STATE SCIENTIFIC CENTER —
RESEARCH INSTITUTE OF ATOMIC REACTORS

RIAR

ROSATOM STATE CORPORATION

MIR reactor: fifty years in operation

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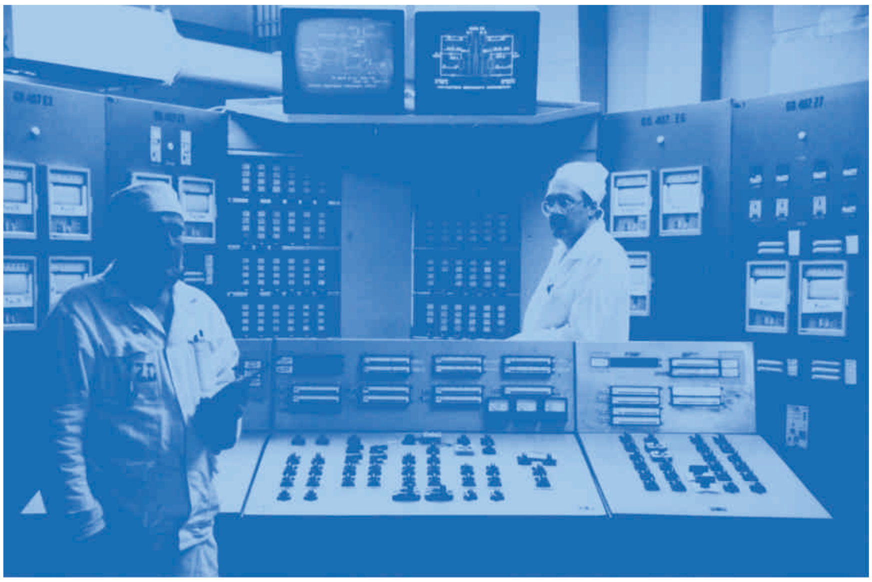

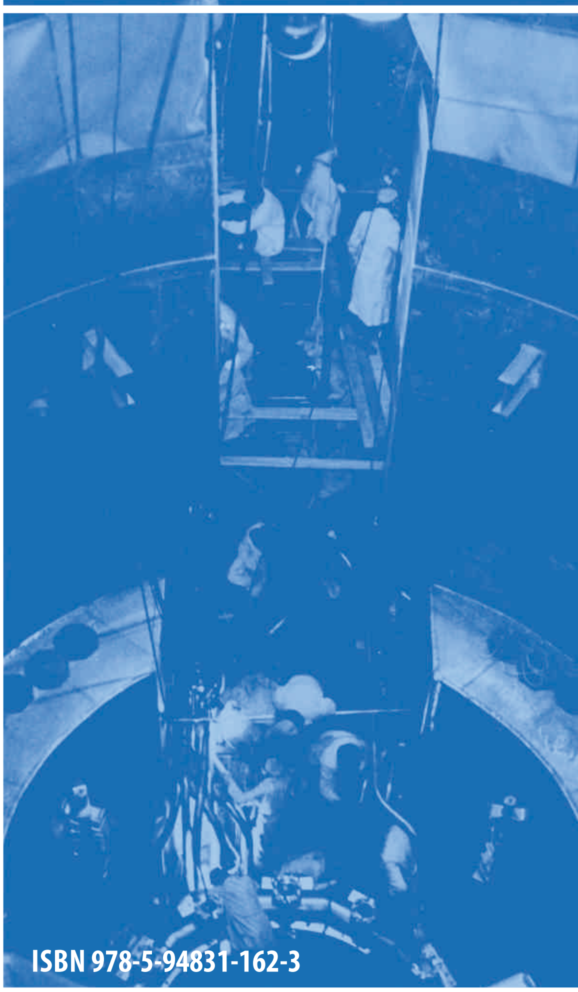

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Reactor MIR: 50 years in operation

1950

1956
Start of activities to design a loop-type research reactor thus addressing the development of experimental works in the nuclear engineering area

1958–1959
Experiments were done at the Nuclear Energy Institute to specify the MIR physical layout

1960

October 1966
MIR physical model was commissioned

December 1966
MIR first criticality

1967
MIR first criticality with loops PV-1 and PVK-1

1968
Sodium-cooled loop PM-1 was commissioned

1970

1975
First refurbishment and renaming into MIR.M1

1975
Water-cooled loops PV-2 and PVK-2 were commissioned

1980

1980
Loop PO-1 with the organic coolant was commissioned

1983
Commissioning of loop PVP-1, where experimental fuel rods are cooled with either water or water steam

1989
Loop PVP-2 with the water-steam coolant was commissioned

1990

1990
Gas-cooled loop PG-1 was commissioned

2000

2005–2015
Upgrading of loops PV-1,2 and PVK-1,2; replacement of core components, upgrading of process systems to extend the reactor lifetime till December 31, 2025

Reactor MIR.M1

The loop-type research reactor MIR.M1 is designed mainly to test fuel elements and fuel assemblies for different types of power and research reactors under the steady-state and transient operating conditions as well as for accident simulations

At present, the MIR.M1 reactor operates seven loops:

- two high-temperature water loops;
- two high-temperature boiling water loops;
- two steam-water loops to test experimental fuel elements and fuel assemblies under accident conditions;
- gas-cooled loop to test fuel elements and materials of high-temperature gas-cooled reactors.

The reactor building is also equipped with:

- reactor physical model to experimentally specify the neutronic irradiation condition;
- two hot cells for non-destructive examinations of fuel elements and handling of experimental rigs and fuel assemblies to either disassemble them for further tests or utilize them;
- laboratory to analyze the coolant quality and measure the fission products activity.

MIR.M1 parameters

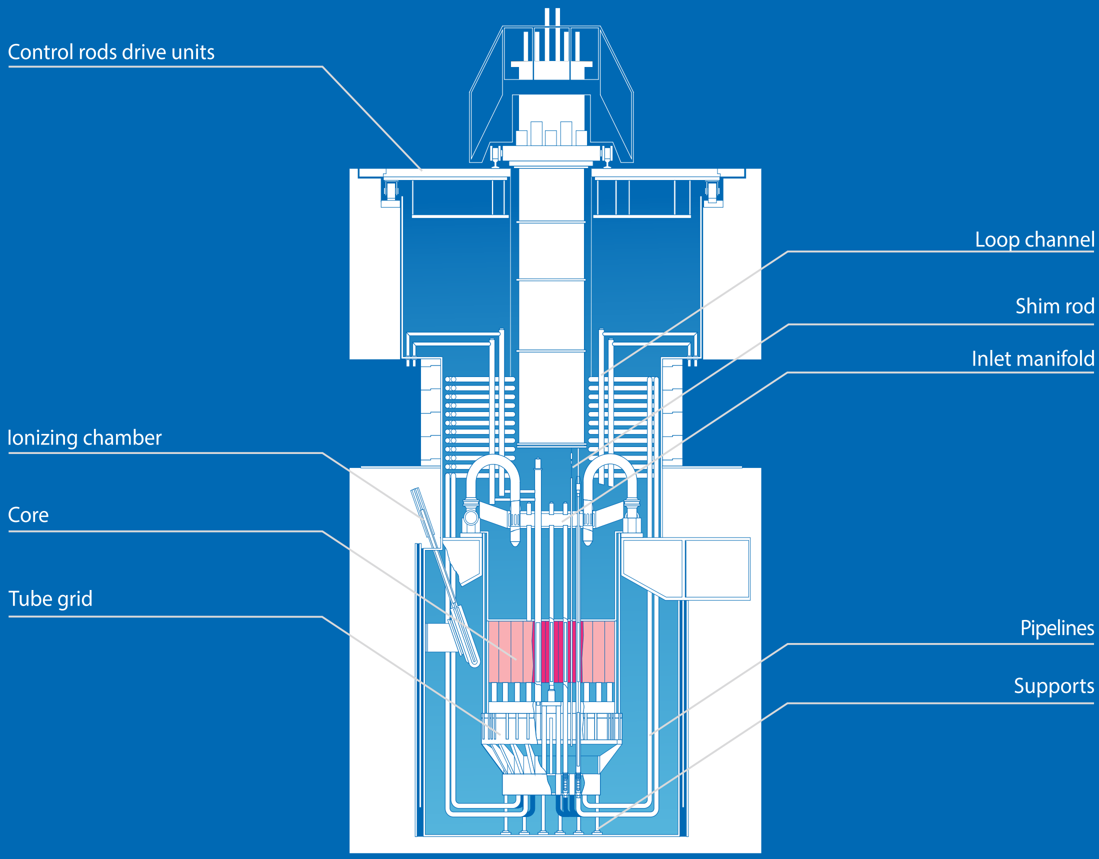
MIR.M1 is a channel-type reactor with the core immersed in the water pool. The reactor core is arranged of hexagonal beryllium blocks (148.5mm width across flats) containing zirconium channels for standard fuel assemblies and loop channels for experimental rigs. The standard fuel assembly is composed of four concentric annular fuel elements containing ceramic metal as fuel (UO_2 and Al mixture) cladded with aluminum alloy.

Several movable fuel assemblies are attached to absorbers to change reactivity. Shim rods located in the beryllium blocks are also used for power regulation in the core and loop channels. Experimental rigs can be inserted into the core with no use of the loop channels.

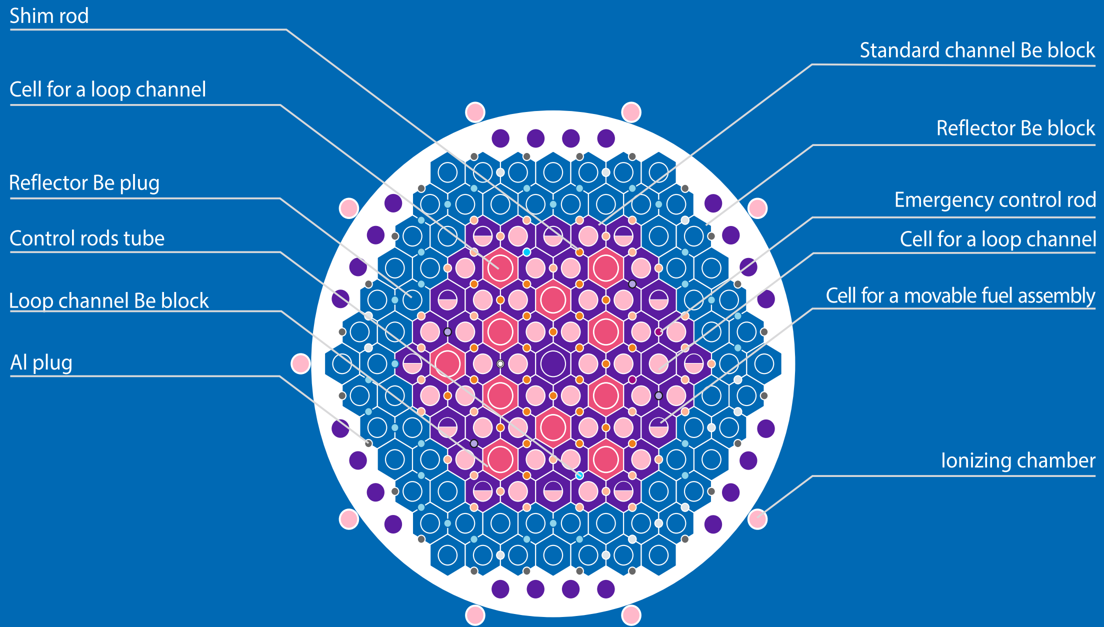
Technical Specifications

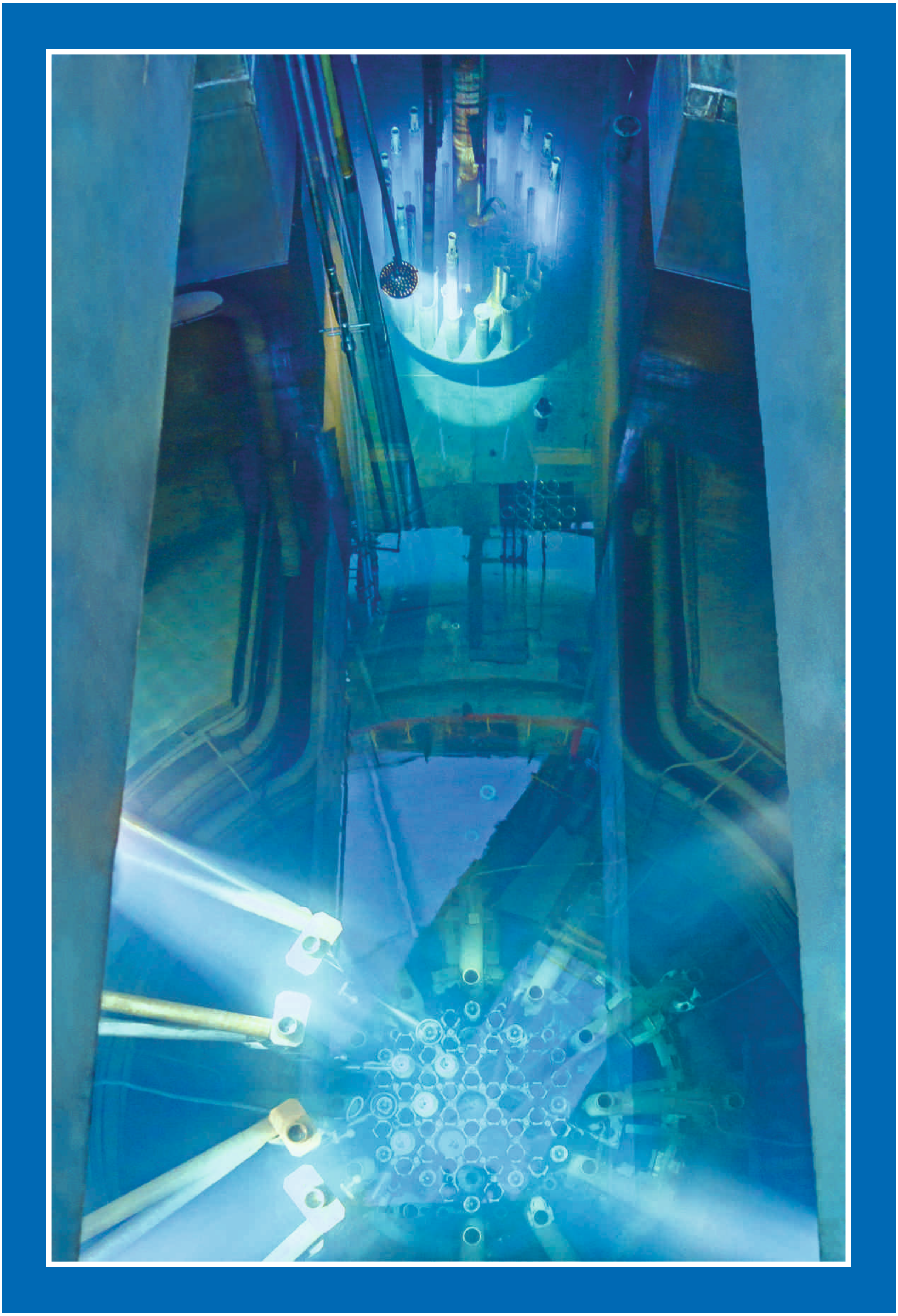
Parameter	Value
Max thermal capacity, MW	100
Max neutron flux density, $m^{-2}\cdot s^{-1}$	$5 \cdot 10^{18}$
Fuel	UO_2 in Al matrix
Enrichment in U-235, %	90
Moderator	Be, water
Reflector	Be
Primary coolant	Water
Temperature, °C:	
at the core inlet	30–70
at the core outlet	Up to 98
Coolant flow rate, m^3/h	no higher than 3000
Coolant inlet pressure, MPa	1,25
Control rods:	
emergency control rods	2
shim rods	22
scram rods	6
Channels with movable assemblies	12
Uranium-235 burnup, %:	
in the core	20–25 (average)
in the discharged fuel	Up to 60
Loop channels:	
pressurized water loop channel	4
boiling water loop channel	4
steam and water loop channel	1–2
gas loop channel	1
Power operation days per year	Up to 240

Vertical cross-cut



Reactor core





Loop facilities

Seven loops are available in the MIR.M1 reactor each connected to one or two loop channels that accommodate experimental rigs, fuel assembly dummies or components.

Equipment:

- circulation circuit (pumps, heat exchangers, pressurizes, a separator, condensers);
- cladding integrity control system (by delayed neutrons and coolant gamma-activity);
- systems for coolant chemistry treatment, feeding and sampling, and ion exchange filters;
- emergency heat removal systems;
- equipment for vacuum insulation of loop channels;
- systems for on-line parameters measurements and recording.

Parameters of Loops:

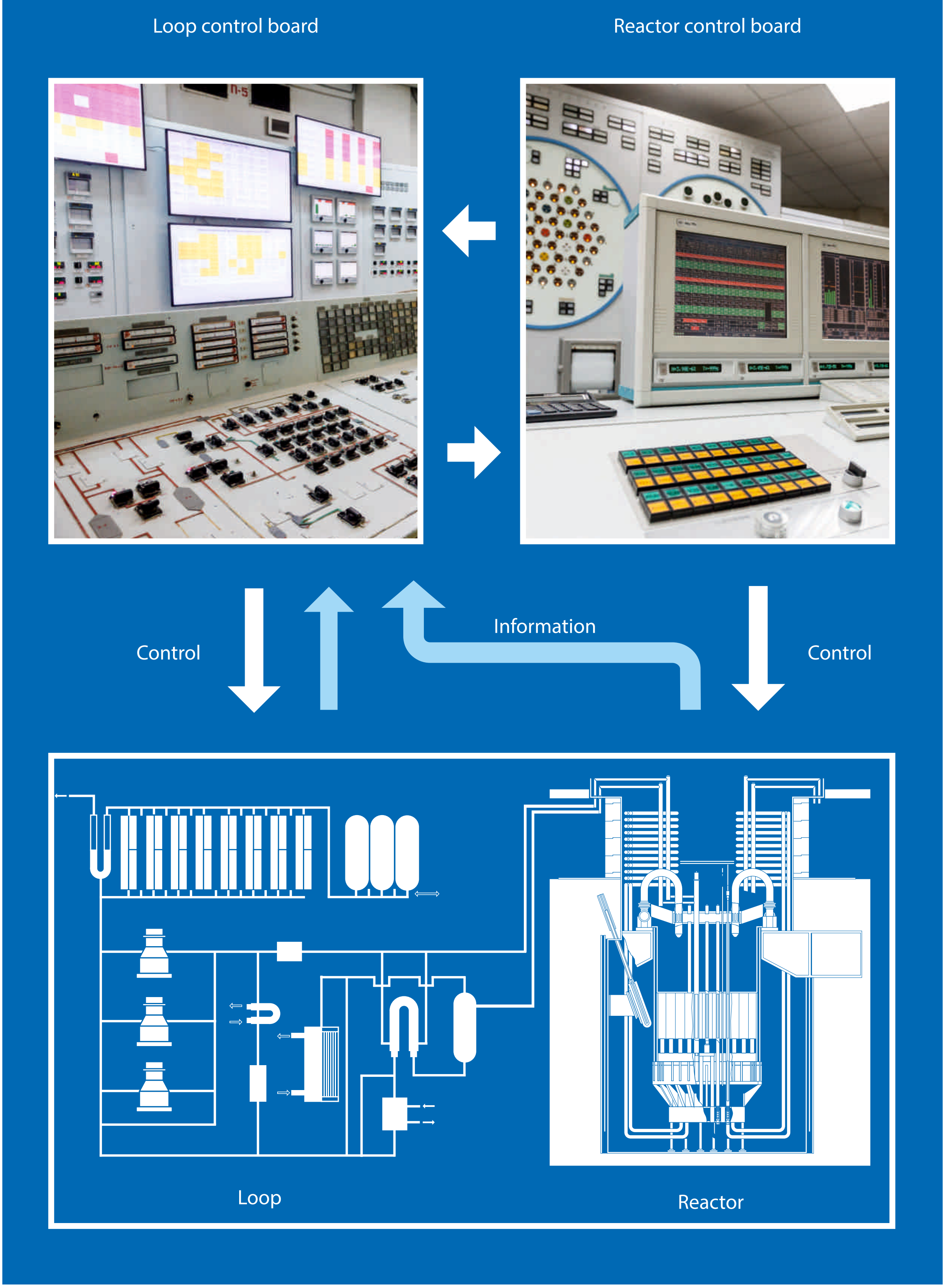
Parameter	PV-1	PV-2	PVK-1	PVK-2	PVP-1	PVP-2	PG-1
Number of channels	2	2	2	2	1	1	1
Coolant	Water	Water	Water, boiling water	Water, boiling water	Water, steam	Water, steam	He+Xe,N
Pressure, MPa	16,8	17,8	16,8	17,8	8,5	20	20
Temperature, °C	350	350	350	355	500	550	600
Flow rate, kg/h	16 000	16 000	14 000	14 000	675	10 000	4 680

Note. The last three parameters are given with max values.

Types of experiments:

- RAMP;
- RIA;
- Lifetime and comparative tests under different water chemistry conditions;
- Power cycling;
- Comparative tests of structural elements;
- LOCA;
- Re-irradiation of refabricated and full-size fuel rods.

How tests in the loops are controlled



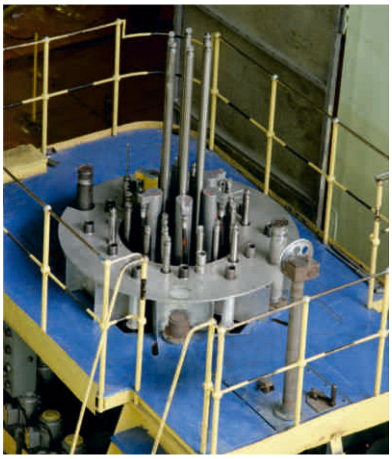
MIR.M1 critical assembly

A critical assembly is a physical model of the MIR.M1 reactor. The geometry of its core and reflector and the material composition are the same as the reactor one.

The critical assembly is used to study the neutronic characteristics of the core and irradiation rigs, to select the means and methods for provision of safe irradiation conditions, to justify safe modes of reactor operation and to verify techniques and software for neutronic calculations.

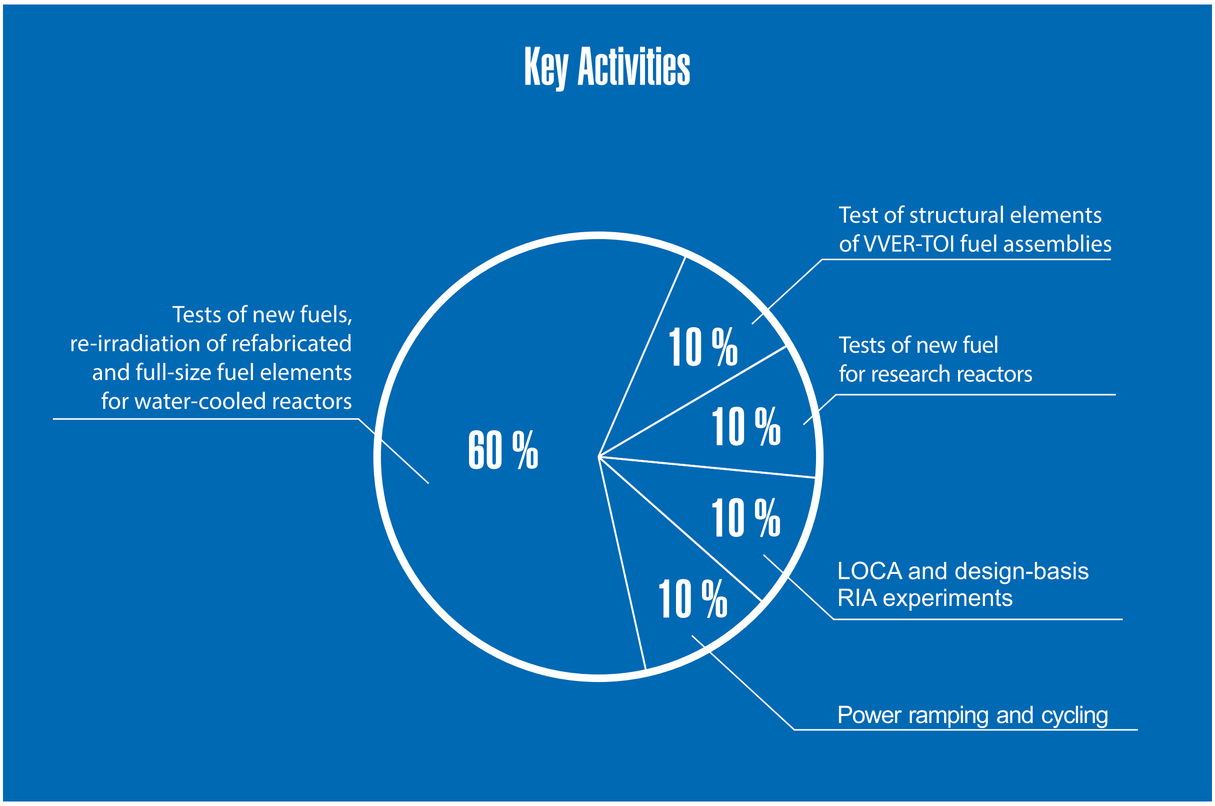
The critical assembly core may be loaded with MIR.M1 loop channels mockups to insert there either experimental assemblies or their dummies to study them before irradiation in the reactor.

Current activities



Control rods drive units

- Development of new techniques to test improved fuel elements for water-cooled reactors (VVER, low-capacity NPP, propulsion and floating reactors) under normal, transient, cycling and accidental conditions and to examine their characteristics.
- Irradiation tests and examinations of fuel elements and structural materials for PWRs.
- Irradiation tests of fuel elements and fuel assemblies for high-temperature gas-cooled reactors.
- Irradiation tests of fuel elements and fuel assemblies of research reactors.
- Irradiaiton tests of leaky fuel elements to study the FGR mechanism.
- Interim examinations of fuel assemblies and fuel elements in the reactor hot cells and cooling pool.

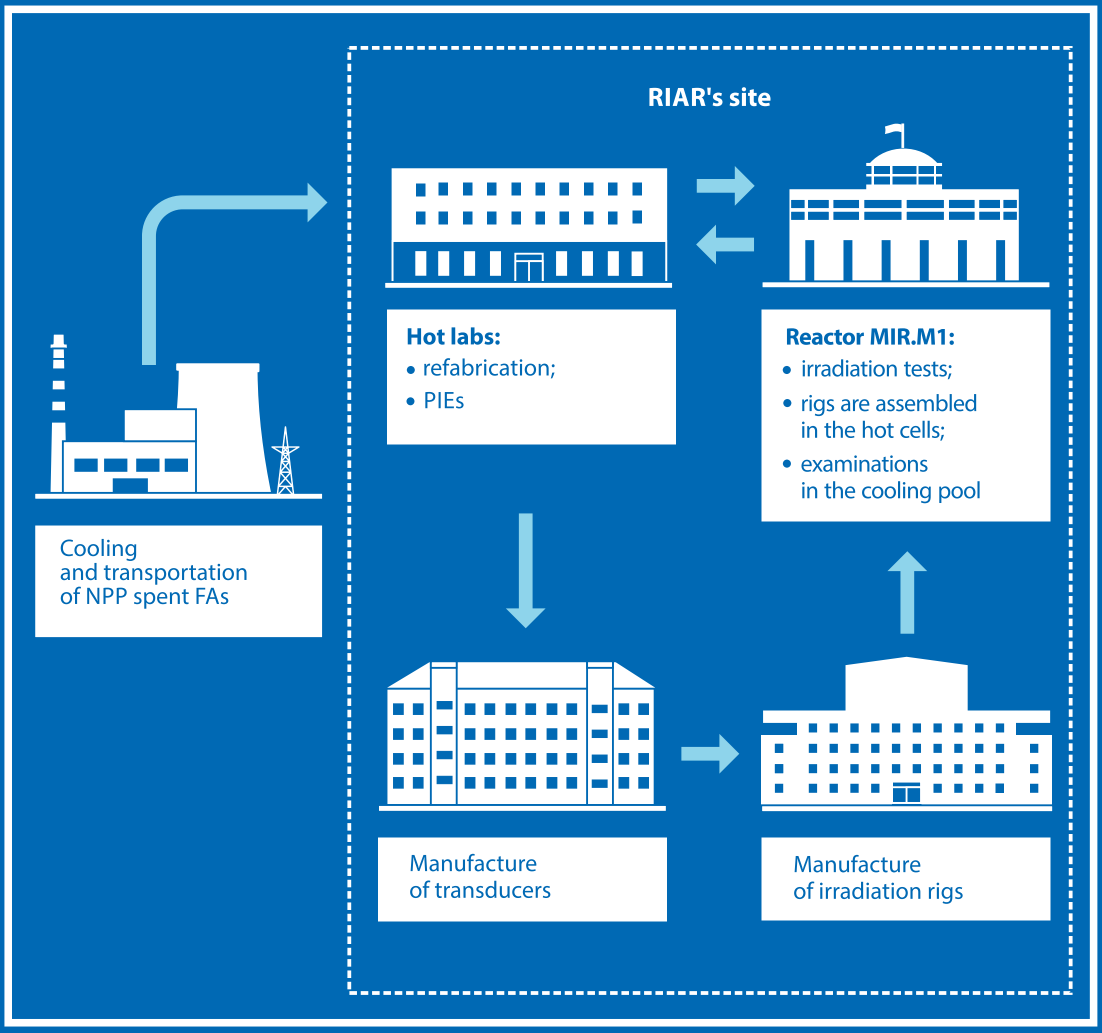


Preparation and testing of NPP refabricated and full-size fuel rods

JSC "SSC RIAR" carries out all required test-supporting activities:

- designing and manufacture of experimental and irradiation rigs and special-purpose transducers and some types of experimental fuel rods;
- characterization of irradiated full-size and refabricated fuel rods removed from either standard or experimental fuel assemblies of power reactors;
- instrumentation of fuel rods with transducers;
- in-pile tests;
- interim and post-irradiation examinations;
- waste disposal and SNF temporary storage.

How experiments are prepared and performed in the MIR.M1 reactor

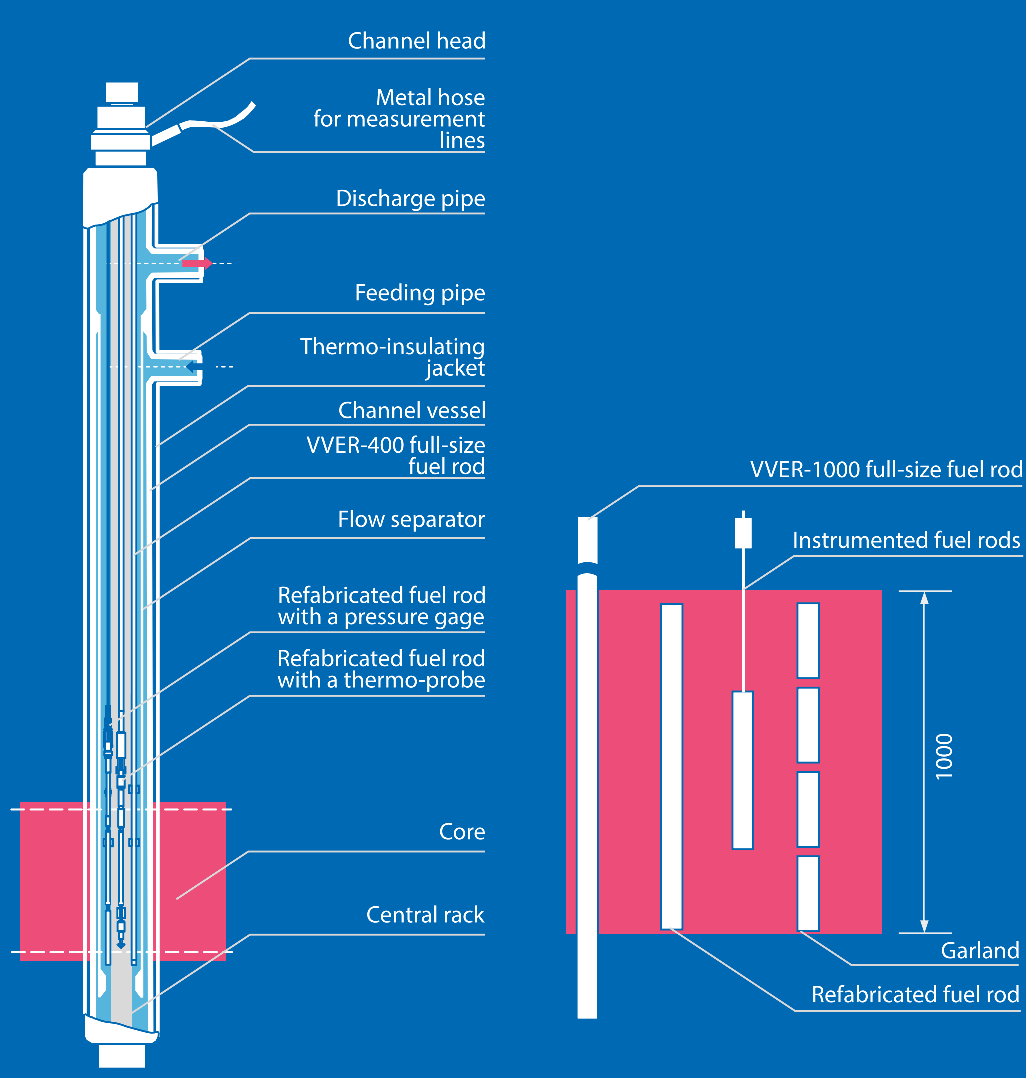


Dismountable rigs to test NPP full-size and refabricated fuel rods

For testing NPP fuels, there were designed:

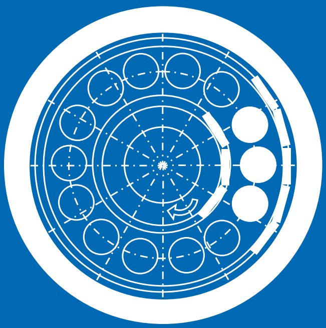
- several types of dismountable and instrumented rigs containing up to 19 refabricated and full-size fuel rods;
- rigs with several shortened fuel rods installed one above another heightwise the reactor core;
- rigs for re-irradiation and special experiments with full-size and refabricated fuel rods.

Loop channel with different experimental fuel rods

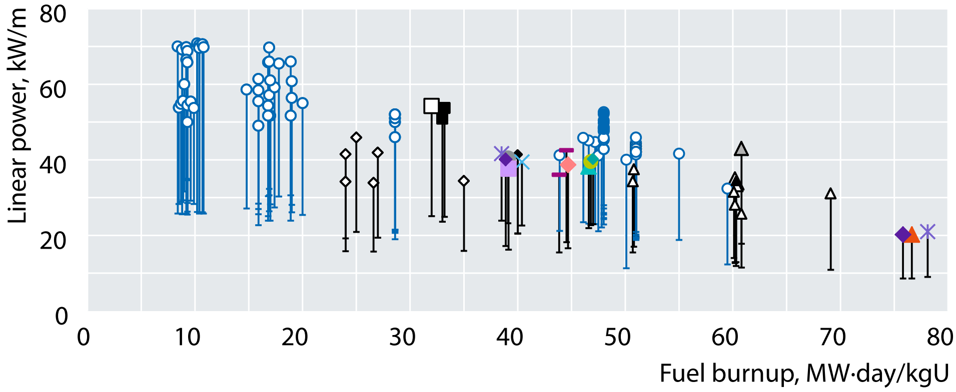


RAMP tests

During the experiment, the fuel rod power is increased 1.5-3 times for 1-30 minutes depending on the simulated abnormality of the NPP operation mode. Before 2010, 12 experiments with VVER fuel rods were performed. Since 2012, the experimental program was restarted to perform 16 experiments with fuel rods of improved design, five of which have been already conducted by now.



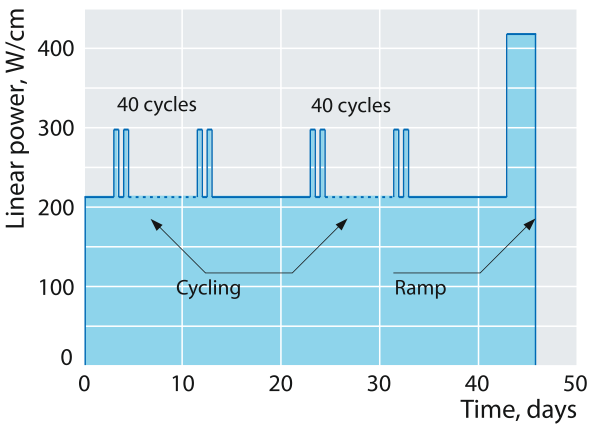
Cross-section of an irradiation rig, where fuel rods or screens are rotated under power ramping mode



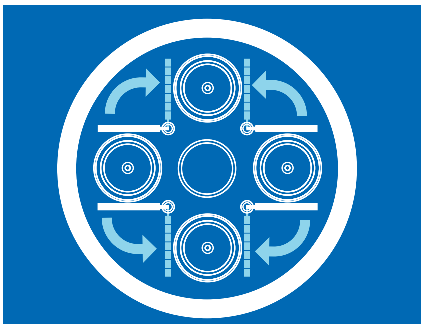
Ranges of power ramps during RAMP experiments with VVER fuel rods of different designs

Tests under power cycling conditions

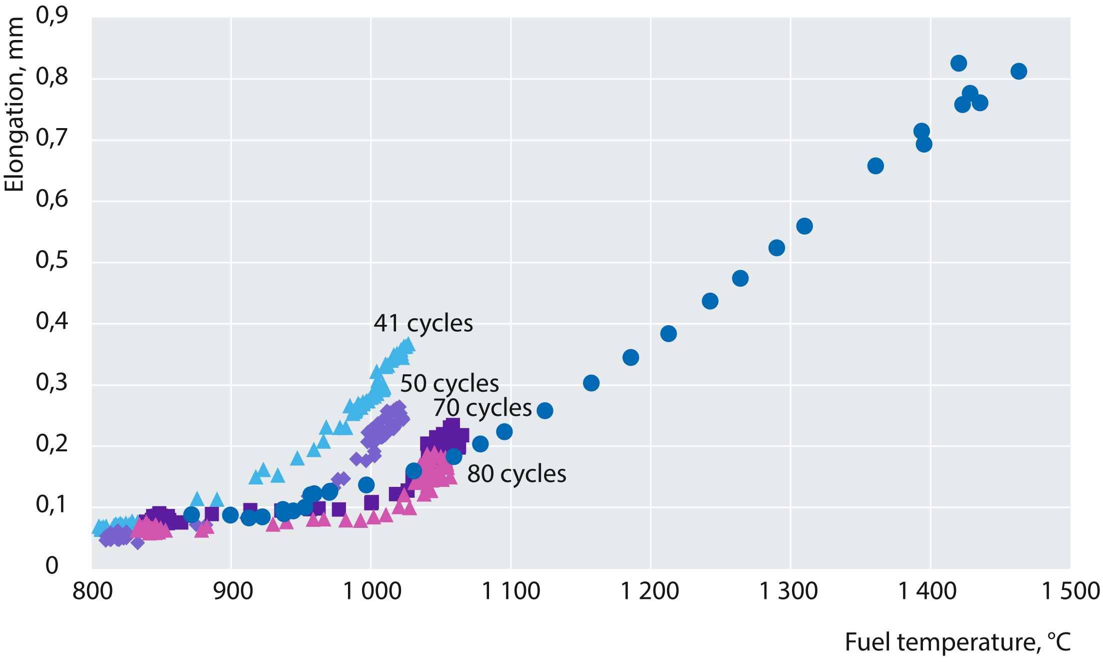
Experiments with refabricated fuel rods having a burnup of 50-60MW·day/kgU for the Russian PWR type reactors (VVER-440 and VVER-TOI) were done under the power cycling conditions. Two of four VVER-TOI fuel rods underwent power ramp test after the cycling experiments.



LP change



A rig to test fuel rods under power cycling conditions

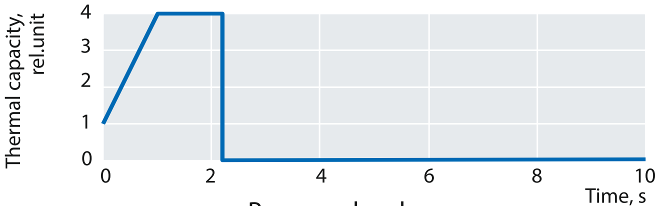


Elongation of a fuel rod under power cycling conditions

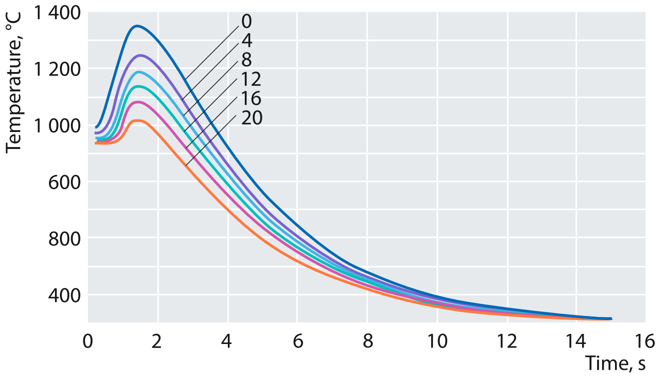
Reactivity initiated accident (RIA) experiments

A power pulse is formed in one channel of the reactor operating at a constant power when the absorbing screen that surrounds fuel rods in the initial state is removed. An additional absorber that moves simultaneously with the screen is introduced into the core to compensate the reactivity effect. A fast-acting hydraulic drive was developed to move the screening system at a high speed (up to 200mm/s).

The instrumented experimental rig contains three fuel rods, two of which are refabricated instrumented high-burnup fuel rods of the VVER-1000 reactor. The fuel enthalpy increment is measured by the pulse amplitude and duration at the maximal power.



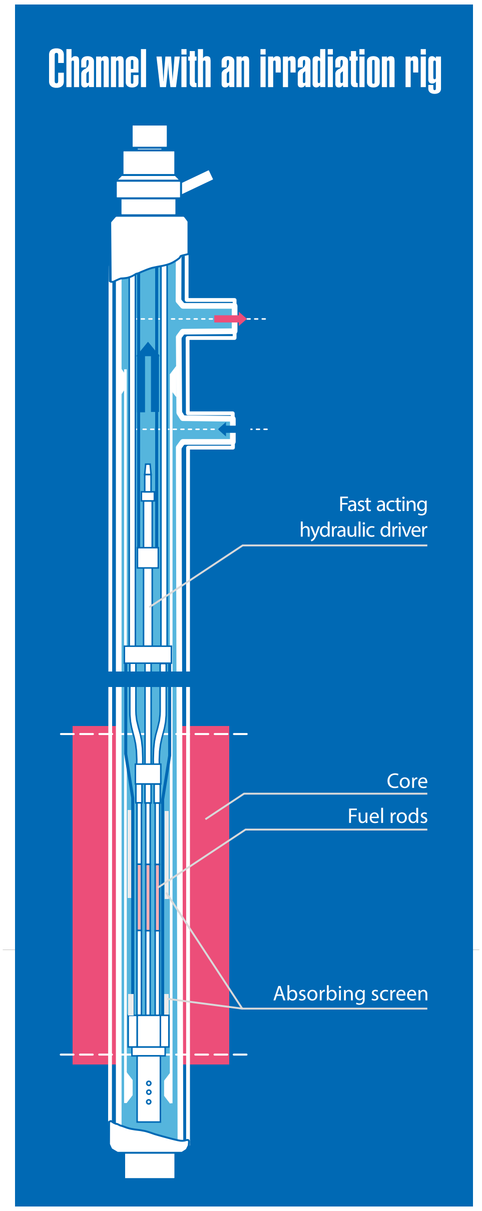
Power pulse shape



Change in fuel temperature at a power pulse heightwise the fuel rod (cm)

Test conditions

Parameter	Value
Coolant pressure, Mpa	15,7
Coolant temperature, °C	Up to 310
Coolant flow rate, m^3/s	Up to 6
Initial linear heat power, W/cm	Up to 250

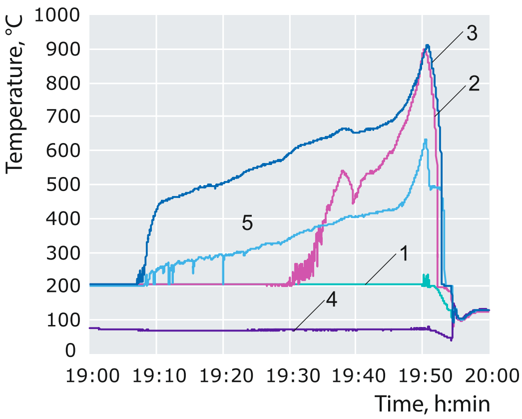


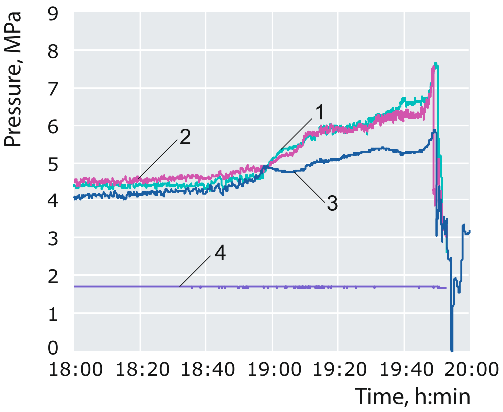
Testing of VVER-1000 FA fragments under LOCA

The test is carried out in the MIR leak-tight loop at a constant pressure and flowing coolant.
To simulate the pressure drop on the cladding, the initial under-cladding helium pressure is increased.
The low coolant flow is created and measured by a specific system.

During the test, the following parameters are continuously measured:

- coolant temperature at the fuel rod bundle inlet (4);
- coolant temperture at the fuel rod bundle outlet (5);
- cladding temperature heightwise the fuel rod (1–3);
- temperature of the fresh and spent fuel meat center;
- under-cladding gas pressure (1–3) and cladding temperature are measured at a time;
- coolant pressure (4).





Dynamics of parameters change during the experiment

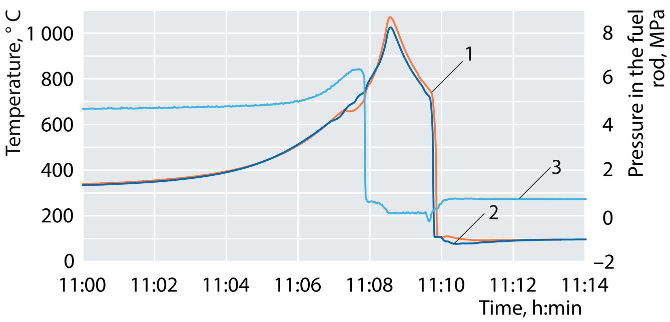
Testing of a single high-burnup VVER-1000 fuel rod under the LOCA conditions

One of the priority tasks of the LOCA experiments is to study the fragmentation of high-burnup fuel, its axial displacement and release into coolant as a result of cladding rupture. In this case, the experiments with FA fragments are not representative. The non-uniform heat rate and cooling of fuel rod bundle make it impossible to define the testing conditions for each fuel rod with a desired accuracy necessary to study the fragmentation, displacement and dispersion of fuel.

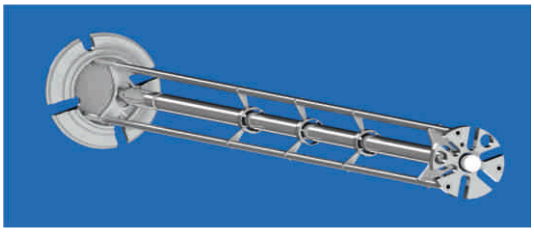
Recently, there has been developed an experimental technique with the use of one spent fuel rod. Its location along the axis of the reactor core channel allows eliminating the above non-uniformities.

The following parameters are measured on-line during the experiment:

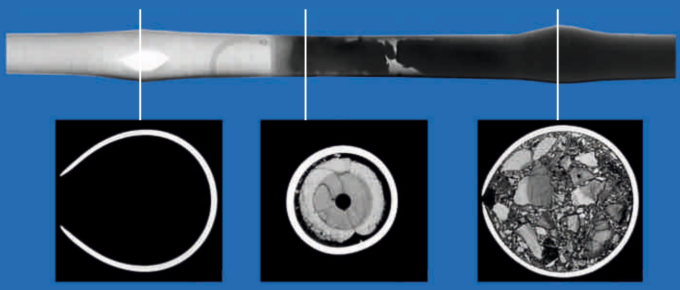
- coolant temperature at the inlet of the experimental rig (water) and at its outlet (overheated water vapor);
- cladding temperature where the spacer grids are located (1, 2);
- relative heat rate in the channel (in-reactor direct-charge hafnium detector is used as well as standard ionizing channels);
- gas pressure under the cladding (3).



Parameters measured during the experiment



A fuel rod in the experimental rig

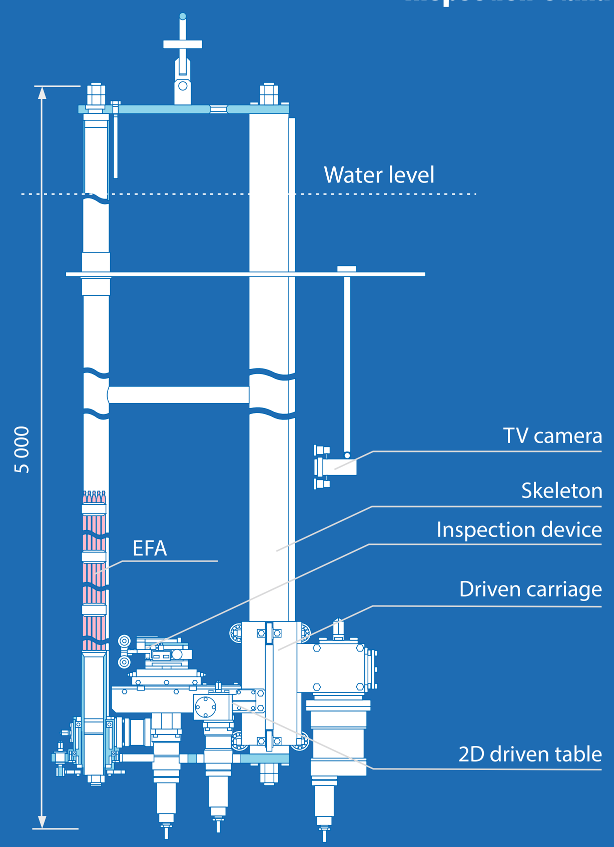


A fuel rod after the experiment

The behavior of high-burnup fuel under accidental conditions is notable for its high fragmentation that causes its displacement and release through a cladding rupture

Examination of experimental fuel rods and FAs with their interim inspection in the MIR.M1 cooling pool

Inspection stand

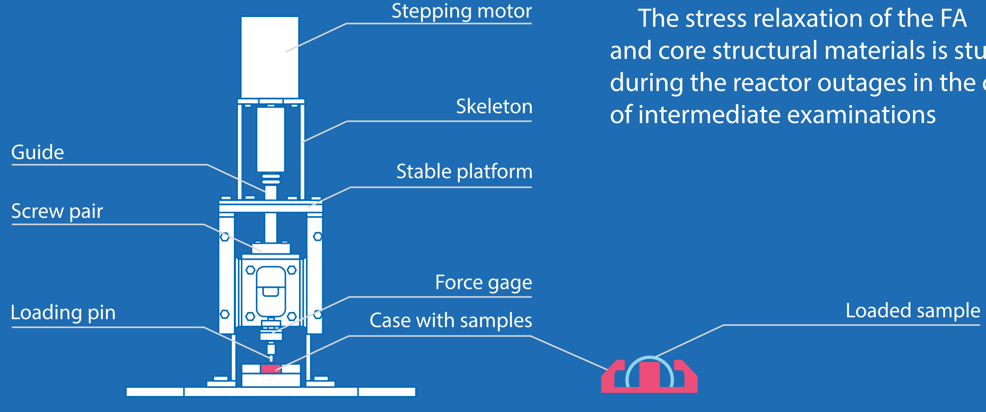


The inspection stand is intended for interim examinations of irradiated fuel rods and structural elements in the MIR.M1 cooling pool.

Capabilities of the inspection stand:

- visual inspection with video recording;
- oxide film thickness measurement;
- measurement of geometry of fuel rods and structural elements

Relaxometer

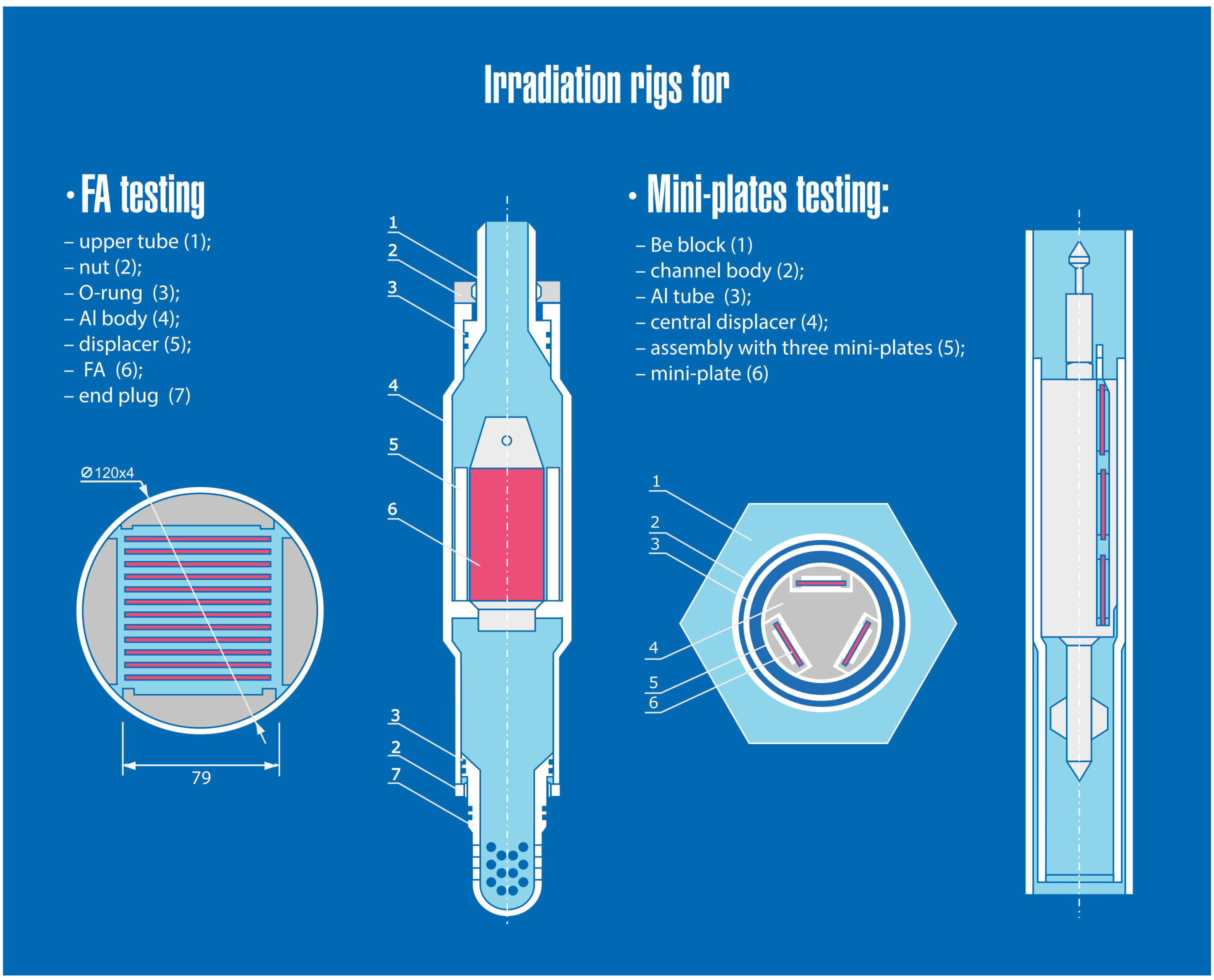


The stress relaxation of the FA and core structural materials is studied during the reactor outages in the course of intermediate examinations

Experimental base to test and qualify research reactors fuels

Over the last few years, several tests were performed in the MIR.M1 reactor to test and qualify fuel for MR and MTR research reactors. The fuel was tested at low parameters (P~1MPa,~50 °C); the experimental channels were connected to the reactor primary circuit. In particular, the experimental channels were used to qualify the MTR plate-like fuel (two irradiation rigs for in-reactor tests of fragments of plate fuel and full-size FAs).

Fuel assemblies 75×80 in size were tested in the MIR.M1 channel with outer diameter of 120mm. The reactor design provides a possibility to increase the channel diameter up to 148mm, and the FA dimensions can be 100×100mm. The irradiation rig consists of a cylinder, end plugs to remotely insert the IR into the core and displacers ensuring the coolant flow through the fuel plates.



The irradiation rig for in-reactor tests of mini-plates consists of three dismountable experimental fuel assemblies containing three mini-plates each. Any of the assemblies can be removed from the IR for video examinations of the mini-plate surface, gamma-scanning and measurement of the oxide film thickness with an eddy-current detector, the mini-plates remaining in the assembly.

Pin-type U-Mo mini fuel elements were tested in the MIR.M1 reactor to obtain experimental data on the properties of the fuel column, cladding materials and fuel elements integrity after different burnups were achieved.

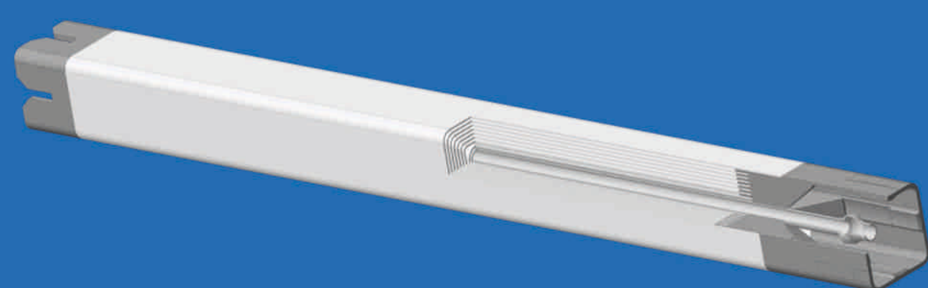
An irradiation rig was designed and installed in the MIR.M1 channels to test mini fuel elements. The dismountable design enables periodical examinations or replacement of mini fuel elements in the IR in the hot cell.

Full-size IRT experimental fuel assemblies of various design are tested in the MIR.M1 reactor as well.

Irradiation rig with mini fuel elements

At present, the IRT-type FAs are used at many research reactors of Russian design: IR-8, IRT-MEPhI, IRT-T (Russia), LVR-15 (Czech), VVR-SM (Uzbekistan). To provide hydro-dynamic test conditions closest to the operational ones, a channel was designed and manufactured consisting of different parts with differently-shaped through sections.

Heat from the EFA is removed by the primary coolant going straightforwardly top-bottom.



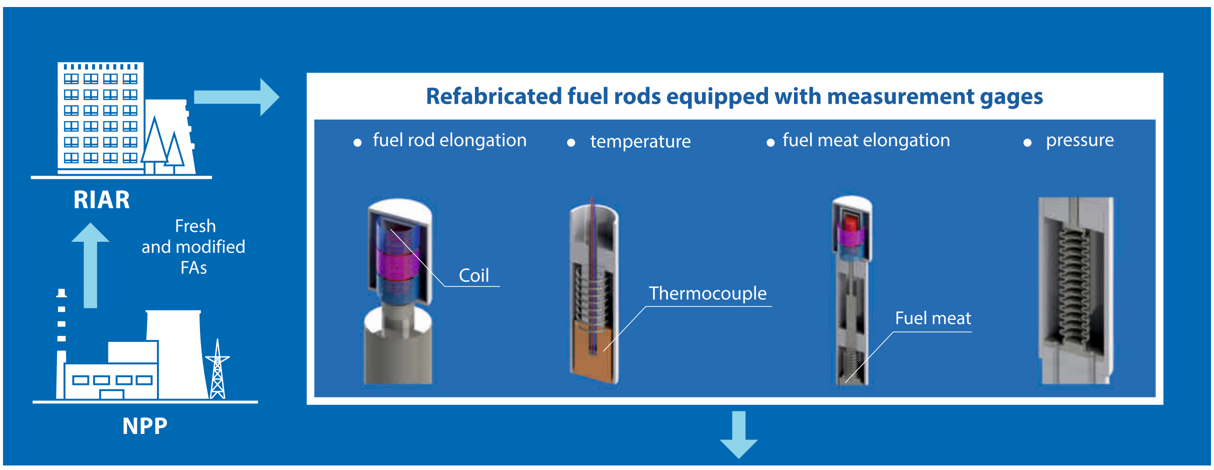
Experimental fuel assembly IRT-3M

Types and parameters of gages to instrument irradiation rigs and fuel elements

The majority of experiments in the MIR.M1 reactor provide for measurements of the following parameters:

- fuel and cladding temperature;
- gas pressure under the cladding;
- fuel rod deformation (fuel meat and cladding length, fuel rod diameter);
- dynamics in the neutron flux density change.

Gages manufactured at the RIAR's Research Reactors Complex showed high performance and did not exceed the limited measurement errors during the tests.



Parameter	Value	Error, %	Gage characteristics		
			Type of gage	Diameter, mm	Length, mm
Temperature, °C:					
coolant, cladding	Up to 1 100	0,75	Chromel-alumel cable-type thermocouple	0,5–3	Up to 10 000
fuel	The same	The same	Chromel-alumel cable-type thermo-probe	The same	The same
	Up to 2 300	About 1,5	Thermo-probe VR 5/20, (Mo+BeO)-duct	1,2–2	Up to 500
Gas pressure in the fuel rod plenum, MPa	0–20	Specific calibration	Bellows + DT	9–16	80
Elongation, mm:					
cladding	0–10	The same	DT	The same	The same
fuel meat	The same	»	The same	»	»
Neutron flux density, $cm^{-2} \cdot s^{-1}$	10^{11}–10^{15}	About 1	DCS Rh, Hf	2–4	50–100

Note. DT — differential transformer; DCS – direct charge sensor.

Water chemistry for reactor experiments

Fuel rods, FAs and structural materials tested in the MIR.M1 loops are in the water chemistry that simulates the conditions typical for various nuclear reactors.

The following water chemistries are simulated:

- ammonia;
- ammonia-boric-potassium — VVER;
- boron-lithium with dosing of gaseous-hydrogen — PWR.

To maintain the desired range of reagents concentration, the following systems are provided:

- system of ion exchange filters with related ion-exchange materials;
- feeding system consisting of an electrically heated tank to make a concentrated boric acid solution;
- system to introduce chemical reagents with a supply of gaseous hydrogen and continuous dosing of micro-components.

Methods for chemical control include both well-known techniques (photometry, pH and conductivity measurements) and modern computerized equipment

Ion chromatograph to control anion impurities

Automated gas analyzers with high-performance sensors and modern computerized chromatograph to measure gases

AA spectrometer to measure cation impurities

Our employees

Our personnel – shift staff, process control staff, groups for nuclear materials account and control, mechanics, electricians, safety and control system and IT provision staff, radiation safety officers and loop test labs researchers – provide for safe operation of the MIR.M1 reactor






Further extension of the MIR.M1 experimental capabilities and development of promising areas of research:

- Improvement of techniques to control parameters and measure the fuel rods characteristics under irradiation;
- Tests in justification of improved and new fuels for VVER and PWR reactors under different design-basis conditions;
- Application of gas-cooled loops to test core components and FA dummies of high-temperature gas-cooled reactors;
- Reactor tests to improve and justify fuels for new cores of floating reactors, SNPPs and ice-breakers;
- Development of a universal loop to simulate operating conditions of water-cooled power reactors and upgrade the first-priority loops;
- Enlargement of the output and nomenclature of accumulated isotopes;
- Improvement of experimental devices;
- Extension of the MIR.M1 reactor lifetime as well as its process systems, including the replacement of Be blocks

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We are always glad to provide you with more details about JSC "SSC RIAR"

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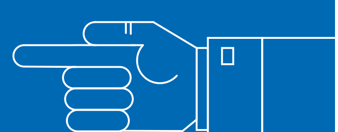







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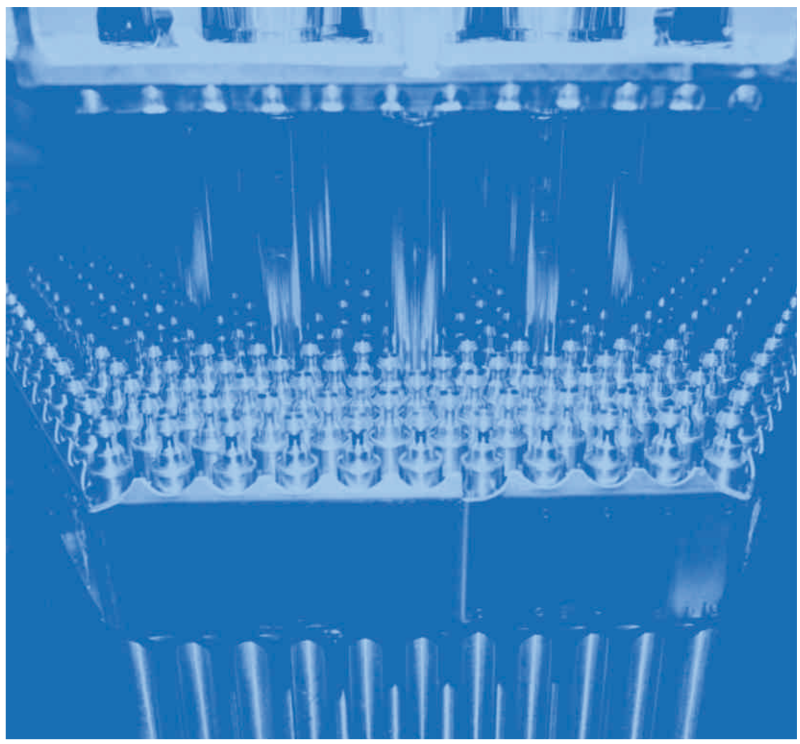
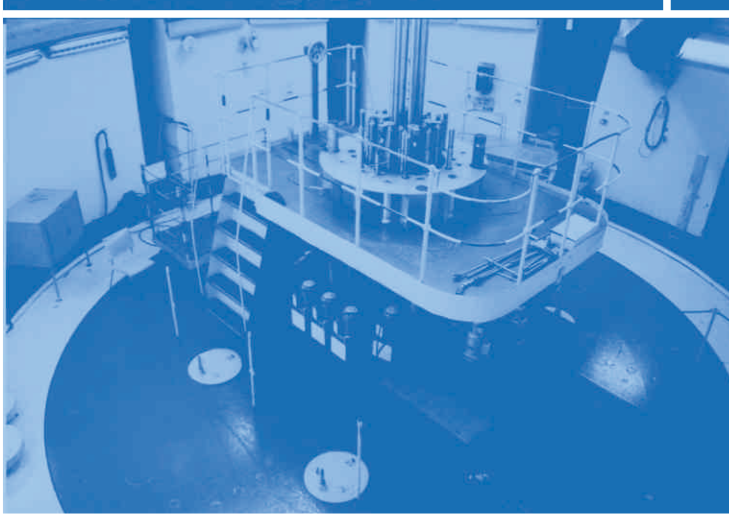
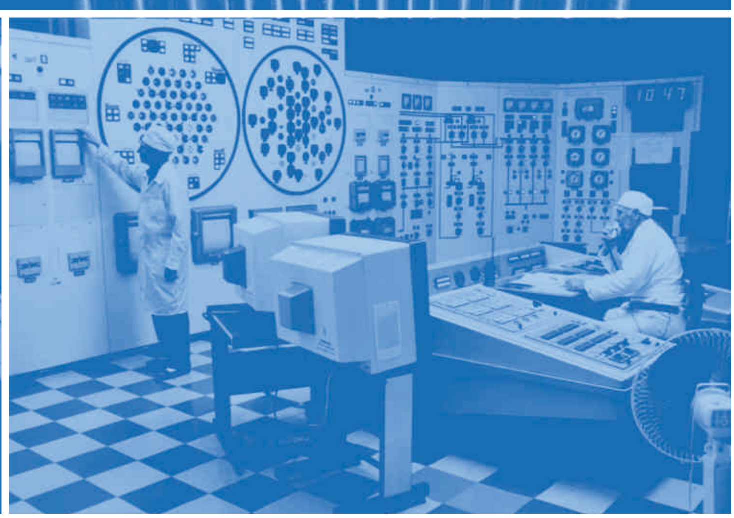

Booklet

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