DEVELOPMENT OF RESEARCH NUCLEAR FACILITY WITH MBIR MULTI-PURPOSE FAST NEUTRON RESEARCH REACTOR

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Introduction

The decision on the development of a multi-purpose high flux fast neutron research reactor was taken at Scientific and Technical Council No.1 of Rosatom State Corporation on November 22, 2007. The basis for the project implementation is the Federal Target Program “Nuclear Power Technologies of the New Generation for the Period from 2010 till 2015 and up to 2020” approved by RF Government Order No.50 as of 03.02.2010.

The availability of an experimental base at JSC “SSC RIAR”, which includes a material testing complex dedicated to structural material and fuel composition studies, a pilot plant for fuel element fabrication, facilities for production of medical and industrial radioisotopes, has determined the scientific relevancy, economic reasonability and technical feasibility to construct the MBIR facility at the RIAR site.

The purpose of MBIR construction is to create a high flux fast neutron research reactor with unique user’s properties in order to implement the following objectives: the performance of in-pile and post-irradiation studies, electricity and heat generation, final elaboration of the new technologies for production of radioisotopes and modified materials.

1. Project implementation specifics

1.1 Project participants

The development and implementation of the MBIR project are carried out through cooperation of the leading enterprises of Russian nuclear industry with the involvement of the organizations having Rostekhnadzor licenses for the respective activities: JSC “SSC RIAR” (Customer and Constructor; operator; developer of fuel elements and CPS control members basic designs); JSC “NIKIET” (Chief Designer; developer of MBIR basic design, manufacturer of control member actuators and CPS thimbles); JSC “ATOMPROEKT” (General Architect-Engineer); JSC “SSC RF-IPPE” (Research Leader); JSC “OKBM Afrikantov” (developer of reactor coolant pumps and heat-exchange equipment); JSC OKB “GIDROPRESS” (developer of electric heaters and heat insulation); JSC “CKBA” (developer of sodium pipeline valves), JSC “CKMB” (developer of refueling machines of handling system), JSC “AEM-technology” (manufacturer of reactor vessel and internals), LLC “Management Company “Uralenergostroy” (General Contractor), etc. The tender procedures towards selection of the organizations to manufacture the MBIR components are still in progress.

In order to assess the compliance with the federal regulations when developing and manufacturing the components, a specialized authorized organization has been outsourced (JSC “VPO ZAES”).

1.2 International status of the project

The Rosatom State Corporation has announced the establishment of the International Research Center on the basis of the MBIR nuclear research facility (IRC MBIR).

In September 2010, at the 54th IAEA session S.V. Kirienko, head of the Rosatom State Corporation, came forward with an international initiative towards the establishment of the international center on the basis of the MBIR RR.

On June 27, 2013, the Rosatom State Corporation, the U.S. Department of Energy and the French Atomic Energy Commission signed a Memorandum of Understanding concerning the establishment of the IRC MBIR.

On September 23, 2014, within the framework of the 58th session of the IAEA General Conference a special briefing was held, which was devoted to the MBIR project progress status and the views of the Rosatom on the prospects of technical and scientific cooperation within the frameworks of the IRC MBIR establishment.

1.3 Project implementation stages

According to the milestones of the MBIR project (Fig. 1), the first reactor criticality is expected at the end of 2019, and the power startup is expected at the end of 2020.

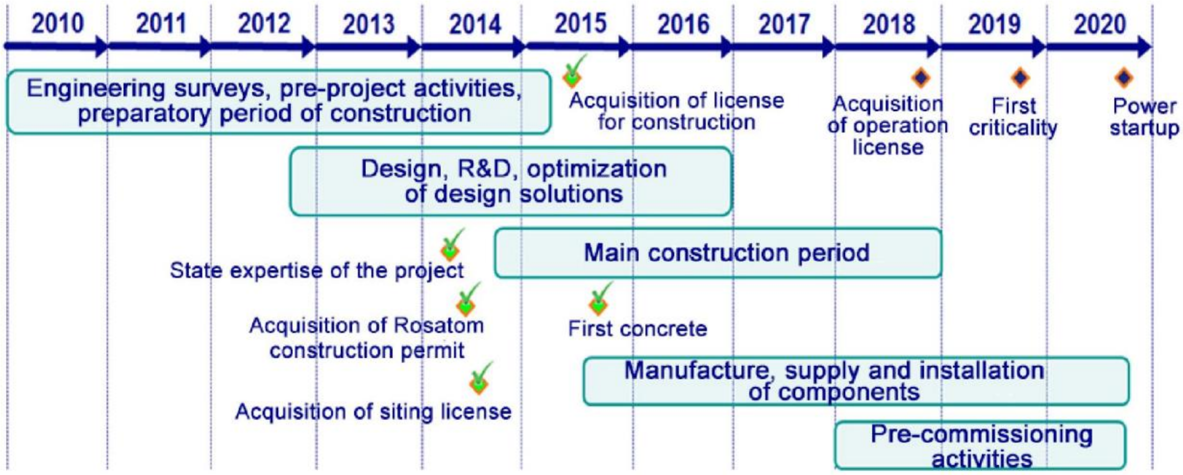

Fig. 1. Milestones of MBIR project

2. Site selection considerations

In 2010–2011, in order to justify the site selection for MBIR, detailed comprehensive pre-project surveys were conducted at the territories of three potential sites.

According to the analysis of the obtained survey results and considering the technogenic conditions and design requirements, the priority in terms of MBIR allocation was given to the site in the south-eastern part of the existing territory of JSC “SSC RIAR”, which is 5 km south-west of Dimitrovgrad, Ulyanovsk Region.

The MBIR site is non-susceptible to flooding, particularly in case of breach wave occurrence, because its location relative to the only nearby dam of the Kuibyshev storage reservoir is far higher up the Volga river flow.

The MBIR project accounts for the engineered features and protective measures, which ensure radiation exposure confinement in case of any potential accident within the controlled area boundaries in accordance with the requirements to radiation hazardous facilities of the category II.

3. Design basis

To ensure safe and reliable operation of the MBIR reactor, it is provided for the highest possible application of the reference approaches.

The MBIR development project is based on the proven technologies used in the BOR-60 reactor. Its design basis includes a three-circuit system of heat removal from the reactor to the environment. Sodium is used as a coolant for the primary and secondary circuits, and the working medium of the tertiary circuit is steam-water mixture.

The layout of the buildings and facilities is based on the modular concept, which provides for the maximum autonomy of the MBIR research facility and the explicit separation of the units and buildings in terms of their responsibilities for safety.

When deciding upon the general layout for the MBIR research facility (Fig. 2), the following requirements were accounted for:

- zoning of the territory allocated to the main production buildings and auxiliary buildings;
- optimal locking of the main production buildings and facilities, as well as of the auxiliary production buildings and structures;
- provision of the straight trunk routes (corridors) for laying of the engineering lines;
- reduction of the process, transportation and pedestrian communications.

The main production zone is located in the center of the site and consists of the functional and process units of the main MBIR research facility building, which comprise a single building volume.

Fig. 2. General view of MBIR nuclear research facility site

4. Design features of MBIR nuclear research facility

4.1 Reactor

Main parameters and technical characteristics of the MBIR reactor (Fig. 3) and its experimental volumes are presented in Tables 1 and 2. Layout of the reactor core is shown in Fig. 4.

Table 1

Main parameters and technical characteristics of MBIR reactor

Parameter	Value
Rated thermal power of reactor, MW	150
Maximum / average neutron flux in reactor core, $cm^{-2}s^{-1}$	5.3×10^{15} / 3.1×10^{15}
Pitch of reactor core elements, mm	75
Number of cells for material test assemblies or isotope production assemblies in reactor core	14
Number of cells for installation of experimental channels	3
Number of cells for loop channel installation	7
Fuel type in standard FAs	Mixed uranium-plutonium oxide fuel
Height of active portion of fuel element, mm	550
Arrangement	Loop-type
Number of cooling loops	2
Number of cooling circuits	3
Primary coolant	Sodium
Coolant flow direction through reactor core	Upward
Principle of heat removal from reactor core	Forced circulation during reactor power operation; cooldown by means of natural circulation during reactor shutdown
Primary coolant temperature: – at reactor inlet, °C – at reactor outlet, °C	330 512
Cover gas in cavities of main and safeguard reactor vessels	Argon
Designed reactor lifetime, years	50
Reactor capacity factor	0.65
Operation period between fuel reloads, eff. days	100
Duration of reactor shutdown for preventive maintenance including fuel reloads, days	35 - 45

Table 2

Experimental volumes of MBIR reactor

Experimental volume	Location	Number of experimental devices	Thermal neutron flux at level of reactor core central plane, 10^{15} $cm^{-2}\cdot s^{-1}$	Dimensions, mm
Loop channels: central peripheral	Reactor core center 1st and 3rd rows of side reflector screens	1 2	4.9 2.1 / 1.3	D 100, 7 cells with width across flats of 72.7 each
Instrumented experimental channels	Reactor core	3	Up to 4	Cell with width across flats of 72.2
Cells for material test assemblies and isotope production assemblies	Reactor core	Up to 14	2.4 - 4.7	Cell with width across flats of 72.2
Vertical experimental channels (VEC)	Outside reactor vessel in thermal shield at R1675 mm	6	0.0124	D 342
	Outside reactor vessel in thermal shield at R2670 mm	2	1.5910^{9} *	D 34
* The data given is not recalculated to 10^{15} $cm^{-2}\cdot s^{-1}$.				

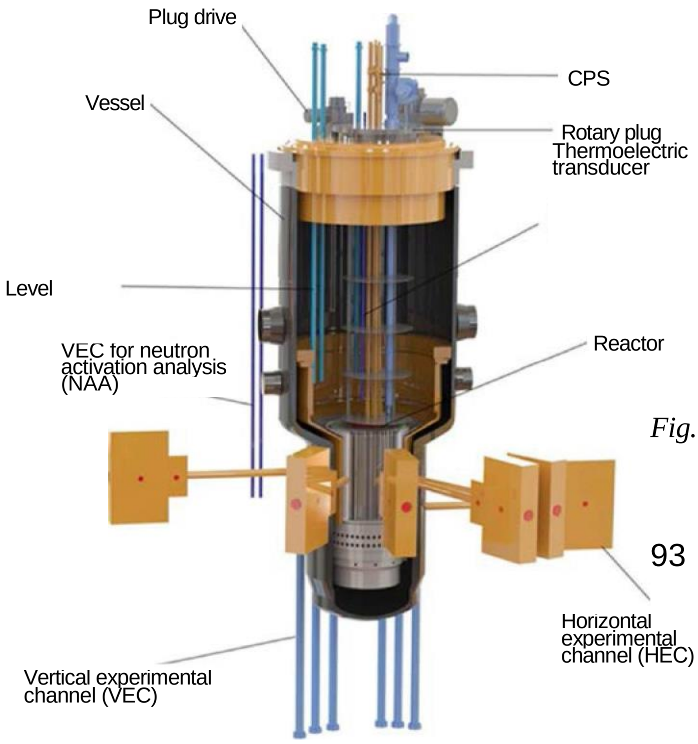

Fig. 3. MBIR reactor

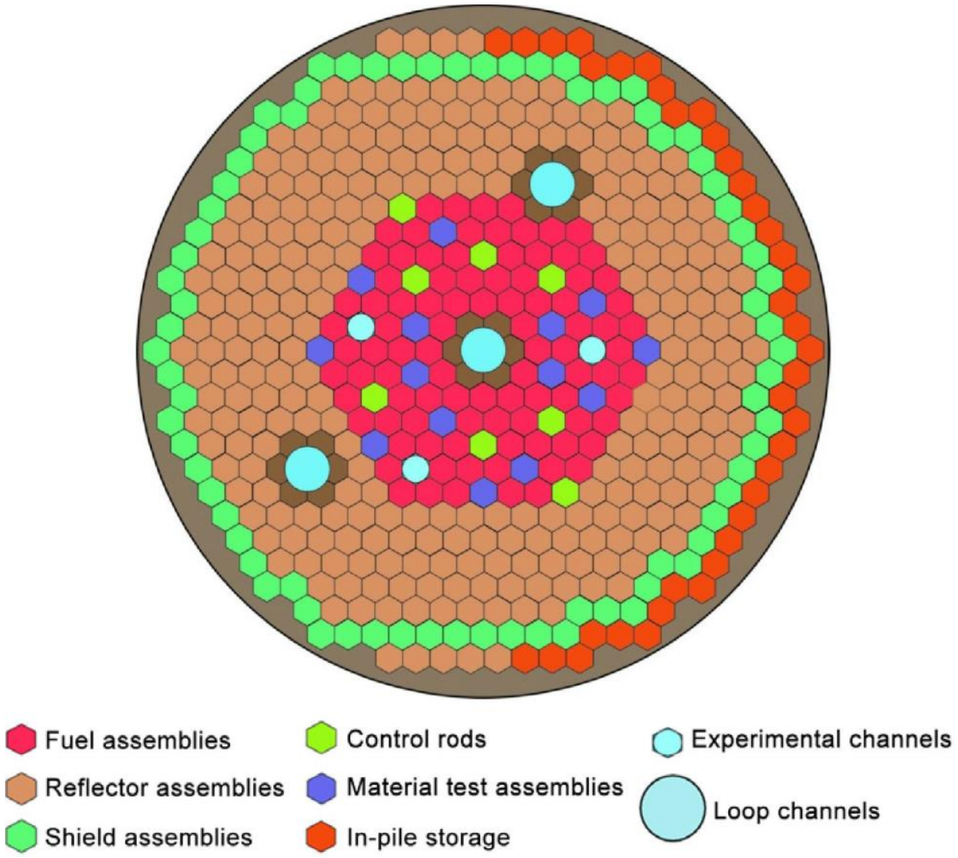

Fig. 4. Layout of MBIR reactor core

4.2 Primary circuit

The primary reactor circuit consists of two symmetrical cooling loops. The whole primary circuit including the reactor, the circuit components, valves and piping is enclosed in a safeguard vessel, which maintains the sodium level above the outlet nozzles in the reactor vessels and the circulation pumps in case of sodium leakage from the primary circuit. The leaktight safeguard vessel is filled with argon. The vessel is divided into three leaktight compartments. The volume of the largest compartment is such that its filling does not lead to uncovering of the reactor outlet nozzles, thus preventing the breaks in the primary circuit circulation.

The primary pipelines and components are equipped with the electrical heating and heat insulating system in order to maintain the sodium temperature at a level that provides the required quality of the coolant in terms of solubility of sodium oxides in each of the reactor operation modes.

4.3 Secondary circuit

The secondary circuit of the MBIR reactor is a safety barrier between the radioactive primary sodium and the steam-water circuit of the turbine.

Heat from the secondary coolant is transferred to the coolant of the tertiary circuit through the heat-exchange surfaces of the reverse-type steam generator. The MBIR reactor incorporates two parallel secondary loops, which transfer the heat from the reactor to the steam generators and which are equally involved in the heat removal. The circulation in the secondary circuit is provided by means of the electromagnetic pumps.

The secondary pipelines are equipped with the electrical heating and heat insulating system in order to maintain the sodium temperature at a level that provides the required quality of the coolant in terms of solubility of sodium oxides in each of the reactor operation modes.

4.4 Circuit of Emergency Heat Removal System (EHRS)

The EHRS circuit is a safety system, which is intended both for the emergency cooldown of the reactor and the scheduled heat removal from the reactor core in an amount equal to 4 % of the reactor thermal power. Thus, each EHRS loop removes 3 MW of thermal power.

The principle scheme of the MBIR reactor heat removal includes the EHRS connected to the emergency heat exchanger located in the by-pass line of the intermediate heat exchanger in each of the two facility loops.

The EHRS ensures cooling the reactor core when heat removal using the steam generators is impossible, and during the temporary reactor shutdown.

Circulation in the EHRS circuit is natural both during the scheduled and emergency cooldowns, and is achieved thanks to the elevated arrangement of the components. The heat removal in the EHRS is carried out by means of the air heat exchanger, with the heated air being discharged into the vent stacks.

The pipelines of the EHRS circuit are equipped with the electrical heating and heat insulating system in order to maintain the sodium temperature at a level that provides the required quality of the coolant in terms of solubility of sodium oxides in each of the reactor operation modes.

4.5 Tertiary circuit

The tertiary circuit of the MBIR reactor is designed to remove heat from the steam generators and to generate steam, which is fed to the turbine. The tertiary circuit provides for the reactor cooldown by means of the steam generators.

4.6 Handling systems

The structural arrangement of the handling operations performed at the MBIR research facility is governed by the following specific reactor features: the reactor arrangement (loop-type), the coolant used (liquid sodium), the characteristics of fresh and spent fuel (high level of decay heat), and the presence of in-pile experimental devices (long-length loop channels and channel-loops).

The above factors determined the following handling scheme arrangement:

- a fresh fuel storage with a refueling machine, turning device and gauge slot;
- a drum for storage of fresh fuel assemblies;
- a refueling machine for FA handling;
- a reloading machine for handling loop and experimental channels, long-length channels;
- an in-pile reloading mechanism;
- an in-pile storage of spent FAs;
- a drum for handling of spent FAs;
- water-steam cleaning sits and a room for placement of defective spent FAs into canisters;
- storage pools for spent FAs with an inclined hoist.

Starting from the drum with fresh FAs and ending with cleaning sits, all handling of the reloaded reactor core components is performed in inert ambient conditions (argon, nitrogen).

5. Experimental capabilities of MBIR nuclear research facility

The MBIR research facility is designed to house experimental devices both in the reactor core and outside the reactor vessel.

The reactor core provides for accommodation of 20 irradiation devices, including one central loop channel and two peripheral loop channels (each channel occupies seven reactor core cells), three cells for installation of the instrumented experimental channels or the channel-loop devices, and 14 cells for accommodation of the material test assemblies and the assemblies for isotope production.

Outside the reactor vessel inside of the thermal shield, six horizontal experimental channels for physical studies and eight vertical experimental channels are provided, six of which are intended for a silicone doping device and the other two – for a neutron activation analysis.

Characteristics of the experimental volumes of the MBIR reactor are presented in Tables 2 and 3.

Table 3

Characteristics at MBIR horizontal channel outlets

Performance	HEC-1, $cm^{-2}s^{-1}$	HEC-2, 3, $cm^{-2}s^{-1}$	HEC-4, $cm^{-2}s^{-1}$	HEC-5, $cm^{-2}s^{-1}$	HEC-6, $cm^{-2}s^{-1}$
Neutron flux (E>0.1 MeV)	3.28E+09	9.00E+08	-	8.36 E+09	3.28E+09
Neutron flux (0.01 MeV < E<0.1 MeV)	2.06E+09	1.42E+09	-	8.73 E+09	2.06E+09
Neutron flux (0.4 eV < E<0.01 MeV)	4.51E+09	2.45E+09	2.40E+05	1.38E+10	4.51E+09
Neutron flux (E<0.4 eV)	2.38E+08	6.79E+07	3.69E+05	1.34E+09	2.38E+08
Channel purpose	Physical research	Physical research	Neutron radiography	Physical research	Physical research
HEC position	Outside reactor vessel				
HEC diameter, mm	D180				

Conclusions

During the project development, the account was taken for the possibility to use the existing infrastructure, unique operating experience and workforce capacities of JSC "SSC RIAR".

Compliance with the legislative and regulatory requirements with respect to siting and construction of MBIR, which is one of the evaluation criteria in carrying out expert examination, was verified by the positive expert conclusions of the Federal Service for Supervision of Natural Resource Usage "Gosprirodnadzor" (the State environmental expert review of supporting materials for siting and construction licenses), FAE "RF Glavgosekspertiza" (the State expert review of the design documentation), FBI "SEC NRS" (assessment of the safety case during siting and construction).

The mandatory licensing procedures, which allow proceeding with the main stage of the MBIR construction, ended in the acquisition of the license for the MBIR construction. A ceremony devoted to the first concreting was held on September 11, 2015, and it served as the official commencement of works on concreting the main building bedplate.

The creation of MBIR will allow expanding the experimental capabilities of the national nuclear power industry, even considering the decommissioning of the operating BOR-60 research reactor, as well as providing the experimental and research resources required for justification and support of the innovative and evolutionary reactor technologies.