УДК 621.039.5

INVESTIGATION OF VVER-440 REACTOR INTERNALS IRRADIATION CONDITIONS

S. M. Pugach, O. V. Grytsenko, V. L. Diemokhin, V. N. Bukanov

Institute for Nuclear Research, National Academy of Sciences of Ukraine, Kyiv

The calculational procedure for determination of irradiation conditions of VVER-440 reactor internals is presented. Using the developed procedure, irradiation conditions of Rovno NPP Unit1&2 VVER-440 reactor internals – baffle, basket and barrel – are determined. Distributions of neutron flux functionals at surfaces of these internals at both reactors are analyzed for different core arrangements.

Introduction

One of the main tasks for Ukrainian nuclear power engineering is VVER power units safety lifetime extension over design limits. That task takes special urgency for Rovno NPP Unit1&2 VVER-440 reactors, which are under operation more than half of design limit.

Determination of nuclear power reactor internals (RI) irradiation conditions is one of the issues that are needed for safety lifetime extension. VVER-400 reactor design excludes the possibility for direct determination of neutron flux functionals (NFF) at RI elements. Determination of those NFF requires a usage of special calculating methodologies. Such methodology was developed at the department of nuclear reactor dosimetry problems of INR of NASU.

Calculational methodology for RI irradiation conditions determination

At the department of nuclear reactor dosimetry problems of INR of NASU MCPV package program [1] was developed, intended for calculation of NFF at VVER-1000 pressure vessel. That program package was modernized to use it for the determination of NFF at VVER-440 RI. Modernization, mainly, concerned transport program, which performs neutron transport calculation by Monte-Carlo method in multigroup approximation of transport theory in complex heterogeneous environment of nuclear reactor.

On the base of design and commission documentation of Rovno NPP Unit 1 & 2 calculational reactor models (CRM) of those power units were developed (Fig. 1). Developed models imitate in more details VVER-440 RI. In particular, (Fig. 1, *b*), facetted sectors were modelled in space between baffle and basket.

Calculation detectors added in CRM for NFF determination at surfaces and inside baffle, basket and barrel have following dimensions: azimuth width - 2^0 for basket and barrel and ¼ edge width for baffle, thickness – 10^{-4} m, height – no more than $9.76 \cdot 10^{-2}$ m. Detectors heights were selected so as to have the possibility of NFF determination at RI surfaces at facetted sectors level if needed.

The variance reduction scheme for particle track modeling is used in transport program for the purpose of computer time reduction [1]. However, its efficiency depends on geometry and material parameters of CRM in number and location of calculation detectors. Therefore, used in transport program scheme was modernized too. In particular "weight conservation method" parameters were revised.

Analysis of RI irradiation conditions

Irradiation conditions analysis was carried out for present/absent dummy cassettes (DC) and installation fresh/burned up fuel at core periphery. Following notations are used for the identification of core arrangement:

DC located at core periphery (Rovno NPP Unit 1 CRM):

DF – cycle with fresh fuel at core periphery,

DB – cycle with burned up fuel at core periphery.

DC absence at core periphery (Rovno NPP Unit 2 CRM):

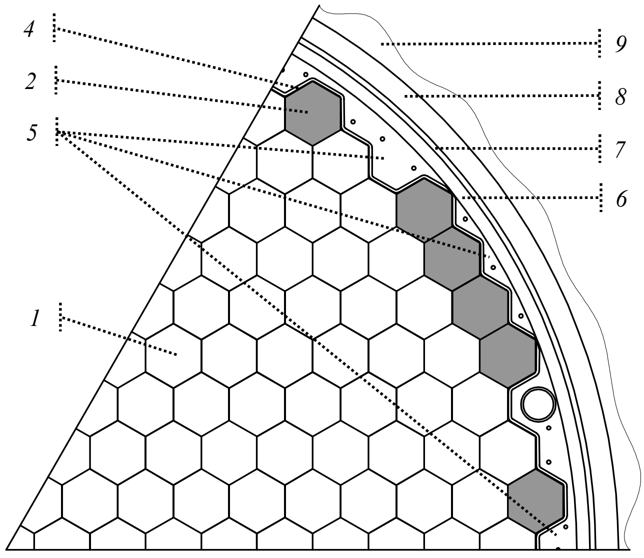
FF – cycle with fresh fuel at core periphery,

FB – cycle with burned up fuel at core periphery.

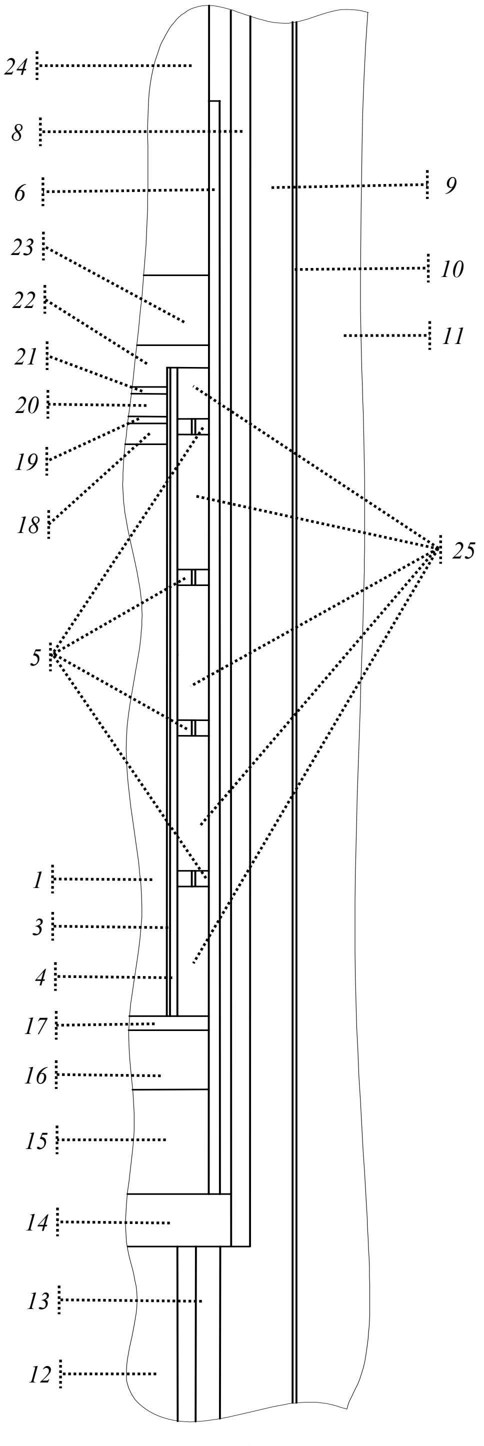
Irradiation conditions analysis is carried out for barrel as main supporting structure and baffle, which takes maximal radiation exposure. First of all distributions of neutron flux density (NFD) with $E_n > 0.5$ MeV ($\varphi_{0.5}$) were analyzed. Its determination is necessary according to regulation requirements [2]. Also the spectral index ($SI_{0.5}$) distributions were analyzed. It is the ratio of NFD with $E_n > 0.5$ MeV and $E_n > 3.0$ MeV and therefore, in some degree, characterizes fast neutron spectra shape.

The analysis of $\varphi_{0.5}$ (Fig. 2) and $SI_{0.5}$ (Fig. 3) axial distributions are shown, that their shape virtually does not depend on either DC presence at core periphery or fuel cycle characteristics. The attention is paid to splashes at facetted sector regions. Especially it is visible at $SI_{0.5}$ axial distribution (see Fig. 3).

As for azimuth distributions of considered NFF at RI surfaces, they have much more complex structure.



a

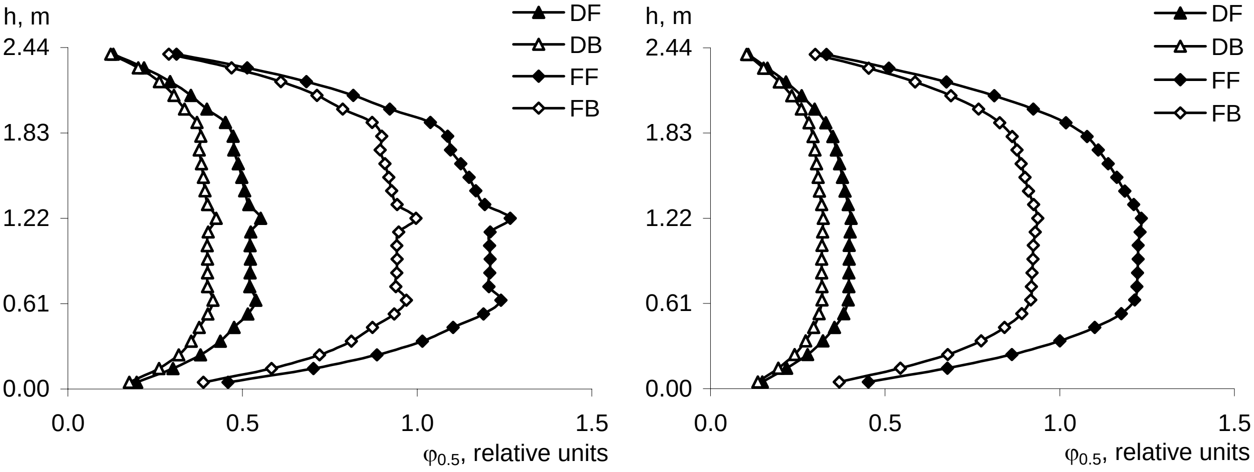


b

Fig. 1. CRM: *a* – 60-degrees symmetry sector part of 360-degrees CRM horizontal section from core to downcomer region at core level; *b* – CRM vertical section part up to pressure vessel. There are shown following zones: *1* – assembly; *2* – dummy cassettes (Unit 1 model) or assembly (Unit 2 model); *3* – water gap between core and baffle; *4* – baffle; *5* – facetted sectors; *6* – basket; *7* – water gap between basket and barrel; *8* – barrel; *9* – downcomer region; *10* – cladding; *11* – pressure vessel; *12* – lower pipe space; *13* – removing bottom; *14* – barrel bottom plate; *15* – basket bottom; *16* – bottom nozzles; *17* – lower pin tips and spacer grids; *18* - compensating volume; *19* – upper pin tips; *20* – water volume; *21* – lower part of assembly heads; *22* - upper part of assembly heads; *23* – plate of protective pipe block; *24* – upper pipe space; *25* – water volume.

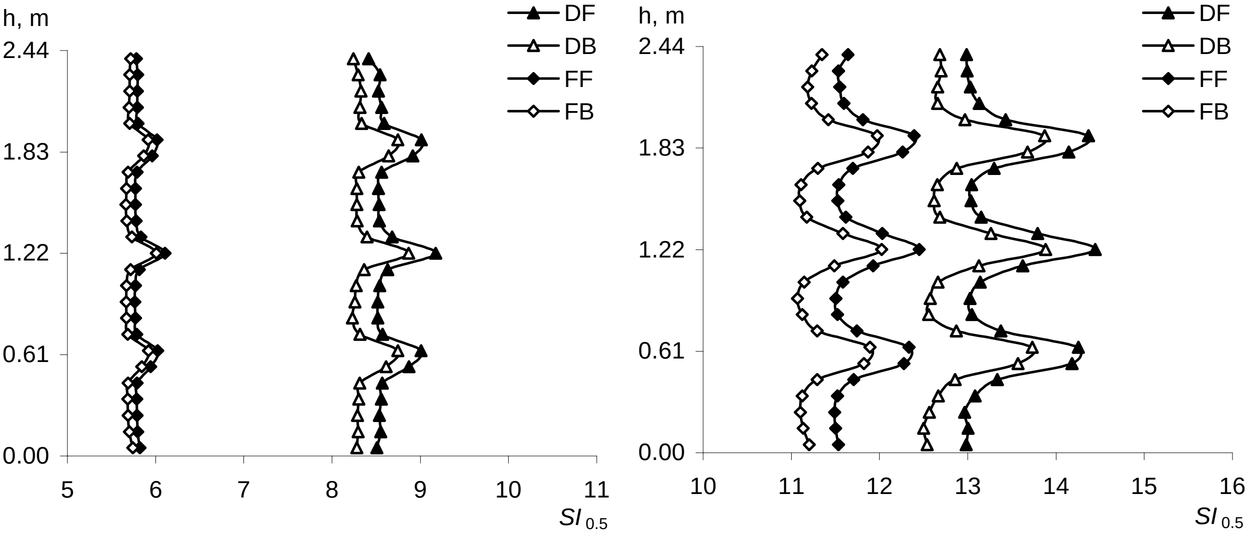
Azimuth distribution of $\varphi_{0.5}$ at barrel outer surface is shown in Fig. 4. It is noted, that $\varphi_{0.5}$ distributions at basket surfaces and at other barrel surfaces are having very similar shape to one presented in Fig. 4. From Figure one can see, that presence DC led to principal change of $\varphi_{0.5}$ azimuth distribution shape. The maximum location in case of DC installation at core periphery corresponds to the minimum location for the absence, thereof and vice versa.

Joint analysis of $\varphi_{0.5}$ axial and azimuth distributions, which were depicted in Fig. 2 and 4, showed that DC installation at core periphery is very efficient step for decreasing radiation exposure at basket and barrel, as well as at pressure vessel. Maximum radiation exposure is decreased around 3 times on the average. Using low leakage core loadings with burned up fuel at core periphery led to decreasing of radiation exposure also. In that case maximal radiation exposure decreased for approximately 30 %.



a *b*

Fig. 2. Axial distributions of $\varphi_{0.5}$ at baffle inner surface (*a*) and at barrel outer surface (*b*).



a *b*

Fig. 3. Axial distributions of $SI_{0.5}$ at baffle inner surface (*a*) and at barrel outer surface (*b*).

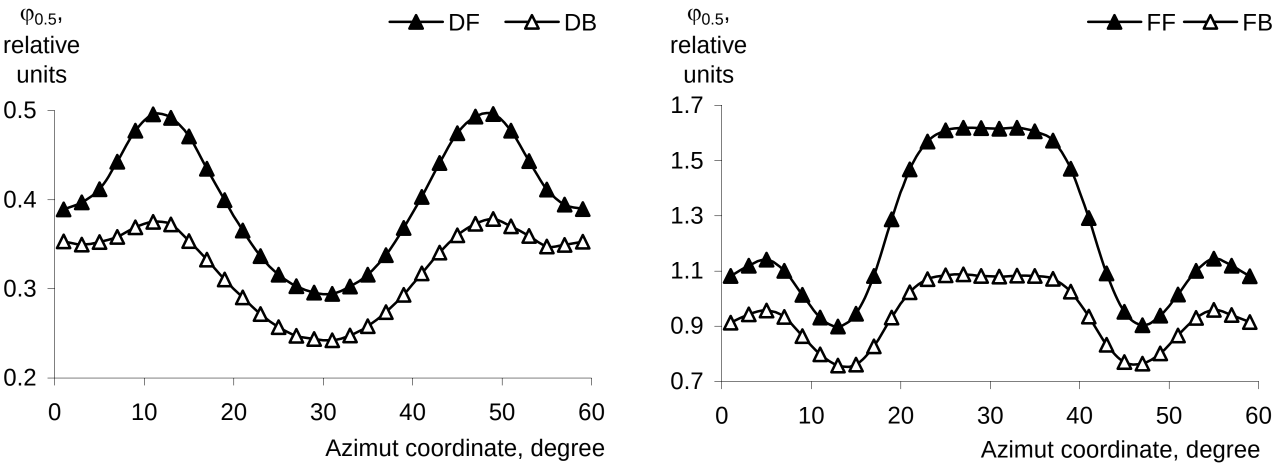


Fig. 4. Azimuth distributions of $\varphi_{0.5}$ at barrel outer surface at 1.22 m from core bottom.

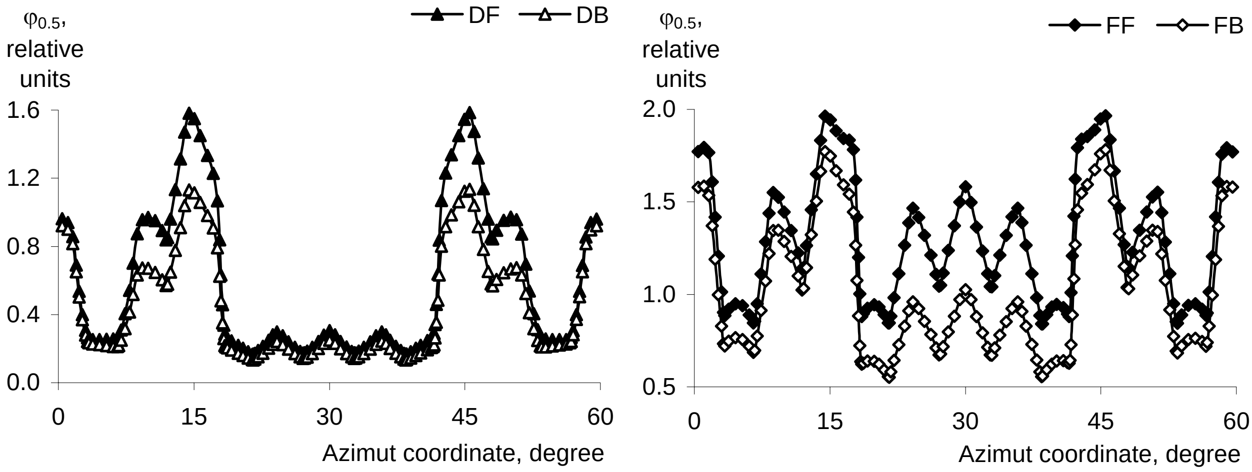


Fig. 5. Azimuth distributions of $\varphi_{0.5}$ at baffle inner surface at 1.22 m from core bottom.

Separate review requires azimuth distribution of $\varphi_{0.5}$ at baffle in view of its special construction. Azimuth distributions of $\varphi_{0.5}$ at baffle inner surface are presented in Fig. 5. Their analysis shows that DC presence at core periphery much less influences $\varphi_{0.5}$ azimuth distribution at baffle than one at basket and barrel. Nevertheless, DC insertion and using core loadings with burned up fuel at core periphery lead to decreasing of baffle radiation exposure.

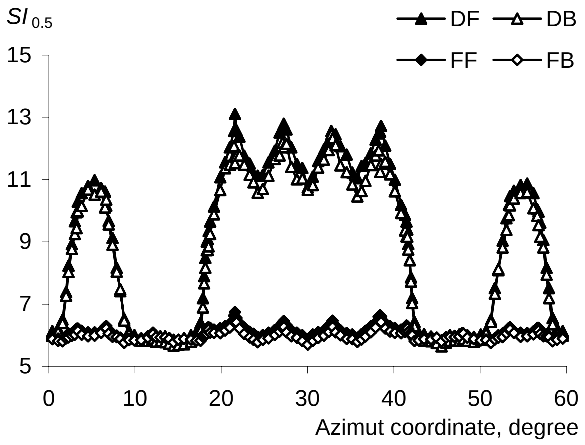


Fig. 6. Azimuth distributions of $SI_{0.5}$
at baffle inner surface at 1.22 m from core bottom.

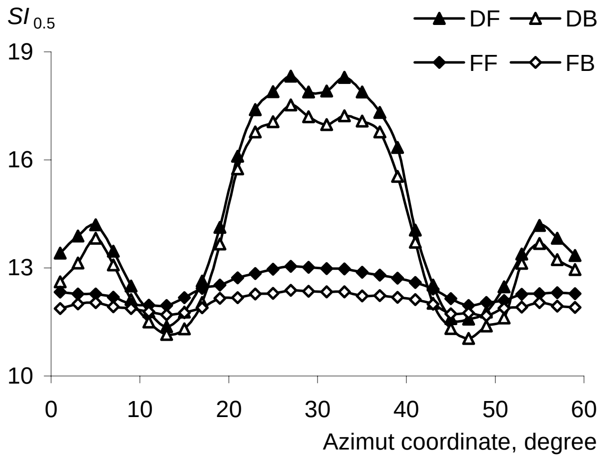


Fig. 7. Azimuth distributions of $SI_{0.5}$
at barrel outer surface at 1.22 m from core bottom.

Spectral index behavior at RI surfaces (Figs. 6 and 7) is interesting. From distributions presented in figures one can see that in case of DC absence at core periphery value of $SI_{3.0}$ weakly varied along azimuth. The insertion of DC at core periphery led to sharp fast neutron spectrum softening whiles their installations. Wherein core loading characteristics do not influence on $SI_{0.5}$ azimuth distribution shape at RI surfaces.

Conclusions

The shape of $\varphi_{0.5}$ and $SI_{0.5}$ azimuth distributions virtually is not influenced by presence of DC and burned up fuels at core periphery. However it is necessary to take into account the presence of facetted sectors in space between baffle and basket, because splashes of $\varphi_{0.5}$ and especially $SI_{3.0}$ values are observed their locations.

DC presence at core periphery led to virtually mirror changing of $\varphi_{0.5}$ azimuth distribution at basket and barrel surfaces as well as pressure vessel. Wherein at DC locations it is observed significant fast neutron spectrum softening that is necessary to take into account when determining RI radiation exposure.

Complex analysis of obtained results showed that DC presence at core periphery leads to sharp decreasing radiation exposure of majority RI. In addition to that using of core loadings with burned up fuel at core periphery also leads to decreasing of RI radiation exposure for both reactors.

REFERENCES

1. *Буканов В. Н., Гриценко А. В., Демехин В. Л., Пугач С. М.* Пакет программ MCPV для расчета функционалов нейтронного потока, воздействующего на корпус ВВЭР-1000. - Киев, 2005. - 28 с. - (Препр. / НАН Украины. Ин-т ядерных исслед.; КИЯИ-05-6).
2. *Правила* устройства и безопасной эксплуатации оборудования и трубопроводов атомных энергетических установок (ПН АЭ Г-7-008-89). - М.: Энергоатомиздат, 1990. - 168 с.

ДОСЛІДЖЕННЯ УМОВ ОПРОМІНЕННЯ ВНУТРІШНЬОКОРПУСНИХ ПРИСТРОЇВ РЕАКТОРА ВВЕР-440

С. М. Пугач, О. В. Гриценко, В. Л. Дємьохін, В. М. Буканов

Представлено розрахункову методику визначення умов опромінення внутрішньокорпусних пристроїв реактора ВВЕР-440. За допомогою розробленої методики визначено умови опромінення внутрішньокорпусних пристроїв реакторів ВВЕР-440 енергоблоків № 1 та № 2 Рівненської АЕС – вигородки, корзини та шахти внутрішньокорпусної. Досліджено розподіли функціоналів нейтронного потоку на поверхнях цих внутрішньокорпусних пристроїв в обох реакторах при різних компонуваннях активної зони.

ИССЛЕДОВАНИЕ УСЛОВИЙ ОБЛУЧЕНИЯ ВНУТРИКОРПУСНЫХ УСТРОЙСТВ РЕАКТОРА ВВЭР-440

С. М. Пугач, А. В. Гриценко, В. Л. Демехин, В. Н. Буканов

Представлена расчетная методика определения условий облучения внутрикорпусных устройств реактора ВВЭР-440. С помощью разработанной методики определены условия облучения внутрикорпусных устройств реакторов ВВЭР-440 энергоблоков № 1 и № 2 Ровенской АЭС – выгородки, корзины и шахты внутрикорпусной. Исследованы распределения функционалов нейтронного потока на поверхностях этих внутрикорпусных устройств в обоих реакторах при различных компоновках активной зоны.

Received 09.06.08,
revised - 22.12.08.