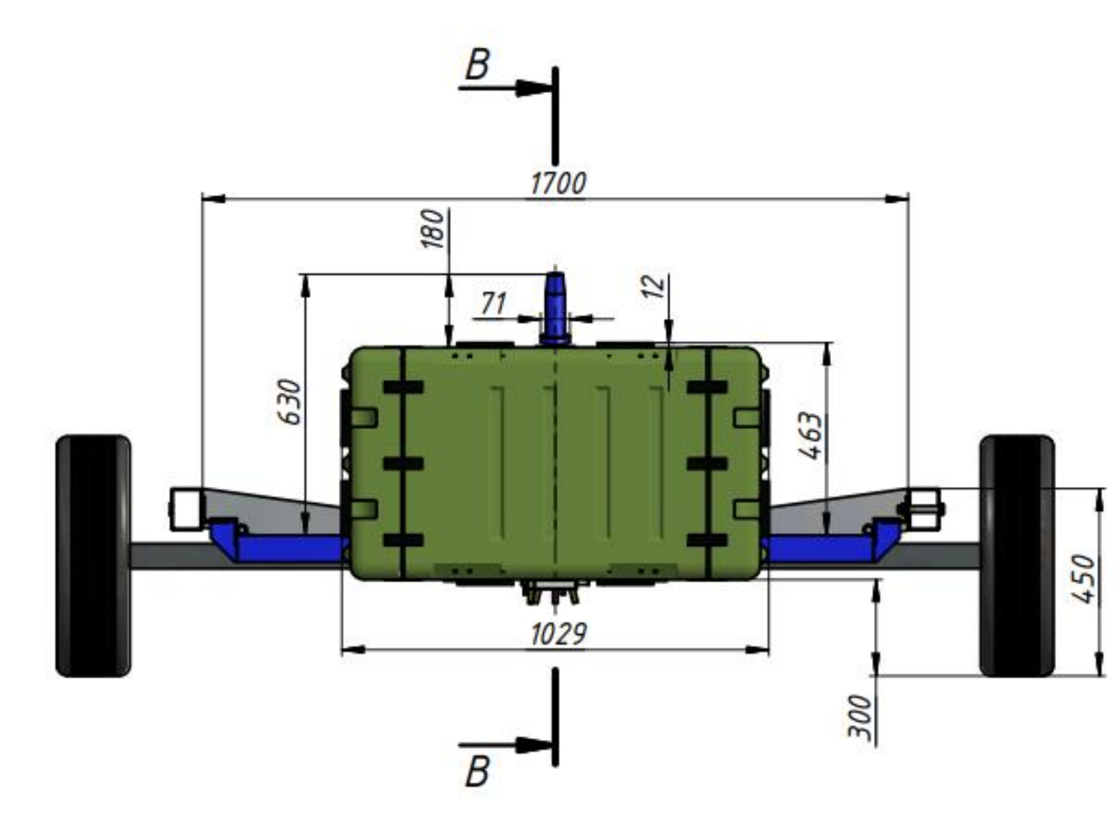



In 2024 it is planned to measure γ-ray emission cross sections for light elements: B, C, N, O, F, Na, Mg, Al, Si, P, S, Cl, K, Ca, Ti, V, Cr, Mn, Fe , Co, Ni, Cu, Zn, Sn.

# Construction of a pilot mobile setup for determining the carbon content in soil using the Tagged Neutron Method (in collaboration with LLC "Diamant").

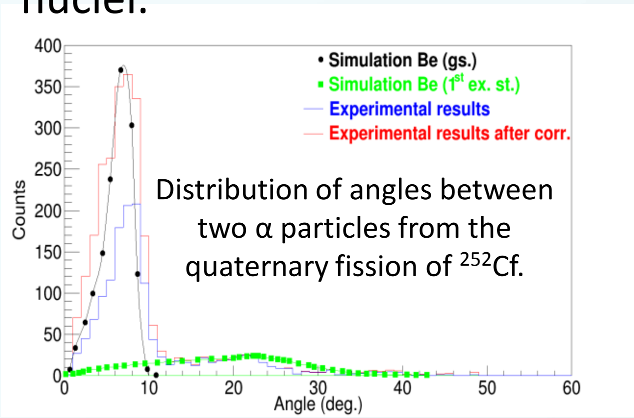


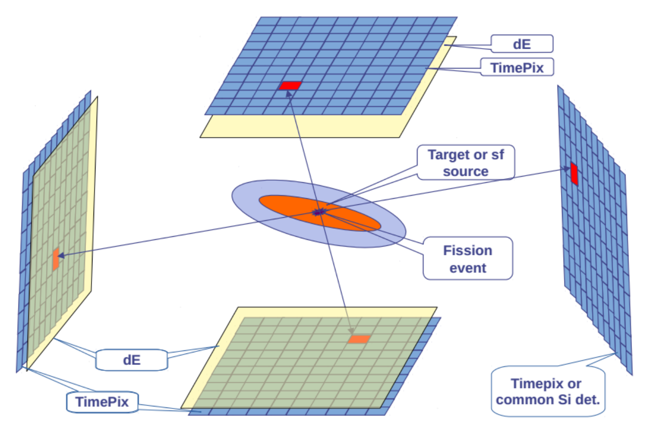



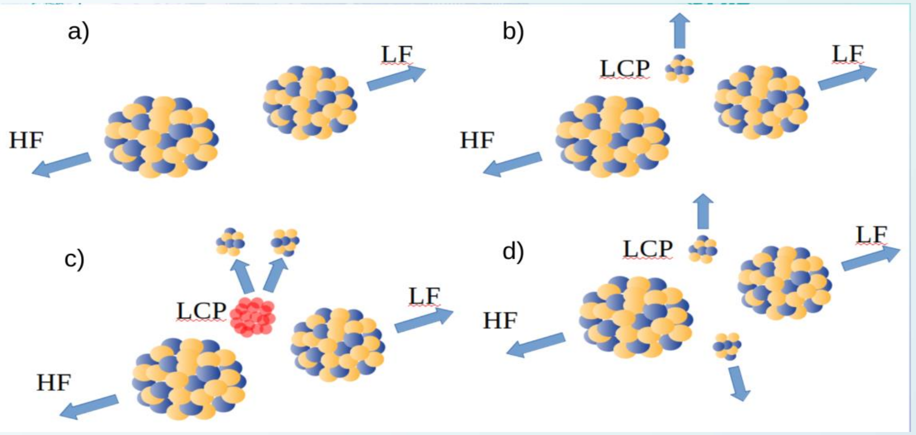
# Study of rare fission modes and prompt neutron emission in nuclear fission

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

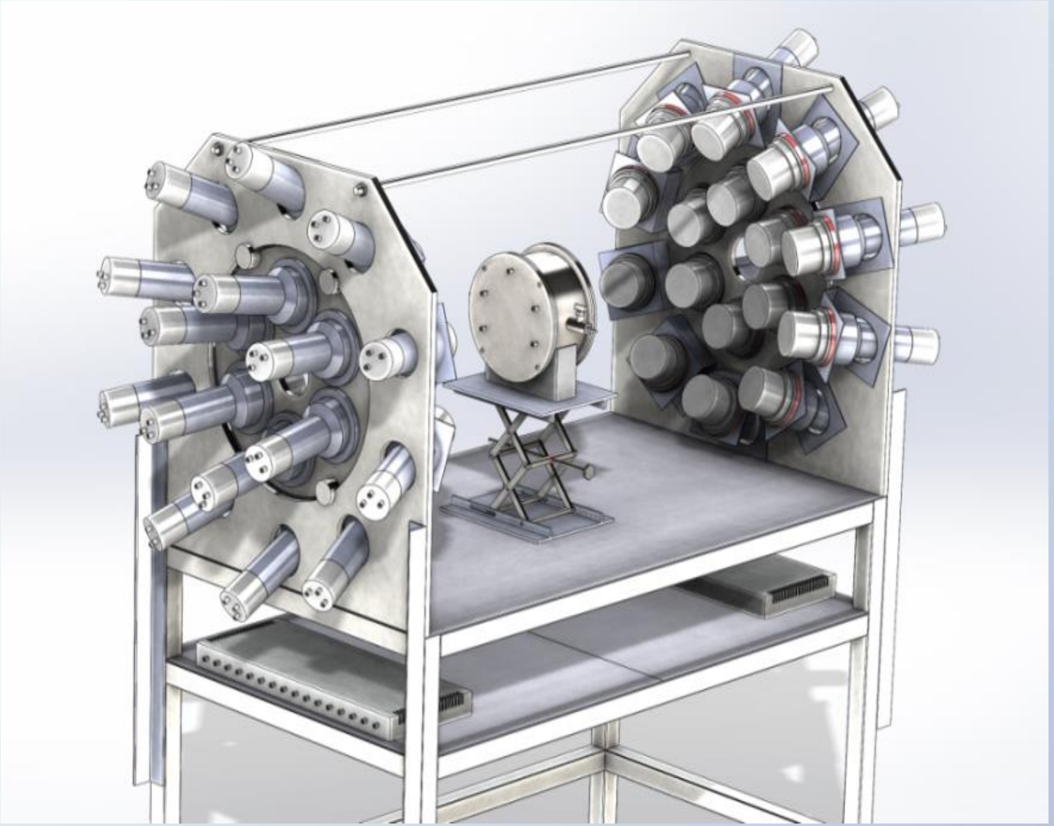



Distribution of angles between two α particles from the quaternary fission of $^{252}$Cf.




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

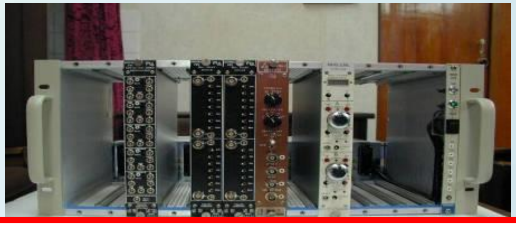


- Targets: $^{235}$U, $^{237}$Np, $^{239}$Pu.
- Measurements are planned at IREN resonance neutron source.

# 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



**Today:**

1. *Alexander Chernikov* Cryogenic sample environment systems at instruments at the IBR-2 reactor

**Tomorrow:**

2. *Viktor Bodnarchuk* Development of neutron detectors with boron converter in FLNP
3. *Vasil Milkov* Development and application of He-3 and scintillation neutron detectors at instruments at the IBR-2 reactor
4. *Vasiliy Shvetsov* Data acquisition system at instruments at the IBR-2 reactor 1
5. *Anastasiya Kazliakouskaya* Data acquisition system at instruments at the IBR-2 reactor 2
6. *Andrey Kirilov* Software for data acquisition and instrument control Sonix+

**Day after tomorrow:**

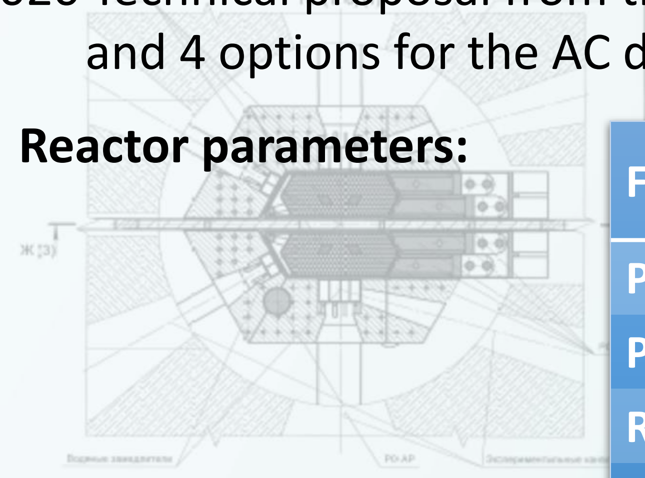
7. *Valentin Sadilov*

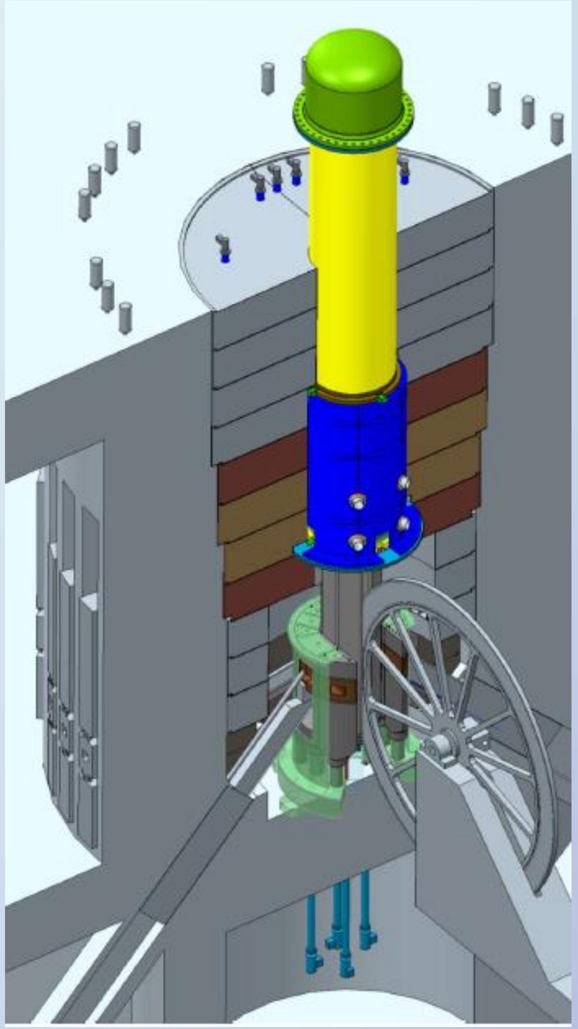
DAN neutron generator

DAN Detectors

# 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)



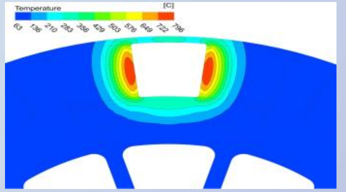


**Reactor parameters:**

| Fuel | NpN,<br>NpN+UN (on the periphery ) |
|---|---|
| Power | 15 MW |
| Pulse duration | 200 μs |
| Repetition rate | 10 Hz |
| Average flux density on moderator surface | $5 \div 10 \cdot 10^{13} cm^{-2} s^{-1}$ |

**Priority open questions :**

- Dynamic stability of the reactor.
- Optimization of the reactor vessel and the reactivity modulator to reduce thermal capacity and deformation.



# Conclusions:

- IBR-2 will remain one of the main sources in Russia with world-level parameters over the next 15 years.
- The FLNP scientific program covers almost all modern areas of research with thermal and cold neutrons.
- We hope that we will be able to implement the idea of pulsed UCN accumulation at IBR-2, which will make it possible to obtain a world-class UCN source.
- IBR-2 and CSNS have similar parameters as neutron sources for neutron scattering research.
- The similarity of parameters and methods at IBR-2 and CSNS, close scientific topics opens prospects for close cooperation, and we must identify priority tasks for such cooperation.

# Thank you for attention