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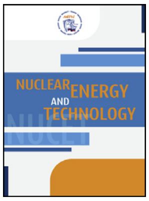

Improvement the value of sodium void reactivity effect of the fast neutron reactor by the instrumentality of the Monte Carlo code

P.A. Maslov, V.I. Matveev, I.V. Malysheva*

State Scientific Center of the Russian Federation – Institute for Physics and Power Engineering n.a. A.I.Leipunsky. 1, Bondarenko sq., Obninsk, Kaluga reg., 249033 Russia

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Abstract

To fulfill safety of fast sodium reactors in a beyond design-basis accident (BDBA) like unprotected loss of flow accident (ULOF), the sodium void reactivity effect (SVRE) should be close to zero. Its value depends on the fuel burnup – the higher burnup the higher value of SVRE. We analyze limitation of the fuel burnup in the core of a large sodium reactor imposed by SVRE.

The model of a large sodium-cooled reactor core is chosen for analysis. Two fuel types are considered – MOX and nitride uranium-plutonium. For both we follow the transition of the core from reactor startup to equilibrium reloading state, where the core passes consequently through different stages of fuel burnup. Calculations of maximal and average burnup together with corresponding value of SVRE have been done for a homogeneous model with the codes TRIGEX and MMKKENO. The latter employs transport approximation (the Monte Carlo method) and allows detailed heterogeneous representation of fuel assemblies and safety rods. The results obtained for the MOX fuel show that after the end of second core cycle (maximal burnup about 8%) the refined value of SVRE exceeds two times its maximal acceptable value (0.3% $\Delta k/k$). For the nitride fuel this exceeds is found at the end of 3rd fuel reshuffling (maximal burnup is about 8.75%); however it is considerably lower as compared to that found for MOX.

Keywords: Fast reactor; MOX fuel; Nitride fuel; Sodium void reactivity effect; Maximal burnup; Transient; Safety.

Introduction

The new version of the nuclear safety regulations (PBYa RU AS-89) issued after the Chernobyl accident has contained a new requirement for BN reactors – reactivity coefficients for coolant temperature and volumetric fraction must be negative at abnormal operation and in design-basis accidents. In the ultimate case when the coolant volume fraction becomes zero, the corresponding reactivity effect is denoted as the sodium void reactivity effect (SVRE). This term describes reactivity of the core with sodium, removed from the core and reflectors – lateral and axial breeding zones. A technical solution to fulfill this requirement has been found in late 80 s in IPPE (Institute for Physics and Power Engineering, Obninsk) and OKBM (Afrikantov Experimental Design Bureau for Mechanical Engineering, Nizhny Novgorod) – a sodium plenum above the core, implemented as empty fuel assembly wrappers. Numerical investigations and later experiments on the BFS facility have proven that even more strict requirement is met: a close to zero value of integral SVRE, that describes voiding in all fuel assemblies in the core, sodium plenum and upper boron shield axial zones, i.e. without breeding zones. Design technical specifications have been elaborated for the BN-800 reactor [1]. At present, this solution is utilized also in the advanced fast sodium reactors of high power. The core safety analysis [2] has shown that one of the most severe accidents caused by failure of the primary and secondary coolant loop main pumps (the ULOF accident) does not lead to core melting even in the absence of active and passive protection systems.

Calculation investigations postulate the maximal acceptable value of SVRE of +0.3% $\Delta k/k$. All major calculation investigations in the field of fast reactor physics are curried out with diffusion codes, although some important

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* Corresponding author.

E-mail address: imalysheva@ippe.ru (I.V. Malysheva).

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Table 1
SVRE calculated with TRIGEX and MMKKENO for several BN-1200 core designs.

Core height, cm	100									85		
Design index	1			2			3			4		
Number of FA without breeding zone at core periphery	66									–		
Breeding zone height, cm	20									–		
Breeding zone displacement, cm	0			−5			−9			–		
Code (A – TRIGEX, B – MMKKENO)	A	B		A	B		A	B		A	B	
		hom	het		hom	het		hom	het		hom	het
SVRE (active height, SA ends, Na plenum, boron shield) at EoC, % $\Delta k/k$	0,70	1,17	0,91	0,45	1,00	0,72	0,24	0,81	0,56	0,18	0,85	0,58

characteristics, in the first place SVRE, require more precise methods of solving the neutron transport equation. One of them is the Monte Carle method that is able to represent most precisely the complex geometry of fast reactors modern design. The MMKKENO code [3], used in IPPE, allows us to effectively compute refined characteristics of fast reactors [4]. Preliminary assessments of SVRE [5–8] with this code have shown noticeably higher value as compared to predictions of the diffusion code TRIGEX.

It is known that SVRE increases with the amount of fission products in the core [9]. One can assume that at some burnup level, SVRE will exceed its maximal acceptable value and thus will impose a limit to the burnup.

Preliminary calculations of the SVRE refined value with Monte Carlo codes for the BN-1200 reactor

Previously we compared the value of SVRE for the BN-1200 reactor obtained with MKKKENO and TRIGEX. Among with the reference core model of 85 cm height, several other variants have been considered, with axial breeding zone containing depleted uranium. The breeding zone was introduced into the core design to optimize SVRE and excess reactivity [5]. Variants differ by the breeding zone axial position with respect to the core center.

A model describing the average stationary state has been used for calculations. For MMKKENO calculations a heterogeneous model with detailed geometry of fuel assemblies and control rods has been prepared in addition to the homogeneous one. Results of calculations (see Table 1) show the following:

1. For the core without breeding zone, the value of SVRE as obtained with MMKKENO and TRIGEX differs by 0.4% $\Delta k/k$.
2. For cores with breeding zone, the difference in SVRE amounts to 0.2–0.3% $\Delta k/k$. In some cases, already TRIGEX predicts SVRE above the maximal acceptable value of 0.3% $\Delta k/k$.

The main task of the investigation is to analyze the limits of fuel burnup due to safety. We have considered the transient from reactor's startup up to the equilibrium fuel cycle, where the core passes consequently through different stages of fuel burnup.

Table 2
Core main parameters.

Thermal power, MW	2800	
Core cycle length, effective days	330	
Fuel	(U-Pu)O2	(U-Pu)N
Fuel cycle length, effective days		
Central – 282 SA	5 × 330	4 × 330
Next to last row – 66 SA	6 × 330	5 × 330
Last row – 84 SA	7 × 330	6 × 330
Number of SA in the core	432	
Number of SA in radial breeding zone	174	
SA flat-to-flat and hexcan thickness, mm	181 × 3,5	
Number of pins	271	
Clad diameter and thickness, mm	9,3 × 0,6	
Fuel effective density, g/cc	9,2	11,5
Breeding material	UO2	UN
Breeding material effective density, g/cc	9,5	12,5
Core height, mm	850	
Sodium plenum height, mm	380	

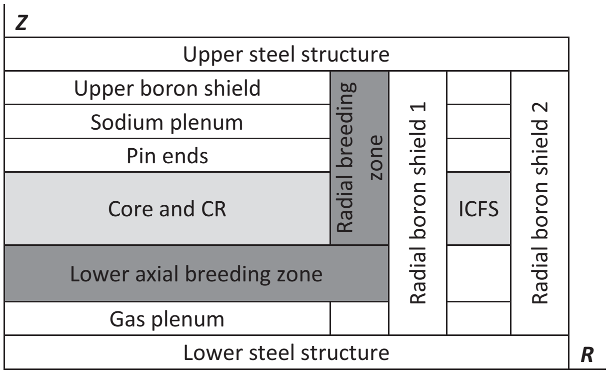

Fig. 1. The core model, R-Z geometry (ICFS – in-core fuel storage) Refined SVRE and burnup excess reactivity in BN-1200 type reactor.

The model with breeding zones, with MOX or nitride fuel has been chosen for analysis. The core geometry for both fuel types was the same; the cases differ only by fuel composition and burnup level. Main core characteristics are given in Table 2. Fig. 1 illustrates the model in R-Z geometry.