Eurasian Journal of Physics and Functional Materials

2022, 6(3), 190-197

Experimental data on the IVG.1M RCCS influence on the reactor downtime between start-ups

R.A. Irkimbekov, A.S. Azimkhanov, G.A.Vityuk, A.S. Surayev*, I.K. Derbyshev

National Nuclear Center of the Republic of Kazakhstan, Kurchatov, Kazakhstan

E-mail: suraev@nnc.kz

DOI: **10.32523/ejpfm.2022060304**
Received: 15.09.2022 - after revision

The paper describes an experience of the IVG.1M research reactor operation with the core water-cooling system, which includes an auxiliary reactor coolant cooling system, designed for forced coolant cooling in periods of long-term reactor shutdown. The IVG.1M reactor is cooled by a limited amount of coolant circulating in a closed circuit, heated and uncooled during reactor operation. In this regard, duration of continuous operation of the reactor and frequency of startups are restricted due to limited value of water temperature at the core inlet. Prior to commissioning of the reactor coolant cooling system, it was cooled by means of natural heat transfer to the environment, while full-scale reactor startups were conducted with a frequency of approximately once per month. With forced coolant cooling, provided by use of the reactor coolant cooling system, its temperature decreases to acceptable values approximately within a week after the next startup, and, accordingly, full-scale startups of the IVG.1M reactor can be conducted once a week. This significantly expands potential of using the reactor and at the same time accelerates burnup of nuclear fuel and decrease in the reactor reactivity margin. Estimation of the fuel burnup rate will allow organizing timely supply of fresh fuel to replace the burnt out fuel. The paper contains the measurement results of the coolant temperature after a series of reactor startups, based on which it can be concluded that the IVG.1M RCCS has an effect on reducing the reactor downtime time between startups. The obtained results can be used to select and justify options for implementing the reactor campaign and its fuel.

Keywords: IVG.1M reactor; reactor downtime; coolant temperature; RCCS; experimental results

Introduction

The IAE Branch of the RSE NNC RK has been operating the research high-temperature gas reactor IVG.1 since 1972. Initially, it was used for testing fuel for creating nuclear rocket engines. In 1990, fresh highly enriched uranium fuel was charged into the reactor, which was converted to water cooling. The modified IVG.1M reactor was used for material research as a source of a high-density neutron flux [1]. In the context of a final part of the campaign, the IVG.1M reactor with highly enriched uranium fuel was used for life tests of pilot FAs with low enriched uranium fuel, which triggered changes in the approach to coolant cooling technology between reactor startups.

A specific feature of the reactor operation is a coolant temperature restriction at the core inlet to ensure that there is no possibility of a boiling crisis on the surface of fuel elements. Another important feature of the reactor is that the cooling system is a closed circuit, which does not provide for a cooling system for the coolant during reactor operation. As a result, duration of continuous reactor operation is limited due to gradual heating of the coolant, and duration of the forced reactor downtime directly depends on speed of the coolant cooling. The total water volume in the reactor cooling system is about 1500 m^3, provided that total heat capacity when the coolant temperature changes from 20 $^\circ$C to 55 $^\circ$C, which is the maximum allowable water temperature at the core inlet, is about 130 GJ, which corresponds to the energy release in the reactor of 36 $MW \cdot h$ without forced cooling. After such a startup, the coolant is cooled only due to natural heat transfer to the environment, while in summer and autumn coolant cooling to a temperature of 20 $^\circ$C takes more than one month.

For life testing of pilot FAs with low-enriched uranium fuel, it is required to perform several dozen full-scale reactor startups. In order to speed up the reactor coolant cooling between startups and to reduce the reactor downtime, in July 2019, the reactor coolant cooling system (RCCS) was put into operation. In accordance with the current regulatory restrictions, the RCCS can only be activated during the period between startups and it cannot be used during the reactor startup. Despite this fact, intensity of testing after RCCS commissioning increased at least 4 times. The possibility of regular reactor startups expands the range of applications and confirms the relevance of optimal solutions for organization of the reactor fuel campaign. To date, in the context of the IVG.1M reactor conversion, low-enriched uranium fuel is charged into the core [2]. Neutronic studies of the core parameters are underway [3]. Optimization of the fuel campaign is studied in depth using the reactor design models [4] for the MCNP code [5].

Below the RCCS design is considered and experimental data are provided that characterize capabilities and confirm performance and efficiency.

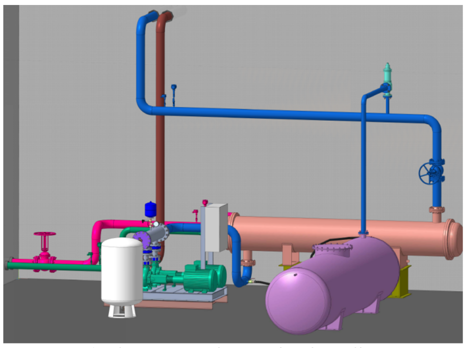
Description of the RCCS

The RCCS of the IVG.1M reactor is designed for forced cooling of the reactor coolant in order to cut time intervals between startups when performing a series of successive reactor startups. During the operating startup of the IVG.1M reactor, the RCCS is disconnected from the reactor cooling system by shut-off valves and is not used directly during the startup. The use of RCCS at the end of a startup enables reducing the interval between startups from one month to four days, even in summer.

The RCCS consists of two working circuits and equipment for filling (emptying) the system with coolant [6]. The first circuit (Figure 1) is designed for forced cooling of the reactor coolant during the period between startups and consists of a heat exchanger and a main pipeline with shut-off valves and control ones. The second circuit, which includes the "WILO" pumping station, a group of cooling towers and a main pipeline with shut-off and control valves (Figure 2), is designed to cool the coolant of the primary circuit with a coolant [7, 8], which, in turn, is cooled by the surrounding air pumped by fans through cooling towers. Table 1 provides the main characteristics of the working circuits.

Table 1.
Technical characteristics of the RCCS working circuits.

Technical characteristics	Primary circuit	Secondary circuit
Safety class	4n	4n
Coolant type	distillate water	55 ethylene glycol aqueous solution
Coolant flow, m^3/h	60	120
Pressure, mm w.g.	132	60
Inlet temperature,°C	55	up to 41
Outlet temperature,°C	max 35	max 33



a) The RCCS primary circuit outline

b) «WILO» pumping station

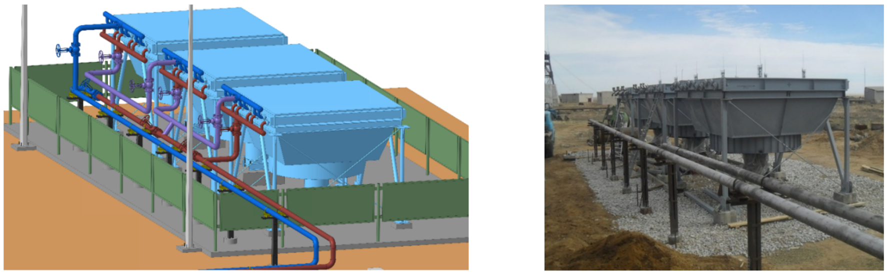
c) heat exchanger

d) ethylene glycol tank

Figure 1. The RCCS primary circuit.

Experiment results of the RCCS operation

When testing pilot FAs with low-enriched uranium fuel, a series of reactor startups with a total power output of 1080 MW · h have been conducted over a period



a) 3D model of the RCCS secondary circuit b) cooling towers

Figure 2. The RCCS secondary circuit.

of two years. At the same time, in each of the individual startups, maximum possible energy release in the reactor with respect to the coolant temperature was achieved (the maximum achieved value was 36 $MW \cdot h$). Figure 3 shows the graph of power generation in a series of startups, which shows the change in the intensity of the reactor startups after the RCCS commissioning. In the period between July 24, 2019 and October 30, 2019, 12 test cycles have been implemented at the reactor, each of which included the startup of the IVG.1M reactor and subsequent RCCS operation to cool the reactor coolant. Each cycle lasted seven days. The integral energy release in the reactor over this short period of time (less than 2.5 months) amounted to 415 $MW \cdot h$.

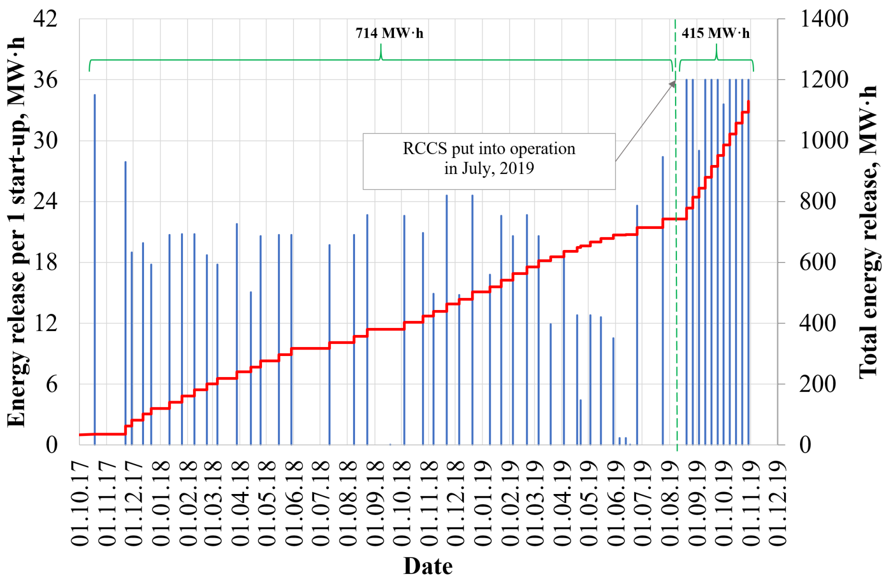


Figure 3. Energy release in the reactor.

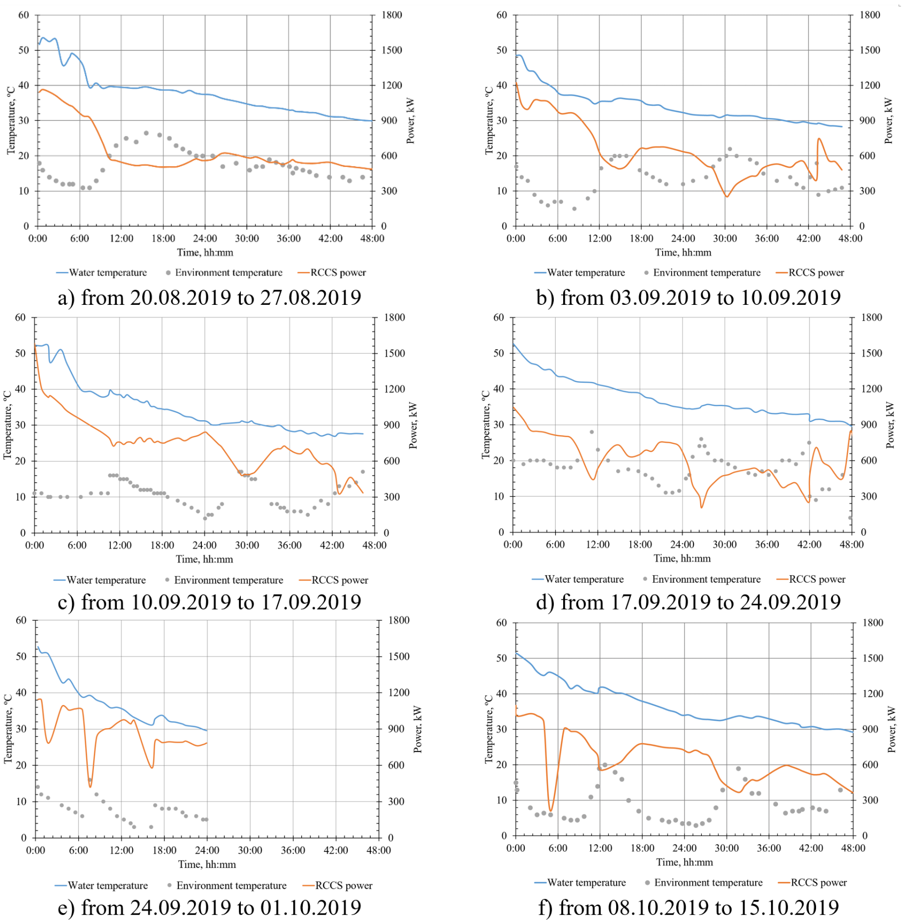
Based on the registration data of the RCCS technological parameters, graphs have been constructed (Figure 4) of change in the reactor coolant temperature, the thermal power removed from the reactor coolant in the RCCS, and changes in the ambient air temperature.

Figure 4a shows the registration data of the RCCS parameters corresponding to the cycle implemented in the period from August 20, 2019 to August 27, 2019. The total RCCS operating time in this period was 48 h 02 min. During this time, the IVG.1M coolant was cooled from 51.7° C to 29.9° C. Figure 4b shows the data recorded in the period from September 03, 2019 to September 10, 2019. The total operating time of the RCCS in this period was 46 h 45 min. During this time, the IVG.1M coolant was cooled from 48.6 ° C to 29.7 ° C.

Figure 4c shows a graph corresponding to the cycle implemented between September 10, 2019 and September 17, 2019. During the total time of the cooling system operation, equal to 34 h 15 min, the coolant temperature decreased from 52.3 ° C to 30 ° C.

Figure 4d shows the data of RCCS parameters recorded in the period from September 17, 2019 to September 24, 2019. The total operating time of RCCS in this period was 47 h 47 min. During this time, the IVG.1M coolant was cooled from 52.6 ° C to 29.8 ° C.

Figure 4e shows a graph corresponding to the cycle implemented in the period from September 24, 2019 to October 1, 2019. During the total time of cooling system operation, equal to 23 h 26 min, the coolant temperature decreased from 52.7 ° C to 29.9 ° C. In the period from October 08, 2019 to October 15, 2019 (Figure 4f), the IVG.1M coolant was cooled during the startup from 51.4 ° C to 30 ° C in 44 h 06 min.



a) from 20.08.2019 to 27.08.2019

b) from 03.09.2019 to 10.09.2019

c) from 10.09.2019 to 17.09.2019

d) from 17.09.2019 to 24.09.2019

e) from 24.09.2019 to 01.10.2019

f) from 08.10.2019 to 15.10.2019

Figure 4. Data of RCCS parameter registration.

Results and Discussion

Based on the results of the coolant temperature measurement after startups, a number of conclusions can be drawn regarding the duration of the forced reactor downtime between startups.

In summer, when maximum ambient temperature during a day reaches more than 30 ° C, and at night the temperature drops to 10 ° C, the coolant cooling time is about 48 hours.

In spring and autumn, duration of coolant cooling may vary depending on the average air temperature from 46 hours (average air temperature – 14 ° C, maximum – 22 ° C, minimum – 5 ° C) to 23 hours (average air temperature – 8 ° C, maximum – 16 ° C, minimum – 3 ° C).

The RCCS effectiveness in any season can be assessed by a slope of the water temperature graph. The cooling efficiency is directly related to the temperature difference between the water to be cooled and the environment. The maximum efficiency of RCCS is achieved at the maximum temperature of the reactor coolant, while its temperature drops from 50 ° C to 40 ° C in 12 hours maximum. Then the RCCS effectiveness decreases. The graphs clearly show the inverse dependence of the RCCS efficiency on the ambient temperature. In summarizing the above findings, it can be noted that the RCCS power in the initial cooling period in all cases exceeds 1.0 MW. This is 10 % of the nominal power of the IVG.1M reactor.

The results evidence that if conditions are created for the use of RCCS directly during the IVG.1M reactor startup, the duration of the reactor operation will be increased, and with certain parameters of the reactor and RCCS, the reactor can be operated at a constant power of 1 MW very long period of time. However, this requires measures to change the IVG.1M reactor design with a double-circuit cooling system. Figure 5 shows the dependence of the IVG.1M coolant cooling time on the ambient temperature. The coolant cooling down to 30 ° C at an average ambient temperature of 17 ° C was the longest one. This is about 5 ° C below the average monthly air temperature in the East Kazakhstan region for July, the hottest month of the year. It can be seen from the graph that the ambient temperature has a primary influence on intensity of the reactor coolant cooling, but deviations are possible. When comparing the periods of reactor operation from September 10 to 17 and from October 8 to 15, it can be observed that at a higher ambient temperature, coolant cooling occurred 10 hours faster. Consequently, other weather conditions, such as wind, precipitation and cloudiness, also affect the RCCS efficiency.

The obtained experimental data show that frequency of the IVG.1M reactor startups can be increased up to two times a week. However, now this is impossible due to routine maintenance restrictions at the reactor between startups.

Conclusion

Currently, the optimal duration of reactor downtime between startups is no more than one week. This is in good agreement with the work arrangement of a startup

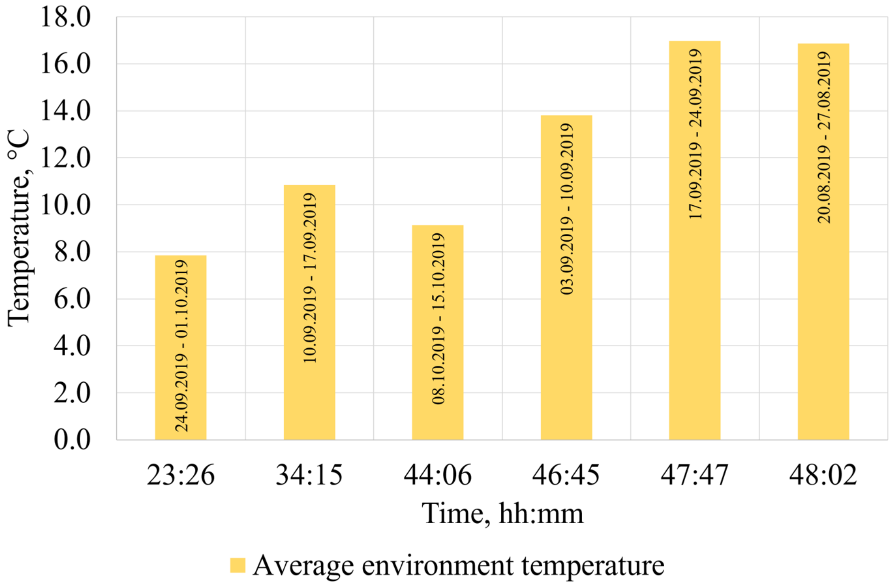


Figure 5. Graph of the IVG.1M coolant cooling time dependence on the ambient temperature.

shift and implementation of a set of routine maintenance before startup. Startups with such a frequency were tested at the IVG.1M reactor during the testing period in 2019. Thus, performing startups with an integrated power of 36 MW · h with a frequency of 1 time per week, it is possible to implement up to 40 startups at the IVG.1M reactor in one year and generate up to 1440 MW · h. These data take into account the planned reactor maintenance.

Experimental results show that incorporation of the RCCS has a potential to provide up to two startups per week. This will allow conducting up to 80 startups per year and generate up to 2880 MW · h. However, to increase the startup frequency, a change in organization of the reactor operation is required. Technically, RCCS may be included in the nuclear reactor design in the future. In this case, RCCS can be used as the second circuit of the IVG.1M reactor and ensure its long-term operation at a power of 1.0 MW. Obtained results are necessary for evaluating the fuel campaign when considering scenarios for using the IVG.1M reactor.

Acknowledgments

This work was supported by the Ministry of Education and Science of the Republic of Kazakhstan (project "The IVG.1M Reactor Nuclear Fuel Campaign Optimization", IRN AP08856242).

References

[1] Y. Gordienko et al., Fusion Science and Technology **76**(6) (2020) 703–709. [*CrossRef*]
[2] E.G. Batyrbekov et al., Bulletin of NNC RK **2** (2015) 6-18. (In Russian) [*WebLink*]

[3] L.K. Zhagiparova et al., Bulletin of NNC RK **3** (2017) 59–64. (In Russian) [*WebLink*]
[4] R.A. Irkimbekov et al., Atomic Energy, **127**(2) (2019) 69–76. [*CrossRef*]
[5] J.F. Briesmeistere, A General Monte Carlo N-Particle Transport Code. Los Alamos National Laboratory (2008) LA-UR-03-1987. [*WebLink*]
[6] E.Z. Akbolatov et al., Bulletin of NNC RK **4** (2019) 108–112. (In Russian) [*WebLink*]
[7] U. Koztayeva et al., Bulletin of Kazakh Humanitarian Juridical Innovative University **4** (32) (2016) 199–202. (In Kazakh) [*WebLink*]
[8] E.E. Serikkan et al., Proceedings of the X International scientific conference "Technocongress" Kemerovo (2017) 37–39. (In Russian)