FEATURES OF THE PHYSICS OF THE MBIR REACTOR CORE

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Abstract. Cores of research reactor facilities (RRF) as opposed to those of power reactors are designed taking into account their research function. This is their unique peculiarity reflected, among other features, in the flexibility (i.e. transformation in safe and reasonable limits) of the core arrangement according to the changing goals of specific experiments. Power generation for research reactor is a secondary function, significant as it is, therefore for RRF it is quite acceptable to change the power level and transform the arrangement of the core according to experimental requirements rather than to the plan of power generation. Flexibility of the MBIR core makes it possible to address many different tasks simultaneously. For example, the starting core can be considerably smaller than the design one, yet it can provide technologically acceptable transition to core arrangements that are more research and production intensive without the necessity of reloading unburnt assemblies.

The MBIR core has a small size and a very large (up to 25%) neutron leakage outside the core with fast neutron spectrum. As a result, there is no positive sodium void reactivity effect in the MBIR core whatever isotopic composition of plutonium. Neutron leakage also ascertains the stability of neutron flux and energy release distribution in the core.

Due to the high leakage, MBIR reactor features relatively high plutonium enrichment, hence even at very high power density of the core, the neutron flux density and the rate of the damaging dose accumulation in MBIR are quite moderate and lower than in BN-600 and BN-800-type power reactors. For the same reason (due to high enrichment), MBIR demonstrates significant increase of neutron flux density per micro-campaign, reduced energy release in the fuel assemblies per campaign, and significant loss of reactivity with fuel burnup.

However, despite the fact that MBIR reactor is inferior to power reactors in terms of the neutron flux and the rate of damaging dose accumulation (which are critically important characteristics for research reactors), it provides conditions for a wide range of various experiments or isotope production.

High experimental volumes of the MBIR reactor and high sensitivity of fast neutron core to the location of research and irradiation subjects, as well as high thermal power of the reactor require gradual and careful testing of reactor power taking into account its physical characteristics.

Key Words: MBIR, core, flux

The effectiveness of a research reactor is determined by the number of excess neutrons that can be absorbed in experimental devices. Thus, the more “free” neutrons per power-unit are generated in the research reactor, the more effective it is. The higher the k_∞ of the fuel composition is, the more such neutrons there are in the reactor. That is why highly enriched fuel is often used in research reactors, which makes it possible to have small high leakage cores [1].

Fast research reactors are preferable firstly because of high fission neutron yield, which is characteristic of fast spectrum, and secondly because of a lower value (by a factor of two!) of neutron cross sections. Hence, neutron flux density is higher by a factor of two in fast reactors.

A characteristic feature of the MBIR core [2], which is related to the core small size (the height is 55 cm, the diameter is ~90 cm), is a very high neutron leakage: 50% of the neutrons are not absorbed in the fuel but in the structures surrounding the core and in the irradiation devices. The leakage determines stability of various reactor parameters when the number and arrangement of FAs and irradiation assemblies in the core change significantly.

Stability of parameters results in the adjustable core structures of such reactors, which makes a fundamental difference between research and power reactors. Since generation of electricity is not the main purpose for a research reactor, decrease (or increase) in thermal power as well as change in the core design according to the actual experimental needs is fairly acceptable to it.

Adaptability of the core structures lets many different tasks be done simultaneously. To take an example, the initial core, which is much smaller than the design one, provides for near design irradiation conditions and a smooth transition to the design layout [3]. Uncertainty of the experimental volume content can be taken as another example: the volumes can contain both fuel and strong neutron absorbers/moderators. Here, reactor criticality can be provided both by reducing the core (i.e. reducing the number of regular FAs) and adding to it (i.e. increasing the number of regular FAs).

This property of the core can be very useful, for example, when bulk irradiation of new fuel materials is necessary, reduction in the core size compensating for their excess reactivity. And, vice versa, when bulk irradiation of neutron absorbing materials or production of isotopes in moderated irradiation devices is needed: in this case reactor criticality can be maintained by adding to the core, without taking a risk of «spoiling» the power density field and reactivity balance to the utmost. At that, it is important to understand that if the core is reduced, its thermal power will have to be reduced proportionally, whereas in case of adding to the core, power can’t be increased because of the heat exchange equipment constraints on the reactor facility.

The basic parameter of a research reactor is the peak neutron flux density; in MBIR it is to be not less than ~$5*10^{15}$n/cm^{2}sec (averaged over the refueling interval) [4,5].

Neutron flux density is determined by the core power density and fissile isotope enrichment. In MBIR, the core power density is high and provided by using small-diameter (6 mm) FE (like in BOR-60). Despite it, however, neutron flux density proves to be by ~40% less in MBIR than in the BN-800 power reactor because of the high Pu content (~$5*10^{15}$ versus ~$8.5*10^{15}$ n/cm^{2}sec). It is due to the fact that neutron leakage in BN-800 is not 50% but only 20% (i.e. just 20% of the neutrons are absorbed not in the fuel), therefore, Pu content in the fuel is twice as low in BN-800 (~20%) as in MBIR (~40%).

If MBIR is compared with its predecessor BOR-60, neutron flux density in MBIR is by 50% higher than in BOR-60, which is again related to the core size [6]. Thermal power of BOR-60 is over two times less than that of MBIR (65 versus 150 MW), its core size is, thus, smaller while neutron leakage is higher. Fuel enrichment is correspondingly higher in BOR-60.

Another consequence of high neutron leakage in the MBIR core is change in the sign of certain dependences. Thus, in power reactors where it is not the leakage but the neutron absorption in U-238 that has a decisive role, reduction in fuel density leads to increase in neutron flux: U-238 is an absorber here and reduction in its amount brings about decrease in the critical loading of fissile isotopes. Since the reactor thermal power is kept constant, neutron flux should increase. It is not the same in MBIR: leakage is very sensitive to fuel density, reduction in density leads to increase in core «transparency» for neutrons and to fast growth of leakage. As a result, reduction in fuel density causes rise in the critical loading of fissile isotopes and decrease in neutron flux.

One of the main parameters of a research reactor is not only neutron flux itself but its effect – dpa rate in the structural materials, which depends on neutron spectrum very much. The harder the spectrum is, the higher the dpa is. So, one can speak about the flux quality which can be defined as the ratio of dpa to neutron flux.

Due to high Pu content in the fuel in MBIR, contribution of inelastic moderation for U-238 is small, neutron spectrum is quite hard, so dpa is by 20% higher in MBIR than, for instance, in BN-800 if neutron flux density is the same [3]. Hence, the amount of moderating materials (for example, oxygen or nitrogen, which are part of fuel) should be minimized whenever possible in order to have the optimum performance of such a reactor.

It is worth mentioning other characteristic features of the MBIR research reactor. In the course of reactor operation fissile nuclei in the fuel burn up, they are hardly bred from U-238 and since the reactor thermal power is kept constant, neutron flux density rises. Thus, it rises over the refueling interval (100 eff. days) from ~$4.6*10^{15}$n/cm^{2}sec at the beginning to ~$5.5*10^{15}$ n/cm^{2}sec at the end. On the contrary, the peak fuel power density is achieved in new FAs (~50 kW/m) but as the fuel burns up, their power density falls steadily (to ~36 - 38 kW/m).

Another effect of high Pu content in the fuel is the lower value (as compared with power reactors using MOX fuel) of the effective delayed neutron fraction (0.0030 versus 0.0036 in power reactors), which is related to a smaller contribution of U-238 threshold fissions due to its low content in the fuel. Besides, whatever the Pu isotopic composition is, positive SVRE, which is typical of sodium cooled fast reactors, cannot be observed in MBIR because of high neutron leakage, which is accounted for by the dominant «leakage» component in forming the sodium dense reactivity effect and SVRE.

The most important feature of the MBIR research reactor is the possibility for irradiating new fuel types, fuel element designs and structural materials both in steady-state and transient conditions modelling accidents and emergencies [7]. It is much easier to obtain permission from regulatory authorities (Rostekhnadzor) for placing them into a research reactor than into a power reactor. In addition, this reactor allows for production of short-lived isotopes that can’t be produced in power reactors because of the requirement for periodic shutdowns (or for other reasons).

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