Justification of Arrangement, Parameters, and Irradiation Capabilities of the MBIR Reactor Core at the Initial Stage of Operation

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Abstract. Reactor MBIR will start operating in the absence of loop channels, which represent technologically complex equipment. At the initial stage of operation this will make it possible, on the one hand, to develop technological modes of reactor facility operation with small amount of experimental devices, and on the other hand, with this development, to gradually fill the cells intended for the loop channels additional irradiation assemblies. For example, central loop channel occupies 7 cells in the center of the core. It is unreasonable to use all the seven cells for irradiation assemblies, because of their strong influence on each other. To eliminate this impact, it is possible to fill the central loop channel cells with three irradiation assemblies and four fuel assemblies.

To level the energy release, it is reasonable to install one more irradiation assembly in the core and compensate the critically loss by installing 4 additional fuel assemblies on the core periphery. Consequently, core at the initial stage of operation will consist of 85 fuel assemblies (93 assemblies in the design), 8 cells with CPS control rods and 21 irradiation assemblies.

Thus, the number of the irradiation cells can be increased from 17 to 21 at the initial stage of operation by eliminating central loop channel. Reactor power at this stage must be reduce from 150 to 137 MWt.

With this modification of the core, fuel with the design plutonium weight content is used, enabling transition to a design version of the core without changing the fuel assemblies design. For the same reason, the neutron flux and damaging dose in the irradiation assemblies at the initial stage of operation are almost the same as the design values.

The rate of damaging dose accumulation in the irradiation assemblies located in the core is from 16 to 16.7 dpa per micro-campaign (100 eff. days). Inner volume of one irradiation assembly is 2.28 l. General rate of damaging dose accumulation in the MBIR reactor at the initial stage of operation is 1370 dpa*l/year. In the BOR-60 reactor this parameter equals 300 dpa*l/year.

Key Words: MBIR, flux

1. Introduction.

The Federal Target Program “Nuclear Power Technologies of a New Generation for the Period of 2010-2015 and until 2020” is currently being implemented in Russia. It envisages development and construction of a multi-purpose research fast reactor (MBIR) by 2020.

The MBIR reactor concept [1] implies the idea that the future research reactor is being developed with the aim to perform a wide array of reactor studies that will include testing of new types of fuel and structural materials (SM) in combination with different coolants, to solve the problems related to safety, reliability and economic efficiency for NPP projects with fast reactors of a new generation.

The concept of R&D work program for the stage of 2020-2030 to be implemented at the MBIR reactor is presented in papers [2, 3]. It shows that the principal trend in the MBIR studies will be to justify the operability and lifetime of structural materials and fuel for advanced fast and thermal neutron reactors at high and super-high burnup and increased temperature values, both under steady-state and transient conditions. In order to implement these tasks, the MBIR core design envisages housing three loop channels, three instrumentation channels, and 14 cells for material testing and isotope production assemblies. The MBIR reactor loop channels are part of the loop units that represent complicated systems which include independent heat removal loops with the required set of respective equipment and pipelines, as well as inherent auxiliary engineering and transport systems, whose commissioning as part of the MBIR reactor will be a long-time process, individual for each loop unit. At the initial stage, it seems reasonable to test the reactor operation conditions without putting the technologically complicated experimental systems, namely, the loop channels into parallel operation, with gradual fitting of the reactor with the required experimental devices.

In view of that, it seems essential to evaluate the maximum irradiation capacity of the reactor at the initial stage of its operation without loop channels.

2. MBIR reactor design characteristics.

The design version of the research nuclear facility MBIR envisages 20 irradiation channels, with 1 central loop channel (the CLC covers 7 cells), 2 peripheral loop channels (each also covering 7 cells), 3 instrumentation channels, and 14 cells for isotope production assemblies (Fig.1). All in all there will be (17 + 7) cells within the core for different irradiation assemblies, with the useful volume of the in-wrapper space of an assembly like this equal to ~2.28 l (the inner flat-to-flat cell size of 6.92 cm, the core fuel column height of 55 cm).

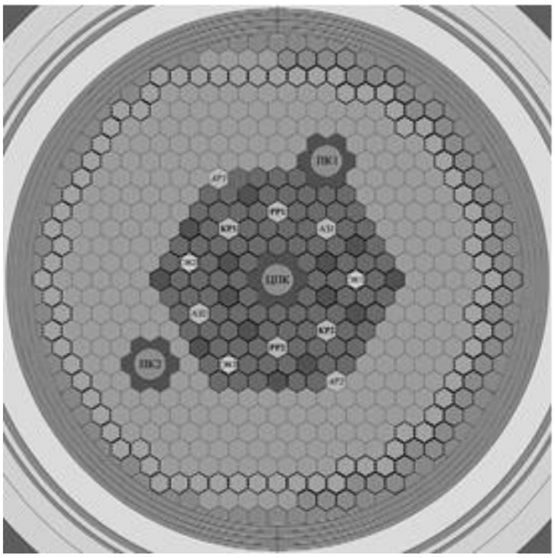


Figure 1. MBIR in-vessel configuration with indication of location of experimental devices as well as radial blanket assemblies (RBA), in-pile storage (IPS), in-pile storage shielding (IPSSh).

The main parameter of the research reactor is neutron flux density, which in some irradiation cells goes to ~$5*10^{15}$n/cm^{2}s [4]. It should be stressed that during a micro-campaign (100 eff. days) the neutron flux density value varies significantly: it grows from 4.6* 10^{15}n/cm^{2}s in the beginning to $5.5*10^{15}$n/cm^{2}s at the end of the micro-campaign, which is related to burnup of fissile plutonium isotopes. The neutron flux density averaged over the micro-campaign in irradiation cells at the level of the core median plane is illustrated in Figure 2; the rate of damaging dose accumulation is shown in Figure 3.

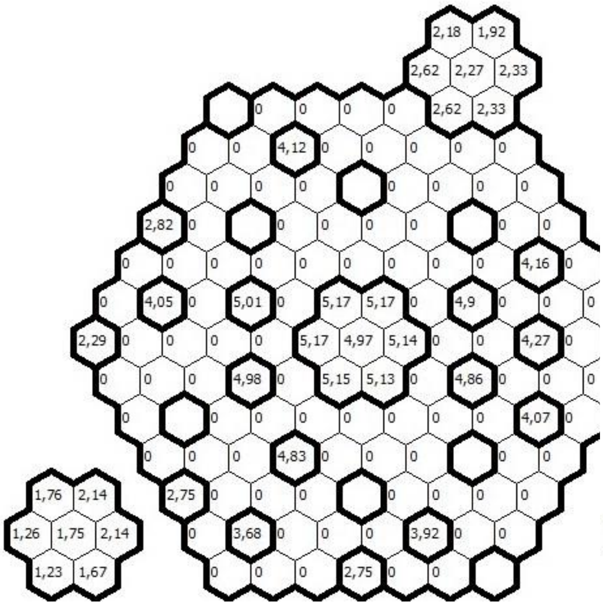


Figure 2 – Neutron flux density in irradiation cells at the level of the core median plane, 10^{15}n/cm^{2}s

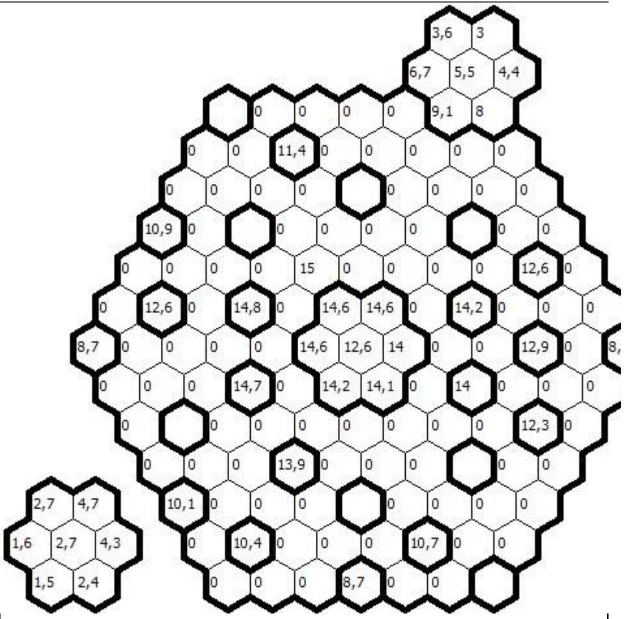


Figure 3 – The rate of damaging dose accumulation in irradiation cells at the level of the core median plane (dpa/100 eff. days)

The core criticality under conditions of MBIR reactor steady uniform partial refueling is provided by 93 FAs. The duration of their irradiation in the central part of the core is 4*100 eff. days and is restricted by the damaging dose on the fuel cladding.

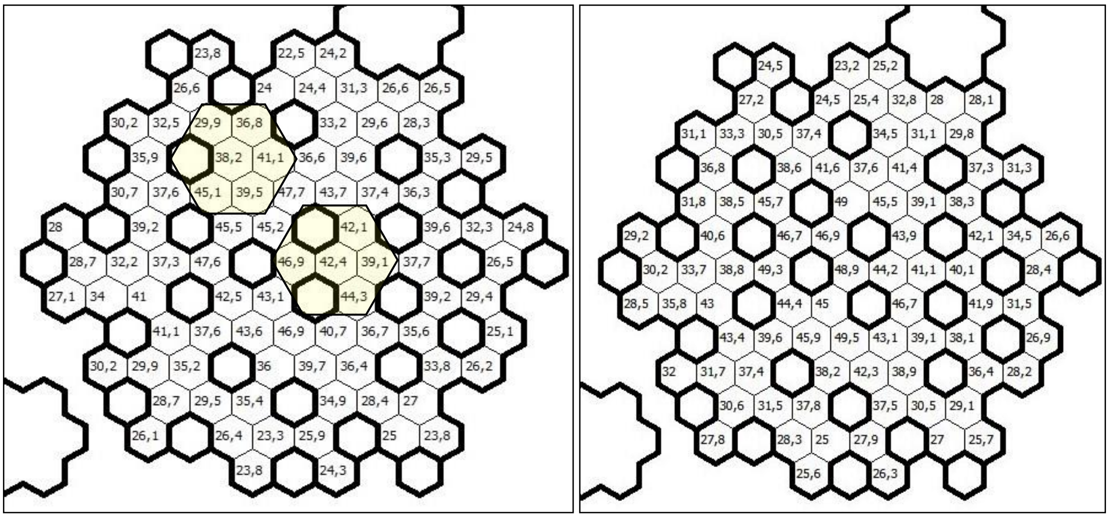
3. Irradiation capabilities at the initial stage of operation.

Apparently, there will be no loop channels in the core at the initial stage of MBIR operation. This will make it possible, first, to develop operating modes of the reactor facility with smaller amount of experimental devices, and then, with this development, to gradually increase MBIR irradiation capabilities by commissioning loop devices. In the context that the development of loop channels is not finished at this point and their design can change before commissioning, there were no loop devices identified explicitly in the design, their intended locations being filled by steel assemblies. It is not important for the loop channels located outside the core, but the seven cells located in the position of the central loop channel represent a research volume of considerable value and in the absence of a loop device, it is reasonable to fill them with irradiation devices. In this case, there will be 24 cells with irradiation capabilities in the core.

However, when all seven of the central cells are filled with irradiation devices, their strong influence on one another may lead to the reduction of the neutron flux in the center of the core and, particularly, in the central cell. In this case, it would be more reasonable to place only three irradiation devices in this area, filling the remaining four cells with steel assemblies. In this case, there will be 20 cells with irradiation capabilities in the core.

At the same time, it wouldn't be optimal to fill the most valuable central area of the core with steel assemblies. In the absence of the central loop device, it would be reasonable to place several fuel assemblies at its location. For example, four fuel assemblies and 3 irradiation assemblies can be located inside the CLC cells (see Figure 4a).

The resulting arrangement features a group of seven fuel assembly cells adjacent to the central cell, which will inevitably cause a local burst of energy release. To eliminate this burst and level the energy release over the core, it is reasonable to place 1 irradiation assembly in the center of the seven-assembly group (see Figure 4b). With this variant of central space arrangement, the MBIR core can contain 21 irradiation cells. Figures 5 and 6 show average values of neutron flux density and damaging dose accumulation rate in the irradiation cells of the modified core at the initial stage of operation.



a) b)

Figure 4 – Power density distribution in the core at the initial stage of operation, kW/m

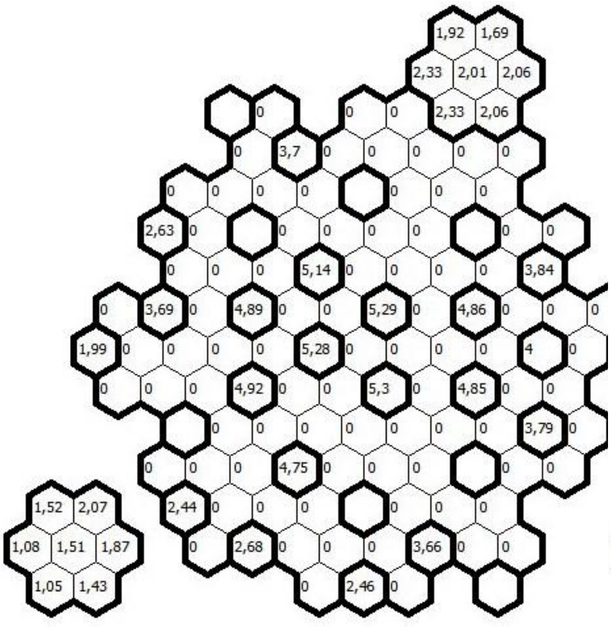


Figure 5 – Neutron flux density in the irradiation cells of the modified initial stage core at the median plane level, 10^{15}n/cm^{2}s

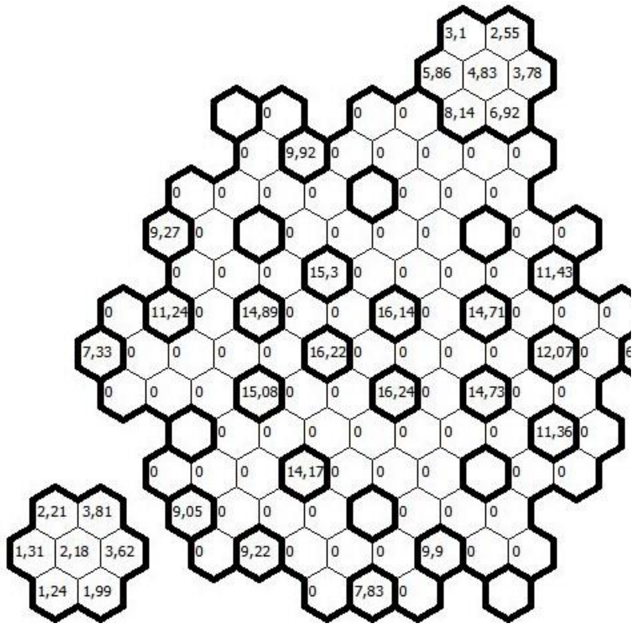


Figure 6 – Rate of damaging dose accumulation in the irradiation cells of the modified initial stage core at the median plane level, dpa/100 eff. days

This version of the core features 3 more fuel assemblies that appear in the most "important" area of the core – its center. It is obvious that such a core will have excessive criticality. To bring the criticality to the design level, the number of fuel assemblies in the core should be reduced to 85. To avoid fuel overheating in such a reactor, its thermal power should be reduced from 150 to 137 MW. It is acceptable for a research reactor, because electricity generation is not its primary purpose. Moreover, such a solution will make it possible to achieve fuel economy while retaining the level of neutron flux and the rate of damaging dose accumulation. It must be emphasized that this effect becomes possible because in this version the central volume is partially filled with fuel assemblies, as opposed to the design arrangement, where it is occupied by a big loop channel.

It should be noted that on all occasions consideration is given to the core with the steady refueling mode and partially burnt-up fuel that, in the course of refueling, is fueled by design MOX-fuel assemblies with the plutonium mass fraction assumed in the design. This is reasonable both from the technological and organizational points of view, among other things for smooth transition to the configuration with CLC.

For evaluation of research reactor irradiation potential, a value of the integral damaging dose accumulation rate can be introduced, which is defined as a product of the dose accumulation rate averaged over irradiation volumes and the total volume of irradiation cells. For the above three versions of arrangement at the initial stage of MBIR operation (the group of seven cells fully filled with irradiation assemblies, three irradiation assemblies in the group of seven cells, additional fuel assemblies in the central area with modified core configuration) the average damaging dose accumulation rates (with regard to axial nonuniformity) amount to 10.9, 10.6, 10.5 dpa per micro-campaign (100 eff. days), respectively. The number of cells for irradiation assemblies is 24, 20, 21, respectively. Inner volume of each assembly of this kind is 2.28 l. The reactor availability factor is assumed equal to 0.65. It follows that the integral rate of damaging dose accumulation in the MBIR reactor for the three different versions of configuration at the initial stage of operation will be 1410, 1150, 1190 dpa*l/year. However, it should be noted that the last-mentioned value is reached at reduced power and with higher-quality arrangement of irradiation cells (all the irradiation cells are surrounded with fuel assemblies).

For comparison it can be mentioned that the similar characteristic in the BOR-60 reactor equals ~ 300 dpa*l/year.

4. Conclusion.

The options of effective operation of the MBIR reactor were proposed on the assumption that at the initial stage of reactor operation the loop channels were not available.

Within the framework of maintaining the design core configuration there are potential options of seven or three irradiation assemblies arrangement at the CLC location. In these cases there are respectively 24 and 20 cells in the core for irradiation devices arrangement, the integral rate of damaging dose accumulation will be 1410 and 1150 dpa*l/year, respectively.

A more complicated, but more efficient option is a modified core configuration, when the fuel assemblies are located in the central area that allows reactor reactivity properties to be improved by way of arranging the core out of 85 (instead of 93) regular fuel assemblies. At the same time, the reactor power should be reduced from 150 to 137 MW (thermal), which will result in fuel saving with the neutron flux and damaging dose accumulation rate remaining at the same level. With this solution the core will accommodate 21 cells for irradiation assemblies, and the integral rate of damaging dose accumulation will be 1190 dpa*l/year (at the power of 137 MW).

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