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INVESTIGATION OF FUNCTIONALS OF NEUTRON FLUX INFLUENCING ONTO VVER-440 REACTOR PRESSURE VESSEL

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Irradiation conditions of VVER-440 reactor pressure vessel are determined with the presence and absence of dummy cassettes at a core periphery. Distributions of neutron flux functionals onto the inner surface and in the depth of pressure vessel are investigated for various core loadings.

Introduction

The lifetime control program for the equipment of nuclear power plant unit requires developing and introducing a methodology of reactor pressure vessel (RPV) irradiation conditions determination at the modern scientific and technical level.

It is practically excluded by the construction of VVER type reactors a direct determination of characteristics of the neutron flux influencing onto RPV. Special methodologies should be applied to solve this problem [1]. Such methodology providing determination of the neutron flux functionals characterized VVER-440 vessel irradiation conditions has been developed by our group [2]. First of all such linear functionals are referred to those ones as the neutron fluence with energy above 0.5 MeV, flux above 0.5 MeV averaged on the nominal reactor power through the fuel cycle ($\varphi_{0.5}$), number of displacement per atom (DPA) caused by neutrons above 0.5 MeV, and DPA rate averaged on the nominal power through the fuel cycle. Besides, such nonlinear functional, as the spectral index that is the ratio of the neutron fluences or fluxes above 0.5 MeV and 3.0 MeV at the same point is related to those neutron flux functionals.

The comprehensive analysis of the VVER-440 vessel irradiation conditions have been carried out on the basis of the results obtained for all fuel cycles of Rovno-1 and Rovno-2. The units are respectively operated with and without of dummy cassettes at the core periphery during all fuel cycles.

Space distributions of neutron flux linear functionals

Axial distribution shape of any neutron flux linear functional at the RPV inner surface is slightly depended on core configuration type (i.e. with the presence or absence of dummy cassettes at the core periphery) as it is seen from example in Fig. 1. In all cases there are the distribution maximum at the height ~ 90 cm from the core bottom and its "shelf" about between 80 and 150 cm.

The neutron flux functional axial gradient for a lower part of a core can be characterized with the ratio of the maximal value to the value at weld № 4, i.e. on height 21.5 cm. This ratio are approximately equaled 1.8 for the 1st cycle and varied in the range from 1.5 to 1.7 for all following cycles of any core configuration type that is a numeral proof of the distribution conservatism represented in Fig. 1.

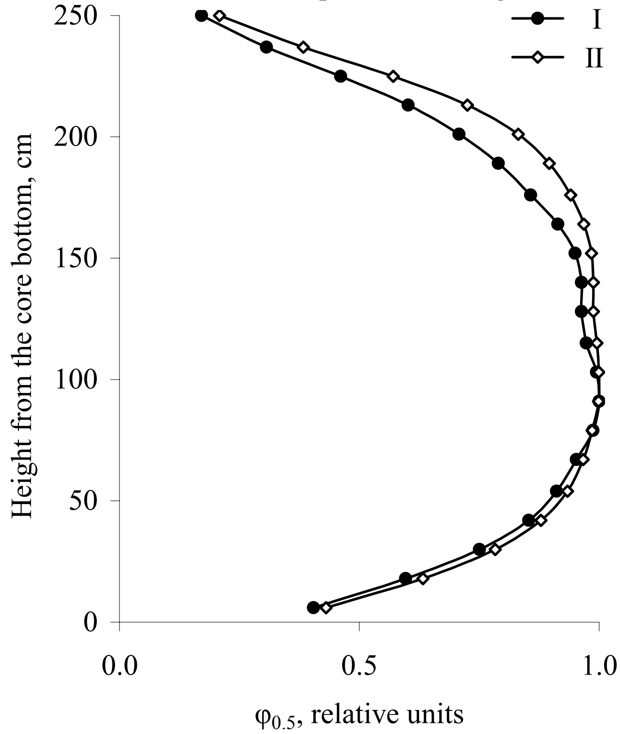

Fig. 1. Axial distributions of the neutron fluxes above 0.5 MeV at the RPV inner surface with (I) and without (II) dummy cassettes at the core periphery.

Azimuth distribution shape of any neutron flux linear functional at the VVER-440 vessel inner surface is practically not depended on fuel loading characteristics for any core configuration type as it is seen from example in Fig. 2. The distribution in a reactor 60-degrees symmetry sector with dummy has global and local minima at the coordinates ~30° and ~0° (60°) respectively and two maxima at the coordinates ~12° and ~48°. If dummy cassettes are absent in a core the global and local maxima and two minima of the distribution take correspondingly the same coordinates up, i.e. the second distribution

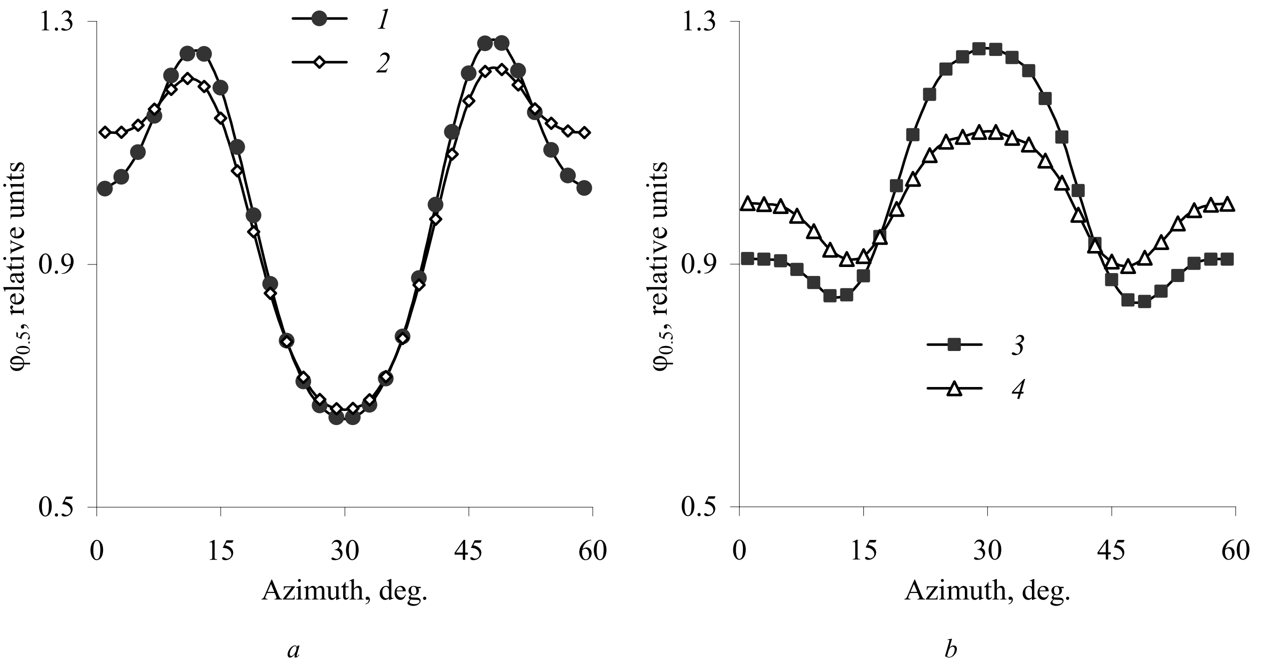

Fig. 2. Azimuth distributions of the neutron fluxes above 0.5 MeV at the RPV inner surface at the maximal radiation exposure level with the presence (*a*) and absence (*b*) of dummy cassettes in the core: *1*, *3* – cycles with fresh fuel assemblies at the core periphery; *2*, *4* – cycles with burned fuel assemblies at the core periphery.

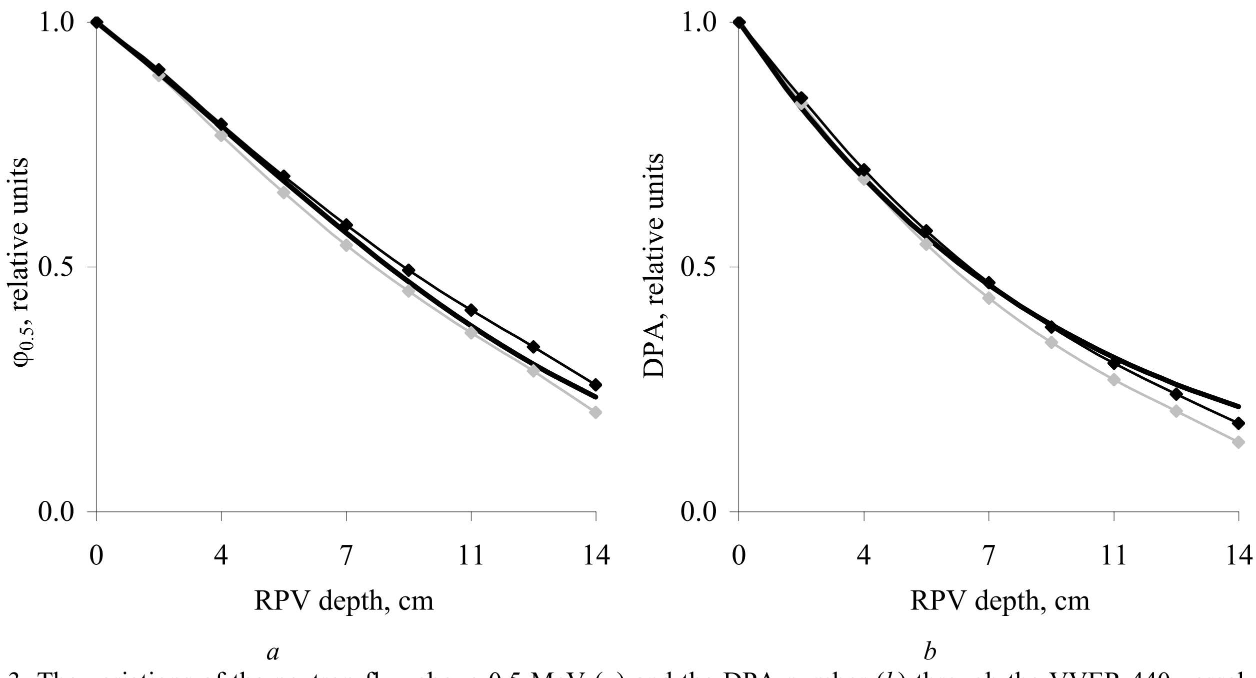

Fig. 3. The variations of the neutron flux above 0.5 MeV (*a*) and the DPA number (*b*) through the VVER-440 vessel wall in the region of the azimuth distribution maximum (-◆-) and minimum (-◆-) as well as approximating curves.

may be named conditionally inverse to the first. This conditional character of the inversion relates with different ratios between maximal and minimal values of neutron flux functional for given level. For various fuel cycles with and without dummy cassettes at a core periphery, for example, the ratio values of flux are in the ranges 1.7÷2.0 and 1.2÷1.6 respectively as well as ones of DPA are in the ranges 1.8÷2.1 and 1.2÷1.5. By the way, it is seen with this values that neutron field at a reactor near-vessel space is more conservative with the presence of dummy cassettes in a core than with their absence. This conclusion is verified with the comparison of cycle maximal fluence values. Their ranges are $1.6\div2.8\cdot10^{18}$ and $3.5\div9.8\cdot10^{18}$ cm^{-2} with and without dummy cassettes correspondingly. It is clearly visible both absolute and relative range widths in the first case are much smaller than in the second.

To compare the RPV irradiation conditions for various fuel cycles it is more in the radiation exposure's point corrected the maximal neutron fluxes above 0.5 MeV use [3]. Comparison of the value ranges with the dummy presence ($0.7 \div 1.1 \cdot 10^{11}$ $cm^{-2}s^{-1}$) and with their absence ($1.8 \div 3.2 \cdot 10^{11}$ $cm^{-2}s^{-1}$) has been shown that a RPV radiation exposure is decreased approximately in 2.5 - 3 times if the dummy cassettes are loaded onto a core periphery.

Analysis of obtained results has been shown that variation of any neutron flux linear functional through the VVER-440 vessel wall does not depend on axial coordinate. Although this variation are insignificantly depended on the azimuth and the core configuration type but it can be well approximated as it is seen from Fig. 3 with single formula

$$F(x) = F(0) \cdot e^{-\alpha x},$$

where $F(0)$ – a neutron flux functional at the RPV inner surface; α – an attenuation factor; x – a RPV depth.

The attenuation factor values of the neutron fluence (or flux) and DPA (or DPA rate) are approximately 0.09 cm^{-1} and 0.11 cm^{-1} respectively.

Space dependences of the spectral indexes

Analysis of fast neutron spectra at a near-vessel space of VVER-440 in various zones has been shown that they are sufficiently closed on shape (Fig. 4). That allows using as its sufficient characteristic only one parameter which the spectral index represents. It is noted above the spectral index is the ratio of the neutron fluence above 0.5 MeV and 3.0 MeV. It is obvious that a greater part of high-energy neutrons in a spectrum follows a smaller spectral index value. Such spectrum is possible to be named as harder one. Instead, a greater spectral index value means a softer spectrum.

Analysis of the obtained spectral index values has been shown that fast neutron spectrum shape are depended on azimuth and radial coordinates, but practically not done on height at the core level.

The general shape of spectral index azimuth dependence at the RPV inner surface is slightly depended on fuel loading characteristics for each core configuration type. At the same time the spectral index azimuth distributions have the following general features in a reactor 60-degrees symmetry sector without dependence on the core configuration type (Fig. 5): two global minima at coordinates ~13^0 and ~47^0, one feebly marked local minima at coordinates 0^0 (60^0), two feebly marked

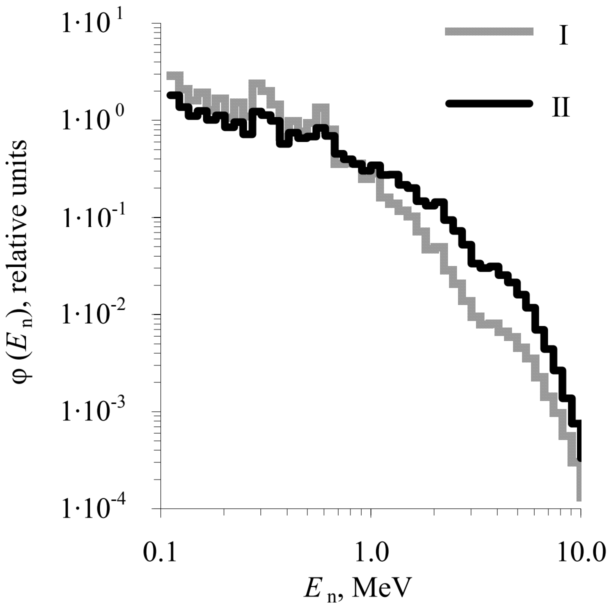

Fig. 4. The normalized neutron spectra at a near- vessel space of VVER-440: I – at the RPV outside surface with the presence of dummy cassettes in the core; II – at the RPV inner surface with the absence of dummy cassettes in the core.

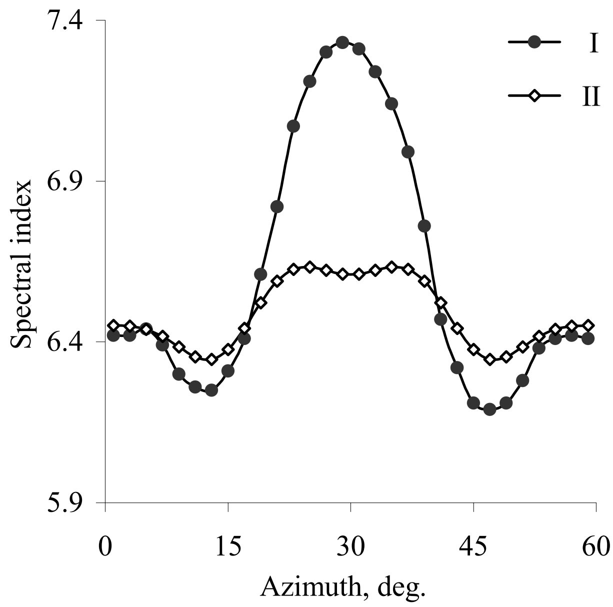

Fig. 5. Azimuth distributions of spectral indexes at the VVER-440 vessel inner surface at the maximal radiation exposure level with (I) and without (II) dummy cassettes at the core periphery.

local maxima at coordinates ~5^0 and ~55^0. There is a difference between the general distribution shapes of two configuration type of core in the angle range from 23^0 to 37^0. With the absence of dummy cassettes in the core this distribution is sensibly constant with feebly marked extreme at 30^0 and with their presence it has obvious global maximum at the same coordinate. Here is the absolute maximal spectral index value 7.3 for some cycles, i.e. the neutron flux with the softest spectrum influences onto VVER-440 vessel. The neutron flux onto RPV with the hardest spectrum is in the azimuth distribution global minimum where spectral index value is 6.1 for some cycles with dummy cassettes in the core. It should be reminded the maximum of a fluence azimuth distribution of this core configuration type is also approximately here. Without dummy cassettes in the core there is the inverse dependence, i.e. a neutron flux has a softer spectrum in the global maximum region than in the minimum one. At the same time the spectral index value range of various cycles with the dummy cassettes (6.1 - 7.3) contains one without their (6.4 - 6.9).

The variation of a spectral index trough the RPV wall is practically not depended on core configuration type, as well as azimuth and axial coordinates.

Summary

The irradiation conditions of VVER-440 vessel are determined and analyzed with the presence as well as absence of dummy cassettes in a reactor core.

It is shown that azimuth and axial distribution shapes of the neutron flux linear functionals at the RPV inner surface are practically not depended on characteristics of a fuel loading for each core configuration type, i.e. with or without of dummy cassettes.

The burned fuel assembly loading at the core periphery decreases the RPV radiation exposure approximately in 1.5 times.

The dummy cassettes loading at the core periphery decreases the RPV radiation exposure approximately in 2.5 - 3 times.

With the presence of dummy cassettes in a core the maximal neutron flux influencing onto VVER-440 vessel has the hardest spectrum and the minimal flux does the softest one. With the absence of dummy cassettes the spectral index values are smaller variable and the maximal neutron flux has the softer spectrum than the minimal one.

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ДОСЛІДЖЕННЯ ФУНКЦІОНАЛІВ НЕЙТРОННОГО ПОТОКУ, ЩО ДІЄ НА КОРПУС РЕАКТОРА ВВЕР-440

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Визначено умови опромінення корпусу реактора ВВЕР-440 при наявності та відсутності касет-екранів на периферії активної зони. Досліджено розподіли функціоналів нейтронного потоку на внутрішній поверхні та в товщі металу корпусу реактора при різних варіантах паливних завантажень.

ИССЛЕДОВАНИЕ ФУНКЦИОНАЛОВ НЕЙТРОННОГО ПОТОКА, ВОЗДЕЙСТВУЮЩЕГО НА КОРПУС РЕАКТОРА ВВЭР-440

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Определены условия облучения корпуса реактора ВВЭР-440 при наличии и отсутствии кассет-экранов на периферии активной зоны. Исследованы распределения функционалов нейтронного потока на внутренней поверхности и в толще металла корпуса реактора при различных вариантах топливных загрузок.

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