SM-3 REACTOR CHARACTERISTICS AFTER CORE MODERNIZATION

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ABSTRACT

In the period 2017-2019, the SM-3 overaged core bearing frame is scheduled to be replaced. At the same time, the reactor core will be modernized as follows:

– the number of irradiation positions in the neutron trap will be increased, thus enabling an increase in the accumulation of transuranium elements, including Cf-252, and high specific activity radionuclides, such as Co-60, Se-75, W-188, Sr-89, etc., by more than 1.5 times;

– new fuel will be developed and justified providing for:

♦ decreased annual consumption of highly enriched uranium by some 22%;

♦ increased thermal neutron flux density in the core experimental channels by about 1.8 times;

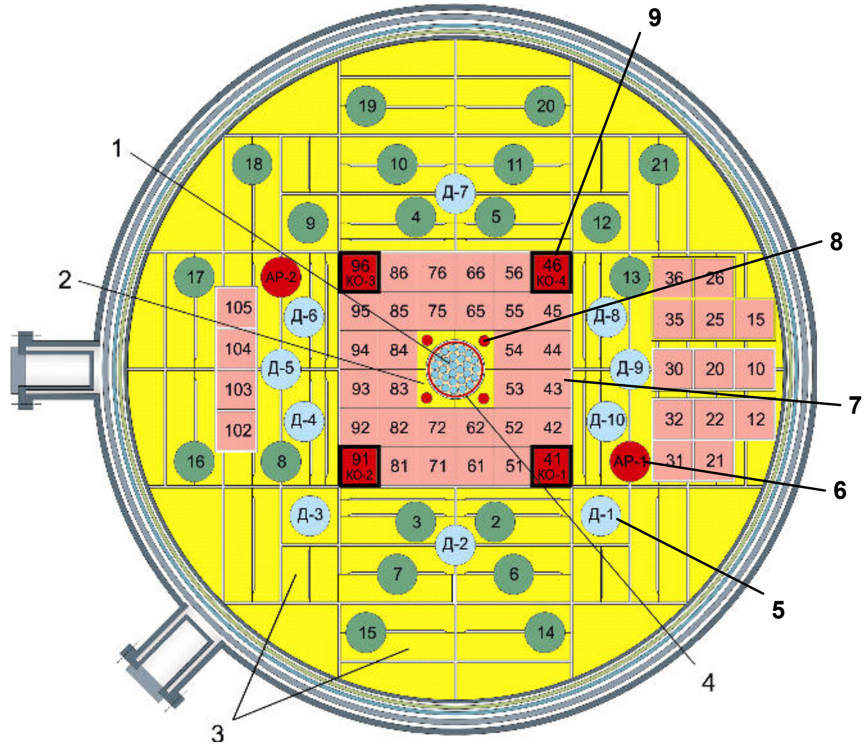
♦ increased thermal neutron flux density in the reflector channels and total accumulation of radionuclides, such as Ir-192, Co-60, by some 15%;

1. Introduction

In accordance with the approved concept of reactor core two-stage modernization, the first stage was successfully completed in 2005. This stage was aimed at enhancing the fuel cycle and enabling channels up to 60 mm in diameter to be installed in the core to perform long-term irradiation of materials at a damage rate of up to 20 dpa. In this regard, it was necessary to increase the amount of fuel in fuel rods by 20%. The second stage objectives are to enhance the reactor fuel cycle, increase the thermal neutron flux density in the core experimental channels and reflector channels, and increase the irradiation volume in the neutron trap. All of these will contribute to improving conditions for radionuclide accumulation both in terms of the total and specific activity, and extending the list of radioisotopes and capacity of isotope accumulation. The second stage of modernization will be implemented in 2019 to coincide with the core bearing frame replacement [1].

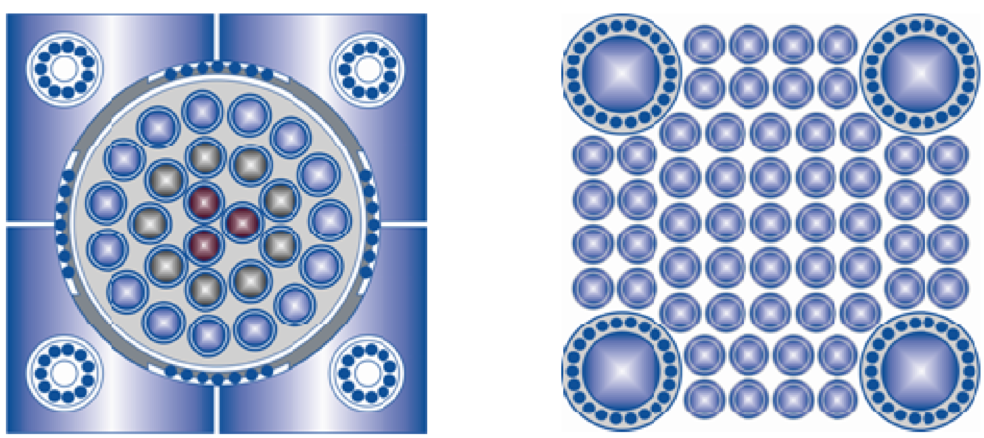
2. Neutron trap modernization

The SM-3 neutron trap and core (Fig. 1) will be modernized to broaden the reactor experimental capabilities by increasing the number of irradiation cells in the neutron trap to have 57 instead of 27 positions (Fig. 2), and removing the central shim rod and beryllium inserts. Modifications will be introduced into the design and actuating mechanisms of the shim rods by combining emergency protection and reactivity compensation functions. Such design modifications are targeted at enhancing the reactor robustness and ensuring conditions for reactor lifetime extension at least until 2030. They will provide for increasing by 1.7 times the accumulation of transuranium elements and high specific activity radionuclides, such as selenium-75, tungsten-188, cadmium-109, iron-55, etc.



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

Fig. 1. SM-3 core cross-section



a b

Fig. 2. Neutron trap schematic representation before (a) and after (b) modernization

The design work and neutronic calculations have shown that the safety-shim rod can be increased by 1.5 times in diameter, and the number of absorber elements – by 1.6 times.

2. SM-3 reactor characteristics after core modernization

Both modification of the neutron trap design and reactor conversion to a new fuel will lead to a variation in the heat rate distribution in the core and neutron flux density in the cells of the neutron trap itself, core and reflector, as well as to changes in the refueling and reactor fuel utilization schemes.

Core modernization covers two stages:

- at the first stage, the core bearing frame and neutron trap will be replaced, the central shim rod will be removed, and the safety-shim rod will be installed;
- at the second stage, the reactor will be converted from standard 6 g U-235 fuel in the copper matrix to 4 g U-235 fuel in the aluminium matrix with low neutron poisoning (LNP).

The SM-3 control and safety specifications before and after neutron trap modernization are given in Table 1.

Parameter	Trap	
	Before modernization	After modernization
Total efficiency of the shim rods, β_{eff}	11.3	11.4
Efficiency of the safety rods, β_{eff}	4.2	4.2

Table 1: Calculated parameters of the shim and safety rods before and after neutron trap modernization

To level the field of the heat rate in the core and reduce the maximal fuel heat rate in the LNP fuel rods, burnable absorber rods will be used. Substantially decreased neutron absorption in the structural materials of the LNP fuel rods enables reducing the uranium mass in a fuel assembly (FA) by 1.5 times. Thus, despite a small increase in the annual FA consumption, annual uranium consumption is substantially reduced.

Table 2 shows calculated parameters of the SM-3 fuel cycle before and after modernization.

Parameter	Before modernization	After modernization	
		Stage 1	Stage 2
Fuel rod	standard	standard	LNP
U-235 content in a fuel rod, g	6	6	4
Average fuel burnup in the core, %			
Reactor run start	22÷23	20÷21	28÷29
Reactor run end	25÷26	24÷25	33÷34
Average fuel burnup in discharged FAs, %	44÷49	41÷46	60÷65
Average annual consumption of FAs	60÷62	64÷66	70÷72
Average annual consumption of uranium, rel. units	1.00	1.08	0.80

Table 2: SM-3 fuel cycle parameters

Due to substantially decreased neutron poisoning in the fuel rods, uranium mass in the FA can be reduced by about 1.5 times based on the calculations. Therefore, despite a small increase in the annual consumption of FAs, the consumed uranium mass will be decreased considerably.

The key physical characteristics of the SM-3 reactor before and after modernization are shown in Table 3.

Parameter	Value	
	Before modernization	After modernization
Average reactivity margin at the reactor run start, β_{eff}	10.7	6.83
Reactivity effect of the core heat up when moving from zero to nominal power, β_{eff}	-0.62	-0.93

Steady-state xenon-135 poisoning, β_{eff}	-5.1	-5.8
Temperature coefficient of reactivity at the core operating parameters, $\beta_{eff}/^{o}C$	-0.020	-0.018
Reactivity effect of fuel burnup and poisoning including burnable absorber rods burnup in the new fuel, β_{eff}	-4.8	-1.1
Reactivity loss rate per fuel burnup, β_{eff}/MWd	-0.0054	-0.0012
Power coefficient of reactivity for the reactor "hot poisoned" state, β_{eff}/MW	-0.0047	-0.0043

Table 3: SM-3 physical characteristics before and after the second stage

Table 4 provides the irradiation cell parameters.

Parameter	Before modernization	After modernization	
		Stage 1	Stage 2
Neutron trap			
Experimental volume, l	0.74 (1)	1.56 (2.1)	1.56 (2.1)
Neutron flux density, 10^{14} $cm^{-2}s^{-1}$			
fast	8.6 (1)	9.5 (1.11)	8.8 (1.03)
intermediate	5.0 (1)	4.7 (0.93)	4.4 (0.88)
thermal	23.5 (1)	19.7 (0.84)	19.0 (0.81)
Irradiation efficiency, rel. units	**1**	**1.77**	**1.71**
REFLECTOR			
Experimental volume, l	22	22	22
Neutron flux density, 10^{14} $cm^{-2}s^{-1}$			
fast	1.4(1,0)	1.4 (1.0)	1.5 (1.08)
intermediate	1.01 (1)	1.06 (1.05)	1.08 (1.07)
thermal	7.4 (1)	7.4 (1.0)	8.51(1.15)
Irradiation efficiency, rel. units	**1**	**1**	**1.15**
CORE			
Experimental volume, l	1.6	1.6	1.6
Neutron flux density, 10^{14} $cm^{-2}s^{-1}$			
fast	16.0 (1)	15.7 (0.98)	16.5 (1.03)
intermediate	3.5 (1)	3.4 (0.96)	4.1 (1.16)
thermal	1.0 (1)	0.96 (0.96)	1.8 (1.82)
Irradiation efficiency, rel. units	**1**	**0.96**	**1.82**
REACTOR			
Irradiation efficiency, rel. units	**1**	**1.07**	**1.21**

Table 4: Core comparative analysis

4. Conclusion

Modernization of the SM-3 reactor core will enable broadening its experimental capabilities, enhancing fuel and reactor utilization, improving the irradiation efficiency in the reactor by about 1.2 times.

The number of irradiation positions in the neutron trap will be increased to have 57 instead of 27, thus enabling an increase by about 1.7 times in the accumulation of transuranium elements, including Cf-252, and high specific activity radionuclides, such as Se-75, W-188, Cd-109, Fe-55, etc.;

Introduction of the new fuel with low neutron poisoning will enable:

- decreasing annual consumption of highly enriched uranium by ~22%, and increasing thermal neutron flux density in the core experimental channels by 1.8 times
- increasing thermal neutron flux density in the reflector channels, the volume of which makes up ~ 90% of the reactor experimental volume, as well as increasing the total accumulation of radionuclides, such as Ir-192, Co-60, etc., by 15% in the reflector experimental channels.

References

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