Instrumentation program at PIK reactor

Vladimir Voronin

Workshop “International mega-science projects”
3-4 December 2014, JINR, Dubna
PIK reactor parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power</td>
<td>100 MW</td>
</tr>
<tr>
<td>Reactor core volume</td>
<td>50 l</td>
</tr>
<tr>
<td>Core height</td>
<td>500 mm</td>
</tr>
<tr>
<td>Moderator</td>
<td>H₂O</td>
</tr>
<tr>
<td>Maximal neutron flux in moderator</td>
<td>1.3x10^{15} n/cm²c</td>
</tr>
<tr>
<td>Maximal neutron flux in central trap</td>
<td>5x10^{15} n/cm²c</td>
</tr>
<tr>
<td>Operation cycle</td>
<td>~30 day</td>
</tr>
<tr>
<td>Experimental channels</td>
<td></td>
</tr>
<tr>
<td>- Horizontal (HEC)</td>
<td>10</td>
</tr>
<tr>
<td>- Vertical (VEC)</td>
<td>7</td>
</tr>
<tr>
<td>- Inclined (IEC)</td>
<td>6</td>
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</table>

Mega-science projects, Dubna, 3-4-Dec. 2014
The goal and tasks

**Goal is** building the unique instrument base at PIK reactor consisting of specialized neutron instrument complexes whose characteristics exceed the world level.

The minimal task is the construction of reactor complex with the 32 neutron stations supplied with **three sources of cold and ultracold neutrons**. The neutron stations are located in three experimental halls: 15 stations in the **neutronguide hall**, 14 stations in **hall of horizontal channels** and 3 stations in the **hall of inclined channels**.
The instrumentation program of PIC reactor are realized in the framework of two investment program

1. **Reconstruction of PIK laboratory complex (first phase) (2014 – 2019)** – one CN source and 12 experimental stations will be installed

2. **Creation of the experimental station complex at PIK reactor (second phase) (2015 – 2020)** – one CN and one UCN sources and 20 experimental stations will be created
The 11 workgroups on various topics were organized to develop the conception of PIK reactor instrumentation program.

More than 50 scientists from neutron center of Russia and Europe:
- PNPI NRC «Kurchatov institute»
- Joint Institute for Nuclear Research (Dubna),
- Helmholtz-Zentrum Geesthacht (Germany)
- Institut Laue-Langevin (Grenoble, France)
- European Spallation Source (Lund, Sweden).
- and other ...

actively worked under this conception.

Nine national and international workshop were organized.
General Concept for Instrumentation Program of Neutron Research Centre PIK
Main direction of the instrumentation program realization:

Infrastructure of the experiments
- Cold and ultracold neutron sources
- Neutronguide complex
- Sample environments
- Neutron detection technology
- Computer information center

Experimental stations for condense matter physics
- Diffractometry complex
- Neutron spectroscopy
- Small angle neutron scattering
- Reflectometry

Experimental stations for nuclear physics and elementary particles physics
- Ultracold beam positions and experimental stations
- Neutrino experiment
- Cold and thermal neutron beam positions and experimental stations
- Nuclear spectroscopy
# Road map of instrumentation program

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<tbody>
<tr>
<td>Development of the project</td>
<td></td>
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<td></td>
<td></td>
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<tr>
<td>State expertise</td>
<td></td>
<td></td>
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</tbody>
</table>

## Neutron sources

<table>
<thead>
<tr>
<th>Replacement of some reactor channels, CNS (HEC-3) with neutronguides</th>
<th>2015</th>
<th>2016</th>
<th>2017</th>
<th>2018</th>
<th>2019</th>
<th>2020</th>
</tr>
</thead>
<tbody>
<tr>
<td>CNS at HEC-2 and UCNS, neutronguides; commissioning CNS &amp; UCNS</td>
<td></td>
<td></td>
<td></td>
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## Experimental stations

<table>
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<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Nuclear physics &amp; elementary particle physics, 2nd phase (7 instruments)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Condensed-matter physics, 1st phase (9 instruments)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Condensed-matter physics, 2nd phase (13 instruments)</td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

## Sample environment

|-----------------------------------|------|------|------|------|------|------|
Cold neutron sources workgroup

Staff:
1. **V.A. Mitukhliiaev** – group leader, PNPI NRC KI
2. **M.S. Onegin** – PNPI NRC KI
3. **V.V. Nesvizhevskii** – ILL, France
4. **F. Mezei** - ESS, Sweden
5. **K. Batikov** – ESS, Sweden
6. **Tamas Grosz** – BNC, Hungary
7. **A. Yu. Muzichka** – JINR, Dubna
8. **S.A. Kulikov** – JINR, Dubna
1. Cold neutron source at HEC-3 (first phase)
2. Cold neutron source at HEC-2 (second phase)
3. UltraCNS (second phase)

The construction of these source allows to have up to 50 beam positions with neutrons of different energy at PIK reactor
## CNS parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>ANSTO</th>
<th>PNPI</th>
<th>PNPI</th>
<th>ILL (V / H)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reactor power, MW</td>
<td>20</td>
<td>100</td>
<td>100</td>
<td>57</td>
</tr>
<tr>
<td><em>Thermal neutron flux at CNS location</em></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1,65×10^{14}</td>
<td>4,0 10^{14}</td>
<td>5,0 10^{14}</td>
<td>4,6×10^{14} / 8×10^{14}</td>
</tr>
<tr>
<td>Cold neutron flux at reactor face, ( \lambda &gt; 4\text{Å} ), ( \text{n cm}^{-2}\text{c}^{-1} )</td>
<td>((1,8-2,5)\ 10^{10})</td>
<td>(6,0\ 10^{10})</td>
<td>(1,7\ 10^{11})</td>
<td>(\approx 10^{10}/4 \times 10^{10})</td>
</tr>
<tr>
<td><em>Cold neutron flux at neutron guide hall</em></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(6,4\ 10^{9})</td>
<td>(\approx 10^{10})</td>
<td>(&gt;10^{10})</td>
<td>(5,4\ 10^{9}\ (H17))</td>
</tr>
<tr>
<td>Moderator</td>
<td>LD(_2)</td>
<td>LD(_2)</td>
<td>LD(_2)</td>
<td>LD(_2)</td>
</tr>
<tr>
<td>Average Moderator Temperature, K</td>
<td>23</td>
<td>19,5-25</td>
<td>23</td>
<td>25/25</td>
</tr>
<tr>
<td>Moderator chamber volume, l</td>
<td>20</td>
<td>24</td>
<td>20</td>
<td>20/6</td>
</tr>
<tr>
<td>Total heat load, kW</td>
<td>4-5</td>
<td>6,5-7,1</td>
<td>7,8</td>
<td>6/3</td>
</tr>
<tr>
<td>CNS standby mode</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
<td>no</td>
</tr>
</tbody>
</table>
Cold Neutron Source for Channel HEC-3 of the reactor PIK

UCN source - parameters
Liquid deuterium - 25 L, $T = -250^\circ C$
The distance from the active zone of the reactor - 60 cm
The flux density of cold neutrons - $6 \times 10^{10} \text{ n cm}^{-2}\text{c}^{-1}$, which is 3-5 times higher than the same values of the CNS at high-flux reactors HFR at the ILL and OPAL at ANSTO.
Staff –
1. A.P. Bulkin - group leader, PNPI NRC KI
2. N.K. Pleshanov - PNPI NRC KI
3. P.I. Konik - PNPI NRC KI
4. V.A. Ulyanov - PNPI NRC KI
5. Yu.I. Gusev - PNPI NRC KI
Neutronguide system is the system of optical channel for neutron beam splitting, transportation and focusing. Main conception – optimization for the purpose of experimental station.

Two phases of the system creation

1-st phase is the neutronguide system of HEC-3 (5 channel)

2-nd phase is the neutronguide system of HEC-2 (5 channel)
Front view of the neutron guide system of the reactor PIK

Neutron guides of the first phase at HEC-3

Neutron guides of the second phase at HEC-2
Main direction of program realization:

Infrastructure of the experiments
- Cold and ultracold neutron sources
- Neutronguide complex
- Sample environments
- Neutron detection technology
- Computer information center

Experimental stations for condense matter physics (20 stations)
- Diffractometry complex
- Neutron spectroscopy
- Small angle neutron scattering
- Reflectometry

Experimental stations for nuclear physics and elementary particles physics (12 stations)
- Ultracold beam positions and experimental stations
- Neutrino experiment
- Cold neutron beam positions and experimental stations
- Nuclear spectroscopy
INTERNATIONAL COOPERATION

7 neutron stations (with the total cost of 30 mln. euro) were transferred from the Helmholtz Center Geesthacht (Germany) to the Petersburg Nuclear Physics Institute of NRC "Kurchatov Institute".

Placing of small-angle scattering spectrometer at the neutronguide hall of reactor PIK.
Neutron stations transferred to PNPI RNC KI from HZG (Geesthacht)

- **DC4** - polarized neutron diffractometer with a two-dimensional detector POLDI
- **DC6** - Texture diffractometer TEX
- **DC2** - Stress diffractometer ARES

According to the instrumentation program for PIK

The PNPI NRC KI stations which temporary are at ILL now

- **MT** - Installation for measurement of the neutron lifetime using a magnetic storage of ultracold neutrons
- **GT** - Large gravitational trap for measuring the neutron lifetime
- **EDM** - magnetic resonance spectrometer to measure the EDM using UCN

According to the instrumentation program for PIK

According to Project for Reconstruction of the Laboratory Complex PIK
Neutron stations transferred from the WWR-M
- **D2** - powder diffractometer of cold neutrons
- **R1** - polarized neutron reflectometer with a vertical plane of reflection REVERANS

Neutron stations transferred to PNPI RNC KI from HZG Geesthacht
- **DC5** - perfect crystal diffractometer DCD
- **S-4** - small-angle scattering setup of polarized neutron SANS-2
- **S-5** - small-angle scattering setup of polarized neutrons SANS-3
- **R4** - polarized neutron reflectometer with polarization analysis NERO
Instrumentation program at PIK reactor (second phase)

Hall of Horizontal Channels (8)

According to the instrumentation program for PIK

D1 - high resolution powder diffractometer of thermal neutrons
D3 - high flux diffractometer of thermal neutrons
DC1 - four circle diffractometer
IN1 - triple axis spectrometer of thermal neutrons
IN3 - triple axis spectrometer with full polarization analysis

According to the project of reconstruction of Laboratory Complex PIK

According to the instrumentation program

np-dy - Setup “neutron β-decay”
IRINA - Radioisotope IRIN facility for nuclear-laser investigations
n4 - Setup «Neutrino» (located in the under-reactor space)

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According to the instrumentation program for PIK

According to the project of reconstruction of Laboratory Complex PIK

**Neutron Guide Hall (9)**

- **IN2** - triple axis spectrometer of cold neutrons
- **IN4** - multifunctional Time-of-Flight (TOF) spectrometer
- **IN5** - Spin-Echo spectrometer
- **S1** - high resolution SANS diffractometer of polarized neutrons
- **S2** - SANS apparatus
- **S3** - Spin-Echo SANS (SE-SANS) facility
- **R2** - reflectometer for neutron optics
- **R3** - reflectometer with 3D polarization analysis
- **DEDM** - crystal-diffraction setup for neutron EDM search
Hall of Inclined Channels (3)

**NF2** - Correlation investigations in fission

**PBS** - Nuclear spectroscopy in the capture of thermal neutrons

**NA** - Neutron Activation Analysis.
Diffractometry complex workgroup

Staff –
1. A.I. Kurbakov – group leader, PNPI NRC KI
2. Y.P. Chernenkov - PNPI NRC KI
3. I.V. Golosovsky - PNPI NRC KI
4. I.A. Zobkalo - PNPI NRC KI
5. A.M. Balagurov - JINR, Dubna
6. V.T. Um – NRC KI, Moscow
7. V.B. Rybakov – MSU, Moscow

Group meetings:
• PNPI Workshop, "Neutron Diffraction" on February 21, 2014
• PNPI Winter School on March 11, 2014
• RNSI-KS-2014, Peterghoff, October 2014
Recommended diffractometers

1. **High resolution powder diffractometer of thermal neutrons** dedicated for the determination of atomic and magnetic structures in compounds, mostly inorganic, in polycrystalline form and with low unit cell dimensions;

2. **High resolution powder diffractometer of cold neutrons** with ability to resolve crystalline and magnetic structures in molecular crystals with large number of atoms in the unit cell, commensurate and incommensurate superstructures with long periods, etc;

3. **High flux diffractometer of thermal neutrons** for investigations of the atomic scale arrangement in micro-samples, and samples under extreme conditions, as well as of amorphous and liquid states;

4. **Four circle diffractometer of thermal neutrons** dedicated for detailed studies of complex magnetic and atomic structures in single crystals;

5. **Polarized neutron single crystal diffractometer with 2D detector** (in cooperation with HZ Geesthacht, Germany) probing e.g. spin density distributions;

6. **Texture diffractometer** (in cooperation with HZ Geesthacht, Germany);

7. **Residual stress diffractometer** (in cooperation with HZ Geesthacht, Germany).

Petersburg Nuclear Physics Institute of the NRC “Kurchatov Institute”

Mega-science projects, Dubna, 3-4-Dec. 2014
Neutron spectroscopy workgroup

Staff –
1. **P.A. Alekseev** – group leader, NRC KI, Moscow
2. E.S. Klementiev - INR, Troitsk
3. S.B. Vakhrushev - PTI, St. Petersburg
4. A.S. Ivanov - ILL, France
5. E.V. Moskvin - PNPI NRC KI
6. A.A. Podlesnyak - IMP, Ekaterinburg

Group meetings:
• PNPI Winter School on March 11, 2014
• PNPI Workshop on Inelastic Neutron Scattering, “Spectrina-2014" on June 20, 2014
• RNSI-KS-2014, Peterghoff, October 2014
Recommended inelastic scattering spectrometers

1. The triple axis spectrometer of thermal neutrons probing high energy branches of collective excitations spectrum in single crystals;

2. The triple axis spectrometer with full polarization analysis optimized for investigations of magnetic excitations in single crystals;

3. The triple axis spectrometer of cold neutrons probing low energy excitations in single crystals;

4. The multifunctional Time-of-Flight (TOF) spectrometer utilizing a broad band of incoming neutron energies is dedicated for detailed studies of atomic and molecular dynamics in solids and liquids;

5. The Spin-Echo spectrometer providing access to e.g. relaxation dynamics in soft matter over the time scale $10^{-12} – 10^{-8}$ s.
Small angle neutron scattering workgroup

Staff –
1. E.V. Moskvin – group leader, PNPI NRC KI
2. S.V. Grigoriev - PNPI NRC KI
3. M.V. Avdeev - JINR, Dubna (on agreement)
4. D.I. Lebedev - PNPI NRC KI

Group meetings:
• PNPI Workshop on small-angle neutron scattering "MURomets-2013" on September 20, 2013
• PNPI Workshop, "Polarized neutron physics" on December 21, 2013
• PNPI Winter School on March 11, 2014
• RNSI-KS-2014, Peterghoff, October 2014
Recommended SANS instruments

1. **The High resolution SANS diffractometer of polarized neutrons** for fundamental and applied research in the field of nano-magnetism and electrodynamics of superconductors;

2. **The High intensity SANS diffractometer** mostly dedicated for soft matter and biological problems, as well as to probe of small samples;

3. **The SANS machine** with extended range of wave vector transfer achieved with e.g. TOF option and the use of a high resolution position sensitive detector in the near forward direction along with bands of multidetectors recording larger scattering angles. Diffractometer is dedicated for investigations over exceptionally large range of scales required to the determination of multiscale structures, such as components of biological cells;

4. **The SANS apparatus** with an equipped pair of position sensitive detectors can simultaneous record two complementary scales of the wave vector transfer;

5. **The Ultra Small Angle Neutron Scattering (USANS) Double Crystal Diffractometer (DCD)** accessing physical information at exceptionally small wave vector transfer;

6. **The Spin-Echo SANS (SE-SANS)** facility probing extra-large structures up to a submillimeter scale in direct space. This facility may be applied to study e.g. Biological agglomerates and substances with dimensions comparable to live cells.
Reflectometry workgroup

Staff –
1. N.K. Pleshanov – group leader, PNPI NRC KI
2. V.I. Bodnarchuk - JINR, Dubna
3. A.A. Vorobyev - ILL, France
4. K. Zhernenkov - TU Bochum, Germany
5. A.I. Joffe - FZ Juelich, Germany
6. E.A. Kravtsov - IMP, Ekaterinburg
7. B.P. Toperverg - PNPI NRC KI

Group meetings:
• PNPI Workshop on small-angle neutron scattering "MURomets-2013" on September 20, 2013
• PNPI Workshop, "Polarized neutron physics" on December 21, 2013
• PNPI Winter School on March 11, 2014
• RNSI-KS-2014, Peterghoff, October 2014
Recommended reflectometers

1. The high resolution reflectometer with the horizontal plane of specular reflection (vertical orientation of reflecting surface) specialized for investigations of solid state thin films and multilayers e.g. with lateral microstructures. The machine operates in the angular dispersive mode with a constant, but variable wave length of incident neutrons, providing an extended range of the wave vector transfer;

2. The high luminosity reflectometer with the horizontal plane of specular reflection specialized for investigations of ultrathin, e.g. mono-molecular, layers;

3. The high luminosity reflectometer with the vertical plane of specular reflection (horizontal surface) probing liquid surfaces and interfaces, e.g. in native biological membranes, electrolytes, etc. This machine is supposed to operate in either the angular dispersive, or TOF mode.

4. The reflectometer for neutron optics operating in the angular and the wave length varied (TOF) modes.
Experimental stations for nuclear and elementary particles physics

The main direction

• Ultracold beam positions and experimental stations and neutrino experiment
• Experimental stations at cold and thermal neutron beam
• Nuclear spectroscopy
Workgroups

**UCNs and neutrino experiments**

**Staff** —
1. **A.P. Serebrov** – group leader, PNPI NRC KI
2. A.K. Fomin - PNPI NRC KI
3. E.A. Kolomenskii - PNPI NRC KI
4. V.A. Lyamkin - PNPI NRC KI
5. E.V. Lychagin - JINR, Dubna
6. V.I. Morozov – NRC KI
7. V.N. Shvetsov - JINR, Dubna

**Cold neutron beam experiments**

**Staff** —
1. **V.V. Fedorov** – group leader, PNPI NRC KI
2. F.S. Dzheparov – ITEP NRC KI, Moscow
3. I.A. Kuznetsov - PNPI NRC KI
4. A.N. Pirozhkov - PNPI NRC KI
5. A.S. Vorobyev - PNPI NRC KI

**Nuclear spectroscopy**

**Staff** —
1. **I.A. Mitropolskii** – group leader, PNPI NRC KI
2. V.N. Panteleev - PNPI NRC KI
3. V.G. Zinoviev – PNPI NRC KI

Mega-science projects, Dubna, 3-4-Dec. 2014
UCN beam positions at PIK reactor

Ultracold neutron source with superfluid He converter. 
The production rate of UCNs expected about \(100 \text{ cm}^{-3} \cdot \text{s}^{-1}\). 
The expected UCN density \(>10^3 \text{ cm}^{-3}\), that exceeds the available and planed density of the world UCN sources at one order of value.
Physics with UCN and neutrino

Recommendations is to equip three UCN beam positions for the experiments of first-priority

1. Neutron EDM search.
   *Goal* is to get the *best world accuracy* – up to $10^{-28}$ e cm.

2. Neutron life time experiments
   1. In large material trap
      *Goal* if to get accuracy $\sim 0.2$ s.
   2. Magnetic trap with well control of neutron loss.

4. Sterile neutrino experiment.
   *Goal* is to study the neutrino oscillation at (5-15) m with *best world accuracy* and solve the problem of deficit of reactor neutrino
1. **Beam position with cold neutron.** *(NG hall)*

**Goal** is to equip the beam position for the wide range experiments in nuclear physics and physics of elementary particles and to install the setup (Crystal-diffraction neutron EDM experiment).

2. **Polarized cold neutron beam position** *(hall of HEC)*

**Goal** is to equip the beam position with the world highest flux of polarized cold neutrons and install the setup for neutron decay asymmetry measurement with accuracy $10^{-3}$

3. **Thermal neutron beam position for nuclear fission physics** *(hall of IEC)* and install the setup for fission fragments study.
1. Mass separator laser-nuclear complex IRINA. *(hall of HEC)* (ISOL+ISOLTRAP)

**Goal** is to study the properties of nuclei with a large number of neutrons, the study shape the nuclei near the boundary of neutron stability.

Precision measurements of masses of nuclei far from the line of beta-stability.

**Production of high purity radioisotopes for nuclear medicine.**

2. Nuclear radiation spectrometer. *(hall of IEC)*

**Goal** is the measurement of emissions from neutron capture reaction cores for the study of nuclear structure.

3. Neutron activation analysis. *(hall of IEC)*

**INAA** - Instrumental Neutron Activation Analysis.

**NRA** - Neutron Radiation Analysis
Summary

Research neutron facility with unique opportunities will be created.

It will be equipped with

- Sources of cold and ultracold neutrons
- Systems of the neutronguide and neutroguide hall
- Sample environment systems
- Computing center
- **22 experimental station for condensed matter physics** and molecular biology
- **10 beam positions and experimental stations** for particle and nuclear physics

This concept is a step towards to the creation of a world-class neutron facility on the base of the RK PIC and its transformation into the **International Center for Neutron Research.**
Thank you for your attention