SM REACTOR CORE MODERNIZATION PROGRAM

A.L.IZHUTOV, A.P.MALKOV, A.L.PETELIN, S.A.SAZONTOV, and V.A.STARKOV
JSC “SSC RIAR”
9, Zapadnoye Shosse Dimitrovgrad, Russian Federation, 433510

ABSTRACT

The high-flux research reactor SM has been in operation since 1961. It is intended to perform irradiation testing of reactor materials under the target conditions and produce transplutonium elements and radionuclides of high specific activity. The reactor has been modernized several times during its long-term operation. Its latest modernization dates back to 1992.

Nowadays the work program for the SM-3 core modernization is available. The modernization work is to be done from 2017 till 2020s. The work program provides for replacement of the core structure components including the neutron trap, shim and safety control elements of the reactor and beryllium blocks of the reflector. Moreover, the existing fuel elements will be replaced in order to reduce annual consumption of highly enriched uranium.

This modernization will make it possible to increase a number of irradiation positions in the neutron trap where neutron flux is higher than $2{\cdot}10^{15}$ $cm^{-2}{\cdot}s^{-1}$. There will be 57 irradiation positions instead of existing 27. The annual consumption of highly enriched uranium shall be decreased down to 22 %. The modernization will help to extend the reactor operational lifetime at least until 2030.

1. Introduction

The SM-3 reactor was last modernized in the early 1990s. Owing to the latest modernization, a new reactor vessel and its internals were inserted into the old reactor vessel. First of all the installation of the new vessel was driven by the need to enhance the operational safety of the reactor. Supply and removal of the reactor coolant were provided in the upper part of the reactor vessel to minimize possibility of coolant loss accident. Moreover, operational safety systems and safety-related systems were upgraded: reactor control and safety system, emergency core cooling system, fuel charging machine, radiation protection and radiation monitoring systems, emergency power supply systems and emergency fire suppression system etc. Modernization made it possible to enhance the reactor safety, experimental capabilities and it also contributed to fulfilling modern safety requirements. The first criticality of the SM-3 reactor was achieved in December 1992 and in April 1993 it was started up.

The modernized reactor has been in operation for almost 25 years with its design operating characteristics without any major modification of its design. However, nowadays the reactor calls for its next modernization to adapt to new challenges and objectives. The core load bearing and support structures need to be replaced. It will be necessary to perform design engineering of a new neutron trap to increase irradiation capabilities. New reactor control elements and actuating mechanisms need to be designed and manufactured. Beryllium blocks are also to be replaced. The reactor fuel elements and fuel assemblies are to be redesigned. Moreover, their operational performance is to be verified.

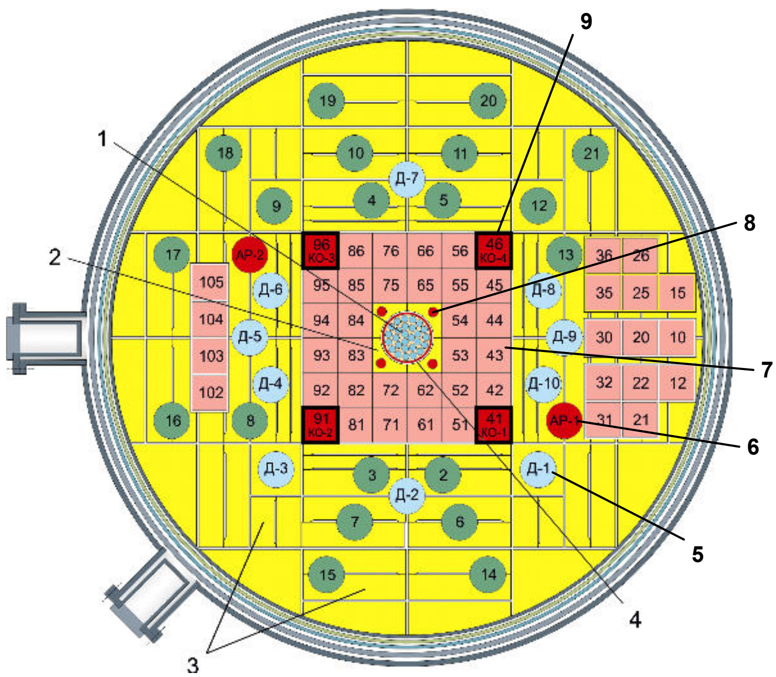
2. Specifications and experimental capabilities of the SM-3 reactor

For the first time ever the reactor design implemented production of thermal neutron flux of high density in a moderating trap located in the core center where the neutron spectrum is hard [1]. Beryllium and water in various combinations are used as neutron moderator in the trap. The reactor specifications are given in Table 1.

Reactor characteristic	Value
Reactor type	Pressurized water-cooled and water-moderated reactor, Intermediate spectrum reactor with the neutron trap
Power output, MW	100
Max thermal flux density, $cm^{-2}s^{-1}$	$5{\cdot}10^{15}$
Reactor operation at full power per year, days	230-240
Fuel	Uranium dioxide, 90% enriched U-235
Core geometry	Square with the neutron trap in the center
External dimensions of the core, mm	420×420
The number of cells for fuel assemblies	32
Core height, mm	350

Table 1. SM-3 specifications.

Shown in Fig. 1 is a schematic representation of the SM-3 core.



1 – experimental channels in the neutron trap; 2 – beryllium insert; 3 – reflector beryllium block; 4 – central shim rod; 5 – experimental channel cell in the reflector; 6 – control rod; 7 – core cell with a FA; 8 – safety rod; 9 – shim rod

Figure 1. The SM-3 core arrangement

The reactor core is enclosed in the reflector made of beryllium metal. There are vertical straight holes in the reflector. They are located at various distances from the core to accommodate test channels and irradiation rigs. Thermal neutron flux density is lower in the test channels compared to the neutron trap but it is also rather high (no higher than $1.5{\cdot}10^{15}$ $cm^{-2}{\cdot}s^{-1}$). The reactor is both water-cooled and water-moderated.

The test rigs can be inserted in the central neutron tarp (27 irradiation positions), in the reactor reflector (30 positions), in special fuel assemblies (no more than 6 pcs. with 4 cells in each, 4 pcs. with 1 cell in each). Experimental capabilities of the SM-3 [2] reactor are summarized in Table 2.

A number of irradiation positions including	No more than 85
Neutron trap	1 (block based design- central beryllium block of transuranium targets- 27 positions for targets Ø 12 mm in diameter; channel based design - 17 positions for targets Ø12 mm in diameter)
Core	No more than 6 fuel assemblies with 4 cells Ø12mm in diameter, no more than 4 fuel assemblies with one cell for targets Ø24.5 mm in diameter
Reflector	30 (20 positions out of 30 are intended for channels enabling the experimental data outputting or coolant removal through the reactor head).

Table 2. Experimental capabilities of the SM-3 reactor.

The SM-3 reactor also has loop facilities VP-1 and VP-3. They are intended to conduct irradiation testing of fuel, experiments with failed fuel elements to study release of gaseous fission products from them and the ways of their removal from the primary circuit, as well as to conduct irradiation testing of structural and absorber materials. Table 3 shows specifications of these loop facilities.

Characteristic	VP-1	VP-3
Max operating pressure, MPa	5.0	18,5
Coolant temperature, °C	90	300
Flow rate, m^3/h	30	5÷8
Thermal power output	500	90
Coolant	Water	Water

Table 3. Specifications of loop facilities VP-1 and VP-3.

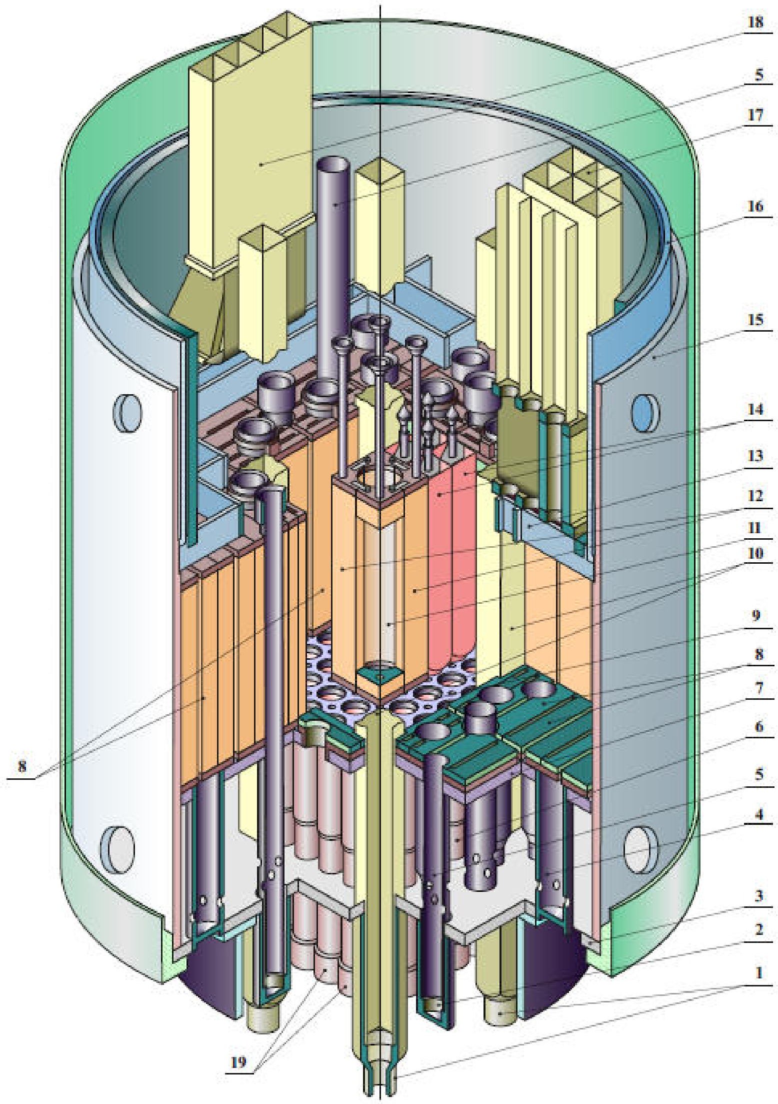
Extensive experimental capabilities enable conducting of the following experiments:

- To perform irradiation testing of the materials used for core components of power and advanced reactors in support of new reactor design concepts of the next generation (creep properties and corrosion behavior of cladding materials; behavior of moderators and absorber materials; release of fission products and fuel expel from different fuel elements, irradiation of research reactor fuels etc.) at a damage dose rate of 25 dpa/yr. in a wide range of temperatures;
- To produce transuranium elements such as curium-244-248, americium-243, californium-248, -249, -252;
- To produce radionuclides of high specific activity such as phosphorous-33, gadolinium-153, irridium-192, cobalt-60, tungsten-188, nikel-63, iron-55, -59, tin-113, -119m, strontium-89, selenium-91, iodine-125, lutetium-177, molybdenum- 99.

3. Major modernization work in the SM core

3.1 Replacement of the load bearing and support structures

The SM support steelwork (the core area) was fully replaced in 1965, 1977-78 and in 1991÷93 during the entire existence of the reactor. Each replacement was preceded with design modifications to address identified drawbacks. The reflector material was also replaced. The core height was increased. The improved design of the support steelwork integrated into the reactor vessel in 1991÷1993 during the SM reactor modernization (Fig. 2) can be deemed as the most successful and durable.



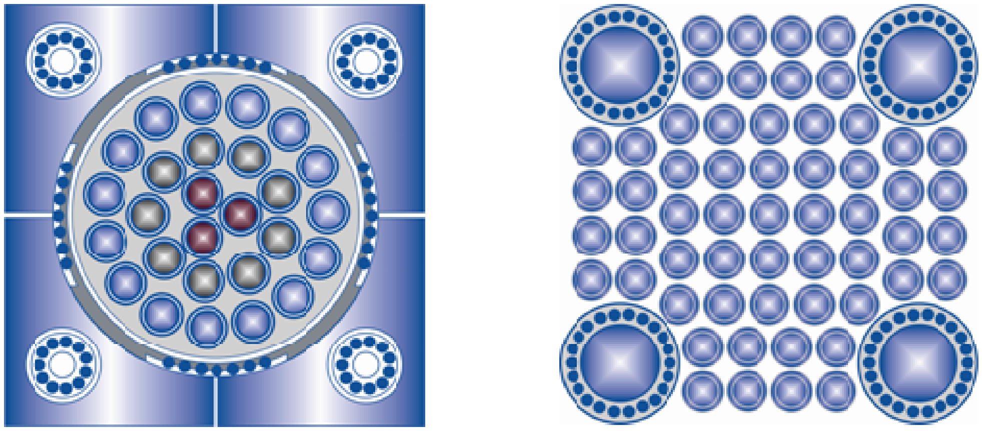
1 – mounting socket of the shim rod tube; 2 – mounting socket of the automatic control rod tube; 3 – lower support plate; 4 – support plate rack; 5 – tube for automatic control rod; 6 – FA socket; 7 – upper support plate; 8 – beryllium block; 9 – FA socket; 10 – tube for shim rod; 11 – neutron trap; 12 – Be insert in the neutron trap; 13 – the reflector retaining lattice; 14 – FA; 15 – core vessel; 16 – reactor vessel shield; 17 – FA storage area #1; 18 – FA storage area #2;19 – the diffusers

Figure 2. Schematic representation of the SM-3 core area

The latest modification of the reactor core area represents itself heavy-duty rigid weldment made of steel 12X18N10T. It is comprised of support plate, core tank, core lattice, reflector stacking of beryllium blocks and shell of the bottom head. Fuel assemblies (FAs) are mounting on the support plate, which together form the reactor core. In 2019 the SM-3 core area is to be replaced after operation for 26 years:

- Steel construction members (support plate, shell, retaining lattice, reshuffling platforms, guide tubes of test channels);
- Beryllium reflector (44 beryllium blocks, 800 kg in total weight);
- control elements and actuating mechanisms including guide tubes.

The neutron trap is to be modified to increase a number of irradiation positions in it from 27 up to 57 positions and to exclude the central shim rod and beryllium segments (Fig. 3).



Existing neutron trap   Upgraded neutron trap

Figure 3. Schematic representation of the neutron trap before and after its upgrade

The central shim control element and safety elements located in the neutron trap will be replaced during the reactor modernization. At the moment, there are four safety elements and the central annular-shaped shim element in the neutron trap of the SM reactor. The SM core modernization program provides for removal of the central shim element to enlarge the space in the neutron trap to conduct irradiation testing of materials, make the space more readily accessible to the targets and to reduce the number of control rods. To maintain the same total reactivity worth of control elements, it is expected that a diameter of four safety elements will be increased. They are also envisaged to have two functions: reactor safety and shim elements. This engineering solution makes it possible to simplify the existing system of reactor control, avoid using of bulky central shim element because of its complicated movement system. This, in turn, enhances the reliability, performance and safety of the reactor.

As evidenced by the experiment-based and numerical estimation analysis (experiments were performed using the critical assembly test facility), four safety control elements of the SM reactor could operate as the combined shim- safety elements. Such analysis made it possible to identify the impact of the modified core on the efficiency of control elements and estimate reactivity effects attributable to these modifications. It was demonstrated that the total reactivity worth of shim elements located in the corners and modified shim-safety elements will make it possible to attain the same duration of the reactor operation cycle provided for desired subcriticality level for staring.

3.2 New fuel development and adaptation

So far RIAR [3] in collaboration with A.A.Bochver Institute for Inorganic Materials have already developed, fabricated and performed irradiation testing of three dispersion-type fuel elements. They are cross-shaped. Fuel is dispersed in aluminum matrix and enclosed in stainless steel cladding:

1) Uranium dioxide dispersed in aluminum matrix;
2) Uranium dioxide (the fuel element has aluminum displacer in the center that takes a form of square at the cross-section);
3) Uranium intermetallic compound.

Fuel elements of three above-listed design modifications underwent irradiation testing in the SM reactor under the conditions similar to their operating conditions in the modernized reactor core. UAl_3-based fuel element was chosen based on the results of irradiation testing. By 2019 a pilot scale batch of full-size fuel assemblies shall be fabricated and subjected to irradiation testing.

4. Work implementation plan

An outline schedule of work under the project can be broken up into 5 major stages which are shown in Table 4 below. Actually a preparatory stage concerned with the development of conceptual began in 2000s. The present-day SM core modernization concept was defined in in 2015 and it was updated in early 2017.

The SM core modernization project is to be completely implemented from April 2017 until February 2020.

#	Work description	Completion date
1.	**Preparatory stage**	
1.1	Elaboration of the core modernization concept	June, 2015
1.2	Approval of updated concept and modernization project readiness for investment	June 2017
1.3	Decision on investing and modernization launching.	April 2017
2.	**The SM-3 core modernization**	
2.1	Design engineering of the SM core area and its release	September2017
2.2	Design engineering and manufacturing of equipment	September 2019
2.3	Preparation and replacement of the reactor core area	September 2019
2.4	Disposal of solid radioactive waste	September 2019
3	**Safety assessment of modernized fuel**	
3.1	Design engineering of fuel element, fuel assembly and burnable poison	October 2017
3.2	Detailed engineering development and fabrication of the pilot scale batch of full-size fuel assemblies	December 2018
3.3	Irradiation testing of one FAs batch	April 2019
3.4	Fabrication of fuel assemblies for startup core loading	December 2019
3.5	**Finalization of the package of design and operational documents for licensing of the SM-3 modernized core:**	
3.6	Elaboration of the operational documents and documents to be submitted for the SM-3 modernized core licensing	September 2018
3.7	Expert review of documents to be submitted for issuing the reactor operating license	September 2019
3.8	Updating the reactor operating license with due consideration for the SM-3 modernized core	September 2019
4	**First criticality**	December 2019
5	**Power start-up**	February 2020

Table 4. Milestone work schedule.

5. Conclusion

The high-flux research reactor SM-3 is intended for irradiation testing of materials at high-dose values and production of transuranium elements and radioactive nuclides of different elements. As to its neutron flux density, the HFIR reactor (Oak Ridge National Laboratory, USA) could compete with SM-3.

Nowadays the SM-3 core modernization program has been worked out and some work is under way to implement it from 2017 until 2020.

The modernization provides for replacement of the core structure components, control members of the reactor and beryllium blocks of the reflector. The neutron trap is to be redesigned to increase the number of irradiation positions from 27 up to 57 ones. It will be necessary to verify operational performance of fuel dispersed in aluminum matrix instead of copper one. Ultimately, the reactor core conversion to the new fuel will make it possible to reduce annual consumption of highly enriched uranium by 22% as well as to increase the neutron flux density in the core and in the reflector.

Modernization will enable extending operational lifetime of the SM-3 reactor till 2030.

References

1. Nuclear Research Facilities in Russia/Edited by N.V. Arkhangelsky, I.T. Tretijakov, V.N. Fedulin, M.: OJSC NIKIET, 2012.

2. A.L. Izhutov, A.V. Burukin, S.A. Ilenko et al “Modern methods to test materials and fuel in research reactors of RIAR”, International Conference on Research Reactors: Safe Management and Effective Utilization, IAEA Headquarters, Vienna, Austria, 16–20 November 2015.

3. A.V.Klinov, N.K.Kalinina, N.Yu.Marikhin, V.V.Pimenov, A.L.Petelin, V.A.Starkov, and V.E. Fedoseyev Irradiation testing of low neutron poisoning fuel elements in the SM reactor, Izvestiya vuzov (News of Higher Educational Institutions), Yadernaya Energetika, 2013. #2. P.114-122.