ЭКСПЛУАТАЦИЯ ОБЪЕКТОВ АТОМНОЙ ОТРАСЛИ
OPERATION OF FACILITIES NUCLEAR INDUSTRY

УДК 621.039.516.22 : 621.039.524.44
DOI 10.26583/gns-2022-04-05
EDN FTHHGS

ВЛИЯНИЕ ВЫГОРАЮЩЕГО ПОГЛОТИТЕЛЯ (Gd) НА КОЭФФИЦИЕНТ РАЗМНОЖЕНИЯ (k_∞) В ПРОЦЕССЕ ВЫГОРАНИЯ ТОПЛИВА ДЛЯ ПОЛНОМАСШТАБНЫХ И ПОЛИЯЧЕЕЧНЫХ МОДЕЛЕЙ ДЛЯ РЕАКТОРА ВВЭР

© 2022 Рахман Анисур С.К.[1], Увакин Максим Александрович[2]

[1]Управление по Регулированию Атомной Энергии Бангладеш (БАЭРА), Агаргаон, Дакка-1207, Бангладеш
[2]Национальный исследовательский ядерный университет «МИФИ», Москва, Россия
[1]ranisur01@gmail.com, https://orcid.ord/0000-0001-7803-8234
[2]uvakin_ma@grpress.podolsk.ru, https://orcid.ord/0000-0002-4917-1770

Аннотация. В статье рассмотрены различные концентрации выгорающего поглотителя (ПВ) гадолиния (Gd) в системе компенсации избыточной реактивности реактора типа ВВЭР при длительных кампаниях. Здесь проанализировано влияние метода на полномасштабную и полиячеечную модели размещения выгорающего поглотителя в топливе с гадолиниевыми стержнями (твэг). Показано сильное влияние состава выгорающего поглотителя (ПВ) в топливе с гадолиниевыми стержнями (твэг) на зависимость коэффициента выгорания топлива.

Ключевые слова: выгорающий поглотитель, компенсация, реактивность, полномасштабная модель, полиячеечная модель, коэффициент размножения, выгорание.

Для цитирования: Рахман Анисур С.К., Увакин М.А. Влияние выгорающего поглотителя (Gd) на коэффициент размножения (k∞) в процессе выгорания топлива для полномасштабных и полиячеечных моделей для реактора ВВЭР // Глобальная ядерная безопасность. – 2022. – № 4(45). – С. 54-60. http://dx.doi.org/10.26583/gns-2022-04-05

Поступила в редакцию 15.07.2022
После доработки 30.09.2022
Принята к печати 12.10.2022

Introduction

The general methods available for reactivity control, the insertion and withdrawal of neutron absorbers, generally referred to as control rods, is the approach usually taken for power reactors. A burnable poison, (a nuclide that has a large neutron absorption cross section) or a chemical shim (a neutron-absorbing chemical, usually boric acid, which is dissolved in the moderator or coolant) is employed for reactivity control depending on reactor types. There are three methods to control the reactivity of a power plant. The first method (by the insertion and withdrawal control rod) has a negative effect on the axial power distribution, and the insertion or withdrawal control rod will change the power of reactor. The second method is chemical shim (a neutron-absorbing chemical, usually boric acid, which is concentrated in the moderator or coolant), this method has a better effect on the radial and axial power distribution, but in depending on burnup, the concentration of boric acid in the moderator should be decrease by operator or automation system to conserve the criticality state and any mistake will happen in this system will cause accident in the core. The third method is burnable absorber [1-2] (a nuclide that has a large neutron absorption cross section), and there are many nuclides using in the fuel as an absorber like Gd, Pu, Cm, Np, Am and Th etc. All these elements change the reactivity of the power reactor.

Objective

In operating WWER-1200 reactors, which use extended campaigns up to one and a half to two years, the number of fuels with gadolinium rod 18–24 pieces, and the weight content of Gd_2O_3 is 5–8 wt.%. Due to this arrangement, the burnable absorber is permanent and completely disappears at the end of the campaign.Inhereevaluated the concentration of Gadolinium in the fuel with gadolinium rod (tveg) for the full-scale loadingandpoly cells model.

Description of the program GETERA-93

The GETERA-93 program is designed for neutron-physical calculation of cells and poly-cells of nuclear reactors, both fast and thermal, in spherical, cylindrical and planar geometry. The program can be used to solve a wide range of problems: preparation of small-molecule cross sections for subsequent large-scale calculations, investigation of various characteristics of reactors in cell and poly-cellular models, solving problems related to burnout of fuels, modeling of various reactor regimes. The neutron-physical distribution of neutrons is calculated in the probability method of the first collisions [3-4].

The GETERA-93 program can be used to solve a wide range of tasks, both research and applied. With its help, it is possible to study the neutron-physical characteristics of the reactors at the cell and poly cells level. The algorithm for the multiplicity of the cell makes it possible to simulate sufficiently large fragments of the reactor on a small number of cells. In addition to calculations of the fragments of the reactor, the built-in algorithms allow modeling the burnup processes in the reactor and calculating the characteristics of fuel cycles: for example, the coarse fuel burnup in reactors with cyclic and in reactors with continuous fuel overload.Another large area of application of this program is the preparation of libraries of small sections so that they can later be used in full-scale models. The program allows you to take into account the environment of the cell when preparing sections, which is important when preparing the correct constants for small programs [5-6]. The program prepares both macromicro-sequences and constants for dynamic software complexes.

Full-scale and Poly-cells model

Fuel assembly (FA) contains four types of rod

1. Fuel rod (tvel)
2. Fuel with gadolinium rod (tveg)
3. Central rod
4. Guide channel

Fuel rod and fuel with gadolinium rod (Figure-1) are divided into five zones. The first zone, which is contains «He» gas. The second zone, which is contains fuel (U^{235}) (for the tvel) and fuel with gadolinium (for the tveg) [7-8]. The third zone which is contains clearance zone. Forth zone contains shell zone and the fifth zone is coolant zone.

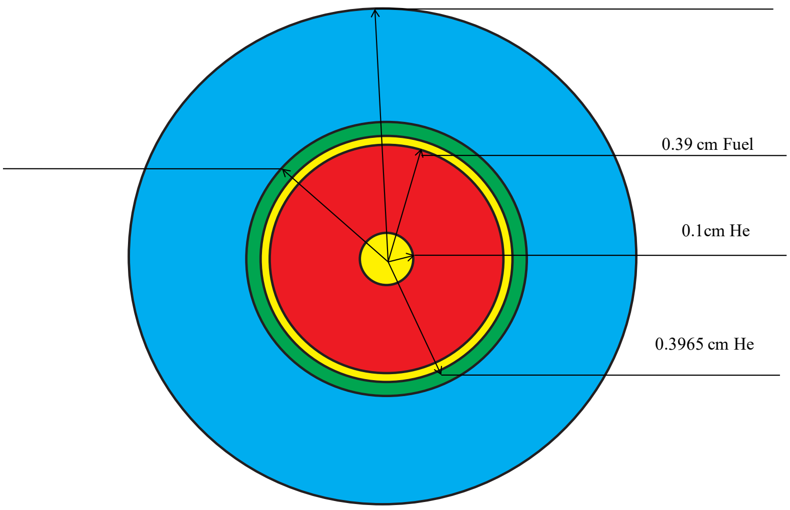

Figure 1 – Fuel zone (tvel) or Fuel with gadolinium (tveg) zone position in 0.39 cm radius

In Figure 2, it is shown that there are 312 rods in the fuel assembly. If n- fuel with gadolinium rod, then 312-n = fuel rods. In Russian WWER reactors, the ratio of the fuel with gadolinium (tveg) and fuel rods is - 1: 6, 1: 12, 1: 18 and 1: 24. So, 1: 6, N (Total) = (1+6) =7, 312 / 7≈45 fuel with gadolinium rods and (312-45) = 267 fuel rods. In the same way, for the 1:12, N = 13, 312 / 13≈24 fuel with gadolinium rods and (312-24) = 288 fuel rods, for the 1:18, N = 19, 312 / 19≈17 fuel with gadolinium rods and (312-17) = 295 fuel rods, for the 1:24, N = 25, 312/25≈ 12 tags and (312-25)=300 fuel rods. In this calculation, we can say that the poly cells model is 1: 6, 1: 12, 1: 18 and 1: 24 and full-scale model is 45: 267, 24: 288, 17: 295 and 12: 300. [9-10]

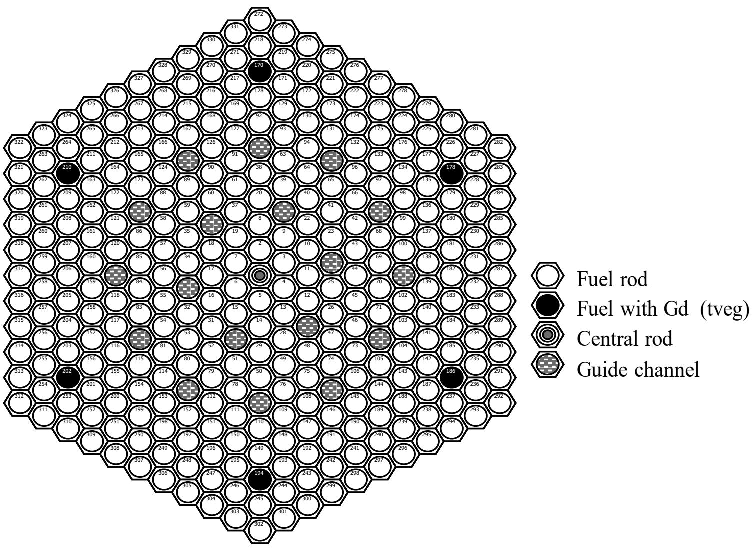

Figure 2 – 312 Fuel rods assembly

Calculate the multiplying coefficient characteristic for the Full-scaleand Poly cells model

For the full-scale fuel assembly (when 45 fuel with gadolinium rods and 267 fuel rods) and poly cells: (1fuel with gadolinium rod and 6 fuels rod), then the multiplying coefficient vs time was calculated by the program GETERA-93 for the different (0.1%, 0.25%, 0.5%, 0.75% and 1%) concentration of gadolinium, which is shown in the figure 3*a* and figure 3*b* respectively. In here full-scale fuel assembly and poly cells are given the same result. [11-12]

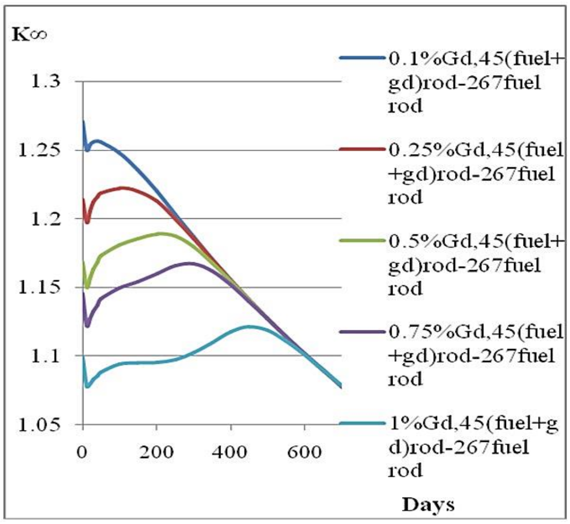

Figure 3*a* – Multiplying coefficient vs Days in full scale 45 (Fuel+Gd)rods and 267 fuel rods model

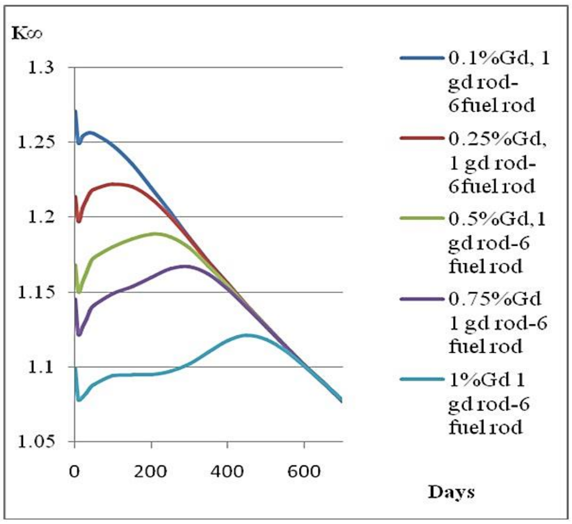

Figure 3*b* – Multiplying coefficient vs Days in full poly cells 1(Fuel+Gd) rod and 6 fuel rods model

Graph analysis: When the concentration of gadolinium is 0.1% in the full-scale (45 tveg rods and 267 tvelrods) model, then the gadolinium rod (tveg) very soon (approximately 50 days) absorbed neutrons and after that only fuel $U^{235}$was burned. In the same way, when a little much more gadolinium 0.25% then approximately100 day's gadolinium fuel rod absorbed neutrons, after that only fuel $U^{235}$was burned. In here it was seen that, more concentration of gadolinium absorbed neutrons for a long time until all gadolinium was burned, and then only fuel $U^{235}$was burned. Same result was shownin the poly cells model (fig. 3*b*).

When in the fuel assembly has 24(Fuel+Gd)rods and 288 fuel rods for the full scale and poly cells 1(Fuel+Gd) rod and 12 fuel rods, then the multiplying coefficient vs days shown in the figure 4*a* and figure 4*b* accordingly. But in here, 24 fuel with gadolinium rods which is less than <45 fuel with gadolinium rods. For this reason, for the concentration of (0.5%, 0.75%, 1.5% and 3%) gadolinium, 24 fuel with gadolinium rods absorbed neutrons for a long time and then burned fuel U^{235}.

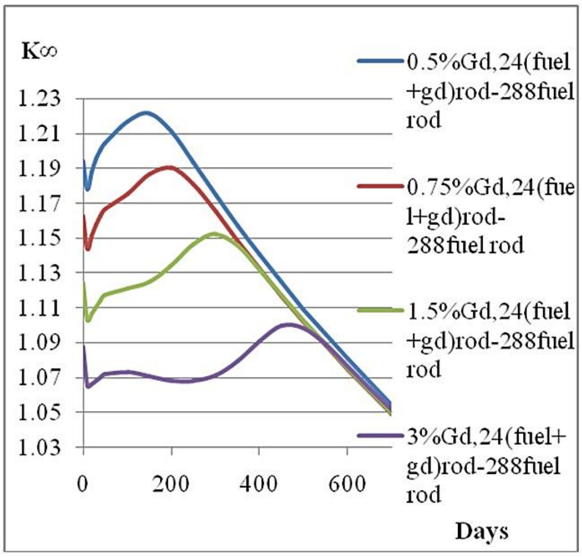

Figure 4*a* – Multiplying coefficient vs Days in full scale 24 (Fuel+Gd) rods and 288 fuel rods model

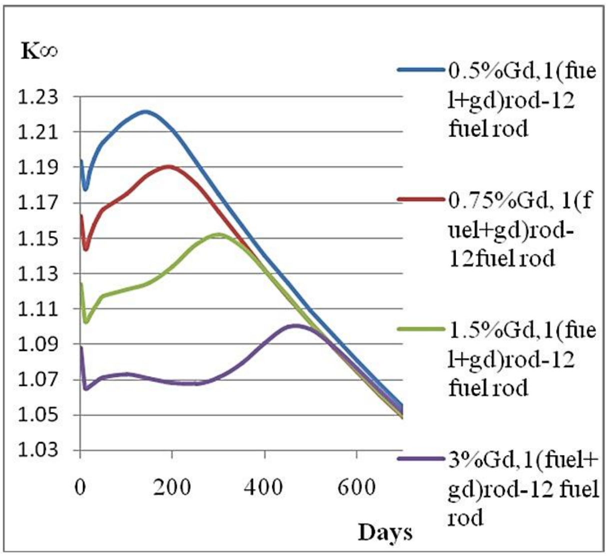

Figure 4*b* – Multiplying coefficient vs Days in poly cells 1 (Fuel+Gd)rod and 12 fuel rods model

For the fuel assembly 17 (Fuel+Gd) rods and 295 fuel rods and his poly cells 1 (Fuel+Gd) rod and 18 fuel rods, fuel assembly 12 (Fuel+Gd) rods and 300 fuel rodsfor the full-scalemodel and his poly cells model 1 (Fuel+Gd) rod and 24 fuel rods was calculated by the program GETERA-93. Which is shown in figure 5*a*, 5*b* and 6*a*, 6*b* accordingly.

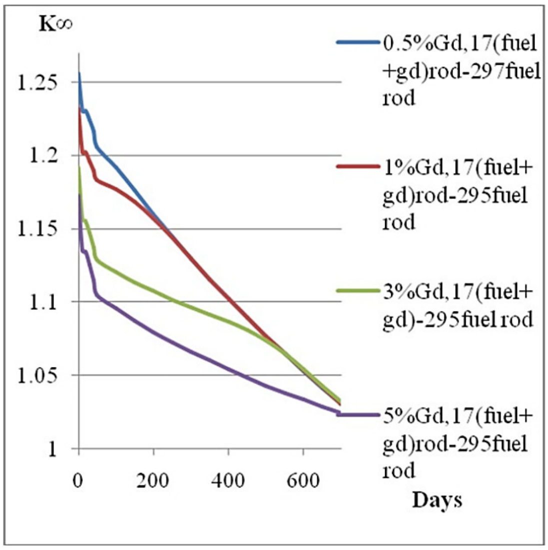

Figure 5*a* – Multiplying coefficient vs Days in full scale17 (Fuel+Gd)rods and 295 fuel rods model

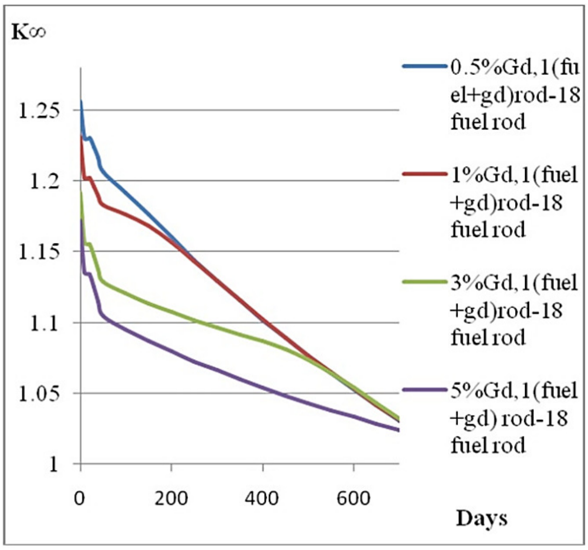

Figure 5*b* – Multiplying coefficient vs Days in poly cells 1(Fuel+Gd)rod and 18 fuel rods model

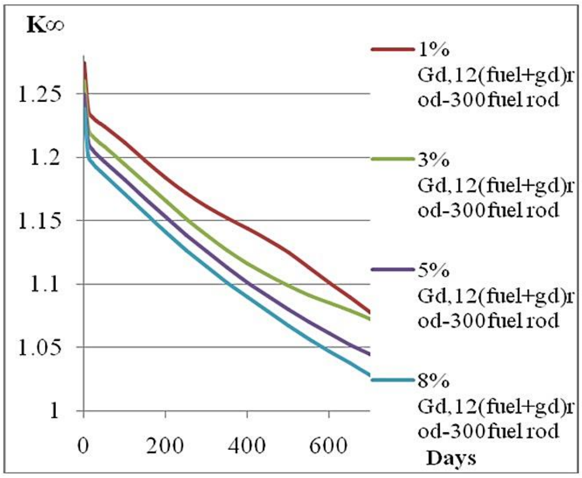

Figure 6*a* – Multiplying coefficient vs Days in full scale 12 (Fuel+Gd)rods and 300 fuel rods model

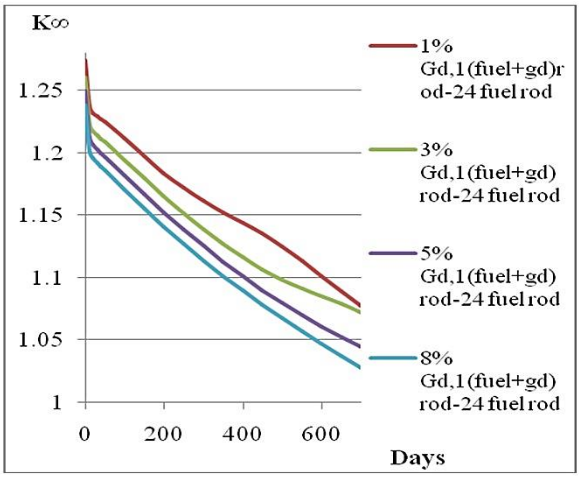

Figure 6*b* – Multiplying coefficient vs Days in poly cells 1 (Fuel+Gd)rod and 24 fuel rods model

Graph analysis: Figure 5*a*, 5*b* and 6*a*, 6*b* shows that, when in the full-scale has 17 (Fuel+Gd) rods, then absorption time is less than 12(Fuel+Gd) rods absorption time.

Result

It is shown that the placement of a burnable absorber in a fuel assembly has both a quantitative and a qualitative effect on the change in the multiplication factor in the process of fuel burnup. It should also be noted that the duration of gadolinium burning depends on its amount and distribution inside the fuel assembly.

Conclusion

Calculation results on a full-scale model of a WWER polycell simulating fuel assemblies with pin-by-pin nodalization showed that varying the amount and location of the burnable poison inside the fuel assemblies get possible to control the reactivity margin for burnup and increase the efficiency of nuclear fuel usage in WWER reactors. Such problem is an optimization problem and can be solved by calculation.

СПИСОК ИСТОЧНИКОВ

1. *Рахман, Анисур С.К.* Сравниние результатов анализа неопределенности в физических расчетах ячеек ВВЭР в суточном графике маневрирования двумя программам GETERA и WIMS / С.К. Анисур Рахман, М.А. Увакин // Глобальная ядерная безопасность. – 2019. – № 1(30). – С. 90-100.
2. *Рахман, Анисур С.К.* Исследование изменения концентрации поглотителя при работе реактора ВВЭР-1000 в режиме маневрирования / С.К. Анисур Рахман, М.А. Увакин // Глобальная ядерная безопасность. – 2020. – № 2(35). – С. 83-91.
3. *Anisur, R S K, Uvakin M A,* Uncertainty analysis in the physical calculation of WWER cells in the daily maneuvering schedule. (2018) Journal of Physics: Conference Series, 1133(1), Article № 012048.
4. *Николаев, А.Л.* Исследование реактивности ВВЭР в режиме с неконтролируемым извлечением группы ОР СУЗ при минимально возможном начальном потоке нейтронов / А.Л. Николаев, М.А. Увакин // Проблемы атомной науки и техники. Серия: Ядерно-реакторные константы. – 2019. – № 2. – С. 170-179.
5. *Петкевич, И.Г.* Анализ неопределенностей результатов расчета режима с разрывом паропровода на установке АЭС-2006 по коду КОРСАР/ГП с применением программы LINQUAD / И.Г. Петкевич, М.А. Увакин // Вопросы атомной науки и техники. Серия: Физика ядерных реакторов. – 2013. – Вып. 2. – С. 51-60.
6. *Увакин, М.А.* Анализ коэффициентов реактивности ВВЭР в режимах нормальной эксплуатации с изменением внешней нагрузки / М.А. Увакин, А.П. Демехин // Атомная энергия. – 2017. – № 4. – С. 193-195.
7. *Bryukhin V.V., Kurakin K.Y., Uvakin M.A.* Analysis of the uncertainties in the physical calculations of water-moderated power reactors of the WWER type by the parameters of models of preparing few-group constants. Physics of atomic nuclei, 79, 2016 (8), p. 1305-1314.
8. *Uvakin M.A., Alekhin G.V., Bykov M.A., Zaitsev S.I.* Verification of three-dimensional neutron kinetics model of TRAP-KS code regarding reactivity variations. *KERNTECHNIK*, 81, 2016 (4), p. 394-400.
9. *Гетя, С.И.* Моделирование температурных неоднородностей в пучке твэлов ТВС ВВЭР-1000 / С.И. Гетя, В.Г. Крапивцев, П.В. Марков, В.И. Солонин // Атомная энергия. – 2013. – Т. 114, № 1. – С. 69-72.
10. *Аверьянова, С.П.,* Метод офсет-мощностной фазовой диаграммы для управления энерговыделением реактора / С.П. Аверьянова, Н.С. Вохмянина, Д.А. Злобин, П.Е. Филимонов, В.И. Кузнецов, В.Б. Лаговский // Атомная энергия. – 2016. – Т. 121, № 3. – С. 123-127.
11. *Melikhov V.I., Melikhov O.I., Yakush S.E.* A Study of Boron Dilution in WWER-1000 Reactor. Thermal Engineering. 2002. Vol. 49, № 5. P. 372-376.
12. JANIS Online version, no Java required – Nuclear Energy Agency. http://www.oecd nea.org/janisweb/.

REFERENCES

[1] Rahman Anisur S.K., Uvakin M.A. Sravniniye rezul'tatov analiza neopredelennosti v fizicheskikh raschetakh yacheyek WWER v sutochnom grafike manevrirovaniya dvumya programmam GETERA i WIMS [Compare the Result of Uncertainty Analysis in the Physical Calculations of WWER Cells in the Daily Maneuvering Schedule by GETERA and WIMS Programs], Global'naya yadernaya bezopasnost' [Global Nuclear Safety], 2019, no. 1(30), pp. 90-100 (in Russian).

[2] Rahman S.K. Anisur, M.A. Uvakin, Issledovaniye izmeneniya kontsentratsii poglotitelya pri rabote reaktora WWER-1000 v rezhime manevrirovaniya [Investigation of Absorber Concentration Changes during Maneuvering Operation in WWER 1000 Reactor], Global'naya yadernaya bezopasnost' [Global Nuclear Safety], 2020, № 2(35), pp. 83-91 (in Russian).

[3] Anisur, R S K, Uvakin M A, Uncertainty Analysis in the Physical Calculation of WWER Cells in the Daily Maneuvering Schedule. (2018) Journal of Physics: Conference Series, 1133(1), Article № 012048 (in English).

[4] Nikolaev A.L., Uvakin M.A. Issledovaniye reaktivnosti WWER v rezhime s nekontroliruyemym izvlecheniyem gruppy or suz pri minimal'no vozmozhnom nachal'nom potoke neytronov. [Investigation of WWER Reactivity in a Mode with Uncontrolled Extraction of a CPS OR Group at

the Lowest Possible Initial Neutron Flux], Problemy atomnoj nauki i tekhniki. Seriya: YAderno-reaktornye konstanty [Problems of Atomic Science and Technology. Series: Nuclear Reactor Constants], 2019, no. 2, pp. 170-179 (in Russian).

[5] Petkevich I.G., Uvakin M.A. Analiz neopredelennostey rezul'tatov rascheta rezhima s razryvomparoprovoda na ustanovke AES-2006 po kodu KORSAR/GP s primeneniyem programmy LINQUAD [Uncertainty Analysis of the Results of the Calculation of the Mode with a Break in the Steam Pipeline at the AES-2006 Unit Using the KORSAR/GP Code Using the LINQUAD Program], Voprosy atomnoj nauki i tekhniki. Seriya: Fizika yadernyh reaktorov [Issues of Atomic Science and Technology. Series: Physics of Nuclear Reactors], 2013, no. 2, pp. 51-60 (in Russian).

[6] Uvakin M.A., Demekhin A.P. Analiz koeffitsiyentov reaktivnosti WWER v rezhimakh normal'noy ekspluatatsii s izmeneniyem vneshney nagruzki [Analysis of Reactivity Coefficients of a WWER Reactor in Normal Operation Modes with a Change in External Load]. Atomnaya energiya [Atomic Energy], 2017, vol. 123, no. 4, pp. 193-195 (in Russian).

[7] Bryukhin V.V., Kurakin K.Y., Uvakin M.A. Analysis of the Uncertainties in the Physical Calculations of Water-Moderated Power Reactors of the WWER Type by the Parameters of Models of Preparing Few-Group Constants. Physics of Atomic Nuclei, 79, 2016 (8), p. 1305-1314. (in English)

[8] Uvakin M.A., Alekhin G.V., Bykov M.A., Zaitsev S.I. Verification of Three-Dimensional Neutron Kinetics Model of TRAP-KS Code Regarding Reactivity Variations. KERNTECHNIK, 81, 2016 (4), p. 394-400 (in English).

[9] Getya S.I., Krapivtsev V.G., Markov P.V., Solonin V.I. Modelirovaniye temperaturnykh neodnorodnostey v puchke tvelov TVS WWER-1000 [Modeling Temperature Nonuniformities in a Fuel-Element Bundle of WWER-1000 Fuel Assembly]. Atomnaya energiya [Atomic energy], 2013, v. 114, no. 1, pp. 69-72 (in Russian).

[10] Averyanova S.P., Vokhmyanina N.S., Zlobin D.A., Filimonov P.E. Kuznetsov V.I., Lagovsky V.B. Metod ofset-moshchnostnoy fazovoy diagrammy dlya upravleniya energovydeleniyem reaktora [Offset-Power Phase Diagram Method for Controlling the Energy Release of the Reactor]. Atomnaya energiya [Atomic energy], 2016, vol. 121, no. 3, pp. 123-127 (in Russian).

[11] Melikhov V.I., Melikhov O.I.,Yakush S.E. and others. A Study of Boron Dilution in WWER-1000 Reactor. Thermal Engineering. 2002, vol. 49, no 5, pp. 372-376 (in English).

[12] JANIS Online version, no Java required – Nuclear Energy Agency. http://www.oecdnea.org/janisweb/. (in English).

Effect of the Burnable Absorber (Gd) on the Multiplying Coefficient (K∞) in the Process of Fuel Burnup for Full-Scale and Poly Cells Models for the WWER Reactor

Rahman S.K. Anisur[1], Maksim A. Uvakin[2]

[1]*Bangladesh Atomic Energy Regulatory Authority (BAERA), Authority Bhabon, E-12/A, Agargaon, Dhaka-1207, Bangladesh*
[2]*National Research Nuclear University (MEPhI), Kashirskoyeshosse, 31, Moscow, Russia 1154091*
[1]*ranisur01@gmail.com, ORCID iD, 0000-0001-7803-8234, WosResearher ID: D-3381-2019*
[2]*uvakin_ma@grpress.podolsk.ru, ORCID iD, 0000-0002-4917-1770, WosResearher ID: E-1027-2019*

Received by the editorial office on 07/15/2022
After completion 09/30/2022
Accepted for publication on 10/12/2022

Abstract. The paper considers various concentrations of burnable absorber (BA) Gadolinium (Gd) in the system of compensation of excess reactivity in the reactor of WWER type at the extended campaigns. It is analyzed the influence of the method for the Full-scale and Poly-cells model placing the burnable absorber in the fuel with gadolinium rods (tveg). The strong influence of the BAs composition in the fuel with gadolinium rods (tveg) dependence on the multiplication factor of the fuel burnup is shown.

Keywords: burnable absorber, compensation, reactivity, full-scale model, poly-cellular model, multiplication factor, burnup.

For citation: Rahman Anisur S.K., Uvakin M.A. Effect of the Burnable Absorber (Gd) on the Multiplying Coefficient (K∞) in the Process of Fuel Burnup for Full-Scale and Poly Cells Models for the WWER reactor // Global Nuclear Safety. 2022. Vol. 4(45). P. 54-60. http://dx.doi.org/10.26583/gns-2022-04-05.