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Calculations of Fission Rate Distribution in the Core of VVER-1000 Mock-up on the LR-0 Reactor Using Alternative Methods and Comparison with Results of Measurements

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ABSTRACT

General review of experimental and calculation researches on VVER-440 and VVER-1000 mock-ups on the reactor LR-0 was introduced on the 20th Symposium AER [1].

The experimental core fission rate distribution was obtained by means of gamma-scanning of the fuel pins - 140La single peak (1596 keV) measurements and wide energy range (approximately 600-900 keV) measurements. Altogether from 260 to 500 fuel pins were scanned in different experiments. The measurements were arranged in the middle of the fuel (the active part of pin).

Pin-to-pin calculations of the VVER-1000 mock-up core fission rate distribution were performed with several codes: Monte Carlo codes MCU-REA/2 and MCNPX with different nuclear data libraries, diffusion code RADAR (63 energy groups library) and code SVL based on Surface Harmonics Method (69 energy groups). Calculated data are compared with experimental ones.

The obtained results allow developing the benchmark for core calculations methodologies, evaluating and validating source reliability for the out-of-core (inside and outside pressure vessel) neutron transport calculations.

Key words: SVL, surface harmonics method, VVER, LR-0

INTRODUCTION.

Experimental stand LR-0 [2] NRI Řež is designed to study the neutron-physical characteristics of the VVER-type reactors (VVER). The possibilities of LR-0 can model the core of VVER at 60 degree symmetry. The experimental data obtained on LR-0 are used for verification of calculation methods of VVER core. There are some works in which the calculated analysis is performed for experiments on the assembly LR-0 for mock-up of VVER-1000 core [2-4].

The special importance of these experiments results for us consists in the fact that there are measurements of fission density the fuel elements beside the reflector. The fact that the error in the identification of neutrons source introduces the main contribution in calculation error for the estimation of fluence on reactor vessel. But the error in the source is primarily determined by the error in capacity calculating for fuel elements nearby to the core.

The purpose of our work was the calculation analyses of experiments by SVL, used to maintenance of reactor operation. The lower limit of uncertainty in the calculation of source can be estimated with a comparison of experimental results and calculations by other programs.

In this work we calculated the density distribution in segments of the VVER-1000 core by SVL and compared them with experimental results and calculations by other programs that were published early.

SVL is certified by Rostekhnadzor and used as code for calculation core analyses and as a part of in-core control.

DESCRIPTION OF CALCULATING MODEL OF LR-0 ASSEMBLY

The modeling core consists of 24 fuel assemblies (FA) with 2% enriched uranium 235, 6 FAs with 3% and 2 FA with an enrichment of 3.3%. The height of the fuel part is 125 cm. Dry channel for the neutron spectrum was located in the core. FA with 3 control rods of boron carbide in each were placed symmetrically in the core in FA 19 and 23 and were moved out at half of the core height during the experiment. The concentration of boric acid in the coolant was 4.6 g/kg. The assembly of the 24 tapes was placed in a tank with water and structure simulated a real reflector VVER-1000 at one side. Fig.A1.1 in Appendix 1 shows the experimental assembly LR-0 scheme. An irregular grid was used for the calculations of the core. The basis of grid was the hexagon with a step h = 1.275 corresponding to the mesh-size of VVER-1000 cell "turnkey". Fig. A1.2 in Appendix 1 shows a cartogram of the core for the calculation by SVL. An example of the grid in the place of regularity break for the lattice at the junction of FAs is shown in Fig.A1.3. A grid of the core was extended in a natural way to the reflector. Fig.A1.4. shows an example of mesh in the reflector.

We used 3F approximation of the surface harmonics method for calculations, 69 groups for the calculation of test functions in cells and 4 groups for the core calculation. Note that the fragmentation in space and energy used in our work is common in the calculation of real cores by SVL.

RESULTS OF CALCULATION

The SVL code was used for some calculations of LR-0 modeling VVER-1000 core. The values of energy for each FA were obtained. The diagrams of the energy distribution in the peripheral rows of FAs and graphs of energy distribution in FAs which located along the symmetry axis of the assembly were also obtained. The influence of gap between the last row of FA and a reflector on the results was investigated in [3]. We also made such studies performed calculations with a gap of 0 mm (noted in Figures as gap =0) and with a gap of 2 mm (noted in Figures as gap =2).

Appendix 2 shows the dependency graphs of calculation-measurement deviation for 1st, 2nd, and 3rd rows of fuel elements along the reflector (Fig. P2.1-A2.3 respectively). The numeration of FAs corresponds to the same in the Figures P1.1. Fig.A2.4. shows the deviation (%) of various programs calculations from the experiment for the whole set of measurements. The standard deviation of the measurement for SVL program was 3.5%.

CONCLUSIONS:

In general, the results of the program SVL confirm the results of the program Moby-Dick [2], MCU [3] Radar [3]. At the same time the deviation from the experimental results is within 10%. In addition the standard deviation (one standard) is 3.5% for SVL.

It is worth noting that during the calculations of this work was found some uncertainty in the results obtained during the experiment. Fig. A2.1 shows that calculation at all programs for the left of the junction 13 and 21 FAs yields the value above experiment and the right of the junction is less than the experimental value with error jump about 7%. The reason for this deviation behavior is not understandable and requires further consideration.

Nevertheless, the experimental results agree with all the calculated values well within the declared calculated error and can be used to develop a benchmark for the substantiation of methods of calculation of the core, to evaluate and study the sources used in the calculation of neutron transport in vessel and near vessel of reactor.

The analysis of calculated and experimental results allows us to estimate the lower level of uncertainty at 4% (one standard) in the calculation of the neutron source for vessel; the same value corresponds to the maximum accuracy of SVL for the calculation of this value.

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APPENDIX 1.

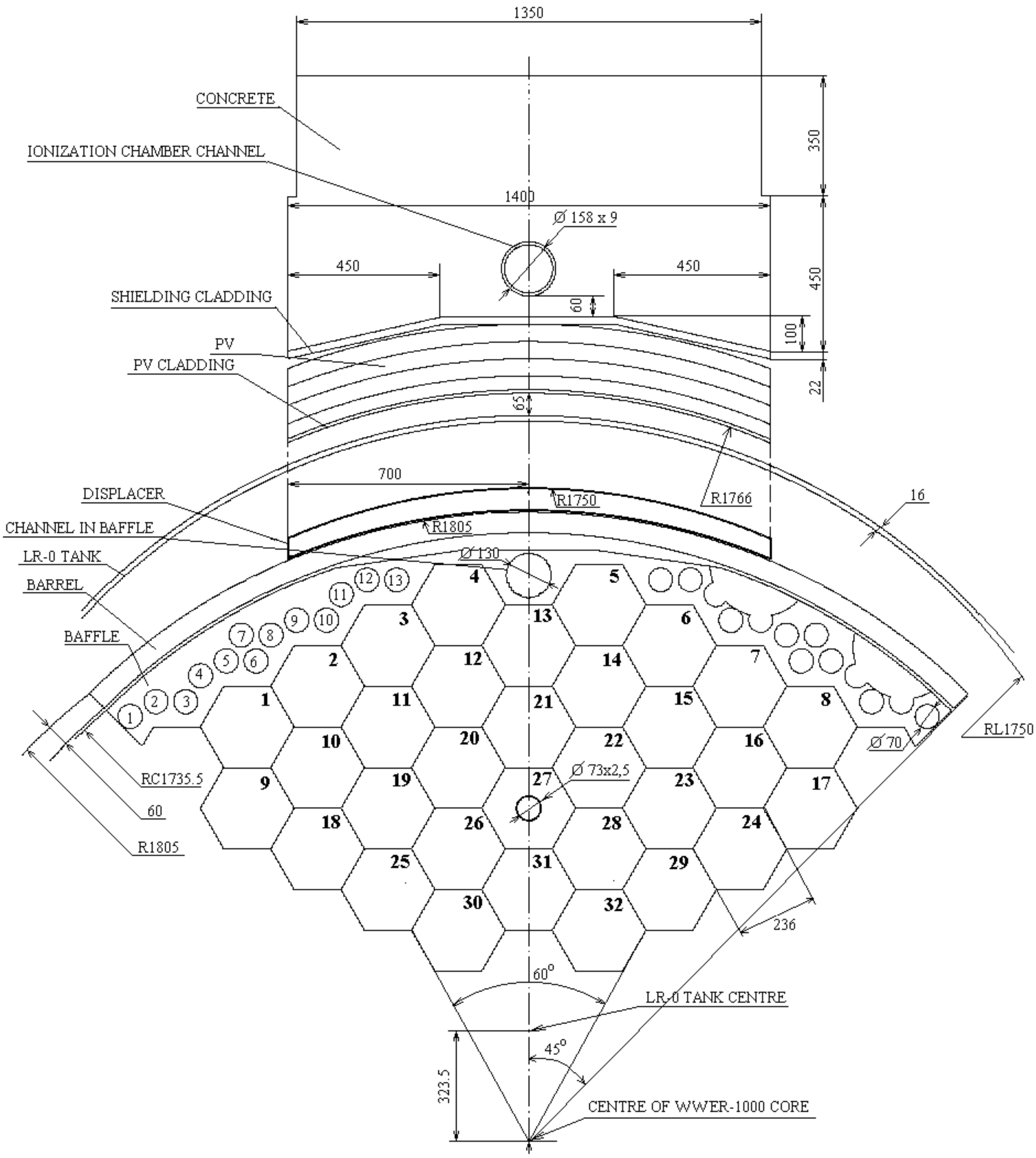

Fig.A1.1 Schematic of the experimental assembly LR-0 (Figure taken from [2])

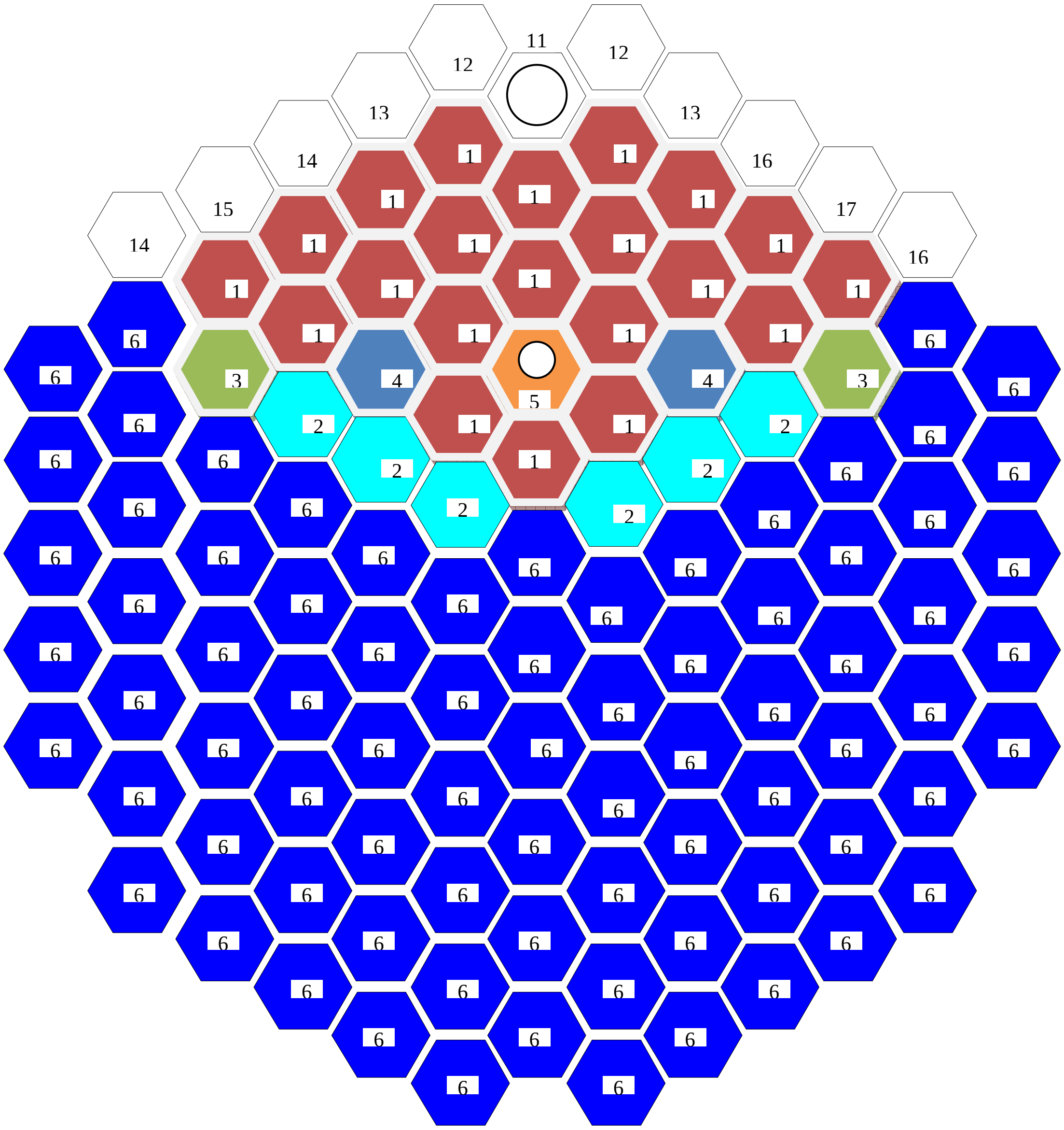

Fig. A1.2 An example of the cartograms of the core program for the calculation of SVL

1 – FA with 2% enrichment
2 - FA with 3% enrichment
3 - FA with 3.3% enrichment
4 – FA with the control rods and enrichment fuel of 2%
5 – FA with the dry experimental channel
6 – water FA
11 – 17 – reflector

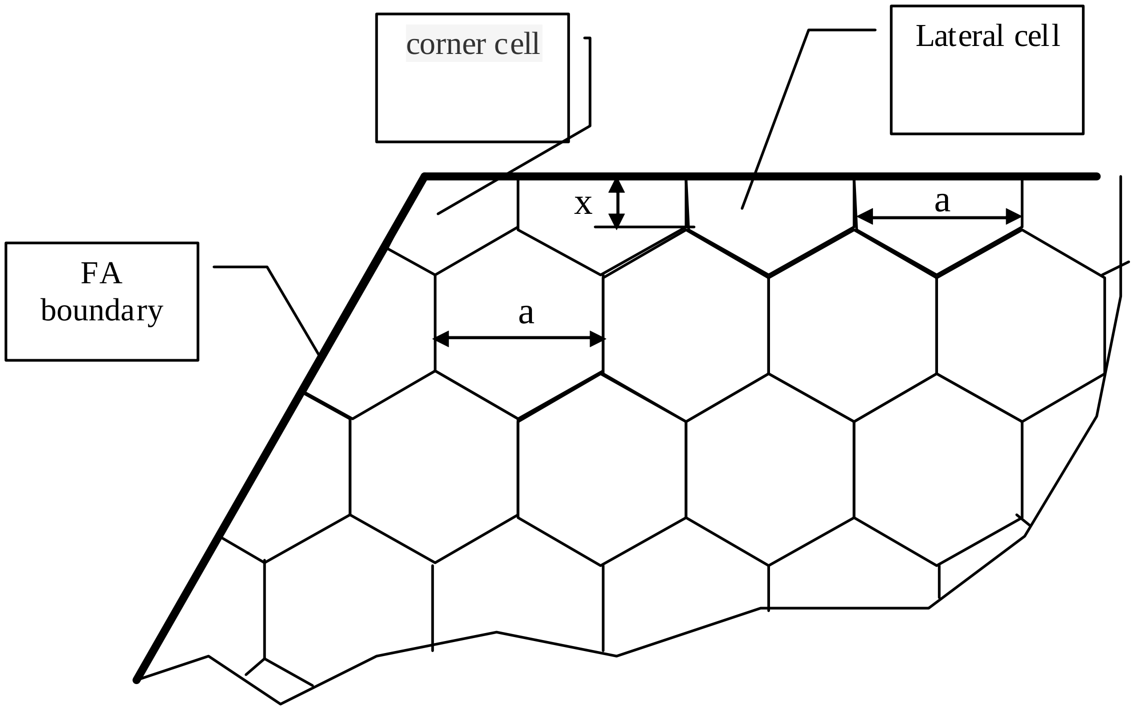

Fig. A1.3. Grid in place of violation of regularity on the boundary of FA VVER type

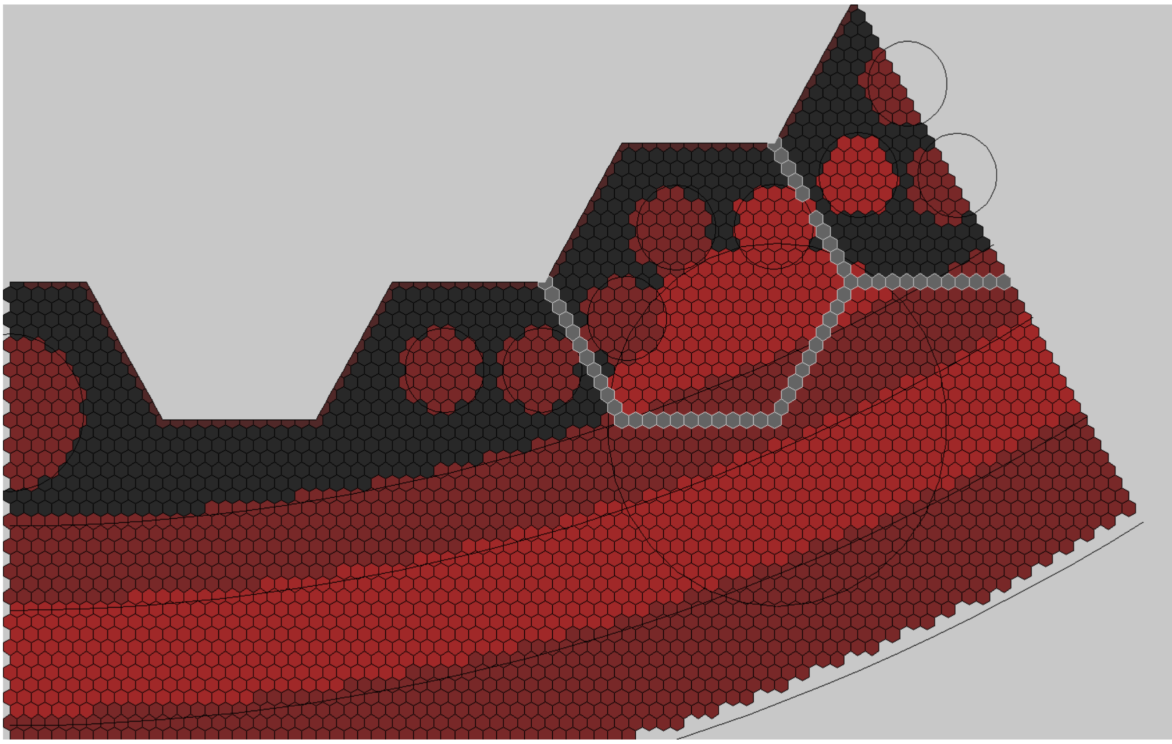
Fig. A1.4. Calculation grid in reflector. Build by SVL-REF code.

APPENDIX 2.

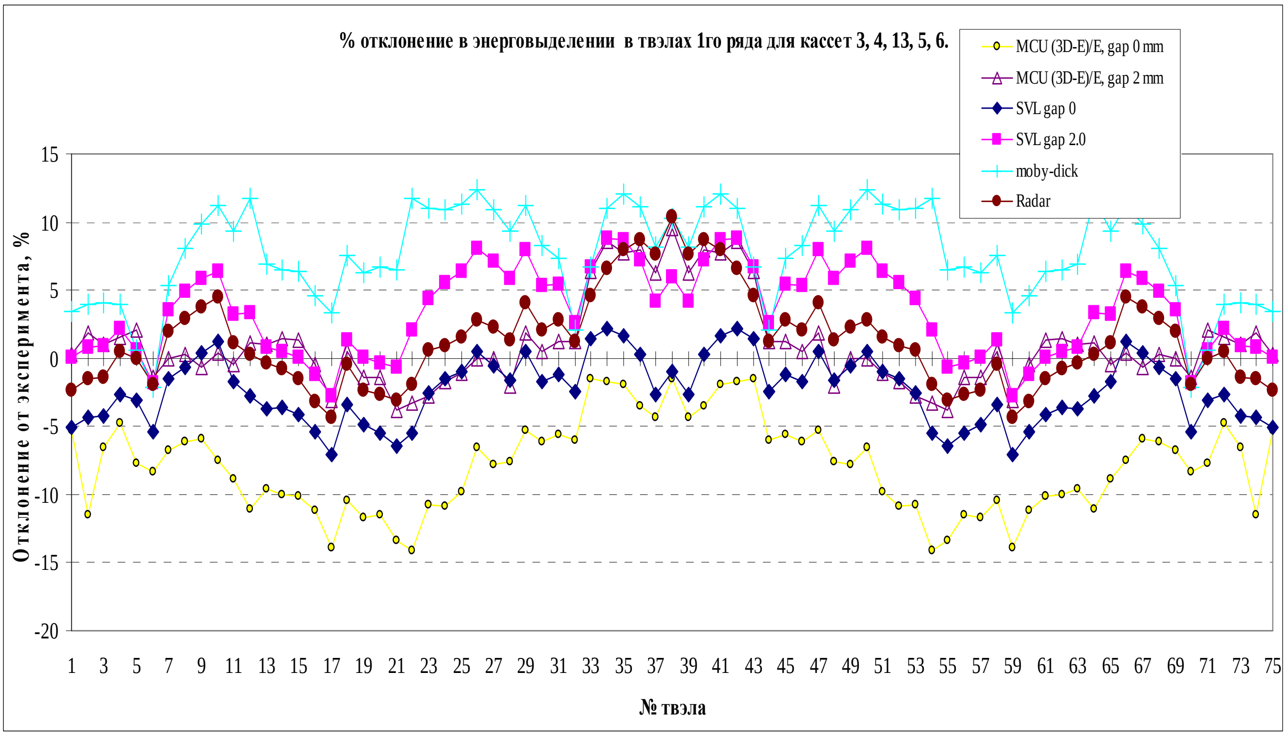

Fig.A2.1. Deviation calculations on the various codes from experimental data for fuel elements for the first row along the reflector. The numbering corresponds to the numbering of the fuel elements [1].

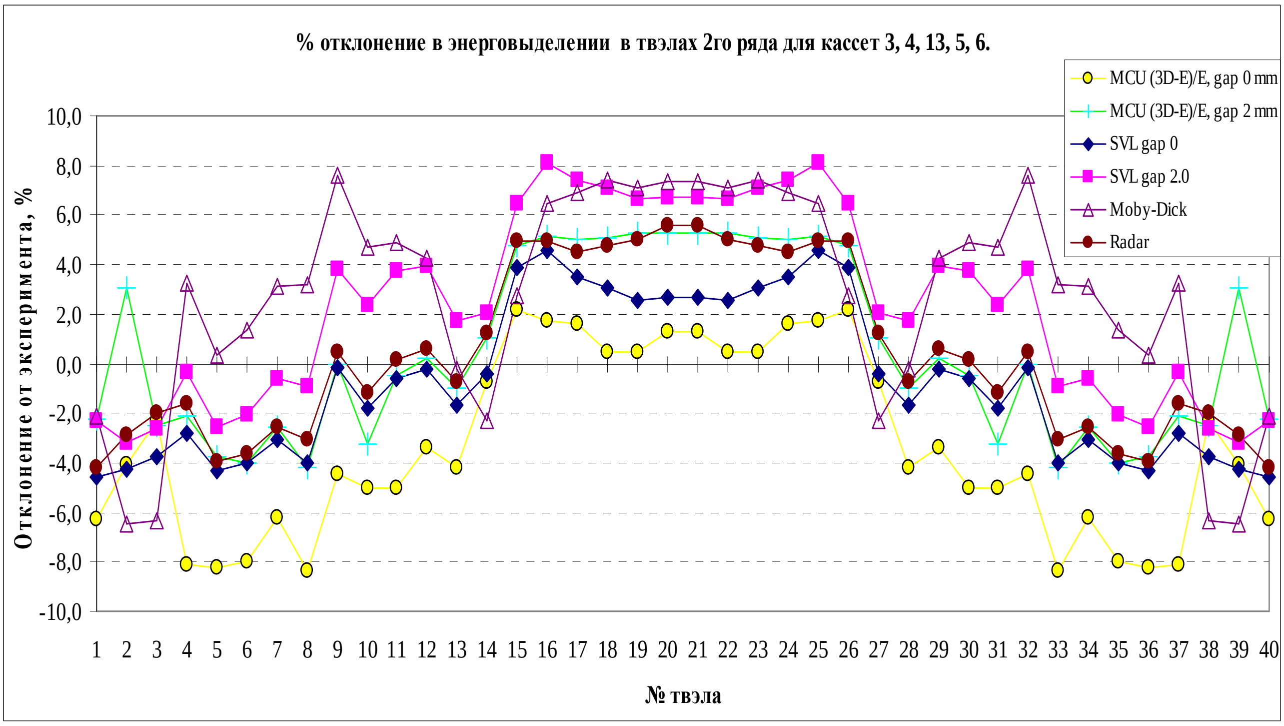

Fig.A2.2. Deviation calculations on the various codes from experimental data for fuel elements for the 2-nd row along the reflector. The numbering corresponds to the numbering of the fuel elements [1].

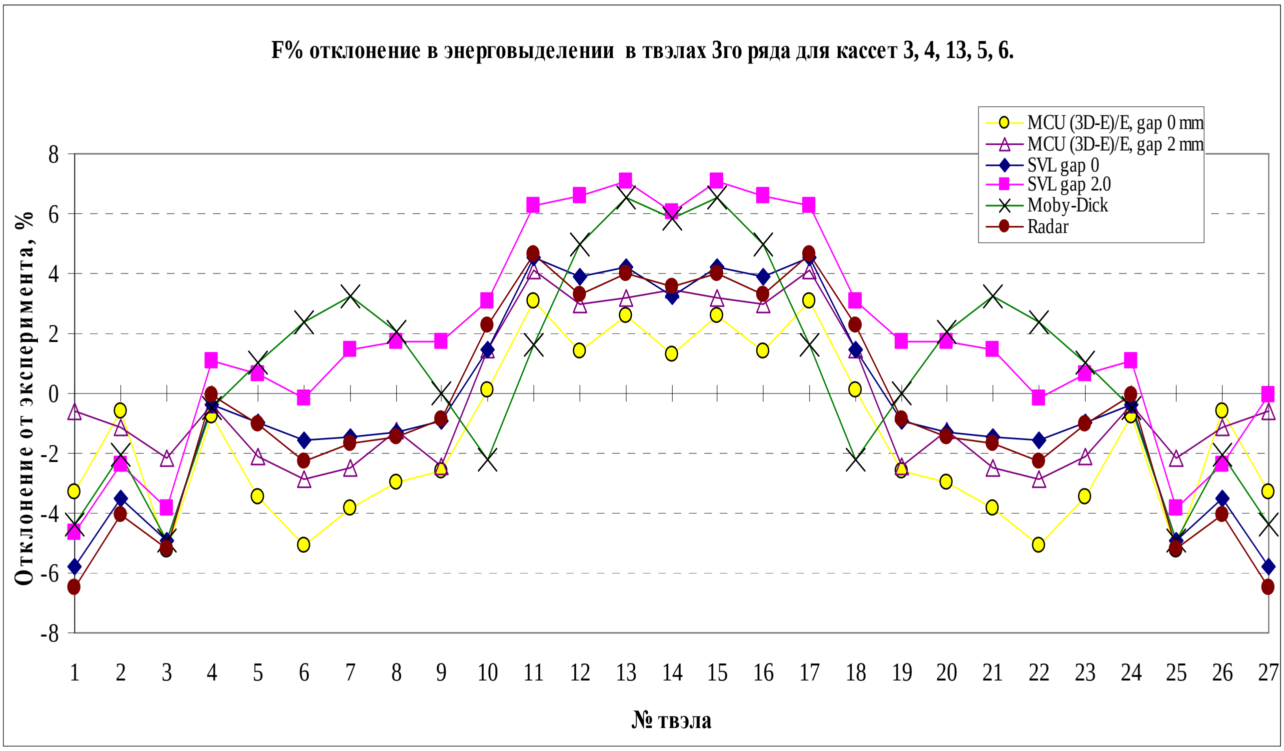

Fig.A2.3. Deviation calculations on the various codes from experimental data for fuel elements for the 3-d row along the reflector. The numbering corresponds to the numbering of the fuel elements [1].

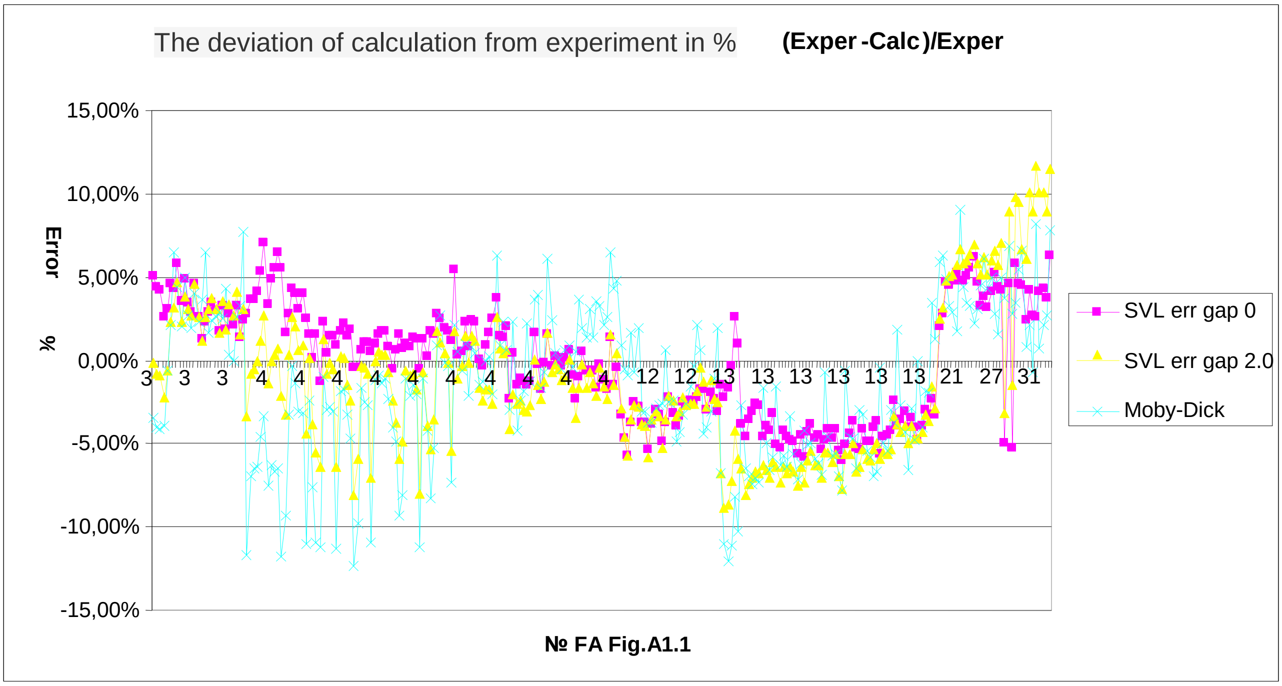

Fig.A2.4. Deviation in % the calculations of the various programs of the experiment, for the entire set of measurements. X-axis indicate the number of FA in accordance with Fig.A. 1.1.