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# REPORT

on the project

«Construction of a Complex of Cryogenic Moderators at the IBR-2 Facility»

Theme: «Development of the IBR-2 Facility with a Complex of Cryogenic Neutron Moderators»

January 2020 - May 2021

Current status of the project

Theme code: 04-4-1105-2020/2022

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**Annotation**

The report has been prepared in accordance with the recommendations of the PAC for Condensed Matter Physics of April 29, 2021. The report presents the results obtained in the course of work carried out from the beginning of 2020 through May 2021 within the framework of the project "Construction of a complex of cryogenic moderators at the IBR-2 facility".


Dubna 2021

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## Introduction

At the IBR-2 reactor, a complex of cold neutron moderators is being developed and constructed, which is unique both in terms of the principle of operation as well as in the composition and shape of the moderating material. The complex consists of three moderators surrounding the reactor core and forming the required and individual neutron flux for each of the eleven IBR-2 instruments. The optimum and individual spectrum of the neutron flux for each of the IBR-2 instruments can be achieved with the complex configuration of the head part of the moderator, which comprises water and cryogenic chambers, as well as by changing the temperature of the moderator material in the temperature range from 25 K to 100 K. The possibility of changing the temperature of the moderating material in each of the moderators appeared after the modernization of the cryogenic cooling system of the complex. The moderators are an integral part of the reactor and form the neutron flux, as well as influence the reactivity, and without them, the operation of the IBR-2 would be impossible.

In 2012, the first cryogenic moderator for beamlines 7, 8, 10, 11 (CM-202) was put into trial operation for physics experiments. To date, this moderator has operated for 4560 h. As a result of its operation, new results were obtained, as well as old systems were modified and new systems were developed, which were installed and are in operation as part of the infrastructure of the cryogenic moderator of the next stage (CM-201) for beamlines 1, 4, 5, 6, 9, which was commissioned into trial operation in December 2020.

## 1. General information on the operation of CM-201 and CM-202 from January 2020

In accordance with the schedule of operation of the IBR-2 reactor in 2020, in cycles 2 and 9, CM-202 operated in the cryogenic mode for physics experiments for 257 h. In 2021, in cycle 2 – 264 h and in cycle 3 – 261 h. The total energy generation in the “at-power” mode was 1665 MW·h. In cycle 9, a voltage drop occurred during the operation of the cryogenic system. At the same time, the engineering systems of the cryogenic moderator and the cryogenic system of the complex of moderators operated normally without malfunctions and accidents.

Since September 2020, CM-201 and CM-202 are in operation within a single system and provide service to 9 out of the 11 experimental IBR-2 beamlines under the project.

In January-July 2020, the components of the technological and cryogenic systems of the CM-201 cryogenic moderator were manufactured and installed.

The CM-201 as part of the IBR-2 cryogenic moderator complex, has been further developed, fit-checked, installed and operated in the thermal mode since September 2020, and in the cryogenic mode since November 2020. During this period, CM-201 operated in the cryogenic mode in cycle 9 of 2020, in cycles 2, 3 (according to the schedule of IBR-2 operation) and 5 (at the request of users). The total number of hours of operation for experiments was 1074 h, and energy generation – 1712 MW·h.

## 2. Brief review of the completed activities under the project for the period from January 2020 through May 2021

During the reporting period, in accordance with the project for the development of a complex of cryogenic moderators of the IBR-2 reactor, the following activities were carried out:

- ***Unit for counting pellets by optical method***

As an alternative method for monitoring the movement of pellets during loading, an optical pellet-counting unit was developed, manufactured and put into service for CM-201. The essence of the method is that a light emitter and receiver are installed in the transport pipe, and passing pellets interrupt the light beam, causing the generation of signals, which are then counted by the motion control program. This unit was developed and manufactured in 2020. Laboratory tests at room temperature have shown that the method has the highest sensitivity when the emitter and receiver are placed at an angle of 45° to each other, thus allowing each pellet to be detected individually. In July 2020, the unit was installed in the CM-201 transport pipeline and tested at a temperature of loading of 80 K. At present, the unit is operated as part of the CM-201 technological loading system in the area with a high radiation level; it has operated for more than 1074 h in ionizing radiation fields without any malfunctions and failures. The error in counting pellets does not exceed 5%.

- ***Unit for measuring the mass flow rate of helium (diaphragm)***

A Pitot-Prandtl tube is used to measure the mass flow rate and control the circulation of helium in the CM-202 moderator. During the period of the CM-202 operation, it was found that after 5 days of operation, the mass flow rate readings begin to fluctuate significantly, and become incorrect. The most likely cause of the failure is considered to be clogging of the dynamic and static tubes of the device with fine mesitylene dust and pellet fragments formed as a result of destruction during the loading process, and circulating in the system. Taking this fact into account, as a flow meter for CM-201, it was decided to install a diaphragm with a larger cross-section than that of the openings of the Pitot-Prandtl tube. In November 2019, the diaphragm was tested and calibrated in the range from 20 K to 300 K on the full-scale test stand of the CM-201 cryogenic moderator. Since November 2020, the diaphragm has been operating as part of the CM-201 control system, no failures in the operation of the system were revealed. The readings are stable throughout the entire operating cycle of the moderator.

- ***Study of the viscosity of the working material and the volume fraction of released hydrogen after irradiation in one working cycle***

The experimental data on the dependence of the viscosity of the working material on the radiation dose for CM-201 were obtained, analyzed and compared with the radiation dose and viscosity values for the working material in CM-202. Studies have shown that the viscosity in the chamber of CM-201 is higher than in the CM-202 chamber for the same number of hours of operation, and was found to be 54 cP and 17 cP, respectively. At the same time, it should be noted that there is no risk of polymerization of the working material. For comparison, the viscosity of VM4 vacuum pump oil was studied and found to be 364 cP. Mesitylene before irradiation was taken as a standard with a value of 1 cP (Table 1).

Table 1. Viscosity of materials

| Name | CM-201 | CM-202 | Vacuum oil | Mesitylene |
|---|---|---|---|---|
| Viscosity (cP) | 54 | 17 | 356 | 1 |

Studies of the volume fraction of accumulating radiolytic hydrogen in the working material of the CM-201 moderator also showed an increase of up to 55%, while for CM-202 this figure amounts to 22%. At the same time, no explosive mixture is formed in the system, and the hydrogen concentration is constantly monitored.

To determine the causes of the increase in the viscosity and volume fraction of hydrogen in one of the moderators, modeling and calculations were carried out at the beginning of 2021, as a result of which it was found that the radiation dose for the working material is different and amounts to 132 MGy for CM-201 and 99.8 MGy for CM-202. This difference is explained by the different shape, geometric dimensions and location of the cryogenic chamber in each moderator relative to the reactor core, and, consequently, radiation dose for the working material. At present, the moderators and control systems operate trouble-free at full capacity. The operating time of the moderators has reached the design values.

- ***Preparation of documents and performance tests of the complex in different modes with simulation of emergency situations***

A series of experiments were carried out to determine the technological modes of operation of the moderator in routine and emergency situations. The actions of the personnel in response to simulated malfunctions in the operation of technological systems were worked out. The algorithm of actions of the personnel when switching the moderator from cryogenic to thermal mode without lowering the reactor power and interrupting the work of experimenters on beamlines was determined.

- ***Neutron physical characteristics of the CM-201 moderator***

In cycle 9 (2020) with the operation of CM-201 in the cryogenic mode at a temperature of the moderating material of ~ 25 K, neutron flux spectrum measurements were carried out on beamlines 4, 5, 6 and 9. The data were compared with those obtained for the thermal mode of operation of CM-201 (Appendix 1).

***Beamline 4 (YuMO)***

For beamline 4, in the cryogenic mode of operation of CM-201, the gain factor in the region of cold neutrons with a wavelength from 3 to 8 Å was from 2 to 6; in addition, the range of detected wavelengths was expanded to 8.2 Å. The Instrument Responsible considers the results to be satisfactory and suggests that each cycle should be carried out in the cryogenic mode.

***Beamline 5 (HRFD)***

For beamline 5, in the cryogenic mode of operation of CM-201, the gain factor in the region of cold neutrons was from 4 to 9.

***Beamline 6 (DN-6)***

For beamline 6b, in the cryogenic mode of operation of CM-201, the gain factor in the region of cold neutrons was from 2 to 7. No decrease in the region of thermal neutrons was observed.

***Beamline 9 (REFLEX)***

For beamline 9, in the cryogenic mode of operation of CM-201, the gain factor in the region of cold neutrons was up to 7. No decrease in the region of thermal neutrons was observed.

- A cooling system independent of the IBR-2 systems (cooling tower) for turbine modules and compressors of cryogenic systems of the complex of cryogenic moderators was installed.
- A technical specification was developed, and part of the equipment was purchased for the systems of pumping helium from cryogenic and physical research units into tanks for storage and reuse.
- The operation of the cryogenic system was optimized for the operation of two moderators simultaneously with the setting of individual temperatures in the working chambers of each of them.
- A storage facility for the WM-301 water moderator was designed and mounted in room 165. The radiation dose level was reduced by a factor of more than 100.
- A special place for manufacturing component parts and units with strength and tightness testing was organized. The staff was trained, passed exams, received certificates with the right to conduct tests and issue certificates of strength and tightness testing.

## 3. Planned activities under the project until the end of 2021

- Continuation of operation of CM-201 and CM-202 for users.
- Continuation of studies of the viscosity of the working material depending on the radiation dose and operating temperature.
- Study of the dependence of the neutron flux spectrum on the temperature of the moderating material of CM-201 in the range from 20 K to 100 K.
- Installation and trial operation of a pellet-feeding dispenser of a larger volume with a viewing window on the CM-201 full-scale test stand.
- Installation and commissioning of a new cryogenic machine, optimization of the parameters of the cooling system equipment of the moderators' complex. The expected result is a decrease in the temperature of the working material down to 20 K. Backing-up of systems.
- Development of a control and automation system for technological systems of the moderators' complex for the operator's work in a single-window mode.
- Determination of the status and calculation of the shape of the head part of CM-203.
- Preparation of documentation, technical expertise appraisal necessary for putting CM-201 and CM-202 into general industrial operation.

## Conclusions

During the reporting period, the new CM-201 cryogenic moderator was installed, passed the first stage of testing, and was put into operation supplementing the suite of moderators at the IBR-2 reactor. At present, two cryogenic moderators (CM-201 and CM-202) are in service at the IBR-2 reactor, forming a cold neutron flux for beamlines 1, 4 - 11. In 2020-2021, the CM-202 and CM-201 moderators operated for physics experiments in the cryogenic mode for 654 and 735 hours, respectively. The cryogenic system of the moderators operates in the design mode, the main refrigerator is KGU 1200/10. Technological systems (cryogenic, vacuum, etc.) providing the operation of the moderator, operate normally and are ready for regular operation. New units and devices were introduced into the technological system of CM-201. Studies of the viscosity of the working material of the moderator were conducted; the neutron-physical parameters of CM-201 were determined. In 2021, it is planned to carry out additional tests of CM-201 in the cryogenic mode; upgrade the cryogenic system and put a new refrigerator into operation; determine the status of CM-203; prepare documentation and undergo an expert examination for putting CM-201 and CM-202 into general industrial operation.

As a result of the work performed during the reporting period, a paper was published in the journal "Journal of Surface Investigation: X-ray, Synchrotron and Neutron Techniques", a state registration certificate was obtained for the software of the cryogenic moderators' complex, three papers are being prepared for publication (studies on the viscosity of the working material, neutron flux spectrum from CM-201, cryogenic system of the complex), work is underway together with the JINR Department of Licensing and Intellectual Property on the preparation of a patent application for an invention relating to the optical pellet-counting device.

The data obtained as a result of the realization of the project are of great interest to the international user community of cold neutron sources, which is confirmed by numerous reports at IAEA technical meetings, at international conferences and local discussions.

Using the experience and expertise gained within the framework of the implementation of the project, under an agreement between JINR and PNPI, our specialists participate in the development of a cold moderator for the compact neutron source "DARIA".

**Appendix 1**

**Neutron flux spectrum and gain factor for beamlines 4, 5, 6, 9 in thermal and cryogenic modes of operation of the CM-201 moderator**

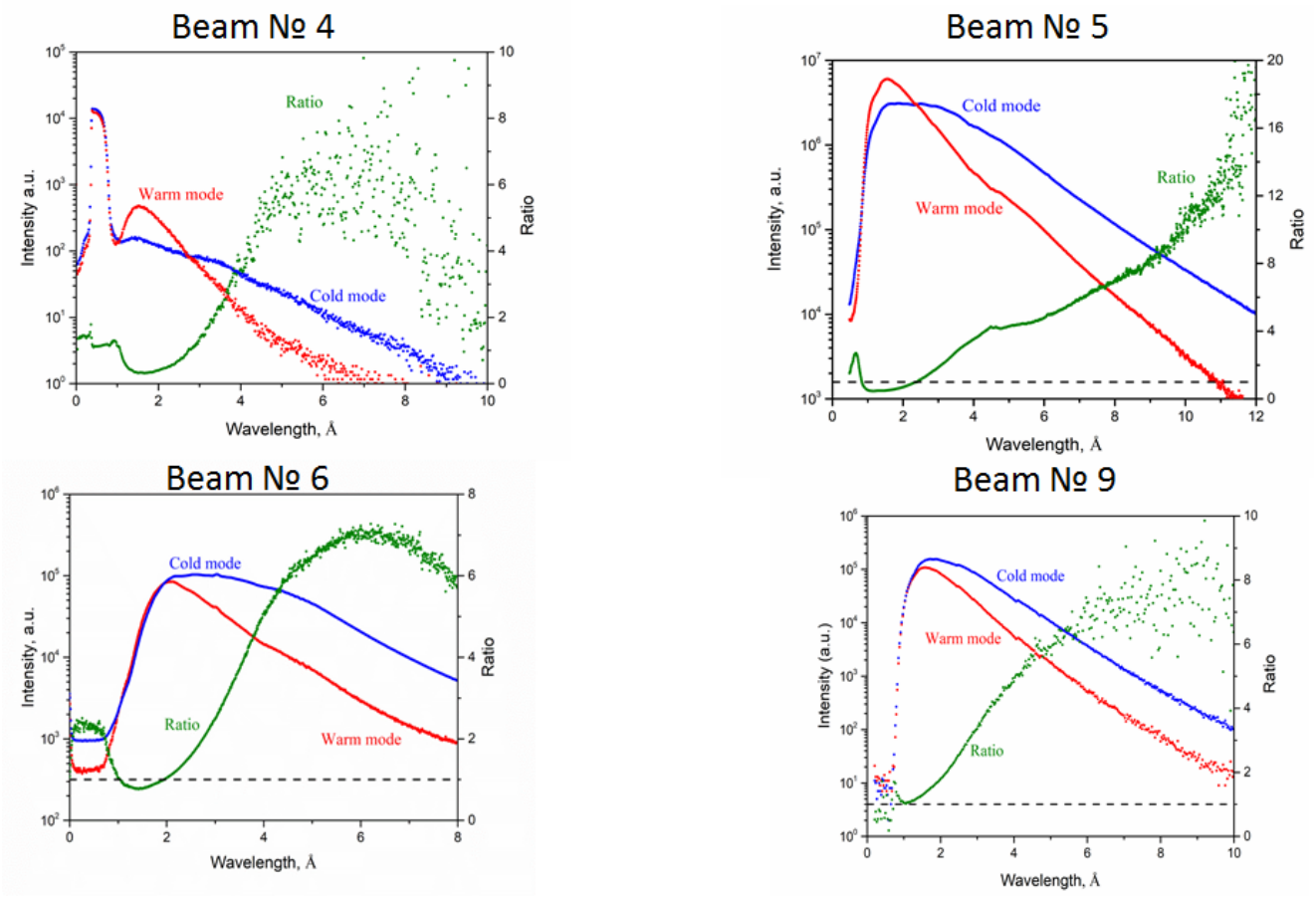


**Table 1. Calculation and experimental data of gain factor for 4, 5, 6, 9 beamlines in cold and thermal modes of operation of the CM 201 moderator**

| Wavelength, Å | Beam 4 | | Beam 5 | | Beam 6 | | Beam 9 | |
|---|---|---|---|---|---|---|---|---|
| | Calcul. | Exp. | Calcul. | Exp. | Calcul. | Exp. | Calcul. | Exp. |
| 9 – 6 | 5.74 | 5.6 | 7.11 | 6.4 | 6.9 | 6.4 | 8.83 | 7 |
| 6 – 4 | 4.8 | 5 | 5.95 | 4.5 | 5.2 | 4.8 | 6.55 | 5 |