Status and perspective of development of cold moderators at the IBR-2 reactor

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Abstract. The modernized IBR-2M reactor will start its operation with three water grooved moderators in 2011. Afterwards, they will be exchanged by a new complex of moderators. The complex consists of three so-called kombi-moderators, each of them containing a pre-moderator, a cold moderator, grooved ambient water moderators and post-moderators. They are mounted onto three moveable trolleys that serve to deliver and install moderators near the reactor core. The project is divided in three stages. In 2012 the first stage of development of complex of moderators will be finished. The water grooved moderator will be replaced with the new kombi-moderator for beams #7, 8, 10, 11. Main parameters of moderators for this direction will be studied then. The next stages will be done for beams #2-3 and for beams #1, 9, 4-6, consequently. Cold moderator chambers at the modernized IBR-2 reactor are filled with thousands of beads (~3.5 - 4 mm in diameter) of moderating material. The cold helium gas flow delivers beads from the charging device to the moderator during the fulfillment process and cools down them during the reactor cycle. The mixture of aromatic hydrocarbons (mesithylen and m-xylene) has been chosen as moderating material. The explanation of the choice of material for novel cold neutron moderators, configuration of moderator complex for the modernized IBR-2 reactor and the main results of optimization of moderator complex for the third stage of moderator development are discussed in the article.

1. Cold moderators at the modernized IBR-2 reactor
New complex of moderators of the modernized IBR-2 reactor will consist of three parts, or kombi-moderators. Each of them is going to provide neutrons for spectrometers situated onto the adjacent neutron beams (Fig.1.). The composition includes water pre-moderator and additional post moderators that are at ambient temperature, cold moderator with mixture of aromatic hydrocarbons with moderating media at about 20 K. Each of three cold moderators is going to be with the same design.

In the first stage of construction of moderator complex the part of the complex for beam 7, 8,10,11 will be installed [1].
Fig 1. The schematic view of the modernized IBR-2 reactor with three parts of moderators surrounded it and 11 beam ports for neutron spectrometers (I-reactor core and stationary reflector, II - moderators)

The mixture of mesitylene and m-xylene has been chosen for some reasons:
- It has good moderating property [2-4];
- It suffers not dramatically of radiation [5];
- It is not explosive material;
- It might operate at wide range of low temperatures, etc.

It is well known, that hydrogenous materials are the most proper for solid cold neutron moderators [6-8]. The common way of cold moderator construction is that hydrogenous material is frozen to the very low temperature from a liquid phase and forms one bulk peace. The main problem with such a moderator is that molecules of moderating material are decomposed under the fast neutron radiation and hydrogen accumulates inside the bulk. Then, it builds up the pressure to the matrix of material in the process of heating up a moderator. The material expands and presses walls of a vessel that can be destroyed with such a pressure [9]. Another technical challenge for engineers is how to take off the heat induced by radiation from the bulk material with low thermal conductivity.

The main difference of the advanced cold moderator of the modernized IBR-2 reactor from existing solid cryogenic neutron moderators is in a fact that the cold moderator chamber is filled with thousands of separate beads (~3.5 - 4 mm in diameter) of moderating material occupying about 0.6-0.7 of volume of the chamber. The cold helium gas flow delivers beads from the charging device to the moderator before operation and then cools down them in the reactor cycle. It is possible to take off high radiation heat from beads due to their large surface area and small diameter. Free space between beads allows to expand material under the radiation without damaging of moderator vessel. With such a construction of a moderator and due to negligible radiation effects in aromatic hydrocarbons, thickness of pre-moderator can be decreased, and the cold moderator can be installed at the maximum of thermal neutron flux, opposite to the former solid methane cold moderators at the IBR-2 reactor. Broadly speaking that solid methane is the best moderating material for cold moderators [2-4], it is not absolutely true in case of the IBR-2 reactor. Cold moderator as a bulky solid methane shows even lower cold neutron production in comparison with a moderator of beads of aromatic hydrocarbons due to higher temperature of stable operation and thicker pre-moderator.
2. Optimization of moderator configuration for beams #1, 9, 4-6

The optimization of configuration of moderator complex for beam #1, 9, 4-6 (Fig. 1.) has been done by Monte Carlo simulations. Some approaches have been applied to increase neutron flux such as utilization of additional water grooved reflector, surrounding of cold moderator by a water post moderator, a cold grooved beryllium filter, etc. The thickness of water pre-moderator was 5 cm.

Results of optimization show that the best thickness of cold moderator is 4 cm (Fig. 2 (a,b)). The flux distribution along the surface of such moderator is shown in the Fig 3 (a,b).

Fig. 2. Horizontal (a) and vertical (b) cut-offs of the geometric model of modernized IBR-2 reactor used for neutron transport simulation (I - reactor core, II- water pre-moderator, III - cold moderator)

a)

b)

Fig .3. Results of Monte-Carlo calculation of cold (a) and thermal (b) neutron fluxes distribution along the surface of cold moderator at the reactor power of 2 MW with combination of water pre-moderator (5 cm) + cold moderator 4 cm.

Distribution of thermal neutrons along the surface of moderator is not uniform (Fig. 3b). The additional water post-moderators above and below the cold moderator (Fig. 4.) give more bright pattern of thermal neutrons (Fig. 5a) and increase the area of high intensity of cold neutrons (Fig. 5b). Unfortunately, it is not possible to install water post-moderators at the left and right sides as
spectrometers at the beams # 1, 9 view these sides of the cold moderator (Fig.1.). This result shows that a post-moderator additionally thermalizes and reflects neutrons back to a cold moderator and increases cold neutron flux. Otherwise, these neutrons would leak out of the moderating system and would be lost for spectrometers.

Fig. 4. Vertical cut-off of the model of modernized IBR-2 reactor used for neutron transport simulation (I - reactor core, II- water pre-moderator, III - cold moderator, IV-water post moderator)

Fig. 5. Results of Monte-Carlo calculation of cold (a) and thermal (b) neutron fluxes distribution along the surface of the cold moderator at the reactor power of 2 MW with combination of water pre-moderator + cold moderator + water post-moderator (4 cm thick) above and below the cold moderator.

This prospective result allows us to go further and increase (optimize) the thickness of post-moderator and add post-moderators at the left and right side of the cold moderator out of view of beams #1 and #9 (Fig. 6) then.
Optimized thickness of the post-moderator was calculated to be as high as 14 cm. It gives significant increase of the area with highest neutron fluxes both of cold and thermal neutrons. (Fig. 7 a,b)

Another attempt to increase neutron fluxes has been done by utilization of grooved 10 cm thick Be reflector (T=77K) in front of the cold moderator. Gain factor of cold neutrons intensity appeared to be as high as 2.3 to a bare cold moderator and 1.6 to the best composition with water post-moderator. Nevertheless, this approach is not producible in this project due to effect of Be threshold and necessity of additional cooling to take off the heat from Be. Beryllium reflector might be optional for future improvements of moderators at the modernized IBR-2 reactor.

Generally speaking, neutron calculations for beams #1, 9, 4-6 have shown that utilization of optimized geometry will significantly increase cold neutron flux. The configuration has been chosen in such a way that the thermal neutron flux for beams #4-6 will not be dramatically decreased (Fig. 8).
3. Conclusions
The modernized IBR-2M reactor will start its operation with water grooved moderators in 2011. In 2012 the first stage of development of complex of moderators will be finished. New kombi-moderator will replace a water ambient temperature grooved moderator for beams #7,8,10,11. Afterwards, the main parameters of the cold moderator and the complex of moderators for this direction will be studied. The next stage will be done for beams #2-3, and at the final stage - for beams #1, 9, 4-6.

The first results of computer optimization of configuration of moderators for beams #1, 9, 4-6 are optimistic. It appeared possible to increase cold neutron flux, not depressing significantly thermal neutron flux. As construction of moderators for this direction is planned to be done at the final stage of the project, it gives us a time to change slightly the geometry if experience with operation of the first two kombi-moderators shows it is necessary.

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