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МЕТОДИКА ФИЗИЧЕСКОГО ЭКСПЕРИМЕНТА

CURRENT STATUS OF ADVANCED PELLETIZED COLD MODERATORS DEVELOPMENT FOR IBR-2M RESEARCH REACTOR

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The world's first advanced pelletized cold neutron moderator is prepared to be put into operation at the IBR-2M pulsed research reactor. It provides long-wavelength neutrons to the most of neutron spectrometers at the beams of the IBR-2M reactor. Aromatic hydrocarbons are used as a material for cold moderators. It is a very attractive material because of its high radiation resistance, good moderating properties, incombustibility, etc. It is shown that the idea of beads transport by a helium flow at cryogenic temperatures is successful. The recent progress and plans for moderator development at the IBR-2M reactor as well as the experimental results of beads transport are discussed in the paper.

На исследовательском импульсном реакторе ИБР-2М подготовлен к запуску первый в мире криогенный шариковый замедлитель нейтронов. Он позволит обеспечить большинство спектрометров на пучках реактора нейтронами с большой длиной волны. В качестве рабочего вещества применяются ароматические углеводороды. Этот материал очень привлекателен благодаря высокой радиационной стойкости, хорошим замедляющим качествам, негорючести и т. д. Показано, что идея транспорта шариков потоком гелия при криогенных температурах оказалась удачной. В работе обсуждаются планы по развитию, текущее состояние замедлителя на реакторе ИБР-2М, а также результаты экспериментов по транспорту шариков.

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1. COLD MODERATOR FOR THE IBR-2M REACTOR

Cold (long-wavelength) neutrons have come to play a prominent role in the cutting-edge research carried out with neutrons, and in all likelihood this is going to be even more true in future applications of neutron-scattering technique. Utilization of cold neutron sources can improve many characteristics of experiments on neutron beams. For example, one may refer to the research of matter surface properties, the small-angle scattering method, the investigation of large-scale structures, etc.

Aromatic hydrocarbons were chosen as a moderating substance in the proposed pelletized cold neutron moderator. There were some convincing reasons for our choice. Currently, the standard cold moderators used in high-power neutron sources are based on liquid or supercritical hydrogen circulation to ensure satisfactory heat removal and absence of radiation

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damages [1]. The main shortcoming of these moderators is the complexity of technology that needs to meet strong demands for radiation and nuclear safety, especially when used at nuclear pulsed research reactors. Other prospective hydrogenous materials (solid or liquid methane, and methane hydrate) suffer bad radiation resistance [2, 3]. Using aromatic hydrocarbons gives us an opportunity to avoid a lot of problems related to the irradiation effects, such as spontaneous release of the accumulated radicals' energy, polymerization, and high pressure of radiolytic hydrogen on moderator chamber walls during heating up. The hardness of toluene and mesitylene (1, 3, 5-trimethylbenzene) to neutron and gamma irradiation at low temperatures has been tested at the cryogenic irradiation facility of the IBR-2 reactor [4]. Mesitylene appeared to be twenty times more stable than solid methane: it keeps integrity and temperature at least up to the fast neutron fluence of 10^{18} cm^{-2}. Moreover, mesitylene and its mixture with m-xylene have appropriate neutron moderation properties. This was proven by Dr. I. Natkaniec [5]; the data libraries for this material at different conditions have been prepared by a group of Dr. Granada [6]. Preliminary consideration, including the Monte Carlo optimization of the IBR-2M research reactor complex of moderators in which the mesitylene pelletized cold moderator plays an important part, showed that the mesitylene optimized moderator at 20 K is preferred to solid methane when taking all inputs into account — neutronic, thermal, and radiation.

The frozen mixture of mesitylene+m-xylene was supposed to be used as separated pieces (small beads) filling the volume of a moderator's chamber. Such a decision helps avoid heat exchange problem (low thermal conductivity of mesitylene) and prevents the moderator chamber from destruction due to internal pressure of radiolytic hydrogen stored during irradiation. The mesitylene balls will be delivered into the moderator chamber by a helium flow, which will be used as a coolant as well [7].

The principal scheme of the cold moderator and its equipment is shown in Fig. 1. The beads are dosed into a charging tube (*2*) from a charging device (*3*) and then deliv-

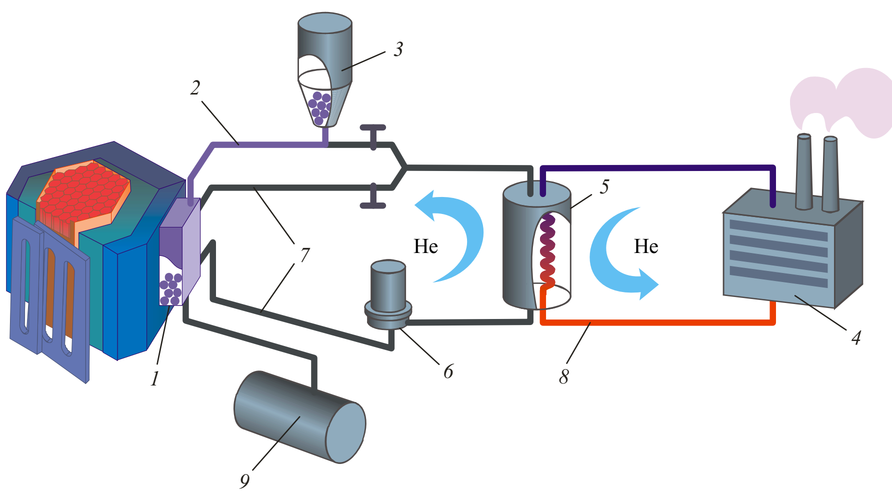

Fig. 1. The pelletized cold moderator and its operating principle at the IBR-2M reactor: *1* — cold moderator; *2* — charging pipeline; *3* — charging device; *4* — helium refrigerator; *5* — heat exchanger; *6* — helium blower; *7* — primary helium loop; *8* — secondary helium loop; *9* — used mesitylene receiver

ered down to the moderator (*1*) by a flow of helium gas, which is circulated by a helium blower (*6*) through the loop from a heat exchanger (*5*) to the moderator. Two helium loops (one from the cryogenic machine (*4*) to the heat exchanger (*5*), and the other (*7*) from the heat exchanger to the moderator) prevent the cryogenic machine from pollution by mesitylene. Helium is also supposed to cool the beads down during the moderator's operation. After several days of operation, the helium blower is to be switched off, beads are to be melted, and the liquid is to be collected in a receiver (*8*) through a discharging pipeline. The moderator can afterwards be recharged.

The main problem with this principle is transportation. It consists in the absence of both the experimental and theoretical data on elastic–plastic, adhesive and tribological properties of solid amorphous mesytilene (that is, the mixture of 70% mesytilene with m-xylene), and the data on movement of a single ball through a wide cylindrical pipe, taking into account the rolling and sliding friction as well as the deviations from sphericity. All this made it difficult to calculate the parameters of the conveying system. It was decided to solve this problem experimentally at the full-scaled stand with the cryogenic moderator prototype [8].

2. EXPERIMENTS ON FULL-SCALED STAND OF PELLETIZED COLD MODERATOR TRANSPORT SYSTEM

The main challenge of solid mesitylene beads transportation along the tube of complicated geometry is how to avoid fracture of the beads: its brittleness resistance is very poor, and speed limit for 3.7-mm balls contracting the walls at right angles is ~ 7 m/s. The total amount of time required to fill the moderator chamber of 1-litre volume with beads (about 27 thousand pieces) was estimated based on the working plan of the reactor and should be less than 8 h. To find the appropriate conveying gas parameters for the implementation of a safe method of beads transportation, a full-scaled model of the conveying path and the IBR-2M cryogenic moderator's technological system was fabricated (Fig. 2) [9]. At the same time, the main parameters of the cryogenic moderator's technology system, which is expected to provide the working capacity and the serviceability of the cold-neutron moderator based on solid mesitylene beads, have been tested.

To meet the objectives listed above, the following was arranged: detecting the ball movement, monitoring the process of filling the chamber with beads, measuring the flow rate and the temperature of gas, supplying sufficiently high vacuum, providing the cryostat with cool helium from cryogenic machine, etc.

Experiments on the full-scaled model provided a lot of information. Some parts of the installation were modified during the experiments. The most essential consequences are the following:

— The metering tank was modified to make its operation easier and to enhance bead loading into the conveying pipe.

— The hydrodynamical method of counting the number of balls coming into the conveying pipe was also modified using the mathematical processing of shape of the differential pressure pulse.

— The procedure of removing nitrogen penetrating into the helium volume has been optimized.

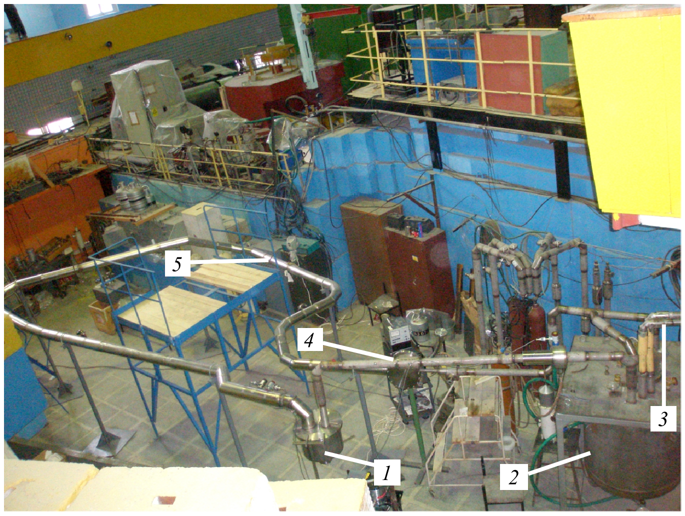

Fig. 2. The full-scaled model of the conveying path and the technological system of the IBR-2M cryogenic moderator installed at the experimental hall of the IBR-2 reactor: *1* — the chamber-imitator of the cryogenic moderator; *2* — the cryostat (with the heat exchanger and the helium blower inside); *3* — the cryogenic pipeline from/to the refrigerator; *4* — the charging device; *5* — the cryogenic pipeline for conveying mesitylene beads

Fig. 3. Photo of the cold solid beads of mesitylene at $T \sim 40$ K inside the chamber-imitator of the moderator chamber

The main result is that reliable and fast pneumoconveying of solid mesitylene beads into the moderator chamber is feasible [10]. In Fig. 3, one can see a heap of cold solid beads charged into the model of the moderator chamber.

Some important results of the investigations on the full-scaled model of the conveying path and the IBR-2M cryogenic moderator's technological system are shortly summarized below:

— Applicable parameters of the conveying helium gas are 2 g/s, 50 K, and 10 m/s.

— Applicable rate of charging beads into the conveying pipe is 6–8 beads/s.

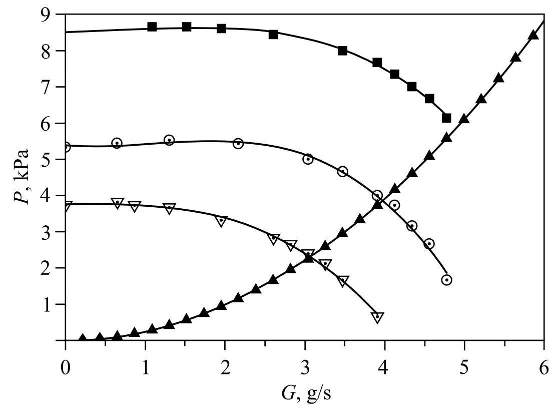

Fig. 4. Flow rate–pressure drop relation of the helium blower at some values of the blower rotation speed: squares — 22 500 rev./min, circles — 18 000 rev./min, void triangles — 15 000 rev./min; solid triangles — hydrodynamic resistance of the conveying pipe

— Total amount of time required to fill the moderator chamber with beads is 1–1.5 h.
— A diagram (p, G) of the helium blower is restored (see Fig. 4).

3. CURRENT STATUS OF COLD MODERATOR AT THE IBR-2M REACTOR

We have just finished work on installation of the cold moderator into the IBR-2 reactor after the success in the beads transport experiments. As can be seen in Fig. 5, the cold moderator vessel along with the premoderator and the water moderator [7, 11] have been

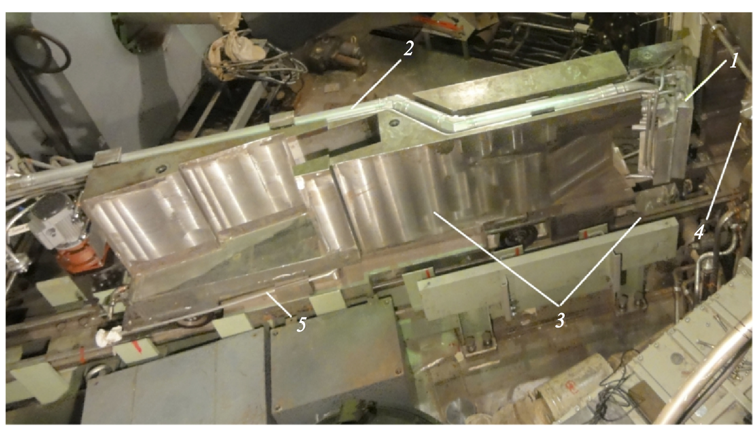

Fig. 5. Moveable trolley with cold moderator and the biological shielding installed on the rails in ready-to-move-to-active-core position: *1* — cold moderator with vacuum shielding and water premoderator; *2* — cold helium and beads support pipelines; *3* — trolley on the rails; *4* — entrance of a passing through the stationary biological shielding of reactor to the active core; *5* — drain pipeline of liquid mesitylene

mounted onto the moveable trolley with a biological shielding and supplying pipelines (in/out water, beads, in/out gas of cold helium, and liquid mesitylene drain).

Cryogenic pipelines and other parts of the installation (heat exchanger, charging device, helium blower, flowmeter as well as other technological equipment) are already mounted at their places and connected.

In the next couple of months, we are going to test a new KGU-700 refrigerator, to finish installation of control equipment and software, and start the tests of bead transport down to the chamber of the moderator. The first tests of the cold moderator with the reactor powered up are planned to start at the end of May 2012.

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