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3.7. A.I. LEYPUNSKY INSTITUTE OF PHYSICS AND POWER ENGINEERING

S.G. KALYAKIN
Acting General Director
SSC IPPE

The history of the Institute of Physics and Power Engineering (IPPE) dates back to December 19, 1945, when Laboratory "V" was established by a decree of the USSR Council of People's Commissars as the country's first research organization for development of power reactors. Laboratory "V" was incorporated into the First General Office of the USSR Council of Ministers in 1949 and was subordinated to the Ministry of Medium Machine Building in 1953, keeping this affiliation through all the later years and several reforms of the Ministry. In 1960, the Laboratory came to be referred to as the Institute of Physics and Power Engineering, in 1994 its status was changed to a State Scientific Centre, and in 1996 it was named after A.I. Leypunsky.

Main building of the Institute

In 1949 through the early 1950s, A.I. Leypunsky organized initial calculations for reactors with various core configurations, coolants, protection features, etc., which largely shaped the plans for subsequent development of the Institute and the main line of its independent scientific activities – the fast and intermediate neutron reactors. As suggested by I.V. Kurchatov, Laboratory "V" was entrusted with the work on design of the First Nuclear Power Plant under guidance of Laboratory Director D.I. Blokhintsev. Thus, in the first half of the 1950s, the efforts of A.I. Leypunsky and D.I. Blokhintsev gave a final form to the Institute's long-term research program – which is valid to this day.

This long-term program of the IPPE focused on the following areas:

- thermal neutron reactors for nuclear power plants;
- fast neutron reactors for nuclear power plants;
- reactors for nuclear power systems of submarines;
- reactors for nuclear power systems of space vehicles.

It was clear that for the goals set to be attained, the Institute needed strong experimental and technological capabilities, and preparations to this end were started in the early 1950s. All in all, the rigs it had and operated at IPPE included 7 research reactors and 22 critical facilities.

The AM reactor of the First NPP was one of such experimental facilities, which served the purposes of neutronic research, studies in the solid-state physics, tests of fuel elements and thermionic channels, isotope production, etc., to the shutdown of the plant.

Owing to its unique experimental and technological capabilities, the IPPE succeeded in guiding the design of more than 120 various reactor facilities, including the AMB reactors of the Beloyarsk NPP, experimental fast reactor BR-10 (Obninsk), pilot fast reactor BOR-60 (Dimitrovgrad), the world's first fast power reactor BN-350 (Aktau, Kazakhstan), fast reactor BN-600 operating in the grid of the Urals, EGP-6 reactors of the Bilibino nuclear co-generation plant, pulsed fast reactor IBR (Dubna), lead-bismuth-cooled reactors for nuclear submarines (hulls 645 and 705), space thermionic conversion reactors BUK and TOPAZ.

D.I. Blokhintsev
Director of Laboratory "V" in 1950–1956

A.I. Leypunsky
One of the Laboratory "V" founders and scientific leader of IPPE in 1959–1972

Nuclear research facilities of the SSC IPPE

Type	Name	Thermal power, kW	First criticality year	Status	Operation period, years*
RR	BARS-6	10.00**	1994	In operation	18
CF	AMBF-2-1600	0.10	1984	In operation	28
CF	BFS-1	0.20	1962	In operation	50
CF	BFS-2	1.00	1969	In operation	43
CF	MATR-2	0.40	1963	In operation	49
CF	FS-1M	0.10	1970	In operation	42

** As of 2012*
*** In static conditions*

SSC IPPE is a diversified scientific organization of the nuclear industry, which is a leader in development of various nuclear power systems.

Over the decades of research and engineering activities, the IPPE nurtured ten schools of thought to the world level. Almost all of them take their rise from the first and outstanding school raised by A.I. Leypunsky in the sphere of nuclear science, reactor physics and engineering.

TWO-CORE PULSE REACTOR BARS-6

The two-core pulse fast neutron reactor BARS-6 of self-quenching action is the corner-stone of the reactor-and-laser facility Rig B which offers unique experimental capabilities for dealing with a whole number of scientific and engineering problems.

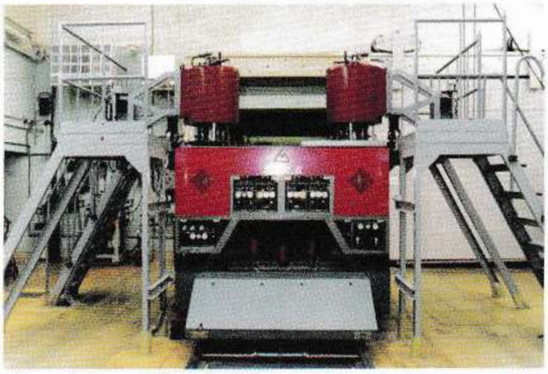
BARS-6 reached its first criticality on December 30, 1994, and first power on July 13, 1995. Extensive experiments at the reactor were launched in 1996.

The BARS-6 reactor has two small size cores, each built of uranium-molybdenum fuel disks with a special protective coating. Each core contains 105 kg of ^{235}U (of 90 % enrichment). The cores are surrounded by an amorphous ^{10}B screen 5 mm in thickness. The main reactivity controls are also made of uranium-molybdenum alloy, with the exception of the pulse rod and the reactivity regulator. The distance between the cores can be varied in the range from 337 to 1500 mm to shape the neutron and gamma radiation fields at test specimens.

Rig B building

BARS-6 can operate in the pulse and static modes.

In its main operating mode BARS-6 generates sharp and strong neutron and gamma radiation pulses at a rate of 1…2 pulses in 24 hours. Each pulse is followed by forced air cooling of the reactor. Besides, the reactor can operate in a static mode at power up to 10 kW.



General view of BARS-6 (the cores are behind a biological shield)

Main performance of the BARS-6 reactor

Pulse mode

Number of fissions per pulse in one core........$\leq 2\cdot10^{17}$

Neutron pulse duration.............................70…300 μs

Peak power..$\leq 10^{11}$ W

Effective delayed neutron fraction.............0.0069 β_{eff}

Prompt supercriticality................................$\leq 0.4\ \beta_{eff}$

Neutron fluence in the irradiation area....$\leq 2\cdot10^{14}$ cm^{-2}

Gamma dose in the irradiation area ....$\leq$ 1000 Gy

Gamma dose rate in the irradiation area ....$\leq 10^{7}$ Gy/s

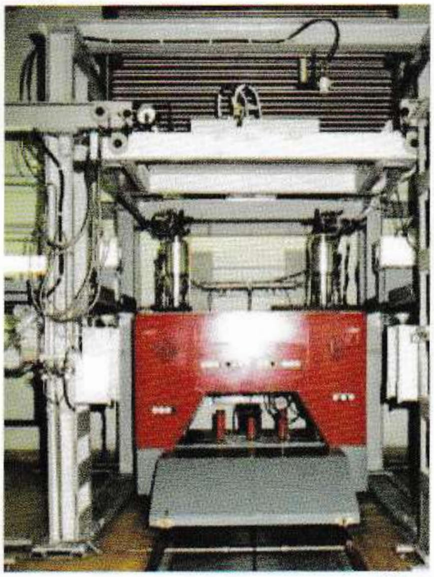
Static mode

Power...$\leq$ 10 kW

Neutron fluence in the irradiation area over 100 min with operation at 1 kW..........$\sim10^{14}$ cm^{-2}

Cumulative dose in the irradiation area per shift (5 hours) with operation at 1 kW.......................................$\leq$ 1000 Gy

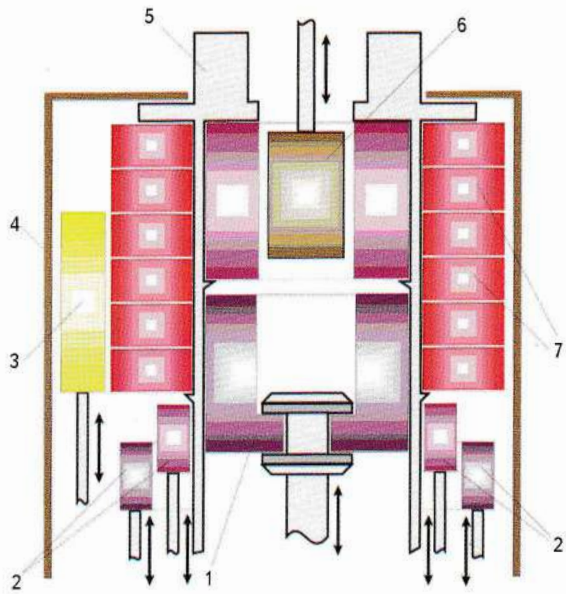
Fast neutron flux ($\geq$0.1 MeV) in the irradiation area with operation at 1 kW...$\leq 10^{10}$ $cm^{-2}\cdot s^{-1}$



a

b

The reactor-and-laser system of Rig B:
a – laser block raised; b – laser block lowered



BARS-6 core map:
1 – safety unit; 2 – controls; 3 – pulse rod; 4 – shield; 5 – support tube; 6 – reactivity regulator; 7 – fuel disks

Experimental capabilities of BARS-6

Experimental measurements of thermal and mechanical characteristics of fast reactor fuel under conditions of power ramps.

Tests of active laser components with different active laser media.

Pulse operation together with the subcritical laser block.

Radiation resistance tests of various diagnostic systems for thermal and fast reactor parameters.

Main areas of studies

The BARS-6 reactor can travel by the rail track between its two work places – the extreme positions in the reactor room.

Operations at the first position:

– studies on basic processes in nuclear-induced plasma;

– development of reactor-laser technologies and search for promising active laser media;

– studies on basic problems in physics of pulsed multicore reactor systems;

– studies on radiation and heat resistance of electronics, reactor components, other products, materials and substances;

– research in radiation chemistry;

– medical and biological studies.

At the other position, BARS-6 acts as the driver reactor unit of a powerful mockup laser system built around a nuclear pumped laser amplifier (OKUYAN).

Besides the reactor unit, the OKUYAN mockup – a unique 3-core pulse reactor system – comprises a laser block converting fission energy to laser energy directly.

For the fission pulse to be generated, the whole system is brought to prompt supercriticality by quick withdrawal of the reactivity regulator (at a rate of ~100 β_{eff}/s) from one of the BARS-6 cores, with the laser block and the reactor proper remaining subcritical (in terms of prompt neutrons). Neutrons from both reactor cores enter the laser block, are moderated and multiplied there, causing uranium fission in active laser elements.

By giving off part of their energy, fission products give rise to non-equilibrium (in recombination term) nuclear-induced plasma in the active laser medium. The energy stored in this medium can be brought out of ALEL by means of a special optical system.

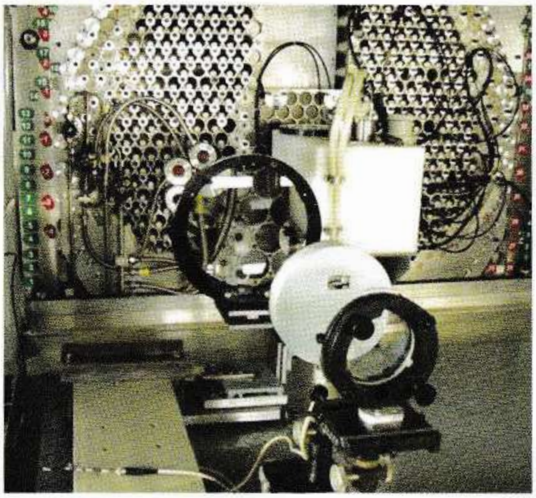
The output laser energy is increased by replacing the ALEL simulators with regular active laser elements.

Main activities

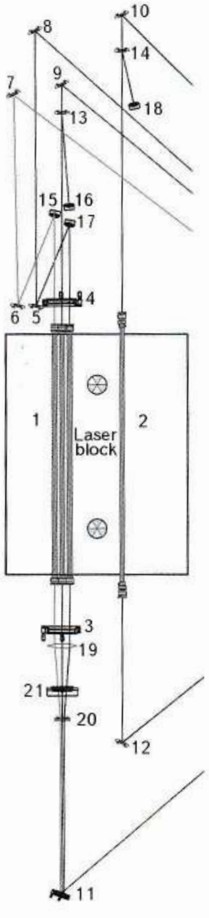
In 2011, the reactor utilization factor made 0.27.

A new fission pulse generation mode is implemented, with reactivity "modulation" by forced insertion of safety units.

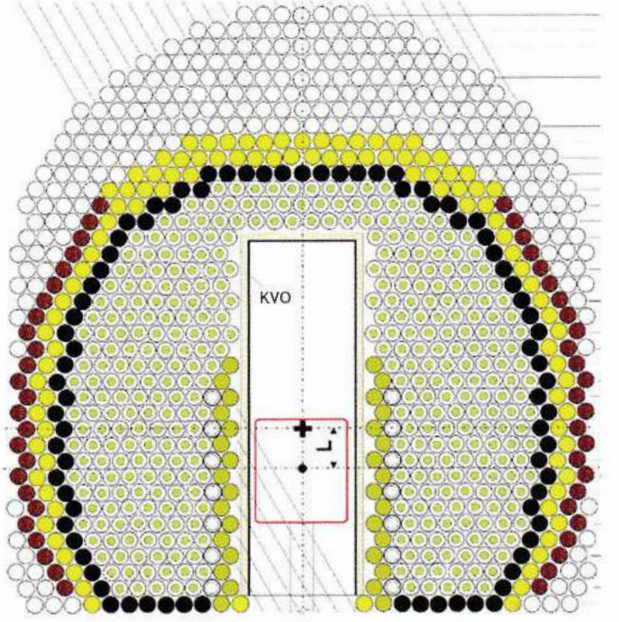
Visible and infrared laser light of high specific characteristics was for the first time emitted from the multi-element laser channel under the



Multi-element laser channel in the laser block of the reactor-laser system of Rig B



Laser optics system:
1 – experimental laser channel; 2 – separate ALEL; 3, 4 – dielectric-coated mirrors of the laser channel resonator; 5–12 – aluminum-coated swivel mirrors; 13, 14 – dielectric-coated split mirrors; 15 – 18 – calorimeters KDM-3; 19, 20 – telescope lenses; 21 – calorimeter BKDM



Laser block map:

- *– outer paraffin-filled neutron reflector;*
- *– ALEL simulator with a polyethylene rod;*
- *– aluminum tube;*
- *– power increase channels;*
- *– laser block centre;*
- *– BARS-6 core centre;*
- *– outer graphite-filled neutron reflector;*

KVO – box-type inner reflector

conditions of a subcritical laser block controlled by the driver reactor neutron flux.

A multi-channel system was set up for recording dynamic power and thermal characteristics of test specimens.

Near-term activities include:

– upgrading of the radiation monitoring system of the reactor and laser complex;

– optimization of the OKUYAN mockup optical system;

– improvement of the system for measuring thermal and mechanical parameters of irradiated specimens during pulsed variations of energy release;

– provision of a working place for life tests of prospective neutron and gamma-quantum diagnostic systems.

Contact person

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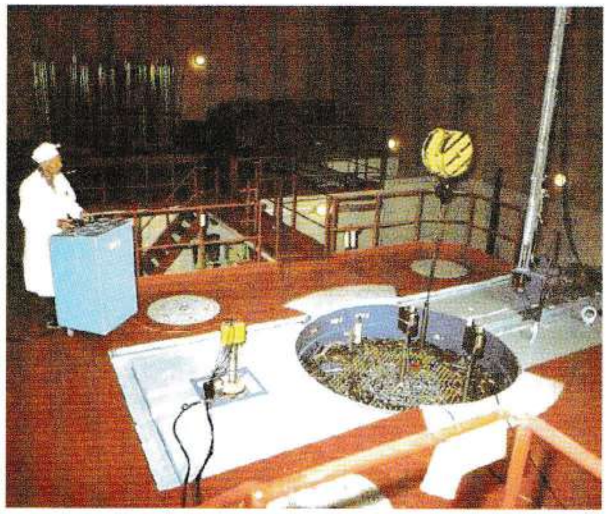
FAST NEUTRON FACILITY BFS-1

The BFS-1 critical facility comprises a critical assembly which makes it possible to model fast neutron reactors cooled by sodium or lead, reactors of the VVER type (with water simulated by slugs of polyethylene) and/or uranium-thorium and/or plutonium fuel with 5 to 70 % enrichment in fissile isotopes. The facility reached its first criticality on February 20, 1962.

The BFS-1 is designed for full-scale studies of the neutronic characteristics of fast reactors under development.

The facility vessel is a vertical steel tank 2 m in diameter and 2.7 m in height which is large enough to accommodate full-size models of fast neutron research and power reactors under design up to 1000 MWt in capacity with cores and screens of various configurations. At the bottom, the tank has a spacer grid which appears as a steel plate 100 mm in thickness with holes of diameter 35 mm placed in a triangular lattice with a pitch of 51 mm. The tank is fully taken up by steel or aluminum tubes (~1500) with the diameter of 50×1 mm, whose tailpieces enter the openings in the spacer plate. The tubes are loaded with pellets of fuel, fertile material, structural materials and coolant in the order, quantities and proportions to match their composition in the cores, blankets and reflectors of the modeled reactors.



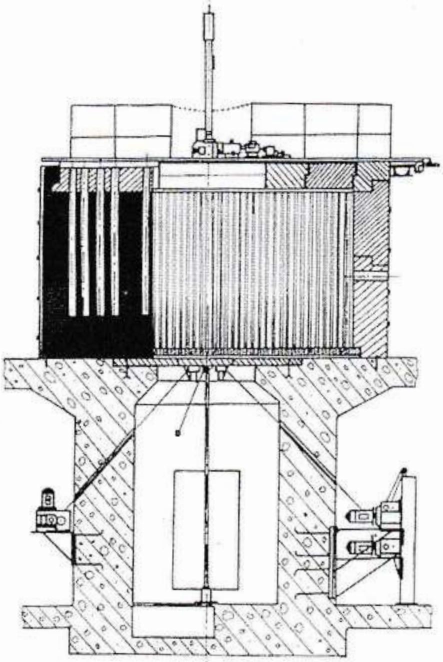
BFS-1 loading pad

Main performance of BFS-1

Power	0.2 kW
Moderator in LWR models	Distilled water, boric acid solution, polyethylene
Simulated coolant	Na, Pb, Pb-Bi
Reflector	U, UO_2, Pb, Pb-Bi, steel
Fast neutron flux, max.	10^{10} $cm^{-2} \cdot s^{-1}$
Core cooling	Natural convection or forced air cooling

Some tubes found in the central part of the tank have block-cable linkage and perform the functions of emergency protection, reactivity compensation and chain reaction regulation members in the core. These tubes are parts of the CPS components. Their composition (a set of pellets of the reactor materials in the core and screens) is similar to that of the surrounding core rods.

The BFS-1 facility has three emergency protection (EP) components, which leave the core by gravity in response to an emergency signal, three shim components and two automatic control (AC) components. Each of the EP and shim components occupies two tubes



BFS-1 in section

A specimen of the BFS-1 fuel rod

of the critical assembly, while the AC components take up one tube each. In response to an emergency signal, the shim and AC components exit from the critical assembly at the maximum speed.

The designs of the EP, shim and AC components copy that of a fuel assembly, with the only difference that the tubes of the CPS components are longer and there are slugs or tubes with neutron absorber (boron carbide, boron carbide plus polyethylene, europium dioxide) above the top end screen.

The BFS-1 facility was used for studying models of fast reactors, such as IBR-2, BOR-60 and BN-350.

The facility fuel is a composition of slugs of plutonium and/or uranium metal (with 36 and/or 90 % enrichment in ^{235}U) with slugs of fertile or feed materials, such as thorium metal, uranium and/or dioxide of depleted uranium and neptunium dioxide.

The BFS-1 assembly can simulate fuel of metal, oxide, monocarbide and, in a longer term, nitride varieties. The fissile material inventory is large enough (~ 8 t of highly enriched uranium and plutonium) to allow building full-size models of cores and blankets of large fast reactors.

The ample quantities of neptunium dioxide and thorium metal make it possible to carry out experimental studies of reactor cores designed for burning (transmutation) of minor actinides or producing uranium-233.

When critical assemblies are studied, miniature fission chambers moving with the help of a measurement device, measure the neutron flux distribution in the critical assembly volume. For such measurements, miniature fission chambers are placed in the space between the tubes of the core and screens. During activation measurements, the irradiated indicators are found in fuel rods between disks of the materials forming the composition of the critical assembly core.

Main areas of studies

The BFS-1 facility is used for:

– studies to substantiate safe operation of sodium- or lead-cooled fast reactors and reactors of the VVER type;

– development and introduction of new techniques for determining the neutronic characteristics of fast reactors and VVERs;

– experiments for verification of neutronic analysis procedures and codes for fast reactors and VVERs.

FULL-SIZE PHYSICAL MODEL OF A LARGE POWER REACTOR OF THE BN TYPE – BFS-2

The BFS-2 critical assembly is designed for studies of large fast reactors. BFS-2 reached first criticality on September 30, 1969.

The BFS-2 design is similar to that of BFS-1, but is large enough for building models of fast reactors with rated thermal power as high as 7000 MW. Its tank measures 5 m in diameter, 3.3 m high, and houses about 10 000 tubes. The tubes have the same diameter as in BFS-1 and are filled with the same sort of reactor material pellets when critical assemblies are configured.

Main performance of BFS-2

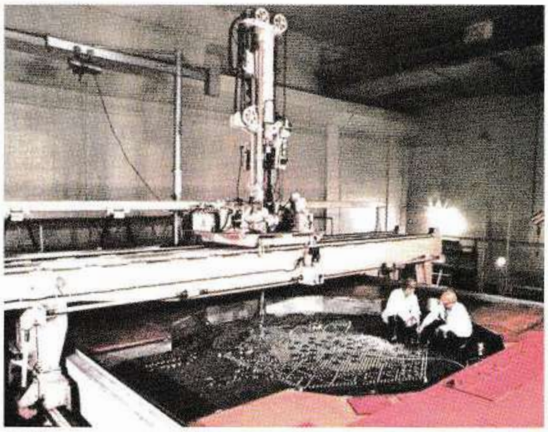
Power	1.0 kW
Moderator (for modeled LWR)	Distilled water, boric acid solution, polyethylene
Simulated coolant	Na, Pb, Pb-Bi
Reflector	U, UO_2, Pb, Pb-Bi, steel
Fast neutron flux, max.	10^9 cm^{-2}·s^{-1}
Core cooling	Natural convection or forced air cooling

The BFS-2 facility can use 8 emergency protection components, each comprising four tubes, 9 shim components of six tubes, 2 control components each housed in two tubes, and 1 control component arranged in one tube.

The BFS-2 facility is equipped with a rectilinear manipulator which is used for rearrangement of tubes in the tank, automatically controlled positioning of specimens and detectors within the critical facility, and can operate in the oscillator mode.

BFS-2 lattice

It was involved in experimental studies on core and blanket models of the BN-600, BN-800 and BN-1600 reactors (with uranium oxide fuel), as well as in simulations of fast reactors with fuel of various types.



BFS-2 reactor compartment

BFS-2 CF control room

Reactor models are built of reactor material slugs loaded into steel tubes 50×1 mm in diameter, which are installed in a hexagonal lattice with a pitch of 51 mm in a tank of diameter 5 m.

The fuel is a combination of plutonium, and/or uranium, and/or uranium dioxide slugs (with 36 and/or 90 % enrichment in ^{235}U) with slugs of fissile materials (depleted uranium, thorium, depleted uranium dioxide, and neptunium dioxide).

Main areas of studies

The BFS-2 critical facility is used for:

– studies to substantiate safe operation of large fast power reactors with sodium coolant;

– development and introduction of new techniques for determining the neutronic characteristics of large fast reactors cooled by sodium;

– experiments for verification of neutronic analysis procedures and codes for large sodium-cooled fast reactors.

International collaboration

The BFS-1 and BFS-2 critical facilities serve for experimental studies ordered by: the USA (studies on models of geological repositories of highly enriched uranium to investigate their safety in the event of water ingress), China (studies on models of the CEFR reactor with uranium oxide fuel), Korea (studies on models of the KALIMER reactor with uranium oxide and uranium-plutonium metal fuel), France (comparison of measurement methods, experimental investigations into the problem of burning minor transactinides in a fast reactor), Japan (studies on models of fast reactors of the BN-800 type for NPP), India and other countries.

Main activities

The BFS-1 and BFS-2 facilities were used for experimental studies of SVBR-100 and BN-800 reactor models. The utilization factor of these facilities approximates 0.80. The BN-800 and SVBR modeling is completed, studies on the Korean reactor model is in progress.

Considering that the BFS facilities have been in operation for about 50 years, it is planned to upgrade their engineered systems and to procure new materials for core models and hardware for research work. These objectives are included in the Federal Targeted Program (FTP).

The FTP "Nuclear Power Technologies of a New Generation for the Period of 2010–2015 and to 2020" envisages upgrading and retrofitting of the complex of large physical facilities for modeling fast reactors and their fuel cycles with the aim of completing validation of the design features and safety characteristics of BN-800 reactor and providing for experimental studies on models of fast reactors BN-1200, BREST-300, SVBR-100, MBIR and other prospective reactors being designed for NPP.

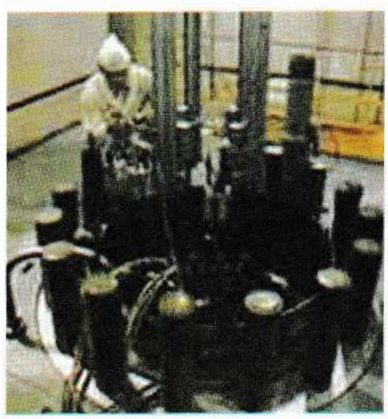
In view of the above, the current plan is to continue using BFS-1 till 2030 and BFS-2 till 2035.

PHYSICAL MODEL OF SMALL TRANSPORTABLE REACTOR MATR-2

The critical facility MATR-2 (small-size transportable nuclear reactor) is a high-temperature uranium-water physical model of a small nuclear transportable reactor. MATR-2 reached first criticality on August 2, 1963.

The facility is intended for investigating the temperature effects of reactivity of uranium-water lattices of small power reactors and regular lattices to assess the operational safety of advanced VVER and to verify the accuracy of their physical characteristic calculations.

MATR-2 has undergone several upgrades. Its service life is extended to February 22, 2014.



Critical facility MATR-2

The facility can heat up its uranium-water critical assemblies ~1.2 m^3 in volume to 240 °C at pressures up to 7.3 MPa.

Main areas of studies

Research work.

Main activities

In the absence of orders for experimental studies, the facility has been in prolonged shutdown since August 01, 2010.

The basic equipment is obsolete and aged.

Work is in progress to prepare MATR-2 for decommissioning.

Contact person

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Main performance of MATR-2

Power	Up to 400 W
Number of fuel assemblies	Up to 55
Number of fuel elements	Up to 5000
Fuel	UO_2
Enrichment in ^{235}U	5 %
Thermal neutron flux	~10^8 cm^{-2}·s^{-1}
Fast neutron flux	~10^9 cm^{-2}·s^{-1}
Moderator	Water
Reflector	Iron and water
Circuit pressure	Up to 7.3 MPa
Moderator temperature	Up to 240 °C

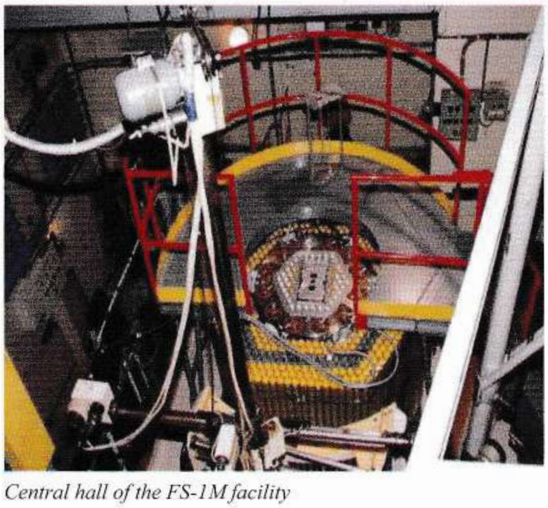
VERSATILE PHYSICAL FACILITY WITH A BERILLIUM REFLECTOR FS-1M

The FS-1M facility comprises a zero-power fast reactor with a beryllium reflector. It was brought to first criticality on March 3, 1970.

Its purpose is to substantiate the neutronic characteristics of thermionic fast neutron reactors.

After its upgrading in 2003, the FS-1M facility with a critical assembly (FS-1-4.37.R) has been used for radiation tests of electronics and materials of various domestic organizations and enterprises, for characterisation of neutron detectors and their certification.

The FS-1-4.37.R critical assembly is a heterogeneous intermediate neutron facility with



Central hall of the FS-1M facility

a central cavity measuring 200×320×500 mm in the core, intended for accommodation of test objects, and a side beryllium reflector containing 12 placed in a circle and equally spaced rotary CPS elements with neutron absorber material.

The central cavity has a propylene shell located on its boundary to set up an intermediate neutron spectrum in the cavity volume.

The radial and axial peaking factors of the certified neutron and gamma-ray fields in the central cavity are estimated at 1.02 and 1.05, respectively.

The FS-1M facility allows conducting radiation tests of products in the central cavity of the critical assembly at power levels up to 200 W during time periods from several hours to several days.

Experimental capabilities

The effects of special factors achieved at FS-1-4.37.R critical assembly include: total neutron fluence – $1.3 \cdot 10^{15}$ cm^{-2}; fast neutron fluence – $5.5 \cdot 10^{14}$ cm^{-2}; absorbed dose of γ-quanta – $6.2 \cdot 10^{7}$ J/kg; temperature – no higher than 55 °C.

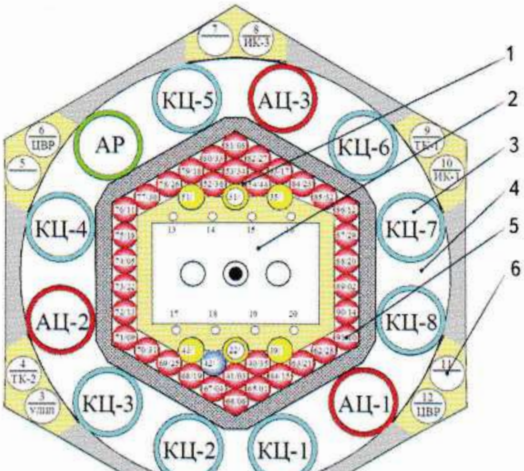
The metrological and dosimetric support of radiation tests is provided from the workstation of the FS-1M facility:

– the on-line mode involves fission chambers KNTK-2, -5, -8 and KNK-56 (for neutron fluence monitoring), gamma counters SI-29B, diamond dosimeter DKDa-01 (for absorbed gamma dose monitoring) and thermocouples KTKhS-I (for temperature monitoring);

– the off-line mode involves activation detectors (gold and nickel foils) of neutron fluence and absorbed gamma dose (special quartz glass).

Main performance of the FS-1M facility

Thermal power	Up to 200 W
Height of the critical assembly core	740±10 mm
Volume of the critical assembly core	167 dm^3
Critical load in ^{235}U	228 kg
Reactivity, highest possible	6.5 β_{eff}
Worth of CPS rods	12 β_{eff}
Reactivity of test objects, max.	-4.0 β_{eff}
Delayed neutron fraction, eff. (calculated)	0.0071



FS-1M facility in section:
1 – core; 2 – central cavity; 3 – CPS member; 4 – beryllium reflector; 5 – FA; 6 – CPS channel

LARGE URANIUM-GRAPHITE FACILITY AMBF-2-1600

Central hall of AMBF-2-1600

The AMBF-2-1600 critical facility contains a heterogeneous uranium-graphite assembly. It was brought to first criticality on November 22, 1984.

The experience of AMBF-2-1600 operation proves its reliability and safety.

SSC IPPE is the Chief Designer of the AMBF-2-1600 facility and acts as a scientific supervisor of its operation.

The AMBF-2-1600 critical facility is meant for:

– experimental studies with instrumentation and methods for monitoring parameters important to the safety of nuclear power facilities;

– integrated tests of the equipment developed and manufactured in the Nuclear Safety Division for nuclear power facilities;

– development and testing of reactivity monitoring methods.

Main performance of the AMBF-2-1600 facility

Maximum power	100 W
Reactivity β_{eff}	0,65 %
Reactivity margin	$\leq 0.3\ \beta_{eff}$
Reactivity, highest possible*	$2.8\ \beta_{eff}$
Temperature coefficient of reactivity	$-2\cdot10^{-5}$ °C^{-1}
Prompt neutron lifetime	$1.2\cdot10^{-3}$ s
Fuel element lattice pitch	200×200 mm
Number of emergency protection rods	3
Number of shim rods	2
Number of manual control rods	1
Time taken by CPS rods to enter the core in response to an emergency signal	< 1 s
Minimum number of fuel rods to form a critical load	56

** In operation with neutron-absorbing experimental devices*

Contact person

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