Reactor PIK construction

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Abstracts

The construction work at the 100 MW researches reactor PIK in year 2002 was in progress. The main activity was concentrated on mechanical, ventilation and electrical equipment. Some systems and subsystems are under adjustment. Hydraulic driving gear for beam shutters are finished in installation, rinsing, and adjusting. Regulating rods test assembling was done.
On the critical assembly the first reactor fueling was tested to evaluate the starting neutron source intensity and a sufficiency of existing control and instrument board.
Mainline of the PIK facility design and neutron parameters are presented.

1. Introduction

In 2002 the tempo of the PIK reactor construction has been in the direct dependence of the financing. Last three years the reactor construction has been financed as much as 200 mln rubles annually. Taking into account inflation rate, this is equivalent to a gradual decrease of the annual work scope. Since there is no chance to increase considerably the financing, the construction tactics remains the same [1] – to focus efforts on preparing the reactor for start-up at low power (100kW), and to postpone construction of the systems needed for the reactor operation at 100MW. Such tactics leads to a certain delay, which actually will not affect the beginning of neutron beams usage, since preparation of research instrumentation is delayed as well.

The fact of the reactor start-up itself, even at a low power, is expected to stimulate the increase of financing needed to complete the construction.

2. Construction status

In the reactor vault the equipment installation is mainly completed. Today we are aligning the start and stop rods, being a part of the heavy water reflector tank, completing manufacturing of experimental channels and preparing the fuel assembly loading mechanism for adjustment. The primary cooling circuit has been installed already, now the primary circuit subsystems, ventilation systems and some other systems are being assembled.

The highly clean demineralized water production plant has been installed and commissioned in order to ensure the reactor systems flushing. The coolant chemistry control laboratory has been commissioned.

The first hydraulic system of the system of hydraulic control of the protective cut-off gates in the horizontal channels has been flushed and adjusted.

A lot of work has been done in 2002 for the electrical systems. By the beginning of the year 2003 there have been laid approximately 50% of all cables and all power supply panels have been installed. Installation activities at the reactor main control room and control panel are in progress. Fire control equipped by up-to-date low temperature (≈ 200° C) automatic aerosol fire fighting and fire alarm systems have been installed and adjusted.

Due to insufficient financing in the year 2002, there was no chance to purchase and start installation of the reflector cooling circuit. The only reflector tank and heavy water discharge and storage tanks have been assembled.

Reactors buildings are presented in fig.1.

3. Preparation for the commissioning

At the Saint Petersburg Institute of Nuclear Physics there is a full-scale simulator of the PIK reactor – the so-called critical facility. The core startup fuel loading has been checked with the help of this facility. In the course of the PIK equilibrium fuel cycle, control rods compensate the reactivity margin, needed for reactor operation during the specified life time. At the beginning of every cycle all 18 fuel assemblies are loaded. Some of fuel assemblies are fresh, some remain since the previous cycle. The average fuel burnup in the core decreases the reactivity margin down to the required level. Within the start-up range a provision shall be made for special measures aimed at reactivity decrease, namely replacement of certain fuel assemblies for displacers.

There have been performed the experiments on research of the main neutron-physical characteristics of the core equipped with 3 and 6 external aluminium displacers for reactor operation under startup conditions.

The core with 3 displacers is considered ultimate regarding the number of fuel assemblies during physical start-up (fig.5). Energetic startup begins with such core arrangement, then the core is transferred to the standard mode of partial refueling with a step-by-step after-loading of remaining fuel assemblies. The control rods efficiency corresponding to a non-standard fuel loading with incomplete number of fuel assemblies has been determined. The energy release non-uniformity coefficients are derived. The method of compensating the excess reactivity with the help of displacers is substantiated. The efficiency of control rods located opposite the cells, replaced for displacers, has not changed. Displacers do not distort the energy release field. The maximum energy release non-uniformity coefficient Kv is equal to 2.7 ± 0.2 at the fuel profile assumed for the startup arrangement of fuel assemblies. This value is lower than the allowable Kv, assumed in the design. The obtained data allow reliably determine the reactor safe operation limits and conditions during the transient period of bringing the reactor to power.

The researchers have assessed the neutron source intensity required for the startup and for determining a need of additional startup instrumentation. It has been proved that at the design sensitivity of the existing neutron measurement equipment, the neutron source as intensive as 10^8 n/s is required. In this case there is no need to develop and install the additional control and protection instrumentation.

The PIK reactor simulator [2] is the reactor mathematical model software complex allowing modeling of a wider range of operating conditions and processes in the real or accelerated time mode. As an illustration of thermal processes modeling, there has been investigated the case of the reactor preparation for a start-up during winter time. The ingress of cold water during starting up of the pumps leads to considerable temperature and reactivity fluctuations. As a result, the researchers have determined the rate of water temperature variation in the reactor circuits when put into operation, the time of reaching the steady-state conditions and temperature at every stage of the reactor circuits operation.

Combination of electrolyses and catalytic exchange (CECE) process was in progress for the development of the alternative design of the PIK reactor de-tritiumization and de-protiumization plant [3,4].

The radiation monitoring of surroundings for background data collect begins.

4. Reactor purposes

The sphere of application of research reactors grew from year to year– from pure science up to modern methods of technological control, from fundamental research of neutron properties and neutron interaction with nucleus and substance up to neutron therapy. Research reactors are used in the field of physics, chemistry, biology, engineering, geology, material science, medicine, semiconductor production technology, industry etc.

Request for neutron flax density increased with increasing of sophistication of methods and instrumentation used on research reactors.

For more than three decades the international nuclear research society has been exploiting the best in the world high-flux research reactor at the Laue Langevin International Institute (LLII). As for the performances, the PIK reactor is not worse, whereas its certain parameters are expected even better (maximum neutron flux, number of positions on the beams, possibility of irradiation materials in the core etc.).

Today in Russia there is the only one up-to-date research pulsed reactor IBR-2 at Joint Institute of Nuclear Energy in Dubna, generating the impulse neutron flux $\approx 10^{16}$ n/cm^2·s, at the average neutron flux $\approx 10^{13}$ n/cm^2·s, that is absolutely not sufficient for a large variety of experiments. Other four Russian research beam reactors commissioned or reconstructed in 50s – 80s, are able to generate a neutron flux $\approx 10^{14}$ n/cm^2·s, but do not meet the up-to-date experiment requirements.

In these circumstances there is a really unique advanced project of the up-to-date steady neutron flux source – the high-flux beam reactor PIK (generating neutron flux $\approx 10^{15}$ n/cm^2·s), being under construction at the Petersburg Nuclear Physics Institute of the Russian Academy of Sciences (PNPI). At the same time it is the only one research reactor under construction in Russian Federation.

The PIK reactor features high experimental potential not only due to the high intensity neutron beam, which is approximately by one order higher than that at the existing medium-power reactors, but due to availability of the sources of hot, cold and ultracold neutrons as well. Therefore, as compared to the research reactors created in 50-60s, the PIK reactor will give unique opportunities for extending the neutron beam research activities conducted currently in Russia, as well as for launching new researches that are technically impossible at the moment.

Reactor is planned as a base for international research center. The PIK reactor R&D program is conceived to be open for any interested Russian or foreign scholars.

The figures 6 and 7 shows the preliminary arrangement of experimental equipment in the horizontal beam hall and neutron guide hall.

The experimental equipment planned to be installed in the PIK reactor horizontal channels hall include:

1- Electromagnetic mass separator, 2-Neutron multi-rotor monochromator, 3-Crystal-diffraction neutron polarizing spectrometer, 4-Triaxial crystalline polarized neutron spectrometer, 5-Low-angle polarized neutron diffractometer, 6-Multi-rotor transit time spectrometer, 7-Correlating spectrometer intended for research of neutron decay, 8-Equipment for neutron electric dipole moment search by a diffraction method, 9-Fission products transit time spectrometer, 10-Focusing diffraction spectrometer, 11-Double-crystal diffraction spectrometer, 12. Four-circle diffraction spectrometer, 13-Four-circle monocrystal polarized neutron diffractometer, 14- Superposition multi-section powder-type diffractometer, 15. Multi-detector powder-type diffractometer, 16. Four-circle monocrystal thermal neutron diffractometer, 17. Equipment for measuring of γ-quantum emission asymmetry at the $np \rightarrow \gamma d$ reaction, 18. Triaxial crystalline thermal neutron spectrometer.

The experimental equipment planned to be installed in the PIK reactor neutron guide hall include:

1-Textual reflectometer, 2-Correlating diffractometer "Skorpion", 3-Polarized neutrons fundamental research equipment, 4- Fourier- diffractometer "Sfinks", 5-Low-angle diffractometer "Membrana", 6-Low-angle polarized neutron spectrometer "Tenzor", 7-Reflectometer with a horizontal reflecting surface, 8-Modulating spin-echo spectrometer, 9-Texturometer, 14-70-detector superposition powder-type diffractometer, 15-Biaxial diffractometer for monochromator testing.

Some places are not laid out.

5. Reactor PIK parameters.

Short description of the reactor was presented in [1] and inevitably is partly repeated here. In the same report [1] where also all the references are given. Reactor cross-section is given on fig.2.

The 50l core is cooled by light water and protected by a heavy water reflector. The core is a 100MW compact intensive fission neutron source (see table 1). The heavy water reflector ensures the optimum thermal neutron flux-to-power ratio at a low γ-background. The thermal neutron flux in the heavy water reflector exceeds 10^{15} n/cm^2·s, whereas in the light water trap (central experimental channel) it makes up to $5 \cdot 10^{15}$ n/cm^2·s.

As fuel elements, the crosswise fuel elements in stainless steel clad are used, which are well mastered in production (Fig. 3). In the SM-2 reactor, fuel elements of such type have already been operating many years under the specific maximal load of Q_v = 8 MW/l and more [5]. In the PIK reactor, $Q_{v\,max}$ is at the level of 6 MW/l. Fuel elements are assembled into fuel assemblies of two types (Fig. 4). The core is loaded by 18 fuel assemblies.

Some positions in the fuel assemblies, that can not be filled with fuel elements, are occupied by a burnable absorber [6]. In two square fuel assemblies are disposed samples for irradiation in the core, including PIK reactor vessel surveillance samples. These material science fuel assemblies allow the samples irradiation in the fast neutron flux $\Phi \sim 1\cdot10^{15}$ n/cm^{2}s (? $>$ 0.7 MeV) [7] at a temperature limited by boiling on its surface (about $270^{?}$?).

The regulation is carried out by means of two absorbing cylinders made from hafnium at the interface with the central trap. The same cylinders are used for emergency shut-down. 8 absorbing plates are situated in the heavy-water reflector, 6 of which are used for the start-up and 2 – for emergency shut down (Fig. 2).

The core is cooled by water under the pressure of 50 atm and is contained in a double-wall cylindrical vessel made from stainless steel. Heavy water under the pressure of 16 atm used to cool the vessel is circulating in the gap between the vessel walls. This vessel is substitute item and can be changed wen stainless steel is out of condition due to irradiation or for replacement the core design. Thanks to the interchangeable core vessel, the core parameters can be widely varied.

The reactor is equipped with horizontal, inclined and vertical experimental channels. In the reflector tank originate one radial, three through, one V-shaped and three tangential experimental channels. Two horizontal channels will be equipped with neutron guide systems intended for thermal and cold neutron beams, correspondingly. Neutron guides, included into a common protection, carry the thermal and cold neutron beams to the special neutron guide hall. It is planned to create two cold sources. The deuterium source will be placed within one of the reactor vertical channels. The other one, a multi-purpose liquid hydrogen source of ultracold neutrons, is located within the horizontal channel . The reflector will house the hot neutron source and a cryogenic loop. The standard horizontal channel is 10cm in diameter, but it can be extended up to 25cm if need be, because all channels are interchangeable. In the reflector originate also six inclined channels, inner diameter 8 – 14cm, carrying neutron beams to the inclined channel hall located over the main experimental hall of horizontal channels.

One of the inclined channels originates in the hot neutron source. The reflector tank houses 5 vertical channels (inner diameter 41mm) and one channel (inner diameter 155mm) intended to irradiate the container with specimens. Moreover, the light water trap houses the central experimental channel carrying a unique neutron flax about $5\cdot10^{15}$n/cm^{2}s.

Basic parameters of experimental channels, hot and cold neutron sources as well as neutron guide system are presented in table 2.

The PIK reactor neutron guide system* includes 8 neutron guides: 4 thermal neutron guides and 4 cold neutron guides .

The preliminary parameters of neutron guides [8].

Four neutron guides begins in heavy water, neutron flux at the channel bottom is $\approx 10^{15}$ *n/cm^{2}s*
Its curvature radius are in the range from 3300m to 8500m, guide lengths from 26m to $\approx$ 52m, guide section from 1,5×20 cm^{2} to 3×20 cm^{2} and coming out neutron flux $\approx 1{,}4\cdot10^{9}$ *n/cm^{2}s*
Four neutron guides connected with cold source. Neutron flux at the channel bottom is $3{,}5\cdot10^{14}$*n/cm^{2}s* Its curvature radius are in the range from 600m to 2400m, guide lengths from 14m to $\approx$ 40m, guide section is 3×20 cm^{2} and coming out neutron flux $1.8\text{-}2.5\cdot10^{9}$ *n/cm^{2}s*

The above data are preliminary at the moment, they will be corrected taking into account the neutron spectrum characteristics of the particular equipment.

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Table 1. PIK reactor parameters

Power	100 MW
Maximal specific power	6 MW/l
Core volume	50 l
Core diameter	390 mm
Core height	500 mm

Fuel assemblies of the PIK type
- enrichment 90%
- fuel UO_2 in the copper-beryllium matrix
- uranium density in the matrix 1.5 g/cm^3
- cladding: stainless steel with the thickness of 0.17 mm
  fuel concentration by uranium-235 – 600 gram per litter of the core

Reflector D$_2$?
  Diameter - 2.5 m
  Height - 2 m

Cooling circuit
  Coolant - ?$_2$?
  Pressure - 50 atm
  Flow-rate - 2400 m^3/hour
  Inlet/Outlet temperature - 50/70$^?$?

Table 2. Reactor PIK experimental channel parameters

Central loop channel in the core

Thermal neutron flux	$4.5 \cdot 10^{15}$ n/cm^{2}s
Fast neutron flux (E>0.7 MeV)	$7\cdot10^{14}$ n/cm^{2}s
Channel diameter	100 mm

Horizontal channels– 10 units

Thermal neutron fluxes on bottoms	$(0.1 \div 1.2)\ 10^{15}$ n/cm^{2}s
Thermal neutron fluxes at the outlet	$(0.2 \div 3)\ 10^{11}$ n/cm^{2}s
Diameters	$100 \div 250$ mm

Inclined channels – 6 units

Thermal neutron fluxes on bottoms	$(0.2 \div 1) \cdot 10^{15}$ n/cm^{2}s
Fast flux (E>0.7 MeV) on bottom (IEC5)	$2\cdot10^{14}$ n/cm^{2}s
Thermal neutron fluxes at the outlet	$(0.4 \div 2) \cdot 10^{10}$ n/cm^{2}s
Channel diameters	60 – 100 mm

Vertical channels– 7 units

Thermal neutron fluxes on bottoms	$(1\div 3)\ 10^{14}$ n/cm^{2}s
Channel diameters	60 mm

Cold neutron sources –2 units

1. In the vertical channel for the neutron outlet to the neutron guide hall.

Average flux value over CNS	$4\cdot10^{14}$ n/cm^{2}s

2. In the horizontal channel HEC2 for the ultra-cold neutron outlet

Thermal neutron flux	$1.2 \cdot 10^{15}$ n/cm^{2}s

Hot neutron source – 1 unit

Average thermal neutron flux value	$3 \cdot10^{14}$ n/cm^{2}s
Wavelength at maximum	0,5Å
Flux at the outlet	$3 \cdot 10^9$ n/cm^{2}s

Fig.1. Reactor PIK building

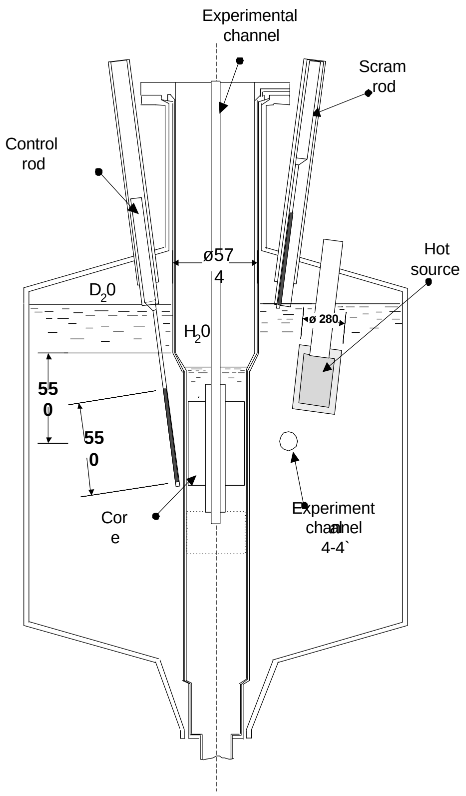


Fig. 2. Reactor PIK

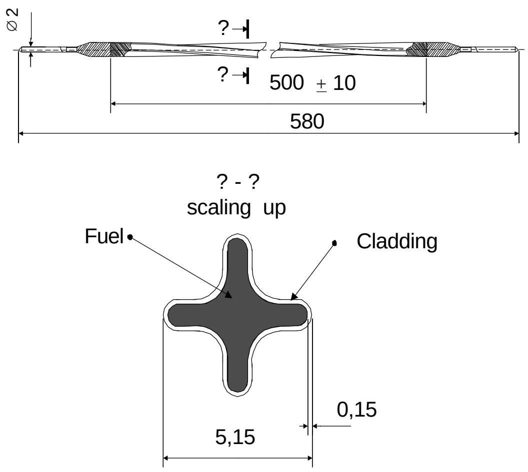
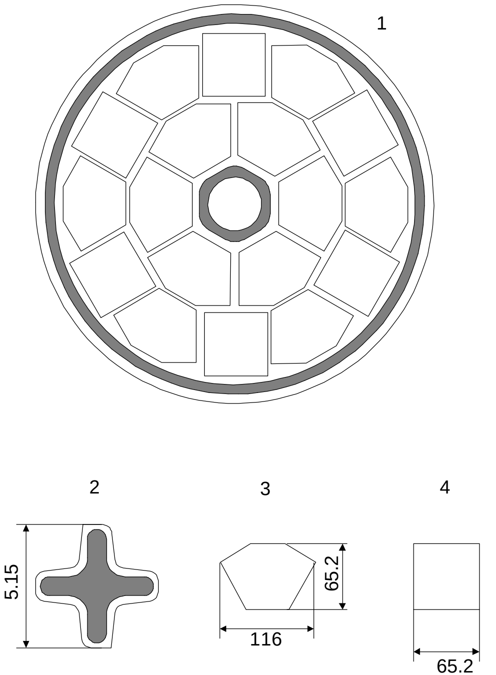
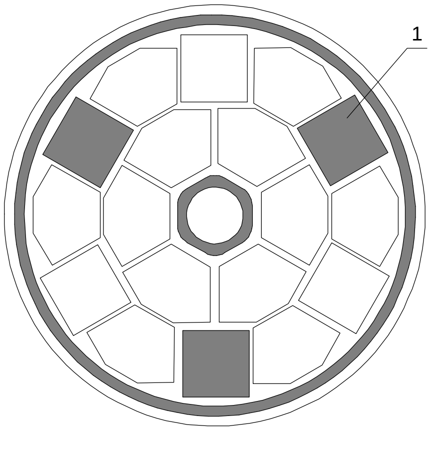


Fig.3. Reactor PIK fuel element



1 - PIK reactor core
2 - Fuel element
3 - Hexagonal fuel assemble
4 - Square fuel assemble
Fig.4. Reactor PIK fuel assemble



1 - Al. dumbs
Fig.5. First loading

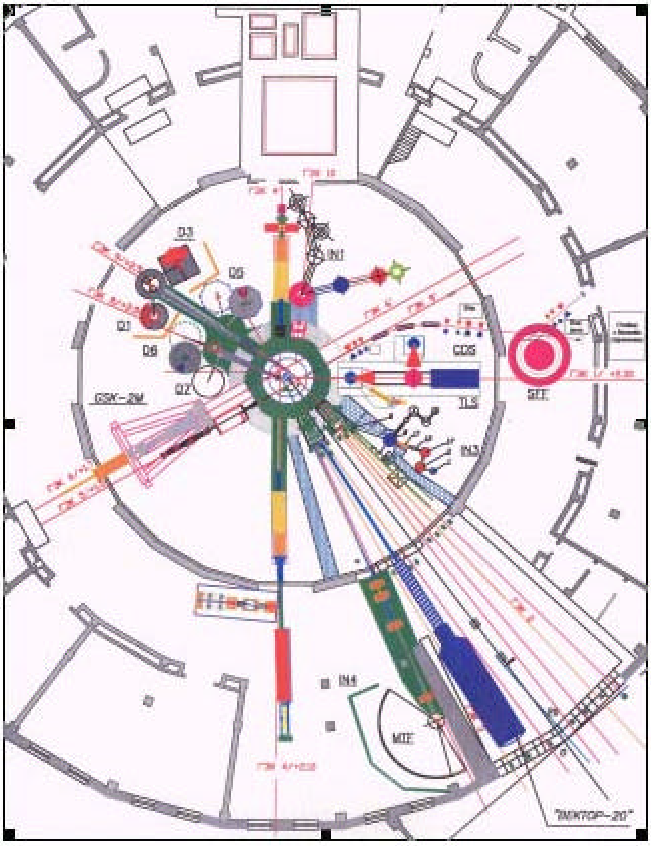


Fig.6. Experimental hall

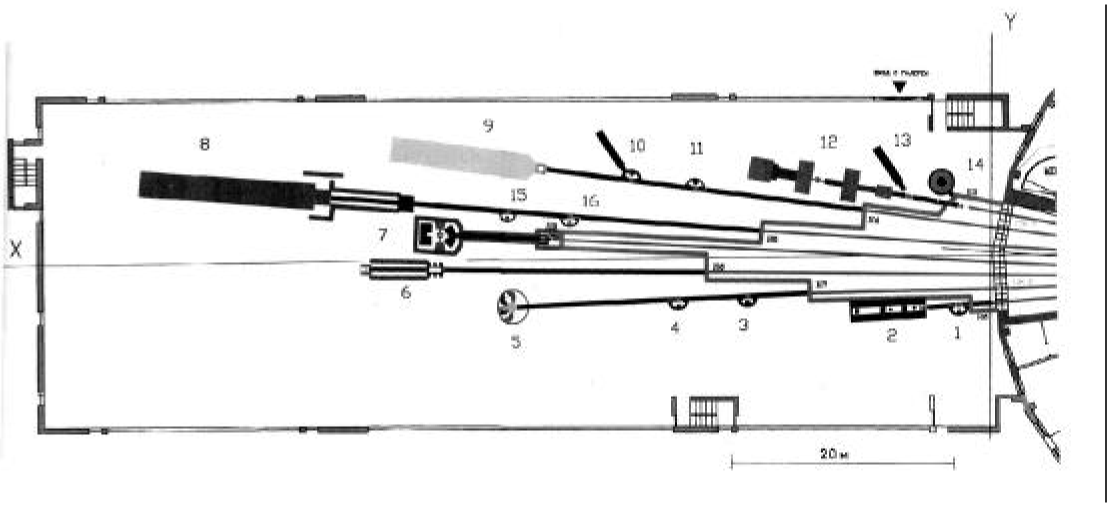


Fig.7. Neutron guide hall