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Influence of Spacer Grids Homogenization on Core Reactivity and Axial Power Distribution

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ABSTRACT

The paper presents the influence of spacer grid homogenization during cross section generation on core reactivity and axial power distribution. Homogenization calculation was performed at fuel assembly level using FA2D code. The first approach is to smear uniformly all centrally located spacer grids along 120 inches of fuel assembly and carry out 2D transport calculation. The second approach is to smear spacer grid within 6 inches of fuel assembly and perform homogenization calculation. That composition is then assigned to closest 6 in axial subdivision of the core calculation. The last analysed option is to do additional localization of spacer grids and carry out homogenization within 2 inches of fuel assembly height. The additional subdivision is afterward performed of the closest regular axial core subdivision in nodal core calculation. The core calculation was performed using modified PARCS 2.5 code for NPP Krško cycle 29. The normalized axial power distributions obtained by PARCS for three different ways of spacer grid homogenization are then compared to quantify the influence of modelling. Similar comparison was performed for critical boron concentration. As expected larger influence is present for axial power distribution (more details for fine localization), with some influence on axial power offset and global reactivity.

Keywords: *homogenization, spacer grids, FA2D, PARCS, axial power distribution, axial offset*

1 INTRODUCTION

Reactor of NPP Krško is Westinghouse PWR with two cooling loops and consists of 121 fuel assemblies (FA). Each 16×16 VANTAGE+ FA consists of 235 fuel rods, 20 guide tubes and one instrumentation tube. Fuel is in form of uranium oxide, cladding is made of ZIRLO alloy, and IFBA and soluble boron are used for control of excess reactivity. NPP Krško works in 18-month cycles and current cycle is Cycle number 30.

We have tried to quantify the influence of axial homogenization of the spacer grids on usually calculated core operation data and to see is it possible to calculate axial power profiles that can offer similar information as power profiles measured with in-core instrumentation. In addition, we wanted to see if a new approach of smearing of spacer grids can decrease discrepancies between our axial offset (AO) results and measured data and results of reference calculation. That is especially true for sudden increase in Westinghouse BOC axial relative power profile at the middle of active core height. Commonly, six spacer grids are smeared over 304.8 long central part of FA, and one spacer grid was smeared over bottom axial blanket region (15.24 cm), and now they are smeared over 15.24 cm long part of FA (one PARCS axial node).

As shown in Figure 1 there are eight spacer grids in each fuel assembly. Seven of them are within active core height, and one is in upper axial reflector region. The lowest spacer grid is in the axial blanket region, and remaining grids are inside central region with a nominal fuel enrichment. Spacer grid positions and their heights are shown in Figure 1. Distribution of material compositions and location of spacer grids within them are shown in Figure 1 too. The localization of spacer grids is adjusted to fit original PARCS axial meshing and minimize number of spectral calculations. The spacer grid number 6 is really in material compositions at places 18 and 19. Considering that it requires two additional spectral calculations at FA level and spacer grid number 6 was shifted up by approximately 1 cm. This means that material composition at place 18 is without spacer grid, and material composition at place 19 is with spacer grid.

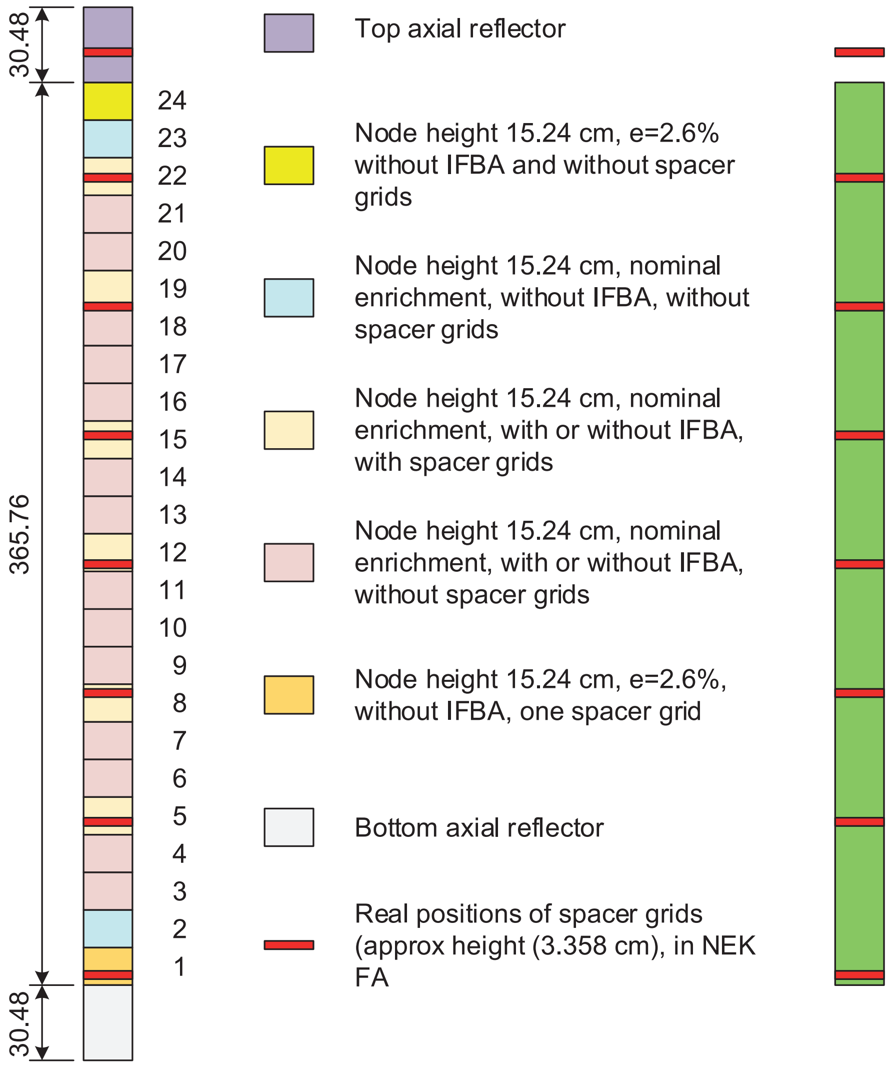

Figure 1 Material compositions and spacer grids positions in NPP Krško FA

2 CALCULATIONAL TOOLS

A modified 3D nodal core simulator PARCS v2.5 [1] used to obtain whole-core power distribution and global reactivity. Homogenized few-group constants obtained using two-dimensional collision probability lattice code FA2D [2]. The code is verified by benchmark calculations at fuel assembly level, as well as fuel management calculations for the NPP Krško and two advanced reactors IRIS and I^{2}S-LWR. FA2D was originally developed at the Faculty of Electrical Engineering and Computing, University of Zagreb, but some parts of the code rely on geometrical code package MARSLIB [3] from ORNL (Oak Ridge National Laboratory).

For each material composition heterogeneous depletion calculation was performed at a constant power density of 40.5 W/gU up to burnup of 60 GWd/tU and predictor-corrector method is used during the depletion calculation. The code uses 97-group cross-section library based on ENDF-B/VI.5 data files. The library consists of 290 different isotopes. Assumed state point thermal-hydraulic variables were: effective fuel temperature 810.9 K, gap temperature 810.9 K, cladding temperature 616.5 K, moderator temperature and pressure 15.51 MPa and 580.6 K, boron concentration 500 ppm. Inter assembly gap was explicitly treated but cold nominal dimensions were assumed. Inconel spacer grids are homogeneously mixed with moderator and boron from ZrB_2 coating is smeared over the fuel rod gap.

To form collision probability matrix fuel assembly was covered with a mesh of parallel lines, mutually distant 0.05 cm, and having 16 equally spaced angles. The convergence criterion for fundamental mode calculations was 1.0E-6.

Originally NRC's code PARCS was developed for steady-state and transient (RIAs) standalone calculations, or as a part of coupled code together with TRAC or RELAP5 to provide 3D neutronic core information. PARCS 2.5 has been modified at the FEEC and the main modifications of PARCS 2.5 were done to:

1. Provide internal depletion capability
2. Perform multi-cycles fuel management calculations
3. Make possible usage of XS tables prepared by FA2D code
4. Calculate burnup weighted local history variables to be used as independent variable in interpolation routine
5. Calculate burnup dependent fuel temperature to be used in fuel rod model.

All required data for multi-cycles analysis are provided within fuel assembly description Fuel Assembly Specification (FAS) files. Each fuel assembly has one FAS file and it can be updated at the end of each depletion cycle. Integral parts of the FAS files are links to separate files with cross section (XS) tables that describe fuel assembly material compositions. Usually FA consists of several material compositions which vary by number of IFBA pins, fuel and IFBA enrichments and presence of spacer grids. For NPP Krško cycle 29, 30 fuel compositions and 10 reflector compositions are used. Cross-section tables are calculated just once in the life-time of the plant using any cross-section generation code (FA2D in our case).

Branch point calculations were performed at selected burnup points using isotopic compositions calculated during depletion under average conditions. The special post-processing program saves two-group cross section data for each material composition in a format similar to the cross section library format given in the OECD MSLB benchmark [4]. In addition to macroscopic cross section data assembly average neutron fluxes, power form factors, discontinuity factors, corner flux discontinuity factors, fractions and decay constants of delayed neutrons, fission yields of ^{135}I, ^{135}Xe and ^{149}Pm, number densities of ^{135}I, ^{135}Xe, ^{149}Pm and ^{149}Sm are saved too.

A trilinear interpolation procedure is part of the library implementation. Separate cross section library is used to describe rodded fuel assemblies. There is a separate library with history variables correction too.

3 RESULTS

The reference depletion calculation is performed for NEK Cycle 29 core with 24 equdistant axial subdivisions in active core and 2×2 radial subdivisions in each fuel assembly. That calculation uses 18 fuel material compositions (cross section data) with 6 spacer grids homogenized within FA central part (304.8 cm, 120 in) and 10 radial and axial reflector material compositions. It is labeled 5S. The second calculation is performed using cross section dana calculated so that spacer grid is smeared over length of 15.24 cm (6 in). The number of fuel material compositions is now 30. We are still using equidistant axial core subdivision and material compositions with spacers are assumed in node which contains whole spacer grid (or most of it). The results are labeled with 1S. Last calculation assumes homogenization of spacer grid over length of 5.08 cm (2 in). That node is still longer than actual spacer height (around 3.3 cm). Existing PARCS equidistant nodes are additionaly subidvided in two or three parts (2-4, 4-2, 2-2-2) with one part having homogenized spacer and another is without. Number of fuel materal compositions is the same (30) and number of axial subdivisions within active core length is 34. Label LS is used for those results.

When moved from original homogenization labelled as 5S to homogenization 1S we noticed increase of critical boron concentration for about 40 ppm. The further localization of homogenization (LS) has very small influence on critical boron concentration. Critical boron concentration as found in Nuclear Design Report (NDR) [5] for Cycle 29 is shown in Figure 2 together with our reference calculation (5S) and more localized 1S calculation. 5S calculation gives critical boron concentration very close to Westinghouse one and 1S values are above for between 40 and 20 ppm (depending on burnup). In Figure 3 we have together measured critical boron concentration (flow corrected and B10 corrected values), Westinghouse NDR values and our 1S values. 1S and LS CB values are somewhere between NDR and measured values. It is not completely clear why critical boron concentration increased due to different homogenization length of spacer grids. In both case we have the same amount of material, but flux weighting can result in some change of reactivity.

The expected influence of spacer grids homogenization can be seen in normalized axial power profiles calculated at 150 and 20520 MWd/tU, Figure 4 and Figure 5. When compared with available measured NEK profiles (in-core instrumentation) we can say that rather good prediction was obtained, especially with LS localization, Figure 6. It is clear that measured data use finer spatial raster than calculation. The spacer grids are localized to within 5.08 cm, in LS case, with spacer grid axial position again deviation up to 5.08 cm. The influence of spacer grid homogenization to AO is rather small, going in the direction of less negative AO in the first part of depletion cycle. That is good direction of change compared to measured data, but calculated AO is still more negative than measured plant data.

The influence of spacer grid axial homogenization on radial power distribution is expected to be small. The reference prediction of assembly power is within -3.7 to +5.21% from NDR values for BOC data and within -2.26 to + 4.50% from NDR values for EOC data, Figure 7 and Figure 10. The relative difference between LS and 5S radial power distribution at BOC is within -0.87% and 1.34%, Figure 8. For EOC values the difference between LS and 5S values is within range from -0.33 to 0.49%, Figure 11. Both, for BOC and EOC, the relative difference between LS and 1S radial distributions is within 0.1% for BOC, Figure 9, and within 0.05% for EOC.

The overall experience with this new type of homogenization of spacer grids and capability of PARCS code to perform that type of calculation is positive one and we will continue to use it in parallel with old one. The only drawback of this approach is increased number of spectral homogenization calculations needed in preparation of cross section libraries.

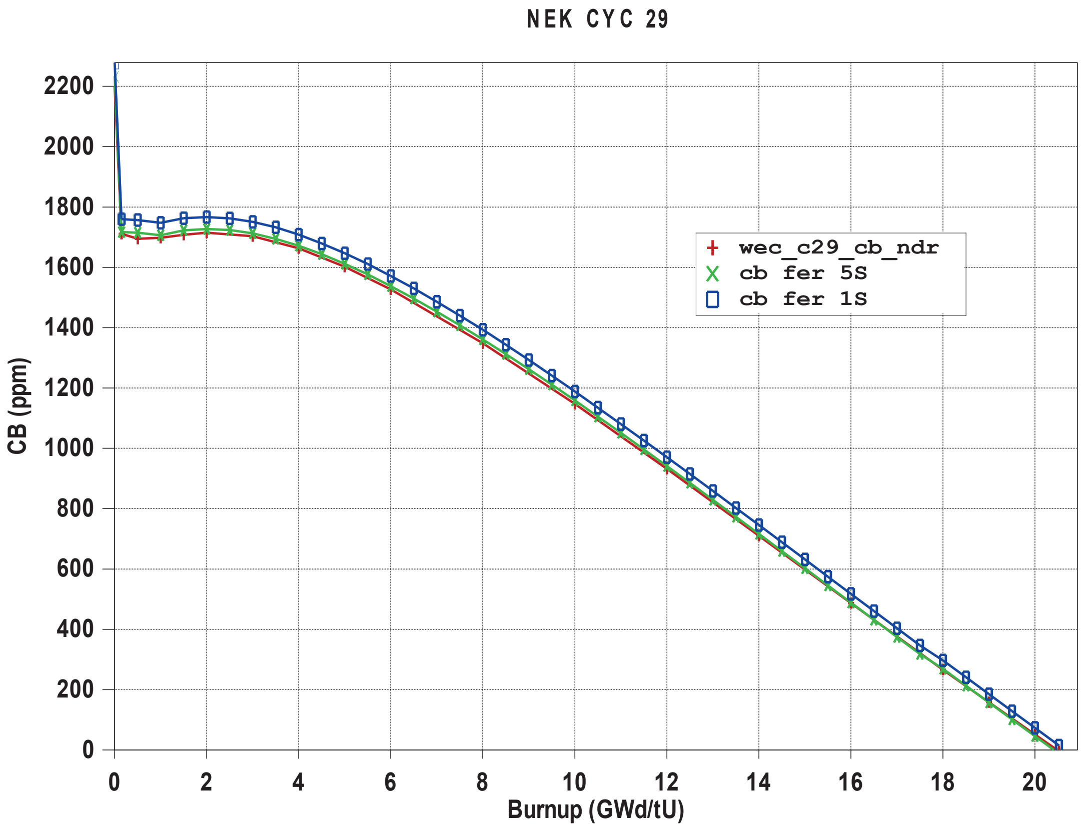

Figure 2 Influence of spacer grid homogenization on critical boron concentration

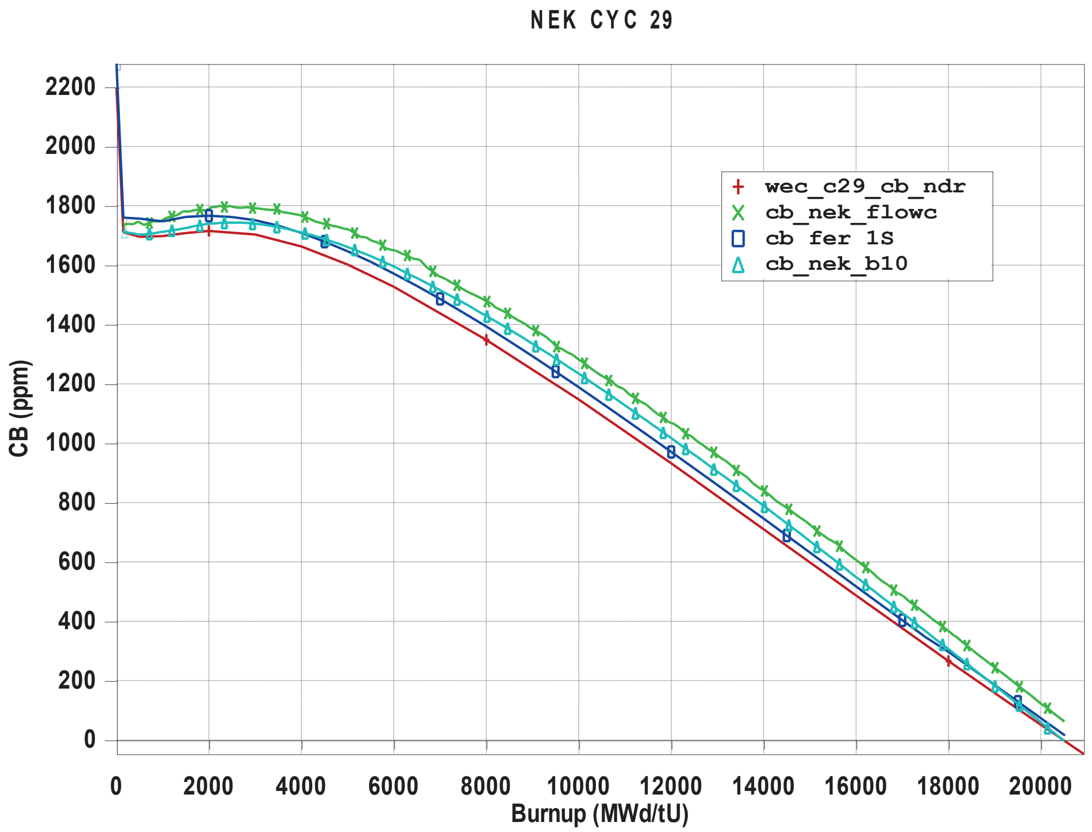

Figure 3 Critical boron concentration depending on burnup

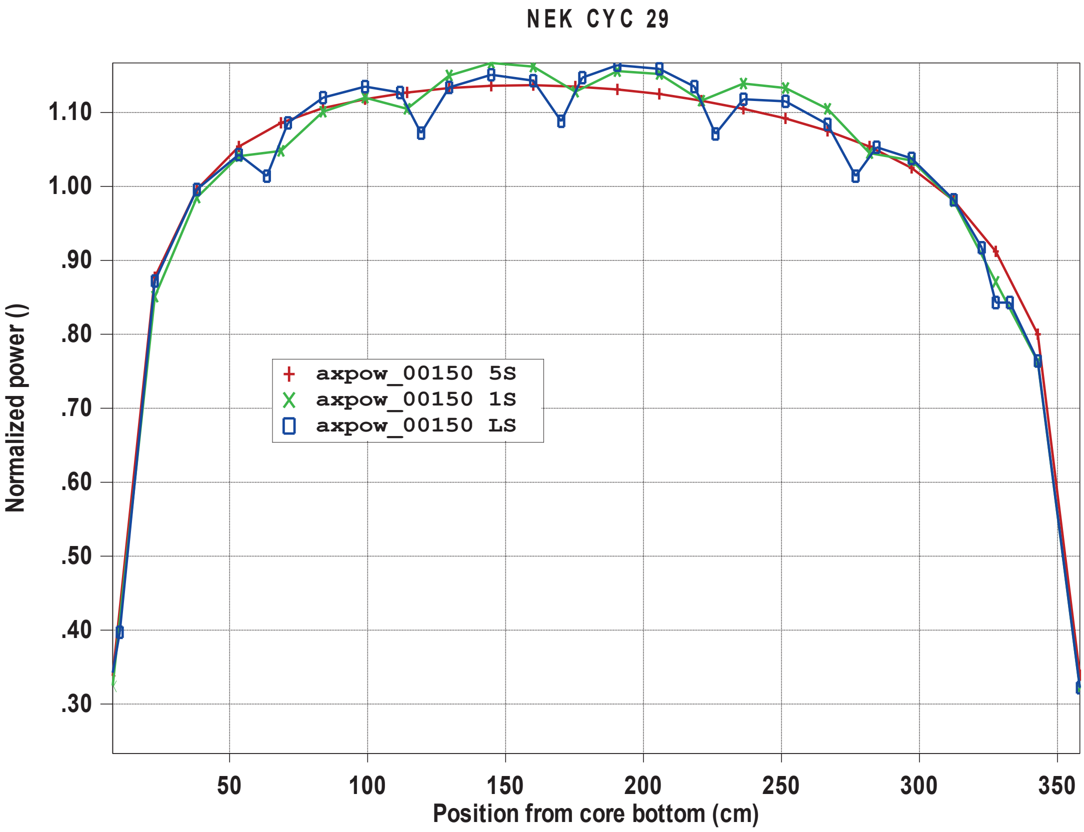

Figure 4 Axial power profile for three different ways of grids smearing - BOC

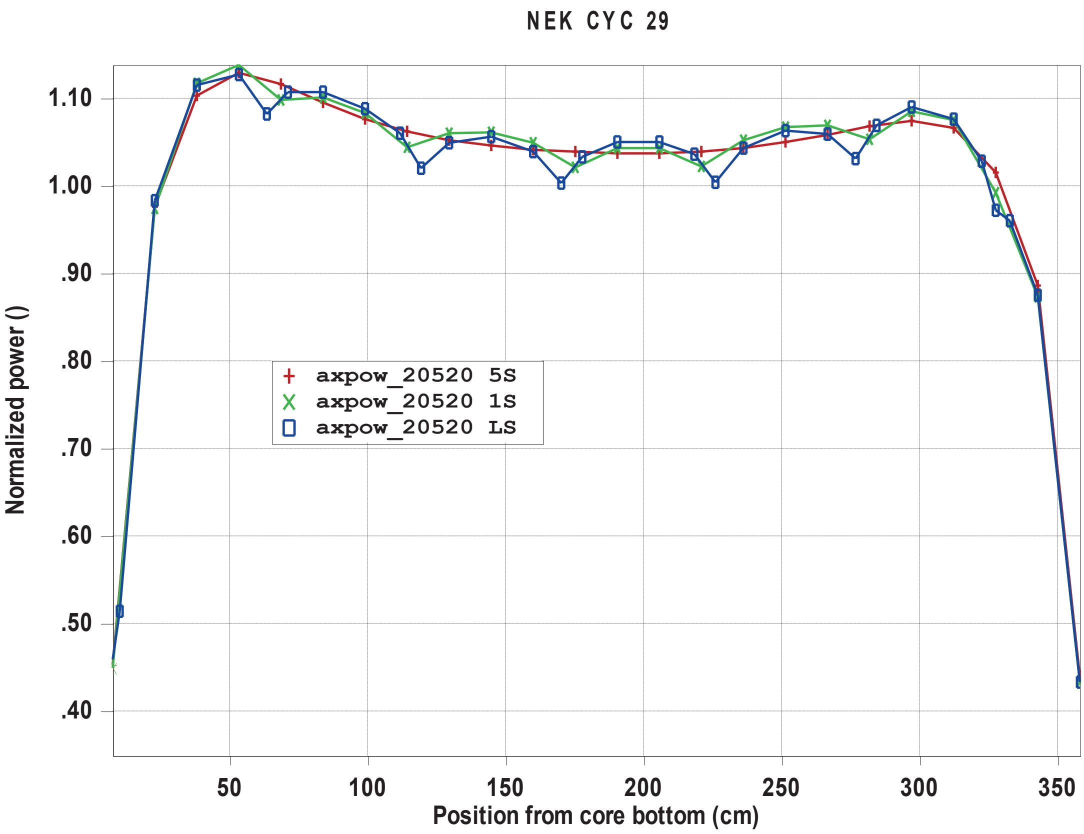

Figure 5 Axial power profile for three different ways of grids smearing - EOC

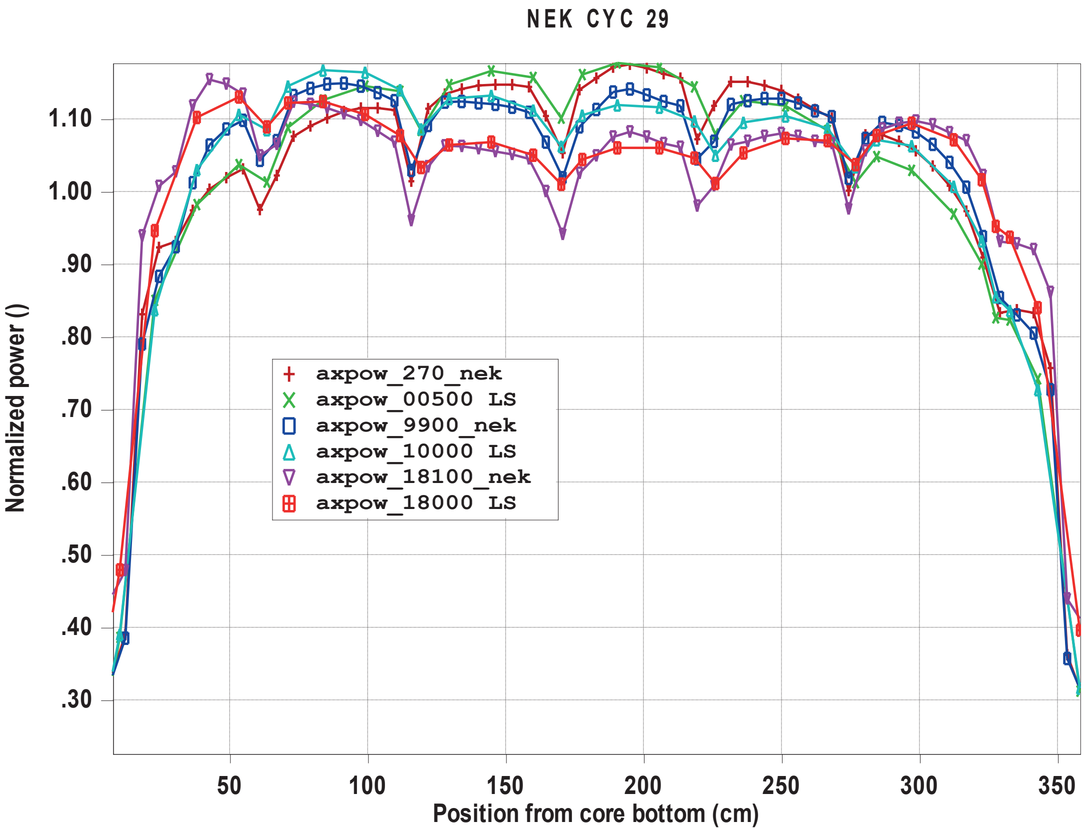

Figure 6 Comparison of axial power profiles with measured data at BOC, MOC and EOC

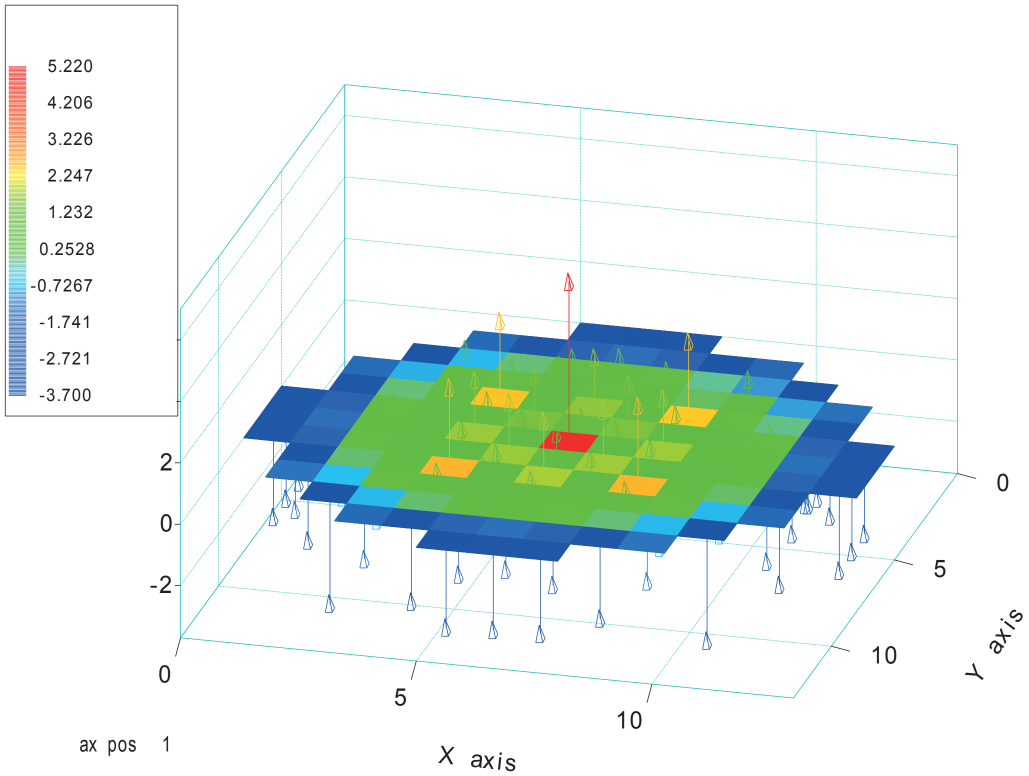

Figure 7 Relative differences of radial power distribution; WEC vs. 5S – BOC

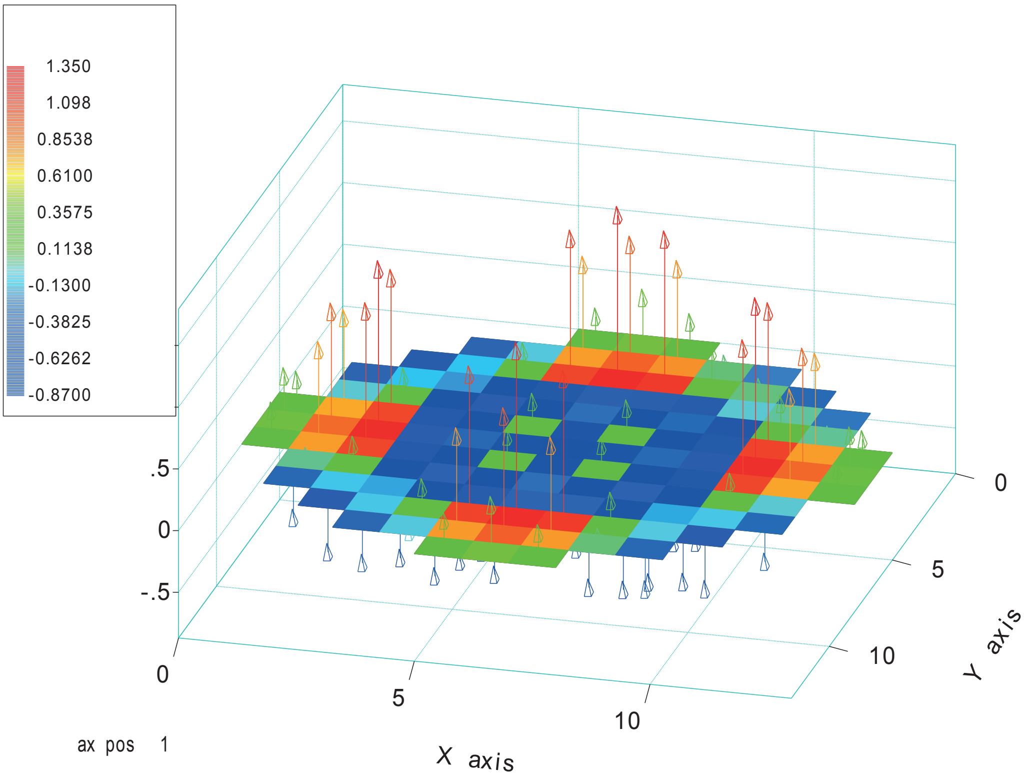

Figure 8 Relative differences of radial power distribution; LS vs. 5S – BOC

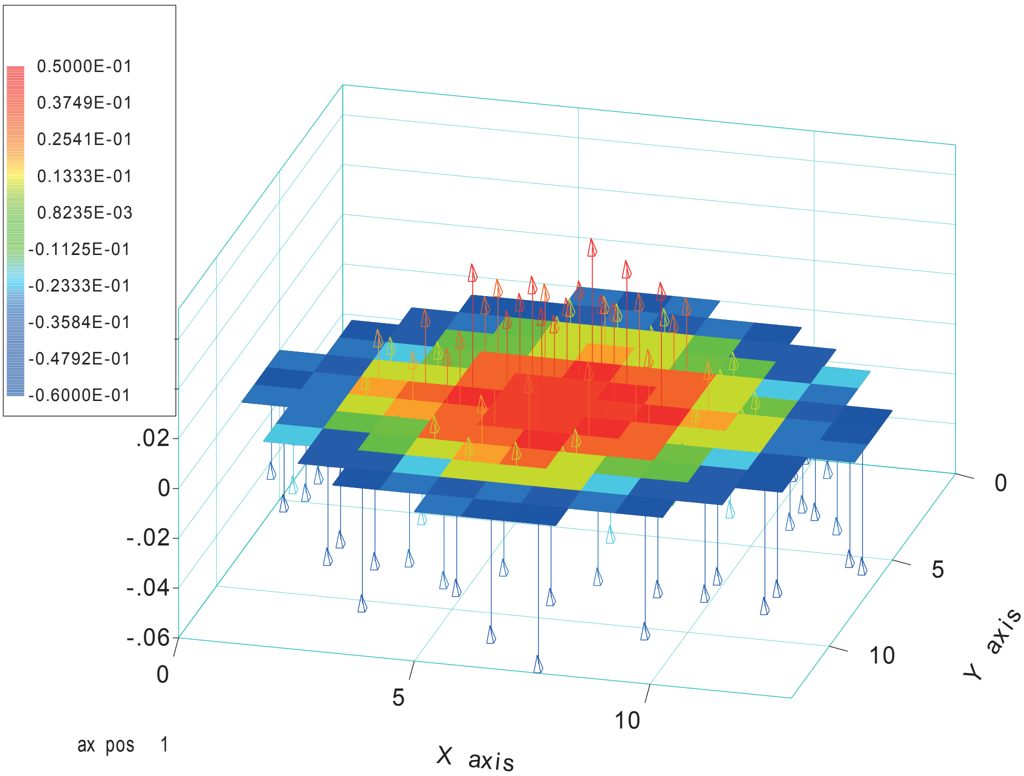

Figure 9 Relative differences of radial power distribution; LS vs. 1S – BOC

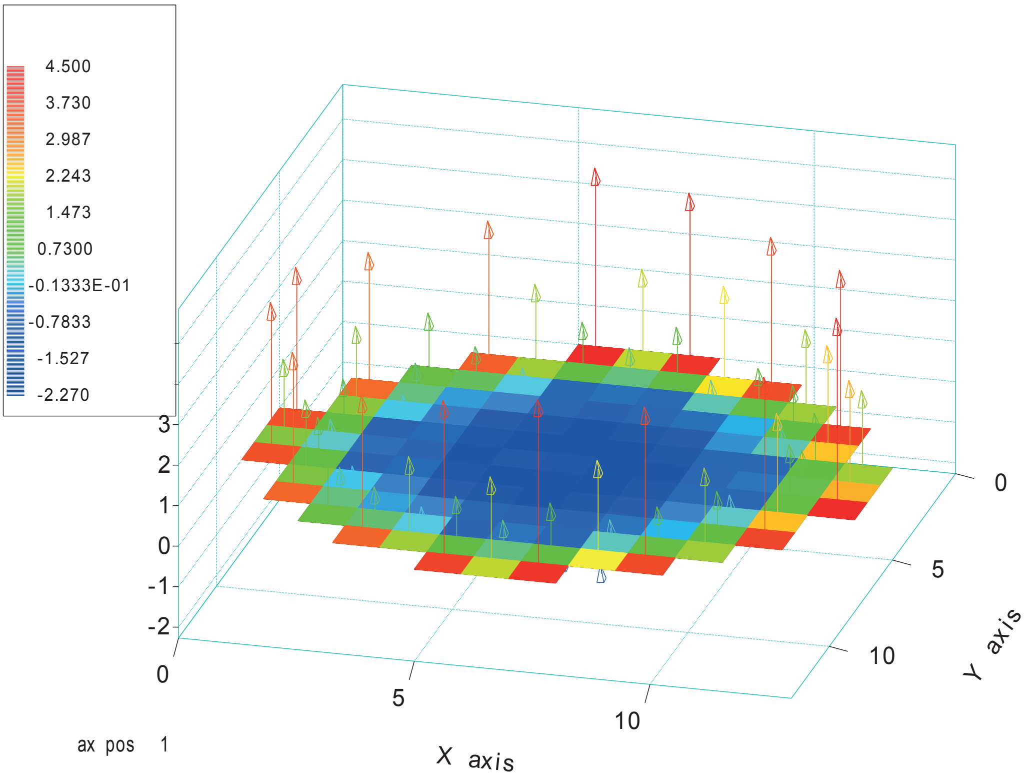

Figure 10 Relative differences of radial power distribution; WEC vs. 5S – EOC

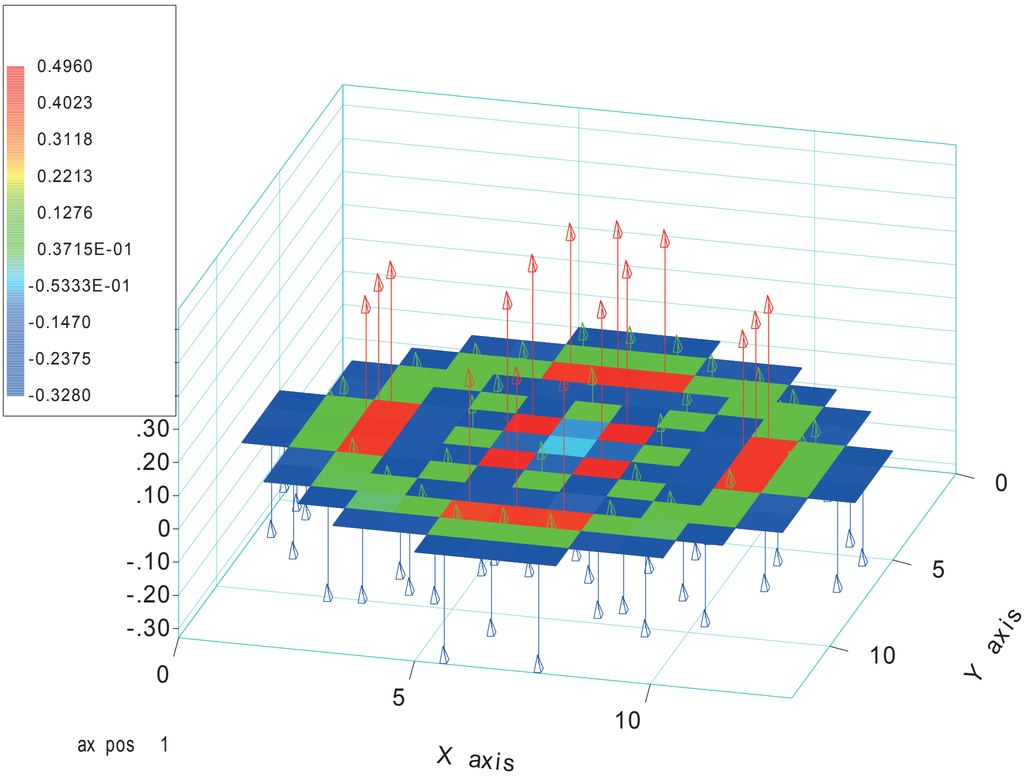

Figure 11 Relative differences of radial power distribution; LS vs. 5S – EOC

4 CONCLUSION

3D nodal core depletion calculation usually assumes homogenized spacer grid taken into account within fuel assembly cross section data. Our usual approach is to homogenize 6 spacer grids within central part of NPP Krško fuel assembly (results labelled with 5S). Lowest spacer grid is homogenized within lower axial blanket material composition (15.24 cm, 6 in) and highest is within top axial reflector. We have tried to quantify the influence of axial homogenization of the spacer grids on usually calculated core operation data and to see is it possible to calculate axial power profiles that can offer similar information as power profiles measured with in-core instrumentation. Our reference PARCS 3D nodal calculation used constant axial node size of 15.24 cm (6 in). First logical choice was to homogenize spacer grid (approximate length of 3.3 cm) over that length (1S). Next step was to decrease homogenization length three times, down to 5.08 cm (2 in) (LS). That means, for each combination of enrichment and IFBA number, calculation of two additional homogenized cross section libraries. The material composition was assigned to spatial node closest to spacer grid actual axial position. When moved from original homogenization labelled as 5S to homogenization 1S we noticed increase of critical boron concentration for about 40 ppm. The further localization of homogenization (LS) has very small influence on critical boron concentration. Axial power profiles are reasonably well predicted compared to measured NEK data especially with LS localization. The influence to AO is rather small going in direction of less negative AO in the first part of depletion cycle. AO is still more negative than measured plant data. The influence of spacer axial homogenization on radial power distribution is within 1% when going from 5S to 1S and negligible after that.

The experience with new type of homogenization of spacer grids and capability of PARCS code to perform the calculation is positive one and we will continue to use it in parallel with old one.

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