PIK reactor state of construction.

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SYNOPSES

The Report gives description of the current status of PIK reactor that is under construction at Petersburg Nuclear Physics Institute. Powerful research reactor has thermal neutron flux of $5 \cdot 10^{15}$n/cm^{2}sec.

Plans of complete construction work and putting reactor PIK in operation are considered.

Second part of report gives results of critical experiments supported reactor first criticality program.

In the past years the reactor construction has been financed at a poor level less then 200 million rubles annually. All this time we press for remarkable increase and prepare three construction phases to finalize design. At present time Government approved the decision of finalizing reactor PIK construction on year 2012 and of financing all the rest of PIK estimate sum. .

The equipment for the first phase is about 90% mounted. Practically all subsystems of the primary coolant circuit are completed. Water test on these systems and primary coolant circuit itself begins. Electrical and instrumentation systems are also tested. Fire control system and physical protection systems for the first phase are partly in operation.

On the reactor full-scale critical facility startup core are examined.

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 ultra cold neutrons as well. Therefore, compared with 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.

INRODUCTION

There are a number of research reactors in Russia and at first glance there should be no problems with performing of research and development works [1]. On the other hand rather complicated situation with research reactors designed for physical researches, i.e. beam reactors has developed in Russia. As a matter of fact we got four medium power reactors remaining only with flux $\leq 10^{14}$ n/cm$^2 \cdot$sec after the dissipation of the USSR. All of them were built in sixties of past century. Putting it mildly they don't meet requirements of modern experiment to the full extent despite the fact that modernization has been made on some of them. IBR-2 reactor in Joint Institute of Nuclear Research, town of Dubna, unconditionally pertaining to world-class neutron sources is a grand exception. But this is a pulse reactor with time related mean power of 2 MW, which explicitly not enough for performing of a wide range of works demanding collection of considerable number of events.

In our opinion the necessary alternative for such developments is completion of construction of PIK high flux reactor complex which is under way on PNPI site.

PIK reactor is as good as the best world-wide HFR beam research reactor of International Institute named after Laueh-Langevenah, city of Grenoble, France, in its parameters and research and research capabilities. There is no doubt that full-scale implementation of PIK Project will cope with the demands of all the agencies in Russia, interested in use of neutron methods of substance mater research. PIK reactor is to be considered as arrangement of Grenoble type international neutron centre [2,3].

The declarations that the Project is out of date heard from time to time are totally groundless. We remind that selected reactor configuration, including compact active core, cooled by light water and heavy-water reflector is advantageous for beam reactors, and above all neutron-flux density in beams of PIK reactor hits record high.

PIK REACTOR

Design was done by cooperation of scientific leader Petersburg Nuclear Physics Institute, chief designer Research and Development Institute of Power Engineering (NIKIET), chief planner All Russia Design and Scientific Research Institute for Complex Power Technology (VNIPIET) , chief planner Sosnovy Bor Design and Survey Institute (JSC SPII VNIPIET)
and some particularized licensed entities.

PIK reactor core is akin to the core of SM-2 reactor in its design. Fuel pins (Fig.1) of the same type with the ones of SM-2 reactor with height increased to 500 mm have been used [4]. The reactor is presented in Fig.2 schematically.

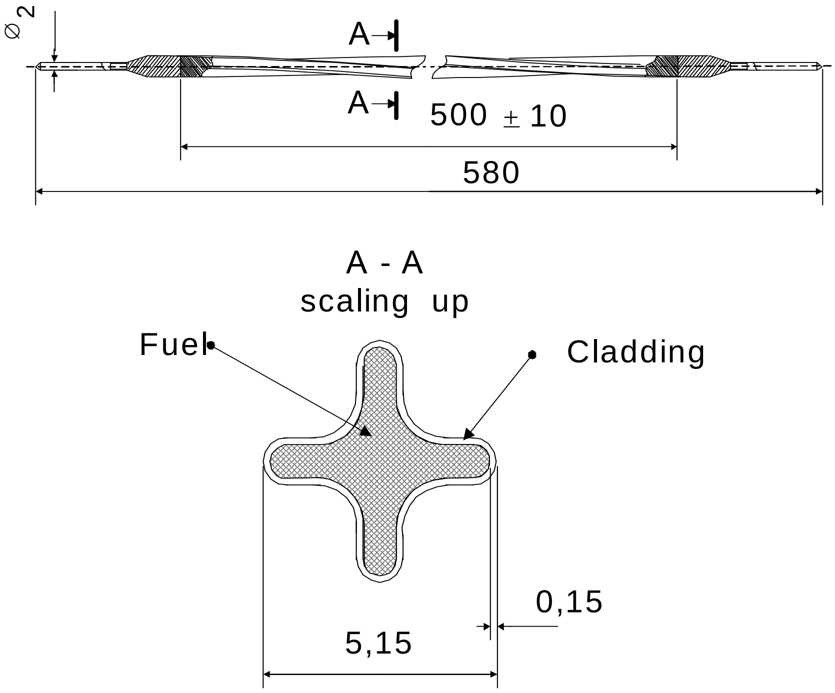


Fig.1 Reactor PIK fuel element

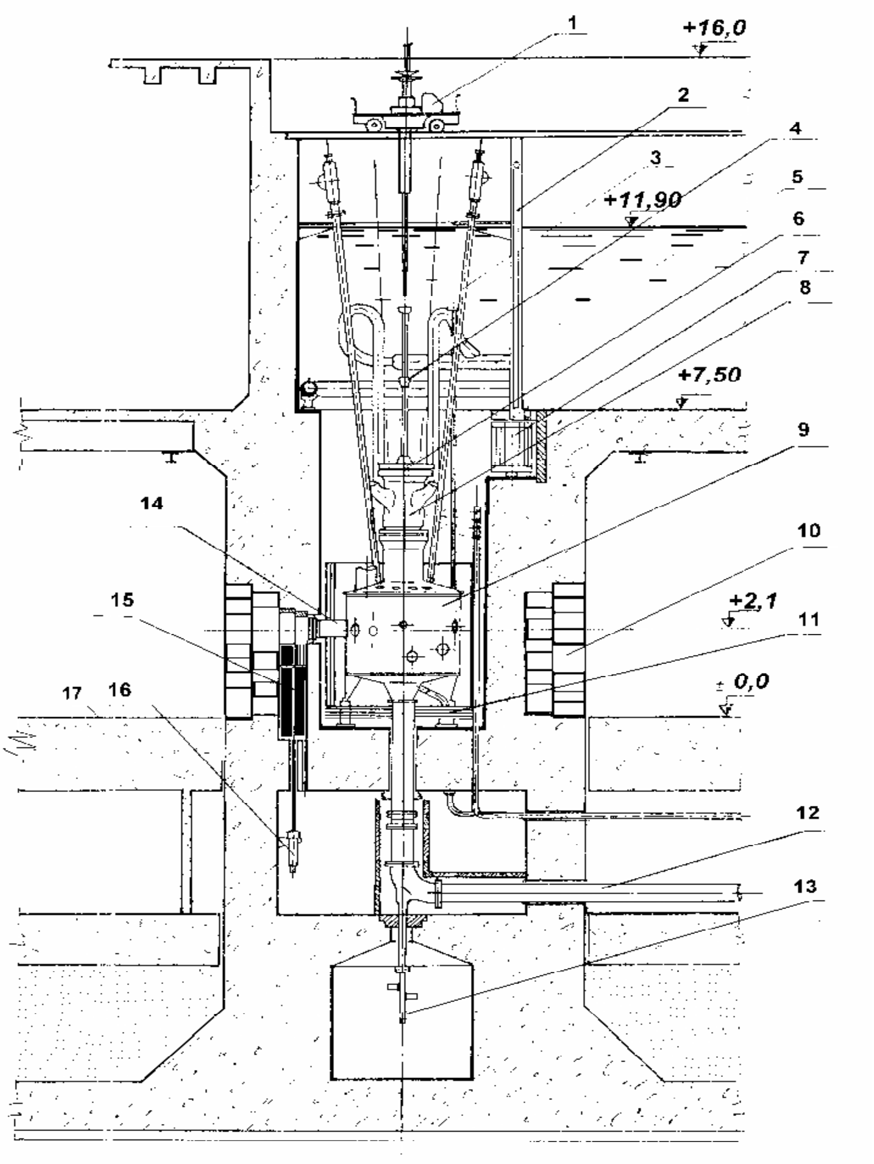


Fig.2. PIK reactor section.

1. Fuel-handling machine. 2. Sluide gate. 3. Side control rod channel 4. Central experimental channel. 5. Inlet pipe. 6. Top cover of reactor. 7. Transfer drum. 8. Top vessel. 9. Heavy-water reflector tank. 10. Biological shield. 11. Iron – water shield. 12. Outlet pipe. 13. Central control drive. 14. Horizontal experimental channel. 15. Beam gate. 16. Beam gate hydraulic drive.

17. Vibration protecting of experimental hall.

Fuel rods of that type have already been in operation in SM-2 reactor for many years under peak specific load of Q_v = 8 MW/l and more [5]. $Q_{v\ max}$ is at level of 6 MW/l in PIK reactor. The fuel rods are put together in cassettes of two types (Fig.3). 18 fuel rod assemblies form reactor core with central channel – neutron trap.

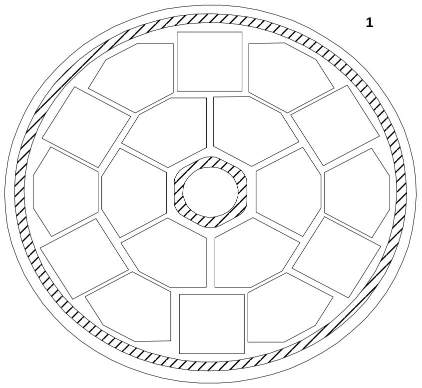
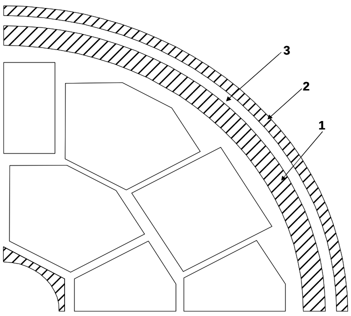


Fig.3. Reactor PIK core and fuel assemblies



1. Inner vessel
2. Outer shroud
3. Cooling water

Fig 4. Reactor PIK vessel

Differences in design of SM and PIK reactors are connected with their application. PIK reactor is designed mainly for pursuance of the research of outlet neutron beams. Heavy water, making it possible to have significant volume with high density of slow neutron flux is used as reflector.

The core is cooled with water under pressure of 50 bar and is contained in double wall stainless steel cylindrical vessel (Fig.4). Heavy water under pressure of 16 atm. circulates in gap spacing between two vessels for cooling of vessels. At first it was supposed to use this gap spacing also for reactivity control by gadolinium nitrate solution in heavy water. The quick brake of stainless steel pressure shell is considered to be incredible. The extension of hypothetical crack in extreme case may lead to detectable and insignificant water leaking from the core to gap spacing between the shells. Nevertheless, the use of gadolinium nitrate solution to compensate the burn-off has been rejected for reasons of add-on safety. It is possible to use this absorber as additional system only for increasing of negative reactivity on shut down reactor in some very rare circumstances. The reactivity control and automatic shutdown is carried out by two hafnium absorbing cylinders at the boundary with central trap. There are 8 absorbing plates disposed in heavy water reflector of which 6 plates are used for start-up and 2 ones for automatic shutdown.

The reduction in weight of controls due to refusal from gadolinium nitrate solution has been overcompensated by use of burnable absorber in a form of rods (burnable absorber rods) [6].

PIK new fuel assembly with burnable absorber rods and with change of shrouds' stainless steel material by zirconium has been developed. The obtained by change of cassettes shrouds' material add-on reactivity margin is planned to be used for arrangement in the core of materials samples for radiation treatment, including surveillance samples of PIK reactor vessel.

The start-up of reactor shall be carried out by a fuel assemblies of initial design with steel shrouds and without burnable absorber rods. This set was procured for start-up in eighties, which failed to take place due to changes of requirements for reactors safety made after accident at Chernobyl Nuclear Power Plant.

Parameters of PIK reactor are produced in Tables 1 and 2.

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 elements 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 0.16 mm
	- core fuel concentration by uranium-235 – 600 g/l
Reflector	D_2O
Diameter	- 2.5 m
Height	- 2 m
Cooling circuit	
Coolant	- H_2O
Pressure	- 50 bar
Flow-rate	- 2400 m^3/hour
Inlet/Outlet temperature	- 50/95^{o}C

Table 2 Parameters of experimental channels

Central loop channel in the core	
Thermal neutron flux	$5 \cdot 10^{15}$ n/cm^{2}s
Fast neutron flux (E>0.7 MeV)	$7 \cdot 10^{14}$ n/cm^{2}s
Channel diameter	100 mm
Diameter of container for irradiation	41mm
At the pressure of 50 atm, the cooling power is	400 kW
Pressure range	1.5 ÷ 50 atm.
Horizontal channels– 10 units	
Thermal neutron fluxes on bottoms	(0.1 ÷ 1.2) 10^{15} n/cm^{2}s
Thermal neutron fluxes at the outlet	(0.2 ÷ 3) 10^{11} n/cm^{2}s
Diameters	100 ÷ 250 mm
Inclined channels– 6 units	
Thermal neutron fluxes on bottoms	(0.2 ÷ 1) $\cdot 10^{15}$ n/cm^{2}s
Fast flux (E>0.7 MeV) on bottom (IEC5)	$2 \cdot 10^{14}$ n/cm^{2}s
Thermal neutron fluxes at the outlet	(0.4 ÷ 2) $\cdot 10^{10}$ n/cm^{2}s
Channel diameters	90 – 140 mm
Vertical channels– **7** units	
Thermal neutron fluxes on bottoms	(1÷ 3) 10^{14} n/cm^{2}s
Channel diameters	60 mm
Cold neutron sources CNS –2 units	
1. In the vertical channel for the neutron outlet to the neutron guide hall.	
Average flux value over CNS	$4 \cdot 10^{14}$ 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 H N S– 1 unit	
Average thermal neutron flux value	$3 \cdot 10^{14}$ n/cm^{2}s
Wavelength at maximum	0,5Å
Flux at the outlet	$3 \cdot 10^{9}$ n/cm^{2}s
Neutron guides – 7 units (with possible growth up to 9)	
Wavelength	λ = 1.0 ÷ 12 À
Outlet fluxes	(0.3 ÷ 1.5) $\cdot 10^{9}$ n/cm^{2}s

There are two loops available in reactor - one in central experimental channel and the other one in inclined experimental channel №5 in addition to two cassettes in the core for materials radiation treatment in reactor. The central experimental channel is arranged in water trap in centre of epy core. The unperturbed slow neutrons flux in this channel is $5 \cdot 10^{15}$ n/cm^{2}s. The fast neutrons flux in central experimental channel comes up to $7 \cdot 10^{14}$ n/cm^{2}s (E > 0.7 Mev), and power density is about 25 ÷ 50 W/g depending on material [7].

The loop is cooled with water under pressure of 50 bar with design heat takeoff of 400 kW. Operation under low pressure of about 1.5 bar is possible [8]. The required features for cooling of exposed to radiation samples in emergency states have been provided in this channel that makes it possible to make radiation treatment of both non-fissionable and fissionable materials.

Arranged in reflector inclined experimental channel №5 is equipped with helium gas cooling for operation in wide temperature range – from cryogenic temperatures to hundreds Deg.C and designed for research in the field of radiation physics and materials science [9]. Radiation treatment of fissionable materials in this channel is not possible. The fast neutrons flux (E>0.7Mev) gains $2.5 \cdot 10^{13}$ n/cm^{2}s.

The Effective iron-water mixture has been used in biological shield permitting to reduce its thickness and thus increase neutron fluxes at the outlet of horizontal channels. In addition to that the external layer of biological shield has been made as dismountable one that makes it possible to bring elements of experimental plant, e.g. scattering crystal even more nearer to radiation source (Fig. 5).

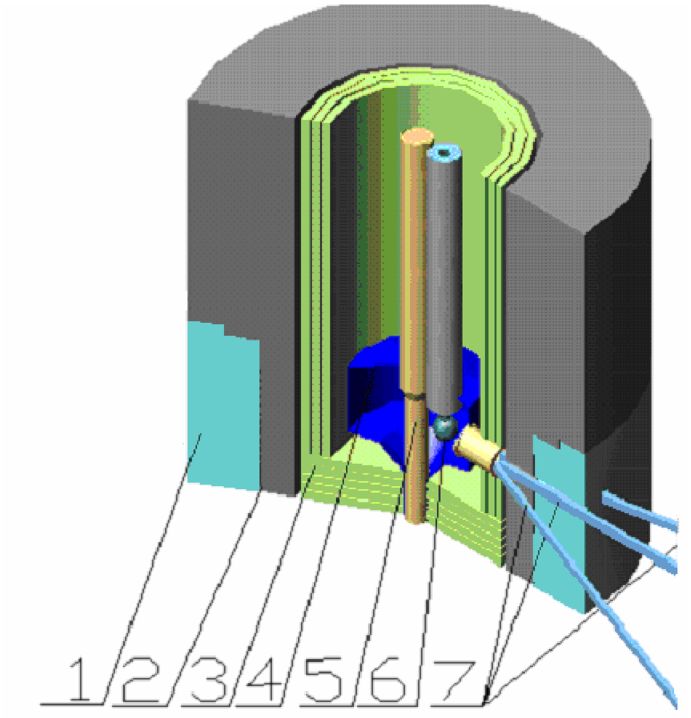


Fig. 5. Biological shield of PIK reactor.

1. Dismountable shield 2. Biological shield 3. Iron-water shield. 4. Reflector tank. 5. Vessel and the core. 6. Cold neutrons source. 7. Neutron guides

Reactor design provides possibility for replacement of channels with change of their configuration. Vessel of reactor is also made as changeable one. This flexibility makes it possible to change parameters of beams and core according to experiments requirements.

It may be possible to get on PIK reactor one and half folds higher densities of neutron beams in the long term. With this aim in view it is necessary to replace steel material of vessel with aluminum alloy and beryllium bronze material of matrix in fuel rods with aluminum also. Now this operation is confined by stage of calculation studies [10].

The replacement of copper matrix of PIK fuel pins with aluminum alloy only is considered as closer perspective. Such replacement frees add-on reactivity, which may be used for increase of volume of exposed to radiation samples or increase of fuel burn-up. Change of copper with aluminum will make it possible to install up to six materials test cassettes in fission core [11].

STATE of CONSTUCTION

Construction of reactor began in 1976. Construction of building was completed and much of installation works were made in 1986. The construction of cooling circuits was completed, control and instrumentation desk mounted and adjustment of circuit pumps and valves started. The requirements for nuclear reactors safety have been revised in the USSR after Chernobyl accident. PIK design failed to meet these requirements and was revised to great extent. Reconstruction design led to significant changes in reactors systems and doubled initial cost.

Construction of containment was most clumsy part of the reconstruction. This led to necessity of dismantling of building roof coating, dismounting of all the equipment on two top floors and preservation of equipment on bottom floors. The changes in engineering part are mainly connected with add-on redundancy of safety systems.

Objectively, the construction of the reactor itself was suspended after Chernobyl accident. In the beginning the pause in construction was governed by search for reconstruction technical solutions and their approval by regulatory bodies and citizens, then by hardships of internal containment construction and later on by decrease of financing to the level close to maintenance and preservation of built structures. Nevertheless we managed to build internal containment and complete major construction works without internal decoration in 1996. In 1999 three departments interested in construction of reactor, namely the Russian Academy of Sciences, the Ministry of Atomic Energy and the Ministry of Industry, Science and Technologies adopted a resolution of the construction joint financing. This made it possible to proceed with installation of reactor systems according to already new design. The size of financing was too small to complete construction in reasonable time. In August 2007 the Russian Federation Government took decision of appropriation of funds remaining according to cost account for completion of construction in full in 2012.

We marked three stages of the design implementation:

The 1st one is performing of first criticality (startup) of reactor. The 2nd one is power startup, i.e. yield of design power of 100 MW after which physical experiment operation is feasible, and the 3rd final one, including installation of hot, cold and ultra cold neutron sources, completion of works relevant to fitting of neutron guide hall and installation of neutron guide systems, development of plant for reflectors heavy water isotope treatment.

What have we managed to do?

Practically all the buildings and structures have been built (Fig. 6).

Fig.6. Reactor PIK

The premises have been finished for installation and adjustment of equipment. Heat, power and water supply have been provided. Power substation of 110/ 6 kV, backup diesel substation and heavy water isotope treatment plant constitute the exemption. The first two of them are required at the stage of power startup, and the last one after reactor operation at design power for buildup of tritium.

The erection in process hall of reactor, including reactor vault in which reactor vessel and heavy water reflector tank are installed has been completed. The main water flow circuit and connected with it systems of emergency cooling, chemical water treatment, pressure maintenance etc. has been assembled. Systems of buffer circuit cooling have been erected.

Beams gates in experimental channels have been arranged. The power control rooms have been fully equipped. 85 % of power lines, checkout cables and small-diameter pipes to instrumentation have been completed. The installation of reactor control room and command console has been practically completed. Considerable part of fire alarm and fire extinguishing system has been installed and put into operation. About 85% of 1st stage works have been performed in general.

PREPARATION for FIRST REACTOR PIK CRITICALITY.

A critical facility “Physical model of PIK reactor” [12] has been developed for study of a set of questions relevant to physics and engineering of reactor under construction, justification of its safety and improvement of its technical performances.The critical facility “Physical model of PIK reactor” repeats design of reactor in core area, reflector and all the channels both process and experimental ones (Fig. 7) The maximum authorized power of critical assembly is 100 W. Dismountable fuel rod arrays are used in fission core.

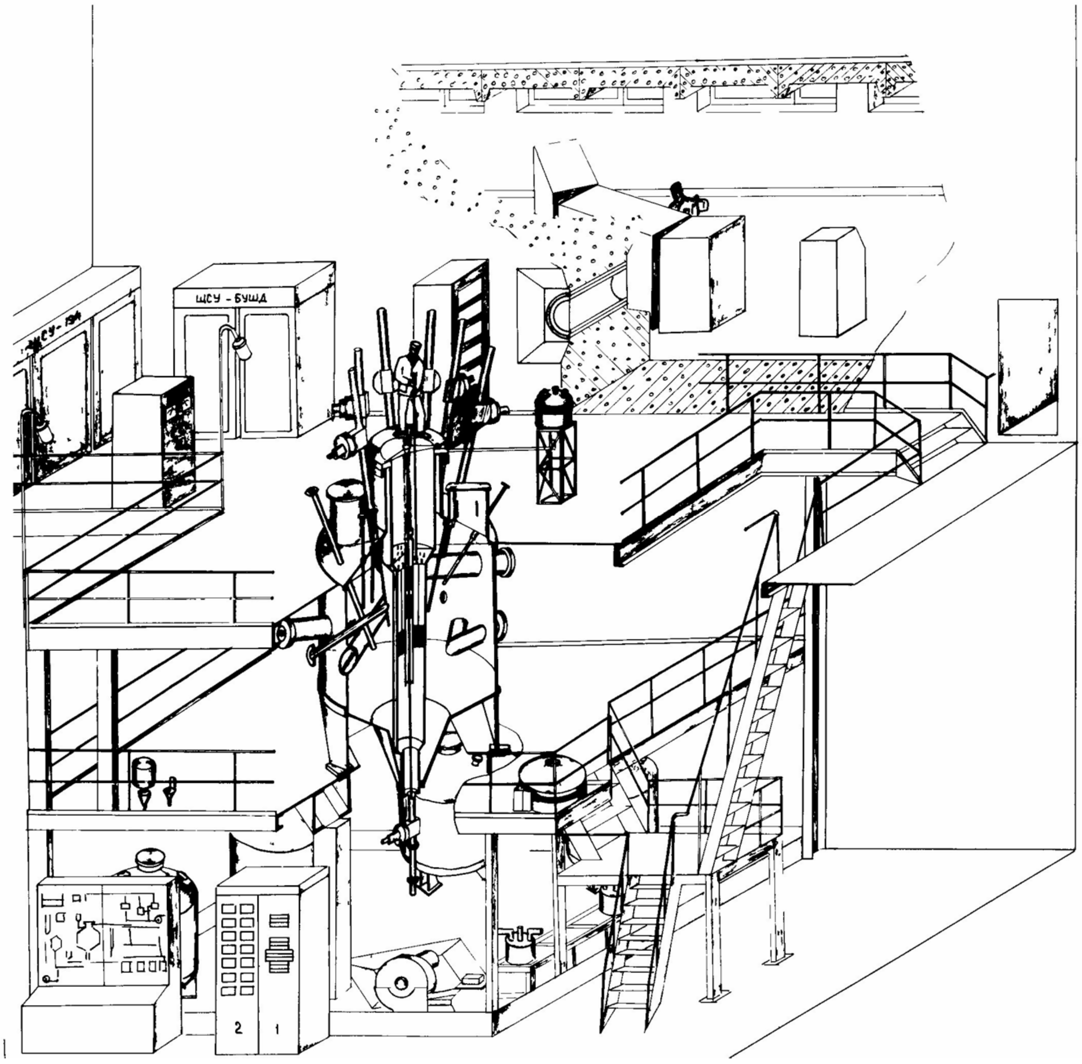


Fig. 7. The critical facility “Physical model of PIK reactor”.

It will be observed that result of calculation programs have closely coincided with experimental data [13] that give confidence in correct foundation of safety.

The development of measures for extension of PIK reactor operation cycle from two to four weeks has been most meaningful result, obtained on critical facility. This has been achieved by insertion of burnable rod absorber instead of part of displacers in the cassettes. Check of burn-off dynamics has been made on WWR-M reactor [14].

Startup set of fuel assemblies had been manufactured before development of burnable absorber rods for PIK reactor. Reactivity of this 18 fuel assemblies is not compensated by operating controls. Partial burn-off of the core is required under current operation. Aluminum displacers are used instead of three fuel road arrays for 1st loading (Fig. 8).

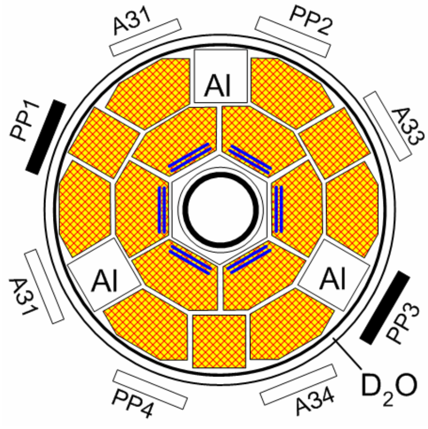


Fig. 8. Loading of 15 fuel assemblies of critical facility PIK with outside displacers. 2 rods are loaded. Depth of shutter loading $H_{шт}$ = 276 mm.

It is necessary to determine power density distribution in core, so called power density irregularity factor K_V for safe power startup. The methodic of fission products activity measuring [15,] in fuel rods drawn from dismounted fuel assemblies has been used for determination of K_V. Fuel rod itself is the indicator of fission rate. An example of power density distribution in most energy intensive internal fuel assembly array is presented in fig. 9 (variant of 15 fuel assemblies).

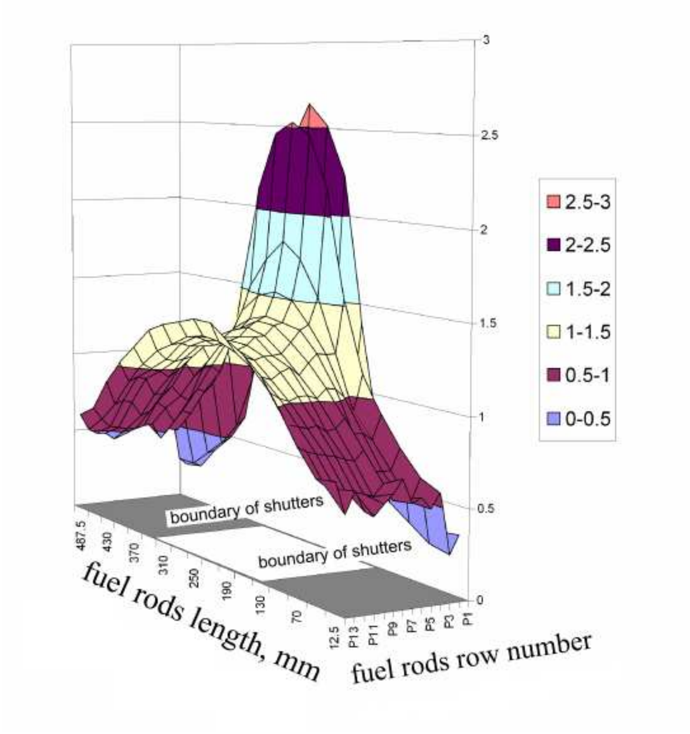


Fig.9. Distribution of power density over fuel rods length in internal fuel rod array.

The Max. value of K_V =2.6±0.2 ha been obtained for fission core of 15 fuel rod arrays. The Max value of K_V =2.7±0.2 has been obtained for fission core of 12 fuel rod arrays. In both cases the first layer of fuel with content of fuel equal to 1/3 of the nominal level proved to have maximum energy density. The 2nd layer also with reduced fuel loading is undercharged strongly. D_f in it is approximately less by 40%. This shows non-optimality of fuel profiling in fuel rod array startup set. K_V=2.5±0.2 in 3rd layer of fuel rods with nominal loading of uranium if the core of 15 fuel assemblies and K_V =2.6±0.2 in the core of 12 fuel assemblies.

The mentioned K_V values are visibly lower than admissible value of K_V =3.3±0.3 for core with complete number of 18 fuel assemblies. Increase of average specific power density by 12 % and by 31% due to reduction of number of fuel rods in startup cores of 15 fuel assemblies and 12 fuel assemblies accordingly will not lead to excess heat loads in most energy intensive fuel pins.

Operation at power up to 100 MW without restrictions is feasible for choused startup loading.

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