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B.P. KONSTANTINOV,
academician of Academy of Sciences of the USSR

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Corresponding Member of the Russian Academy of Sciences, PNPI Director

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Petersburg Nuclear Physics Institute named after B.P. Konstantinov (PNPI) was established in 1956 at the incentive of future academician Boris Konstantinov as a brunch of Leningrad Physical Technical Institute named after A.I. Ioffe. In 1971 it became an independent organization named after its founder.

View of PNPI building complex

PNPI is a multi-purpose institute. Its main objective is to carry out basic and applied researches using irradiation, nuclear materials and nuclear techniques to obtain new knowledge about structure and fundamental properties of the matter. The Institute is located near Gatchina, Leningrad region.

The Institute involves four scientific divisions:

- Division of High-Energy Physics,
- Division of Neutron Research,
- Division of Theoretical Physics,
- Division of Molecular and Radiation Biophysics.

The main scientific activities of the Institute are as follows:

- elementary particle physics and fundamental interaction physics ;
- nuclei physics and nuclear reaction physics;
- nanostructure and condensed matter physics;
- physics and engineering of nuclear reactors and accelerators;
- molecular and radiological biophysics, nanobiotechnologies;
- molecular and cell biology, genetics;
- information technologies and computer-aided science research;
- use of nuclear physical analysis methods in nanotechnologies and applied fields including health care.

By the Decree of the RF Government No. 2125-r dt 30.12.2009 such Institute's unique nuclear physical facilities as VVR-M and PIK research reactor complexes, STs-1000 research accelerator, c-230 synchrotron, Ts-80 cyclotron were declared to be necessary for the activities carried out by National Research Centre "Kurchatov Institute", which acts as a founder of PNPI on behalf of the RF.

Prospects for the development of the Institute are primarily connected with the completion of construction and commissioning of PIK facility, which is 100 MW high flux research reactor. The reactor design is fit for simultaneous neutron irradiation research in various scientific areas including basic and applied tasks in nuclear physics, condensed matter physics, biology and other natural sciences.

S.M. SMOLSKY,
Dy Director of reactor facilities

The Institute has 3 nuclear research facilities. VVR-M reactor and "PIK physical model" critical test bench are now in operation. PIK research reactor is under construction at the moment. In 2010, to reach first criticality and operate the first commissioned facilities Rostechnadzor's permission was

K.A. KONOPLEV,
associate member of Academy of Engineering of the RF
Scientific supervisor of Institute's reactor facilities

obtained to operate PIK reactor as part of the first commissioned facilities.

After the final commissioning of PIK reactor and installation of scientific equipment, part of which has already been used at VVR-M reactor and other Institutes' facilities, PIK research complex will be one of the largest in Europe.

PNPI has necessary power facilities generating heat, hot and cold water. They include workshop for fabricating test and production equipment, transport department, decontamination shop and radiation safety department.

Institute's services for irradiating materials in VVR-M reactor are used by V.G. Khlopin Radium Institute and Central Research Institute of Structural Materials "Prometey", which have some of their production buildings located at the site of the Institute.

Institute's nuclear research facilities

Nuclear research facility type	Name of nuclear research facility	Year of first criticality	State
Research reactor	VVR-M	1959	In operation
Research reactor	PIK	2011	Under construction
Critical facility	PIK physical model	1983	In operation

VVR-M RESEARCH REACTOR

VVR-M reactor reached first criticality on December 29, 1959, and was first commissioned in July, 1960.

Due to the researchers' new demands a number of changes in the reactor design were made during designing, construction and first few years of operation.

The following changes can be considered as the most significant:

– metallic beryllium was used as core reflector;

– a cavity was designed and installed above the reactor. It provided access to irradiation objects and made it possible to house various devices in the reactor core and to remove measuring and process lines outside the core;

– small size servo drives were designed. They were directly installed on CPS channels with control rods. It made the core as high as flexible to house experimental devices;

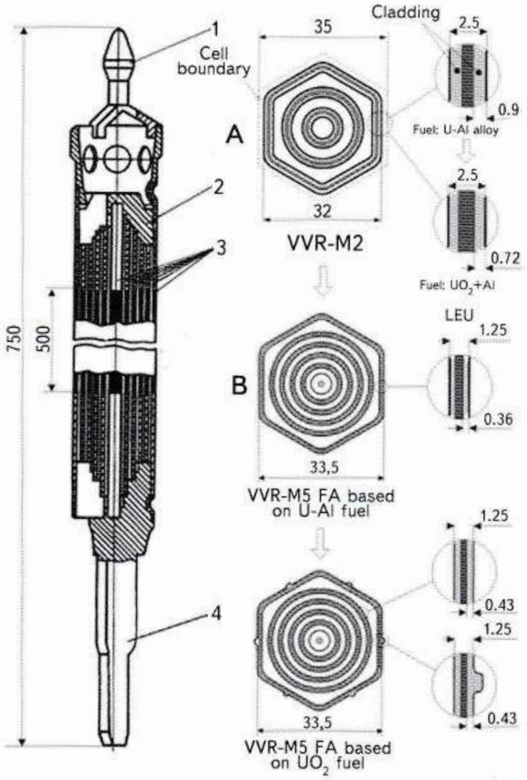
– 7 additional horizontal channels were constructed in the concrete shielding of the reactor in the area of thermal column niche;

– hexagonal-shaped FA with tubular fuel elements was designed. It served as a basis for designing VVR-M5 FA, which was one of the best FAs developed for research reactors, after a number of modifications. A new FA made it possible to increase reactor power up to 18 MW and to double the number of core cells allotted for tests. They have been used in VVR-M reactor since 1980.

VVR-M main hall

VVR-M5 FA showed the possibility of operation at the specific power of up to 900 kW/l. Quality of new FAs was studied in water loop at the development stage.

FAs of the same type are used at other reactors as well. VVR-M2 FA with 19.75 %-enriched fuel and fuel pin-based FAs, which were designed to supply fuel abroad, were successfully tested in VVR-M reactor.



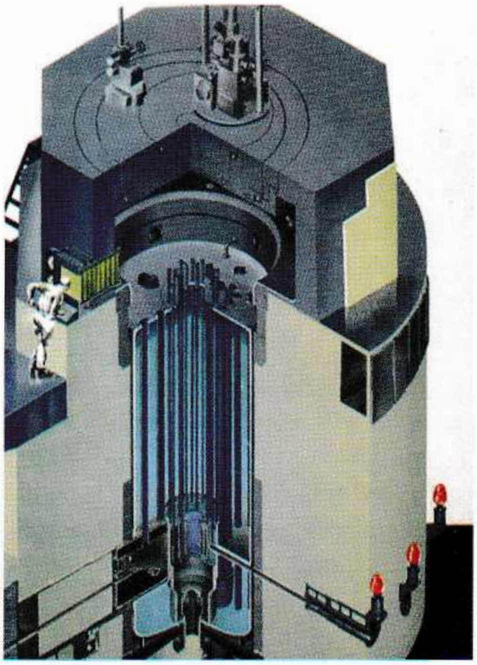
VVR-M FA:
1 – head; 2 – collar; 3 – fuel elements; 4 – mount

Relatively low pitch of FA (35 mm) makes it possible to develop complex core loading arrangements fit for housing large in-core devices.

Reactor is in operation all day round. As a rule, operation cycle lasts 1-2 weeks as per test and irradiation programs. The reactor is shut down for preventive maintenance for up to 3 months depending on the scope of works on reactor system examination, equipment repair or other scheduled activities.

VVR-M main performance

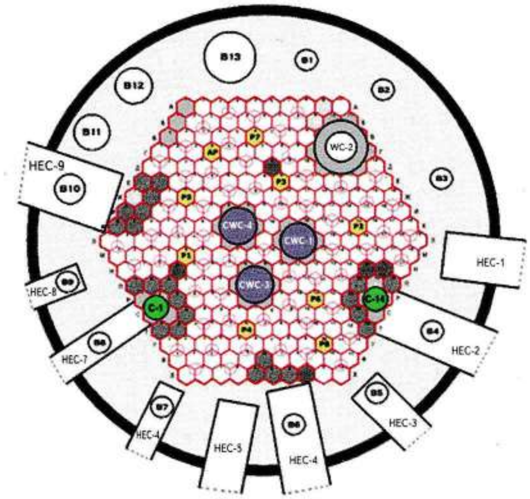
Power .... 18 MW
Moderator .... Water
Coolant .... Water
Reflector .... Beryllium
Maximum thermal neutron flux .... $4.5 \cdot 10^{14}$ $cm^{-2} \cdot s^{-1}$
Number of horizontal channels 17
Number of vertical channels in the reflector 13
Operating time per year .... 3,500 h
Power generation throughout lifetime .... 94,800 MW·days
Operating personnel .... 80 persons



3D-model of VVR-M reactor

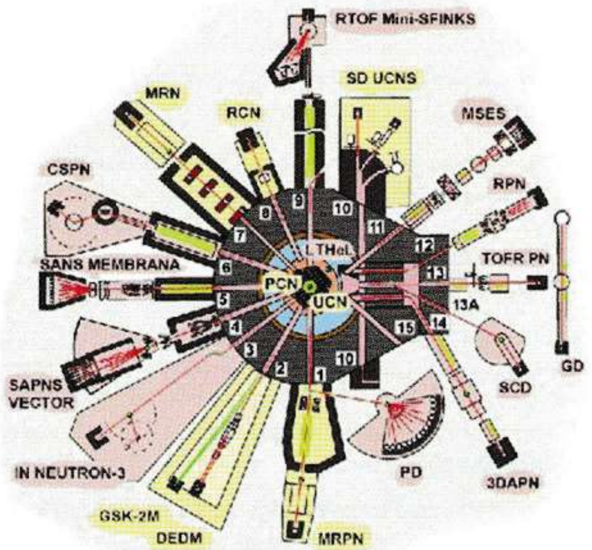
Main parameters of VVR-M FA

Parameter	Type of FA	
	VVR-M2	VVR-M5
Cell square, cm^2	10.609	10.609
FA active length, cm	50	50
Cladding thickness, mm	0.9	0.43
Fuel thickness, mm	0.9	0.39
Volume segment filled with water	0.542	0.571
Enrichment, %	36	90
Fuel tube thickness, mm	2.5	1.25
Heat exchange surface per unit of active part volume, $cm^2 \cdot cm^{-3}$	3.55	6.6
Concentration ^{235}U, g/l	62.4	125

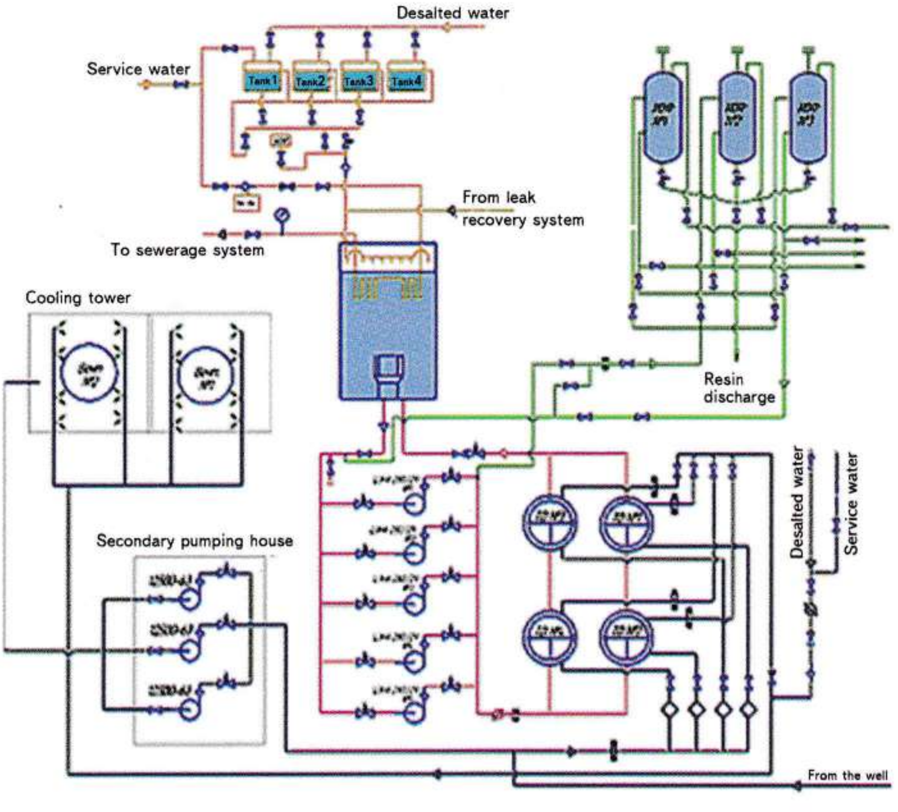


Reactor core map:

- *Serial single FAs*
- *Serial triple FAs*
- *Control rods*
- *Beryllium displacers*
- *Lead displacers*
- *Irradiation ampoules in the reactor core*
- *12-cell water cavity to irradiate experimental devices*
- *7-cell central water cavities*
- *4-cell water cavities (Mo channels)*



Location of exterimental channels and scientific instruments at VVR-M reactor



Legend:

- *Pressure sensor*
- *Gate valve*
- *Electrically-driven gate valve*
- *Back valve*
- *Orifice meter*
- *Pressure gauge*
- *Mechanical filter*
- *Control throttle*

VVR-M core cooling scheme

Test facilities

Facilities for studying condensed matter physics

- ***48-counter powder diffractometer for structural studies (channel 1)***

- ***Triaxial neutron spectrometer with doubled monochromator "Neutron-3" (channel 3)***

- ***"Vector" small-angle diffractometer (channel 4)***

- ***"Membrana-2" small-angle diffractometer (channel 5)***

- ***Polarized neutron diffractometer (channel 6)***

- ***Superpositional multi-section powder diffractometer (channel 9)***

- ***Thermal neutron spin-echo spectrometer (channel 11)***

The facility is being developed, adjusted and tested, so that it could be used at PIK reactor in future, where neutron beam flux will be sufficient for fine measurements of molecular compound dynamic behaviour.

- ***Reflectometer with vertical dispersion (channel 12)***

The facility is designed for studying colloid near-surface layers, gels and interphase boundaries. The facility is being commissioned and will be used at PIK reactor.

- ***RPN-2M double-mode polarized neutron reflectometer (channel 13)***

- ***Four-circle diffractometer for studying magnetic and crystalline structure (channel 13A)***

- ***Polarized neutron small angle diffractometer with 3-D polarization analyzer (channel 14)***

- ***Low-temperature helium loop (LTHL)***

- ***Two Coshua crystal diffraction spectrometers*** are used for studying electronic structure of chemical bonds of rare earths and transuranic elements in complex compounds and nanopores by shifting X-ray lines chemically.

- ***Johann crystal diffraction spectrometer*** is used for studying electronic structure of light metal bounds (e.g. Mn, Co, Fe, etc.) in materials with specific physical properties (manganites, cobaltites, ferrites, multiferroics, etc.) including configurations with limited geometry.

Facilities for conducting research in nuclear and elementary-particle physics

- ***A set of devices for studying fundamental phenomena***, which accompany nuclear matter scission (channels 1, 6). The device has lately been used for the pioneer studies of triple T-odd correlative correspondence between yields of charged light particles and neutrons in the course of uranium isotopes bombardment with polarized cold neutrons.

- ***DEDM crystal diffraction facility*** *(channel 2)*, where neutron spin rotation due to neutron interaction between a neutron and interplanar electric field of ~10^8 V/cm has been detected while the neutron goes through silica crystal. It allowed a new method of neutron electric dipole moment search (neutron EDM search) to be developed. This method is based on neutron diffraction in the crystal without central symmetry.

- ***A complex of facilities for neutron activation and neutron irradiation analyses (channel 8)*** makes it possible to identify both element and isotopic compositions of various objects. Their sensitivity allows nanogram quantities of elements to be detected.

Due to long reactor life an on-going program of maintenance of reactor equipment and systems by replacing worn-out and out-of-date equipment as well as by establishing inspection deadlines and allowable lifetimes is carried out. VVR-M reactor is under author's supervision by NIKIET and is now a steady operating nuclear facility. The Institute has all required licenses and permissions for reactor operation.

Structural material samples to be used for objects of atomic energy use, molybdenum targets for ^{99m}Tc generator and ^{124}Xe targets for producing ^{125}I are irradiated in vertical channels and in the reactor core. Vertical channels and the core are also used to modify topaz minerals and carry out other application works. There are examined 6-7 thou patients a year in St.-Petersbourg using ^{99m}Tc, but the demands for such examination are higher than the capabilities of the reactor. Prototype FAs for research reactors are tested in the core and in the reactor circuit.

The reactor has the unique instrumentation and test facilities to conduct in-core tests including low-temperature helium loop.

Universal cold and ultra-cold neutron source provided ultra-cold neutron flux of just twice as less as that obtained at Institute of Laue and Langevin (ILL), and polarized cold neutron flux is even higher than that obtained at ILL despite the significant difference in initial neutron fluxes. It made it possible to obtain excellent results in measuring neutron EDM, lifetime and correlation constants of decay.

The experience accumulated in developing such sources is actively used by many countries. Reactors in Hungary, Australia, China and other countries are equipped with such sources produced in PNPI.

T-odd asymmetry of escape of prompt fission neutrons generated by bombarding ^{235}U and ^{233}U with cross-polarized slow neutrons ($\lambda \approx 1.5$ Å) has been measured.

Gigantic electric fields (of up to $2 \cdot 10^8$ V/cm) affecting neutron in noncentrosymmetric crystal as well as related effects of neutron depolarization and spin rotation during movement and diffraction in such crystals have been predicted and detected. This makes it possible to use new methods of neutron EDM search.

Critical chirality index have been measured for a range of antiferromagnets. Existence of chiral universality classes has been proved, and a new universality subclass which requires theoretical basis of its existence has been detected.

New methods of nuclear spectroscopy as well as neutron activation and neutron irradiation studies of material composition have been developed.

In RBaCo$_2$O$_{5.5}$ cobaltites with colossal magneto-resistance which show metal-dielectric phase change, crystalline and magnetic symmetry has accurately been identified in all magnetic-ordered phases for the first time ever. This symmetry differs from conventional symmetry and eliminates conflicts of numerous experimental results.

Study of fundamental neutron properties and fundamental symmetries in neutron reactions (measurements of life time, EDM, correlation constants, circular irradiation polarization rate, etc.) makes it possible to study both elementary particle structure and their interaction properties. In addition, they allow a range of questions concerning structure of the Universe and new physics beyond Standard theory to be answered.

Study of new spin phenomena during neutron propagation in noncentrosymmetrical crystals leads to the development of new methods for investigating fundamental interaction symmetries.

Four-wave quantum neutron interferometer has been designed. It provides new possibilities in investigating properties both of neutron itself and substance.

Neutron studies of $Zn_{1-x}Cu_xO$-based catalysts used in commercial production of methyl hydroxide have been conducted, and new data on its structure have been obtained. These data are of great importance for identifying catalyst action mechanism.

Composition, morphology, structure and consistency of metallofulerenes, which are broadly used in practice, are studied.

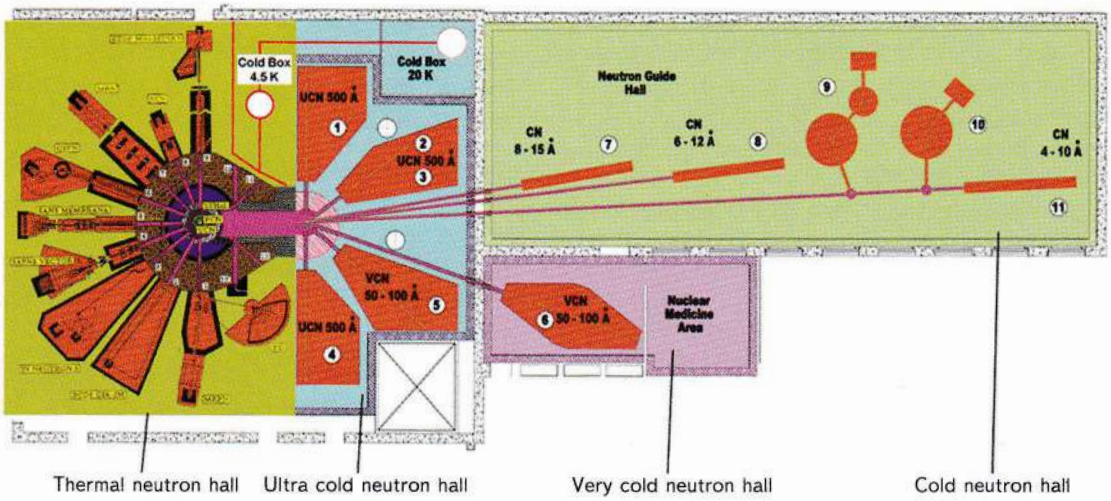
Under the agreement with IAEA the large oil samples are studied using neutron activation analysis.

Main activities on research program "Neutron Studies of Substance Structure and Fundamental Properties of Matter" of Physical Science Division of Academy of Sciences of the RF are carried out at VVR-M reactor.

Project of ultra-cold neutron supersource at VVR-M reactor

Equipping of VVR-M reactor with cold and ultra cold neutron sources as well neutron guide hall has been started. It will allow test capabilities to be significantly enhanced due to enlargement of spectrum of used facilities as well as to provision of low-background neutrons.

Ultra-cold neutron supersource at VVR-M reactor is designed for obtaining high ultra cold neutron density of up to $2 \cdot 10^3$ cm^{-3}. It is a factor of 100 as much as flux at ILL's best high-flux reactor. Such result is acheved due to the use of unique source based on superfluid helium at temperature of 1.2 K. Such source requires special conditions with very low heat generation. Such conditions can be created in the heat column of VVR-M reactor. After development of high-flux cold neutron source Russia will take the priority in cold neutron studies which were started in Russia (Dubna, Gatchina, Moscow) in 1960-1970s.



VVR-M test facilities after reconstruction (in prospect)

Main areas of studies

The research in the following fields is carried out at the reactor:

- nuclear physics,
- elementary particle physics,
- condensed matter physics,
- radiation material science,
- radiobiology,
- other related fields.

The reactor is also used to produce radionuclides for medical and industrial purposes.

International cooperation

The reactor is used for joint research conducted under the agreements between PNPI and ILL, Academy of Sciences of the RF and Hungarian Academy of Sciences, as well as with IAEA, etc.

Main activities

Reactor utilization factor was 0.36 in 2011.

Complex examination of electrical equipment, VVR-M building structures and reactor CPS was carried out.

PNPI operator's decision on extension of VVR-M life till the end of 2015 was made and approved. The decision was agreed with Rosatom State Corporation.

All reactor emergency exit coatings were replaced with state-of-art coatings which met fire safety requirements.

As a prospect for the development of Institute's test facilities, a possibility of developing cold and ultra cold neutron supersource and equipping VVR-M reactor with neutron guide hall is considered.

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PIK RESEARCH REACTOR

PIK research reactor is a stationary reactor. It is designed for physical research using extracted neutron beams.

PIK reactor was designed by NIKIET under scientific supervision of PNPI.

As for physical characteristics it is cooled with light water and has heavy water reflector. In terms of design, it is a tank reactor housed in a water pool. Concept of reactor with a compact core and large volume of reflector contributes to convenient location of dedicated hot, cold and ultra cold neutron sources. It is possible to use neutrons with specified spectrum in the wide range of energies (from fission neutrons to ultra cold neutrons) in the experiments.

Experiments using extracted neutron beams are mostly carried out with low-energy neutrons. Location of tangential channels and use of neutron guides provide extremely low fast neutron and gamma-radiation background during experiments. Use of extensive network of neutron guides ensures simultaneous work of up to 50 groups of researchers.

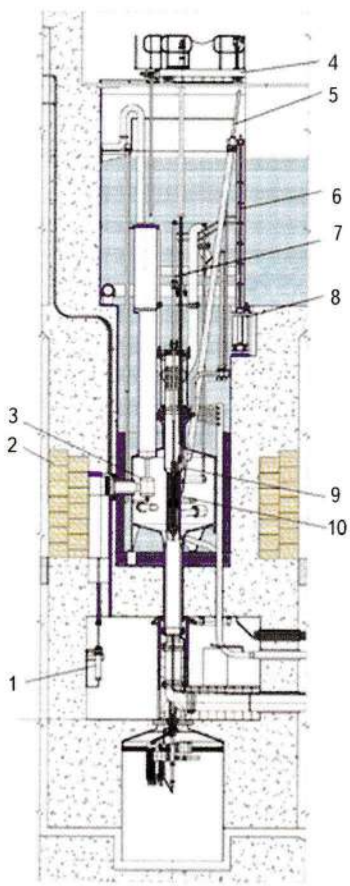
Unlike analogous foreign projects the reactor core can still be used for conventional in-pile material tests. It is mainly due to the use of SM-type small cruciform fuel pins which provide high power density in the core together with the possibility of manufacturing FAs with changed composition and additional cavities for material irradiation.

Light water trap was formed, and central experimental channel equipped with self-contained circuit and safety systems required for testing nuclear engineering materials was installed in the core. Thermal neutron flux is consistent with the highest values obtained in trap-type reactors (SM and HFIR).

In 1994 reactor reconstruction was completed, thereafter structural buildings of production hall were strengthened, and decisions made on radioactive material confining system and radioactive ventilation control system at beyond design-basis accidents were revised.

In revising the design the main control member system, which was absorber screens driven by the same drive, was divided into two independent

PIK reactor complex buildings



PIK reactor section:
1 – drive of horizontal experimental channel shutter; 2 – removable shielding; 3 – cold neutron source; 4 – fuel handling machine; 5 – rod drive; 6 – hydraulic lock; 7 – central experimental channel; 8 – reloading drum; 9 – absorber rod; 10 – vessel with the core

CPS control members with separate drives, and Eu_2O_3-based screen absorbers were replaced with more reliable elements made of metal hafnium at the same time.

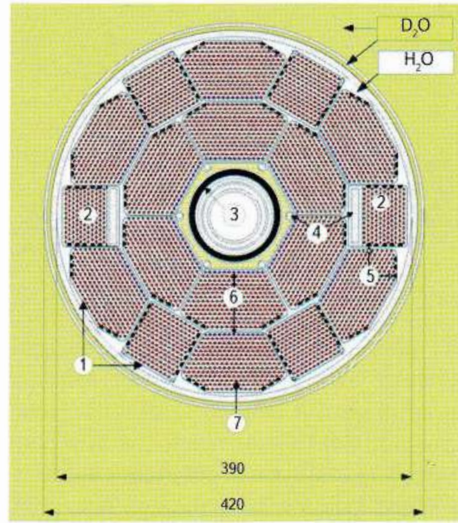
Conversion to new CPS developed on the basis of new elements was performed. Gd-based burnable poison rods for FAs were designed and tested in VVR-M reactor. They make it possible to increase reactor cycle from 15 to 30 days without changing the rest of the reactor equipment. FA version was developed which housed cavities for irradiation of surveillance samples of vessel material.

Designated reactor equipment life is 30 years. Removable units, such as vessel with the core, almost all experimental channels, core and support grid can be replaced during reactor operation.

Core vessel life is specified by fast neutron fluence, it should be clarified on the results of surveillance sample tests with taking into account operation cycling. Location of surveillance samples during irradiation provides predictive value of neutron fluence.

Initial vessel life was conservatively specified as 3 years. Based on mechanical properties of steel, which were obtained in surveillance sample tests, life can be extended up to 10 years.

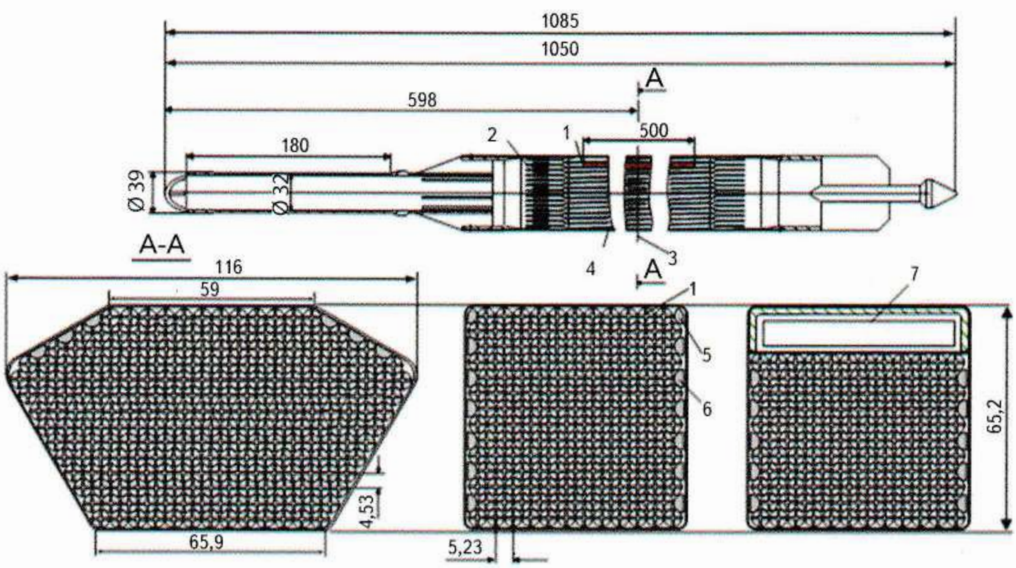
In future it is possible to develop removable vessel and modified fuel elements using low absorbing structural materials which will allow neutron flux in the reflector to be increased by 1.5 without changing the whole reactor equipment and increasing in reactor power. At the same time, the capabilities of in-core irradiation of materials are enhanced and HEU consumption is reduced.



PIK core map
1 – zirconium FA shroud; 2 – FAs with surveillance samples of vessel material; 3 – Hf absorber screens; 4 – irradiated samples; 5 – Gd_2O_3+ZrO_2 burnable poison rods; 6 – fuel elements with low fuel content (0.48 of rated value); 7– fuel elements with rated fuel content

Fuel characteristics

FAs with irregular hexagon-shaped or square-shaped cross-section are used. FA uses cruciform dispersion fuel elements installed



FA for PIK reactor:
1 – fuel element; 2 – spacer cases; 3 – fuel centerline; 4 – FA shroud (E-125 or E-110); 5 – angle displacer; 6 – burnable poison rod; 7 – ampoule with surveillance samples

as per triangular lattice with pitch of 5.23 mm. Fuel claddings are made of stainless steel. As fuel 90%-enriched uranium dioxide dispersed in Cu-Be matrix is used. Active length of modified fuel elements used at PIK reactor is 500 mm. Maximum total number of fuel elements in the core is 3858. Maximum mass of loaded ^{235}U is up to 27.5 kg.

Fuel profiling provided by decrease in fuel content in the fuel row next to the neutron trap is the salient feature of the core design. Fuel profiling reduces volumetric power density from 5.5 to 3.3, and to less than 3.0 during partial reloading of fuel elements with shuffling of FA from the vessel to the neutron trap.

A cavity for housing surveillance samples in the flat ampoule is designed in one of square-shaped FA modifications. It was done due to removal of 3 rows of fuel pins.

FA operation set includes Gd-based burnable poison rods which have semicylinder cross-section and are installed instead of internal displacers.

FAs with burnable poison rods make it possible to use various fuel reload schemes (including whole core replacement) and to change campaign from 15 to 30 days.

Systems for heat removal from FAs and test facilities

The reactor has 3-circuit cooling system. Gauge pressure in the intermediate circuit is lower than that in the primary circuit, and pressure in water recycling circuit is higher than that in the intermediate circuit. So, primary coolant can't be released to the environment. Heat produced by the reactor is transferred to the atmosphere through cooling towers.

Primary circuit is designed for transferring heat from the core to the intermediate circuit as well as for confining radioactive medium. Primary coolant goes through FA downward.

Core vessel has forced cooling from 2 sides. H_2O is coolant on core side, and D_2O is coolant on the reflector side. Independent circuit provides D_2O circulation in the space between vessel shells. Use of D_2O instead of H_2O for external cooling of the vessel provides negative reactivity coefficient in case of LOCA and increases reactor operation safety.

Heat is removed from test facilities and channels housed in heavy-water reflector by heavy water reflector cooling circuit.

Main technical characteristics of PIK reactor

Maximum thermal power	100 MW
Maximum thermal neutron flux	$4.6 \cdot 10^{15}$ cm^{-2}s^{-1}
Maximum thermal neutron flux in the reflector	$1.3 \cdot 10^{15}$ cm$^{-2} \cdot$s^{-1}
Volumetric power density in the core:	
mean	2.0 MW/l
maximum	6.6 MW/l
Coolant:	Water
pressure at the core inlet	5.0 MPa
temperature at the reactor inlet	50 °C
temperature at the reactor outlet	86°C
Coolant flow rate	2,400 m^3/h
Campaign	Up to 30 days
Number of horizontal experimental channels	10
Number of inclined experimental channels	6
Number of vertical experimental channels	6
Number of cold neutron sources	2
Number of hot neutron sources	1
Number of neutron guides	9

To design biological shielding, provide safe maintenance and under-water reloading, enhance reactor safety and limit emergency radioactive release the reactor core and heavy-water coolant tank are submerged into a pool filled with water (reactor vault). Cooling is provided by the circuit which cools iron-water shielding.

Reactor is equipped with emergency cooling system and emergency cooldown system.

Central experimental channel cooling circuit is designed for cooling the cannel with irradiation samples both at normal and emergency conditions of the circuit and PIK reactor operation. Central experimental channel design makes it possible to irradiate objects in two modes:

– at water pressure of up to 5 MPa. This mode is mostly designed for irradiating fissile materials;

– without pressure, with top plug removed from the channel. In this case a part of reactor vault which is filled with water is a pressurizer, and emergency cooling system and pressurizer of central experimental channel should be disconnected.

Internal devices are cooled in some experimental channels by autonomous helium loops.

Hot neutron source capsule with high-temperature graphite block is cooled by reflector water. Heat is transferred through graphite felt layer and walls of hot neutron source capsule. Temperature of the block can be controlled by replacing helium with another gas.

Cold and ultra cold neutron sources are cooled by appropriate cryogenic equipment. Liquid deuterium, liquid hydrogen or their mixtures are low-temperature moderators used to obtain the required neutron spectrum.

Experimental capabilities

PIK reactor is being built for a wide range of users from academician circles, which know the methods of neutron studies and have appropriate expertise in equipment and hardware use. Not only achievements and discoveries in various natural sciences but handling of applied problems are resulted from the development of neutron and nuclear physical techniques and their use in studying substances.

Main test facilities to be housed in the reactor core and reflector

Central experimental channel

Maximum heat generation is up to 400 kW. Undisturbed thermal neutron flux in the channel (E≤0.625 eV) is up to $4.6 \cdot 10^{15}$ $cm^{-2} \cdot s^{-1}$.

Fast neutron flux is up to $6 \cdot 10^{14}$ $cm^{-2} \cdot s^{-1}$.

FA for in-core irradiation of materials

Mass of stainless steel samples loaded into the cavity is ~1.4 kg. Fast neutron flux (E≥1.2 MeV) is up to $8 \cdot 10^{14}$ $cm^{-2} \cdot s^{-1}$.

Number of FAs – 2.

Hot neutron source

The facility is designed for conducting research where hard neutron spectrum is used. It is high-temperature graphite neutron scatterer. Neutrons for physical experiments are withdrawn through horizontal experimental channel 8.

Neutron spectrum shift in heavy-water reflector increases neutron flux in the of energy range from 0.1 to 1.0 eV. Wave length at spectrum maximum is λ ≈ 0.5 Å. For condensed matter dynamic studies it offers an advantage in researching intrinsic oscillations of molecules, optical phonons and magnons, Stoner excitations and excitons; for structural studies – in measuring minimum atomic radius size.

Cold and ultra cold neutron source housed in the vertical channel

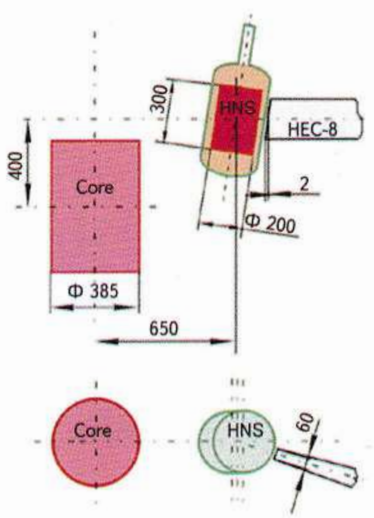
It is designed for producing neutrons with energies of less than 10^{-2} eV, λ= (1…15) Å.

Source working chamber has sealed funnel, 100×190×200 mm, positioned strictly on the center of horizontal experimental channel 3.

Deuterium volume	25 l
Thermal neutron flux in the chamber	$2.3 \cdot 10^{14}$ $cm^{-2} \cdot s^{-1}$
Fast neuron flux	$0.8 \cdot 10^{11}$ $cm^{-2} \cdot s^{-1}$
Total heat generation	6 kW
Heat generation in liquid deuterium	2.7 kW
Heat generation in structural materials	3.3 kW
Distance from the core centre	780 mm
Operating pressure	0.15 MPa
Pressure in warm conditions	0.3 MPa

Polarized cold and ultra cold neutron source in horizontal experimental channel 4-4'

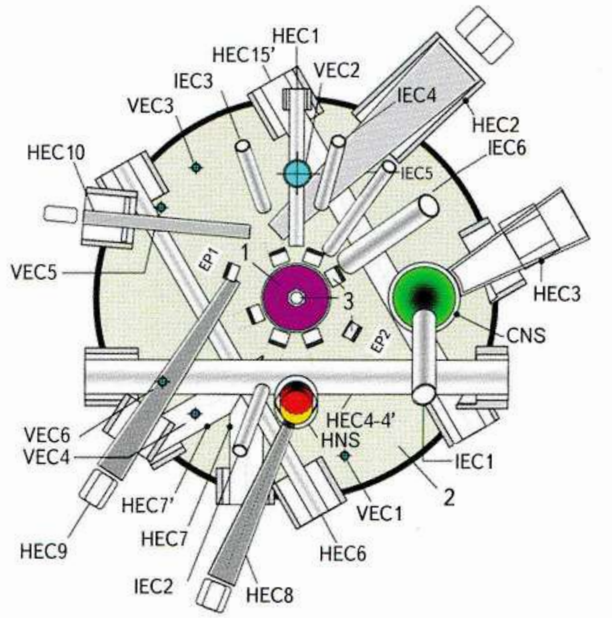
The source is designed for producing cold and ultra cold neutrons. Position of the source in the horizontal experimental channel 4-4' will



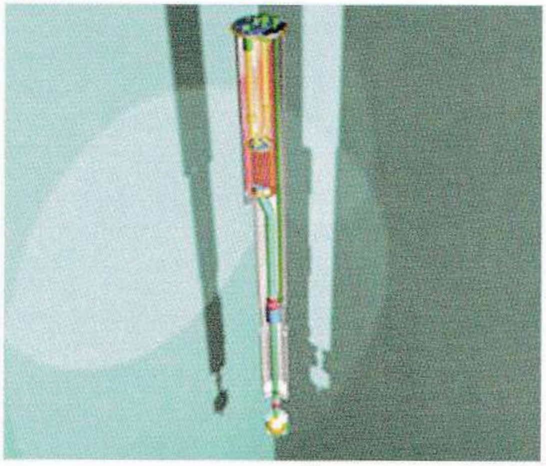
Location of hot neutron source capsule with respect to the core

Hot neutron source capsule

make it possible to withdraw ultra cold neutrons through the neutron guide in the channel in one direction and polarized cold neutrons through polarizing neutron guide in the other direction. It is possible to use moderators based on liquid hydrogen, deuterium or their mixture.

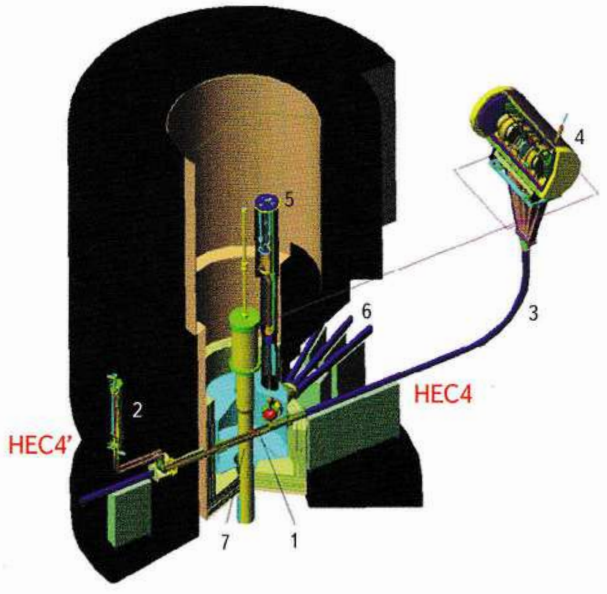


Experimental channel layout:
1 – reactor core; 2 – D_2O reflector; 3 – CPS control members

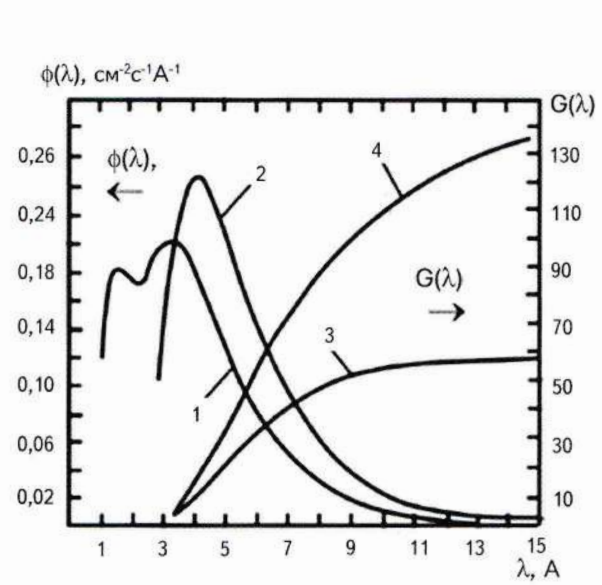


General view of vertical cold neutron source

Chamber housing cold neutron source with sealed funnel

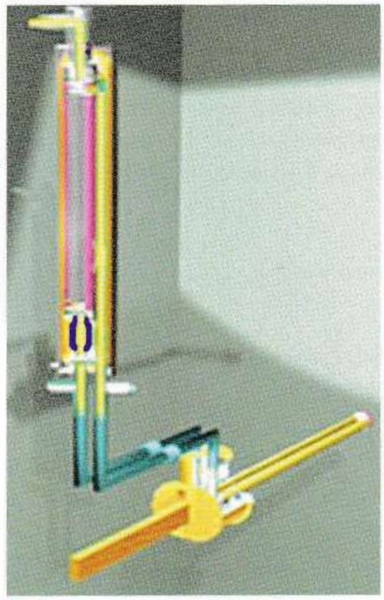


Location of cold and ultra cold neutron sources:
1 – low-temperature moderator chamber in horizontal experimental channel 4-4'; 2 – heat exchanger; 3 – neutron guide; 4 – EDM spectrometer; 5 – vertical cold and ultra cold neutron source; 6 – neutron guides; 7 – vessel with the reactor core



Neutron spectra at the end of the channel and gain factors:
1 – spectrum at the end of the channel; 2 – maxwellian spectrum at T=23 K; 3 – gain-factor for spectrum of the channel; 4 – ultimate gain-factor

Moderator	H_2	D_2
Volume	1.4 l	4.2 l
Thermal neutron flux in the chamber	$6.0 \cdot 10^{14}$ $cm^{-2} \cdot s^{-1}$	
Fast neuron flux	$\approx 10^{13}$ $cm^{-2} \cdot s^{-1}$	
Total heat generation	5.3 kW	5.7 kW
Heat generation in working medium of the chamber	0.9 kW	2.0 kW
Heat generation in working medium of tubes	0.4 kW	0.1 kW
Heat generation in chamber structural materials	2.8 kW	2.8 kW
Heat generation in tube structural materials	1.2 kW	0.8 kW
Distance from the core centre	480 mm	



General view of cold neutron source in horizontal experimental channel 4-4'

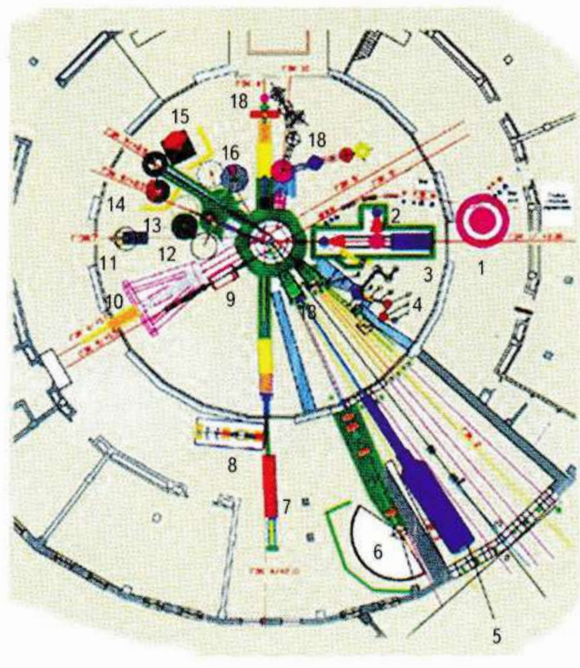
Reflector experimental channels

Horizontal channels withdraw neutrons from cold neutron sources, hot neutron sources and directly from the reflector. Except for the horizontal experimental channel 1 which is oriented to the reactor core, the rest of horizontal channels are tangential to the core. It reduces fast neutron and gamma-background. Thermal neutron flux at channel outlet is $(0.2 \ldots 3) \cdot 10^{11}$ $cm^{-2} \cdot s^{-1}$. Three channels are walk-through. Most of the channels and facilities are equipped with neutron optical elements, such as neutron guides, dedicated collimators and supermirrors.

Inclined experimental channels are handy to house irradiation devices (low-temperature helium loop, rabbit). These channels make it possible to select optimal conditions in terms of radiation spectra and radiation power density.

Vertical experimental channels are mainly located in thermal neutron spectrum area.

Planned experimental facilities to be mounted at extracted neutron beams



1 – electromagnetic mass-separator
2 – neutron multirotor monochromator
3 – crystal diffraction neutron polarizing spectrometers
4 – triaxial crystal spectrometer based on polarized neutrons
5 – polarized neutron small-angle diffractometer
6 – multirotor time-of-flight spectrometer
7 – correlation spectrometer for studying neutron beta-decay
8 – facility for searching neutron EDM by diffraction method
9 – time-of-flight spectrometer for fission products
10 – focusing diffraction gamma-spectrometer
11 – two-crystal diffraction spectrometer
12 – four-circle diffraction spectrometer
13 – four-circle single crystal diffractometer based on polarized neutrons
14 – superpositional multi-section powder diffractometer
15 – multidetector powder diffractometer
16 – four-circle single crystal diffractometer based on thermal neutrons
17 – facility for measuring asymmetry of gamma-emission in the reaction $np \rightarrow d\gamma$
18 – triaxial crystal spectrometer based on thermal neutrons

Main areas of studies

Basic research in nuclear and elementary particle physics including:

– search for neutron EDM;

– study of neutron beta-decay;

– study of spatial parity violation at interaction of polarized cold neutrons with protons and light nuclei;

– neutron diffraction and neutron optics in non-centrosymmetrical crystals;

– search for and study of P- and T-nonvariant effects in neutron reactions between neutrons and heavy nuclei;

– study of fission dynamics at low excitation energies;

– neutrino experiments;

– nuclear spectroscopy at high-flux reactor.

Basic research in condensed matter physics including:

– atomic interactions and phase transfers in a matter;

– magnetic and superconductive properties of a matter, colossal magnetoresistance effect, shape memory effect, etc.;

– heterogeneous (magnetic and structural) states of a matter;

– electronic, atomic and molecular processes on the material surface and phase boundaries;

– effect of neutron irradiation on physical properties of condensed matters at various temperatures.

Applied and basic researches including:

– identification of crystalline and magnetic structure of materials;

– study of physical properties of nanomaterials and nanocomposites, conductive polymers (in the normal and extreme conditions, i.e. at low temperatures, in vacuum, at high pressure, under irradiation of various types), organic compounds, biological objects, ferromagnetic fluids and other dispersed systems;

– development of radiometallofullerene production methods for nuclear medicine;

– study of relation between structural features and pharmacological properties of various compounds to be used in drug development;

– study of materials and nanomaterials to be used in catalytic processes and hydrogen power;

– study of radiation resistance and mechanical durability of materials used in facilities, particularly in reactor and space ones;

– study of radiation-induced structural modification of the materials to obtain new physical and mechanical properties and to develop advanced technologies.

Applied research for the Ministry of Defense of the RF, Rosatom and other organizations including:

– study of mechanism of irradiation-induced changes in material properties;

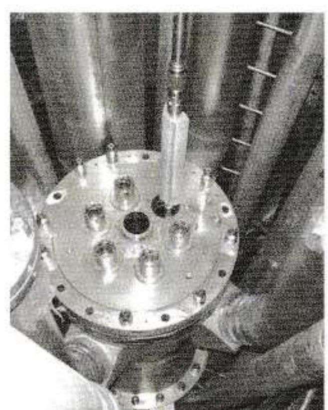
– study of micromechanism of fracture kinetics and development of material pre-fracture state;

– transmutation of SNF long-lived products;

– dynamics of accumulation of fission fragments and products;

Horizontal channel hall

Process hall. Vessel mounting



Handling machine tests. Loading of FA mockup

– low-activated steels to be used at NPPs;

– neutronographical studies of internal stresses in metals;

– study of materials with superconductivity at high temperatures.

Main activities

Beam research complex with PIK reactor is still under construction.

To reach first criticality and operate the first startup complex Rostehnadsor's license for operation of the complex with PIK nuclear research reactor was obtained in 2010.

In February 2011 loading of fuel into the reactor core was started, and PIK reactor reached first criticality as part of the first startup complex.

In the near future, neutronic characteristics of PIK reactor are to be determined, a number of commissioning works are to be carried out for PIK reactor startup within the mix of the first startup complex, and PIK construction are to be continued for commissioning a second and succeeding construction complexes scheduled under the program as well.

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"PIK PHYSICAL MODEL" CRITICAL FACILITY

"PIK physical model" critical facility (hereinafter referred to as PIK PM) is designed for research in physics and mechanics of the reactor under construction. Critical facility (CF) complex is also used for training PIK operators. PM reached first criticality on 26.12.1983.

100 W PIK PM is a full-scale mockup of PIK reactor which is under construction. In addition to PIK PM CF, the complex includes 2 following heavy water process plants designed for studying heavy water production technology and maintaining its quality during tests at PIK PM:

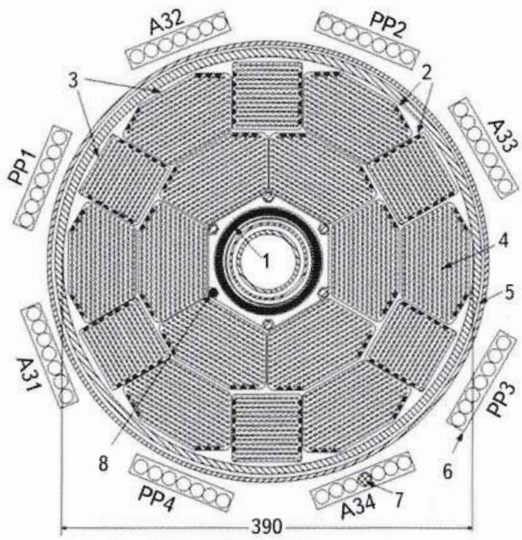
– pilot production facility for isotopic purification (protium removal) of heavy water;

– experimental semiscale facility for water isotopic purification using method of isotopic exchange on hydrophobic catalysts and water electrolysis (WEIP facility).

WEIP facility is used for studying methods of heavy water purification against protium and tritium.

PIK PM complex is located on VVR-M reactor site. Shared engineering, security, power supply, nuclear material control and account, radiation monitoring and fire safety systems are used for its operation. In terms of its physical features, PIK PM is a nuclear facility with light-water core and heavy-water reflector.

FAs are dismountable with the possibility of any fuel element be replaced with a mockup. Moderator (H_2O) is supplied to the core by air-hydraulic system which is used as safety system (additional protection) due to quick discharge of moderator in response to the emergency signals. Preparation for experiment whereby personnel stay in the critical assembly building is carried out only when moderator has been drained that is



PIK PM core map:
1 – absorber screens (Eu_2O_3 or Hf); 2 – Gd_2O_3+ZrO_2 burnable absorber rod mockups; 3 – FA; 4 – retrievable fuel elements; 5 – liquidous compensator cavity; 6 – manual control rods and scram rods in lower position; 7 – absorber (Eu_2O_3); 8 – neutron source (^{252}Cf)

General view of PIK PM

provided by the required interlocks. Temperature is changed by means of preliminary external electrical heating.

PIK PM CTB hasn't got assigned service life of basic equipment. Dismountable units, namely: vessel with the core, almost all experimental channels and the core itself, can be replaced during the operation. Periodic inspections are carried out to extend CPS life. Lives of the other systems involved in VVR-M reactor complex (i.e., power supply, radiation monitoring, radioactive ventilation systems, buildings and structures, etc.) are extended on the results of VVR-M complex survey. A comprehensive on-site program of whole complex survey is to be developed before 30-year service life of the complex expires.

PIK PM main performance

Power	100 W
Moderator	H_2O
Reflector	D_2O
Fuel type	UO_2 in Cu-Be matrix
Enrichment	90 %
Specific concentration of ^{235}U in one FA	Up to 600 g/l
Neutron lifetime at withdrawn CPS control members	$6.7 \cdot 10^{-5}$ s
Reactivity temperature coefficient when simulating mean moderator temperature (70 °C) in relation to CPS control member position	(-0.014)…(-0.019) β_{eff}/°C
Effective share of delayed neutrons for various states of critical assembly	0.748…0.767 % ΔK/K
Maximum reactivity margin (for the core with Al vessel)	14 β_{eff}
Maximum permissible reactivity (is compensated by CPS control members and additional means)	23 β_{eff}
Multiplication factor with the core being fully drained	0.52

Nuclear fuel characteristics

FA design for PIK PM CF is dismountable. Geometrically similar absorbers which simulate neutron absorption by fuel can be installed instead of fuel elements. These simulators are based on boron carbide powder dispersed in copper matrix. Such a design makes it possible to specify a reactivity margin for specific test programs without changing the number of FAs but with maintaining the scattering and absorbing properties of the core.

Dismountable FAs make it possible to try out new core design approaches. Fuel elements with lower fuel content can be installed near the neutron trap providing the required fuel profiling. FA includes 144 stainless steel displacers, which can be replaced with zirconium displacers or burnable absorber rod mockups with various Gd concentration. Shrouds made of stainless steel or E-110 (E-125) alloy are used in FAs. FA length is 1050 mm. In addition to dedicated dismountable FAs, PIK standard FA sets are used during experiments.

Cruciform fuel elements installed as per triangular lattice with pitch of 5.23 mm are used in both sets of FAs. Active length is 500 mm. Fuel claddings are made of stainless steel. The 90%-enriched uranium dioxide dispersed in Cu-Be matrix is used as fuel. Maximum total number of fuel elements in the core is 3858. Maximum weight of loaded ^{235}U is up to 27.5 kg.

FAs are centered in the support grid sockets by bottom nozzles. The other structural parts are made of steel.

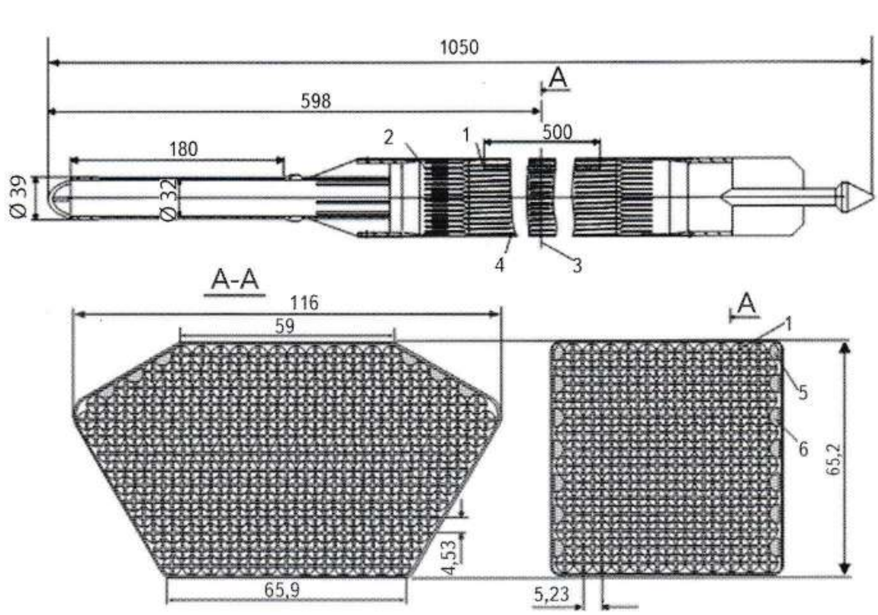
Experimental capabilities of PIK PM

CF equipment

Reactivity compensators used and additional protection system based on water drainage make it possible to work with large reactivity margins which correspond to the design parameters of the reactor simulated.

Studies of critical parameters at full FA load and any given position of CPS control members are envisaged by replacing part of fuel elements with simulators. This feature makes it possible to identify power distribution considering effect of CPS control members. CF can be used to study mutual interference of CPS control members at any combination of their positions, to measure reactivity coefficients related to reactor operation tasks. Experiments at partial FA load are used for justifying reactor first criticality and power startup.

To verify and validate software the special experiments with reactivity compensation means



FA for PIK PM:
1 – retrievable fuel element or mock-up; 2 – spacer cases; 3 – fuel centerline; 4 – FA shroud; 5 – angle displacer; 6 – main displacer or burnable absorber rod

facilitating the calculations, are used. Among them are introduction of homogeneous absorbers into the core, neutron trap, cavity between the core and reflector; and experiments with partial load of FAs without additional absorbers.

Test bench uses CPS drives and control members designed for a high-flux reactor. Long operating experience is taken into account in the adjustment of their designs in order to enhance their reliability in reactor operation.

Test bench is equipped with Canberra state-of-art gamma-spectrometer with HP Ge detector. Power measurement technique is based on the measurement of overall fission product activity and reference nuclide activity in fuel after irradiation. Fuel elements from dismountable FAs are used as detectors for identifying fission reaction rate. It provides high adequacy of specified parameters of power distribution and radiological characteristics normalized to power.

Core vessel can be replaced with Al mockup with the same dimensions to conduct research as per reactor performance enhancement programs.

Critical assembly is used for testing new CPS working members and hardware and has device designed for testing detection assemblies and simulating their location in iron-water shielding structure.

Almost all experimental channels are dismountable. CF is used for testing the channel mockups of various shapes and dimensions, which are made of various materials. Heavy water reflector is equipped with D_2O supply and removal system as well as gas and vacuum drying system. It facilitates placement of various experimental means mockups in heavy water reflector tank and implementation of periodic inspections as well.

Protium removal facility (PRF)

The facility provides reprocessing by rectifying from 500 to 800 kg of heavy water a year to recover its quality in terms of deuterium concentration (≥99.8 at. %). PRF capacity in terms of light water removal is 20 kg H_2O/year.

The facility can operate in the mode of production of free-of-D_2O extra pure light water for scientific purposes.

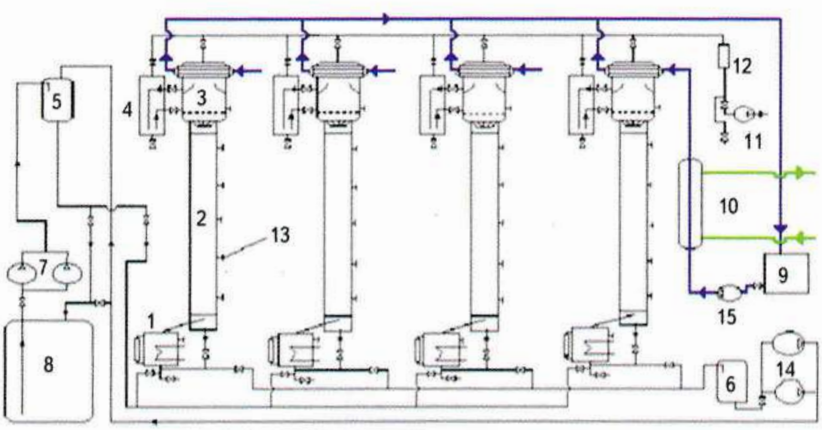
WEIP facility

WEIP pilot facility, which was designed for developing a technology of hydrogen isotope separation based on chemical isotope exchange between water and hydrogen and on water electrolysis (CECE-process), was developed by PNPI in cooperation with CJSC DOL and D.I. Mendeleev University of Chemical Technology of Russia. The facility has been in operation since 1995.

In addition to development of CECE-process the facility is used for reprocessing tritiated heavy water waste.

The main facility operation modes as per scientific and production tasks are as follows:

– to obtain heavy water of the appropriate quality (> 99.8 % in terms of deuterium concent-



Flow diagram of PRF at PIK PM facility
1 – vaporizer; 2 – packed column; 3 – condenser; 4 – upstream reservoir; 5, 6 – heavy water reservoirs; 7, 14 – heavy water supply pumps; 8 – KS montejus; 9 – tank with demineralized cooling water; 10 – heat exchanger; 11 – forvacuum pump; 12 – drying system; 13 – sampling; 15 – circulation pump of cooling circuit with demineralized water

ration) from heavy water waste (with deuterium concentration of 10...85 %);

– to purify heavy water against tritium to the level of less than 74 kBq/kg;

– to conduct trial startups for CECE-process technology developing and studying.

Main areas of studies

– Studies of physical characteristics of PIK reactor;

– justification for changes in the core and reflector designs for enhancing performance of operating reactor;

– study of radiological characteristics of designed experimental devices and facilities which are housed in the core and heavy water reflector; justification for their safety;

– verification of neutronics calculation software;

– development of neutron dosimetry and reactivity measurement techniques when conducting experiments at PIK reactor;

– development of commercial techniques for reprocessing heavy water waste and obtaining heavy water including water purified against tritium and gaseous deuterium;

– development of facility for isotope purification of heavy water, which is to be used in PIK reactor.

International cooperation

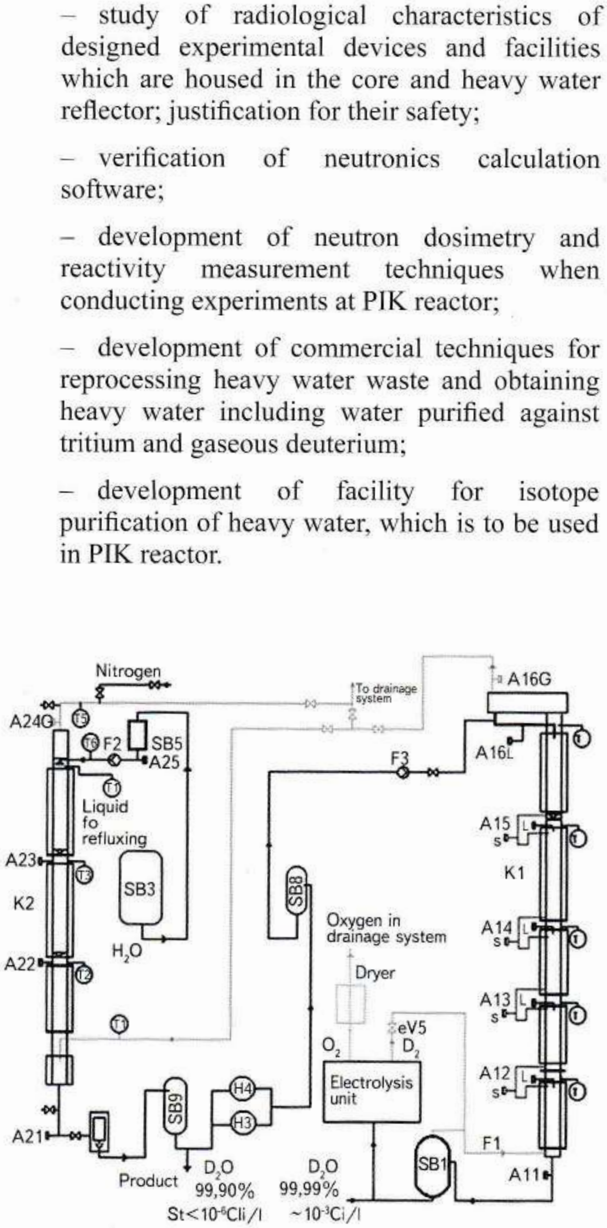
Characteristics of produced hydrogen isotopes comply with worldwide standard and cover the demands of domestic and foreign consumers. Production program implemented at WEIP facility makes it possible to cover the demands of Russian enterprises and organizations for heavy water and deuterium and to export a part of products (to Switzerland, the USA, China, South Korea, Australia, Germany).

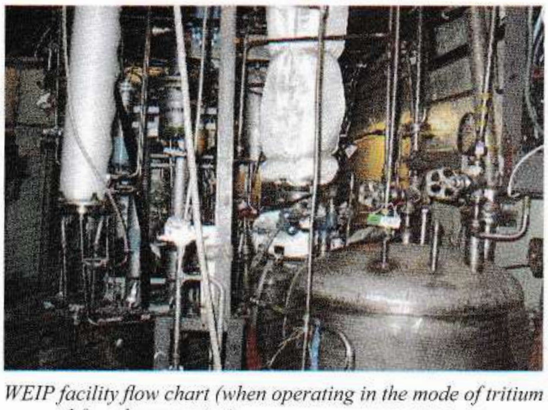
Main activities

In 2009, STC NRS issued a certificate for using MCNP software at PNPI's nuclear research facilities and a license for operation of PIK physical model. This fact made the necessary margin to start up PIK reactor. The results of experiments carried out at PIK PM CF over many years were used in validation of the software. In 2010, personnel of CF and isotope separation lab took part in preparation of documents and equipment so that PIK reactor could reach first criticality.

WEIP facility operation was maintained. Orders for producing highly concentrated heavy water and gaseous deuterium were performed.

Based on techniques for measuring protium in heavy water by IR-spectrophotometers and determining tritium activity concentration in water samples the Federal Agency of Technical Regulation and Metrology certified that





WEIP facility flow chart (when operating in the mode of tritium removal from heavy water):
K1, K2 – catalytic isotopic exchange columns; SB1 – reservoir for heavy water containing tritium; SB3, SB5 – reservoirs for distilled water; SB8, SB9 – reservoirs for tritium-free heavy water; H3, H4 – pumps; A – sampling points; F1, F2, F3 – gas and water flow meters; L – liquid; S – steam; G – gas

Analytical Control Laboratory of Department of Reactor Physics and Engineering had technical competence in isotopic and chemical analysis of heavy water (accreditation certificate No. POCC RU. 0001 517737 dt. 15.03.2010). The techniques had been previously qualified at D.I. Mendeleev VNIIM.

It is planned to continue works within the programs related to PIK reactor commissioning.

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