ANALYSIS OF C5G7 MOX BENCHMARK USING MARPIJ AND COBAYA CODES

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ABSTRACT

A Benchmark for deterministic 2-D/3-D MOX fuel assembly transport calculations without spatial homogenisation (C5G7 MOX) was proposed by Nuclear Energy Agency [1]. This Benchmark was proposed to test the ability of current transport codes to treat reactor core problems without spatial homogenisation.

This Benchmark has been used to test our methodology for PWR reactors: our extended collision probability code, MARPIJ [2], and our standard PWR methodology, using the COBAYA code [3], is also applied to this Benchmark.

1. BENCHMARK DESCRIPTION

The 2D description consists in a configuration of four fuel assemblies (UO2-MOX) and reflector. Symmetry conditions are vacuum boundary conditions (right and bottom) and reflected boundary conditions (left and top). Each fuel assembly is made up of 17x17 lattice of square pin cells (pitch=1.26 cm, cell radius =0.54 cm). Cross sections in seven groups of energy (transport corrected and isotropic scattering) per type of pin-cell (UO2, MOX 4.3%-7%-8.7%, guide tube, instrumentation tube) and moderator zone were provided. A reference seven-group Monte Carlo solution is used as reference solution (providing an eigenvalue in 2D equals to 1.19).

The importance of this Benchmark is to test both the validity of spatial fuel-coolant homogenisation procedures at the fuel pin cell and/or at the fuel assembly level and the ability of current transport codes to treat reactor core problems without spatial homogenisation.

2. METHODOLOGY: MARPIJ CODE VERSUS COBAYA CODE

MARPIJ is a collision probability code. Whole or partial PWR fuel assemblies geometries and color-set configurations are calculated with our extended MARPIJ code with explicit multicell model, using an enhanced collision probability (PIJ) method for 2D transport calculations in multigroups (24-69) of energy.

The extended MARPIJ code (based on WIMSD4 code, PIJ option) has been improved with new tracking and sector division. The lattices of cylindrical fuel or tube guide are configured in square cells, with the moderator subdivided in several zones, within a square boundary with reflective conditions. MARPIJ code performs a explicit 2D multicell calculation in which each type of pin cell is treated as separate cell type, each one with associated moderator.

Benchmark cross sections in seven-groups of energy and explicit 2D full geometry were pre-processed for MARPIJ code. Symmetry conditions (reflective and vacuum) were defined. An extensive analysis to define the optimized tracking definition was performed. The objective is to define an adequate line density to track the volume of all regions with an error less than 1%. The tracking in MARPIJ code is defined by the number of lines used in the PIJ integration mesh (1200) and the number of angles per each type of line (31).

Regular fuel assemblies were calculated with MARPIJ code. The transport fluxes in seven-groups of energy were used to weight the two group cross sections for the different types of pin cells used in COBAYA code. Pin-by-pin transport corrected diffusion discontinuity factors are also obtained.

COBAYA is a detailed pin-by-pin 2D code in two groups of energy (two group cross sections per type of pin cell were obtained with the previous code). This code uses a transport corrected diffusion calculation using a linear discontinuous finite difference formulation. Calculations of full Benchmark problem, including the radial reflector, are performed by COBAYA code.

3. MARPIJ CODE VERSUS COBAYA CODE RESULTS

The extended MARPIJ code shows a maximum discrepancy of +19% (Figure 1). The standard deviation of differences between MARPIJ code from reference solution is aprox. 5%. The k_{effec} obtained is 1.18444, (Δk from reference solution is -0.00211). The differences in pin power distributions are due to the PIJ method used in MARPIJ code. The assumptions of flat-flux approximation, coupling between cells and the iteration flux solution process are the reason of this deficient treatment in large configurations and with high spectrum differences (near reflector).

The 2D COBAYA transport corrected diffusion calculation results show a maximum discrepancy of +15% from reference pin power distribution (Figure 2). The maximum discrepancies occur near reflector region, showing the limit of diffusion calculation. The standard deviation of pin power differences between COBAYA code from reference solution is aprox. 8%. The k_{effec} obtained is 1.18874, (Δk from reference solution is +0.00219).

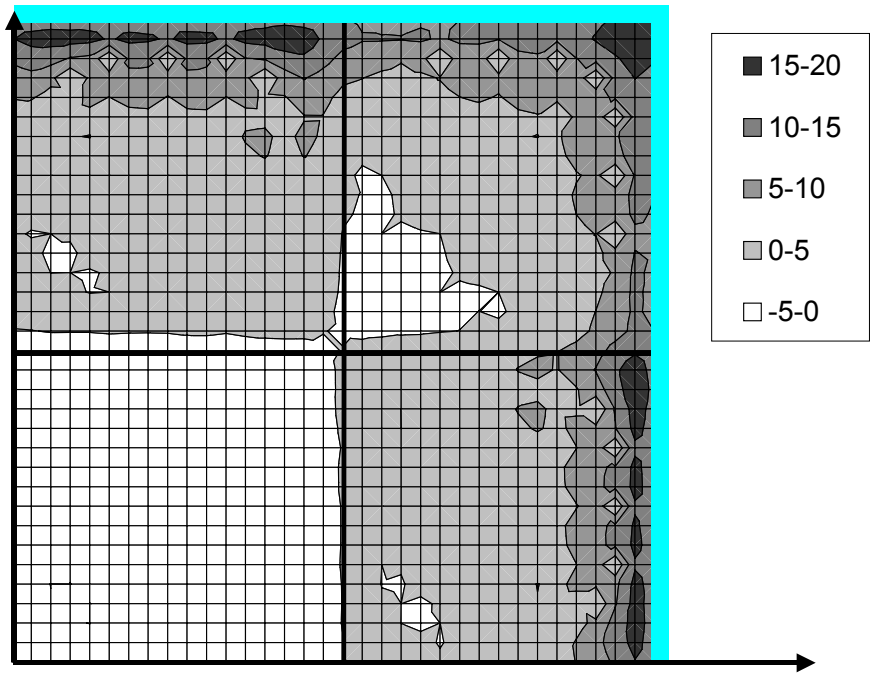

Figure 1. Pin-power distributions differences for Benchmark problem with MARPIJ code.
((REF-MARPIJ)/REF*100).

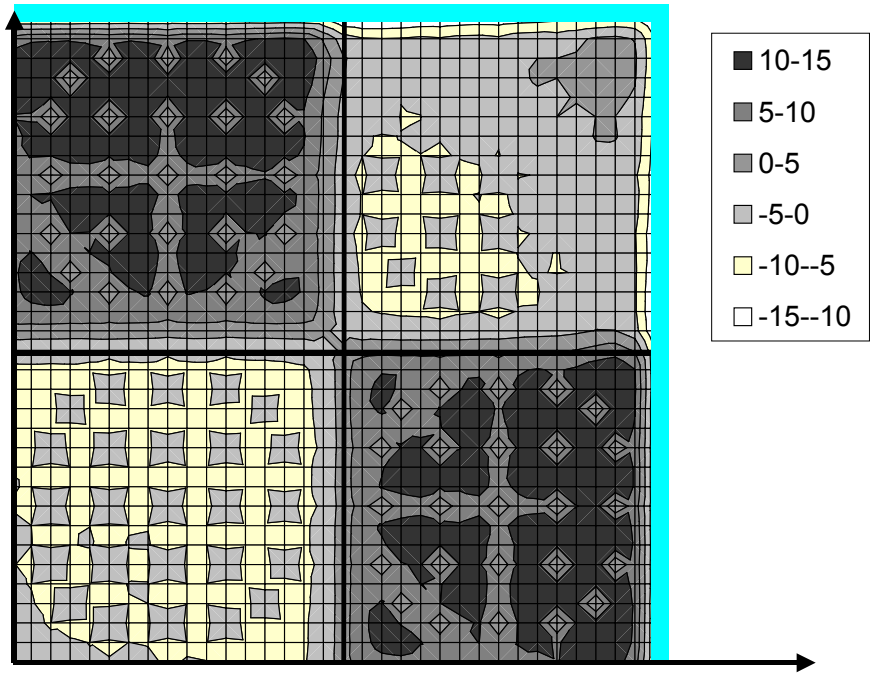

Figure 2. Pin-power distributions differences for Benchmark problem with COBAYA code.
((REF-COBAYA)/REF*100).

4. INTRAGROUP SPECTRAL CHANGES DUE TO NEIGHBORHOOD EFFECT

Boundary conditions with different neighbor cells or nodes (reflector) produce intragroup spectral effects in each type of pin cell. Changes in the two group cross sections and discontinuity factors, for the regular or infinite pin cells or nodes are physically due to changes in the local and global intragroup spectral distribution. [4] Figure 3 shows the Σ_{ab2} versus thermal buckling, for every pin cells embedded in the Benchmark configuration. Neighborhood effect is clearly shown for all pin cells of this configuration (UO2 and MOX with different enrichments), showing the separability of this effect.

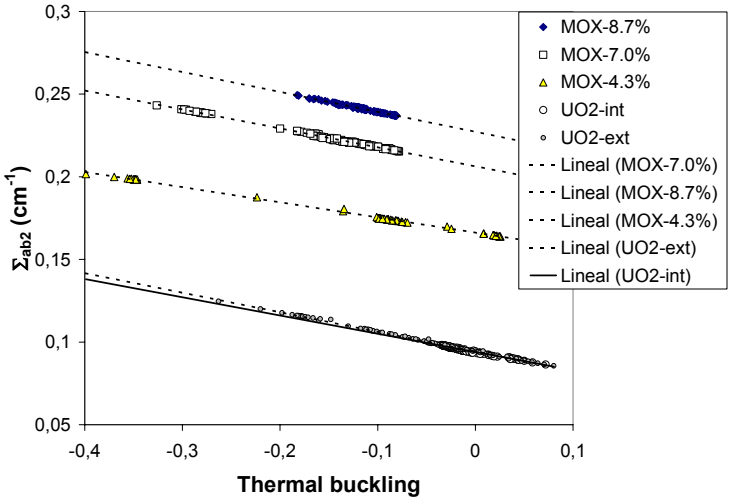

Figure 3. Macroscopic thermal absorption cross section versus thermal buckling for different pin cells (UO2 internal and external fuel assemblies, MOX-4.3%, MOX-7.0%, MOX-8.7%) in Benchmark problem.

Pin-cell discontinuity factors in fine mesh have been calculated, using the calculated pin-by-pin fluxes and cross sections, to preserve the transport net currents in the pin cell formulation:

$$J^{g}_{i\to i+1,j} = -D^{g}_{i,j}\nabla\phi^{g}_{i,j} J^{g}_{i\to i+1,j} = -D^{g}_{i,j}\frac{f^{g}_{i+1/2,j}\cdot\phi^{g}_{i+1/2,j} - \phi^{g}_{i,j}}{h_{i,j}/2} \quad (1)$$

A Gauss-Newton algorithm was formulated with the simplified approximation of:

$$f^{g}_{i\to i+1,j} \approx f^{g}_{i\to i-1,j} \approx f^{g}_{i,j\to j+1} \approx f^{g}_{i,j\to j-1} \approx f^{g}_{i,j} \quad (2)$$

These discontinuity factors include the spectral heterogeneity boundary conditions and also include the transport correction to the solution by diffusion method in a fine mesh calculation. In Figure 4, fast-group discontinuity factors per type of pin cell are shown. Near reflector, where spectral effects are more important, fast group discontinuity factors are higher.

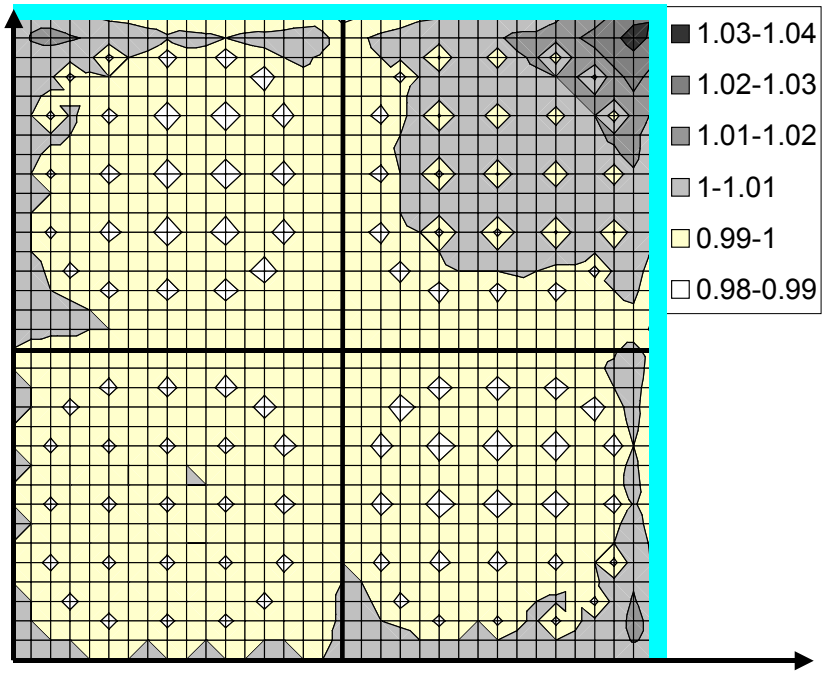

Figure 4. Pin-cell fast-group discontinuity factors in fine mesh calculated for Benchmark problem using MARPIJ code.

5. CONCLUSIONS

The C5G7-MOX Benchmark is an interesting blind exercise to test the ability of current transport codes to treat reactor core problems without spatial homogenisation. With our methodology (MARPIJ and COBAYA codes) we have participated and demonstrated the difficulties to use corrected-transport diffusion codes in this type of problems, due to the spectral heterogeneities relevancy in MOX-UO2 color-set configurations.

Two-group cross sections and discontinuity factors per type of pin cell are analyzed for this case, showing separability dependencies with intragroup spectral changes. This neighborhood effect of each type of pin cell could be examined by performing mini-assembly calculations.

REFERENCES

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3. Aragonés, J.M.., Ahnert, C., A linear Discontinuous Finite Difference Formulation for Synthetic Coarse-Mesh Few- Group Diffusion Calculations", Nuc. Sci. Eng., **94**, 309-322, 1986
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