Surface Harmonics Method for Burnup Calculations of VVER-1000 Fuel Assemblies with Uranium and MOX Fuel

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Abstract

Development of the SUHAM-U code for burnup calculations of VVER-1000 fuel assemblies with uranium and MOX fuel is described. Developed SUHAM-U code has capacity to calculate burnup in each fuel or poison zone of each cell of VVER-1000 fuel assembly. In so doing Surface Harmonics Method is used for calculation of the detail neutron spectra in fuel assembly at separated burnup values.

Verification of SUHAM-U code by burnup calculations of VVER-1000 fuel assemblies with uranium and MOX fuel has been carried out. Comparisons were carried out with calculations by UNK and RECOL codes. UNK code uses the first collisions probabilities method for solution of the neutron transport equation and RECOL code uses Monte-Carlo method with point-wise continues energy presentation of cross-sections.

The main conclusion of all comparisons is the SUHAM-U code calculates the fuel burnup of VVER-1000 fuel assemblies with uranium and MOX fuel with enough high accuracy. Time expenditures are adduced.

KEYWORDS: Surface Harmonics Method, SUHAM-U code, VVER-1000 fuel assemblies, fuel burnup

1. Introduction

Surface Harmonics Method (SHM) [1] is the method for solution of the neutron transport equation in the whole reactor core combining advantages of deterministic (calculational accuracy) and design (time expenditures) methods. It is achieved as result of division of common task of large dimension into many tasks of much less dimension.

SHM has been realized in code system SUHAM-U [2] that is in process of elaboration. SUHAM-U code is intended for neutron-physical calculations of the thermal nuclear reactor core of VVER and PWR types. SUHAM-U code possesses the following features:

- Up-to date microgroup (about 7000 groups) library of cross-sections based on files of nuclear data ENDF-B, JEFF, JENDL.
- Automated and verified procedure for replenishment of library.
- Solving the multigroup neutron transport equation is carried out by SHM.
- Spatial homogenization and diffusion approximation aren't used in any calculational stage.

SUHAM-U code has been verified by the set of mathematical tests (in particular C5G7) [3] and calculations of critical assemblies of VVER and PWR reactor, in particular the assembly VENUS-2 [4].

In the paper [2] the first variant of code system SUHAM-U, namely SUHAM-U -VVER-01, having capacity to calculate from beginning to end one state of two-dimensional layer of VVER-1000 reactor core by SHM was described. In the frame of SUHAM-U verification the selection of the number and boundaries of multigroups for calculation of VVER-1000 reactor core with MOX loading had been carried out. Verification of SUHAM-U code by the benchmark calculations of 16 states of 4 variants of VVER-1000 fuel assemblies (FA-s) with uranium and MOX fuel had been performed. The main conclusion of that verification is practically all values calculated by SUHAM-U code (k_{inf} of FA-s, pin-by-pin power distribution, various reactivity effects, as well as control rods and U-Gd pins worth) are between the values calculated by seven reference codes.

In this work the development of SUHAM-U code for burnup calculations of VVER-1000 FA-s with uranium and MOX fuel is described. Developed SUHAM-U code has capacity to calculate burnup in each fuel or poison zone of each cell of VVER-1000 FA. In so doing SHM is used for calculation of the detail neutron spectra in FA-s at separated burnup values.

2. Description of the Code System SUHAM-U

Code system SUHAM-U is elaborated for calculation of the neutron-physical processes in nuclear reactor core with triangular and square lattices. It unites the capacities of two codes – SUHAM [5] and UNK [6]. Modules of UNK code are used both for preparation of multigroup cross sections and for burnup calculations. Modules of SUHAM code are used for solution of the multigroup neutron transport equation in separated points along burnup value.

2.1 Library of UNK Code

UNK code has own library of nuclear data generated from files of nuclear data ENDF/B, JEF and JENDL. Library generation procedure is automated completely. Basic energy division has 89-groups – 24 groups in slowing down region and 65 ones in thermal region. In addition, resonance region (2.15 eV – 2.15 KeV) is presented in microgroup form – about 7000 groups. In so doing, fine irregular energy grid thickened in vicinity of resonances of different isotopes and wider one in regions between resonances is used. Dimension of microgroups in vicinity of resonances is less than 0.1 eV. Algorithm for condensation of the microgroup cross sections to the multigroup ones was described in [7]. As result of calculational analysis, 12-group division for multigroups with 5 groups in energy interval [2.15 eV – 10 MeV] and 7 groups in energy interval [0 eV – 2.15 eV] has been chosen.

UNK library of nuclear data for solution of the equations of isotopic kinetics consists of two interchangeable parts which have been generated from the files of ENDF/B-VI and JENDL-3.2 correspondingly. These data consist of the yields of fission products, half-lives of unstable isotopes, channels of decays and neutron interactions. Library data provide calculation of the sources of energy release as result of decay of unstable isotopes.

2.2 Calculational Module UNK_BURN for Fuel Burnup

UNK_BURN module is a module for calculation of changing the fuel isotope composition and isotope composition of construction materials. This module has library of yields of fission products, half-lives and decay energy release as well as decays channels generated from files ENDF/B and JENDL for the basic isotopes of uranium, plutonium and thorium.

Burnup calculation can be carried out in two regimes: either with taking into account limited number of fission products for which information about neutron cross sections exists in library (about 200 isotopes) or with taking into account all fission products (1100 – 1300, it depends on the nuclear data library - ENDF/B or JENDL).

It should be noted that files ENDF/B contain data about interaction cross sections for a little more than 300 isotopes. Analysis showed that only approximately 190 isotopes – fission products - have cross sections files in ENDF/B. For the rest of 800 isotopes these data are absent.

For each fissile isotope and each fission product the corresponding burnup equations were written. Its analytical solutions without any approximations were included in the calculational scheme. Equations were written for four successive acts of isotope transformations with different combinations (absorption, fission or decay). More long chains of isotope transformations are calculated numerically by time steps. Calculational practice showed that necessity of use of more long chains is absent.

2.3 Surface Harmonics Method

Surface Harmonics Method (SHM) is the method for solution of the neutron transport equation in the whole reactor core combining advantages of deterministic (calculational accuracy) and design (time expenditures) methods. It is achieved as result of division of common task of large dimension into many tasks of much less dimensions.

In this method the neutron transport equation is solved in small regions (cells, fuel assemblies). In so doing, number of such solutions (trial solutions) is much more than unity and these solutions differ from one another by the boundary conditions. Neutron distribution function in each region is presented as a superposition of trial functions with unknown coefficients. Then the angular moments of these functions are equated at the adjacent sides of these regions. As a result the finite-difference equations for unknown coefficients under the trial solutions are obtained. In this paper SHM finite-difference equations with three trial spatial solutions per each cell are used.

3. Benchmark Calculations of Fuel Burnup in VVER-1000 FA-s with Uranium and MOX Fuel

3.1 Description of Benchmark Calculations.

Objects of benchmark calculations are the VVER-1000 FA-s with uranium (U42G6) and MOX (P39G8) fresh fuel. FA U42G6 consists of two types of fuel pins with uranium fuel: fuel pins U42 and U37 and pins with U-Gd fuel - U33G. FA P39G8 consists of three types of fuel pins with MOX fuel: PU39, PU26 and PU29 and pins with U-Gd fuel - U36G.

Burnup calculations were carried out under the following conditions:

- FA power equals 52.13855 kW/cm (per 1 cm of height) taking into account energy of gamma-quanta appearing after neutron absorption by core components.
- Fuel temperature is 1036.0 K.
- Fuel clad temperature is 600.0 K.
- Coolant temperature is 575.7 K.

Recalculations of all spectra in burning materials were carried out in the following time points: 0.1, 0.4, 0.5 and then in each 1.0 up to 50.0 MWd/kgHM, where HM denotes heavy metals. All geometrical and material parameters of calculated FA-s were described in work [8].

Comparisons were carried out with calculations by UNK and RECOL [9] codes. UNK code uses the first collisions probabilities method for solution of the neutron transport equation and RECOL code uses Monte-Carlo method with point-wise continues energy presentation of cross-sections. All three codes used the same files of nuclear data for cross-sections preparation of the basic isotopes. Calculations with all codes were carried out with burnup in each fuel rod.

The following functionals were used for comparison in separated burnup values:

- K-inf of FA-s.
- Concentrations of the principal isotopes (U-235, U-238, Pu-239, Pu-240, Pu-241, Pu-242) averaged over all FA rods.
- Coefficient of power irregularity.

Additionally, the following collective percent error measures [3] were used for comparison of power distribution:

$$AVG = \frac{1}{N}\sum_{n=1}^{N}|e_n| \qquad RMS = \frac{1}{\sqrt{N}}\sqrt{\sum_{n=1}^{N}e_n^2} \quad , \tag{1}$$

Here N is the total number of fuel pins in FA and e_n is the calculated percent distinction for the n-th pin power. AVG is the average value of module of pin power percent distinction; RMS is the root mean square of the percent distinction.

3.2 Results of Benchmark Calculations and Analysis.

Calculations by all codes were carried out with burnup in each fuel rod. In addition, SUHAM-U code has calculated these benchmarks with number of burnable fuel rods equaled to the number of different fuel rods at the beginning of time: 3 for FA U42G6 and 4 for FA P39G8. Denote these calculations SUHAM-3 and SUHAM-4 correspondingly.

Table 1 shows comparative calculations of FA-s k-inf as function of burnup in MWd/kgHM. In so doing the following designation was used

$$\delta k_{\inf}(I) = 100\frac{k_{\inf}(Suham) - k_{\inf}(I)}{k_{\inf}(I)} \quad , \tag{2}$$

where I – name of code.

One can see from Table 1:

- k-inf calculated by SUHAM-U and RECOL codes have close values: maximum deviation doesn't exceed 0.37 % for FA U42G6 and 0.22 % for FA P39G8.
- k-inf calculated by SUHAM-U and SUHAM-3 codes for FA U42G6 have practically identical values and k-inf calculated by SUHAM-U and SUHAM-4 codes for FA P39G8 have close values - maximum deviation doesn't exceed 0.24 %.

- k-inf values calculated by SUHAM-U and UNK codes have considerable deviations: up to 0.52 % for FA U42G6 and up to -0.90 % for FA P39G8. Apparently, it is connected with the following two facts: 1) UNK code didn't use microgroup division, but carried out the calculations in 89 groups with use equivalence theory; 2) UNK code for U-Gd pins used one burning zone and SUHAM-U code for U-Gd pins used five burning zones.

Tables 2 and 3 show SUHAM-U calculations of averaged isotope composition of fuel (in kg/tHM) for FA-s U42G6 and P39G8 correspondingly at the following values of burnup: 0, 10, 20, 30, 40 and 50 MWd/kgHM as well as deviations of values calculated by SUHAM-U code from values calculated by other codes.

One can see from Tables 2 and 3:

- Maximum deviations (here and further all maximum deviations take into account sign of numbers) of isotopes densities calculated by SUHAM-U code from values calculated by RECOL code are the following: 1) for FA U42G6: 0.91 % for ^{235}U, -2.10 % for ^{239}Pu and -9.30 % for ^{242}Pu; 2) for FA P39G8: 1.18 % for ^{235}U, -0.47 % for ^{239}Pu and 4.53 % for ^{242}Pu;
- Maximum deviations of isotopes densities calculated by SUHAM-U code from values calculated by UNK code are the following: 1) for FA U42G6: 2.94 % for ^{235}U, 1.67 % for ^{239}Pu and -4.10 % for ^{242}Pu; 2) for FA P39G8: 1.63 % for ^{235}U, 1.20 % for ^{239}Pu and 2.01 % for ^{242}Pu;
- Practically identical isotopes densities calculated by SUHAM-U and SUHAM-3 codes are obtained for FA U42G6. Maximum deviations of isotopes densities calculated by SUHAM-U code from values calculated by SUHAM-4 code for FA P39G8 are the following: 1) 1.48 % for ^{235}U, 1.80 % for ^{239}Pu and -0.51 % for ^{242}Pu. These deviations are not large but appreciable.

Tables 4 and 5 show deviations of SUHAM-U calculations of the coefficient of power irregularity from values calculated by RECOL code for FA-s U42G6 and P39G8 correspondingly at the following values of burnup: 0, 10, 20, 30, 40 and 50 MWd/kgHM.

One can see from Tables 4 and 5:

- Maximum deviations of the coefficient of power irregularity calculated by SUHAM-U code from values calculated by RECOL code equal -2.32 % for FA U42G6 and -2.94 for FA P39G8
- Maximum value of AVG equals 0.69 % for FA U42G6 and 0.79 % for FA P39G8 in so doing both maximum values are reached at maximum value of burnup.
- Maximum value of RMS equals 0.81 % for FA U42G6 and 0.88 % for FA P39G8 in so doing both maximum values are reached at maximum value of burnup.
- It should be noted that in all deviations in Tables 4 and 5, deviations in U-Gd pins are not taken into account. The point is that the addition energy release connected with gamma-quanta which appear as result of neutron absorption by isotopes Gd and isotopes of their transmutation (Tb-159, Dy-160, Dy-161, Dy-162, Dy-163, Dy-164) are taken into account in RECOL code and are not taken into account in SUHAM-U code. As result energy release in U-Gd pins calculated by these two codes are very different.

Table 6 shows the SUHAM-U time expenditures on PC-3.2 MHz. In so doing time expenditures on preparation of 12-group cross-sections, solution of 12-group neutron transport equation by SHM and solution of burnup equations are shown separately. Time expenditures of UNK and RECOL codes have many more values.

Table 1: Comparative calculations of FA-s k-inf

MWd/ kgHM	U42G6				P39G8			
	K-inf	$\delta k_{\inf}(I)$, %, I=			K-inf	$\delta k_{\inf}(I)$, %, I=		
	SUHAM-U	UNK	RECOL	SUHAM-3	SUHAM-U	UNK	RECOL	SUHAM-4
0.0	1.25480	0.24	0.10	0.000	1.15949	-0.13	-0.16	0.18
0.1	1.21566	0.24	0.06	0.000	1.13270	-0.20	-0.18	0.19
1.0	1.20344	0.33	0.03	0.000	1.11749	-0.01	-0.14	0.20
2.0	1.19728	0.39	0.01	0.000	1.10738	0.06	-0.16	0.20
4.0	1.18410	0.39	0.03	0.000	1.09321	0.18	-0.16	0.20
6.0	1.17058	0.17	0.20	-0.001	1.08228	0.10	-0.21	0.20
8.0	1.15801	-0.18	0.13	-0.001	1.07373	-0.27	-0.13	0.19
10.0	1.14687	-0.39	0.10	-0.003	1.06722	-0.71	**-0.22**	0.18
12.0	1.13579	-0.14	0.18	-0.003	1.05740	**-0.90**	-0.17	0.16
14.0	1.12196	0.18	0.24	-0.003	1.05740	-0.80	-0.18	0.14
16.0	1.10574	0.29	0.32	-0.005	1.04973	-0.52	-0.13	0.16
18.0	1.08930	0.33	0.30	-0.006	1.03918	-0.29	-0.02	0.18
20.0	1.07334	0.35	0.34	-0.007	1.02690	-0.18	-0.06	0.20
22.0	1.05787	0.38	0.34	-0.008	1.01419	-0.14	0.02	0.21
24.0	1.04286	0.40	**0.37**	-0.010	1.00167	-0.11	-0.06	0.22
26.0	1.02825	0.42	0.31	-0.011	0.98949	-0.10	-0.06	0.22
28.0	1.01400	0.44	0.35	-0.012	0.97768	-0.08	0.02	0.23
30.0	1.00010	0.45	0.36	-0.013	0.96624	-0.07	-0.01	0.23
32.0	0.98653	0.46	0.28	-0.015	0.95515	-0.06	0.02	0.23
34.0	0.97327	0.48	0.34	-0.016	0.94440	-0.05	-0.05	0.23
36.0	0.96034	0.49	0.28	-0.017	0.93399	-0.03	0.01	**0.24**
38.0	0.94772	0.49	0.25	-0.018	0.92390	-0.02	-0.08	**0.24**
40.0	0.93542	0.50	0.15	-0.019	0.91413	0.00	-0.13	**0.24**
42.0	0.92346	0.51	0.17	-0.020	0.90468	0.02	-0.18	**0.24**
44.0	0.91186	0.51	0.11	-0.021	0.89555	0.04	-0.14	0.23
46.0	0.90063	0.51	0.17	**-0.022**	0.88673	0.06	-0.19	0.23
48.0	0.88977	**0.52**	0.12	**-0.022**	0.87821	0.08	-0.18	0.23
50.0	0.87929	**0.52**	0.11	**-0.022**	0.87000	0.10	-0.14	0.23
Max($\delta k_{\inf}(I)$)		**0.52**	**0.37**	**-0.022**	---	**-0.90**	**-0.22**	**0.24**

Table 2: Comparative calculations of averaged isotope composition of fuel in FA U42G6.

MWd/kgHM	0.0	10.0	20.0	30.0	40.0	50.0
U-235	4.0779E+01	3.0411E+01	2.2358E+01	1.6013E+01	1.1106E+01	7.4373E+00
% from RECOL		0.43	0.74	0.91	0.90	0.69
% from UNK		0.54	1.13	1.72	2.31	2.94
% from SUHAM-3		0.000	0.000	0.000	0.009	0.040
U-238	9.5922E+02	9.5300E+02	9.4631E+02	9.3903E+02	9.3115E+02	9.2265E+02

% from RECOL		0.01	0.02	0.03	0.04	0.04
% from UNK		0.01	0.02	0.03	0.03	0.03
% from SUHAM-3		0.001	0.001	0.001	0.001	0.000
Pu-239	0.0000E+00	3.5696E+00	5.2219E+00	5.9985E+00	6.3263E+00	6.4296E+00
% from RECOL		-2.10	-1.01	-0.59	-0.44	-0.28
% from UNK		-0.63	0.08	0.63	1.17	1.67
% from SUHAM-3		-0.003	0.010	0.023	0.041	0.061
Pu-240	0.0000E+00	4.7890E-01	1.2001E+00	1.8823E+00	2.4601E+00	2.9135E+00
% from RECOL		-2.94	-1.03	-0.21	0.33	0.66
% from UNK		-1.94	-1.26	-0.47	0.41	1.28
% from SUHAM-3		0.002	-0.008	-0.016	-0.012	-0.010
Pu-241	0.0000E+00	1.8621E-01	6.7061E-01	1.1748E+00	1.5828E+00	1.8724E+00
% from RECOL		-7.09	-4.22	-2.64	-1.71	-1.04
% from UNK		-1.97	-1.06	-0.47	0.12	0.75
% from SUHAM-3		0.000	-0.003	-0.009	-0.013	0.000
Pu-242	0.0000E+00	1.1728E-02	9.5975E-02	2.7912E-01	5.4649E-01	8.6916E-01
% from RECOL		-9.30	-4.82	-1.89	0.09	1.37
% from UNK		-4.10	-3.14	-2.47	-1.86	-1.29
% from SUHAM-3		0.034	0.025	0.025	0.024	0.017
Total Pu	0.0000E+00	4.2514E+00	7.2179E+00	9.4175E+00	1.1084E+01	1.2367E+01
% from RECOL		-2.49	-1.46	-0.97	-0.64	-0.33
% from UNK		-0.85	-0.31	0.16	0.66	1.17
% from SUHAM-3		0.000	0.006	0.013	0.018	0.032

Table 3: Comparative calculations of averaged isotope composition of fuel in FA P39G8.

MWd/kgHM	0.0	10.0	20.0	30.0	40.0	50.0
U-235	3.7892E+00	3.2287E+00	2.6060E+00	2.0204E+00	1.5170E+00	1.1017E+00
% from RECOL		0.39	0.94	1.13	1.18	1.08
% from UNK		0.06	0.77	1.05	1.34	1.63
% from SUHAM-4		0.16	0.45	0.76	1.11	1.48
U-238	0.0000E-00	9.5456E+02	9.4744E+02	9.3989E+02	9.3184E+02	9.2333E+02
% from RECOL		0.00	0.01	0.01	0.01	0.00
% from UNK		0.01	0.01	0.01	0.00	-0.01
% from SUHAM-4		-0.04	-0.04	-0.04	-0.03	-0.03
Pu-239	0.0000E-00	2.4654E+0	1.8890E+01	1.4609E+01	1.1674E+01	9.7895E+00
% from RECOL		-0.13	0.02	-0.03	-0.21	-0.47
% from UNK		0.12	0.37	0.58	0.85	1.20
% from SUHAM-4		1.52	1.71	1.80	1.75	1.58
Pu-240	3.7892E+00	4.9444E+00	6.5129E+00	7.2191E+00	7.2818E+00	6.9448E+00
% from RECOL		-0.32	-0.28	-0.05	0.21	0.40
% from UNK		0.48	0.69	1.01	1.34	1.66
% from SUHAM-4		0.71	0.73	0.85	0.98	1.10
Pu-241	0.0000E-00	1.8979E+00	3.1490E+00	3.9471E+00	4.2833E+00	4.2578E+00
% from RECOL		-0.16	0.02	0.04	0.03	-0.04

% from UNK		0.04	0.82	1.24	1.64	2.03
% from SUHAM-4		0.49	0.59	0.77	0.98	1.16
Pu-242	0.0000E-00	2.4856E-01	5.2676E-01	9.5942E-01	1.4946E+00	2.0661E+00
% from RECOL		1.55	2.09	2.79	3.65	4.53
% from UNK		-1.13	-0.92	0.05	0.99	2.01
% from SUHAM-4		0.30	-0.38	-0.51	-0.45	-0.31
Total Pu	3.7892E+00	3.1789E+01	2.9133E+01	2.6817E+01	2.4862E+01	2.3246E+01
% from RECOL		-0.15	-0.03	0.02	0.07	0.13
% from UNK		0.16	0.46	0.77	1.13	1.56
% from SUHAM-4		1.32	1.33	1.30	1.25	1.18

Table 4: Deviations (δ_k in %) of SUHAM-U calculations of the coefficient of power irregularity from values calculated by RECOL code for FA U42G6.

Value	MWd/kgHM					
	0.0	10.0	20.0	30.0	40.0	50.0
Max(δ_k) in pins U42	1.02	1.21	1.12	1.22	1.07	1.24
Max(δ_k) in pins U37	-0.61	-1.05	1.72	-1.53	-2.32	-1.99
AVG	0.37	0.37	0.41	0.52	0.56	0.69
RMS	0.42	0.44	0.56	0.65	0.72	0.81

Table 5: Deviations (δ_k in %) of SUHAM-U calculations of the coefficient of power irregularity from values calculated by RECOL code for FA P39G8.

Value	MWd/kgHM					
	0.0	10.0	20.0	30.0	40.0	50.0
Max(δ_k) in pins Pu39	1.60	1.21	-1.19	-1.22	-1.30	1.44
Max(δ_k) in pins Pu29	-0.86	-0.81	-1.31	-1.32	-1.71	-1.13
Max(δ_k) in pins Pu26	-1.05	-1.95	-2.49	-2.31	-2.94	-2.02
AVG	0.59	0.46	0.61	0.56	0.70	0.79
RMS	0.71	0.61	0.77	0.74	0.88	0.88

Table 6: Time expenditures of SUHAM-U code.

Value	FA U42G6		FA P39G8	
	SUHAM-U	SUHAM-3	SUHAM-U	SUHAM-4
Total time	5 h, 18 m, 40 sec	1 h, 20 m, 17 sec	7 h, 21 m, 10 sec	1 h, 32 m, 34 sec
Preparation of 12-group cross-sections	2 h, 56 m, 50 sec	0 h, 49 m, 56 sec	4 h, 9 m, 35 sec	0 h, 57 m, 20 sec
Solution of neutron transport equation by SHM	2 h, 6 m, 40 sec	0 h, 27 m, 16 sec	2 h, 49 m, 48 sec	0 h, 31 m, 29 sec
Solution of burnup equations	0 h, 18 m, 40 sec	0 h, 3 m, 4 sec	0 h, 21 m, 48 sec	0 h, 3 m, 36 sec

4. Conclusion

Development of the SUHAM-U code for burnup calculations of VVER-1000 fuel assemblies with uranium and MOX fuel has been described. Developed SUHAM-U code has capacity to calculate burnup in each fuel or poison zone of each cell of VVER-1000 fuel assembly. In so doing Surface Harmonics Method is used for calculation of the detail neutron spectra in fuel assembly at separated burnup values.

Verification of SUHAM-U code by burnup calculations of VVER-1000 fuel assemblies with uranium and MOX fuel has been carried out. Comparisons were carried out with calculations by UNK and RECOL codes. UNK code uses the first collisions probabilities method for solution of the neutron transport equation and RECOL code uses Monte-Carlo method with point-wise continues energy presentation of cross-sections.

Comparison results of isotopes densities are the following.

Maximum deviations of isotopes densities calculated by SUHAM-U code from values calculated by RECOL code are the following: 1) for FA U42G6: 0.91 % for ^{235}U, -2.10 % for ^{239}Pu and -9.30 % for ^{242}Pu; 2) for FA P39G8: 1.18 % for ^{235}U, -0.47 % for ^{239}Pu and 4.53 % for ^{242}Pu.

Maximum deviations of isotopes densities calculated by SUHAM-U code from values calculated by UNK code are the following: 1) for FA U42G6: 2.94 % for ^{235}U, 1.67 % for ^{239}Pu and -4.10 % for ^{242}Pu; 2) for FA P39G8: 1.63 % for ^{235}U, 1.20 % for ^{239}Pu and 2.01 % for ^{242}Pu.

Comparison results of the coefficient of power irregularity are the following.

Maximum deviations of the coefficient of power irregularity calculated by SUHAM-U code from values calculated by RECOL code doesn't exceed 3.0 % for both FA-s

Maximum value of RMS doesn't exceed 0.9 % for both FA-s in so doing both maximum values are reached at maximum value of burnup.

The main conclusion of all comparisons is the SUHAM-U code calculates the fuel burnup of VVER-1000 fuel assemblies with uranium and MOX fuel with enough high accuracy.

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