Nuclear Mathematical and Computational Sciences: A Century in Review, A Century Anew
Gatlinburg, Tennessee, April 6-11, 2003, on CD-ROM, American Nuclear Society, LaGrange Park, IL (2003)

TECHNIQUE USED IN ACADEM CODE PACKAGE FOR EVALUATION OF FAST NEUTRON FLUENCE ON VVER-1000 REACTOR VESSEL

B. D. Abramov, V. A. Pivovarov
SSC RF IPPE named after A. Leipunsky
249033, Obninsk, Kaluga region, Russian Federation
abbn@ippe.obninsk.ru; piv@ippe.obninsk.ru

N. A. Solovyov
SSC RF IPPE named after A. Leipunsky
249033, Obninsk, Kaluga region, Russian Federation
piv@ippe.obninsk.ru

ABSTRACT

Technique of routine evaluation of fast neutron fluence [1] used in ACADEM [2] reactor code package is presented. This Monte-Carlo based technique make it possible to control current values and forecast fluence of fast neutron with energy E>0.1, 0.5 and 3.1 MeV in over 30000 cells located on the inner and outer surfaces of reactor barrel and vessel, as well as down to 0.25 of the vessel wall thickness and on the welds.

Key Words: reactor VVER-1000 vessel, fluence of fast neutron

1. INTRODUCTION

Technique of routine evaluation of fast neutron fluence [1] used in ACADEM reactor code package [2] is presented. This technique is based on the following assumptions:

-. characteristics of the core and near vessel structures are constant from the standpoint of fast neutron flux assurance,
- fission neutron sources do not depend on coordinate within the boundary of triangle prism, i.e. conventional cells of the core subassemblies.

This means that stable, evaluated in advance functions of influence (worth) of the core cells (triangle prisms) on related cells of reactor cavity and vessel can be used for the fluence evaluation.

Similar assumptions were used earlier in [3], so this technique can be considered as some general case of technique presented in [3] for evaluation of worth of cells using Monte Carlo method for the real 3D geometry of the core, baffle, vessel and adjacent space, without involving usual approximations related to simplified geometry description, multi-group approximation etc.

2. NUMERICAL SCHEME

Let $i=\overline{1,19}$ (see Fig.1) be the numbers of subassemblies in the sector of 30-degree core symmetry, $j=\overline{1,6}$ - numbers of triangles in the subassembly, $k,n=\overline{1,36}$ - numbers of equal thickness axial layers of the core and shielding break-down. Let us break down corresponding symmetry sectors of the barrel and reactor vessel into 3-degree segments having numbers $s=\overline{1,10}$ for the inner surface of barrel, $s=\overline{11,20}$ for the outer surface of barrel, $s=\overline{21,30}$ for the inner surface of pressure vessel (PV), $s=\overline{31,40}$ for ¼ PV thickness and $s=\overline{41,50}$ – for the outer surface of reactor vessel.

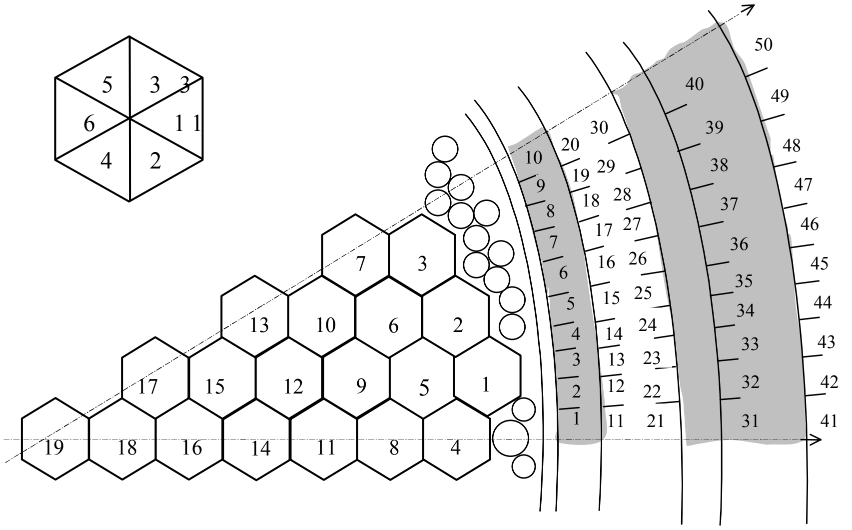

Figure 1 The triangles (up), core, barrel and PV cells numeration scheme

Then, taking into account contribution of only first 8 subassemblies (since the contribution from all other subassemblies is always negligible [1,3,4,6]), the task of evaluation of fluence $F^{p}_{s,n}$ of $E \geq E_p$ neutrons in the barrel or vessel cell having number (s,n) in some approximation can be reduced to calculation by the following relationship [1]:

$$F^{p}_{s,n}=\sum_{i=1}^{8}\sum_{j=1}^{6}\sum_{k=1}^{36} q_{i,j,k} W^{p}_{|n-k|}(i,j\rightarrow s), \tag{1}$$

where $q_{i,j,k}$ - number of fission neutrons integral over (i,j,k) core cells and reactor operation time determined by ACADEM code [2] (in multigroup diffusion approximation on three dimensional triangular grid routinely with one mesh-point per cells), and $W^{p}_{|n-k|}(i,j\to s)$ - worth of (i,j,k) core cells with respect to their contribution to the fluence, evaluated using either Monte Carlo method or by the following relationship

$$W^{p}_{m}(i,j\to s) = \int\limits_{G_s^m} dx \int\limits_{E_p}^{\infty} dE \int d\Omega \psi_{i,j}(x,E,\Omega)/V_s, \tag{2}$$

where G_s^m - G_s cell in $n+m$ (or $n-m$) axial layer of the vessel parallel to this n layer, V_s - its volume, $\psi_{i,j}$ - solution of neutron transport equation:

$$(\Omega\nabla + C)\psi_{i,j,k} = \theta_{i,j,k}(x)\chi_{i,j,k}(E)/4\pi V_{i,j,k} \tag{3}$$

in the 30-degree symmetry sector for central axial layer k, $V_{i,j,k}$ - volume of trihedral prism $G_{i,j,k}$ in the core, $\theta_{i,j,k}(x)$ - its characteristic function, $\chi_{i,j,k}(E)$ - fission neutron spectrum in this prism, $C = \Sigma - S$, Σ - total cross section, S - integral operator describing processes of neutron scattering.

Actual weights $W^{p}_{m}(i;j\to s)$ with $E_p = 0.1,\ 0.5,\ 3.1\ МэВ$ were evaluated by Monte Carlo method using MCNP code for $m=\overline{0,7}$ values within the framework of continuous cross section/energy relationship with homogenization of triangle prism material, where $m \le 7$ condition has been chosen in view of low probability of neutrons flight from the core to the vessel through more than 7 axial layers: in many cases they were not registered even if $4.0E+07$ number of histories per prism was used.

3. NUMERICAL EXAMPLE AND DISCUSSION

Results of evaluation of fluence on the barrel and vessel of VVER-1000 reactor with uranium SA three-year lifetime and OUT-IN-IN refueling (similar to the design of Khmel'nitskaya NPP) are presented in [1]. In particular, the nature of azimuth fluence distribution on the inner surface of the second weld is illustrated by Fig.1 below. Maximal values of the fast neutron fluence with energies E>0.1 and E>0.5 MeV in the moment T=2709.160 eff. days on inner surface of pressure vessel are demonstrated in Table I.

These results are in agreement with known results [3-6] For example, maximal fluence of fast neutrons with energy E>0.5 MeV on pressure vessel of VVER-1000 reactor (Blok №1 Khmel'nitskaya NPP) in the moment T=10 eff. years is 1.11E+19 [5], that is not contradicted our results.

Let us discus some problems of accuracy of the technique. Apart from abovementioned there are some other potential origins of errors: finite-difference multigroup diffusion approximation made in ACADEM code; burn-up, and so on So to estimate the accuracy of the technique in general is a difficult unsolved problem that require the further consideration.

In particular, near the edge of the core, which of course is the mast important source region, the piece-wise constant approximation of $q_{i,j,k}$ is a poor approximation that will cause the fluence to be overestimated probably on 5-7 %, as it is followed from the paper [6], where was shown that if the core hexagonal assembly flat flax approximation estimate the fast neutron flax with energy E>.0.55 Me on inner surface of VVER-1000 PV in 5.E+10, then the core fuel rods flat flax approximation estimate it in 4E+10.

Note that the presented fluence monitoring technique is operative. Really, if $q_{i,j,k}$ and $W^{p}_{|n-k|}(i,j \to s)$ are known, then the time to compute the fluence on 30000 cells of barrel and pressure vessel of VVER-1000 reactor is some seconds on PC.

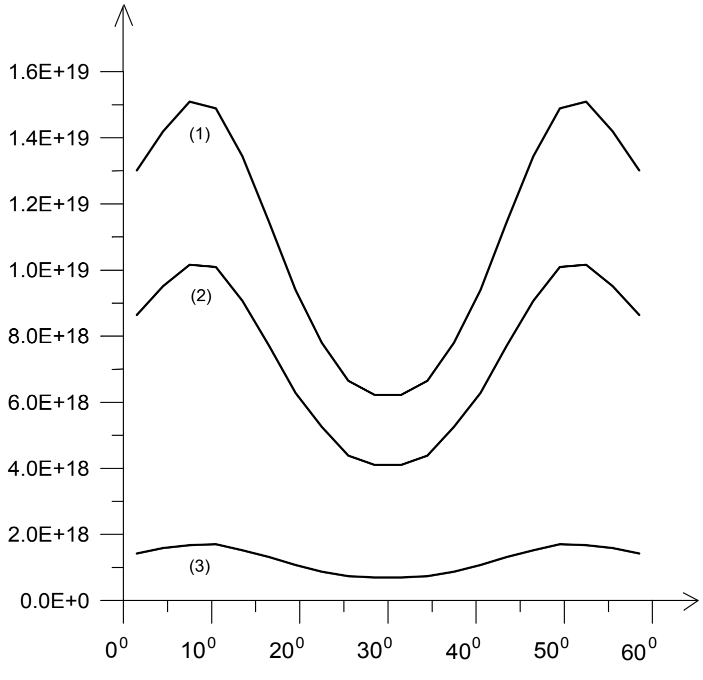

Figure .2. Azimuth distribution of fluence of fast neutrons with energies E>0.1 MeV (1),E>0.5 MeV (2), E>3.1 MeV (3) in 60-degree symmetry sector on the inner surface of the second weld on the vessel in the moment T=2700.160 eff. days.

Table I. Maximal values of fast neutron fluence with energies E>0.1 and E>0.5 MeV in the moment T=2709.160 eff. days; H- distance from bottom of the core

	H cm	Sector	E>0.1 MeV	Sector	E>0.5 MeV
Inner surface of barrel	100-110	51º÷54º	4.496E21	51º÷54º	2.464E21
Outer surface of barrel	100-110	51º÷54º	1.632E21	51º÷54º	8.524E20
Inner surface of PV	100-110	51º÷54º	1.529E19	51º÷54º	1.029E19
¼ PV thickness	100-110	51º÷54º	1.237E19	51º÷54º	7.452E18
Outer surface of PV	110-120	51º÷54º	2.353E18	51º÷54º	1.110E18

4. CONCLUSIONS

The complete methodology for calculating pressure vessel fluence is presented. The algorithm for estimation of the fast neutron flux density and fast neutron fluence distributions on the surfaces of the VVER-1000 barrel and pressure vessel is developed. The neutron flux and fluence are defined as a sums of products of assembly-vise fast neutron source by the influence functions which are calculated using MCNP code. Some numerical examples for VVER-1000 are presented.

REFERENCES

1. B.D. Abramov, A.I. Zinin, V.V. Korobeynikov et al. “Technique of routine evaluation of fluence on VVER reactor vessel”. *Preprint **FEI – 2863**,* Obninsk, Russia, IPPE, (2000).
2. V.M. Dekoussar, E.V. Dolgov, V.G. Ilyunin et al. “Ways and possibilities of use of thorium fuel cycle in the light water and fast neutron reactors”. *Proceedings of Universities. Series: Nuclear Power***,** Moskow, Russia, **№1,** (1999).
3. A.M. Pavlovitchev, S.M. Zaritsky ”Algorithms of evaluation of azimuth distribution of density of fast neutron flux on the inner surface of VVER reactor vessel”. *VANT, Series: Nuclear Reactor Physics,* Moskow, Russia*,* issue **3**, pp. 25-28, (1995).
4. A.A. Abagyan, V.A. Kochanov, V.I. Lobov et al. “Evaluation of fast neutron fluxes on VVER reactor vessel for various parameters of reactor core loading”. *VANT, Series: Nuclear Reactor Physics and Engineering,* Moskow, Russia, issue **4,** pp.52-54, (1986).
5. V.N. Bukanov, E.G. Vasil’eva, I.N. Vishnevsky, at al.“ Radiation loading determination of VVER-1000 vessel”. *Atomnaja energetika ta promislovost.* Ukraina, **№ 11**, pp.13-14 (1999)
6. B.K. Bylkin, A.A. Dorofeev, A.L. Egorov at al. “Baffle montage technological deviations influence on neutron fluence on VVER-1000 reactor vessel”. *Radiation safety and NPP shielding*. Energoatomisdat, Moskow, USSR, **v.12**, pp.62-64, (1987).