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2. NIKIET – chief designer of research reactors

The history of NIKIET begins at the Sverdlovsk NIIkhimmash (Research Institute of Chemical Engineering) where a Hydraulic Engineering Sector was set up in 1946 to design the first production reactor "A". In 1948, the reactor was assembled and brought to the power level of 100 MW. The task of developing more powerful reactors of Type A was transferred to the design bureau of Factory No. 92 (future OKBM), which developed later the first tritium production reactor (AI) to support creation of thermonuclear weapons.

NIIkhimmash initiated development of the reactor (AM) for the first pilot nuclear plant which was commissioned in 1954. By that time (in 1952), its Hydraulic Engineering Sector had been transformed into Research Institute No. 8 (known today as OJSC "NIKIET"). The capacity of the first NPP was a mere 5 MWe. This fact as well as the pilot status of this plant made it akin to research reactors. The history of Russian research reactors, as well as the history of national nuclear power as a whole, dates back to December 25, 1946, when Eurasia's first F-1 reactor was brought to criticality. F-1, which was – and still is – essentially a pilot research reactor with the capacity of only 24 kW and the thermal neutron flux of $5 \cdot 10^9$ $cm^{-2} \cdot s^{-1}$, confirmed experimentally the feasibility of a controlled chain reaction. This reactor is still in operation: it is qualified as the "Working standard of thermal neutron flux" and the "Standard for measurement of intermediate neutron flux". The reactor is under protection of the State as a monument to Russian scientific and engineering thought.

A major event in the history of Russian research reactor engineering took place in 1952 when the Institute of Atomic Energy (IAE) put into operation its reactor RFT for research in physics and engineering, whose thermal power was gradually raised to 10 MW. This research reactor was the first to have channels with self-contained cooling loops (independent of the core cooling circuit), which made possible experimental studies of fuel and other materials under conditions made as close as possible to those of the investigated prototype with the design-basis cooling fluid. The maximum unperturbed thermal neutron flux in the RFT reactor was as high as $8.0 \cdot 10^{13}$ $cm^{-2} \cdot s^{-1}$ in the core center and $2.5 \cdot 10^{14}$ $cm^{-2} \cdot s^{-1}$ in loop channel areas.

The starting grounds for advancement of domestic research reactor engineering were laid by the IAE which developed and put into operation the tank-type 300 kW VVR-2 reactor in 1953 and the pool-type 2.5 MW IRT-2 reactor in 1957. Those reactors had vertical and horizontal experimental channels and served as a model for many research facilities built both at home and abroad.

The early 1950s were the years of dynamic assimilation of the new energy technology based on the uranium fission reaction. Those activities gave rise to high demand for experimental facilities where it would be possible to study fuel and structural materials in real reactor conditions. Also high was the need for scientific experiments with neutron beams which could provide scientists with a new tool for research in nuclear and condensed-matter physics.

The first NIKIET Director N.A. Dollezhal, who had shrewdly foreseen this trend, decided to set up a special division for development of research reactors and field support of their construction and subsequent operation. The decision was brought into effect by Order No. 244 of May 9, 1957, on establishment of Division 6 (Research Reactor Division) with 15 employees, including the Division Head Yu.M. Bulkin.

This turned out to be a watershed event both for NIKIET and the branch as a whole: it was that division of the Institute that made research reactor development crystallized into a special line of reactor engineering. The emergence of Division 6 was also well-timed, as nuclear science and engineering called for an ever-increasing number of facilities with more and more extensive experimental capabilities. More than 25 various research reactors were built in this country and beyond to NIKIET designs or with participation of the Institute.

Following his concept of NIKIET as the institute with facilities available for joint efforts of designers, field engineers and experimenters, N.A. Dollezhal succeeded in getting a pool-type research reactor (IR-50) built in 1961. Being a multipurpose reactor, IR-50 was efficiently used for more than 30 years, serving civilian and defense purposes in the nuclear engineering field. Its main applications were associated with radiation protection physics and engineering, with development of new shielding materials, ionizing radiation detectors, control and protection systems for nuclear facilities.

In the 1960s, research reactors of the IRT type designed by NIKIET appeared one after another in the USSR and in other countries. The most important among them are listed below.

IRT-type research reactors brought into service in the 1960s

Name	Location	Commissioning year	Thermal power, MW
IRT-M	Georgia, Tbilisi	1959	8.0
IR-50	Moscow, NIKIET	1961	0.05
IRT-Sofia	Bulgaria, Sofia	1961	2.0
IRT-5	Latvia, Riga	1961	5.0
IRT-4	Belarus, Minsk	1962	4.0
IRT-8	Northern Korea, Yongbyon	1965	8.0
IRT-5000	Iraq, Al-Tuwaitha	1961	5.0
IRT-MIFI	Moscow, MEPhI	1967	2.5
IRT-T	Tomsk, TPU	1967	6.0

A logical conclusion to development of IRT-type reactors was construction of the IVV-2 reactor at the Sverdlovsk Branch of NIKIET (OJSC "IRM" today) in 1966. It was the first application of the modular approach to equipment arrangement in the practice of research reactor engineering, with the core, primary heat exchanger, circulation pump and pipelines arranged in the reactor pool. Besides, implementation of another idea made it possible to expand the experimental capabilities of the reactor and to enhance the characteristics of experimental positions through sectionalized core layout, with each of the sections forming a neutron trap. The modular configuration of the core and the reflector made the reactor highly adaptable to various experiments.

The experience gained by the Institute's specialists in designing and building reactors of the IRT line helped to create a whole number of special-purpose pool-type facilities, such as the training reactors for the Navy – UR-5 (Leningrad) and IR-100 (Sevastopol), a reactor RG-1 for activation analysis of ore at the Norilsk Mining and Metallurgical Combine, the SVV-1 reactor for medical and biological research (Moscow).

The research reactors built to NIKIET designs in countries outside the former Soviet Union and showing successful performance include the multipurpose pool-type IVV-10 reactor (1982, Libya) 10 MW in capacity and the isotope-producing IVV-9 reactor (1984, Vietnam).

On the whole, more than 20 research reactors were built to NIKIET designs in foreign countries, some of which are still in operation.

While working at expansion of the reactor-based experimental capabilities, NIKIET collaborated with other institutes seeking to increase the neutron flux in a research reactor to the highest possible level. NIKIET is the chief designer of all Russian high-flux reactors with power levels of 100 MW and more (SM-2, MIR-M1, PIK under construction, MBIR being developed).

High on the list of research facilities is SM-2, whose neutron flux level has not been surpassed yet by any water-water reactor. SM-2 was brought into operation with the thermal power of 50 MW on the RIAR site (Dimitrovgrad) in 1961. The philosophy underlying the reactor design belongs to S.M. Feinberg who proposed placing a water trap having high thermal neutron flux in the center of a compact reactor core. This reactor was developed by NIKIET under guidance of N.A. Dollezhal and Yu.M. Bulkin. SM-2 was designed for irradiation of reactor material specimens, post-irradiation investigation of their properties, accumulation of transuranic elements, and experiments in nuclear

Research reactors constructed abroad with NIKIET participation

Name	Type	Power, MW	Country	Status
IRT-2000	IRT	2	Bulgaria	Modified for power level reduced to 0.2 MW
IRT-8	IRT	8	North Korea	No data
IRT-5000	IRT	5	Iraq	Shut down
NRC with IVV-7 (IRT-1)	IRT	10	Libya	In operation
"Eva"	IRT	10	Poland	Shut down
"Maria"	MR	30	Poland	In operation
VVR-SM	VVR	10	Hungary	In operation
VVR-S	VVR	10	Rumania	Shut down
ETRR-1	VVR	2	Egypt	In operation
RFR	VVR	10	Germany	Shut down
LVR-15	VVR	10	Czech Republic	In operation
DRR	IRT	5	Vietnam	In operation
IRT-M	IRT	8	Georgia	Shut down
IRT-M	IRT	5	Latvia	Shut down
IRT-M	IRT	4	Belarus	Shut down
VVR-SM	VVR	10	Uzbekistan	In operation
VVR-M	VVR	10	Ukraine	In operation
VVR-K	VVR	6	Kazakhstan	In operation
IR-100	IRT	0.2	Ukraine	In operation
IGR	Pulsed	10	Kazakhstan	In operation
IVG	Gas-cooled	60	Kazakhstan	In operation

physics. The reactor parameters, including its thermal power, were increased in several stages, until the thermal neutron flux reached $5\cdot10^{15}$ $cm^{-2}\cdot s^{-1}$ at 100 MWth. In the early 1990s, NIKIET together with NIIAR worked out a plan for the reactor upgrading, which resulted in a higher power level, with the main utility characteristics retained; the modified reactor received the name of SM-3.

An important milestone in the work towards expansion of the Russian experimental facilities was the appearance of the multiloop research reactor MIR-M1, which was designed mostly for tests of new fuel and structural materials. This high-flux tank-in-pool reactor was built at NIIAR in 1966. The design of MIR-M1 affords unique experimental capabilities. The reactor allows experiments in 11 loop channels with the maximum neutron flux of $5\cdot10^{14}$ $cm^{-2}\cdot s^{-1}$.

The Institute is especially proud of the unique pulsed reactor of periodic operation – IBR-2, which was developed by NIKIET and built on the JNRI site in the period of 1969–1980. The reactor was put into operation on February 10, 1984, after first-criticality (1977–1978) and first-power (1980–1983) tests and studies. The total time of the reactor operation in the period between 1984 and 2007 came to about 50 thousand hours, while its thermal neutron flux (10^{16} $cm^{-2}\cdot s^{-1}$ in a peak to the moderator surface) made one of the world's highest figures at the relatively low power of 2 MW. In 2000–2003, NIKIET – with the assistance and scientific guidance of the JNRI – developed a plan for the IBR-2 reactor upgrades, seeking to modernize the outdated equipment, to increase the safety level, and to extend the service life of the reactor. By the end of 2011, the upgrading project culminated in successful completion of first-criticality and first-power operations.

Today's approach to experimental equipment envisages the availability of high-flux research reactors as basic facilities for joint use by scientists and researchers of Russia and other countries. This is why Russia is highly motivated to complete the construction of the high-flux PIK reactor with a considerable experimental potential developed by NIKIET for the B.P. Konstantinov Petersburg Nuclear Physics Institute (PNPI) (Gatchina).

PIK is a unique neutron beam reactor, with the steady-state neutron flux exceeding $5 \cdot 10^{15}$ $cm^{-2} \cdot s^{-1}$, which is part of the PIK reactor complex of the PNPI. When completed, the reactor complex will have a neutron source suitable for a multiple research in fundamental and applied spheres of nuclear physics, solid-state physics, biology, and other natural sciences, including the priority lines of science, engineering and technology. PIK was brought to first criticality on February 28, 2011. Construction of the reactor complex is in progress, and the plan is to start physical experiments at the end of 2014.

While the PIK reactor can become a base high-flux research reactor of shared uses for beam studies, the multipurpose fast reactor MBIR, being developed by NIKIET in the framework of the Federal Target Program for Nuclear Energy Technologies of the Next Generation for the Period to 2015 and for a Longer Term to 2020, is to be a multiuser facility for studies of material behavior and production of isotopes. It is expected that MBIR, located on the site of the OJSC "SSC RIAR" in Dimitrovgrad, Ulyanovsk Region, will be brought into service by 2020.

Construction of MBIR should ensure not only continuity of the experimental and research activities performed at the BOR-60 reactor but also growth of the experimental capabilities of the nuclear sector. This reactor should provide the highest ever neutron flux level (upwards of $5.5 \cdot 10^{15}$ $cm^{-2} \cdot s^{-1}$) and unprecedented possibilities for experimental investigations in loop channels with the use of various fluids similar to those of the studied prototypes in terms of type and parameters.

NIKIET acts as chief designer of the following domestic research reactors.

Thus, beginning in 1957, NIKIET specialists together with their colleagues from design and research institutes – first of all IAE as scientific leader of many projects – paved the way for dynamic growth and a broad variety of nuclear research facilities, with their steady-state neutron flux as the key parameter increased by more than two orders of magnitude – from 10^{13} $cm^{-2} \cdot s^{-1}$ to $5.0 \cdot 10^{15}$ $cm^{-2} \cdot s^{-1}$ (for the neutron flux in a pulse, this value made 10^{17} $cm^{-2} \cdot s^{-1}$). Over the same period, more than 10 water-water reactors were built outside the USSR to basic IRT and VVR designs.

The Institute goes on working at creation of high-flux research reactors with a wide spectrum of experimental capabilities, such as PIK and MBIR which are expected to become the pivots of multiuser centers of international scale and significance.

Research reactors designed by NIKIET

Name	Type	Operator	Thermal power, MW	Year of startup (upgrading)
VVR-M	Tank	PNPI (SRC "Kurchatov Institute")	18.0	1959
SM-2 (SM-3)	Pressure vessel	OJSC "SSC RIAR"	100.0	1961 (1993)
IR-50	Pool	OJSC "NIKIET"	0.05	1961
MR	Pressure tube, pool	SRC "Kurchatov Institute"	50	1963
VVR-ts	Tank	Branch of FSUE "NIFHI"	15.0	1964
IRT-2500	Pool	RNU MEPhI	2.5	1966
IVV-2 (IVV-2M)	Pool, modular	OJSC "IRM"	15.0	1966 (1982)
IRT-T	Pool	TPU	6.0	1967
MIR-M1	Pressure tube, pool	OJSC "SSC RIAR"	100.0	1967 (1975)
IBR-2 (IBR-2M)	Pulsed, fast neutron	JNRI	2.0 (1830 in pulse)	1982 (2012)
IRV-M2	Pool	FSUE "NIIP"	4.0	2013 (plan)
PIK	Tank in a pool of heavy water	PNPI (SRC "Kurchatov Institute")	100.0	2014 (plan)
MBIR	Sodium-cooled, fast, loop	OJSC "SSC RIAR"	150.0	2019 (plan)