“PSG2/SERPENT validation on the basis of uranium-graphite critical benchmark”

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Introduction

The presented work is devoted to the validation of PSG2/SERPENT [1] applicability in case of neutron multiplication factor calculation of uranium-graphite critical systems. For this challenge the benchmark on the RBMK critical facility was chosen, which was performed by the Russian Research Center “Kurchatov Institute”.

The description of benchmark [2] contains all necessary information about dimensions and materials of the critical facility for 28 critical experiments. Also the description of the benchmark contains results of neutron multiplication factor calculations for all experiments, which were taken by using MCNP4C [3] and MCU [4] codes.

Overview of experiment

The graphite stack of the RBMK critical facility consists of 324 (18x18) channels. The experiments were performed at room temperature. The maximum power of the RBMK critical facility is 25 watts. All elements of the facility core are identical to similar elements of the RBMK reactor except the height of the core, which is half that of the power reactor. The critical masses studied were in the form of uniform configurations, configurations with empty channels in the core, with water columns, with additional standard absorbers made of boron steel, and a few with thorium absorbers [2].

Basic elements of the RBMK critical facility:

 — Fuel assembly 1.8%)

 — Fuel assembly 2.0%)

 — Fuel assembly 2.2%)

 — Fuel assembly 1.8%) with water

 — Fuel assembly 2.0%) with water

 — Fuel assembly 2.2%) with water

 — Fuel assembly 2.0%) with additional grid spacers (Experiment 14 and 16)

 — Empty channel

 — Empty channel

 — Water column

 — Boron absorber

 — Boron absorber with water

 — Thorium absorber type 1

 — Thorium absorber type 1 with water

 — Thorium absorber type 2

 — Thorium absorber type 2 with water

 — Detector SNM-11

 — Detector KNK-56

 — Boron absorber

 — Boron absorber with water

Cartograms for experiment are presented in fig.1-28.

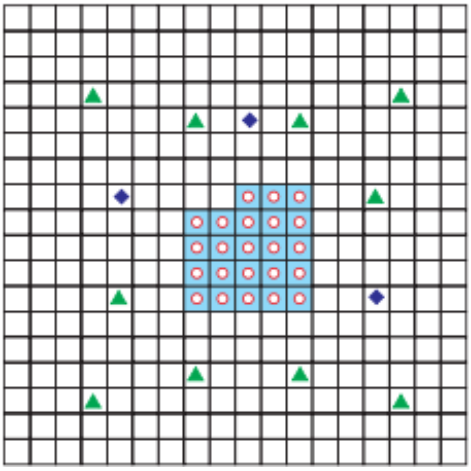

Fig.1 Experiment #1 cartogram

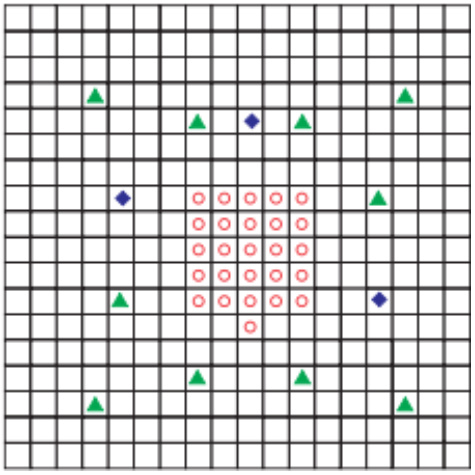

Fig.2 Experiment #2 cartogram

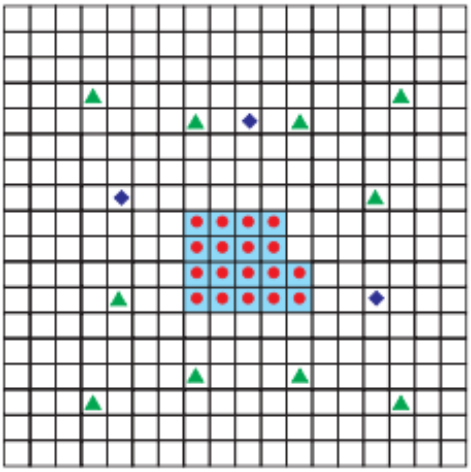

Fig.3 Experiment #3 cartogram

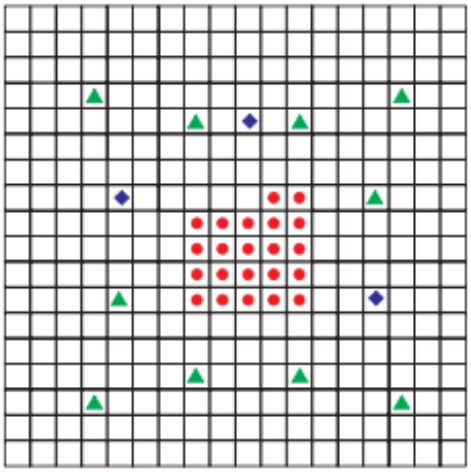

Fig.4 Experiment #4 cartogram

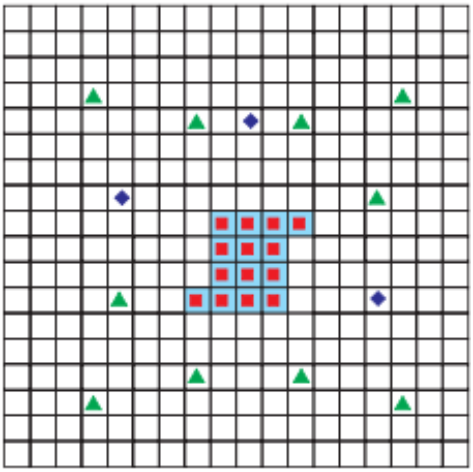

Fig.5 Experiment #5 cartogram

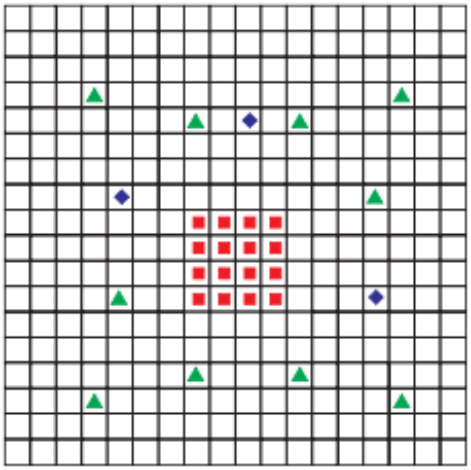

Fig.6 Experiment #6 cartogram

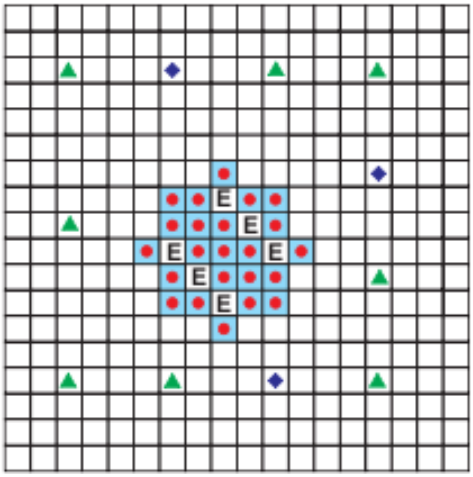

Fig.7 Experiment #7 cartogram

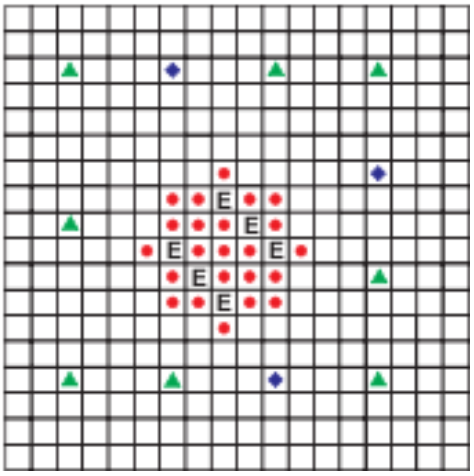

Fig.8 Experiment #8 cartogram

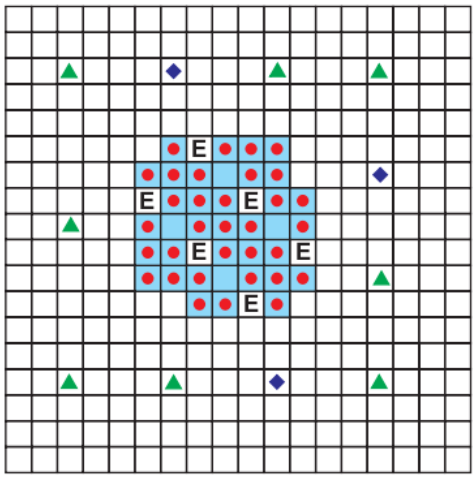

Fig.9 Experiment #9 cartogram

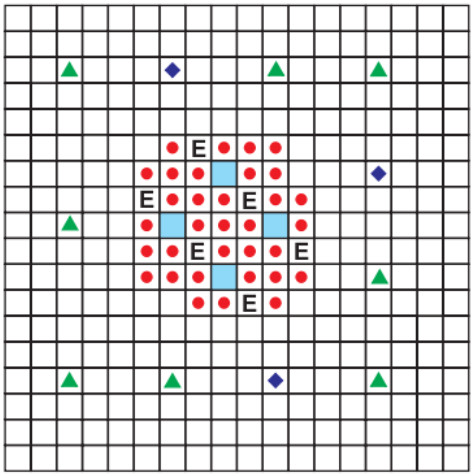

Fig.10 Experiment #10 cartogram

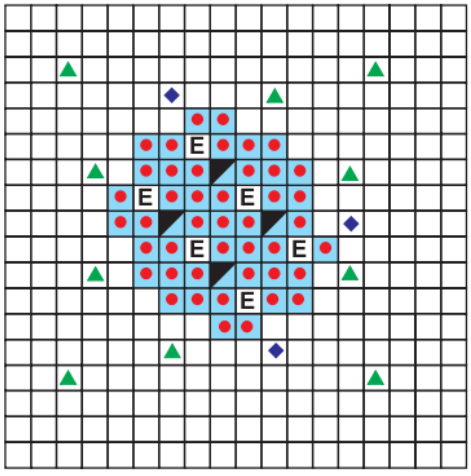

Fig.11 Experiment #11 cartogram

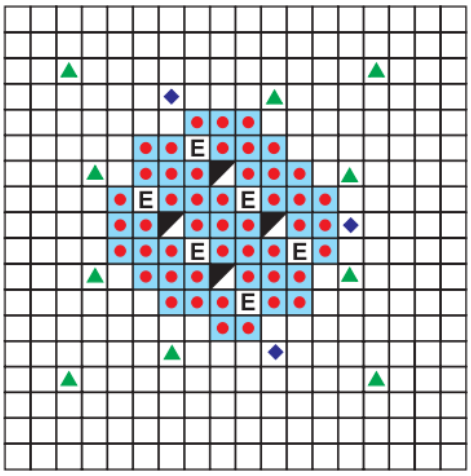

Fig.12 Experiment #12 cartogram

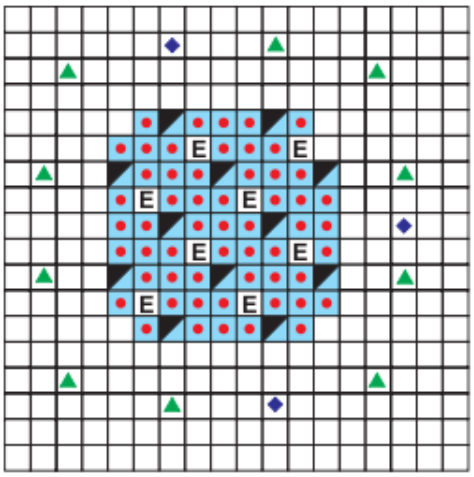

Fig.13 Experiment #13 cartogram

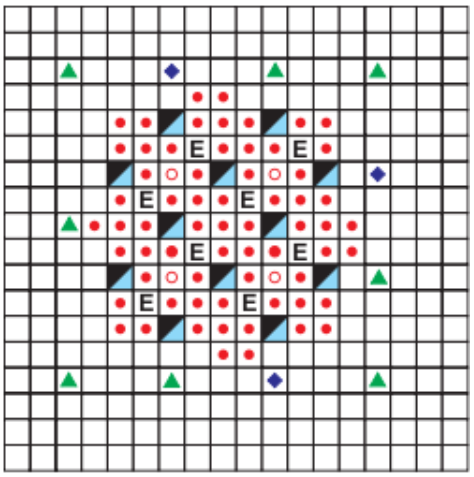

Fig.14 Experiment #14 cartogram

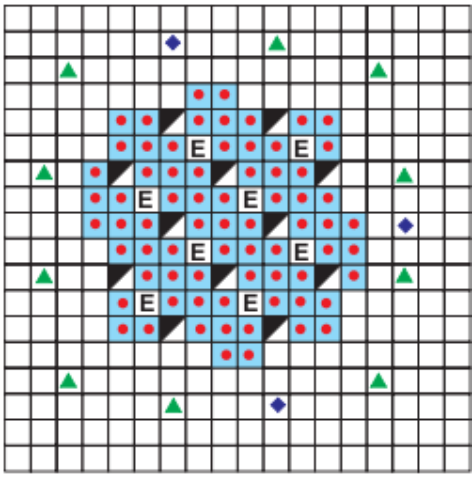

Fig.16 Experiment #16 cartogram

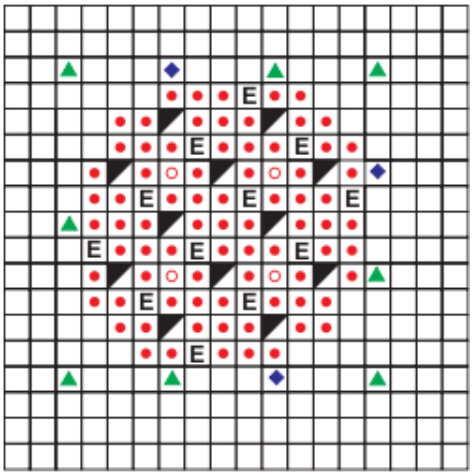

Fig.15 Experiment #15 cartogram

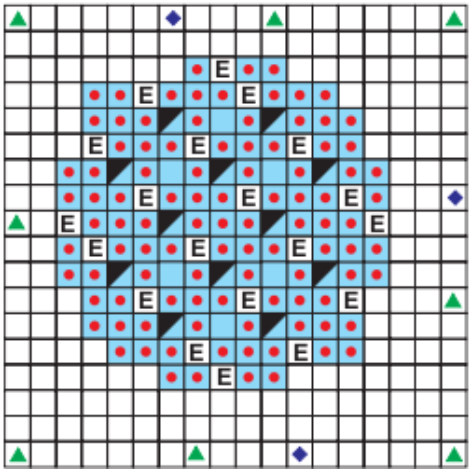

Fig.17 Experiment #17 cartogram

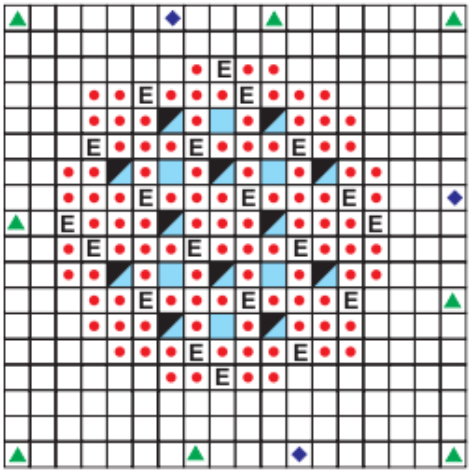

Fig.18 Experiment #18 cartogram

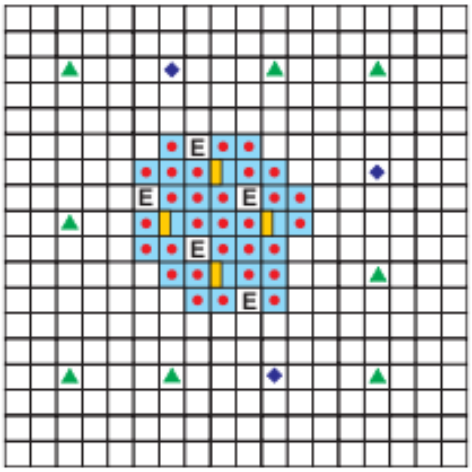

Fig.19 Experiment #19 cartogram

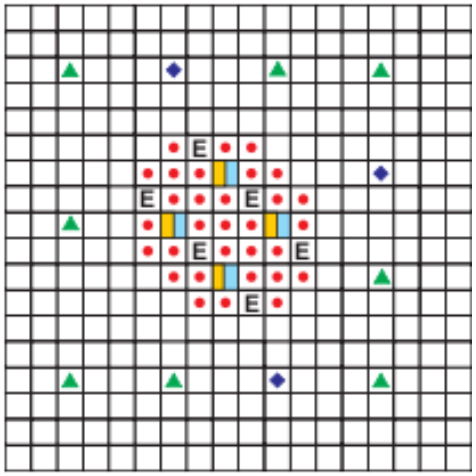

Fig.20 Experiment #20 cartogram

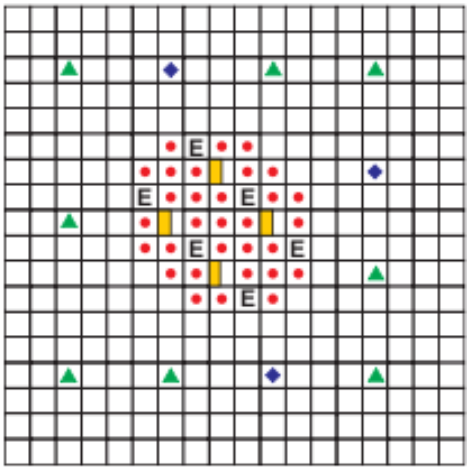

Fig.21 Experiment #21 cartogram

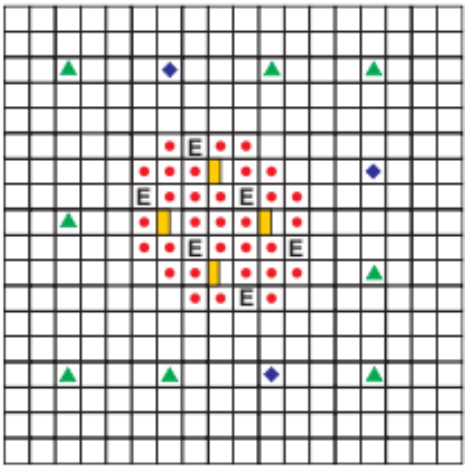

Fig.22 Experiment #22 cartogram

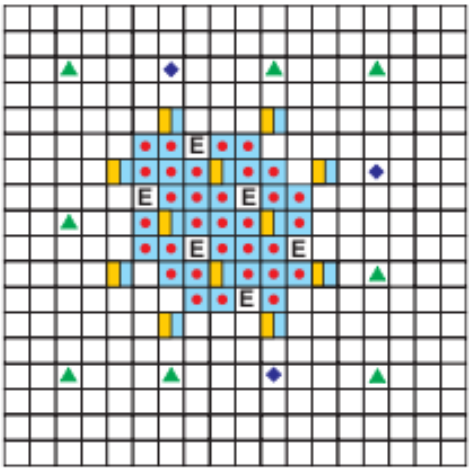

Fig.23 Experiment #23 cartogram

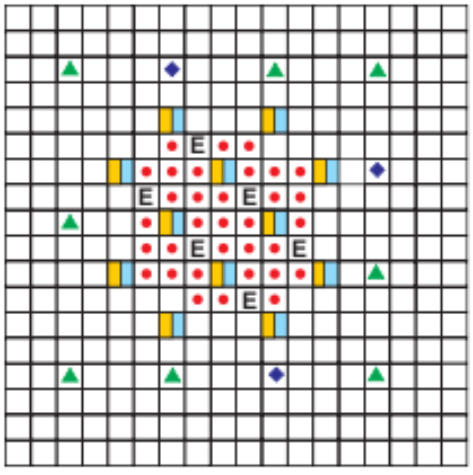

Fig.24 Experiment #25 cartogram

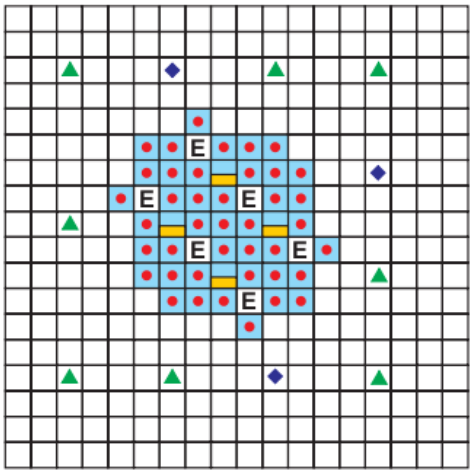

Fig.26 Experiment #26 cartogram

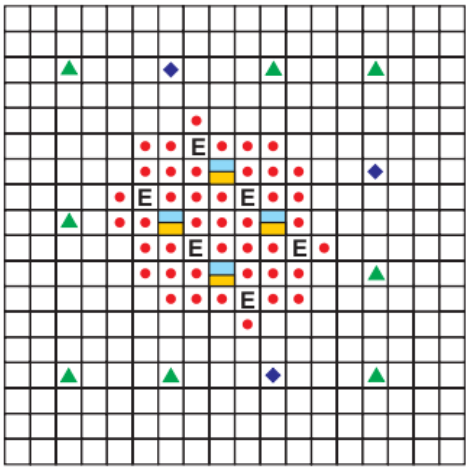

Fig.27 Experiment #27 cartogram

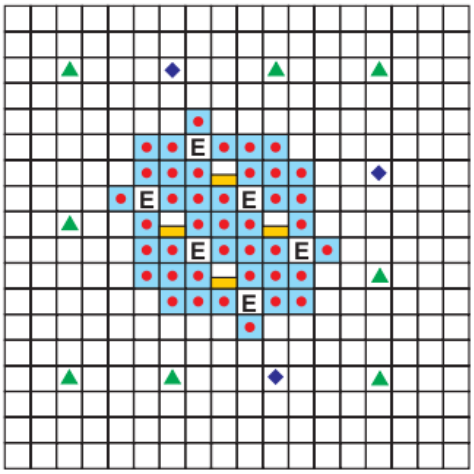

Fig.27 Experiment #27 cartogram

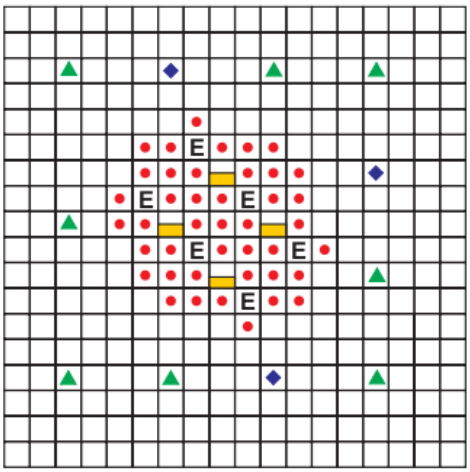

Fig.28 Experiment #28 cartogram

Calculation results.

The geometry and material composition of all 28 experiments were defined in a same way as it was defined in the description of benchmark experiment. Thus we can estimate PSG2/SERPENT accuracy by comparing neutron multiplication factor calculated by PSG2/SERPENT with values calculated by another codes and with experimental one.

The following parameters were used for calculations:

- 2000 neutron sources per cycle;
- 500 active cycles.

Also for better accuracy, unresolved resonance probability tables were used for each

experiment. Calculations of K_{eff} results are presented in table 1 (in the brackets deviations of calculated K_{eff} with experimental values are indicated). For estimation of the deviations of experimental values with calculated ones the following formula was used:

$$D = \frac{K_{eff}(exp) - K_{eff}(i)}{K_{eff}(exp)} \cdot 100\%, \quad (1)$$

where $K_{eff}(i)$ is result of the calculation of each code, $K_{eff}(exp)$ is experimental value.

The statistical uncertainties are 0,0002 in case by MCNP 4C [3] calculations and 0,0006 in case of SERPENT [1] calculations. Statistical uncertainty of MCU [4] calculations is not presented in the benchmark's description [2].

Table 1. – Calculated and experiment K_{eff}

№	PSG2/SERPENT 1.1.13 (ENDF/B-6.8)	MCNP 4C (ENDF/B-V)	MCU (DLC/MCUDAT-2.1)	Experiment
1	0,9998 (-0,08%))	1,0023 (-0,33%)	1,0024 (-0,34%)	0,9990
2	0,9998 (-0,21%)	1,0020 (-0,43%)	1,0069 (-0,92%)	0,9977
3	0,9994 (0,07%)	1,0031 (-0,30%)	1,0049 (-0,48%)	1,0001
4	1,0023 (-0,06%)	1,0044 (-0,27%)	1,0087 (-0,70%)	1,0017
5	1,0002 (0,15%)	1,0043 (-0,26%)	1,0049 (-0,32%)	1,0017
6	0,9900 (0,02%)	0,9937 (-0,35%)	0,9982 (-0,81%)	0,9902
7	1,0010 (0,18%)	1,0075 (-0,47%)	1,0085 (-0,57%)	1,0028
8	1,0030 (0,09%)	1,0106 (-0,67%)	1,0149 (-1,10%)	1,0039
9	1,0041 (0,02%)	1,0082 (-0,39%)	1,0079 (-0,36%)	1,0043
10	1,0021 (-0,07%)	1,0061 (-0,33%)	1,0085 (-0,34%)	1,0014
11	1,0024 (-0,23%)	1,0043 (-0,47%)	1,0062 (-0,71%)	1,0001
12	1,0012 (-0,03%)	1,0038 (-0,42%)	1,0039 (-0,61%)	1,0009

13	1,0014 (-0,04%)	1,0038 (-0,29%)	1,0036 (-0,30%)	1,0010
14	1,0006 (0,09%)	1,0036 (-0,28%)	1,0083 (-0,26%)	1,0015
15	0,9980 (0,32%)	1,0017 (-0,21%)	1,0022 (-0,68%)	1,0012
16	0,9980 (0,27%)	0,9989 (-0,05%)	1,0037 (-0,10%)	1,0007
17	1,0016 (-0,01%)	1,0058 (0,18%)	1,0071 (-0,30%)	1,0015
18	1,0032 (-0,23%)	1,0054 (-0,43%)	1,0086 (-0,56%)	1,0009
19	0,9993 (0,17%)	1,0049 (-0,45%)	1,0044 (-0,77%)	1,0010
20	1,0042 (0,00%)	1,0094 (-0,39%)	1,0061 (-0,34%)	1,0042
21	0,9994 (0,12%)	1,0043 (-0,52%)	1,0044 (-0,19%)	1,0006
22	1,0043 (-0,04%)	1,0084 (-0,37%)	1,0051 (-0,38%)	1,0039
23	0,9989 (0,31%)	1,0057 (-0,45%)	1,0064 (-0,12%)	1,0020
24	1,0007 (0,21%)	1,0070 (-0,37%)	1,0043 (-0,44%)	1,0028
25	1,0008 (0,08%)	1,0060 (-0,42%)	1,0062 (-0,15%)	1,0016
26	1,0015 (-0,19%)	1,0052 (-0,44%)	1,0061 (-0,46%)	0,9996
27	1,0026 (0,05%)	1,0061 (-0,56%)	1,0050 (-0,65%)	1,0031
28	1,0030 (-0,02%)	1,0063 (-0,30%)	1,0083 (-0,19%)	1,0028

Conclusion

Presented results show a good accuracy of the PSG2/SERPENT in case of uranium-graphite critical systems. The deviations are low enough and in the most of experiments even lower than in cases of MCNP 4C [3] and MCU [4].

List of acronyms

K_{eff} - neutron multiplication factor

RBMK - large capacity channel reactor

WWER - water-water energy reactor

References

1. Jaakko Leppänen - PSG2 / Serpent – a Continuous-energy Monte Carlo Reactor Physics Burnup Calculation Code // User's Manual.- May 19, 2010.
2. V.M. Kachanov A.N. Kuzmin V.E. Jitarev - RBMK graphite reactor: uniform configurations of U(1.8, 2.0, or 2.4%) 235U)O2 fuel assemblies, and configurations of U(2.0%) 235U)O2 assemblies, empty channels, water columns, and boron and thorium absorbers, with or without water in channels // LEU-COMP-THERM-060.- NEA/NSC/DOC/(95)03/IV.- september 30, 2004.
3. X-5 Monte Carlo team - MCNP — A General Monte Carlo N-Particle Transport Code // User's manual.- Version 5.- April 24, 2003.- Revised 10/3/05.
4. Gomin E. A. - The MCU Status // electronic presentation.- Russian Research Centre "Kurchatov Institute"RRC KI.