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







Frank Laboratory of Neutron Physics

FLNP staff breakdown (2023):

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

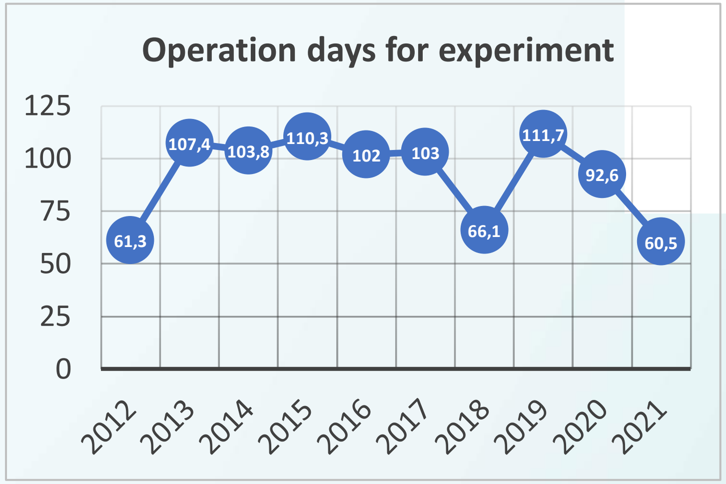
THREE MAIN SCIENTIFIC DEPARTMENTS of FLNP:

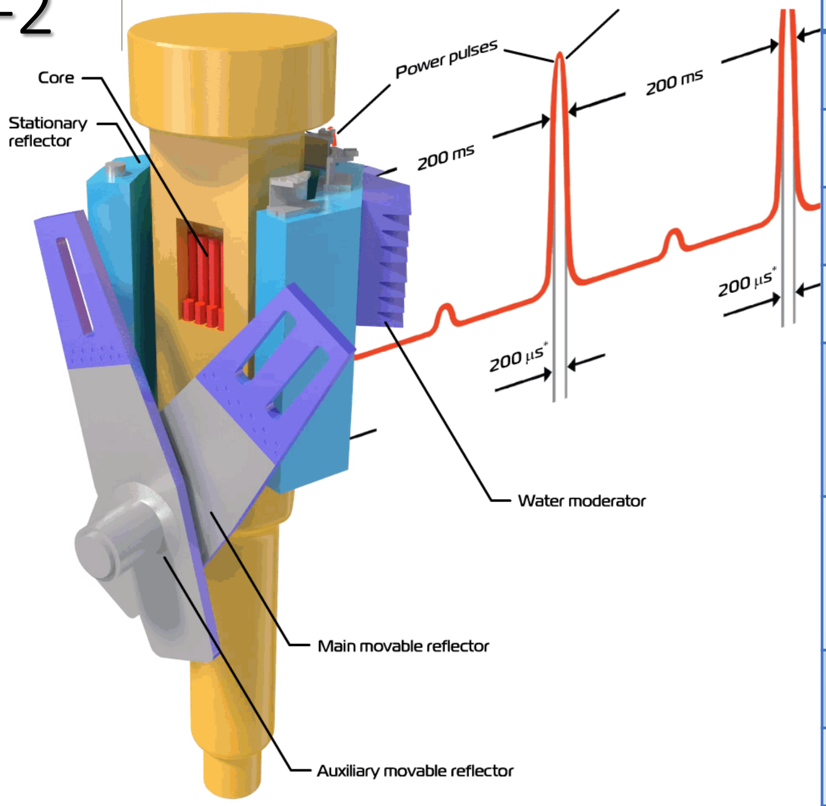
- **Department of nuclear physics** (143 persons)
- **Department of Neutron Investigations of Condensed Matter** (101 persons)
- **Department of Spectrometers Complex IBR-2** (49 persons+23 persons SNSCM)
- **Raman spectroscopy sector** (10 persons)
- **Sector of new neutron source** (24 persons)

Pulsed Reactor IBR-2

Operate since 1984

Deep modernization
was done at 2006-2010



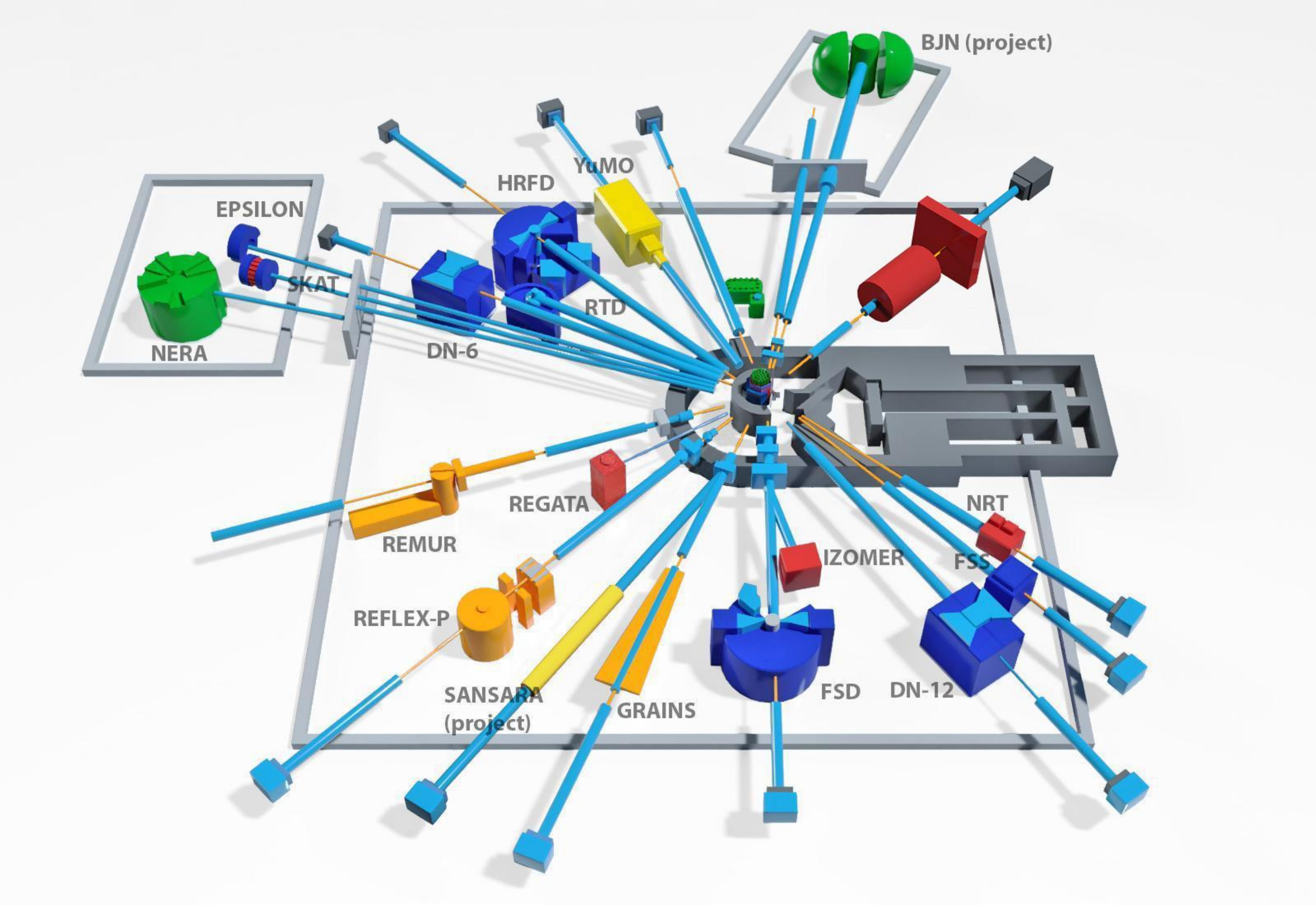


Average power, MW	2
Fuel	PuO_2
Number of fuel assemblies	69
Maximum burnup, %	9
Pulse repetiton rate, Hz	5
Pulse half-width, µs: fast neutrons thermal neutrons	 200* 340
Rotation rate, rev/min • Main reflector • Auxiliary reflector	 600 300
MMR and AMR material	Nickel + steel
MR service life, hours	55 000
Background, %	7.5
Thermal neutron flux density from the surface of the moderator • Time average • Burst maximum	 $\sim 10^{13}$ n/cm^2 s $\sim 10^{16}$ n/cm^2 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-Aangle
YuMo

Reflectometry:
GRAINS
REMUR
REFLEX

Inelastic scattering:
NERA

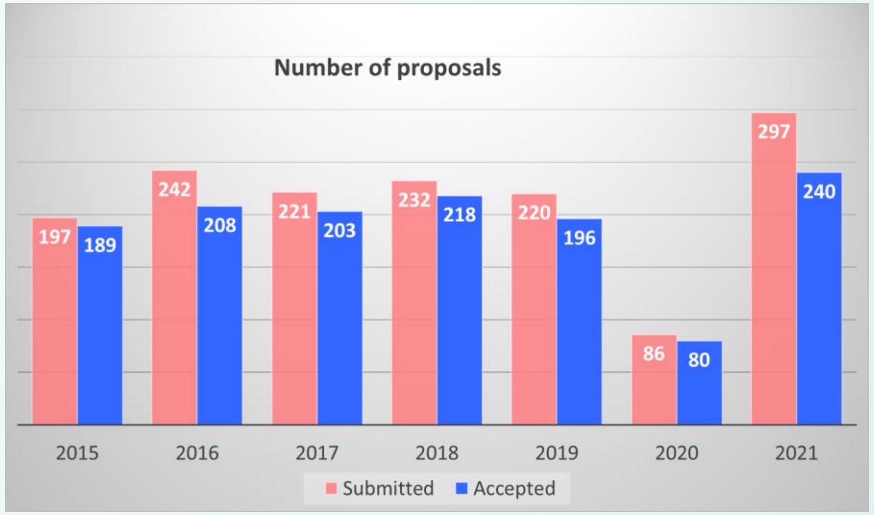
NAA:
REGATA

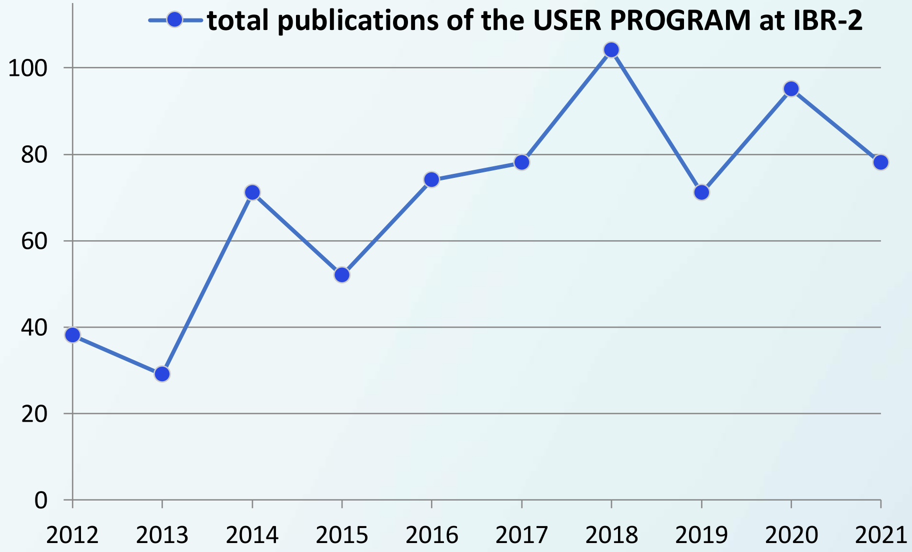
Under construction:
- SANSARA – small angle + imaging (2024)
- BJN – inelastic scattering (2025)

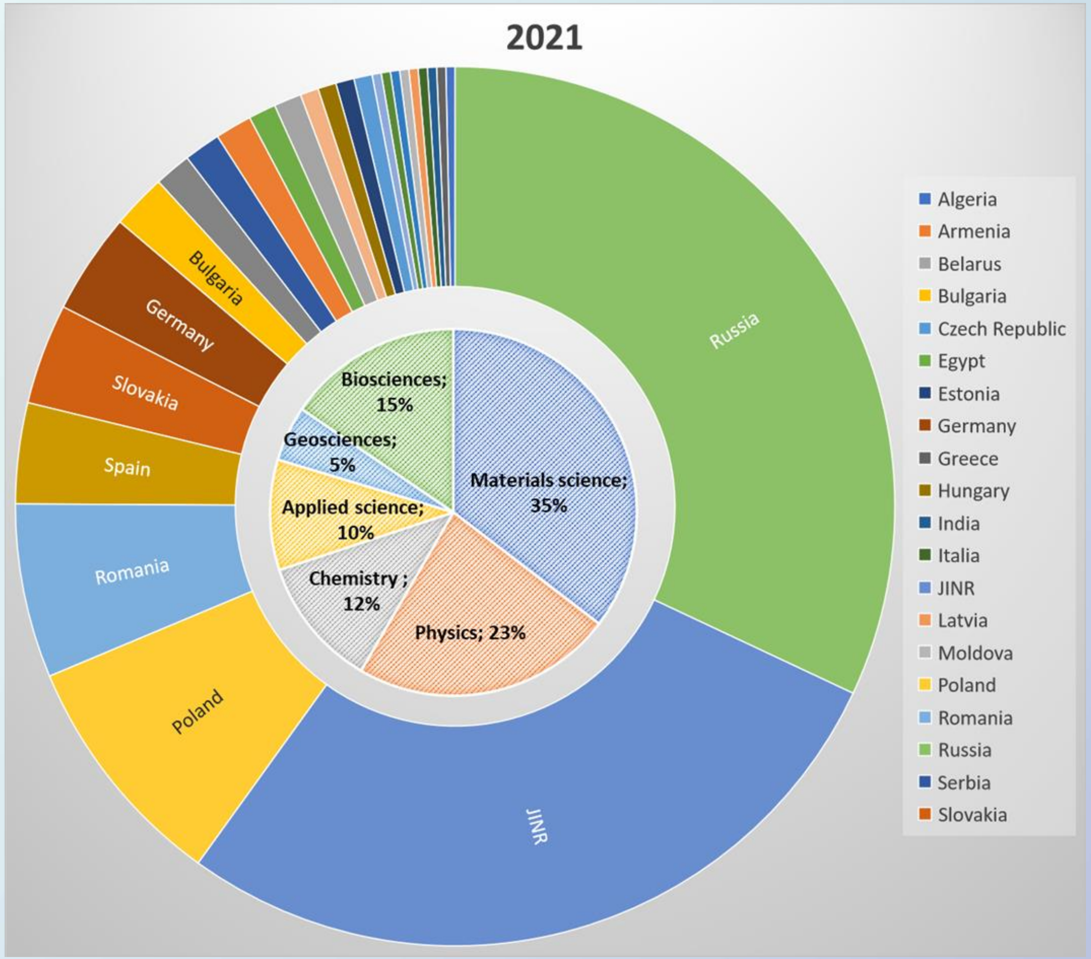
The Instruments parameters could be found at https://flnp.jinr.int/en-us/main/facilities/ibr-2

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

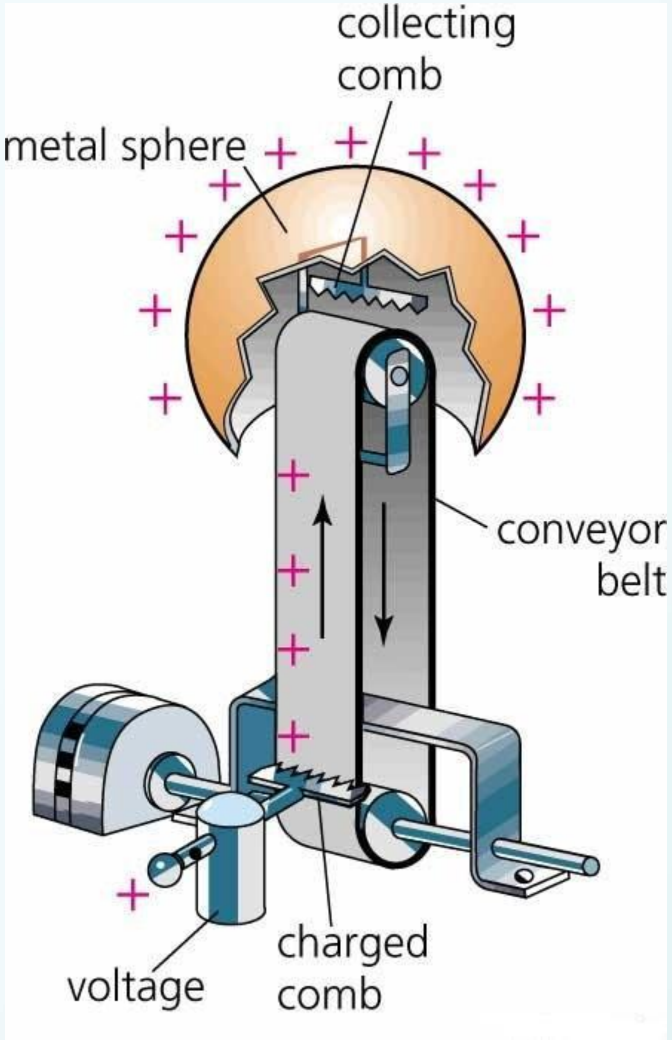
The linear electron accelerator LUE-200 used as a driver for the intense resonance neutron source IREN. The accelerator is positioned vertically. It consists of a pulsed electron gun, an accelerating system, microwave power sources based on 10-cm klystrons with modulators, a focusing-beam transport system, 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)	~3×10^{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.

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

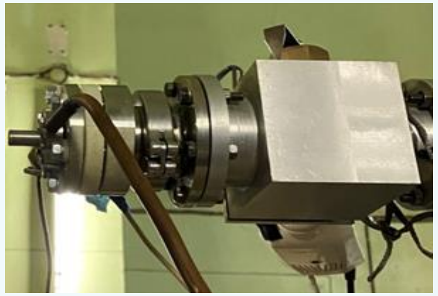
The characteristics of EG-5 Accelerator:
Energy region: 0.9 – 3.5 MeV
Beam intensity for $H+$: 30 μA
Beam intensity for $He+$: 10 μA
Energy spread < 500 eV
Number of beam lines: 6

600 hours/year

Plan of modernization 2023-2025:

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

Fast neutron reactions



Gas Target $D(d,n)^3He$

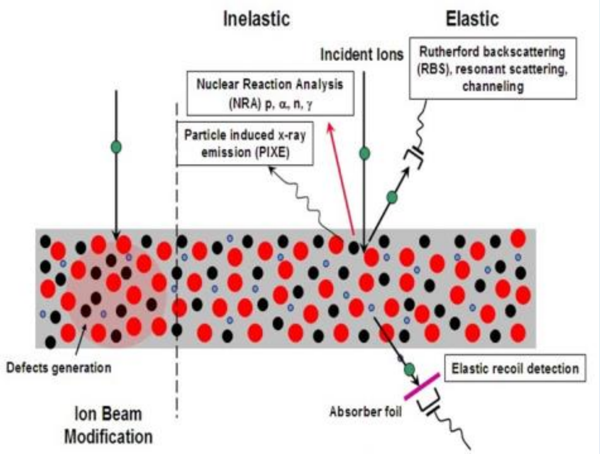
- Neutron flux – 5 10^7 n/s sm^2
- Max. neutrons energy - 5,5 ± 0,1 MeV

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

- Neutrons flux – 5 10^7 pat/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).

EG-5 activities

1. Scientific collaboration 2023

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

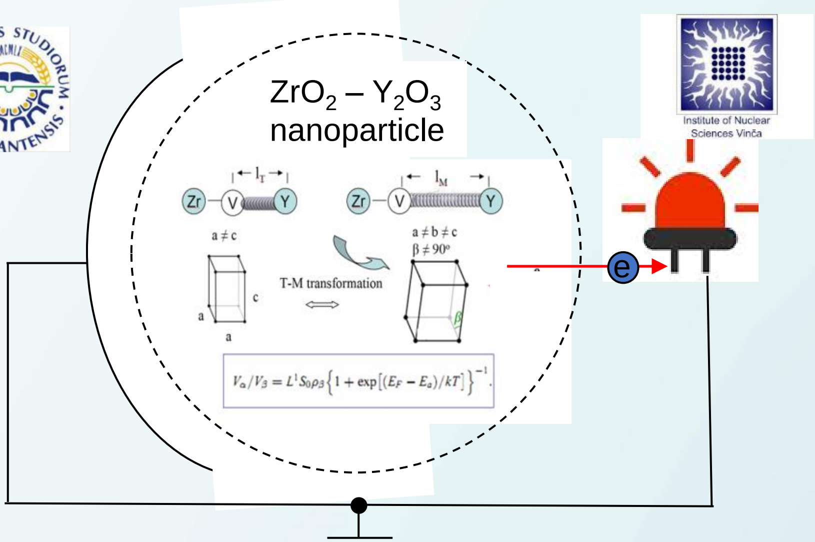
2. Industrial Partners 2023

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

3. Formal performance indicators in 2023

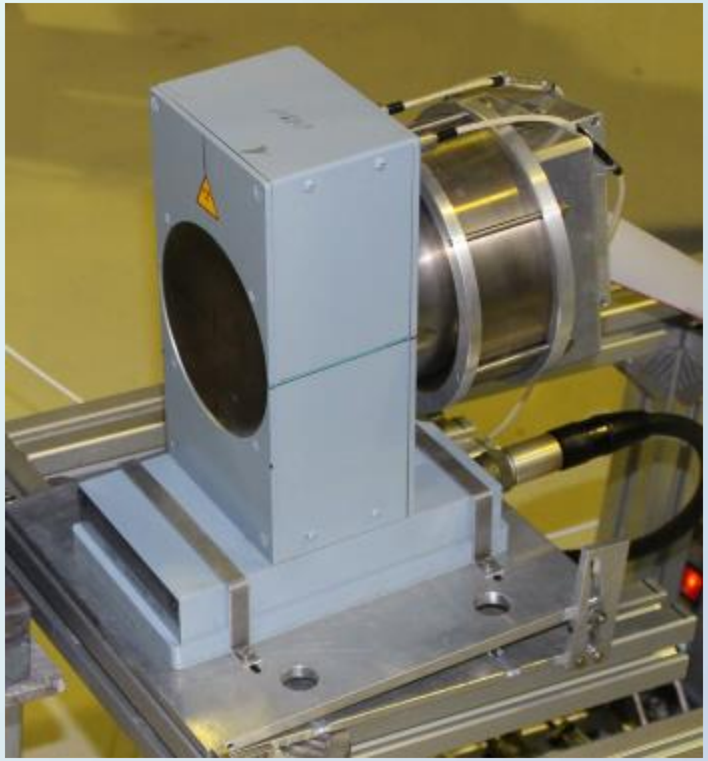
- 39 publications, including Q1 and Q2;
- 20 oral presentations.

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



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

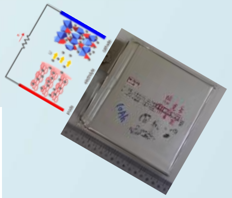
https://flnp.jinr.int/images/Books/Main_page/culture_en.pdf

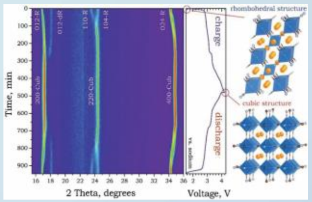
https://flnp.jinr.int/images/Books/Blue_books/LifeSciencesBook.pdf

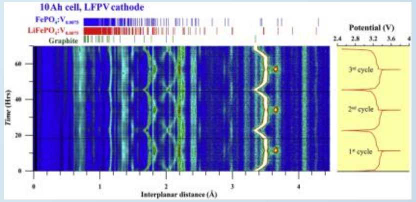
https://flnp.jinr.int/images/box-slider/MaterialsScienceBook.pdf

Diffraction

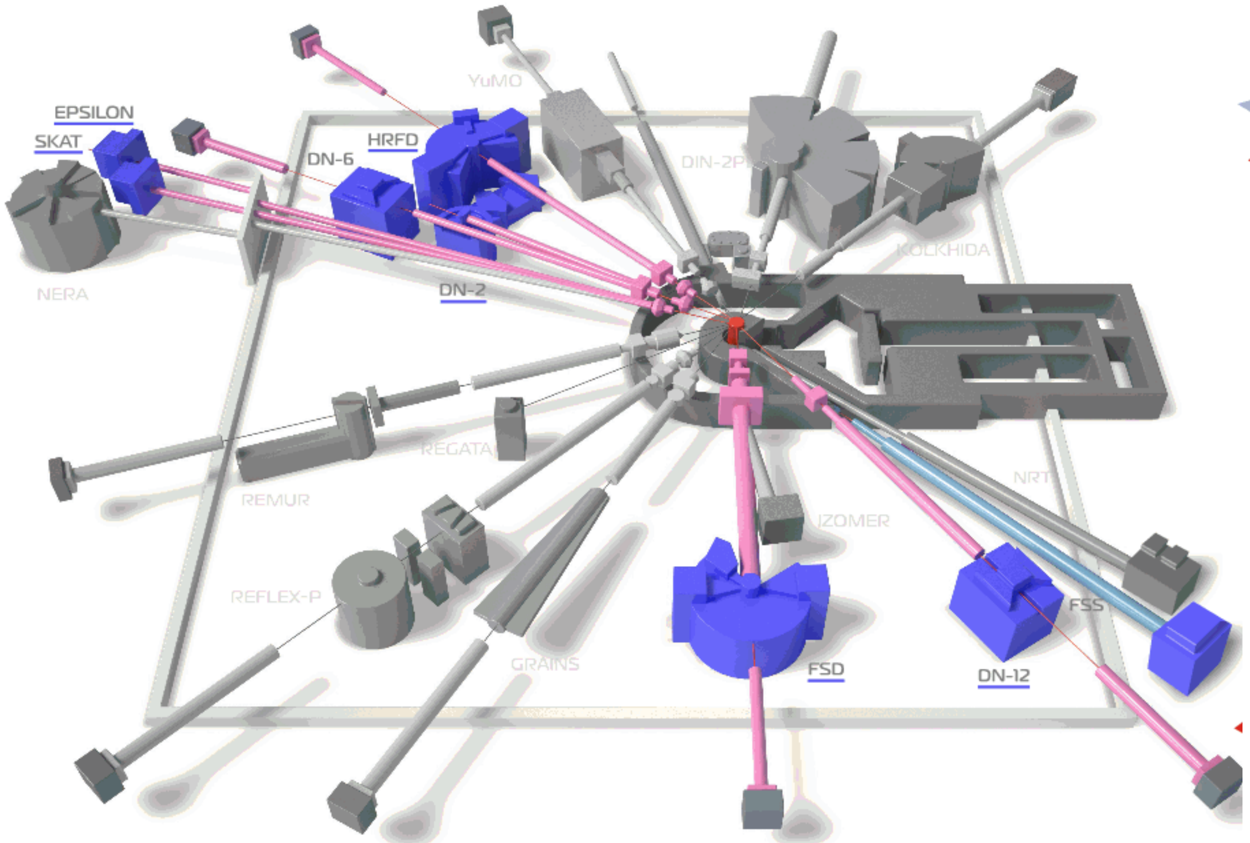
Neutron scattering in condensed matter physics



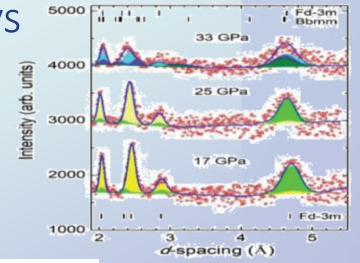


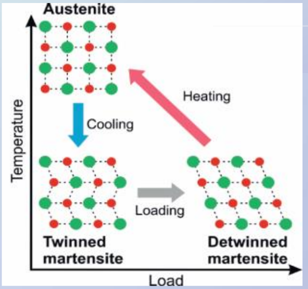


Experimental facilities



- **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

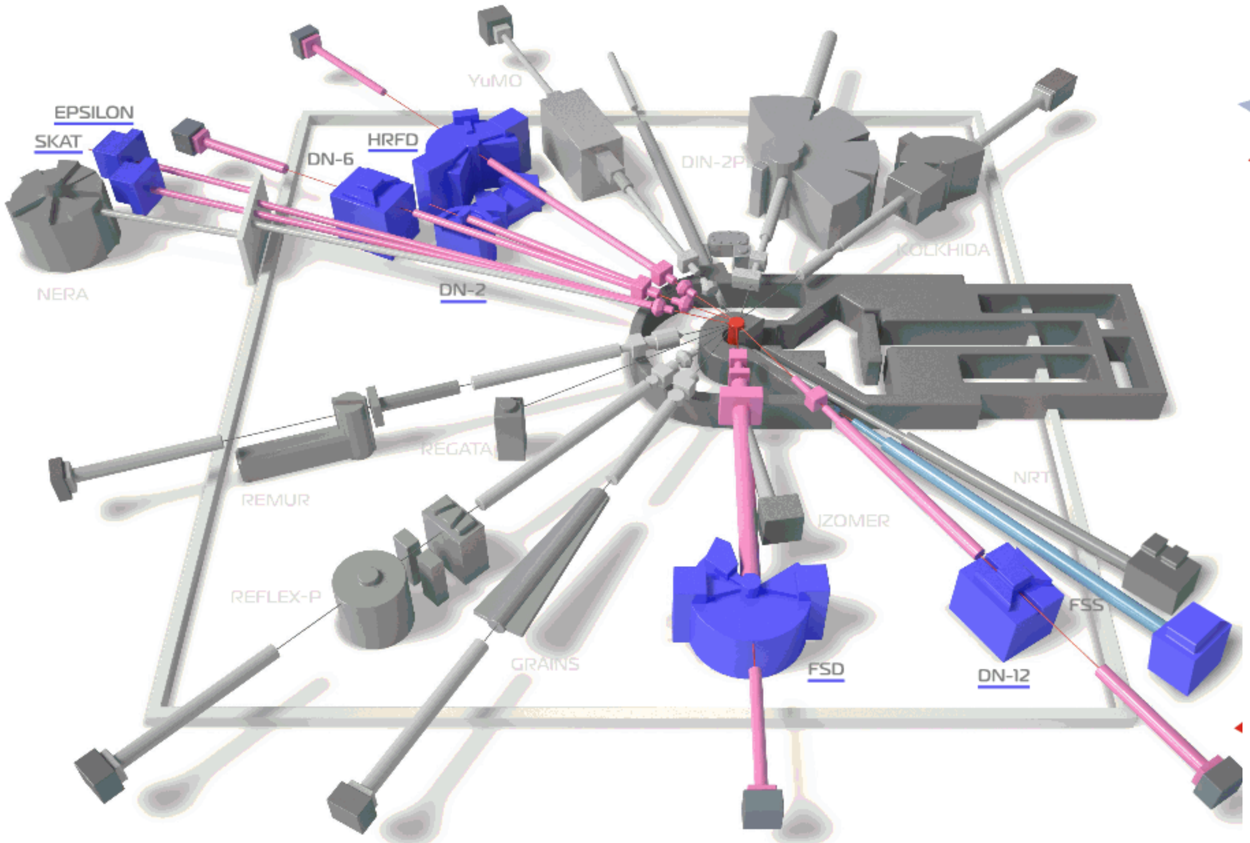




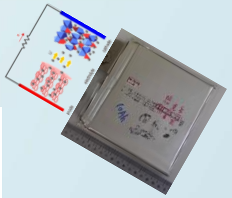
Diffraction

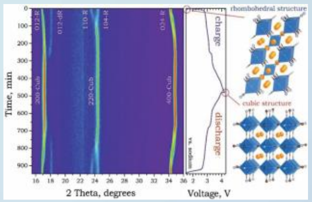
Neutron scattering in condensed matter physics

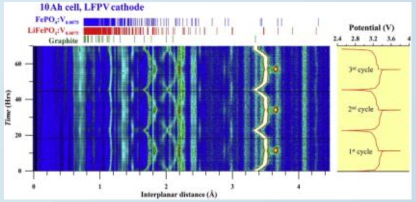
Experimental facilities



Diffraction
DN-2, DN-12, DN-6, FSD, FSS, HRFD, SKAT, EPSILON







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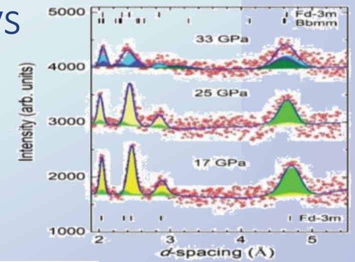
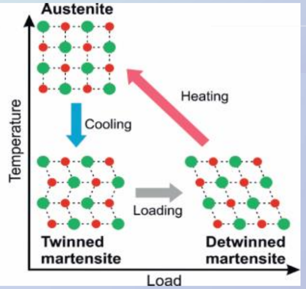


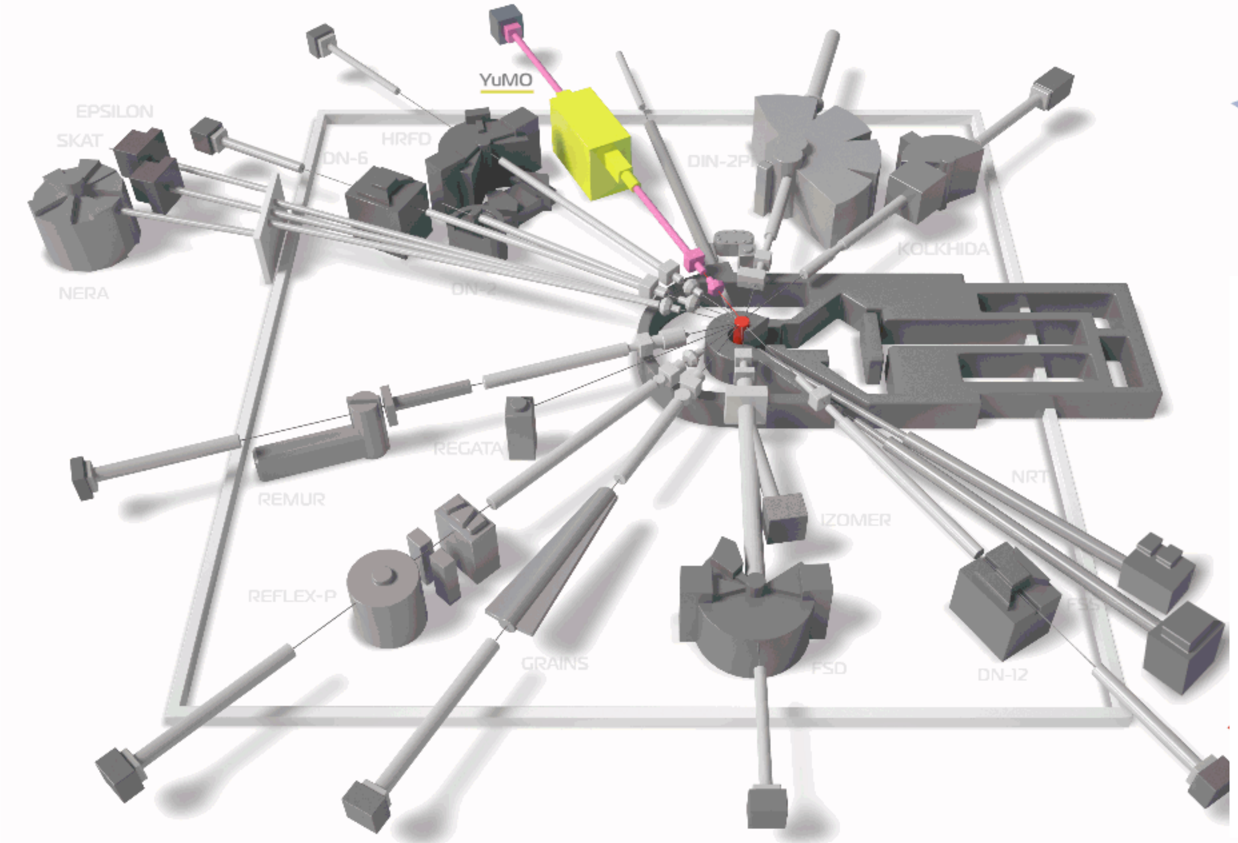
16 April, Tuesday
103 16:10 Olga Lis

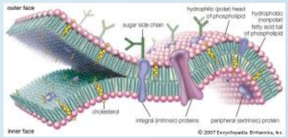


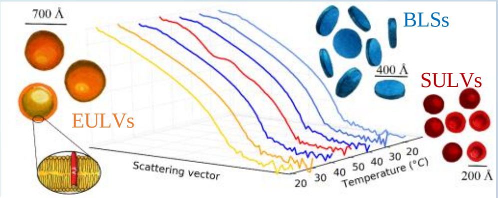
Neutron scattering in condensed matter physics

Small Angle Scattering

Experimental facilities





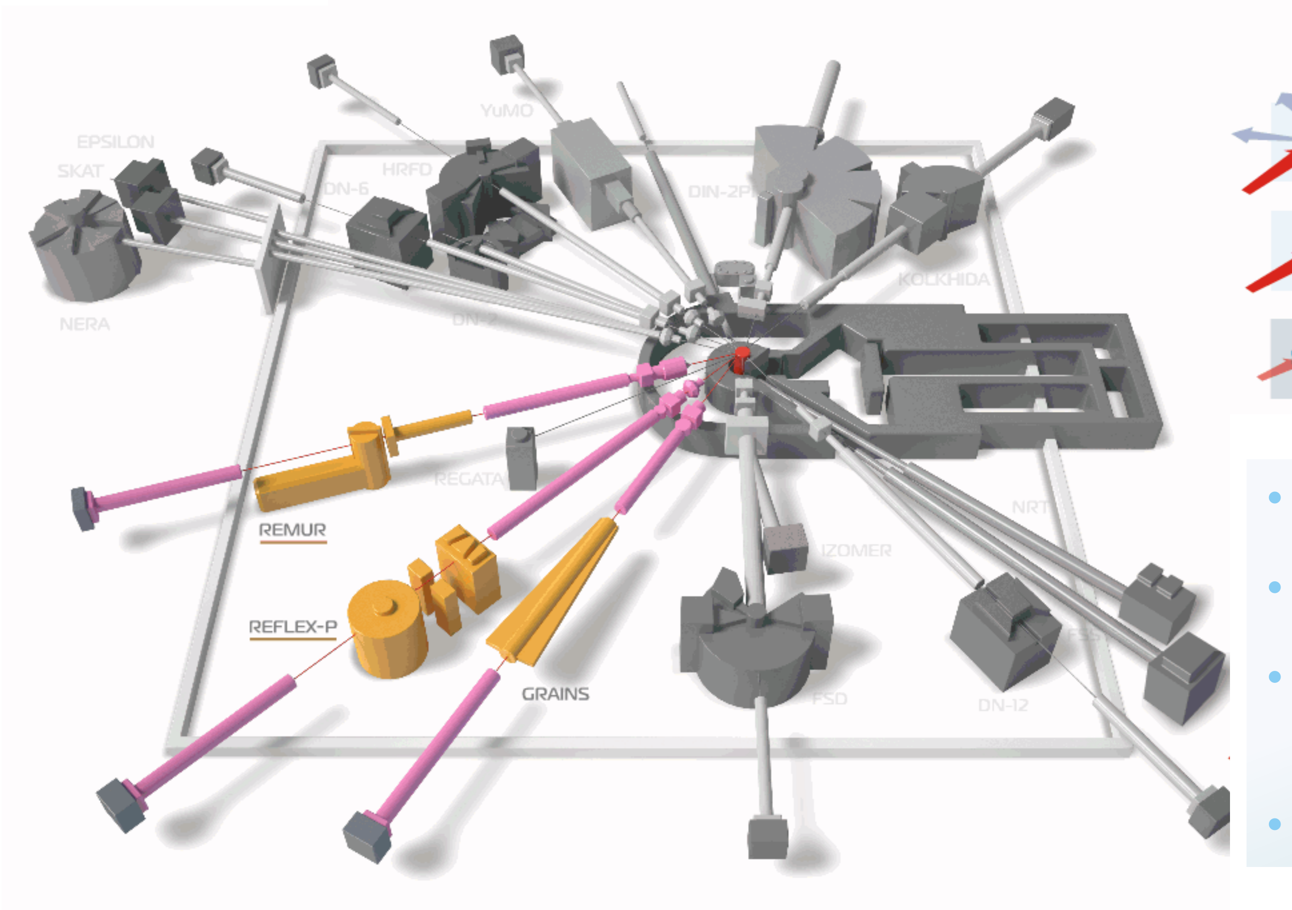


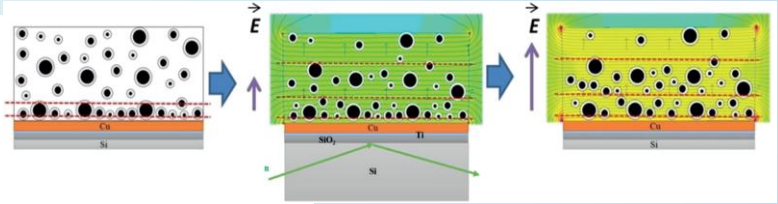
- **Structural organization** and **aggregation** of nanoparticles and **composite systems**
- Interactions of **nanoparticles** with **bio-macromolecules**
- **Nanopores** for magnetic and biomedical applications

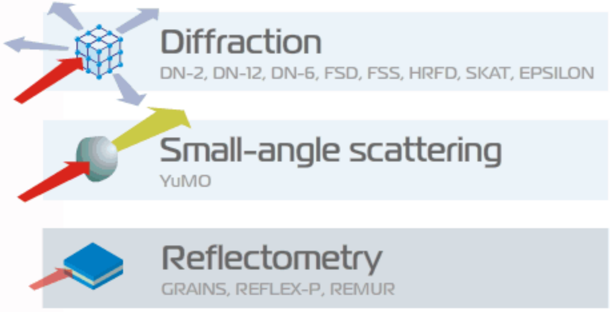
Neutron scattering in condensed matter physics

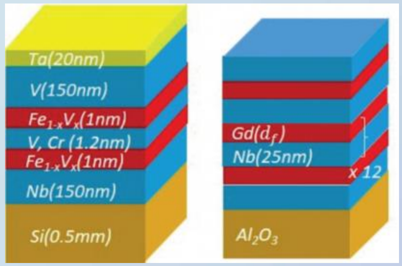
Reflectometry

Experimental facilities







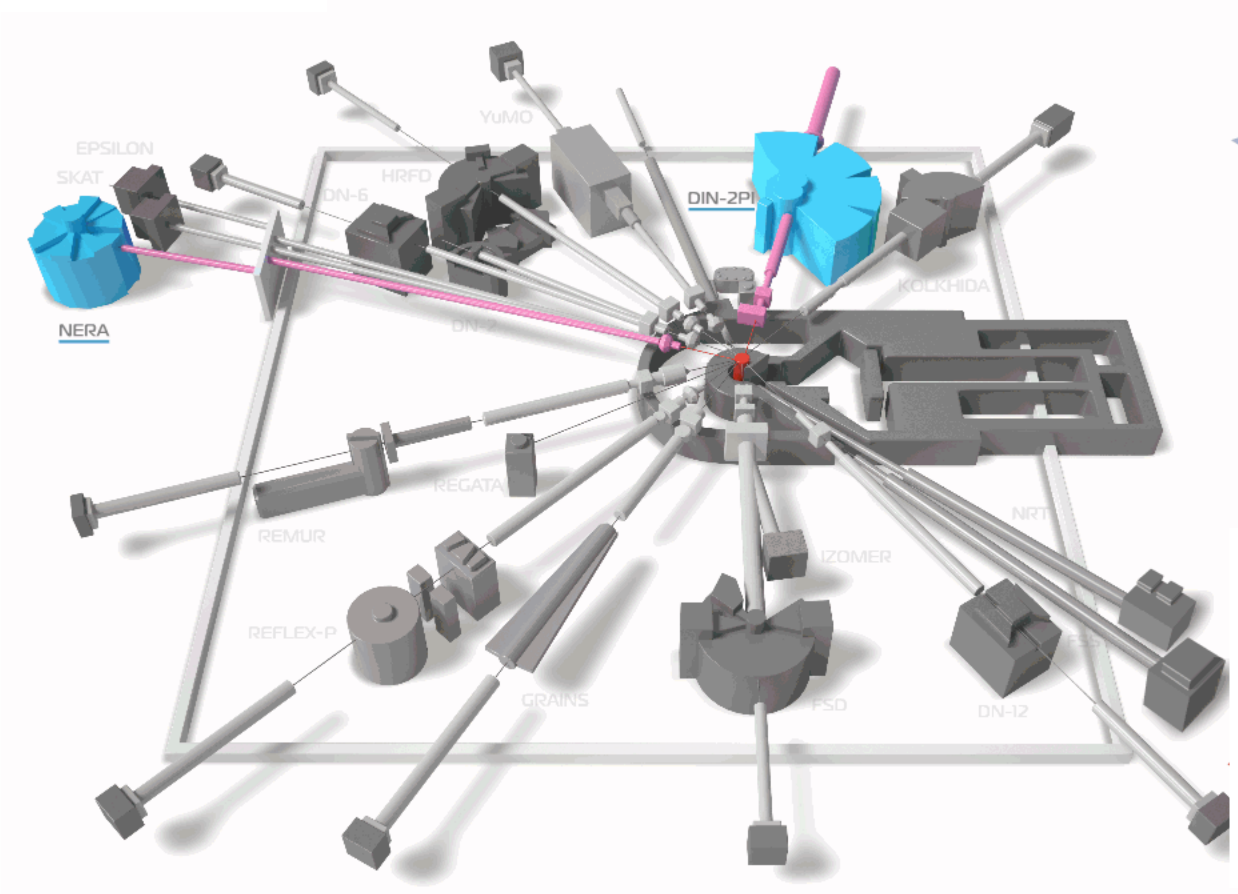


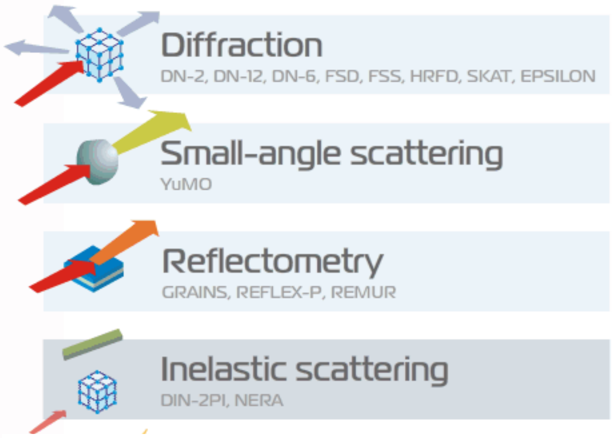
- **Thin films** and surfaces
- **Surface adsorption** of magnetic nanoparticles
- Superconducting and magnetic properties of the **complex layered heterostructures**
- **2D** van der Waals **magnetic materials**

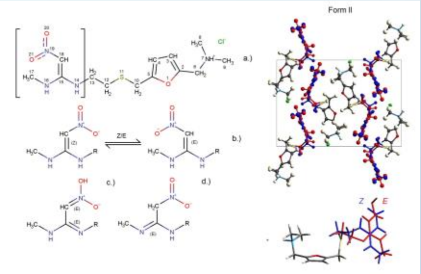
Neutron scattering in condensed matter physics

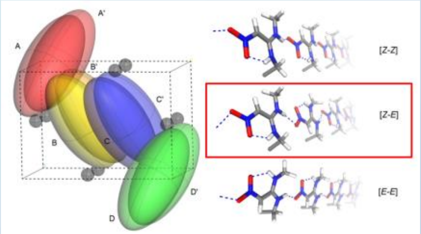
Inelastic Scattering

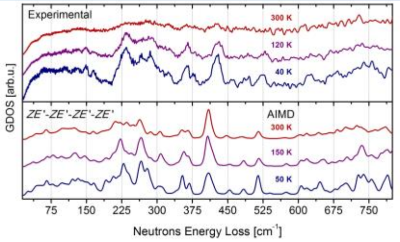
Experimental facilities



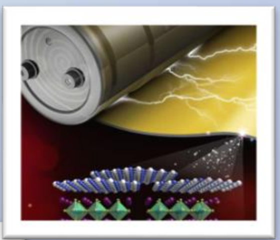


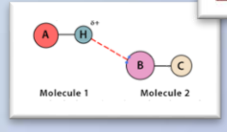


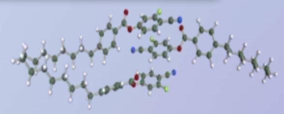




- Molecular structure and **dynamics**
- Isomeric forms of drugs
- Drug delivery systems

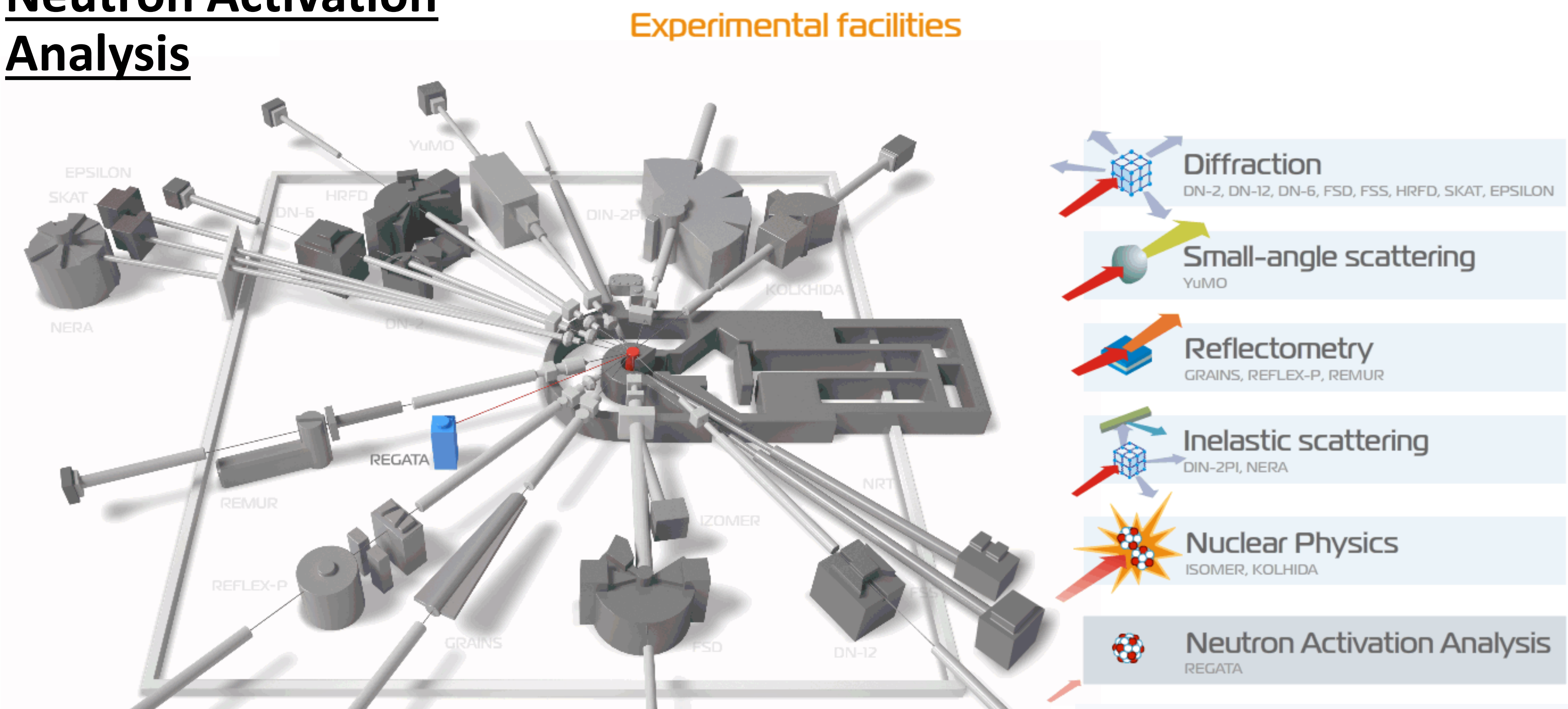


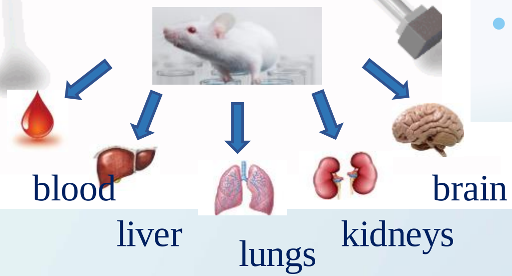


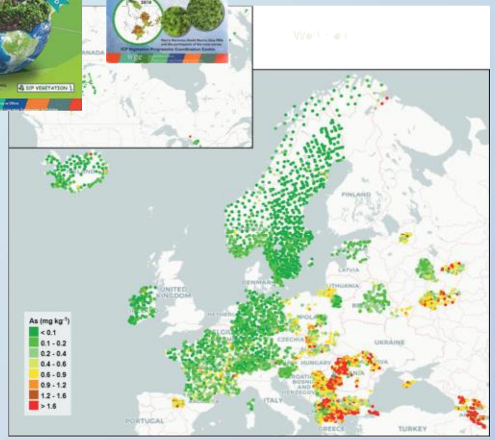


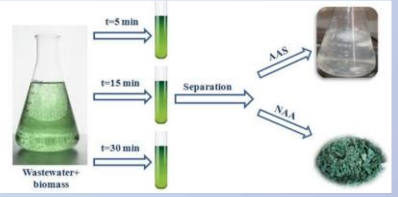
Nuclear analytical method

Neutron Activation Analysis









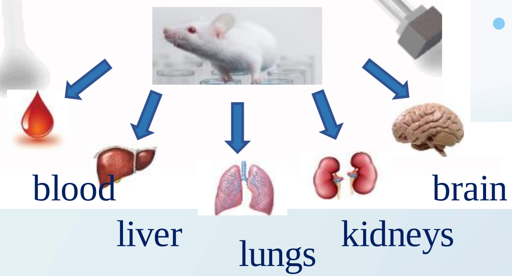
- **Elemental composition analysis** of air, water, and soil or the objects of cultural heritage

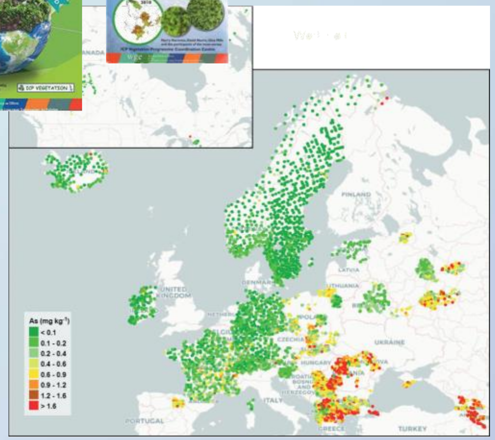
Nuclear analytical method

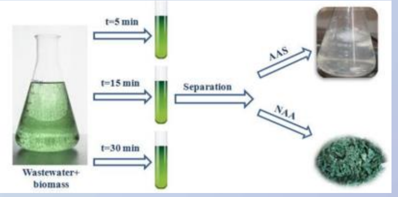
Neutron Activation Analysis

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



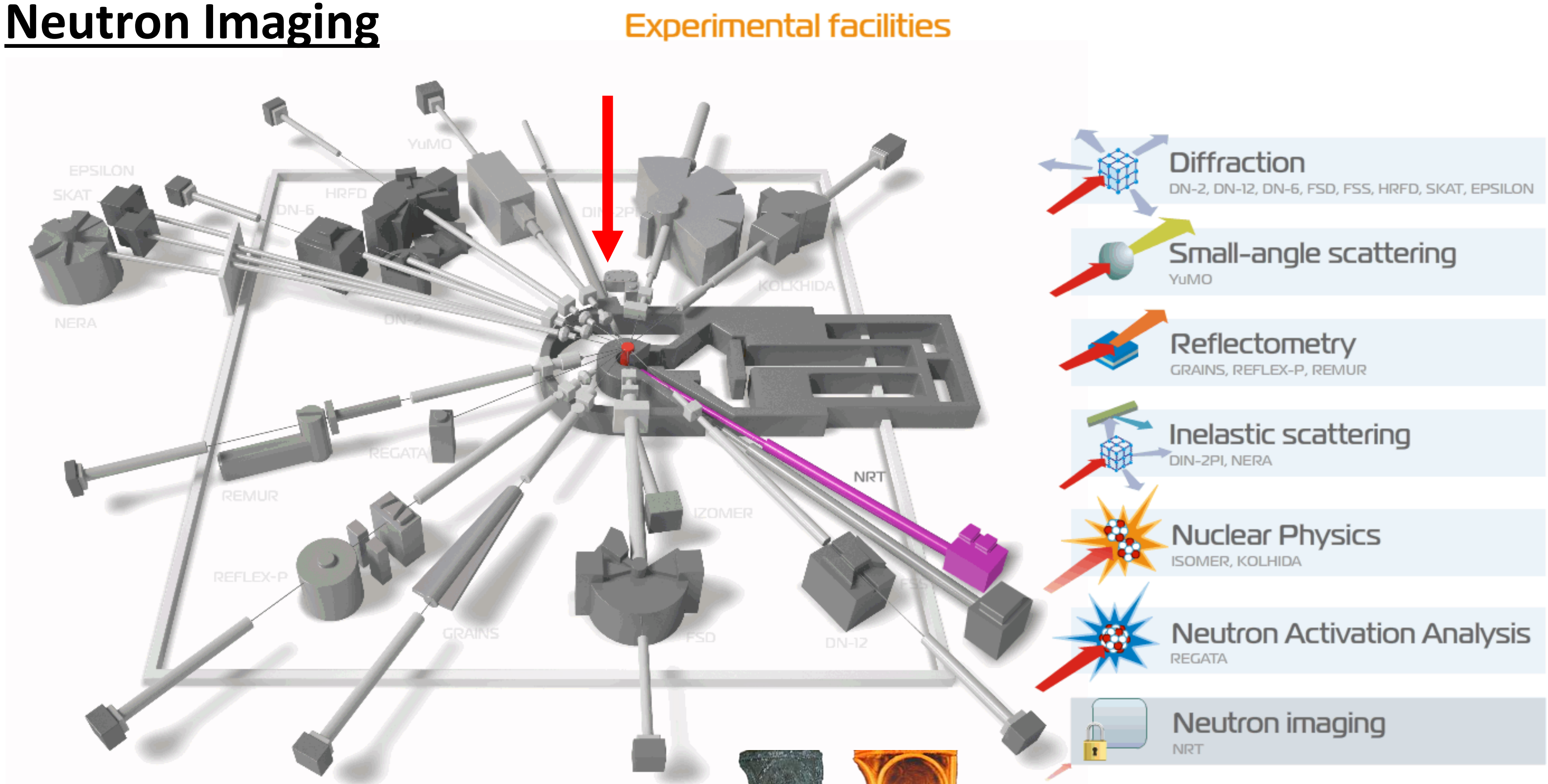


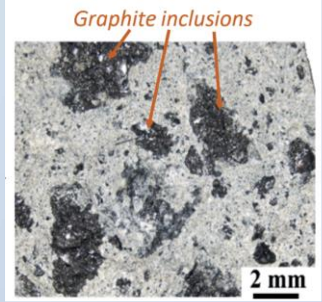


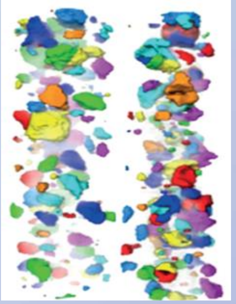
- **Elemental composition analysis** of air, water, and soil or the objects of cultural heritage

Neutron scattering in condensed matter physics

Neutron Imaging





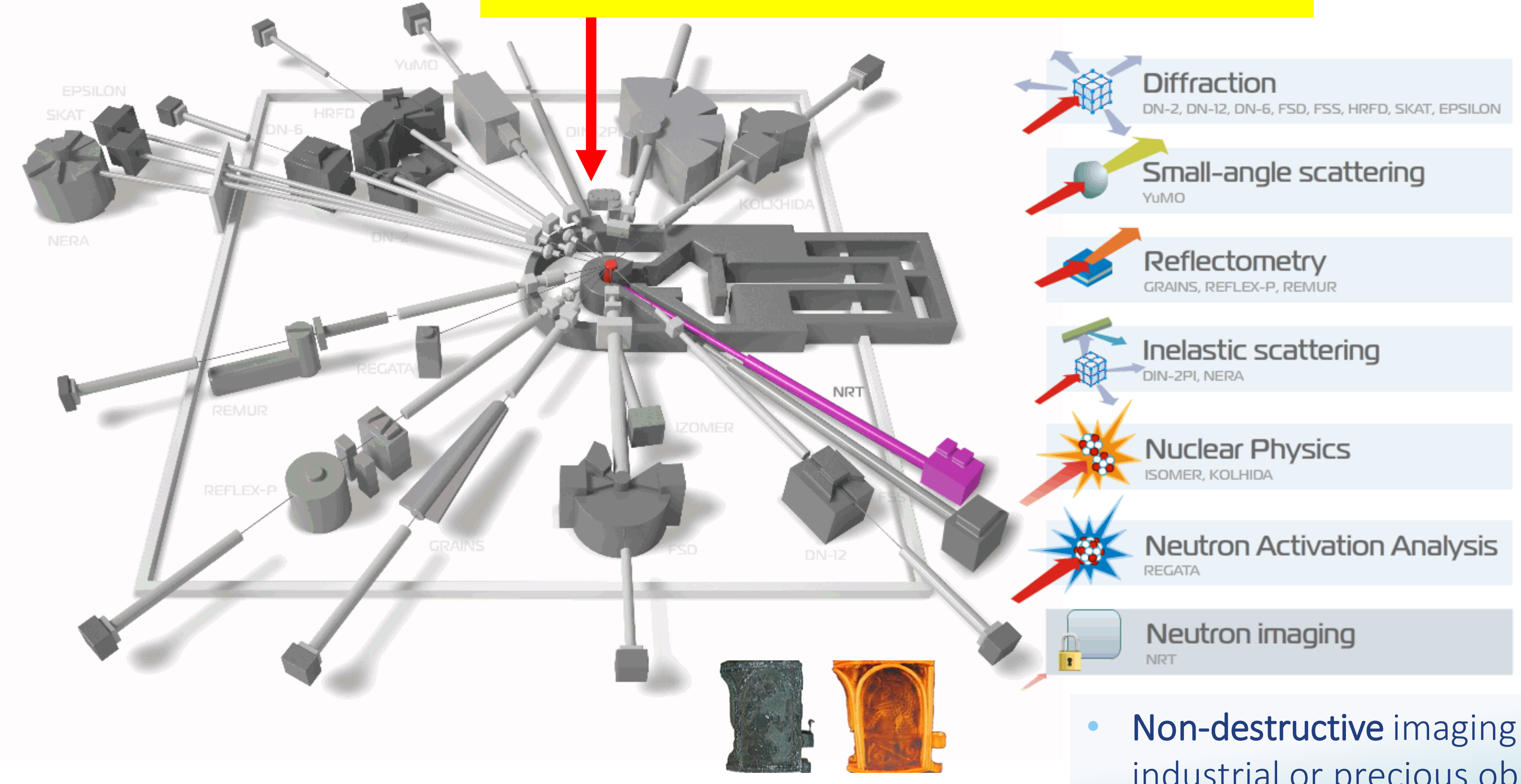


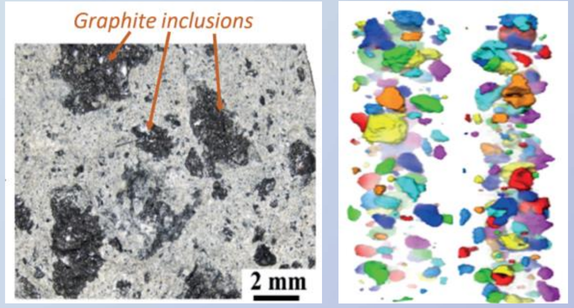
- **Non-destructive** imaging of the industrial or precious objects

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

16 April, Tuesday
100 15:10 Veronika Smirnova

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.

Main activities in the field of nuclear physics

17 April, Wednesday
148 15:10 Almat Yergashov
149 15:30 Sergey Borzakov

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.

Main activities in the field of nuclear physics

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

17 April, Wednesday
148 15:10 Almat Yergashov
149 15:30 Sergey Borzakov

2. **Investigations of the fundamental properties of the n[…] cold and very cold neutrons:**
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Today:
23 14:30 Alexander Frank
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

Investigation of neutron-induced reactions with charge particles emission

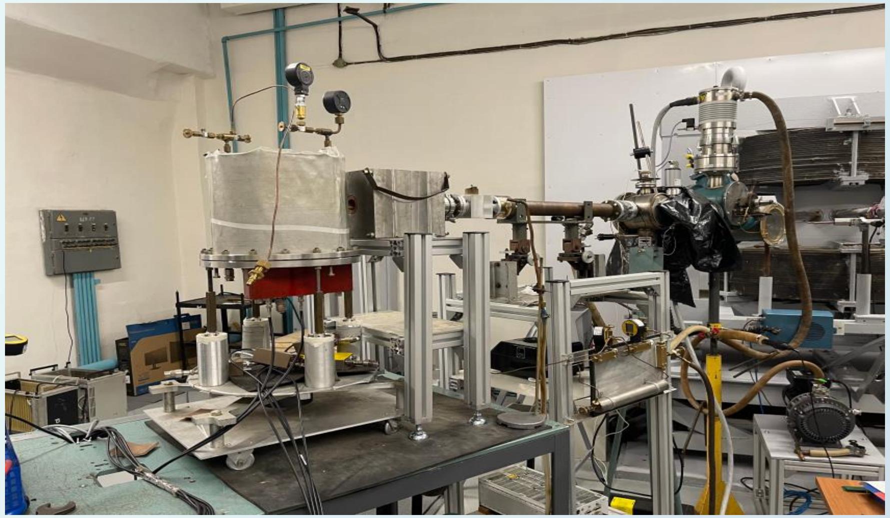
Work is planned to measure cross sections for reactions (n,p), (n,α) on various isotopes.

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.

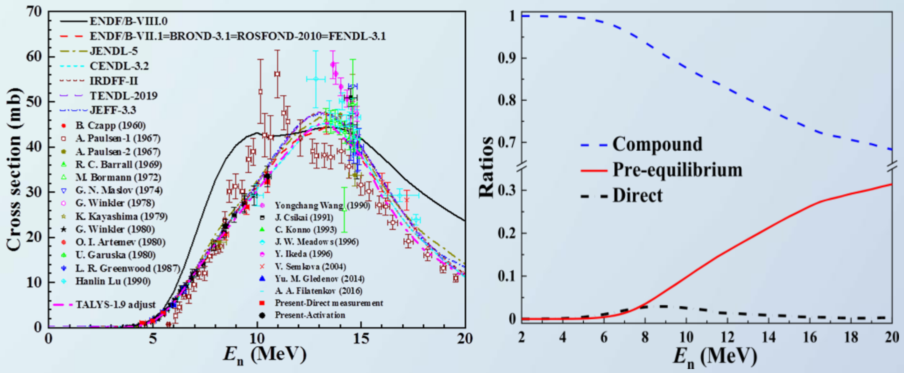
It is also planned to conduct test measurements of reactions (n,p), (n,α) on ^{6}Li and Cl at the IREN facility.

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

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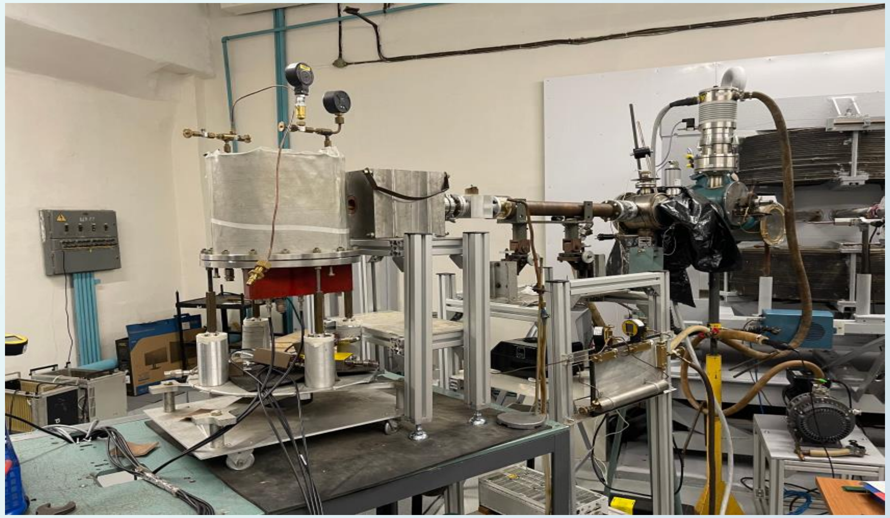
16 April, Tuesday
83 Igor Chuprakov



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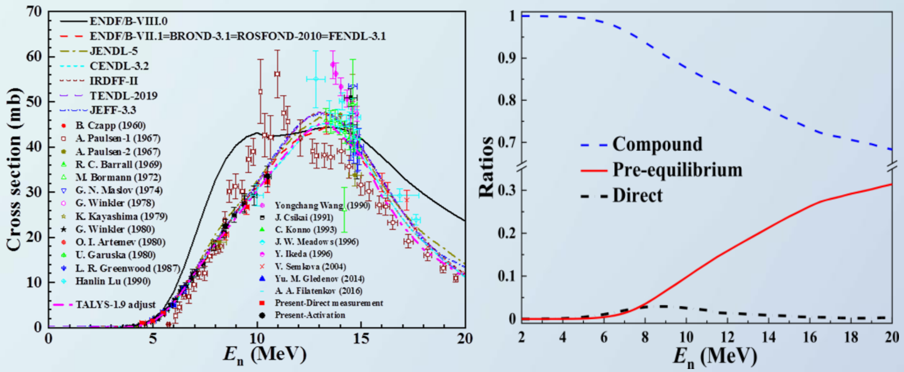

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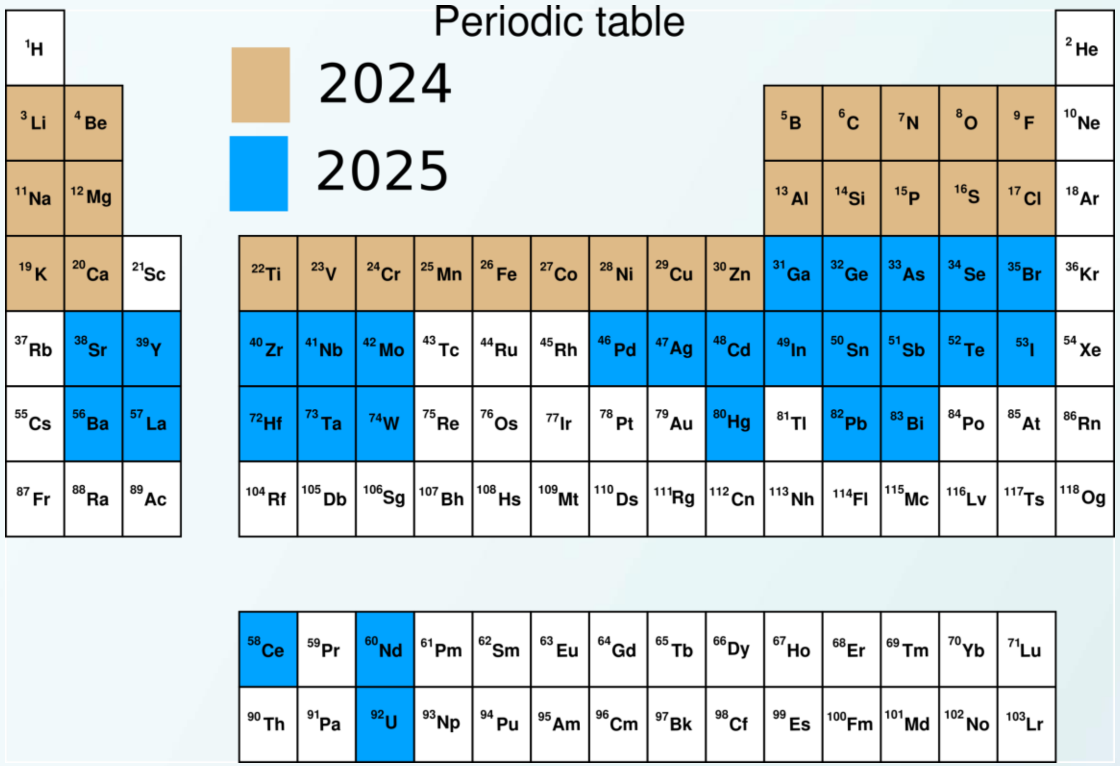
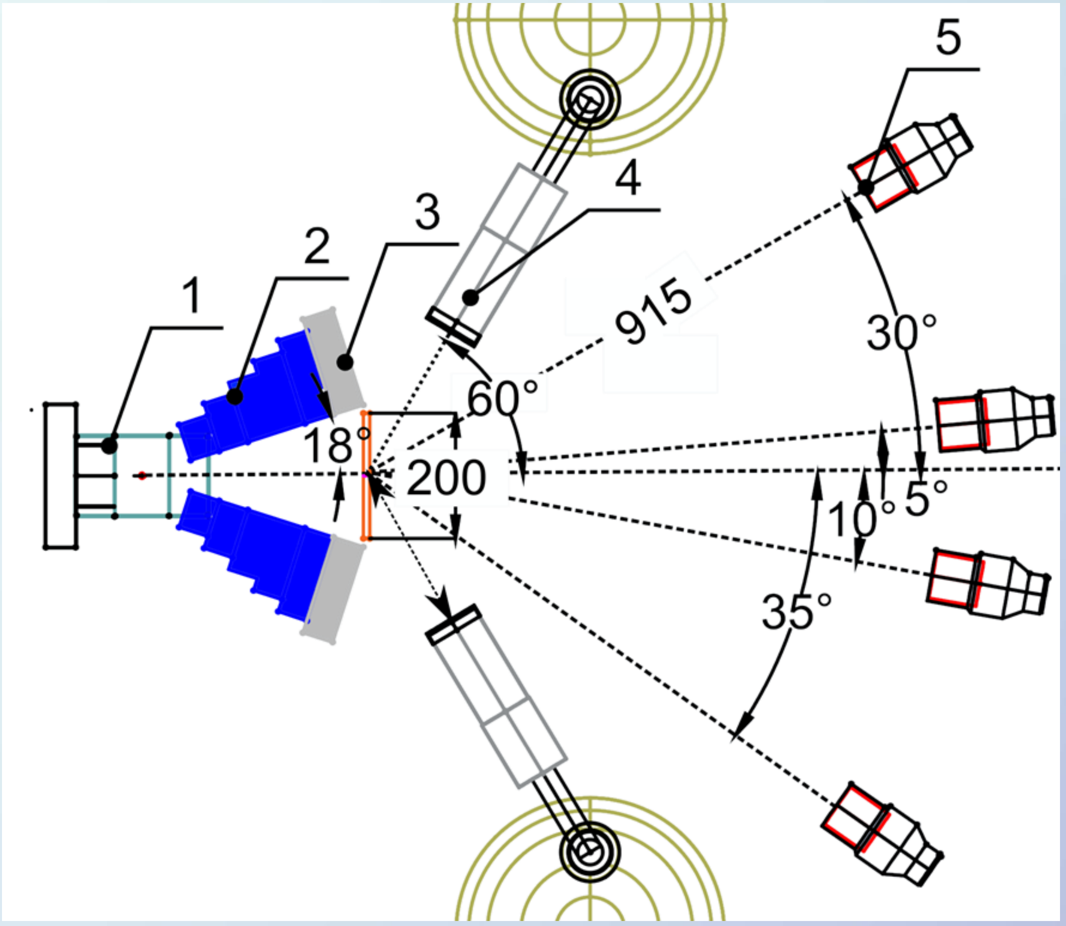


Setup for measuring γ-ray emission cross sections consisting of two HPGe detectors (4) and four LaBr detectors (5).



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.

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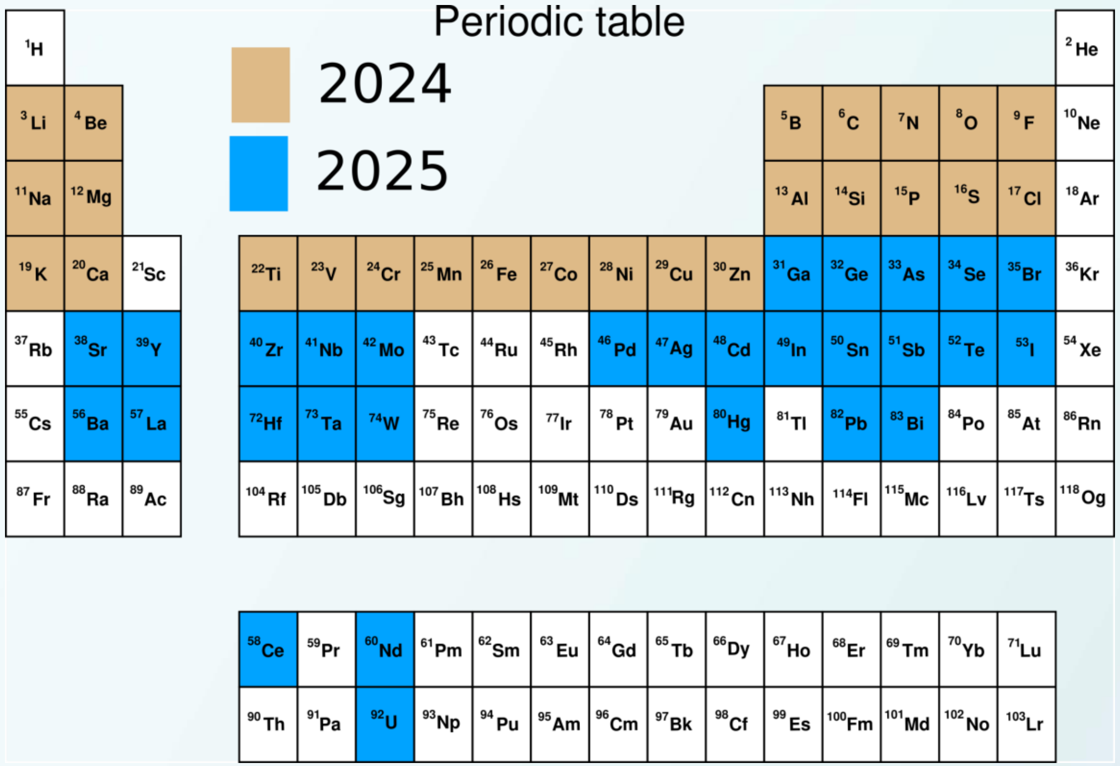

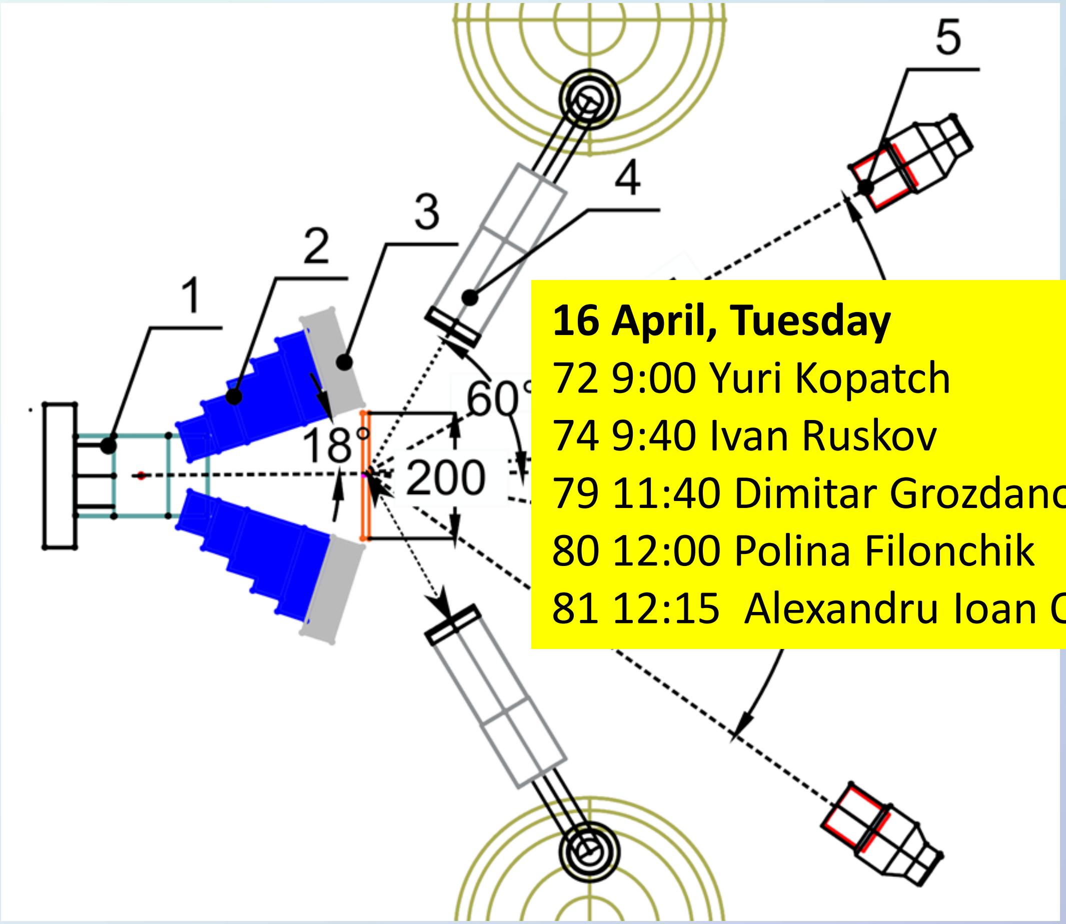

16 April, Tuesday
72 9:00 Yuri Kopatch
74 9:40 Ivan Ruskov
79 11:40 Dimitar Grozdanov
80 12:00 Polina Filonchik
81 12:15 Alexandru Ioan Oprea

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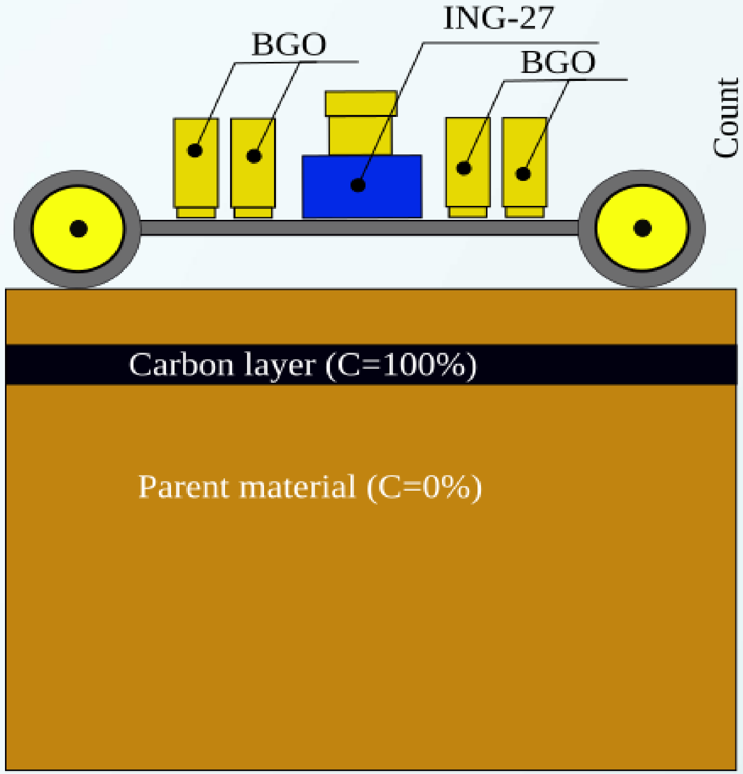
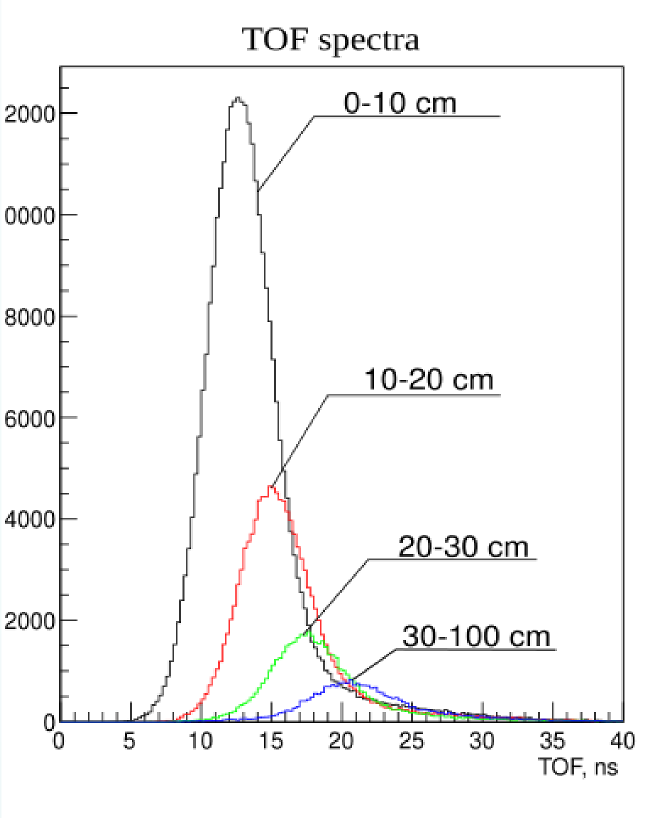
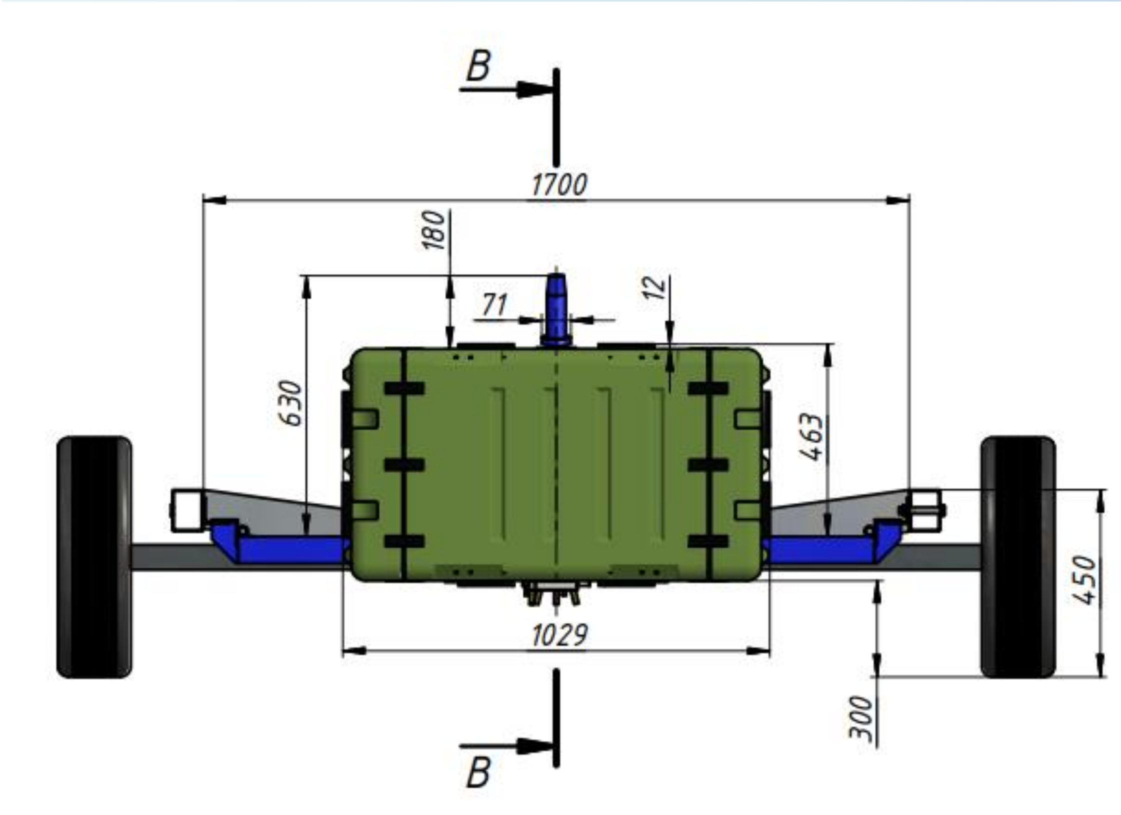
Construction of a pilot mobile setup for determining the carbon content in soil using the Tagged Neutron Method (in collaboration with LLC “Diamant”).

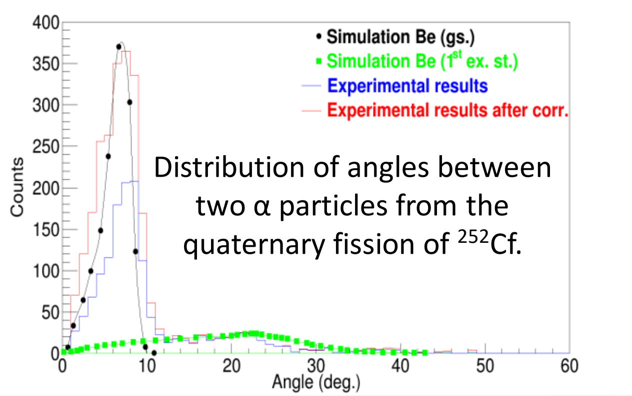


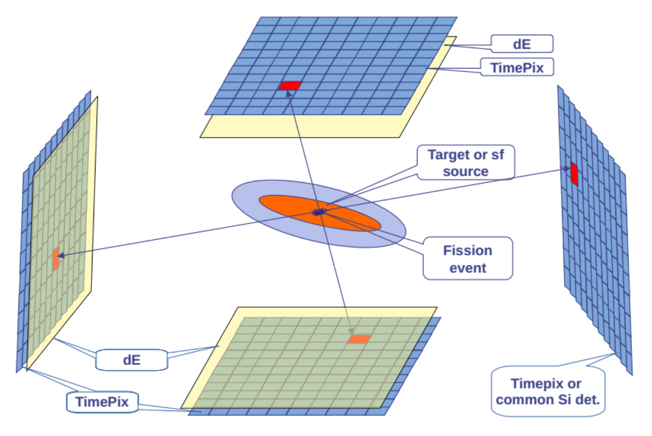


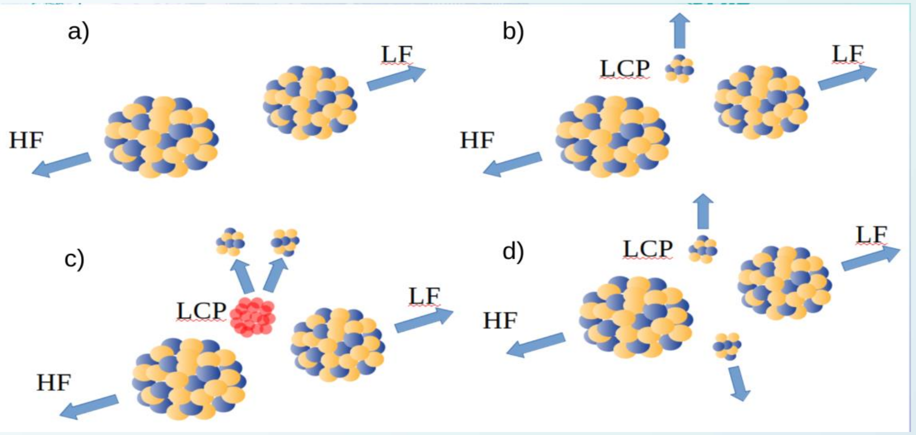


Study of rare fission modes and prompt neutron emission in nuclear fission

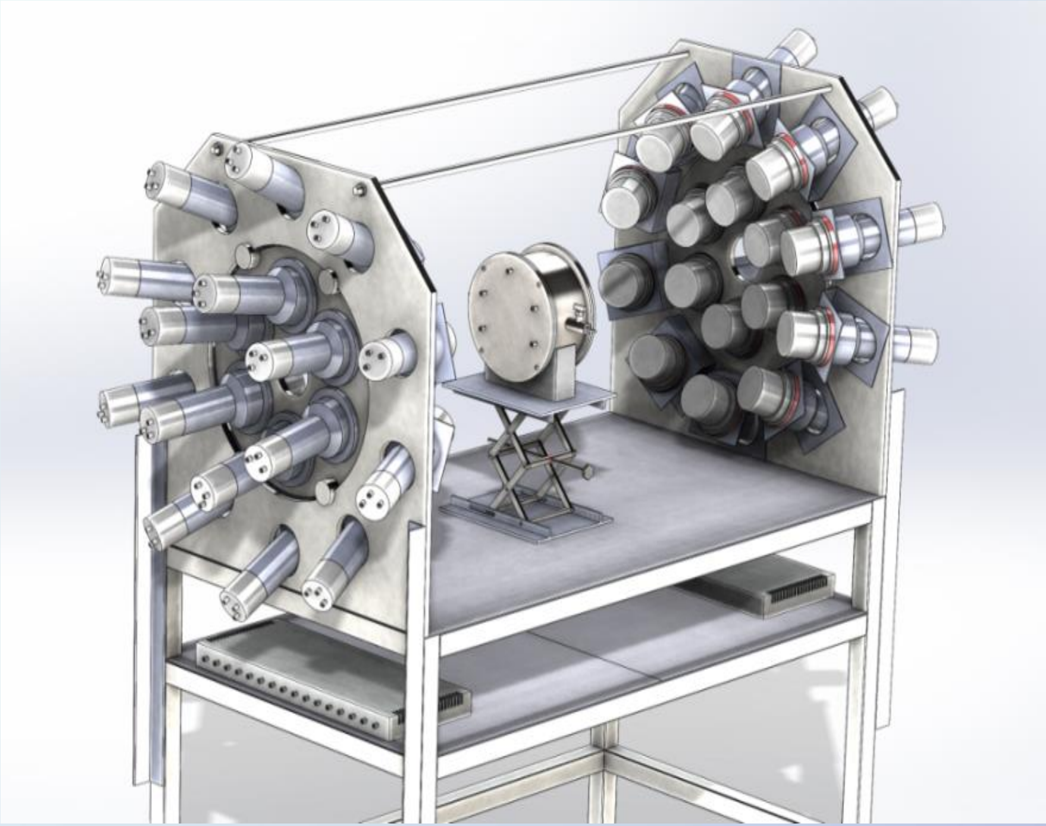
Search for rare and exotic fission modes (quaternary and quinary fission) in thermal neutron induced fission of ^{252}Cf, ^{233}U and ^{235}U nuclei.







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.

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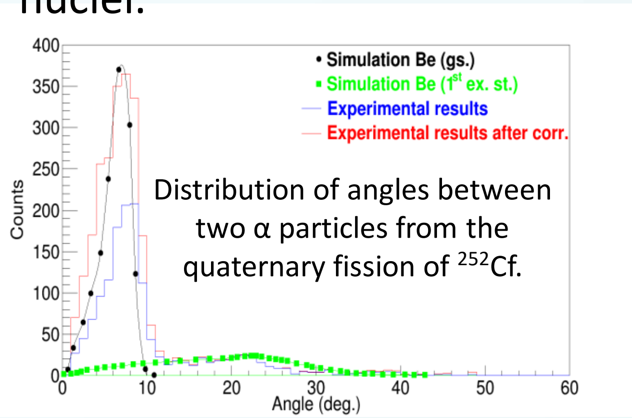
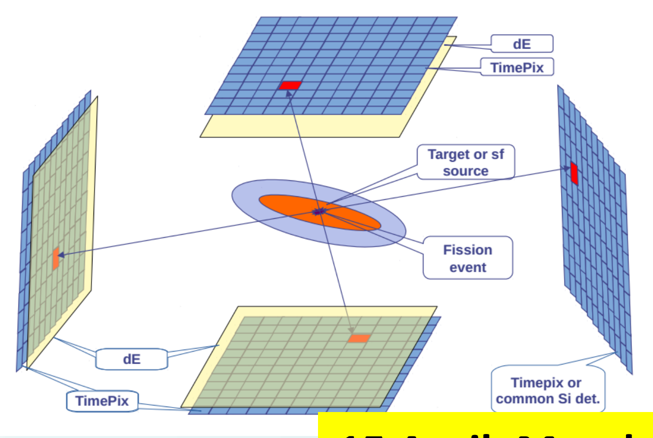
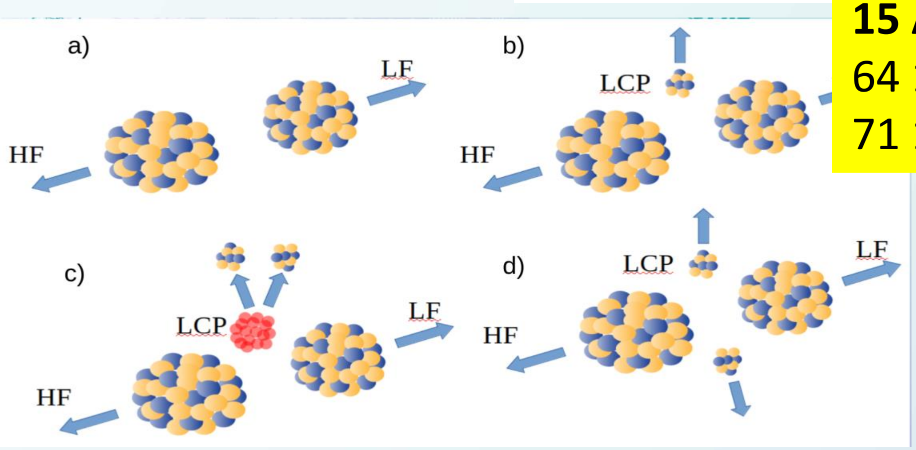
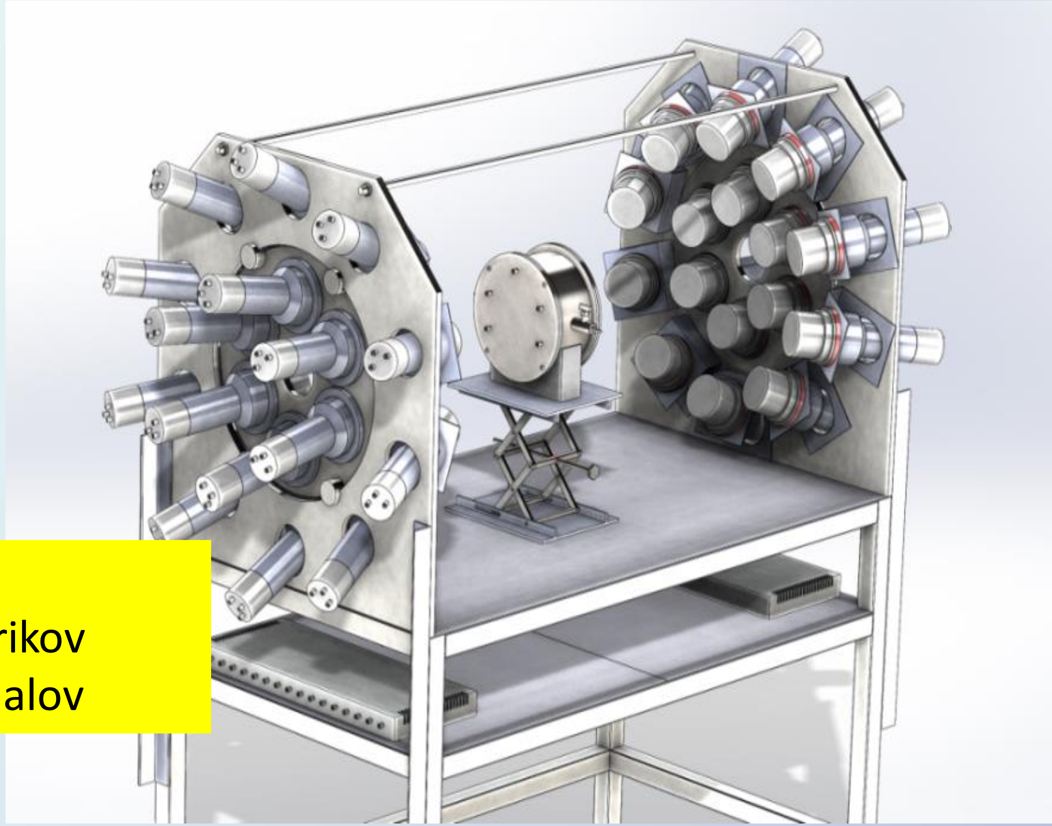


Distribution of angles between two α particles from the quaternary fission of ^{252}Cf.





15 April, Monday
64 15:50 Daniyar Berikov
71 18:10 Shakir Zeynalov



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

Frescoes of Moscow Kremlin Cathedral

- Specialist of **NAA group of FLNP** together with art historians research wall paintings of ancient Russian churches

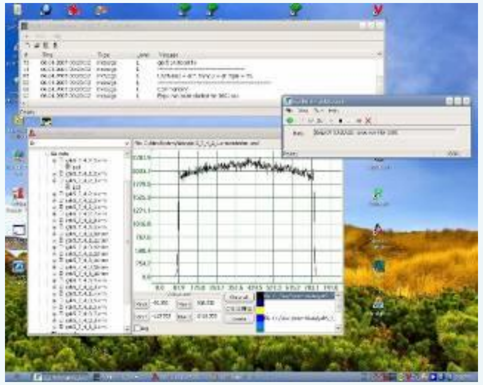
- **Elemental composition analysis** by NAA at IREN and IBR-2, X-ray fluorescence, electron microscopy, infrared and Raman spectrometry
- Determining the fresco colours in their **original reality** by physico-chemical studies to be able to **restore** them

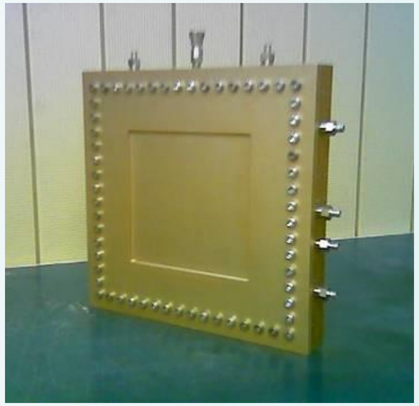
Pre-amplifiers

Crate NIM with analog electronics

Methodical research:

- Neutron spectrometers;
- Detectors;
- Sample environment;
- Hardware & software;
- Cryogenics;
- Network and computing;





DAN neutron generator

DAN Detectors

Pre-amplifiers

Crate NIM with analog electronics

Methodical research:

- Neutron spectrometers;
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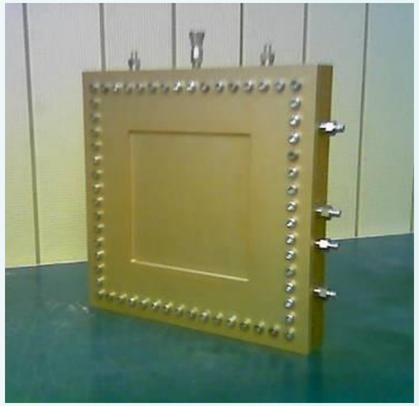
- Network and computing;

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

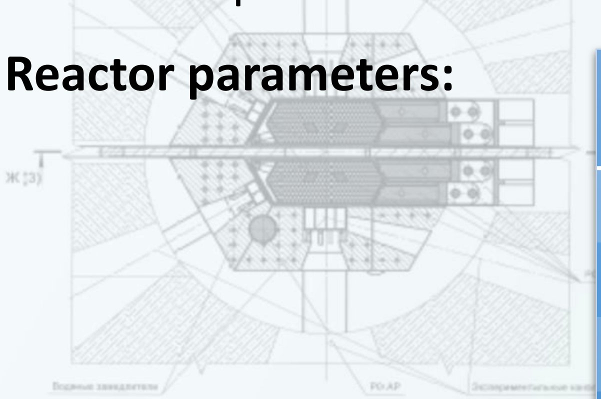


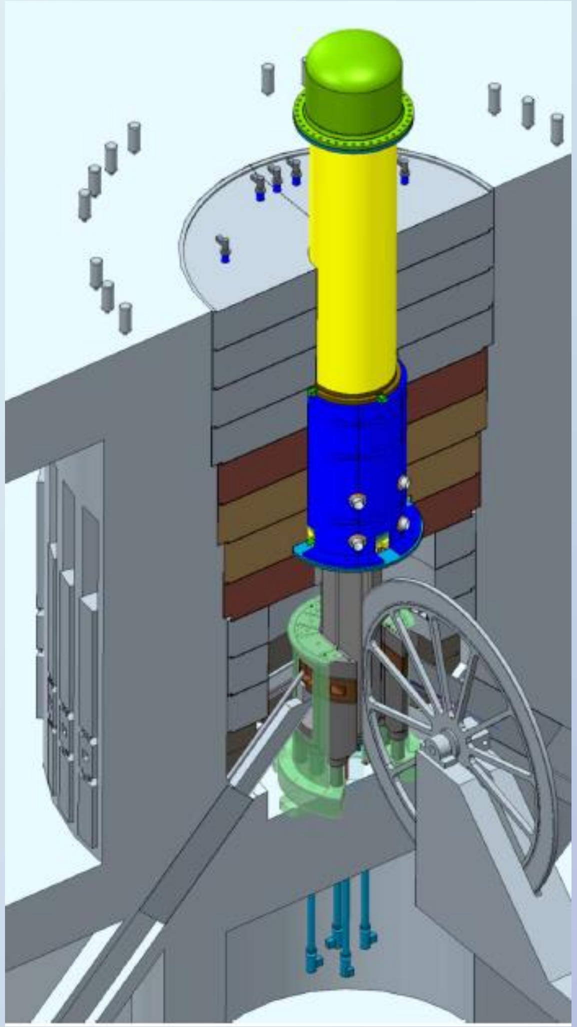
DAN neutron generator

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)



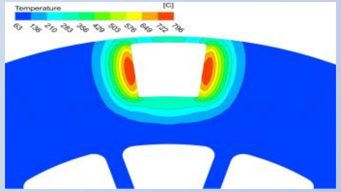


Reactor parameters:

Fuel	**NpN, 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.



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15 April, Monday
39 9:40 Ahmed Hassan
41 10:20 Maxim Podlesnyy
17 April, Wednesday
163 16:40 Tatiana Dikova

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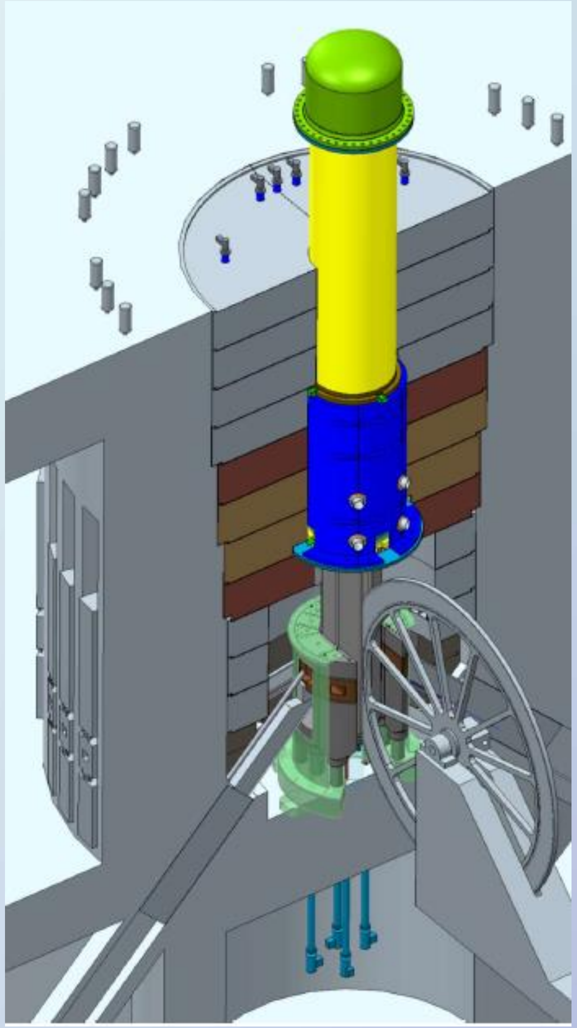

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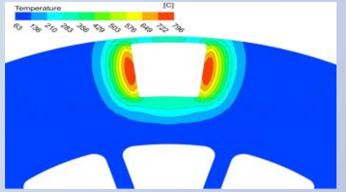

Thank you for attention