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Technical note

Accuracy of a 2-level scheme based on a subgroup method for pressurized water reactor fuel assembly models

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ABSTRACT

Until now, a typical computational scheme for the DRAGON5 lattice code was based on a resonance self-shielding method using the Subgroup Projection Method (SPM) coupled with a flux calculation using the Method of Characteristics (MOC), both solved over a 295-group Santamarina–Hfaiedh energy mesh (SHEM). We are investigating the accuracy of an optimized 2-level computational scheme based on a condensation stage from 295 to 26 energy groups. A first level flux calculation is performed using the Interface Current (IC) method on the 295-group mesh, followed by a detailed second level flux calculation using the MOC on the 26-group mesh. Here, we validate the 2-level scheme by comparison with the 1-level scheme and with Monte Carlo calculations at burnup 0 and with isotopic depletion. Validation results were obtained using Monte Carlo codes SERPENT2 and TRIPOLI4. This study shows that an optimized 2-level scheme is much faster than the corresponding 1-level scheme and leads to numerical results without a significant degradation in term of precision. The proposed 2-level schemes are therefore candidate for CPU-efficient production tools for generating multi-parameter reactor databases.

1. Introduction

Recent developments in DRAGON5 (Hébert, 2014) allow much more flexibility in the design of computational schemes for deterministic calculations, particularly for Light Water Reactors assemblies. Main improvements are specifically the possibility of using an external geometry based on CAD-software such as SALOME (Ribes and Caremoli, 2007) and the use of the Subgroup Projection Method (SPM) with improved 295- or 361-group energy mesh libraries known as SHEM295 and SHEM361 Hébert (2009). The 295-group mesh gives us the possibility to use less groups than the original 361-group mesh designed by Hébert and Santamarina but requires a self-shielding starting at 4.63 eV instead of 22.5 eV Hfaiedh (2006). The 361-group mesh is an optimization of the 281-group Santamarina–Hfaiedh energy mesh (SHEM281) used in the CEA SHEM-MOC scheme where the number of energy groups between 22.5 eV and 11.14 keV is increased so that to accommodate the SPM. Both SHEM295 and SHEM361 can be used with the SPM, but SHEM281 cannot Canbakan (2014).

Recent works showed the viability of a subgroup method in DRAGON5 but only with a 1-level flux calculation (Canbakan, 2014). Here, we try to follow the same methodology for a 2-level scheme, with a burnup 0 and an isotopic depletion validation[1]. In this work, we present our optimized scheme for DRAGON5 with a subgroup/SHEM295 model. The chosen geometry is an eighth PWR assembly with three type of fuel. First, a study with UOX is done, then a MOX case with three values of plutonium content and finally an UOX assembly with UO2 cells containing gadolinium (burnable poison) so as to compensate initial reactivity. They should represent configurations currently used in French PWRs. We have selected fuel assemblies, instead of singular pincells in order to pinpoint errors due to heterogeneities with the water holes.

The validation process is based on three different codes: DRAGON5 as a lattice code running the optimized scheme, SERPENT2 (Leppänen, 2007) as a burnup 0 stochastic reference and as an isotopic depletion code. All SERPENT2 runs were performed with 4000 cycles of 4000 source neutrons each. TRIPOLI4 (Dumonteil et al., 2007) was selected to double-check our burnup 0 validation because we already have results with satisfactory uncertainties (less than 2 pcm). The same TRIPOLI4 reference calculations were used in a previous study related to the development of a new reference scheme in the APOLLO2 code Canbakan (2014, 2015). All TRIPOLI4 runs were performed with 10000 cycles of 10000 source neutrons each.

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[1] The word *validation* is used as a synonym of *code-to-code benchmarking*.

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Two kind of validation is done: a microscopic study with a comparison of the absorption (capture + fission) rates split in two groups (below 0.625 eV as a thermal group and over 0.625 eV as a fast group). In addition, the effective multiplication factor k_{eff} is compared as a macroscopic system characteristic. For the burnup study, k_{eff} is still presented and we show the isotopic concentrations for some actinides and some fission products in selected cells.

2. The 2-level lattice scheme

Here we introduce the concept of a 2-level scheme for Light Water Reactors, as proposed in our work. The main objective of a 2-level scheme is to reduce significantly the execution time required to produce a multi-parameter reactor database in an industrial software environment. Even if this scheme is based on the REL2005 logic (Vidal et al., 2007), our implementation differs.

Beside running a different code (REL2005 is based on APOLLO2), a different self-shielding approach is used. Here, we choose a subgroup approach whereas in the CEA scheme, a Sanchez-Coste (Livolant and Jeanpierre, 1974; Coste-Delclaux, 2006) method is preferred. So it implies a finer mesh above 22.5 eV, which is the reason for selecting SHEM295 instead of a SHEM281.

The methodology behind the proposed scheme is based on two levels. The first-level flux calculation is done with a double-P_1 interface current (IC) approximation (based on cell-wise P_{ij} calculations) with a refined energy mesh (SHEM295) and a coarse spatial mesh based on a DRAGON-defined lattice geometry (i.e., defined using the `GEO:` module). Then a superhomogénéisation (SPH) reaction rate equivalence may be applied (Hébert, 2009) before performing the second level. The second-level flux calculation is a solution of the transport equation based on the Method of Characteristics (MOC) with 26 energy groups and discretized over a refined spatial mesh. This spatial mesh, known as *windmill*-type and depicted in Fig. 2, have been obtained by an external application adapted to the Geometry module of the SALOME platform (Ribes and Caremoli, 2007; Pora, 2011).

Each step of the 2-level scheme is presented in Fig. 1 and can be summarized as follows:

1. In the first step, all necessary elements such as nuclear data and tracking files are read and a resonance self-shielding calculation is performed above 4.63 eV. The self-shielding calculation is performed using the SPM together with a double-P_1 IC calculation for solving the subgroup equations. Here, we chose to split the fuel pellets into 4 rings, so as to give an accurate representation of majors isotopes absorption and in order to represent distributed self-shielding cross sections effects. At this stage, a transport-corrected P_0 scattering is selected.
2. Then, a first-level double-P_1 IC flux calculation is performed over a 295-energy group energy mesh and a coarse spatial mesh. The aim is to get a fast estimation of the flux.
3. An optional SPH equivalence can be done. Because of the cross sections collapsing, a loss of precision is expected which can be partially corrected by the SPH method, as explained in Section 4.4 of Ref. Hébert (2009). The idea is to collapse the

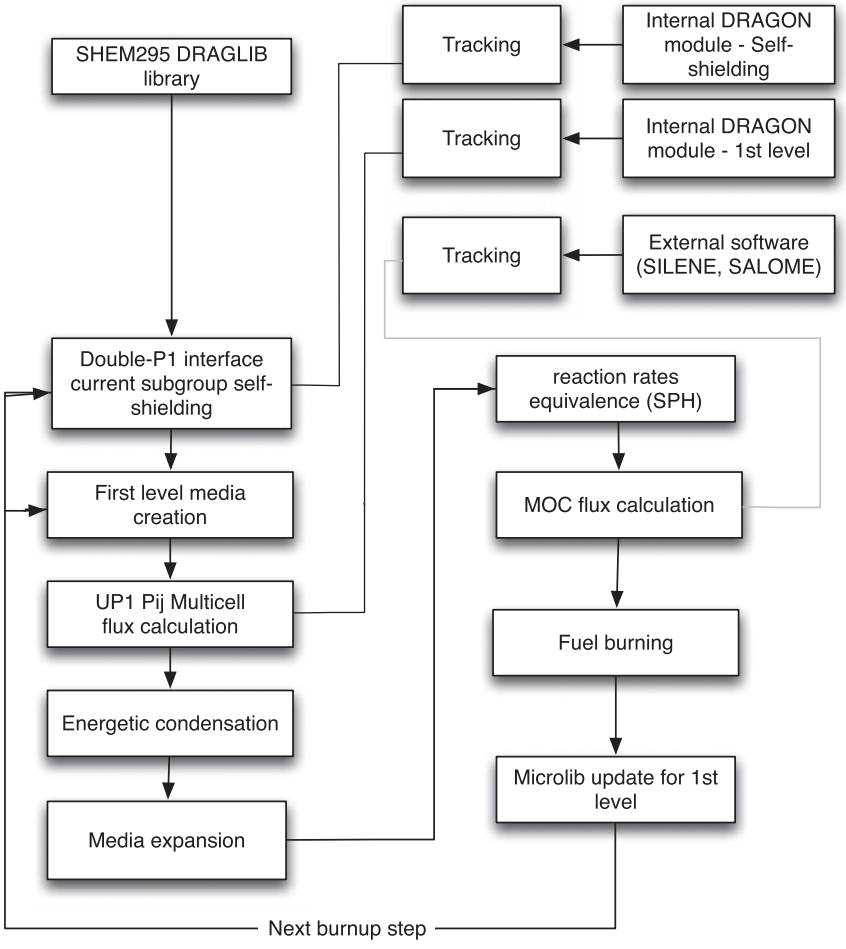

Fig. 1. 2-level scheme for DRAGON5 lattice code.