RUSSIA NEUTRON LANDSCAPE

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Petersburg Nuclear Physics Institute NRC KI (Gatchina)
Joint Institute for Nuclear Research (Dubna)

International Conference  Nucleus -2015, 30th June 2015, St.-Petersburg
Neutrons in Partical and Nuclear Physics (modern trends)
Neutrons and New Physics

Early Universe: $\tau_n$

Bargon asymmetry: EDM

Left-right symmetry: $(n, \alpha)$

Dark energy

Dark matter

UCN gravity resonance spectroscopy

Quantum mechanics
(Schrodinger and Cheshire cats)
Understanding of the nucleus

Nuclear Structure (nuclear models)
Probing exotic (n-rich) nucleus
Phase Transitions in nuclei

Fission Physics
Ducrnel Data

Astrophysics
(where do the heavy elements come from?)
red giant stars (s-process)
super nova (r-process)
New generation of neutron lifetime experiments

**Big Gravitrap**

Goal: to reach accuracy **0.2 sec** by the storage of neutron in material trap

\[ \tau_{\text{beam}} - \tau_{\text{ucn}} = 8.4(2.2) \text{s (3.8}\sigma) \]

**Magnetic trap**

Goal: to reach accuracy **0.2 sec** by magnetic storage of neutron

*A.P. Serebrov and A.K. Fomin, Physics Procedia 17 (2011) 199–205*
UCN magnetic storage and neutron lifetime PNPI-ILL

First trap of permanent magnets

2003

882 ± 16 s.

2003 - 2014

New trap of permanent magnets

2015 -

\( \tau_n = (878.3 \pm 1.9) \text{ s.} \)

(Submitted on 23rd of Dec 2014)

arXiv:1412.7434 [nucl-ex]

expected accuracy 0.2 s
Neutron electric dipole moment

<table>
<thead>
<tr>
<th>Year</th>
<th>Neutron EDM Experimental limit (e·cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1965</td>
<td>$10^{-28}$</td>
</tr>
<tr>
<td>1970</td>
<td>$10^{-27}$</td>
</tr>
<tr>
<td>1975</td>
<td>$10^{-26}$</td>
</tr>
<tr>
<td>1980</td>
<td>$10^{-25}$</td>
</tr>
<tr>
<td>1985</td>
<td>$10^{-24}$</td>
</tr>
<tr>
<td>1990</td>
<td>$10^{-23}$</td>
</tr>
<tr>
<td>1995</td>
<td>$10^{-22}$</td>
</tr>
<tr>
<td>2000</td>
<td>$10^{-21}$</td>
</tr>
<tr>
<td>2005</td>
<td>$10^{-20}$</td>
</tr>
<tr>
<td>2010</td>
<td>$10^{-19}$</td>
</tr>
<tr>
<td>2015</td>
<td>$10^{-18}$</td>
</tr>
<tr>
<td>2020</td>
<td>$10^{-17}$</td>
</tr>
</tbody>
</table>

$|d_n| < 5.5 \times 10^{-26} \text{ e·cm}$

PNPI NRC KI – ILL – Joffe Inst.

Present limit of RAL/Sussex

PNPI NRC KI (prediction)

UCN super source of PNPI NRC KI (prediction)

The study of the P-odd asymmetry in the alpha-particle emission in the reaction $^{10}\text{B}(n,\alpha)^{7}\text{Li}$

Yu.M. Gledenov$^{1}$, V.V. Nesvizhevsky$^{2}$, P.V. Sedyshev$^{1}$, E.V. Shulgina$^{3}$, P. Szalanski$^{4}$, V. A. Vesna$^{3}$

$^{1}$JINR, Dubna, Russia, $^{2}$ILL, Grenoble, France, $^{3}$NRC "KI" PNPI, Gatchina, Russia, $^{4}$LU Lodz, Poland

P-odd asymmetry in the reaction $^{6}\text{Li}(n,\alpha)^{3}\text{H}$ was measured at PF1b at the ILL reactor:

$$a_{\text{P-odd}} = (-8.8 \pm 2.1) \times 10^{-8}$$

Constrains for the neutral weak constant:

$$0 \leq f_{\pi} \leq 1.1 \times 10^{-7} \text{ (at 90\% confidence level)}$$

Goal: To reach the accuracy of P-odd asymmetry in the reaction $^{10}\text{B}(n,\alpha)^{7}\text{Li}$

$\sim 5 \times 10^{-8}$.

Beam time is approved for PF1b instrument cycle n° 176-177
**Experiment “NEUTRINO-4”**  \( \bar{\nu}_e + p \rightarrow e^+ + n \)

PNPI NRC KI (Gatchina), NRC KI (Moscow), NIIAR (Dimitrovgrad)

- **reactor PIK (Gatchina) – project**
- **reactor SM-3 (Dimitrovgrad)**

Laboratory for sterile neutrino. The distance for observations of reactor antineutrino oscillations is in the interval of 6–12 meters from the reactor core.

- Liquid scintillator detector 3 m³ + FEM 64 pcs.
- **Neutrino channel**
- **First measurements**
Neutron Sources in Russia
# Strategy Paper on Neutron Research of National Research Center “Kurchatov Institute” and Joint Institute for Nuclear Research

## Pulsed sources

<table>
<thead>
<tr>
<th>Source</th>
<th>Duration</th>
</tr>
</thead>
<tbody>
<tr>
<td>IBR-2 (JINR, Dubna)</td>
<td>2012 ÷ 2037</td>
</tr>
<tr>
<td>IREN (JINR, Dubna)</td>
<td>2010 ÷ 2045</td>
</tr>
<tr>
<td>GNEIS (NRC KI, Gatchina)</td>
<td>1973, life time?</td>
</tr>
<tr>
<td></td>
<td>proton synchrocyclotron, 1GeV, 1971</td>
</tr>
</tbody>
</table>

## Stady state

<table>
<thead>
<tr>
<th>Source</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>VVR-M (NRC KI, Gatchina)</td>
<td>shutdown mode, 2016</td>
</tr>
<tr>
<td>IR-8 (NRC KI, Moscow)</td>
<td>2007 ÷ 2017 upgrade</td>
</tr>
<tr>
<td>PIK (NRC KI, Gatchina)</td>
<td>2019 ÷ 2049</td>
</tr>
</tbody>
</table>
Modernized IBR-2 High Flux Pulsed Reactor (FLNP JINR)

Operational since 1984

2007-2010: modernization shutdown

2010 – 2011 Physical and power start-up completed

2012 – Regular operation renewed

By D.P. Kozlenko, FLNP, Dubna

Information: [http://flnp.jinr.ru/34/](http://flnp.jinr.ru/34/)

IBR-2M Spectrometers Complex

- Diffractometers:
  - HRFD, DN-12, FSD, SKAT/Epsilon

- Reflectometers:
  - REMUR, REFLEX

- Small Angle Scattering Spectrometer: YuMO

- Inelastic Neutron Scattering Spectrometers:
  - NERA-PR, DIN-2PI

- New Instruments:
  - DN-6. GRAINS, NRT

Reconstruction:

- DN-2 – RTD,
- REFLEX - SESANS

2011: 11 instruments in operation

2014: 14 instruments in operation
User Programme at IBR-2 instruments:

Two calls of proposals per year with deadlines 15 April and 15 October

Applications are collected via web-site http://ibr-2.jinr.ru

200 applications from 16 countries were received in 2014
IREN facility
(Intense REsonance Neutron source)

IREN planned parameters

- Pulse duration: 20-200 ns
- Peak current: 3 A
- Repetition rate: 150 Hz
- Average current: up to 50 rnA
- Electron energy: up to 200 MeV
- Beam power: up to 10 kW
- Target: $^{238}$U
- Integral neutron yield: up to $3.4 \times 10^{13}$ n/s

<table>
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<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>30</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>$10^n$</td>
</tr>
</tbody>
</table>
Fundamental

• Fundamental symmetries in neutron induced reactions
• Nuclear Data
• Nuclear fission
• Fundamental properties of the neutron
• Highly excited states of the nuclei

Applied

• Isotopes production
• Neutron activation analysis
• Nuclear in space
Nuclear data at IREN – first measurements with Gd\textsubscript{nat}


RPI Linac, neutron yield $10^{12}$/s

\begin{figure}
\centering
\includegraphics[width=\textwidth]{gadolinium.png}
\caption{Gadolinium isotopes and neutron yield at IREN.}
\end{figure}

V.N. Shvetsov et al. (2010)
IREN, neutron yield $10^{11}$/s

\begin{figure}
\centering
\includegraphics[width=\textwidth]{shvetsov.png}
\caption{Shvetsov's measurements at IREN.}
\end{figure}

\textbf{natGd (n, γ)}

- $^{152}$Gd - 0.20%
- $^{154}$Gd - 2.18%
- $^{155}$Gd - 14.80%
- $^{156}$Gd - 20.47%
- $^{157}$Gd - 15.65%
- $^{158}$Gd - 24.84%
- $^{160}$Gd - 21.86%

Sample:
- $m_g$ = 172.8 g
- Size: 11.2 x 14.5 cm\(^2\)
- $\rho$: 1.064039 g/cm\(^2\)
- $d$: 1.35 mm

**IREN, Dubna**

- $f$ = 25 Hz
- $I_e$ = 2A; $t_e$ = 100 ns
- $L$ = 58.6 m

- $dt$ = 100 ns
  - $t_{mes} = 14$ h 40 min
- $dt$ = 40 ns
  - $t_{mes} = 19$ h 00 min
Reactor Complex PIK
Central part of the reactor complex PIK
2011 a critical state of the fuel assembly was achieved and a complete test of the reactor systems was produced without coolant at $W = 100$ W
INVESTMENT PROJECTS PNPI NRC KI 2014-2020

Projects for the building of the research reactor complex PIK

- Modernization of engineering infrastructure of the reactor complex PIK (commissioning in 2018)
- Instrumentation program of the reactor complex PIK (commissioning in 2020)
- Reconstruction of laboratory complex PIK (commissioning in 2019)
Reconstruction of the Laboratory Complex PIK
Buildings of the reactor PIK reconstructed during the project
Reconstruction of the Laboratory Complex PIK

Buildings of the Laboratory Complex

Offices and Data Center
Bldg.105
Reconstruction of the Laboratory Complex PIK

**Computer Information System Tier-0**

of the reactor PIK (analog to CERN Data Centre)

- Creating computing power with a speed of about 100 teraflops for data processing and data storage.
- Creating a data collection system connected to the neutron experimental stations and if necessary convert them to an unified data storage format.
- Creation and development of the information infrastructure to provide a mechanism of interaction between participants of the research process.
Reconstruction of the Laboratory Complex PIK

Cold Neutron Source for Channel HEC-3 of the reactor PIK

Project of CNS
Channel HEC-3
of reactor PIK

UCN source - parameters
Liquid deuterium - 25 L, T = -250° C
The distance from the active zone of the reactor - 60cm
The flux density of cold neutrons - $6 \times 10^{10} \text{ cm}^{-2} \text{ s}^{-1}$, 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.

Experience of PNPI NRC KI
Installation of CNS produced for reactor OPAL - Australia

Cold neutron source just before setting to the reactor

(1) The reactor vessel
(2) Heavy water reflector tank
(3) Support tube for CNS
(4) Protection
(5) Steel cladding of light water pool
(6) Biological protection of the reactor
(7) Channel HEC-3
(8) Vacuumcontainer
(9) Thermosiphon
Neutron stations transferred to NRC KI PNPI from HZG (Geesthacht)

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

Hall of Horizontal Channels

According to Project for Reconstruction of the Laboratory Complex PIK

Neutron stations transferred from the reactor ILL
- 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
Ultra Cold Neutron Source on HEC-2

Schematic view of the idea of the helium ultra cold neutron source on thermal neutron source

E.V. Lychagin, A.Yu. Muzychka, G.V. Nekhaev, E.I. Sharapov, A.V. Strelkov (JINR, Dubna), V.V. Nesvizhevsky (ILL, Grenoble)

Placement option for ultra cold neutron source on extracted channel of thermal neutrons of the reactor PIK
According to the Project for Reconstruction of the Laboratory Complex PIK

Neutron Guide Hall

According to the instrumentation program for 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 NRC KI PNPI 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
Instrument Status:

- First containers with instruments have been unpacked
- Inventory of instrument components
- Test of instrument components
- Reconstruction started
Hall of Inclined Channels (3)

- **NA** - Neutron Activation Analysis.
- **PBS** - Nuclear spectroscopy in the capture of thermal neutrons
- **NF2** - Correlation investigations in fission
The project aiming to equip RC PIK with the modern experimental stations for the multidisciplinary research will be started and completed within the period between 2015 and 2020.

The Government of the Russian Federation has approved the idea to organize the International Center for Neutron Research based on the reactor complex PIK.
National Research Centre “Kurchatov Institute”
B.P. Konstantinov Petersburg Nuclear Physics Institute

Reactor Complex PIK

Science editors:
V. L. Aksenov
M. V. Kovalchuk

Volume 1 Concept of the investment project “Modernization of engineering technical systems supporting the operation of the PIK Reactor and the operation of its research stations”

Volume 2 Scientific Case Complex of experimental stations at the PIK Reactor

Volume 3 Concept of the investment project “Reconstruction of the laboratory facilities at the Reactor Complex PIK”

Volume 4 Concept of the investment project “Instrumentation base of the Reactor Complex PIK”

Gatchina 2014
Education:

Physics Faculty in St. Petersburg State University

The dean:
Prof. M.V. Kovalchuk

Plans: Construction of the synchrotron radiation facility in Gatchina at about 1 km away from the reactor PIK
Welcome to Gatchina