# THE BN-800 CORE WITH MOX FUEL

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**Abstract.** The initial BN-800 reactor core (so called hybrid core) is mainly composed of fuel subassemblies (FSAs) with enriched uranium oxide fuel and includes the limited quantity (16%) of MOX FSAs fabricated at experimental production facilities of MAYAK Production Association and JSC “SSC RIAR”.

The full MOX fuel core will be formed as a result of step-by-step replacement (three refuelings) of hybrid core FSAs by MOX FSAs fabricated at the Mining and Chemical Combine. To flatten power distribution, three types of FSAs with the different plutonium content (enrichment) in the fuel are used in the core. A technique to adjust plutonium enrichment depending on the fuel isotope composition makes it possible to fabricate MOX fuel based on plutonium with a wide range of its isotope composition and to retain core operation parameters within the design limits.

To reduce the sodium void reactivity effect, the FSA design has an upper sodium plenum and the upper absorber shield of natural boron carbide.

In the BN-800 core, the ChS-68 steel is used for fuel pin claddings the same as for standard fuel pins in BN-600. The operability of fuel pins with cladding of ChS-68 steel is ensured up to the damage dose of ~ 90 dpa, which as applied to BN-800 corresponds to the average fuel burnup of 66 MWd/kg.

**Key words**: BN-800, core, MOX fuel.

## 1. Introduction

One of the main goals of BN-800 reactor creation is mastering of technologies at different stages of a closed nuclear fuel cycle using fast reactors.

The initial stage of closed nuclear fuel cycle is manufacture of mixed uranium-plutonium fuel and its application in fast reactors.

As it is known, the first Russian reactors BN-350 and BN-600 were oriented to application of technologically simpler uranium fuel (oxide one), because their main task was to master sodium reactor technology [1]. Nevertheless, these reactors played an important role in nuclear fuel mastering. At these reactors principal distinctive features of fuel pins behavior under operating conditions in fast sodium-cooled reactors, which are characterized by high temperatures and intensive neutron flux, were studied. As a result of performed activities on improvement of fuel pins and FSAs the maximum burnup in the BN-600 reactor was increased from ~7% h.a. to ~12% h.a., and average value was increased from 40 MWd/kg to 74 MWd/kg [2]. This experience is very important for creation of the BN-800 MOX fuel core, because the results of investigations have revealed similar behavior of MOX fuel (pellet) and uranium oxide fuel [3].

Operability of fuel pins with MOX fuel was proved also by irradiation of fuel pins in the BN-600 reactor in statistically significant scope [4].

The BN-800 reactor was developed based on application of MOX fuel of any origin, in particular, fuel manufactured on the basis of reactor-grade plutonium, extracted from VVER-440 spent nuclear fuel at the plant RT-1 [5, 6].

Because the item of work arrangement to develop production of standard mixed oxide fuel (MOX) was solved with some delay relative to BN-800 reactor construction work scheduling, the initial fuel load for the BN-800 reactor was formed, mainly, of uranium oxide fuel, and only a part of FAs (16% of total quantity) contains MOX fuel [7], manufactured at experimental production of “MAYAK” Production Association and JSC “SSC RIAR” [8, 9]. Considering the specified feature of this core configuration it is referred as hybrid.

The full MOX core will be formed by stepwise replacement of hybrid core FSAs by standard MOX fuel FSAs manufactured by Mining and Chemical Combine [10,11], with retention of operation cycle length and fuel life.

The present paper gives information on arrangement and performance of the BN-800 full MOX fuel core and an order of its formation.

## 2. Arrangement and Characteristics of the BN-800 full MOX fuel Core

To flatten power distribution the core is divided into three subzones according to fissile material content degree (enrichment): 18.2 % Pu in low-enrichment zone (LEZ), 20.1 % in medium enrichment zone (MEZ), and 23.0 % in high-enrichment zone (HEZ).
Enrichment values are specified based on reactor-grade plutonium application for fuel manufacture (basic plutonium isotope composition: $^{238}$Pu / $^{239}$Pu / $^{240}$Pu / $^{241}$Pu / $^{242}$Pu = 1.2/ 67.4/ 23.4/ 3.4/ 4.6 % [12]).

Under the fuel column there is arranged an axial blanket of pellets of depleted uranium in a common cladding with fuel. Above the fuel column there is a sodium plenum and an upper absorbing shield formed of absorbing elements with natural boron carbide. Application of the FSA design with a sodium plenum ensures decrease of sodium void reactivity effect to a value less than βeff [5].

The core is surrounded by one row of radial blanket (RB) SAs, containing depleted uranium dioxide. Further there are arranged steel shield assemblies (SSA) and boron shield assemblies (BSA) with natural boron carbide, beyond them there is in-vessel storage (IVS) for spent FSAs.

To compensate reactivity margin, to control and protect the reactor, in the core there are 30 CPS (Control Power System) rods, in particular, two control rods with natural boron carbide, 16 shim rods with boron carbide of 60% enrichment by $^{10}$B, nine scram rods with boron carbide of 92% enrichment by $^{10}$B and three hydraulically suspended rods of passive emergency protection (PEP) also with boron carbide of 92% enrichment by $^{10}$B.

CPS rods and steel shield assemblies use hot-pressed boron carbide.

A core layout is given in Figure 1.

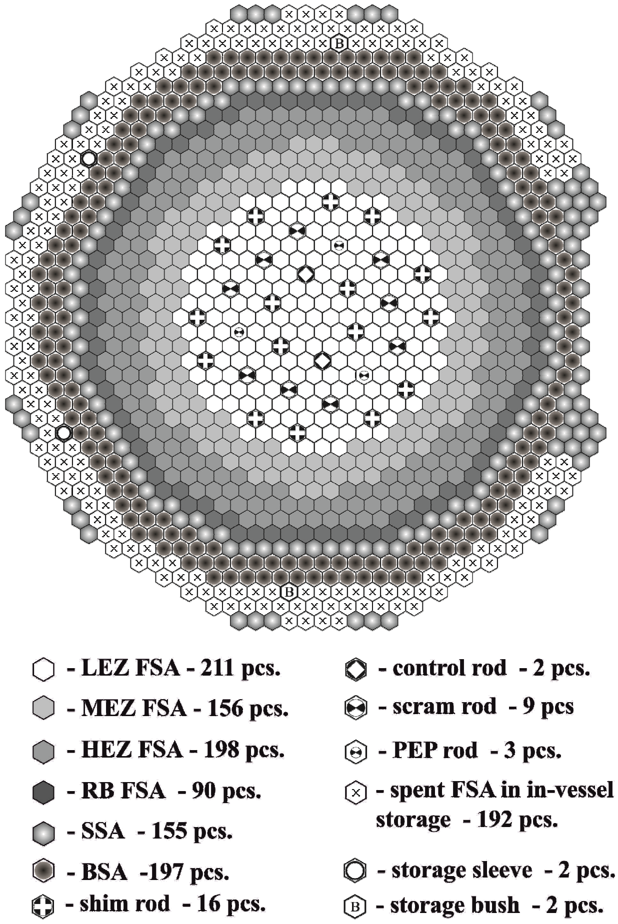


*Figure 1 The full MOX fuel core layout*

Table 1 shows main characteristics of the full MOX fuel core.

TABLE I: MAIN CHARACTERISTICS OF THE FULL MOX FUEL CORE

| Parameter | Value |
|---|---|
| Equivalent diameter, m | 2.56 |
| Fuel column height, cm | 90 |
| MOX fuel inventory, t | 16.4 |
| Operating cycle length, efpd | 155 |
| FSA life, efpd | 465 (620*) |
| Average fuel burnup, (MWd)/kg | 66 |

* - for peripheral HEZ FAs

## 3. Design and Characteristics of FSA

Basic FSA design characteristics are given in Table 2, FSA scheme is shown in Figure 2.

TABLE II: FSA MAIN DESIGN CHARACTERISTICS

| Parameter | Value |
|---|---|
| FSA length, mm | 3500 |
| Width across flats and thickness of hexagonal wrapper tube, mm | 96×2 |
| Number of fuel pins, pcs | 127 |
| FSA wrapper tube material | EP-450 |
| Fuel pin diameter, mm | 6.9×0.4 |
| Fuel pin cladding material | ChS-68 CW |
| Fuel pin length, mm | 2040 |

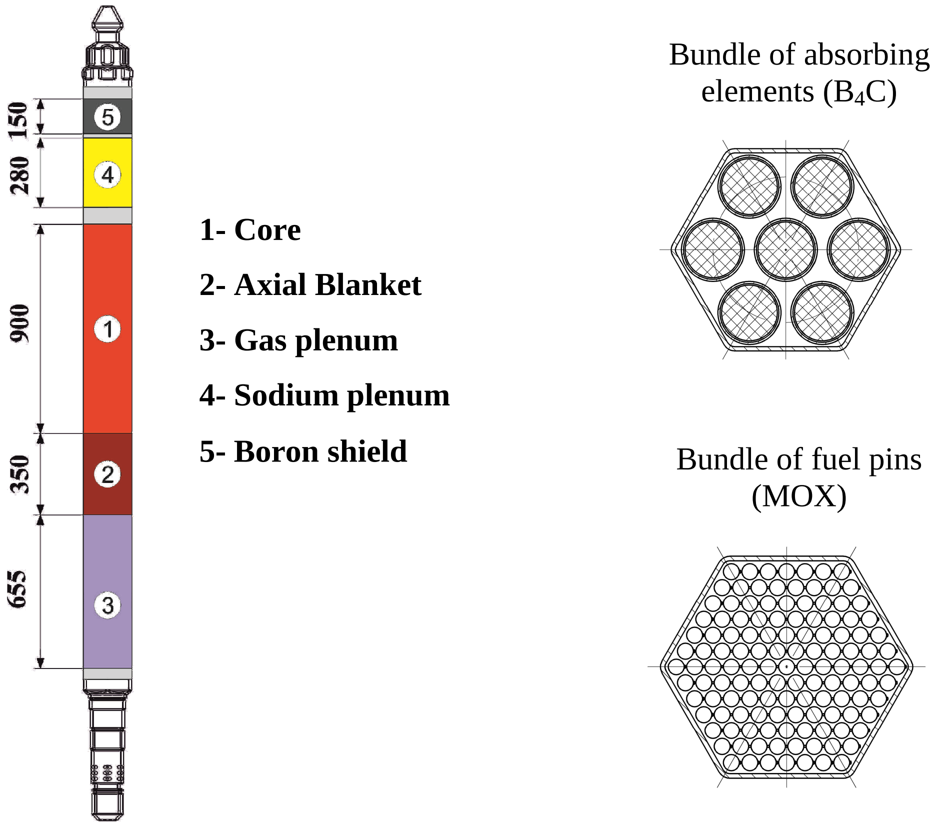


*Figure 2. The FSA scheme*

FSAs for full MOX fuel core will be manufactured on the basis of reactor-grade plutonium, extracted from the spent nuclear fuel of VVER reactors. In case of deviation of plutonium isotope composition from the basic one (accepted according to fuel developer's recommendations for design analysis) plutonium content in fresh MOX fuel should be corrected because of different reactivity worth of plutonium isotopes. A correction procedure for plutonium enrichment [12, 13] of manufactured fuel is based on the principle to retain reactor criticality parameters at the end of operating cycle (at the state with maximum fuel burnup). Under condition of appropriate plutonium enrichment correction core performance and FSA irradiation parameters practically will not change

Operation characteristics of FSAs of the BN-800 full MOX fuel core are given in Table 4.

## 4. Order of the Full MOX Core Formation

In the initial BN-800 operation period (the first four operation intervals) the hybrid core is used. It includes FSAs with uranium oxide fuel (pellet-type), FSAs with pellet MOX fuel and FSAs with vibro-packed MOX fuel. A core layout of the hybrid core in the fourth operation interval is given in Figure 3.

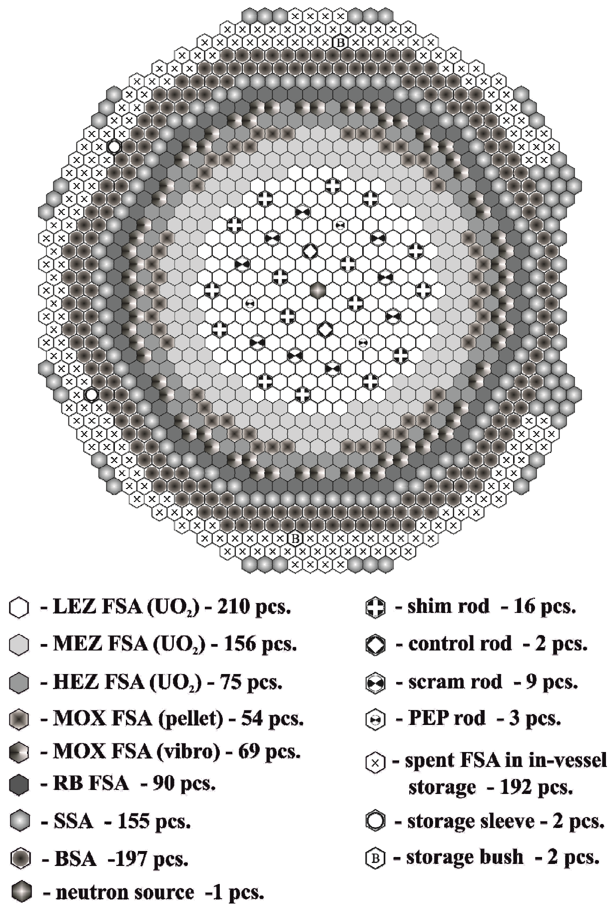


*Figure 3. – The core layout for the fourth operation interval*

The basic design operation mode of the reactor is an equilibrium reloading mode, which is characterized by equal quantities of FSAs, reloaded in one refueling, and equal durations of intervals between refuelings (operating cycles). For the accepted scattered batch refueling scheme FSAs with different irradiation time are operated simultaneously in the core. Three batches of FSAs reloading should be formed within the period of hybrid core operation. Major array FSA life is 465 efpd (three intervals of 155 efpd). Thus, at the beginning of the fourth operation interval of the hybrid core in the reactor there will be three FSAs batches of equal quantity with cumulative operation time of 0 efpd ("fresh" FSAs), 155 efpd and 310 efpd.

Considering the specified division of FSAs into three refueling batches the transition from the hybrid core to the full MOX fuel core will be made by three subsequent refuelings, in which hybrid core FSAs will be replaced entirely by standard FSAs with pellet MOX fuel. The change in core composition during transition to the full MOX fuel core is presented in Table 3.

TABLE III: CORE COMPOSITION CHANGE DURING TRANSITION TO FULL MOX FUEL CORE

| Reactor operation interval | Core composition (No. of FSAs) | | | | | | | Note |
|---|---|---|---|---|---|---|---|---|
| | LEZ | | MEZ | | HEZ | | | |
| | $UO_2$ | MOX pellet | $UO_2$ | MOX pellet | MOX pellet | $UO_2$ | MOX vibro | |
| 4 | 210 | - | 156 | - | 54 | 75 | 69 | Hybrid core, formed by refueling butches |
| 5 | 141 | 69 | 104 | 52 | 99 | 39 | 60 | Beginning of transition (~1/3 FSAs with standard pellet MOX fuel) |
| 6 | 72 | 138 | 52 | 104 | 165 | 15 | 18 | ~2/3 FSAs with standard pellet MOX fuel |
| 7 | - | 211 | - | 156 | 198 | - | - | Complete load of standard pellet MOX fuel (Full MOX core) |

The transient period is characterized by stepwise increase of neutron flux density in the core (from $7.0\times10^{15}$ to $8.2\times10^{15}$ n/cm$^2\cdot$s), which is caused by nuclear-physics features of plutonium relative to uranium-235. Nevertheless, it does not result in necessity to limit reactor power due to decrease of $^{235}U$ concentration in uranium FSAs as fuel burns up. Fuel pins parameters in Table 4 are presented with account of their operation in the transition period.

TABLE IV – FSAs OPERATION CHARACTERISTICS OF THE BN-800 REACTOR CORE

| Parameter | Hybrid core | | | Full MOX fuel core |
|---|---|---|---|---|
| | $UO_2$ | MOX pellet | MOX vibro | |
| Peak pin linear power, kW/m | 49 | 43 | 36 | 48 |
| Peak damage dose, dpa | 81 | 75 | 68 | 90 |
| Peak burnup, % h.a. | 10.3 | 8.5 | 7.4 | 9.7 |
| Maximum fuel pin cladding temperature, °C | 710 | 710 | 710 | 710 |

## 5. Prospects of Fuel Burnup Increase in the BN-800 Reactor

The main factor limiting FSA life is radiation resistance of a structural material of fuel pin cladding. The BN-800 core was developed using steel ChS-68 for fuel pins claddings, as in BN-600 standard FSAs. As it is shown by BN-600 operation experience, operability of fuel pins with claddings of this steel is provided to a damage dose of ~ 90 dpa, which corresponds to maximum (peak) burnup of MOX fuel of 9.7 % h.a. in the в BN-800 reactor at an average value for unloaded fuel of 6.8 % h.a. (66 MWd/kg).

The developed R&D program, aimed at BN fuel life extension, provides transition to application of more radiation-resistant steel of austenitic class EK-164 (07Cr16Ni19Mo2Mn2NiTiB), differing from steel ChS-68 (06Cr16Ni15Mo3NiB) by nickel content increased from 15 to 19% and complex alloying by P, Nb, Ti, V, Ce, B [14,15], as a fuel pin cladding material. The results of operation of experimental FSAs with fuel pin cladding of steel EK-164 in the BN-600 reactor justify their operability at damage doses not less than 110 dpa. If a damage dose of 112 dpa is accepted as a limit, it is possible to extent FSA life to 580 eff. days, i.e. to two years of operation. To justify this life extension it is necessary, at first, to study referent FSAs (during replacement of fuel pin cladding material in standard FSAs), and then, to test and study individual experimental FSAs operated with scheduled life extension.

## 6. Conclusion

The BN-800 core was developed using a large accumulated experience of development and operation of cores with uranium oxide fuel of BN-350 and BN-600 reactors. Considering MOX fuel application for the BN-800 reactor, a FSA design with upper sodium plenum was accepted.

To provide BN-800 operation, at the initial operation stage before commissioning of commercial production of MOX fuel, a hybrid core is used. This core is formed of FSAs with enriched uranium fuel and FSAs with MOX fuel of two types: pellet-type fuel and vibro-packed fuel, manufactured at pilot production of of “MAYAK” Production Association and JSC “SSC RIAR”.

Transition to the full MOX fuel core will begin after the fourth operation interval of the reactor. This transition is planned to perform in three subsequent refueling, during which spent FSAs of the hybrid core will be replaced by FSAs with pellet MOX fuel manufactured by Mining and Chemical Combine.

The average fuel burnup for the full MOX fuel core is 66 MWd/kg. As a material for fuel pin cladding it is planned to use ChS-68 CW steel, which was proved to be successful in the BN-600 reactor, in this case the maximum damage dose for fuel pin cladding will be 90 dpa.

The further prospects to enhance efficiency of BN-800 fuel application are associated with application of EK-164 steel with higher radiation resistance for fuel pin cladding.

**Resistance**

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