**TECHNICAL REPORT**
**IGE-349**

# Implementation of pin power reconstruction capabilities in the DRAGON5/PARCS system

## Final report

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# 1 Context and Algorithms

## 1.1 Context

The mission of the *Service de Neutronique et des risques de Criticité* (SNC) of the IRSN is to develop an expertise in the safety of nuclear reactors. Its two main domains of application are criticality-safety and reactor physics which includes the ORION project. In this project, the SNC uses the transport neutronic code DRAGON5 [1–4] from *École Polytechnique de Montréal*, and the core neutronic code PARCS [5] from *University of Michigan*. This DRAGON5-PARCS association is unique to the SNC. However with the actual configuration, a limitation is encountered regarding the pin-power reconstruction. This feature is available in the PARCS code, but it requires additional information that are not regularly computed or stored in the lattice code DRAGON5. The purpose of this study is then to adapt the DRAGON5-PARCS system to be able to perform PPR. The new feature will tested against full transport and other code systems on simple core configuration (3x3 clusters) [6,7].

## 1.2 Codes

The computer code DRAGON5 is a lattice code designed around solution techniques of the neutron transport equation.[8] The DRAGON project results from an effort made at *École Polytechnique de Montréal* to rationalize and unify into a single code the different models and algorithms used in a lattice code. One of the main concerns was to ensure that the structure of the code was such that the development and implementation of new calculation techniques would be facilitated. DRAGON5 is therefore a lattice cell code which is divided into many calculation modules linked together using the GAN generalized driver[9,10]. These modules exchange informations only via well defined data structures.

Similarly, the computer code DONJON5 is the core code designed around solution techniques of the neutron diffusion equation. The same approach was followed to program the DONJON5 code as for DRAGON5 : modules, defined data structures and the GAN generalized driver. The main interface between the two codes are the data structures used to store cross-sections. There are several types : CPO, MULTICOMPO, SAPHYB, .... The major difference is that cross-sections may depend of the burnup only with the first type, whereas with other types additional parameters can vary. The MULTICOMPO is selected for this project.

PARCS is a three-dimensional (3D) reactor core simulator which solves the steady-state and time-dependent, multi-group neutron diffusion and low order transport equations in orthogonal and non-orthogonal geometries. PARCS is coupled directly to the thermal-hydraulics system code TRACE [11] which provides the temperature and flow field information to PARCS during the transient calculations via the few group cross sections. PARCS is also coupled to the systems code RELAP5 [12] using the PVM message passing interface [13]. PARCS is available as a standalone code for performing calculations which do not require coupling to TRACE or RELAP5. A separate code module, GENPMAXS [14], is used to process the cross sections generated by lattice physics codes such as HELIOS [15] or CASMO [16] into the PMAXS format that can be read by PARCS.

In this project, the following version of the codes were used :

- PARCS : v32m17co
- GenPMAXS : v6.1.3co
- DRAGON and DONJON : v5.0.1. Several development subversions were used. The last version used (ev406) contains all necessary changes in the fortran programming (D2P :, COMPO :, ...) and the documentation.

## 1.3 The Pin Power Reconstruction

### *1.3.1 Theory*

The pin-by-pin power reconstruction method can be seen as a de-homogenization technique for core calculations using homogenized fuel assembly geometries. The approach in PARCS consists in using discontinuity and form factors to retrieve the pin power. The whole theory is explained in detailed in the

PARCS theory manual [5]. In summary, the starting point is the flux distribution obtained with the nodal method and using the *adf* values to guaranty the flux continuity at heterogeneous assembly interfaces. The method provides also the current on the interfaces. Then, the next step is to determine the flux in the corner of the assemblies. Following the obvious principle that neutrons can not accumulate at a corner, a neutron balance equation is formulated at each of corners of the node. This is the corner point balance (CPB). Next, using the flux in the corner, the intra-nodal flux is computed for each pin at a pin position $(x, y)$, $\phi_g(x, y)$. Finally, the pin power $p$ is determined with the form function $f_g$ and the homogeneous intra-nodal flux $\phi_g$, as follows :

$$p(x,y) = \sum_{g=1}^{2} \kappa\overline{\Sigma}_{fg}\phi_g(x,y)f_g(x,y) \tag{1.1}$$

where the form functions, needed for dealing with the local heterogeneity in material composition within a fuel assembly, are generated along with the homogenized group constant during the single assembly calculation. The form functions are defined group-wise as :

$$f_g(x,y) = \frac{\kappa\Sigma_{fg}(x,y)\varphi_g(x,y)}{\kappa\overline{\Sigma}_{fg}\overline{\varphi}_g} \tag{1.2}$$

The pin power reconstruction is then based on the customary assumption that the form function in the core is not very different from the form function generated in a single assembly with reflective boundary conditions.

The pin power reconstruction was also implemented in the DRAGON5/DONJON5 codes as a new module named 'NAP :' [17]. In this report, it was also demonstrated that the flux need to be interpolated for each pin position before the power reconstruction can be made.

### *1.3.2 Algorithm*

The general algorithm for pin power reconstruction is summarized in Fig. 1.

The computation of the *assembly discontinuity factors* (*adf*), *corner discontinuity factors* (*cdf*) and *group form factors* (*gff*) are performed in two steps :

1. DRAGON5 with `EDI:` where the flux value is computed
   - on the sides $adf_a$ → `EDI: MERG COMP ADF 'FD_B' REGI` ... or `MIX` ... (see following note)
   - in the corners $cdf_a$ → `EDI: MERG COMP ADF 'FD_C' REGI` ... or `MIX` ... (see following note)
   - in each pin $gff_a$ → `EDI: MERG CELL [ UNFOLD ] [ REMIX ... ]`
2. DONJON5 with `D2P:` were the relative flux factors are computed.
   - on the sides *adf* → `D2P: ADF DRA 'FD_B'`
   - in the corners *cdf* → `D2P: CDF DRA 'FD_C'`
   - in each pin *gff* → `D2P: GFF DRA`

Note : To compute the flux values $adf_a$ and $cdf_a$ in the `EDI:` module, region numbers corresponding to water gap are required. However this information may be difficult to recover specially if the geometry is finely detailed. To make things easier, the user can declare the regions of interest with a specific mixture number and use the `MIX` keyword afterwards. The 'FD_B' and 'FD_C' names are only examples here.

The number of values for *adf*, *cdf*, *gff* and their format are described in Sec. 17.8.3, 17.8.4 and 17.8.5 of the GenPMAXS manual [14].

In the `D2P:` module, the symmetries are handle as follows. First, since the choice of the PARCS user may be different of the DRAGON user in terms of assembly symmetries, in the phase 2 when the cross-sections are recovered for all burnups of one set of parameters, the temporary *gff* values are stored unfolded. Then, in phase 3, when the HELIOS file is generated, the final values of the *gff* are refolded according to the PARCS user choice (*npart*).

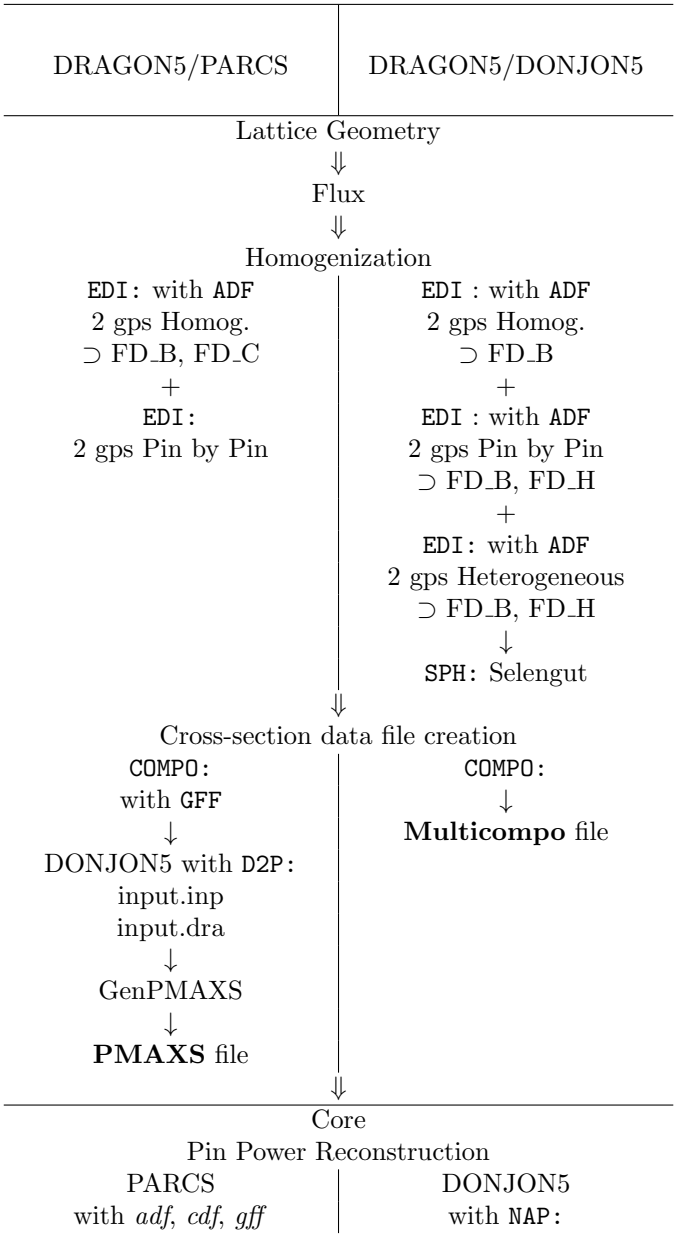



FIGURE 1 – DRAGON5-PARCS vs DRAGON5-DONJON5 general PPR algorithm

### *1.3.3 Definition of the volume associated to GFF*

The GFF have to be computed on the volume of a pin : fuel, cladding and water. However, for the outer pin, it is important NOT to include the water gap, otherwise the *gff* values will be 'diluted'. See definition in the GenPMAXS manual Eq. 10.13 for more details.

### *1.3.4 Definition of an eight-symmetric geometry in PARCS*

PARCS allows to use symmetry in the *gff* definition (*npart*= 0 to 3). Note that in case of a forth (*npart*= 2) or eighth (*npart*= 3) assembly, the user guide of GenPMAXS manual shows that the *gff* value correspond to the South-East quadrant. This information is currently misleading for the HELIOS format were the *gff* have to be specified for the **North-West** quadrant (until Parcs-v32m17co and GenPMAXS-v6.1.3co). However, starting from PARCS v32m18 and GenPMAXS v6.2, this issue will be corrected and the GFF numbering for HELIOS format will be consistent with other codes and the GenPMAXS user guide.

### *1.3.5 Calculations without GFF*

In version v6.1.3co of GenPMAXS, several parameters are set to 0 in the resulting PMAXS file when LGFF is set to false (i.e. no *gff* value provided). This results in an error during the PPR. To get around this issue, the following parameters have to be edited in the PMAXS file :

- MRODS : Maximum number of rods in computed part of assembly for all XS set, in the GLOBAL_V block (first line)
- MCLOA : Maximum number of rod columns in whole assembly for all XS set, in the GLOBAL_V block (first line)
- PITCH : the lattice pitch, in the XS_SET block
- XBE : start position for first column rods (i.e. the water gap size), in the XS_SET block
- YBE : start position for first row rods (i.e. the water gap size), in the XS_SET block

This issue should be fixed in GenPMAXS v6.2. However, as it will be illustrated in Sec. 3.5, it is not recommended to perform PPR without GFF.

### *1.3.6 Relations with PARCS-help*

Several issues were addressed to and answered by PARCS-help along this project by email. The most worth-noticing are listed here :

- No version for Mac OS-X is supported for GenPMAXS and PARCS.
- The GFF numbering documentation was misleading in the HELIOS case. The D2P : guide has been modified to clarify this issue.
- The neutronic mesh is limited at 2x2 per assembly for PPR.
- First results were not coherent with expectations. Better results were obtained when no CDF nor ADF values were used. The issue was coming from the inaccurate values of the *xbe* and *ybe* parameters (centre of the first pin instead of the corner), leading to an interpolation of the flux during PPR at the wrong position. The D2P : guide has been modified to clarify their definition.
- The issue with PMAXS files with several parameters set at 0 when no GFF option is selected (thanks to Xu Yunlin).
- Collaborations were made to test a new solver 'SENM' on this project test case C6. Other cases results should be coming soon from Andrew Ward.
- Changes expected in the coming versions of PARCS and GenPMAXS.

Noticable changes are expected in the next verion of PARCS and GenPMAXS, as explained in a email from A. Ward from PARCS-help :

*... the next version of PARCS v32m18 and GenPMAXS v6.2 will expect the GFF for 1/8 assembly to be*

*in this location. We will set internal values for the pitch, xbe, and ybe if not given, and also, we will warn the user that any calculations are not physical, etc.*

```
*   *   *   *   *   *   *   *   *
*   *   *   *   *   *   *   *   *
*   *   *   *   *   *   *   *   *
*   *   *   *   *   *   *   *   *
*   *   *   *   x   *   *   *   *
*   *   *   *   x   x   *   *   *
*   *   *   *   x   x   x   *   *
*   *   *   *   x   x   x   x   *
*   *   *   *   x   x   x   x   x
```

### 1.4 Data preparation with `D2P:` module

The `D2P:` module reformats the macroscopic cross-section data generated by DRAGON5 into a file readable by the GenPMAXS software. It also produces the input file used by GenPMAXS to create the PMAXS file (for PARCS simulation).

The macroscopic cross-section data previously generated by DRAGON5 can have 2 formats : *Saphyb* (SAP) or *Multicompo* (MCO). The procedure to use the `D2P:` module is very similar in both cases. It follows a 3 phases procedure as illustrated in Fig. 2.

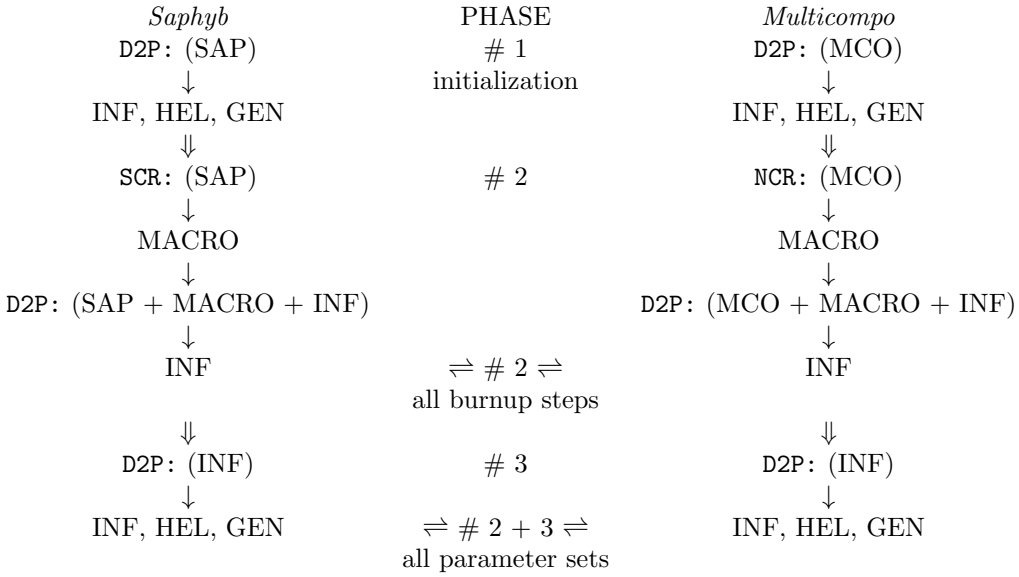



FIGURE 2 – Data preparation with `D2P:` module algorithm

The first phase initializes the HELIOS-like data file (HEL) and the GenPMAXS input file (GEN). Before phase 2 starts, one set of parameter is chosen. Then, for all burnup steps, the macroscopic cross-sections are computed and stored in the INF file. When all burnups are covered, the data are reformated and copied in the HELIOS-like data file and the GenPMAXS input file during phase 3. Phases 2 and 3 are repeated for all sets of parameters.

## 2 Modified modules

Two modules and two data structures have been modified to provide all the requested data by PARCS to perform the Pin Power Reconstruction :

- `COMPO:` from DRAGON5
- `D2P:` from DONJON5
- L_MACROLIB from DRAGON5
- L_INFO from DONJON5

The changes introduced in the `COMPO:` (see Sec. B.1) have consequences on the Pin Power Reconstruction performed with DONJON5. The `NAP:` and `RESINI:` module had to be also modified to take into account the evolution of the MULTICOMPO data structures.

All the modifications are already documented in the different manuals of the DRAGON and DONJON codes. They can be found in the most recent development version. However, in order to keep the information related to this work all in one place, the modifications are reproduced in Appendix B.

# 3 Validation

## 3.1 Test cases description

To test the implementation of the pin power reconstruction in the DRAGON-PARCS association, simplified core are simulated. The tested configurations corresponds to several 3x3 assemblies of PWR-900 including UOX and MOX at different burnup. The simulated clusters were originally proposed by Fliscounakis [7] and also used in a previous work with the DRAGON5/DONJON5 system [17]. They are described below :

Assembly positions by type

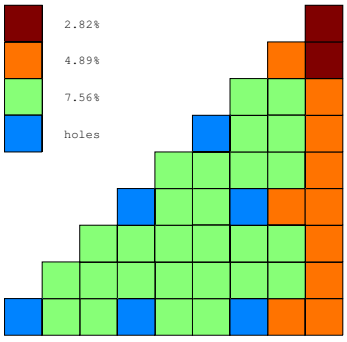
| | | |
|---|---|---|
| C | B | C |
| B | A | B |
| C | B | C |

Assembly types by case

| Case | Burn-up (GWd/t) | | | Boron (ppm) |
|---|---|---|---|---|
| | A | B | C | |
| C1 | 0 (M) | 0 (U) | 20 (U) | 1700 |
| C2 | 20 (M) | 10 (U) | 60 (U) | 715 |
| C3 | 10 (M) | 30 (M) | 20 (U) | 2000 |
| C4 | 20 (M) | 50 (M) | 0 (M) | 1100 |
| C5 | 20 (M) | 20 (U) | 20 (U) | 1600 |
| C6 | 0 (U) | 30 (M) | 30 (M) | 715 |
| C7 | 0 (M) | 0 (M) | 60 (U) | 1100 |
| C8 | 60 (M) | 10 (U) | 40 (M) | 900 |
| C9 | 12 (U) | 12 (U) | 12 (U) | 2200 |
| C10 | 0 (U) | 36 (U) | 12 (U) | 1400 |
| C11 | 20 (M) | 0 (U) | 40 (U) | 2000 |
| C12 | 12 (M) | 12 (M) | 12 (M) | 2000 |

where U and M refers to UOX and MOX assembly respectively

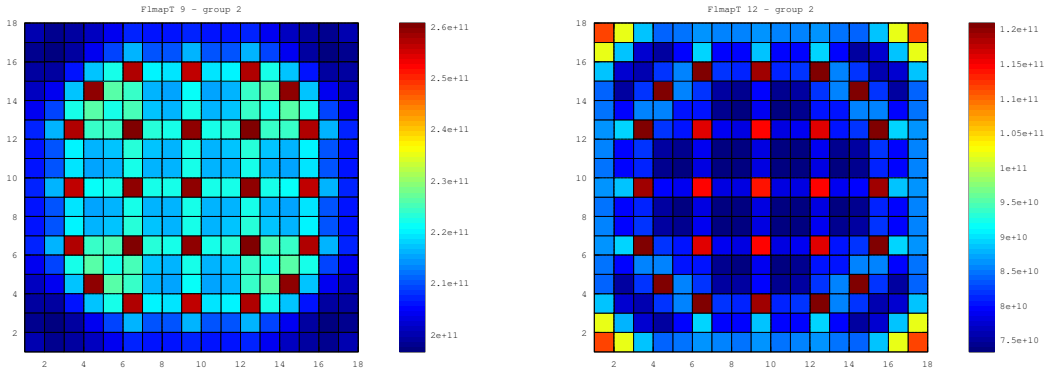
The UOX assembly is enriched at 3.7%. The MOX assembly is composed of 3 different pins where the compositions are : Pu 7.56%(inner) or 4.89%(side) or 2.82%(corner) with depleted U (0.25% enrichment) and dispatched as illustrated below :




The isotopic content of the Pu is :

| Iso. | Fraction (%) |
|---|---|
| Pu-238 | 1.2 |
| Pu-239 | 59.5 |
| Pu-240 | 24.1 |
| Pu-241 | 9.0 |
| Pu-242 | 4.7 |
| Am-241 | 1.5 |

UOX (12GWd/t) MOX (12GWd/t)




(a) (b)

Note : the color difference at the boundary with the average illustrates the approximate value of ADF and CDF in group #2

FIGURE 3 – Average thermal flux for each cell (pin and surrounding water) computed in transport

### 3.2 Preliminary results

The 12 configurations were simulated using typical values of assembly and corner discontinuity factor : ratio of the flux in the water gap all around the assembly and in the corner respectively with the average flux respectively. The preliminary results of the simulations are compared to those obtained directly by transport calculations with DRAGON. The PARCS simulations were performed with the default solver (HYBRID) with larger convergence criteria and a 2x2 neutronic mesh. A summary of the results is presented in Tab. 1. The minimum and maximum difference are expressed in percentage with the full transport computations used as reference (DRAGON). The range of error varies between approximately 3% and 12%, excepted for the 2 uniform configurations where the range is less than 0.7%.

These are general results. To get a better idea of DRAGON-PARCS PPR performance, the distributions of the difference are presented on Fig. 4 for all configurations (only the N-E quadrant is presented since the cluster is symmetrical). The color range is specific for each case, and is defined by [ minimum error - 5% , maximum error + 1% ]. The results show that the main largest difference are usually at the interface between assemblies. This implies that the discontinuity values (*cdf* and *adf*) may have a large influence on the results. The *cdf* and *adf* calculation methodologies will be looked at in the two following sections.

To get a more quantitative understanding of the error distribution, a table of the error distribution is presented on Fig. 5 for the case with the largest range of error (C6).

### 3.3 CDF calculation methodology

In this section, the sensitivity of the results with the CDF is assessed. As previously mentioned, the flux in the corner of the assembly is used to perform the pin power reconstruction. The CDF are defined as follows :

$$cdf = \frac{\phi_{het,c}}{\overline{\phi}} \tag{3.1}$$

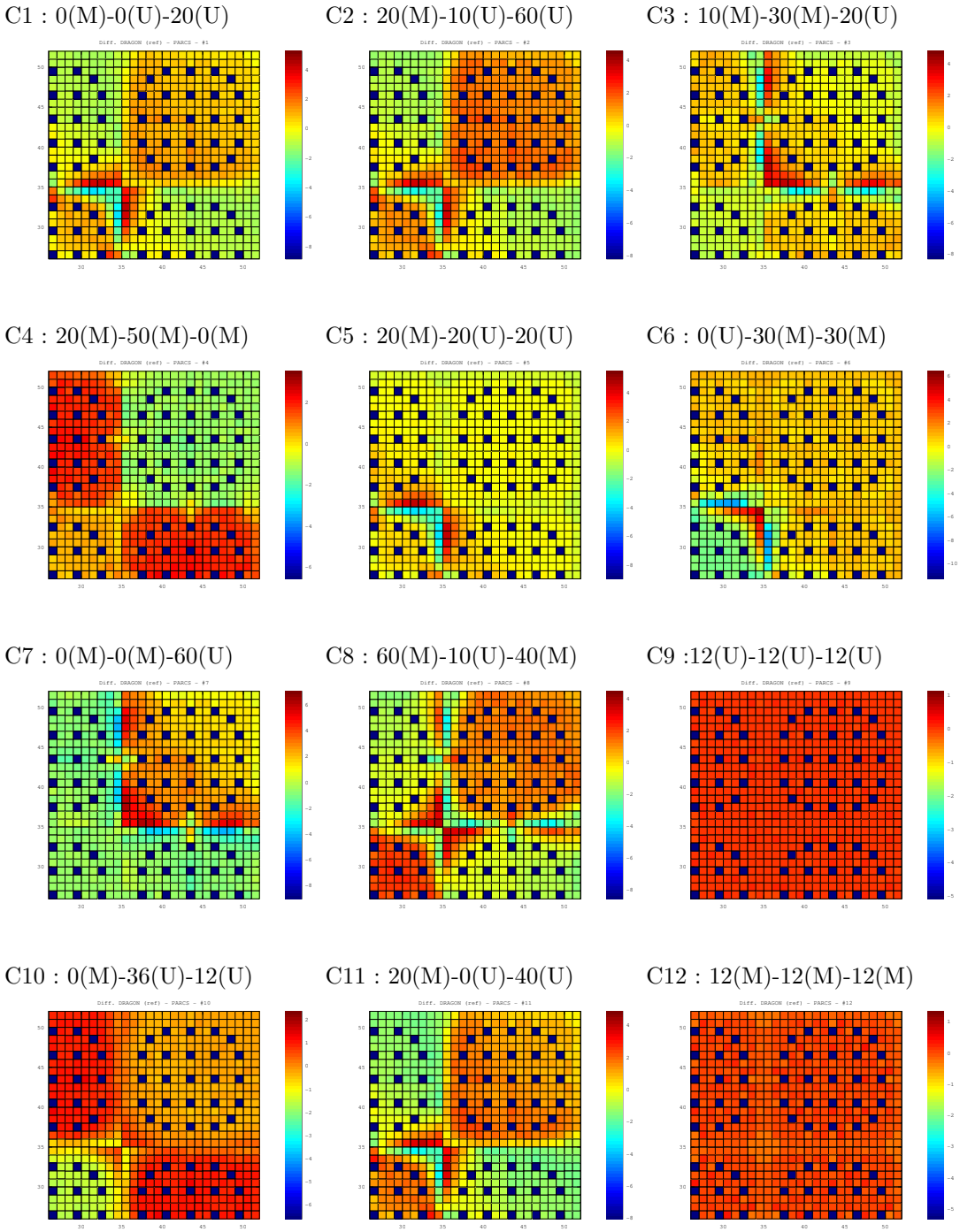



FIGURE 4 – PARCS vs Transport pin power distribution of all clusters (diff. in %), 'FD_C' + 'FD_B' options

TABLE 1 – Relative error between reconstruction and transport calculations, PARCS - DRAGON, FD_C+FD_B

| Case | Description | min | max | $\delta$ | std |
|---|---|---|---|---|---|
| C1 | 0(M)-0(U)-20(U) | -3.85 | 4.23 | 8.08 | 1.11 |
| C2 | 20(M)-10(U)-60(U) | -3.20 | 3.52 | 6.71 | 1.24 |
| C3 | 10(M)-30(M)-20(U) | -3.30 | 3.78 | 7.08 | 1.00 |
| C4 | 20(M)-50(M)-0(M) | -1.59 | 2.52 | 4.11 | 1.37 |
| C5 | 20(M)-20(U)-20(U) | -3.96 | 4.46 | 8.43 | 0.85 |
| C6 | 0(U)-30(M)-30(M) | -6.32 | 5.39 | 11.71 | 1.31 |
| C7 | 0(M)-0(M)-60(U) | -4.03 | 6.03 | 10.06 | 1.96 |
| C8 | 60(M)-10(U)-40(M) | -3.61 | 3.45 | 7.07 | 1.36 |
| C9 | 12(U)-12(U)-12(U) | -0.09 | 0.12 | 0.21 | 0.04 |
| C10 | 0(M)-36(U)-12(U) | -1.62 | 1.36 | 2.99 | 0.75 |
| C11 | 20(M)-0(U)-40(U) | -3.06 | 3.85 | 6.91 | 1.39 |
| C12 | 12(M)-12(M)-12(M) | -0.33 | 0.33 | 0.66 | 0.12 |

FIGURE 5 – Relative error between reconstruction and transport calculations for case 6(%) , FD_C+FD_B

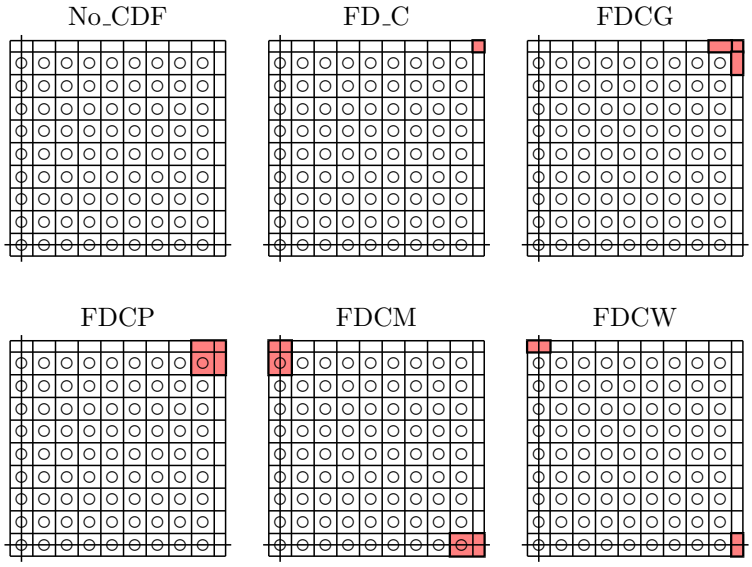
| | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.9 | 0.9 | 0.9 | 0.8 | 0.8 | 0.9 | 0.8 | 1.1 | 1.1 | 1.0 | 1.0 | 0.7 | 0.8 | 0.8 | 0.8 | 0.8 | 0.8 | 0.7 | 0.8 | 0.7 | 0.8 | 0.7 | 0.8 | 0.7 | 1.0 | 1.0 |
| 0.9 | 0.6 | 0.4 | 1.1 | 0.4 | 0.3 | 0.2 | 0.9 | 1.0 | 1.0 | 0.8 | 0.1 | 0.3 | 0.4 | 1.0 | 0.3 | 0.4 | 0.8 | 0.5 | 0.3 | 1.0 | 0.3 | 0.2 | 0.1 | 0.8 | 1.0 |
| ○ | 0.8 | 0.6 | ○ | 0.6 | 0.6 | 0.3 | 0.3 | 0.8 | 0.6 | 0.2 | 0.3 | 0.6 | 0.5 | ○ | 0.4 | 0.7 | ○ | 0.7 | 0.4 | ○ | 0.4 | 0.6 | 0.3 | 0.1 | 0.7 |
| 0.9 | 0.5 | 0.7 | 0.7 | 0.7 | ○ | 0.6 | 0.4 | 0.9 | 0.8 | 0.3 | 0.7 | ○ | 0.6 | 0.7 | 0.6 | 0.5 | 0.6 | 0.4 | 0.6 | 0.7 | 0.6 | ○ | 0.6 | 0.2 | 0.8 |
| 1.0 | 0.5 | 0.5 | 0.7 | 0.7 | 0.7 | 0.5 | 0.3 | 0.8 | 0.8 | 0.3 | 0.5 | 0.6 | 0.6 | 0.5 | 0.5 | 0.4 | 0.9 | 0.4 | 0.5 | 0.5 | 0.7 | 0.6 | 0.4 | 0.3 | 0.7 |
| ○ | 0.8 | 0.9 | ○ | 0.7 | 0.9 | ○ | 1.0 | 0.9 | 0.8 | 1.1 | ○ | 0.7 | 0.6 | ○ | 0.7 | 0.8 | ○ | 0.7 | 0.8 | ○ | 0.5 | 0.7 | ○ | 1.0 | 0.8 |
| 0.6 | 0.7 | 0.6 | 0.9 | 0.7 | 0.8 | 0.6 | 0.5 | 0.9 | 0.8 | 0.4 | 0.4 | 0.5 | 0.5 | 0.7 | 0.4 | 0.6 | 0.7 | 0.5 | 0.6 | 0.8 | 0.5 | 0.6 | 0.4 | 0.3 | 0.7 |
| 0.5 | 0.5 | 0.6 | 0.8 | 0.6 | 0.6 | 0.8 | 0.6 | 0.9 | 0.9 | 0.4 | 0.4 | 0.2 | 0.3 | 0.5 | 0.4 | 0.4 | 0.7 | 0.4 | 0.5 | 0.7 | 0.4 | 0.4 | 0.7 | 0.5 | 0.8 |
| ○ | 0.8 | 1.0 | ○ | 1.4 | 1.1 | ○ | 1.2 | 1.0 | 0.7 | 0.6 | ○ | 0.1 | 0.5 | ○ | 0.2 | 0.6 | ○ | 0.7 | 0.7 | ○ | 0.9 | 0.6 | ○ | 0.8 | 0.7 |
| -0.3 | 0.1 | 0.4 | 0.7 | 0.3 | 0.3 | 0.6 | 0.5 | 1.5 | 0.6 | 0.5 | 0.9 | 0.6 | 0.6 | 0.9 | 0.7 | 0.6 | 0.6 | 0.4 | 0.6 | 0.8 | 0.4 | 0.5 | 0.7 | 0.4 | 0.8 |
| -1.0 | -0.1 | 0.1 | 0.3 | 0.3 | 0.4 | 0.2 | 0.6 | 1.9 | 0.4 | 0.3 | 0.4 | 0.4 | 0.6 | 0.7 | 0.4 | 0.7 | 0.2 | 0.4 | 0.4 | 0.7 | 0.5 | 0.6 | 0.4 | 0.3 | 0.8 |
| ○ | 0.0 | 0.5 | ○ | 0.3 | 0.6 | ○ | 1.2 | 1.8 | 0.4 | 0.9 | ○ | 0.6 | 0.6 | ○ | 0.7 | 0.9 | ○ | 0.5 | 0.7 | ○ | 0.5 | 0.7 | ○ | 1.0 | 0.8 |
| -0.3 | -0.1 | 0.3 | 0.5 | 0.3 | 0.3 | 0.5 | 0.5 | 1.5 | 0.5 | 0.3 | 0.8 | 0.6 | 0.6 | 0.6 | 0.6 | 0.6 | 0.5 | 0.3 | 0.5 | 0.6 | 0.6 | 0.6 | 0.5 | 0.4 | 0.8 |
| -1.1 | -0.4 | -0.0 | -0.2 | 0.3 | ○ | 0.4 | 0.1 | 0.8 | 0.6 | 0.2 | 0.8 | ○ | 0.6 | 0.6 | 0.4 | 0.6 | 0.1 | 0.2 | 0.5 | 0.7 | 0.6 | ○ | 0.6 | 0.3 | 0.8 |
| ○ | 0.2 | -0.1 | ○ | 0.1 | 0.4 | -0.4 | -0.9 | -0.9 | 0.1 | -0.3 | 0.2 | 0.8 | 0.8 | ○ | 0.4 | 0.9 | ○ | 0.4 | 0.4 | ○ | 0.5 | 0.7 | 0.3 | 0.1 | 0.7 |
| 1.3 | -0.8 | -1.6 | -0.6 | -2.1 | -2.4 | -2.3 | -1.6 | -1.8 | 0.2 | -0.1 | -0.3 | 0.2 | 0.3 | 0.9 | 0.3 | 0.5 | 0.6 | 0.4 | 0.4 | 1.1 | 0.3 | 0.3 | 0.2 | 0.8 | 1.0 |
| -1.4 | -4.1 | -5.5 | -5.9 | -6.3 | -6.3 | -4.6 | -1.8 | -1.3 | 0.1 | 0.2 | 0.1 | 0.6 | 0.5 | 0.4 | 0.4 | 0.6 | 0.7 | 0.9 | 0.8 | 0.8 | 0.8 | 0.8 | 0.6 | 1.0 | 1.0 |
| -2.9 | -1.4 | -0.2 | 0.7 | 1.8 | 2.9 | 3.6 | 4.1 | 5.4 | -1.3 | -1.8 | -0.9 | 0.8 | 1.5 | 1.8 | 1.9 | 1.5 | 1.0 | 0.9 | 0.9 | 0.9 | 0.8 | 0.9 | 0.8 | 1.0 | 1.1 |
| -3.3 | -2.3 | -1.8 | -1.6 | -0.8 | -0.1 | 0.7 | 2.1 | 4.1 | -1.8 | -1.6 | -0.9 | 0.1 | 0.5 | 1.2 | 0.6 | 0.5 | 1.2 | 0.6 | 0.5 | 1.0 | 0.3 | 0.4 | 0.3 | 0.9 | 1.1 |
| ○ | -2.5 | -2.3 | ○ | -2.0 | -1.7 | -0.9 | 0.7 | 3.6 | -4.6 | -2.3 | -0.4 | 0.4 | 0.5 | ○ | 0.2 | 0.6 | ○ | 0.8 | 0.6 | ○ | 0.5 | 0.6 | 0.3 | 0.2 | 0.8 |
| -2.3 | -2.4 | -2.4 | -2.3 | -2.2 | ○ | -1.7 | -0.1 | 2.9 | -6.3 | -2.4 | 0.4 | ○ | 0.3 | 0.6 | 0.4 | 0.3 | 1.1 | 0.6 | 0.8 | 0.9 | 0.7 | ○ | 0.6 | 0.3 | 0.9 |
| -2.3 | -2.5 | -2.6 | -2.7 | -2.4 | -2.2 | -2.0 | -0.8 | 1.8 | -6.3 | -2.1 | 0.1 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 1.4 | 0.6 | 0.7 | 0.7 | 0.7 | 0.7 | 0.6 | 0.4 | 0.8 |
| ○ | -2.6 | -2.6 | ○ | -2.7 | -2.3 | ○ | -1.6 | 0.7 | -5.9 | -0.6 | ○ | -0.2 | 0.5 | ○ | 0.3 | 0.7 | ○ | 0.8 | 0.9 | ○ | 0.7 | 0.7 | ○ | 1.1 | 0.8 |
| -2.3 | -2.5 | -2.6 | -2.6 | -2.6 | -2.4 | -2.3 | -1.8 | -0.2 | -5.5 | -1.6 | -0.1 | -0.0 | 0.3 | 0.5 | 0.1 | 0.4 | 1.0 | 0.6 | 0.6 | 0.9 | 0.5 | 0.7 | 0.6 | 0.4 | 0.9 |
| -2.3 | -2.5 | -2.5 | -2.6 | -2.5 | -2.4 | -2.5 | -2.3 | -1.4 | -4.1 | -0.8 | 0.2 | -0.4 | -0.1 | 0.0 | -0.1 | 0.1 | 0.8 | 0.5 | 0.7 | 0.8 | 0.5 | 0.5 | 0.8 | 0.6 | 0.9 |
| ○ | -2.3 | -2.3 | ○ | -2.3 | -2.3 | ○ | -3.3 | -2.9 | -1.4 | 1.3 | ○ | -1.1 | -0.3 | ○ | -1.0 | -0.3 | ○ | 0.5 | 0.6 | ○ | 1.0 | 0.9 | ○ | 0.9 | 0.9 |

The heterogeneous flux in the corner $\phi_{het,c}$ is obtained together with the other properties during the condensation and homogenization procedure. The choice of the regions, where the heterogeneous flux is computed from, influences directly the value of the CDF, and consequently the reconstructed pin power. In PARCS, the user can provide one value of CDF per corner only, or with and additional value for the middle per side of the assembly.

Several choices have been made to compute the CDF in DRAGON :

- case 'No_CDF' : all CDF values are equal to default value of 1.
- case 'FD_C' : the water gap in the corner
- case 'FDCG' : the water gap in corner and along the corner pin
- case 'FDCP' : the whole corner pin and the surrounding water gap
- case 'FDCP+FDCM' : one value for the whole corner pin and the surrounding water gap and one value for the pin and water gap in the middle of the assembly surface
- case 'FD_C+FDCW' : one value for the water gap in the corner and one value for the water gap beside the pin in the middle of the assembly surface

For a better understanding the different options are graphically presented below :




quarter of assembly, water gap is not on scale

The general results are presented on Tab. 2. Again, the PARCS simulations were performed with the default solver (HYBRID) with larger convergence criteria and a 2x2 neutronic mesh.The results show that the default value of 1 for CDF leads to much larger errors and should not be used. Otherwise, the minimum and maximun errors are almost the same whichever the CDF volume is chosen, except for the last option 'FD_C+FCDW' which leads to slightly better results in general. The only exception to the previous observation is the case with the largest range of error (C6). In that case, the maximum error is more dependant of the CDF choice.

Even if the results may look very similar at a first glance, since we noticed in the previous section that the maximum error is located at the interface between the assemblies, a closer look at the error distribution is presented in Tab. 3 for case C6 (the case with the largest range of error). The results shows that the volume choice for the CDF has a non-negligible influence. First, when the default value of 1 is used the error varies differently along the interface in the fresh UOX assembly.

The errors in the corner pins (where the three types of assembly are joined) are for case C6 :

- -3.9/2.0/3.6 with the default option
- 5.4/-1.3/0.1 with the 'FD_C' option
- 4.6/-1.0/0.4 with the 'FDCG' option
- 2.9/-0.4/1.0 with the 'FDCP' option
- 2.7/-0.4/1.0 with the 'FDCP+FDCM' option
- 5.0/-1.2/0.0 with the 'FD_C+FDCW' option

The range of error varies between 3.1% ('FD_C' option) and 7.5% (no CDF option) which represents an approximative 4% absolute difference.

TABLE 2 – Relative error (%) between reconstruction and transport calculations, PARCS - DRAGON, influence of ADF and CDF volume choices (part 1)

| adf | FD_B | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| cdf | No_CDF | | | FD_C | | | FDCG | | | FDCP | | | FDCP+ FDCM | | | FD_C+ FDCW | | |
| | min | max | std | min | max | std | min | max | std | min | max | std | min | max | std | min | max | std |
| C1 | -5.1 | 12.4 | 1.3 | -3.9 | 4.2 | 1.1 | -3.9 | 4.1 | 1.1 | -4.0 | 4.1 | 1.1 | -3.8 | 3.9 | 1.1 | -3.3 | 3.7 | 1.1 |
| C2 | -4.5 | 11.7 | 1.4 | -3.2 | 3.5 | 1.2 | -3.2 | 3.5 | 1.2 | -3.3 | 3.5 | 1.2 | -3.1 | 3.3 | 1.2 | -2.7 | 3.1 | 1.2 |
| C3 | -5.2 | 5.9 | 1.2 | -3.3 | 3.8 | 1.0 | -3.3 | 3.7 | 1.0 | -3.4 | 3.5 | 1.0 | -3.3 | 3.3 | 0.9 | -3.0 | 3.3 | 1.0 |
| C4 | -1.9 | 2.6 | 1.4 | -1.6 | 2.5 | 1.4 | -1.6 | 2.5 | 1.4 | -1.6 | 2.5 | 1.4 | -1.6 | 2.4 | 1.4 | -1.5 | 2.3 | 1.4 |
| C5 | -5.2 | 10.3 | 1.0 | -4.0 | 4.5 | 0.8 | -4.0 | 4.5 | 0.8 | -4.0 | 4.5 | 0.8 | -3.9 | 4.3 | 0.8 | -3.5 | 4.0 | 0.8 |
| C6 | -6.7 | 3.6 | 1.2 | -6.3 | 5.4 | 1.3 | -6.3 | 4.6 | 1.3 | -6.4 | 3.0 | 1.3 | -6.3 | 2.8 | 1.2 | -6.1 | 5.0 | 1.3 |
| C7 | -6.5 | 8.8 | 2.3 | -4.0 | 6.0 | 2.0 | -4.1 | 6.0 | 2.0 | -4.2 | 6.0 | 2.0 | -4.1 | 5.7 | 1.9 | -3.7 | 5.4 | 2.0 |
| C8 | -5.0 | 5.7 | 1.4 | -3.6 | 3.5 | 1.4 | -3.6 | 3.2 | 1.3 | -3.7 | 3.0 | 1.3 | -3.5 | 2.8 | 1.3 | -3.2 | 3.1 | 1.4 |
| C9 | -0.1 | 0.1 | 0.0 | -0.1 | 0.1 | 0.0 | -0.1 | 0.1 | 0.0 | -0.1 | 0.1 | 0.0 | -0.1 | 0.1 | 0.0 | -0.1 | 0.1 | 0.0 |
| C10 | -1.6 | 1.4 | 0.8 | -1.6 | 1.4 | 0.7 | -1.6 | 1.3 | 0.7 | -1.6 | 1.3 | 0.7 | -1.6 | 1.2 | 0.7 | -1.6 | 1.3 | 0.7 |
| C11 | -4.1 | 10.8 | 1.5 | -3.1 | 3.9 | 1.4 | -3.1 | 3.8 | 1.4 | -3.2 | 3.6 | 1.4 | -3.0 | 3.5 | 1.4 | -2.6 | 3.3 | 1.4 |
| C12 | -0.3 | 0.3 | 0.1 | -0.3 | 0.3 | 0.1 | -0.3 | 0.3 | 0.1 | -0.3 | 0.3 | 0.1 | -0.3 | 0.3 | 0.1 | -0.3 | 0.3 | 0.1 |

To explain these results, the *cdf* values are compared between all volume choices for the computation of the heterogeneous flux. In Fig. 6, the *cdf* values are presented as a function of the burnup, for UOX and MOX fuel and for both groups. The *cdf* values for fast group are close to one (difference lower than 3.5%). The difference is much larger for the thermal group : up to 12% for the UOX fuel and 65% for the MOX fuel. Since this group is the main contributor to the pin power, the range of error variation in the corner pins can be directly associated to the choice of volume for the CDF calculation. Looking back at the results of Tab. 3 for case C6, the more different to the default the *cdf* values are, the larger is the difference range in the corner. Indeed, with the 'FD_C' option, the *cdf* values are approximately 1.02 for the central UOX assembly and 1.6 for the MOX assemblies around it. Then, when the corner flux rebalancing is applied in PARCS before the pin power reconstruction, the flux in the corner pin of the central assembly is greatly increased, which explains why the error in this particular pin increases that much for this CDF option (from -3.9% without CDF to 5.4% with 'FD_C' option). For the 'FCDG' and 'FDCP' options the phenomenon is the same, but less intense since the corresponding *cdf* values are closer to one.

In conclusion, the results show that the 'FD_C+FDCW' may represent the best option as a compromise between general results and error distribution. Note that in order to illustrate that these conclusions are not specific to case C6, the error distribution along the assembly interfaces is presented in Appendix A.1 in Tab. 10 and 11 for cases C5 and C8 respectively. Other CDF options where also tested and results are reported in the same Appendix in 12.

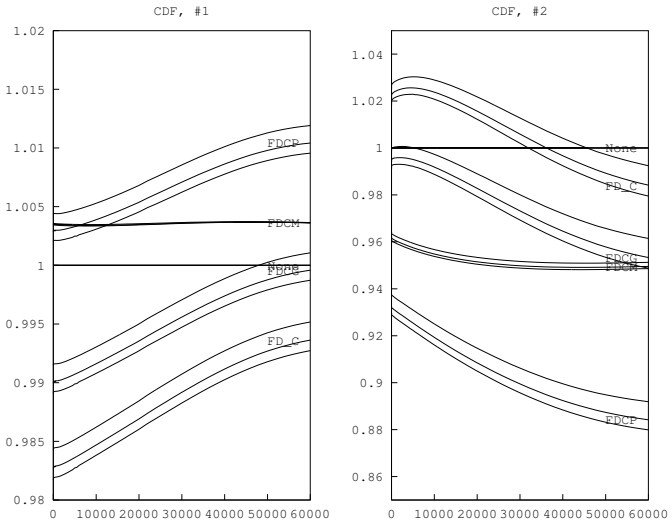
### 3.4 ADF calculation methodology

Similarly to the previous section for the CDF, the sensitivity of the results with the ADF is assessed here. Again, the PARCS simulations were performed with the same setting. Even though the *adf* values are not used directly to perform the pin power reconstruction, they are used to compute the flux distribution, and thus influence the results of the PPR. The ADF are defined as follows :

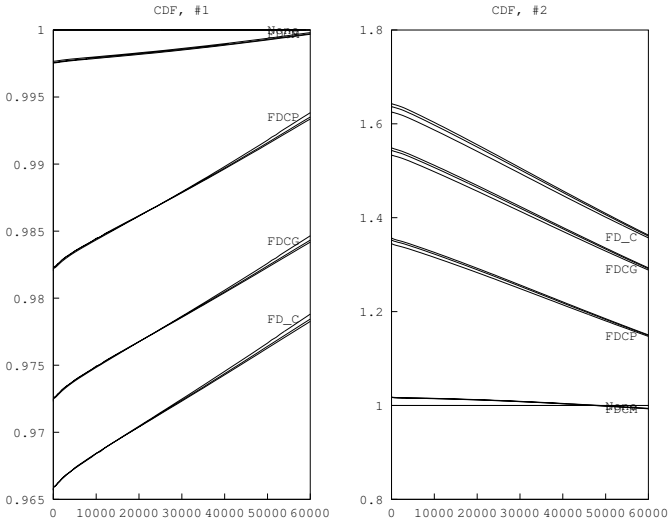
$$adf = \frac{\phi_{het,b}}{\overline{\phi}} \tag{3.2}$$

Three choices of volumes have been made to compute the ADF :
– case 'No_ADF' : all ADF values are equal to default value of 1.
– case 'FD_B' : the water gap
– case 'FD_H' : the first row of pin around the assembly and its surrounding water gap
For a better understanding the different options are graphically presented here :

UOX




MOX



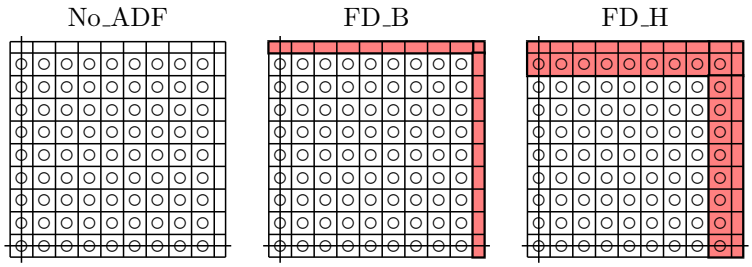

Note : 3 values of boron concentration (min, middle and max)
are presented for each option

FIGURE 6 – CDF value vs. burnup depending of volume choice.

TABLE 3 – Relative error (%) between reconstruction and transport calculations, PARCS - DRAGON, influence of ADF and CDF volume choices (part 1), case #6 : 0(U)-30(M)-30(M)

| ADF | | | FD_B | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| CDF | | | No_CDF | | FD_C | | FDCG | | FDCP | | FDCP+ FDCM | | FD_C+ FDCW | |
| | 17 | 1 col. | | | | | | | | | | | | |
| 17 | B | C | 2.0 | 3.6 | -1.3 | 0.1 | -1.0 | 0.4 | -0.4 | 1.0 | -0.4 | 1.0 | -1.2 | 0.0 |
| 1 | A | B | -3.9 | 2.0 | 5.4 | -1.3 | 4.6 | -1.0 | 2.9 | -0.4 | 2.7 | -0.4 | 5.0 | -1.2 |
| 2 | A | B | -0.6 | -0.6 | 4.1 | -1.8 | 3.7 | -1.7 | 2.8 | -1.5 | 2.6 | -1.4 | 3.6 | -1.4 |
| 3 | A | B | 1.7 | -4.4 | 3.6 | -4.6 | 3.4 | -4.6 | 3.0 | -4.6 | 2.8 | -4.4 | 3.0 | -4.2 |
| 4 | A | B | 2.8 | -6.5 | 2.9 | -6.3 | 2.9 | -6.3 | 2.8 | -6.3 | 2.6 | -6.2 | 2.3 | -5.8 |
| 5 | A | B | 2.8 | -6.7 | 1.8 | -6.3 | 1.9 | -6.3 | 2.0 | -6.4 | 1.9 | -6.3 | 1.5 | -6.0 |
| 6 | A | B | 2.2 | -6.3 | 0.7 | -5.9 | 0.9 | -5.9 | 1.1 | -6.0 | 1.1 | -6.0 | 0.9 | -5.9 |
| 7 | A | B | 1.3 | -5.8 | -0.2 | -5.5 | -0.1 | -5.5 | 0.2 | -5.5 | 0.4 | -5.7 | 0.6 | -6.1 |
| 8 | A | B | -0.3 | -4.1 | -1.4 | -4.1 | -1.3 | -4.1 | -1.1 | -4.1 | -0.5 | -4.6 | 0.5 | -5.9 |
| 9 | A | B | -2.7 | -0.9 | -2.9 | -1.4 | -2.9 | -1.4 | -2.9 | -1.3 | -1.8 | -2.5 | 0.4 | -5.1 |
| row | | | | | | | | | | | | | | |

Note : Results at the central assembly interface are presented here. See first column and Sec. 3.1 for detail.




quarter of assembly, water gap is not on scale

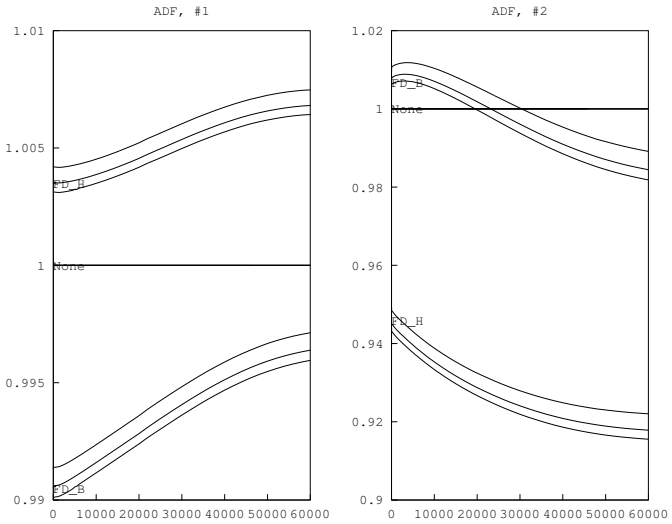
The general results are presented on Tab. 4, and those for the error distribution along assemblies interfaces for case C6 are presented on Tab. 5. In both tables, columns 2 to 4 present the results for the three ADF types with a fixed CDF type ('FD_C'). The two first options give simular results, slightly better for the 'FD_B' option for some cases, slightly better for the 'No_ADF' option for other cases. However those two options are less accurate than the last option 'FD_H'. To explain the difference of performance between these three options, the *adf* value has been plot on Fig. 7 as a function of the burnup, for UOX and MOX fuel and for both groups. The difference with the default value of 1 is much larger for the thermal group : up to 6% for the UOX fuel and 27% for the MOX fuel. At an interface, if the *adf* values are not the same, the side with the higher value tends to increase the flux on the other side, and the opposite is done for the other side. In the case with the 'FD_B' for case C6, assembly 'A' and 'B' are UOX and MOX fuel with an adf value of 1.01 and 1.22 respectively. Then, as expected the flux (and consequently the power) on side 'A' is increased and decreased on side 'B', which changes the distribution and the range of error.

The fixed CDF type 'FD_C' was used for history reasons. However, in the previous section, results showed that it is may not be the best option for CDF, 'FD_C + FDCW' is recommended. Thus, different combinations of options for CDF and ADF have then been explored. Results are presented on columns 5 to 6 of Tab. 4 and Tab. 5. Between the two combinations presented there, the 'FD_B' and 'FD_C+FDCW' options for ADF and CDF respectively is the more accurate, and is chosen as the recommended option.

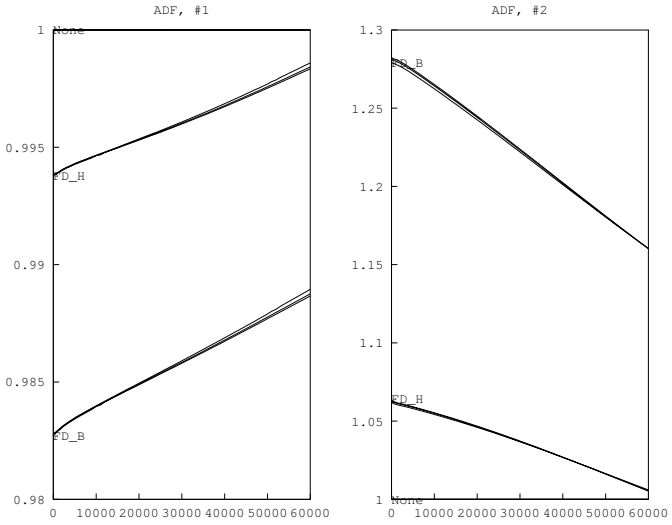
### 3.5 GFF calculation methodology

As explained in Sec. 1.3.1, the Pin Power Reconstruction is based on form factors which represent the relative power in each pin of an assembly. This ratio is computed together with the other assembly properties. If is it not computed, a default value of 1 is used. In this section, the importance of the *gff* value is assessed. Tab. 6 presents the results with and without the use of GFF. The need for GFF values

UOX




MOX




Note : 3 values of boron concentration (min, middle and max)
are presented for each option

FIGURE 7 – ADF value vs. burnup depending of volume choice.

TABLE 4 – Relative error (%) between reconstruction and transport calculations, PARCS - DRAGON, influence of ADF and CDF volume choices (part 2)

| adf | No_ADF | | | FD_B | | | FD_H | | | FD_H | | | FD_B | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| cdf | FD_C | | | FD_C | | | FD_C | | | FD_C+FDCW | | | FD_C+FDCW | | |
| | min | max | std | min | max | std | min | max | std | min | max | std | min | max | std |
| C1 | -3.8 | 4.6 | 1.3 | -3.9 | 4.2 | 1.1 | -2.4 | 2.8 | 1.2 | -2.7 | 3.1 | 1.2 | -3.3 | 3.7 | 1.1 |
| C2 | -3.4 | 4.3 | 1.4 | -3.2 | 3.5 | 1.2 | -2.0 | 2.3 | 1.2 | -2.2 | 3.0 | 1.3 | -2.7 | 3.1 | 1.2 |
| C3 | -3.4 | 2.7 | 1.0 | -3.3 | 3.8 | 1.0 | -1.6 | 2.5 | 0.7 | -2.7 | 2.2 | 0.8 | -3.0 | 3.3 | 1.0 |
| C4 | -1.7 | 2.3 | 1.3 | -1.6 | 2.5 | 1.4 | -1.6 | 2.4 | 1.3 | -1.6 | 2.1 | 1.3 | -1.5 | 2.3 | 1.4 |
| C5 | -2.0 | 3.3 | 0.7 | -4.0 | 4.5 | 0.8 | -1.3 | 2.1 | 0.6 | -1.9 | 2.7 | 0.6 | -3.5 | 4.0 | 0.8 |
| C6 | -5.0 | 2.8 | 1.5 | -6.3 | 5.4 | 1.3 | -4.1 | 3.6 | 1.4 | -6.0 | 3.2 | 1.5 | -6.1 | 5.0 | 1.3 |
| C7 | -3.7 | 4.7 | 1.4 | -4.0 | 6.0 | 2.0 | -1.8 | 3.4 | 1.2 | -3.4 | 3.7 | 1.2 | -3.7 | 5.4 | 2.0 |
| C8 | -4.4 | 3.7 | 1.9 | -3.6 | 3.5 | 1.4 | -2.7 | 3.1 | 1.6 | -2.8 | 3.8 | 1.6 | -3.2 | 3.1 | 1.4 |
| C9 | -0.1 | 0.1 | 0.0 | -0.1 | 0.1 | 0.0 | -0.1 | 0.1 | 0.0 | -0.1 | 0.1 | 0.0 | -0.1 | 0.1 | 0.0 |
| C10 | -1.8 | 1.4 | 0.8 | -1.6 | 1.4 | 0.7 | -2.0 | 1.5 | 0.8 | -2.0 | 1.5 | 0.8 | -1.6 | 1.3 | 0.7 |
| C11 | -3.4 | 4.5 | 1.7 | -3.1 | 3.9 | 1.4 | -2.7 | 3.3 | 1.6 | -2.8 | 3.9 | 1.6 | -2.6 | 3.3 | 1.4 |
| C12 | -0.3 | 0.3 | 0.1 | -0.3 | 0.3 | 0.1 | -0.3 | 0.3 | 0.1 | -0.3 | 0.3 | 0.1 | -0.3 | 0.3 | 0.1 |

TABLE 5 – Relative error (%) between reconstruction and transport calculations, PARCS - DRAGON, influence of ADF and CDF volume choices (part 2), case #6 : 0(U)-30(M)-30(M)

| ADF | | | No_ADF | | FD_B | | FD_H | | FD_B | | FD_H | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| CDF | | | FD_C | | | | | | FD_C+FDCW | | | |
| | 17 | 1 col. | | | | | | | | | | |
| 17 | B | C | -0.1 | -0.1 | -1.3 | 0.1 | -0.8 | -0.1 | -0.6 | -0.2 | -1.2 | 0.0 |
| 1 | A | B | 2.4 | -0.1 | 5.4 | -1.3 | 3.6 | -0.8 | 3.2 | -0.6 | 5.0 | -1.2 |
| 2 | A | B | -0.0 | 1.7 | 4.1 | -1.8 | 1.7 | -0.1 | 1.1 | 0.3 | 3.6 | -1.4 |
| 3 | A | B | -1.6 | -0.3 | 3.6 | -4.6 | 0.6 | -2.5 | -0.0 | -2.0 | 3.0 | -4.2 |
| 4 | A | B | -3.0 | -1.7 | 2.9 | -6.3 | -0.6 | -4.0 | -1.1 | -3.6 | 2.3 | -5.8 |
| 5 | A | B | -4.3 | -1.7 | 1.8 | -6.3 | -1.8 | -4.1 | -2.1 | -3.8 | 1.5 | -6.0 |
| 6 | A | B | -5.0 | -1.7 | 0.7 | -5.9 | -2.7 | -3.9 | -2.5 | -3.9 | 0.9 | -5.9 |
| 7 | A | B | -5.0 | -2.2 | -0.2 | -5.5 | -3.1 | -3.9 | -2.3 | -4.6 | 0.6 | -6.1 |
| 8 | A | B | -4.5 | -2.5 | -1.4 | -4.1 | -3.4 | -3.5 | -1.5 | -5.2 | 0.5 | -5.9 |
| 9 | A | B | -3.5 | -2.8 | -2.9 | -1.4 | -3.6 | -2.4 | -0.3 | -6.0 | 0.4 | -5.1 |
| row | | | | | | | | | | | | |

Note : Results at the central assembly interface are presented here. See first column and Sec. 3.1 for detail.

is obvious. Indeed, when the GFF value are not used, the standard deviation of the error is multiply by a factor of 10 approximately and the inaccuracy can be up to 35%.

### 3.6 PARCS neutronic solver

Several methods as neutronic solver are available in the PARCS code. In this section, the influence of the solver on the pin power reconstruction is assessed. The following methods are looked at :

- FDM - Finite Difference only : See Sec. 3.1 of the PARCS theory manual [5] for details.
- ANM - Analytic Nodal Method : See Sec. 4.1 of the PARCS theory manual [5] for details.
- FMFD - Fine Mesh Finite Difference : See Sec. 6.4 of the PARCS theory manual [5] for details.
- NEMMG - Multigroup Nodal Expansion Method : See Sec. 4.2 of the PARCS theory manual [5] for details.
- HYBRID - ANM/NEM nodal hybrid : Sec. 4.1.2 of the PARCS theory manual [5] for details. (default option if none is selected)

TABLE 6 – Relative error (%) between reconstruction and transport calculations, PARCS - DRAGON, influence of PARCS convergence setting, hybrib 2x2

| Opt. | FD_C and FD_B , Hybrid 2x2 | | | | | |
|---|---|---|---|---|---|---|
| Met. | GFF | | | No GFF | | |
| | min | max | std | min | max | std |
| C1 | -3.9 | 4.2 | 1.1 | -19.0 | 31.0 | 9.6 |
| C2 | -3.2 | 3.5 | 1.2 | -17.5 | 23.8 | 9.2 |
| C3 | -3.3 | 3.8 | 1.0 | -19.4 | 30.9 | 11.3 |
| C4 | -1.6 | 2.5 | 1.4 | -20.7 | 35.9 | 13.2 |
| C5 | -4.0 | 4.5 | 0.8 | -17.8 | 23.3 | 9.4 |
| C6 | -6.3 | 5.4 | 1.3 | -17.4 | 25.9 | 12.5 |
| C7 | -4.0 | 6.0 | 2.0 | -20.7 | 35.6 | 12.0 |
| C8 | -3.6 | 3.5 | 1.4 | -16.0 | 21.9 | 10.7 |
| C9 | -0.1 | 0.1 | 0.0 | -12.3 | 0.0 | 8.9 |
| C10 | -1.6 | 1.4 | 0.7 | -14.1 | 0.0 | 8.8 |
| C11 | -3.1 | 3.9 | 1.4 | -16.8 | 23.9 | 9.2 |
| C12 | -0.3 | 0.3 | 0.1 | -18.7 | 31.1 | 13.9 |

Following several exchanges with the PARCS-help for the exact definition of the *xbe* and *ybe* parameters, A. Ward, developer and member of PARCS-help, has tested another method called SENM not yet available in the current version of PARCS (Parcs-v32m17co) on case C6.

All following results were done with the CDF option 'FD_C+FCDW' and the ADF option 'FD_H'. The PARCS 'PARAM' card was :

```
PARAM
! Basic Iteration Control Parameters
      n_iters    10 500                    !ninmax, noutmax
! Convergence Criteria
!      nodal_kern FDM
      nodal_kern HYBRID
!      nodal_kern ANM
!      nodal_kern FMFD
!      nodal_kern NEMMG
      conv_ss    1.e-6 1.e-5 1.e-4 0.1     !epseig,epsl2,epslinf,epstf
```

All 'nodal_kern' options were tested with both 1x1 and 2x2 neutronic mesh. Results are presented in Tab. 7 and 8. 'FDMD' method is not presented since the pin power reconstruction could not be performed with this option. 'FDM' and 'NEMMG' are not accurate at all. ANM and Hybrid method leads to accurate results. The range of error obtained with the SENM method is approximately the same but the standard deviation is smaller. To see the difference, the accuracy distribution is presented on Fig. 8 to 10. The accuracy maps show that the SENM method predicts the power within a 0.5% range for most of the pins whereas the range is 1% for the HYBRID and ANM methods.

The effect of the PARCS setting for convergence criteria was also studied. Results are presented in Tab. 9. First column reproduces the results presented before for the 'Hybrid' method, and the second column represents the results obtained the same options except for smaller convergence criteria :

```
      conv_ss    1.e-6 5.e-6 1.e-5 0.0001      !epseig,epsl2,epslinf,epstf
```

The results show that a smaller convergence criteria is not necessary.

In conclusion, the default method (HYBRID) with larger convergence criteria and a 2x2 neutronic mesh is recommended, until the SENM is available.

### 3.7 Final results

As final results, the options 'FD_B' and 'FD_C+FDCW' are selected for the ADF and CDF respectively. This results is consistent with experience which tells us that the smaller the volumes are to compute

FIGURE 8 – Relative error between reconstruction and transport calculations for case 6(%) , FD_C+FDCM+FD_H, ANM

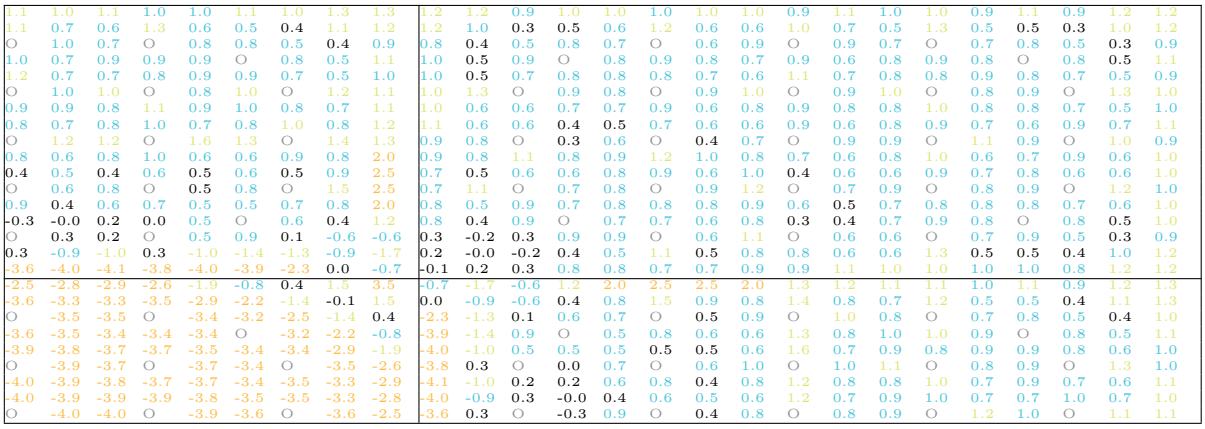


FIGURE 9 – Relative error between reconstruction and transport calculations for case 6(%) , FD_C+FDCM+FD_H

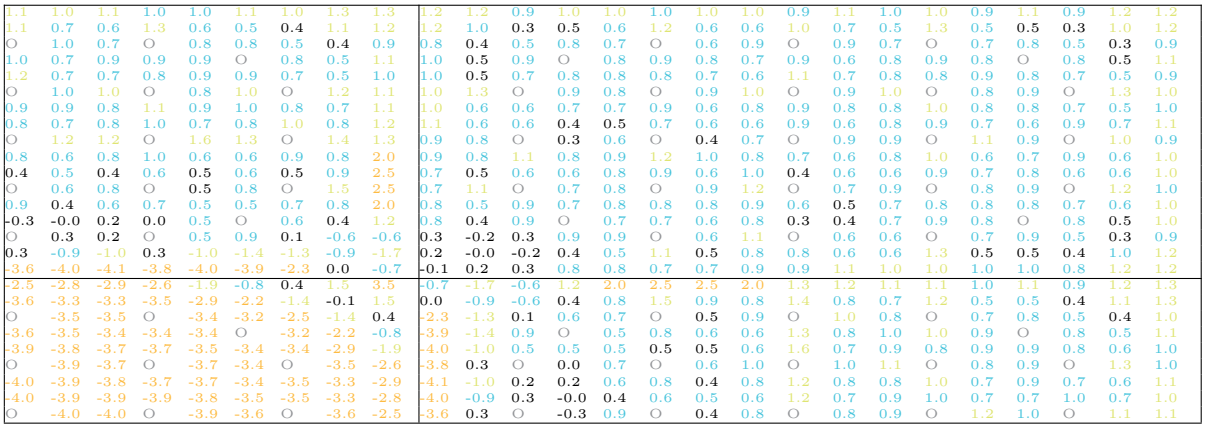


FIGURE 10 – Relative error between reconstruction and transport calculations for case 6(%) , FD_C+FDCM+FD_H, SENM 2x2

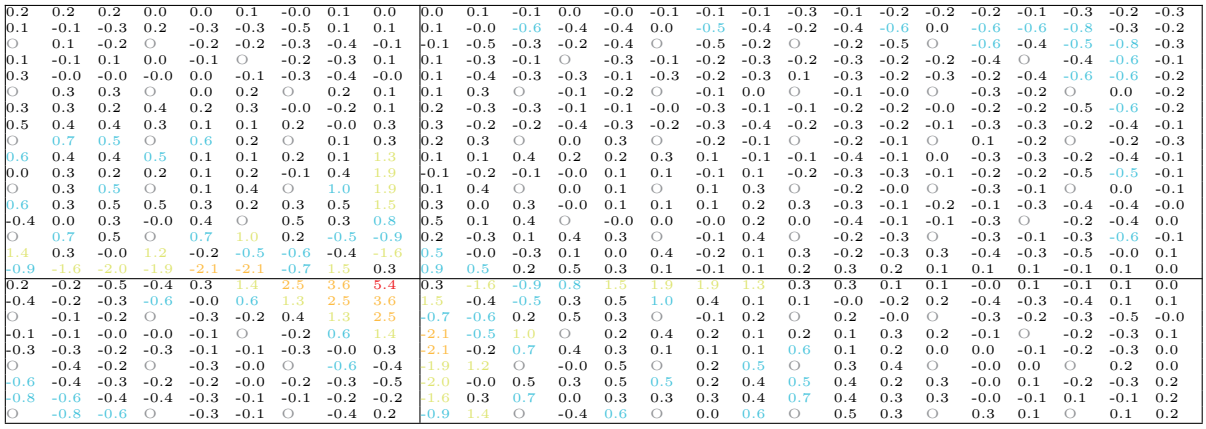


FIGURE 11 – Relative error between reconstruction and transport calculations for case 6(%) , FD_C+FDCM+FD_H, SENM 1x1

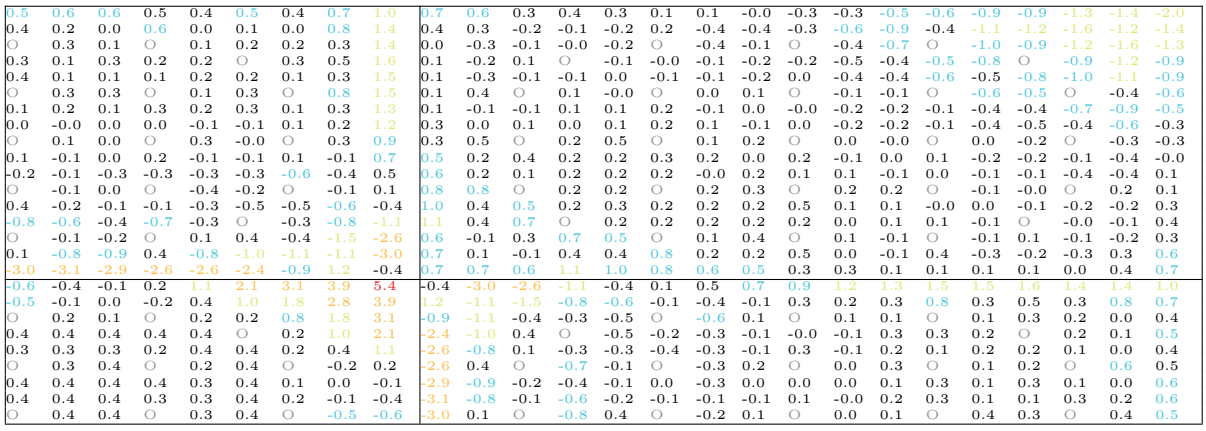


TABLE 7 – Relative error (%) between reconstruction and transport calculations, PARCS - DRAGON, influence of ADF and CDF volume choices, 1x1

| Opt. | FD_C+FDCM and FD_H , 1x1 | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Met. | FDM-1x1 | | | Hybrid-1x1 | | | ANM-1x1 | | | SENM-1x1 | | |
| | min | max | std | min | max | std | min | max | std | min | max | std |
| C1 | -20.2 | 33.1 | 11.2 | -3.0 | 3.2 | 1.2 | -3.0 | 3.2 | 1.2 | – | – | – |
| C2 | -33.8 | 31.7 | 15.0 | -2.7 | 2.5 | 1.3 | -2.7 | 2.5 | 1.3 | – | – | – |
| C3 | -17.2 | 17.0 | 5.7 | -2.0 | 2.9 | 0.8 | -2.0 | 2.9 | 0.8 | – | – | – |
| C4 | -12.9 | 13.2 | 8.8 | -1.6 | 2.0 | 1.2 | -1.6 | 2.0 | 1.2 | – | – | – |
| C5 | -16.3 | 17.7 | 3.9 | -3.1 | 4.0 | 0.9 | -1.4 | 2.2 | 0.7 | – | – | – |
| C6 | -20.3 | 68.9 | 16.8 | -4.9 | 3.7 | 1.4 | -4.9 | 3.7 | 1.4 | -3.1 | 5.4 | 0.8 |
| C7 | -37.4 | 15.3 | 14.8 | -2.0 | 3.9 | 1.2 | -2.0 | 3.9 | 1.2 | – | – | – |
| C8 | -23.6 | 27.3 | 11.7 | -3.3 | 3.2 | 1.5 | -3.3 | 3.2 | 1.5 | – | – | – |
| C9 | -0.1 | 0.1 | 0.0 | -0.1 | 0.1 | 0.0 | -0.1 | 0.1 | 0.0 | – | – | – |
| C10 | -11.9 | 29.3 | 9.2 | -1.3 | 1.4 | 0.7 | -1.3 | 1.4 | 0.7 | – | – | – |
| C11 | -33.1 | 35.7 | 15.8 | -3.7 | 3.3 | 1.6 | -3.7 | 3.3 | 1.6 | – | – | – |
| C12 | -0.3 | 0.3 | 0.1 | -0.3 | 0.3 | 0.1 | -0.3 | 0.3 | 0.1 | – | – | – |

NEMMG is not presented because some cases did not converged
SENM was performed just for case C6 by A. Ward from PARCS-help

the ADF and CDF, the better the results should be.

The error distribution is presented in Fig. 12 for all clusters. The reference pin power and thermal-group flux distributions are presented in Appendix A.3 on Fig. 13 and 14 respectively. The clusters can be separated in three groups :

- Only one type of fuel and the same burnup : C9 & C12. The absolute error is very small (maximum of ±0.3%) which means that the pin power reconstruction has been properly implemented.
- Only one type of fuel but different burnup : C4 & C10. The absolute error is still small (approximative maximum of ±2%). The error is generally positive for higher burned fuel and negative for lower burned fuel.
- Different fuel type and burnup : remaining cases. The absolute error is larger (approximative maximum of ±3.5%, except for case C6 minimum of -6%). The maximum error is located at the assembly boundaries. These results show the limitation of the main assumption for pin power reconstruction : the assembly flux distribution in the core is the same as in the infinite lattice calculation.

The final results of the simulations are also compared to those obtained previously by Pin Power Reconstruction with DONJON (`NAP:` module [6]) or the APOLLO2-COCAGNE [7] which are presented in Appendix A.4. In these previous studies, the PPR was performed using homogeneous (1 mixture per assembly, mesh 4x4) or heterogeneous (3 mixtures per assembly, mesh 4x4*) properties which are defined in Appendix A.4. Pin power was also obtained directly (no PPR) with properties homogenized pin-by-pin. Note that the pin-by-pin properties are needed regardless of the chosen system : in DRAGON5-PARCS to computed GFF, and, in DRAGON5-DONJON5 and APPOLLO2-COCAGNE to compute the enrich factor (pin macro diffusion flux in infinite domain).

The results of the DRAGON5-PARCS are similar to those obtained in APOLLO2-COCAGNE system with heterogeneous calculations, and slightly more accurate than those obtained by DRAGON5-DONJON5 system with heterogeneous calculations. When comparing the results obtained only with homogeneous properties, the DRAGON5-PARCS system is the most accurate.

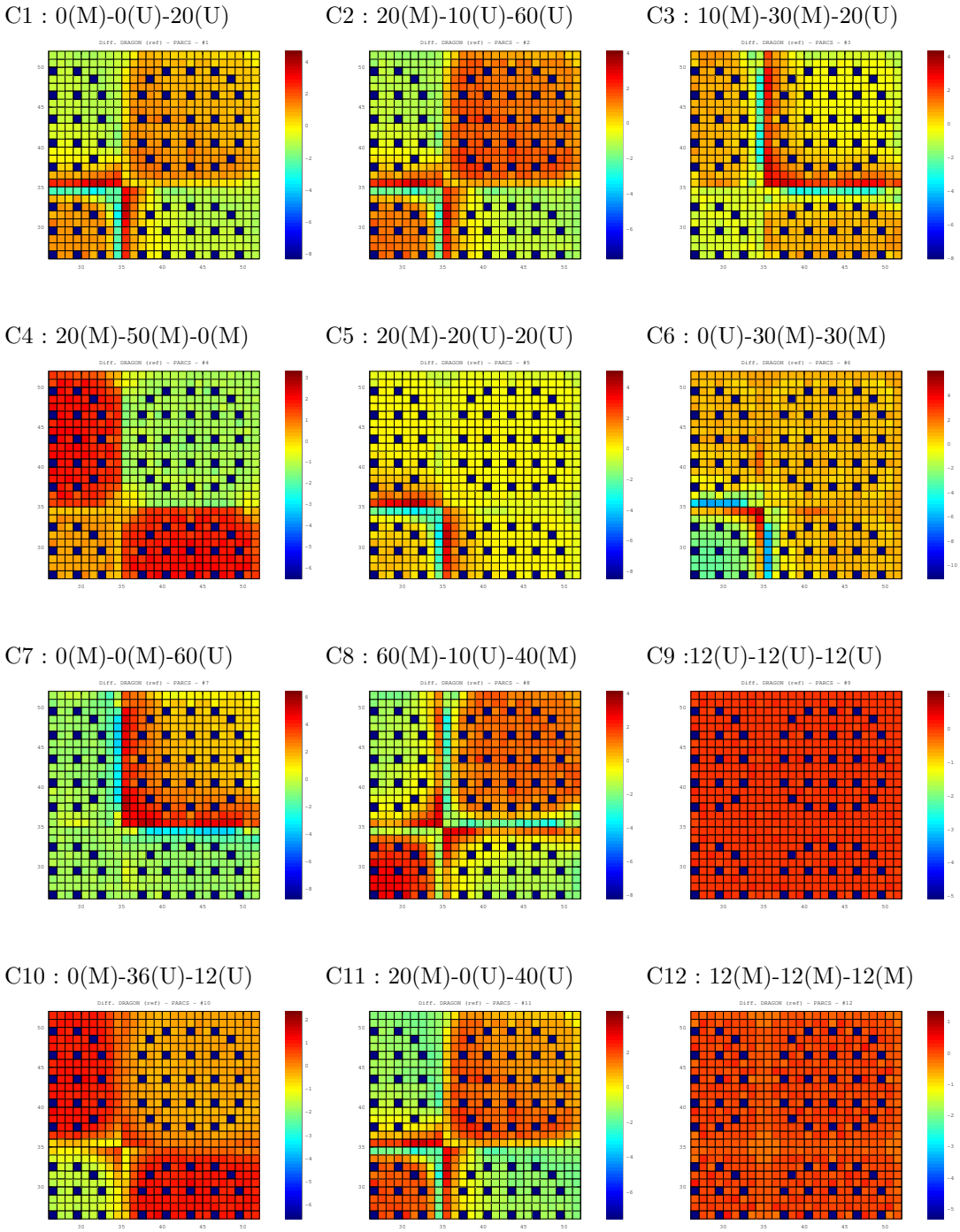



FIGURE 12 – PARCS vs Transport pin power distribution of all clusters (diff. in %), 'FD_C' + 'FDCW' and 'FD_B' options for CDF and ADF respectively

TABLE 8 – Relative error (%) between reconstruction and transport calculations, PARCS - DRAGON, influence of ADF and CDF volume choices, 2x2

| Opt. | FD_C+FDCM and FD_H , 2x2 | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Met. | FDM-2x2 | | | Hybrid-2x2 | | | ANM-2x2 | | | NEMMG-2x2 | | | SENM-2x2 | | |
| | min | max | std | min | max | std | min | max | std | min | max | std | min | max | std |
| C1 | -19.2 | 20.8 | 4.9 | -2.5 | 2.9 | 1.2 | -2.5 | 2.9 | 1.2 | -7.9 | 5.5 | 1.6 | – | – | – |
| C2 | -15.6 | 18.1 | 4.7 | -2.1 | 2.4 | 1.2 | -2.1 | 2.4 | 1.2 | -2.4 | 2.6 | 1.3 | – | – | – |
| C3 | -14.5 | 15.2 | 4.1 | -1.7 | 2.4 | 0.7 | -1.7 | 2.4 | 0.7 | -20.0 | 18.7 | 6.5 | – | – | – |
| C4 | -3.4 | 1.9 | 1.3 | -1.6 | 2.3 | 1.3 | -1.6 | 2.3 | 1.3 | -4.8 | 6.1 | 2.0 | – | – | – |
| C5 | -15.0 | 14.6 | 3.0 | -1.2 | 1.9 | 0.5 | -1.2 | 2.0 | 0.6 | -33.8 | 28.5 | 12.4 | – | – | – |
| C6 | -19.2 | 26.7 | 5.5 | -4.1 | 3.5 | 1.4 | -4.1 | 3.5 | 1.4 | -5.2 | 6.8 | 1.4 | -2.1 | 5.4 | 0.6 |
| C7 | -14.2 | 14.1 | 4.5 | -1.8 | 3.2 | 1.2 | -1.8 | 3.2 | 1.2 | -2.8 | 5.2 | 2.8 | – | – | – |
| C8 | -16.9 | 16.7 | 5.9 | -2.7 | 3.4 | 1.6 | -2.7 | 3.4 | 1.6 | -3.2 | 4.1 | 1.2 | – | – | – |
| C9 | -0.1 | 0.1 | 0.0 | -0.1 | 0.1 | 0.0 | -0.1 | 0.1 | 0.0 | -0.1 | 0.2 | 0.0 | – | – | – |
| C10 | -6.1 | 8.4 | 2.5 | -1.9 | 1.5 | 0.8 | -1.9 | 1.5 | 0.8 | -1.7 | 1.6 | 0.8 | – | – | – |
| C11 | -18.6 | 20.5 | 5.5 | -2.8 | 3.3 | 1.6 | -2.8 | 3.3 | 1.6 | -7.7 | 4.2 | 1.7 | – | – | – |
| C12 | -0.3 | 0.3 | 0.1 | -0.3 | 0.3 | 0.1 | -0.3 | 0.3 | 0.1 | -0.6 | 0.5 | 0.2 | – | – | – |

SENM was performed just for case C6 by A. Ward from PARCS-help

TABLE 9 – Relative error (%) between reconstruction and transport calculations, PARCS - DRAGON, influence of PARCS convergence setting, hybrib 2x2

| Opt. | FD_C+FDCM and FD_H , 2x2 | | | | | |
|---|---|---|---|---|---|---|
| Met. | Hybrid-2x2 | | | Hyb-2x2-Cv | | |
| | min | max | std | min | max | std |
| C1 | -2.5 | 2.9 | 1.2 | -2.5 | 2.9 | 1.2 |
| C2 | -2.1 | 2.4 | 1.2 | -2.1 | 2.4 | 1.2 |
| C3 | -1.7 | 2.4 | 0.7 | -1.7 | 2.4 | 0.7 |
| C4 | -1.6 | 2.3 | 1.3 | -1.6 | 2.3 | 1.3 |
| C5 | -1.2 | 1.9 | 0.5 | -1.2 | 1.9 | 0.5 |
| C6 | -4.1 | 3.5 | 1.4 | -4.1 | 3.5 | 1.4 |
| C7 | -1.8 | 3.2 | 1.2 | -1.8 | 3.2 | 1.2 |
| C8 | -2.7 | 3.4 | 1.6 | -2.7 | 3.4 | 1.6 |
| C9 | -0.1 | 0.1 | 0.0 | -0.1 | 0.1 | 0.0 |
| C10 | -1.9 | 1.5 | 0.8 | -1.9 | 1.5 | 0.8 |
| C11 | -2.8 | 3.3 | 1.6 | -2.8 | 3.3 | 1.6 |
| C12 | -0.3 | 0.3 | 0.1 | -0.3 | 0.3 | 0.1 |

## 4 Conclusions

The pin power reconstruction capabilities was successfully integrated in the DRAGON5/PARCS system. Several test cases were simulated to represent different combinations of assembly type and burnup. The results are usually very good when compared to the full transport reference calculations. In general, the maximum error is lower than 5% and the standard deviation is approximately 1% in average over all cases. In term of accuracy, the DRAGON5/PARCS system leads to similar results as the APPOLLO2/COCAGNE system and slightly better than the DRAGON5/DONJON5 system (standard deviation is approximately 1.5%).

The results show that it is mandatory to use *gff* values, otherwise the error is multiply by a factor 10. Also, the smaller the regions are to compute the *cdf* and *adf* values, the better the results are. Moreover, not using corner discontinuity factors can lead to a maximum error multiplied by a factor 3 for some cases.

Among the available solvers in PARCS, the HYBRID option with larger convergence criteria is currently recommended. Indeed, it is the default solver and it leads to similar results as the ANM solver. The other solvers provide poor results in comparison. However, a new solver named SENM is currently added, and should be looked at closely when fully integrated and released. Indeed, the partial results were promising (standard deviation around 0.5% for case C6, which is less than half of 'HYBRID' results).

Finally, several warnings related to PARCS version have been made, specially about the GFF numbering. Note that the keyword 'VERSION' used to select the PARCS version is then very important. The GFF numbering for PARCS v32m18 and GenPMAXS v6.2 was programmed and verified but need to be tested more extensively when released.

## 5 Acknonledgements

Andrew Ward for the numerous discussions on the GFF numbering and for SENM solver results. Yunlin Xu for help on the no GFF case and precisions on the xbe and ybe values.

# A Appendix A : Complementary results

## A.1 CDF calculation methodology

TABLE 10 – Relative error (%) between reconstruction and transport calculations, PARCS - DRAGON, influence of ADF and CDF volume choices (part 1), case #5 : 20(M)-20(U)-20(U)

| ADF | | | FD_B | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| CDF | | | No_CDF | | FD_C | | FDCG | | FDCP | | FDCP+ FDCM | | FD_C+ FDCW | |
| | 17 | 1 col. | | | | | | | | | | | | |
| 17 | B | C | -1.8 | -3.2 | 2.1 | 0.6 | 1.9 | 0.4 | 1.4 | -0.1 | 1.3 | -0.1 | 1.9 | 0.5 |
| 1 | A | B | 10.3 | -1.8 | -2.6 | 2.1 | -1.9 | 1.9 | -0.4 | 1.4 | -0.3 | 1.3 | -2.4 | 1.9 |
| 2 | A | B | 2.4 | 0.7 | -3.0 | 2.7 | -2.7 | 2.6 | -2.0 | 2.4 | -1.9 | 2.2 | -2.6 | 2.3 |
| 3 | A | B | -2.4 | 3.5 | -3.7 | 4.2 | -3.6 | 4.1 | -3.4 | 4.0 | -3.2 | 3.8 | -3.2 | 3.7 |
| 4 | A | B | -4.8 | 4.6 | -4.0 | 4.5 | -4.0 | 4.5 | -4.0 | 4.5 | -3.9 | 4.3 | -3.5 | 4.0 |
| 5 | A | B | -5.2 | 4.6 | -3.4 | 4.0 | -3.5 | 4.0 | -3.7 | 4.1 | -3.5 | 4.0 | -3.1 | 3.8 |
| 6 | A | B | -4.8 | 4.0 | -2.7 | 3.2 | -2.8 | 3.2 | -3.0 | 3.3 | -3.0 | 3.4 | -2.6 | 3.4 |
| 7 | A | B | -4.0 | 3.0 | -2.1 | 2.3 | -2.2 | 2.3 | -2.4 | 2.4 | -2.6 | 2.7 | -2.6 | 3.2 |
| 8 | A | B | -2.1 | 1.2 | -0.7 | 0.9 | -0.8 | 0.9 | -0.9 | 0.9 | -1.6 | 1.7 | -2.4 | 2.9 |
| 9 | A | B | 1.9 | -1.5 | 1.9 | -1.2 | 1.9 | -1.2 | 1.8 | -1.3 | 0.4 | 0.1 | -1.8 | 2.4 |
| row | | | | | | | | | | | | | | |

Note : Results at the central assembly interface are presented here. See first column and Sec. 3.1 for detail.

TABLE 11 – Relative error (%) between reconstruction and transport calculations, PARCS - DRAGON, influence of ADF and CDF volume choices (part 1), case #8 : 60(M)-10(U)-40(M)

| ADF | | | FD_B | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| CDF | | | No_CDF | | FD_C | | FDCG | | FDCP | | FDCP+ FDCM | | FD_C+ FDCW | |
| | 17 | 1 col. | | | | | | | | | | | | |
| 17 | B | C | -2.4 | 5.7 | 3.5 | -1.6 | 3.0 | -1.2 | 2.1 | -0.2 | 2.0 | -0.1 | 3.1 | -1.4 |
| 1 | A | B | 3.5 | -2.4 | -1.3 | 3.5 | -0.9 | 3.0 | -0.1 | 2.1 | -0.0 | 2.0 | -1.1 | 3.1 |
| 2 | A | B | 0.4 | 0.1 | -1.8 | 3.1 | -1.6 | 2.9 | -1.2 | 2.4 | -1.1 | 2.2 | -1.5 | 2.7 |
| 3 | A | B | -1.4 | 1.9 | -2.0 | 3.1 | -1.9 | 3.0 | -1.8 | 2.8 | -1.7 | 2.6 | -1.6 | 2.7 |
| 4 | A | B | -2.4 | 2.4 | -2.2 | 2.4 | -2.2 | 2.4 | -2.2 | 2.4 | -2.0 | 2.2 | -1.8 | 2.0 |
| 5 | A | B | -2.3 | 2.1 | -1.6 | 1.4 | -1.7 | 1.4 | -1.8 | 1.5 | -1.7 | 1.4 | -1.3 | 1.1 |
| 6 | A | B | -1.8 | 1.5 | -1.0 | 0.4 | -1.1 | 0.5 | -1.2 | 0.6 | -1.1 | 0.6 | -1.0 | 0.5 |
| 7 | A | B | -1.4 | 0.8 | -0.6 | -0.3 | -0.7 | -0.2 | -0.8 | -0.0 | -1.0 | 0.1 | -1.1 | 0.3 |
| 8 | A | B | -0.4 | -0.2 | 0.0 | -0.9 | -0.0 | -0.8 | -0.1 | -0.7 | -0.5 | -0.3 | -1.3 | 0.4 |
| 9 | A | B | 1.5 | -1.5 | 1.2 | -1.6 | 1.2 | -1.6 | 1.3 | -1.6 | 0.2 | -0.7 | -1.5 | 0.8 |
| row | | | | | | | | | | | | | | |

Note : Results at the central assembly interface are presented here. See first column and Sec. 3.1 for detail.

## A.2 ADF calculation methodology

TABLE 12 – Relative error (%) between reconstruction and transport calculations, PARCS - DRAGON, influence of ADF and CDF volume choices (part 1)

| adf | FD_B | | | FD_B | | |
|---|---|---|---|---|---|---|
| cdf | FD_C+FDCM | | | FD_C+FD_B | | |
| | min | max | std | min | max | std |
| C1 | -3.7 | 4.1 | 1.1 | -4.3 | 4.1 | 1.1 |
| C2 | -3.0 | 3.3 | 1.2 | -3.6 | 3.6 | 1.3 |
| C3 | -3.2 | 3.6 | 1.0 | -3.8 | 3.3 | 1.1 |
| C4 | -1.6 | 2.4 | 1.4 | -1.8 | 2.2 | 1.4 |
| C5 | -3.8 | 4.3 | 0.8 | -3.5 | 4.0 | 0.9 |
| C6 | -6.2 | 5.3 | 1.3 | -6.6 | 4.8 | 1.4 |
| C7 | -3.9 | 5.8 | 1.9 | -4.9 | 6.0 | 2.0 |
| C8 | -3.5 | 3.3 | 1.3 | -3.9 | 3.2 | 1.4 |
| C9 | -0.1 | 0.1 | 0.0 | -0.1 | 0.1 | 0.0 |
| C10 | -1.6 | 1.3 | 0.7 | -1.6 | 1.3 | 0.7 |
| C11 | -2.9 | 3.7 | 1.4 | -3.4 | 3.5 | 1.4 |
| C12 | -0.3 | 0.3 | 0.1 | -0.3 | 0.3 | 0.1 |

TABLE 13 – Relative error (%) between reconstruction and transport calculations, PARCS - DRAGON, influence of ADF and CDF volume choices (part 2), case #5 : 20(M)-20(U)-20(U)

| ADF | | | No_ADF | | FD_B | | FD_H | | FD_B | | FD_H | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| CDF | | | FD_C | | | | | | FD_C+FDCW | | | |
| | 17 | 1 col. | | | | | | | | | | |
| 17 | B | C | 0.8 | 0.3 | 2.1 | 0.6 | 1.5 | 0.5 | 1.3 | 0.4 | 1.9 | 0.5 |
| 1 | A | B | 0.2 | 0.8 | -2.6 | 2.1 | -1.3 | 1.5 | -1.0 | 1.3 | -2.4 | 1.9 |
| 2 | A | B | 1.2 | -0.6 | -3.0 | 2.7 | -0.9 | 1.2 | -0.6 | 0.8 | -2.6 | 2.3 |
| 3 | A | B | 1.7 | -0.5 | -3.7 | 4.2 | -1.0 | 2.1 | -0.6 | 1.6 | -3.2 | 3.7 |
| 4 | A | B | 2.0 | -1.0 | -4.0 | 4.5 | -1.0 | 2.0 | -0.6 | 1.6 | -3.5 | 4.0 |
| 5 | A | B | 2.8 | -1.6 | -3.4 | 4.0 | -0.4 | 1.5 | 0.0 | 1.3 | -3.1 | 3.8 |
| 6 | A | B | 3.3 | -2.0 | -2.7 | 3.2 | 0.3 | 0.9 | 0.3 | 1.1 | -2.6 | 3.4 |
| 7 | A | B | 3.0 | -2.0 | -2.1 | 2.3 | 0.5 | 0.4 | -0.1 | 1.4 | -2.6 | 3.2 |
| 8 | A | B | 2.4 | -1.6 | -0.7 | 0.9 | 0.9 | -0.1 | -0.7 | 1.9 | -2.4 | 2.9 |
| 9 | A | B | 1.2 | -1.0 | 1.9 | -1.2 | 1.8 | -1.0 | -1.9 | 2.6 | -1.8 | 2.4 |
| row | | | | | | | | | | | | |

Note : Results at the central assembly interface are presented here. See first column and Sec. 3.1 for detail.

TABLE 14 – Relative error (%) between reconstruction and transport calculations, PARCS - DRAGON, influence of ADF and CDF volume choices (part 2), case #8 : 60(M)-10(U)-40(M)

| ADF | | | No_ADF | | FD_B | | FD_H | | FD_B | | FD_H | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| CDF | | | FD_C | | | | | | FD_C+FDCW | | | |
| | 17 | 1 col. | | | | | | | | | | |
| 17 | B | C | 1.3 | 0.6 | 3.5 | -1.6 | 2.3 | -0.6 | 2.0 | -0.4 | 3.1 | -1.4 |
| 1 | A | B | 0.4 | 1.3 | -1.3 | 3.5 | -0.5 | 2.3 | -0.3 | 2.0 | -1.1 | 3.1 |
| 2 | A | B | 1.0 | 0.2 | -1.8 | 3.1 | -0.4 | 1.6 | -0.1 | 1.2 | -1.5 | 2.7 |
| 3 | A | B | 1.6 | -0.5 | -2.0 | 3.1 | -0.3 | 1.2 | 0.1 | 0.8 | -1.6 | 2.7 |
| 4 | A | B | 1.9 | -1.8 | -2.2 | 2.4 | -0.2 | 0.2 | 0.2 | -0.2 | -1.8 | 2.0 |
| 5 | A | B | 2.6 | -3.0 | -1.6 | 1.4 | 0.5 | -0.9 | 0.7 | -1.2 | -1.3 | 1.1 |
| 6 | A | B | 3.0 | -3.8 | -1.0 | 0.4 | 1.0 | -1.7 | 1.0 | -1.7 | -1.0 | 0.5 |
| 7 | A | B | 2.7 | -3.7 | -0.6 | -0.3 | 1.0 | -2.1 | 0.5 | -1.5 | -1.1 | 0.3 |
| 8 | A | B | 1.9 | -3.0 | 0.0 | -0.9 | 0.9 | -2.0 | -0.3 | -0.7 | -1.3 | 0.4 |
| 9 | A | B | 0.6 | -1.7 | 1.2 | -1.6 | 0.9 | -1.7 | -1.8 | 0.7 | -1.5 | 0.8 |
| row | | | | | | | | | | | | |

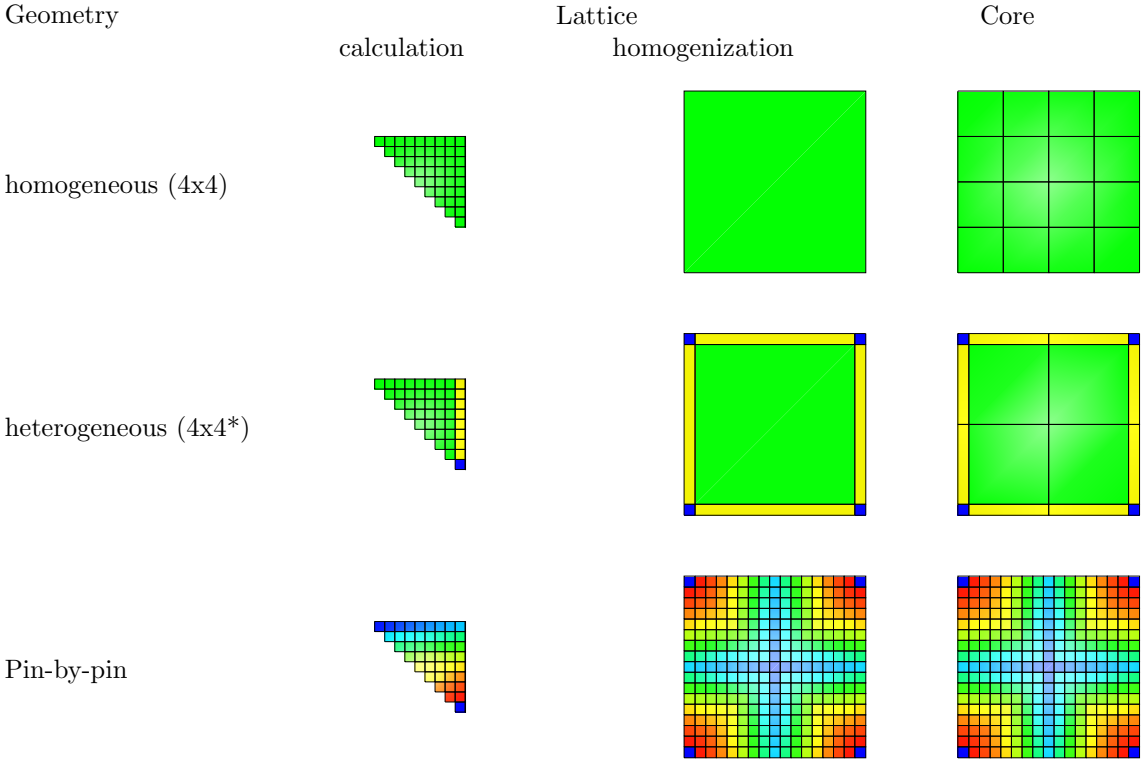
Note : Results at the central assembly interface are presented here. See first column and Sec. 3.1 for detail.

### A.3 Pin power and flux distribution

Reference pin power and flux distribution are presented below in Fig. 13 and 14 respectively.

### A.4 Other codes results

The results presented in the two following sections refer to calculations performed with homogeneous / heterogeneous / pin-by-pin properties. These properties were obtained with different homogenization choices as described below :




#### *A.4.1 APOLLO2-COCAGNE*

Table III of [7] is reproduced below. Cases 9 and 10 of Table III correspond to cases 10 and 11 of this report. Cases 9 and 12 of this report are not presented in Table III.

**Table III: Pin-power distribution accuracy**

| | | Pin-by-Pin calculations (45 media/assemby) 17×17 mesh | | | Heterogeneous calculations (3 media/assemby) 4×4* mesh | | | Homogeneous calculations (1 medium/assemby) 4×4 mesh | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Config | FE Order | min | max | std | min | max | std | min | max | std |
| C1 | RT1 | -1.7 | 2.5 | 0.6 | -0.8 | 2.0 | 0.5 | -7.2 | 7.1 | 1.5 |
| | RT2 | – | – | – | -0.6 | 2.2 | 0.4 | -3.3 | 6.6 | 1.0 |
| C2 | RT1 | -1.4 | 2.2 | 0.9 | -2.0 | 2.8 | 1.0 | -6.5 | 6.6 | 1.7 |
| | RT2 | – | – | – | -1.5 | 2.5 | 0.9 | -2.5 | 6.7 | 1.2 |
| C3 | RT1 | -1.7 | 1.8 | 0.7 | -1.5 | 1.8 | 0.8 | -6.0 | 5.3 | 1.8 |
| | RT2 | – | – | – | -1.3 | 1.3 | 0.7 | -3.2 | 3.5 | 1.1 |
| C4 | RT1 | -1.0 | 1.0 | 0.6 | -0.9 | 1.5 | 0.5 | -2.2 | 2.0 | 0.8 |
| | RT2 | – | – | – | -1.0 | 1.1 | 0.5 | -1.7 | 1.6 | 0.7 |
| C5 | RT1 | -1.3 | 2.2 | 0.5 | -0.9 | 2.0 | 0.5 | -6.4 | 6.3 | 1.4 |
| | RT2 | – | – | – | -0.5 | 2.2 | 0.4 | -2.6 | 6.1 | 0.8 |
| C6 | RT1 | -3.2 | 1.1 | 0.8 | -4.5 | 2.2 | 1.1 | -8.5 | 4.5 | 1.7 |
| | RT2 | – | – | – | -2.8 | 1.3 | 0.9 | -4.8 | 1.5 | 1.1 |
| C7 | RT1 | -2.3 | 3.1 | 1.0 | -2.4 | 3.5 | 0.7 | -7.4 | 8.0 | 2.2 |
| | RT2 | – | – | – | -1.2 | 2.5 | 0.6 | -4.2 | 4.9 | 1.5 |
| C8 | RT1 | -1.8 | 1.6 | 1.0 | -2.2 | 2.9 | 1.2 | -6.0 | 4.5 | 2.1 |
| | RT2 | – | – | – | -1.5 | 2.0 | 1.0 | -3.0 | 3.7 | 1.3 |
| C9 | RT1 | -1.7 | 2.4 | 1.1 | -2.3 | 3.4 | 1.3 | -7.8 | 6.8 | 2.0 |
| | RT2 | – | – | – | -1.7 | 2.9 | 1.1 | -3.1 | 5.2 | 1.4 |
| C10 | RT1 | -1.6 | 1.0 | 0.7 | -2.5 | 1.5 | 0.8 | -2.3 | 1.6 | 0.8 |
| | RT2 | – | – | – | -1.6 | 1.0 | 0.7 | -1.7 | 1.1 | 0.8 |

### *A.4.2 DRAGON-DONJON*

Table 3 of [17] is reproduced below in Tab. 15 .

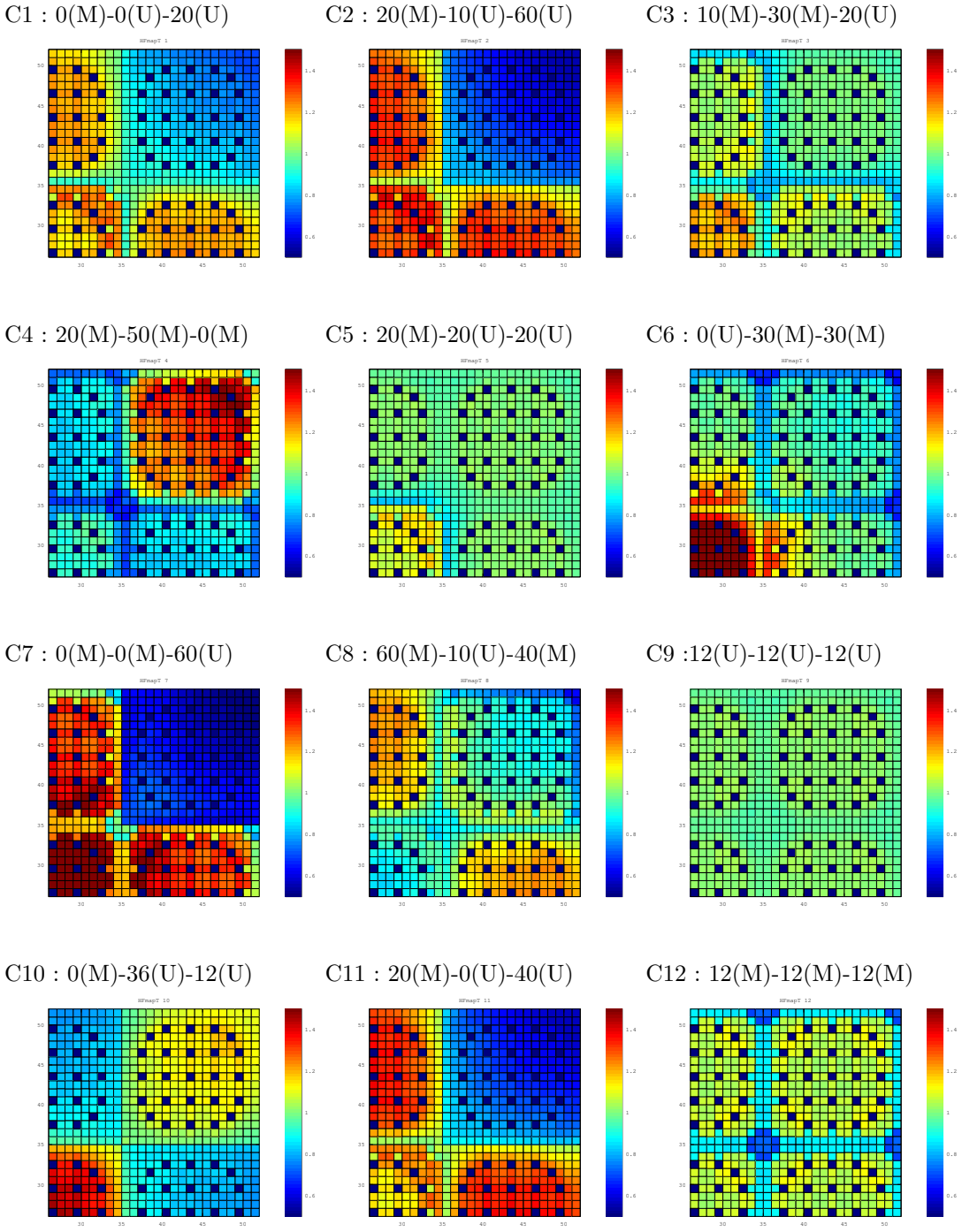



FIGURE 13 – Transport pin power distribution of all clusters (normalized to an average of 1 per pin)

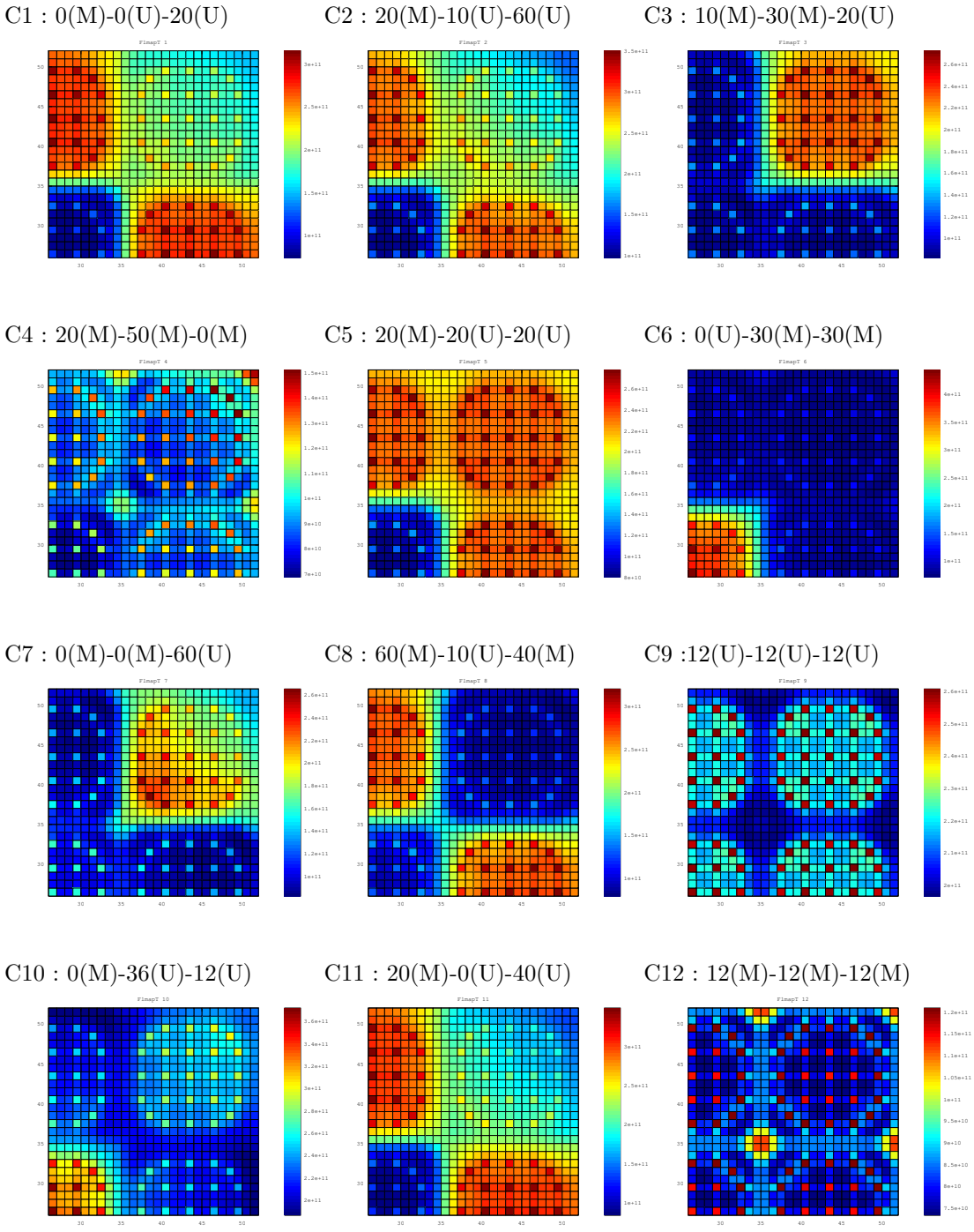



FIGURE 14 – Transport thermal group flux distribution of all clusters

TABLE 15 – Relative error between reconstruction and transport calculations (%), coarse mesh, SELE_FD option in SPH : module

| | | Pin by Pin | | | | Heterogeneous (het2) 4x4* | | | | Heterogeneous (het1) 4x4* | | | | Homogeneous 4x4 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | min | max | rms | $\delta$ | min | max | rms | $\delta$ | min | max | rms | $\delta$ | min | max | rms | $\delta$ |
| C1 | DUAL 2 3 | -6.15 | 4.99 | 1.51 | 11.14 | -2.46 | 3.93 | 1.35 | 6.39 | -5.48 | 5.70 | 1.92 | 11.17 | -7.70 | 7.15 | 1.83 | 14.85 |
| | DUAL 3 3 | - | - | - | - | -2.55 | 3.49 | 1.31 | 6.04 | -4.88 | 5.97 | 1.63 | 10.85 | -2.97 | 6.62 | 1.33 | 9.60 |
| C2 | DUAL 2 3 | -5.76 | 4.61 | 1.67 | 10.37 | -2.54 | 3.42 | 1.53 | 5.96 | -4.52 | 5.13 | 1.94 | 9.65 | -6.46 | 6.03 | 1.81 | 12.49 |
| | DUAL 3 3 | - | - | - | - | -2.42 | 3.31 | 1.50 | 5.73 | -4.46 | 5.50 | 1.75 | 9.95 | -2.70 | 5.93 | 1.50 | 8.63 |
| C3 | DUAL 2 3 | -4.40 | 5.48 | 1.63 | 9.88 | -3.01 | 2.51 | 1.27 | 5.52 | -4.94 | 5.22 | 1.97 | 10.16 | -4.89 | 5.11 | 1.75 | 10.00 |
| | DUAL 3 3 | - | - | - | - | -3.04 | 2.52 | 1.21 | 5.56 | -5.13 | 4.34 | 1.65 | 9.47 | -3.03 | 2.70 | 1.11 | 5.72 |
| C4 | DUAL 2 3 | -1.88 | 1.75 | 1.08 | 3.63 | -1.58 | 2.01 | 1.01 | 3.59 | -2.17 | 2.46 | 1.16 | 4.63 | -1.52 | 1.84 | 1.09 | 3.36 |
| | DUAL 3 3 | - | - | - | - | -1.50 | 1.62 | 0.99 | 3.13 | -2.11 | 1.99 | 1.11 | 4.10 | -1.43 | 1.86 | 1.09 | 3.29 |
| C5 | DUAL 2 3 | -5.59 | 5.26 | 1.25 | 10.85 | -2.45 | 3.75 | 0.94 | 6.19 | -4.89 | 6.06 | 1.47 | 10.95 | -6.12 | 5.39 | 1.31 | 11.50 |
| | DUAL 3 3 | - | - | - | - | -2.24 | 3.70 | 0.90 | 5.94 | -4.25 | 6.16 | 1.26 | 10.41 | -2.53 | 5.60 | 0.89 | 8.13 |
| C6 | DUAL 2 3 | -7.37 | 4.99 | 1.73 | 12.36 | -6.42 | 2.64 | 1.80 | 9.06 | -9.04 | 6.29 | 2.33 | 15.33 | -8.86 | 3.71 | 2.09 | 12.58 |
| | DUAL 3 3 | - | - | - | - | -6.12 | 1.77 | 1.72 | 7.89 | -8.57 | 2.66 | 1.87 | 11.23 | -6.09 | 2.11 | 1.58 | 8.20 |
| C7 | DUAL 2 3 | -5.76 | 8.31 | 2.41 | 14.06 | -4.13 | 4.75 | 1.69 | 8.88 | -6.37 | 8.20 | 2.49 | 14.57 | -5.90 | 7.42 | 2.15 | 13.32 |
| | DUAL 3 3 | - | - | - | - | -4.39 | 4.66 | 1.61 | 9.05 | -6.80 | 7.35 | 2.29 | 14.15 | -4.17 | 5.13 | 1.62 | 9.30 |
| C8 | DUAL 2 3 | -4.25 | 3.21 | 1.90 | 7.46 | -3.09 | 4.16 | 1.77 | 7.25 | -5.02 | 5.67 | 2.60 | 10.69 | -5.62 | 4.84 | 2.37 | 10.47 |
| | DUAL 3 3 | - | - | - | - | -3.05 | 3.68 | 1.69 | 6.73 | -4.63 | 5.13 | 2.07 | 9.77 | -2.99 | 3.64 | 1.68 | 6.63 |
| C9 | DUAL 2 3 | -0.14 | 0.15 | 0.05 | 0.29 | -0.10 | 0.11 | 0.04 | 0.22 | -0.10 | 0.12 | 0.04 | 0.22 | -0.10 | 0.12 | 0.04 | 0.22 |
| | DUAL 3 3 | - | - | - | - | -0.10 | 0.11 | 0.04 | 0.22 | -0.10 | 0.11 | 0.04 | 0.22 | -0.10 | 0.12 | 0.04 | 0.22 |
| C10 | DUAL 2 3 | -1.84 | 1.31 | 0.88 | 3.15 | -2.95 | 1.80 | 0.97 | 4.74 | -3.45 | 2.26 | 1.03 | 5.71 | -2.41 | 1.84 | 0.93 | 4.25 |
| | DUAL 3 3 | - | - | - | - | -2.12 | 1.49 | 0.95 | 3.61 | -2.24 | 1.61 | 0.94 | 3.85 | -1.98 | 1.54 | 0.91 | 3.51 |
| C11 | DUAL 2 3 | -5.26 | 4.20 | 1.77 | 9.47 | -2.76 | 4.57 | 1.76 | 7.33 | -4.79 | 6.03 | 2.19 | 10.82 | -6.93 | 7.26 | 2.09 | 14.19 |
| | DUAL 3 3 | - | - | - | - | -2.50 | 4.10 | 1.73 | 6.60 | -3.96 | 5.73 | 1.91 | 9.69 | -2.29 | 5.51 | 1.70 | 7.80 |
| C12 | DUAL 2 3 | -0.34 | 0.35 | 0.13 | 0.69 | -0.34 | 0.33 | 0.12 | 0.67 | -0.37 | 0.34 | 0.13 | 0.71 | -0.34 | 0.33 | 0.12 | 0.67 |
| | DUAL 3 3 | - | - | - | - | -0.34 | 0.33 | 0.12 | 0.68 | -0.33 | 0.33 | 0.12 | 0.67 | -0.34 | 0.33 | 0.12 | 0.67 |

# B Modified modules

## B.1 The COMPO: module

This component of the lattice code is dedicated to the constitution of the reactor database intended to store *all* the nuclear data, produced in the lattice code, that is useful in reactor calculations including fuel management and space-time kinetics. Multigroup lattice calculations are too expensive to be executed dynamically from the driver of the global reactor calculation. A more feasible approach is to create a reactor database where a finite number of lattice calculation results are tabulated against selected *global* and/or *local parameters* chosen so as to represent expected operating conditions of the reactor.

The COMPO: module is used to create and construct a MULTICOMPO object. This object is generally *persistent* and used to collect information gathered from many DRAGON *elementary calculations* performed under various conditions.

For each elementary calculation, the results are recovered from the output of the EDI: module and stored in a list of *homogenized mixture* directories. The EDI: module is responsible for performing condensation in energy, homogenization in space of the microscopic cross sections and constitution of *macroscopic sets* for collecting together many isotopes. All the elementary calculations gathered in a single MULTICOMPO object are characterized by the same number of *homogenized mixtures* and by a specific output energy-group structure.

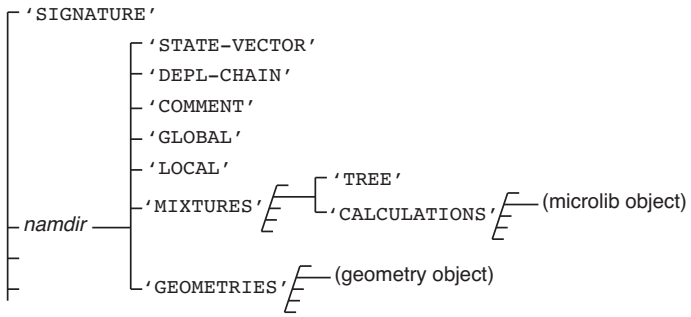



FIGURE 15 – Organization of a multicompo object.

Each elementary calculation is characterized by a tuple of *global* and/or *local parameters* Global parameters are characteristics of the complete lattice, while local parameters are characteristics of each homogenized mixture. These parameters are of different types, depending on the nature of the study under consideration : type of assembly, power, temperature in a mixture, concentration of an isotope, time, burnup or exposure rate in a depletion calculation, etc. Each step of a depletion calculation represents an elementay calculation. The MULTICOMPO object is often presented as a *multi-parameter reactor database*.

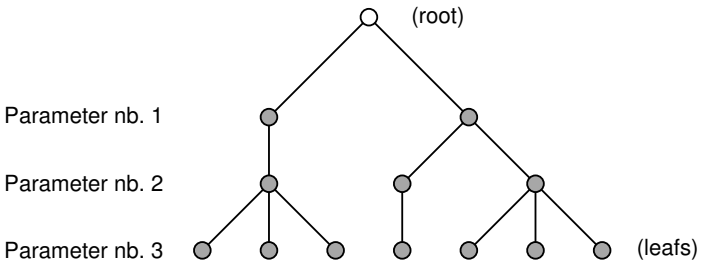



FIGURE 16 – Parameter tree in a MULTICOMPO object

The MULTICOMPO object is organized as shown in Figure 15. The root of the object contains table–of–content information for global and local parameters and two lists of directories. Each component of the

first list (`'MIXTURES'`) contains the directory `'TREE'` (the parameter tree) and the list (`'CALCULATIONS'`) made of MICROLIB objects. Each component of the second list (`'GEOMETRIES'`) contains the homogenized geometry of an elementary calculation.

The localization of an elementary calculation is done using a tuple of global and/or local parameters. The elementary calculation indices are stored in a tree with the number of levels equal to the number of global and local parameters. An example of a tree with three parameters is shown in Figure 16. Each node of this tree is associated with the index of the corresponding parameter and with the reference to the daughter nodes if they exist. The number if leafs is equal to the number of nodes for the last (third) parameter and is equal to the number of elementary calculations stored in the MULTICOMPO object. The index of each elementary calculation is therefore an attribute of each leaf.

In each homogenized mixture component, the `COMPO:` module recover cross sections for a number of *particularized isotopes* and of a single *macroscopic set*, a collection of the remaining isotopic cross sections weighted by isotopic number densities. Other information is also recovered : multigroup neutron fluxes, isotopic number densities, fission spectrum, delayed neutron data, etc.

A different specification of the `COMPO:` function call is used for creation and construction of the MULTICOMPO object.

- The first specification is used to initialize the MULTICOMPO data structure and to set the choice of global and local parameters.
- A modification call to the `COMPO:` function is performed after each elementary calculation in order to recover output information processed by `EDI:` (condensed and homogenized cross sections) and `EVO:` (burnup dependant values). Global and local parameters can optionnally be recovered from MICROLIB objects.
- Another modification call to the `COMPO:` function is used to catenate a *read-only* MULTICOMPO object into a *master* MULTICOMPO object.

The calling specifications are :

TABLE 16: Structure **(COMPO :)**

```
{ CPONAM := COMPO: [ CPONAM ] :: (compo_data1)
| CPONAM := COMPO: CPONAM EDINAM [ EDINA2 ] [ BRNNAM ] [ HMIC1 [ HMIC2 ] ]
          :: (compo_data2)
| CPONAM := COMPO: CPONAM CPORHS :: (compo_data3)
| COMPO: CPONAM :: (compo_data4) }
```

where

| | |
|---|---|
| *CPONAM* | `character*12` name of the LCM object containing the *master* MULTICOMPO data structure. |
| *EDINAM* | `character*12` name of the LCM object (type `L_EDIT`) containing the EDITION data structure corresponding to an elementary calculation. This EDITION data structure is containing homogenized and condensed cross-section information. The EDITION data produced by the last call to the `EDI:` module is used. |
| *EDINA2* | `character*12` name of an optional LCM object (type `L_EDIT`) containing the EDITION data structure corresponding to an elementary calculation. This EDITION data structure is containing *group form factor* information. The EDITION data produced by the last call to the `EDI:` module is used. |
| *BRNNAM* | `character*12` name of the LCM object (type `L_BURNUP`) containing the BURNUP data structure. |
| *HMIC1* | `character*12` name of a MICROLIB (type `L_LIBRARY`) containing global parameter information. |

*HMIC2* `character*12` name of a MICROLIB (type `L_LIBRARY`) containing global parameter information.

*CPORHS* `character*12` name of the *read-only* MULTICOMPO data structure. This data structure is concatenated to *CPONAM* using the *compo_data3* data structure, as presented in Section B.1.3. *CPORHS* must be defined with the same number of energy groups and the same number of homogeneous regions as *CPONAM*. Moreover, all the global and local parameters of *CPORHS* must be defined in *CPONAM*. *CPONAM* may be defined with *global* parameters not defined in *CPORHS*.

*compo_data1* input data structure containing initialization information (see Section B.1.1).

*compo_data2* input data structure containing information related to the recovery of an elementary calculation (see Section B.1.2).

*compo_data3* input data structure containing information related to the catenation of a *read-only* MULTICOMPO (see Section B.1.3).

*compo_data4* input data structure containing information related to the display of a *read-only* MULTICOMPO (see Section B.1.4).

### *B.1.1 Initialization data input for module* `COMPO:`

TABLE 17: Structure **(compo_data1)**

```
[ EDIT iprint ]
[[ [ STEP UP NAMDIR ]
   [ MAXCAL maxcal ]
   [ COMM [[ HCOM ]] ENDC ]
   [[ PARA PARKEY
      { TEMP HMIC imix | CONC HISO1 HMIC imix | IRRA | FLUB |
        POWR | MASL | FLUX | TIME | VALU { REAL | CHAR | INTE } }
   ]]
   [[ LOCA PARKEY
      { TEMP | CONC HISO2 | IRRA | FLUB | FLUG | POWR | MASL | FLUX }
   ]]
[ ISOT nisp (HISOP(i),i=1,nisp) ]
[ GFF ]
INIT ]]
;
```

where

`EDIT` keyword used to set *iprint*.

*iprint* index used to control the printing in module `COMPO:`. =0 for no print ; =1 for minimum printing (default value).

`STEP` keyword used to create the database from a sub-directory named *NAMDIR*. This capability make possible the creation of a single object with many independent MULTICOMPO structures in it. By default, the database is created on directory `'default'`.

`UP` keyword used to move up towards a sub-directory of *CPONAM*.

*NAMDIR* create the MULTICOMPO structure in the sub-directory named *NAMDIR*.

`MAXCAL` keyword used to set *maxcal*.

| | |
|---|---|
| *maxcal* | maximum number of elementary calculations to be stored in the MULTICOMPO. *maxcal*= 10 by default. This maximum size is automatically increased when the number of elementary calculations exceeds the current value of *maxcal*. |
| `COMM` | keyword used to input a general comment for the MULTICOMPO. |
| *HCOM* | `character*80` user-defined comment. |
| `ENDC` | end–of–HCOM keyword. |
| `PARA` | keyword used to define a single global parameter. |
| `LOCA` | keyword used to define a single local parameter. |
| *PARKEY* | `character*12` user-defined keyword associated to a global or local parameter. |
| *HMIC* | `character*12` name of the MICROLIB (type `L_LIBRARY`) associated to a global parameter. The corresponding MICROLIB will be required on RHS of the `COMPO:` call described in Sect. B.1.2. |
| *imix* | index of the mixture associated to a global parameter. This mixture is located in MICROLIB named *HMIC*. |
| *HISO1* | `character*8` alias name of the isotope associated to a global parameter. This isotope is located in MICROLIB data structure named *HMIC*. |
| *HISO2* | `character*8` alias name of the isotope associated to a local parameter. This isotope is located in the MICROLIB directory of the EDITION data structure named *EDINAM*. |
| `TEMP` | keyword used to define a temperature (in Kelvin) as global or local parameter. |
| `CONC` | keyword used to define a number density as global or local parameter. |
| `IRRA` | keyword used to define a burnup (in MWday/Tonne) as global or local parameter. |
| `FLUB` | keyword used to define a *fuel-only* exposure rate (in n/kb) as global or local parameter. The exposure rate is recovered from the *BRNNAM* LCM object. |
| `FLUG` | keyword used to define an exposure rate in global homogenized mixtures (in n/kb) as local parameter. The exposure rate is recovered from the *BRNNAM* LCM object. |
| `POWR` | keyword used to define the power as global or local parameter. |
| `MASL` | keyword used to define the mass density of heavy isotopes as global or local parameter. |
| `FLUX` | keyword used to define the volume-averaged, energy-integrated flux as global or local parameter. |
| `TIME` | keyword used to define the time (in seconds) as global parameter. |
| `VALU` | keyword used to define a user-defined quantity as global parameter. This keyword must be followed by the type of parameter. |
| `REAL` | keyword used to indicate that the user-defined global parameter is a floating point value. |
| `CHAR` | keyword used to indicate that the user-defined global parameter is a `character*12` value. |
| `INTE` | keyword used to indicate that the user-defined global parameter is an integer value. |
| `ISOT` | keyword used to select the set of particularized isotopes. By default, all the isotopes available in the EDITION data structure *EDINAM* are selected. |
| *nisp* | number of user-defined particularized isotopes. |
| *HISOP* | `character*8` names of the user-defined particularized isotopes. These names must be present in the EDITION data structure *EDINAM*. |
| `GFF` | keyword used to enable the recovery of group form factor information from EDITION data structure *EDINA2*. |
| `INIT` | keyword used to create the empty structure in the MULTICOMPO. |

*B.1.2 Modification data input for module* `COMPO:`

TABLE 18: Structure **(compo_data2)**

```
[ EDIT iprint ]
[ ALLX ]
[ STEP UP { NAMDIR | * } ]
[ ORIG orig ]
[[ PARKEY value ]]
[ MACRO ] [ SET xtr { S | DAY | YEAR } ]
;
```

where

| | |
|---|---|
| `EDIT` | keyword used to set *iprint*. |
| *iprint* | index used to control the printing in module `COMPO:`. =0 for no print ; =1 for minimum printing (default value). |
| `ALLX` | keyword used to register the region number of each isotope before merging. This option is useful if the same keyword has been specified in `EDI:` before. This allows to perform subsequent depletion calculations, in taking into account different fuel regions in the diffusion calculation. |
| `STEP` | keyword used to access the database from a sub-directory named *NAMDIR* instead of accessing it from the root of *CPONAM*. |
| `UP` | keyword used to move up towards a sub-directory of *CPONAM*. |
| *NAMDIR* | access the MULTICOMPO structure in the sub-directory named *NAMDIR*. |
| `*` | use a sub-directory name identical to the directory in *EDINAM* where the edition data is coming from. |
| *PARKEY* | `character*12` keyword associated to a user-defined global parameter. |
| *value* | floating-point, integer or `character*12` value of a user-defined global parameter. |
| `ORIG` | keyword used to define the father node in the parameter tree. By default, the index of the previous elementary calculation is used. |
| *orig* | index of the elementary calculation associated to the father node in the parameter tree. |
| `MACRO` | keyword used to recover cross-section information from the macrolib directory in *EDINAM*. By default, the cross-section information is recovered from the microlib in *EDINAM*. |
| `SET` | keyword used to recover the flux normalization factor already stored on *BRNNAM* from a sub-directory corresponding to a specific time. |
| *xtr* | time associated with the current flux calculation. The name of the sub-directory where this information is stored will be given by '`DEPL-DAT`'//`CNN` where `CNN` is a `character*4` variable defined by `WRITE(CNN,'(I4.4)') INN` where `INN` is an index associated with the time *xtr*. |
| `S` | keyword to specify that the time is given in seconds. |
| `DAY` | keyword to specify that the time is given in days. |
| `YEAR` | keyword to specify that the time is given in years. |

*B.1.3 Modification (catenate) data input for module* `COMPO:`

TABLE 19: Structure **(compo_data3)**

```
[ EDIT iprint ]
[ STEP UP NAMDIR ]
[ ORIG orig ]
[[ PARKEY value ]]
[ WARNING-ONLY ]
;
```

where

| | |
|---|---|
| `EDIT` | keyword used to set *iprint*. |
| *iprint* | index used to control the printing in module `COMPO:`. =0 for no print ; =1 for minimum printing (default value). |
| *PARKEY* | `character*12` keyword associated to a global parameter that is specific to *CPONAM* (not defined in *CPORHS*). |
| *value* | floating-point, integer or `character*12` value of a global parameter that is specific to *CPONAM*. |
| `ORIG` | keyword used to define the father node in the parameter tree. By default, the index of the previous elementary calculation is used. |
| *orig* | index of the elementary calculation associated to the father node in the parameter tree. |
| `WARNING-ONLY` | This option is useful if an elementary calculation in *CPORHS* is already present in *CPONAM*. If this keyword is set, a warning is send and the *CPONAM* values are kept, otherwise the run is aborted (default). |

*B.1.4 Display data input for module* `COMPO:`

TABLE 20: Structure **(compo_data4)**

```
[ EDIT iprint ]
[ STEP UP NAMDIR ]
[ EDIT iprint ]
DB-STRUC
;
```

where

| | |
|---|---|
| `EDIT` | keyword used to set *iprint*. |
| *iprint* | index used to control the printing in module `COMPO:`. <2 for MUPLET display only (default value) and parameters values are presented at the end, ≥2 for the parameter value display for each calculation. |
| `DB-STRUC` | `character*12` keyword used to display the content of the *CPONAM* object for the *NAMDIR* directory. |

### B.2 The `D2P:` module

The objective of the `D2P:` module is to produce a file containing the macroscopic cross sections generated by the DRAGON5 lattice code and readable by the GenPMAXS software. This module makes possible the use of DRAGON-integrated XS into the PARCS core code. PARCS (*Purdue Advanced Reactor Core Simulator*) from the U.S. NRC [5] is a full 3D core code for the simulation of nuclear reactor steady state and transient behavior, at a specific burnup state.

The main objective of the `D2P:` module is to produce an output file with which can be accepted by GenPMAXS to produce the PMAXS file. In order to minimize the development in the GenPMAXS code, the choice has been made to reproduce an existing format already accepted by GenPMAXS. The HELIOS output format has been selected.

A Microlib is extracted from a Saphyb (or Multicompo) obtained by DRAGON (or APOLLO) in a previous calculation. The `D2P:` module extracts cross sections contained in this microlib and creates two files :

– an input file needed by GenPMAXS to produce a PMAXS (extention "`.inp`")
– a file containing data cross sections in HELIOS-like format (extention "`.dra`")

Note that the `D2P:` module is compatible with the last version of GenPMAXS (v6.1.3) and PARCS (v32m17 etc.).

#### *B.2.1 The PMAXS format*

The depletion capabilty of the PARCS code is reachable thanks to a specific format of cross section file, named PMAXS (*Purdue Macrosocopic Cross Section File*)[14]. This format is generated using the GenPMAXS code, based on output files of several lattice codes such as HELIOS, CASMO, TRITON, WIMS, CONDOR and SERPENT. This module intend to add DRAGON in this list.

The macroscopic cross sections are stored in the PMAXS file using partial derivatives as a function of state variables. Consequently the PMAXS format is a multi-dimentional table including burnup dependance. This format is a flexible way to obtain a more or less accurate meshing of cross sections. In addition of burnup, the list of state variables around which PMAXS is built is the following :

1. `CR` : control rod fraction
2. `DC` : density of coolant
3. `PC` : soluble poison concentration in coolant
4. `TF` : temperature of fuel
5. `TC` : temperature of coolant
6. `IC` : impurity of coolant
7. `DM` : density of moderator
8. `PM` : soluble poison concentration in moderator
9. `TM` : temperature of moderator
10. `IM` : impurity of moderator
11. `DN` : density difference between neighbor and current assembly
12. `BN` : burnup difference between neighbor and current assembly

These variables **should** be specified in this order. With the exception of burnup, each variable is optional. The following equation is used to compute a cross section $\Sigma$ in the PMAXS formalism (including 4 state variables), with $r$ the reference state and $m$ the mid point between the reference state and the current node state $(CR, DC, \sqrt{TF}, TC)$ :

$$\begin{aligned}\Sigma(CR, DC, \sqrt{TF}, TC) \;=\; & \Sigma^r(DC^r, \sqrt{TF}^r, TC^r) + \Delta DC \left.\frac{\partial \Sigma}{\partial DC}\right|_{(CR, DC^m, \sqrt{TF}^r, TC^r)} + \\ & \Delta\sqrt{TF} \left.\frac{\partial \Sigma}{\partial \sqrt{TF}}\right|_{(CR, DC, \sqrt{TF}^m, TC^r)} + \Delta TC \left.\frac{\partial \Sigma}{\partial TC}\right|_{(CR, DC, \sqrt{TF}, TC^m)}\end{aligned}$$

The PMAXS formalism and the procedure branching generation are completely described in the GenPMAXS manual [14].

The PMAXS file contains eight blocks, few of them are optional and others mandatory. A precise description of each block is proposed in the APPENDIX A of GenPMAXS manual [14]. In this section, a short description of blocks is given.

**Block** `XS CONTROL information (mandatory)`

The first block stores data reflecting the conditions in which cross sections are obtained and what kind of informations is contained in the PMAXS file. It is composed of five integers for the number of energy groups, of delay neuton groups etc. Then, fifteen logical flags indicates if the PMAXS contains the correponding data such as assembly discontinuity factor (ADF), Xe and Sm microscopic cross sections ... The block is ended by five lines of comments to be filled by the user.

```
GLOBAL_V       1  2 6 6 1 1 45 17 F F F F F F F F F F F F F T
 Contents of T/H Invariant Variables(TIV) block and Cross Sections(XS) block
       TIV:
        XS:tr,ab,nf,kf/sct/
 2  Group value of each variable are put together in a line.
 Some variables(separated by ",") share a line,"/" means change line
 Generated by GenPMAXS-V6.1.1
```

**Block** `BRANCHES information (optional)`

This blocks identifies the state variables used for the branching and the correponding states for all branches.

```
STA_VAR    4 CR DC PC TF
BRANCHES   1   2   6  18  54
    RE   1     0.00000     0.71100  1000.00000   900.00000
    CR   1     1.00000     0.71100  1000.00000   900.00000
    CR   2     2.00000     0.71100  1000.00000   900.00000
    DC   1     0.00000     0.66100  1000.00000   900.00000
    DC   2     0.00000     0.75200  1000.00000   900.00000
    DC   3     1.00000     0.66100  1000.00000   900.00000
    DC   4     1.00000     0.75200  1000.00000   900.00000
    DC   5     2.00000     0.66100  1000.00000   900.00000
    DC   6     2.00000     0.75200  1000.00000   900.00000
    PC   1     0.00000     0.66100     0.00000   900.00000
    ...
```

In this example, the PMAXS cross sections depend on 4 state variables : CR, DC, PC and TF. There are 2 branches for control rods, 6 for coolant density, 18 for boron concentration, and 54 for fuel temperature.

**Block** `BURNUP information (optional)`

It contains the number of burnup sets and burnup points. Each cross sections will be repeated for each burnup points.

```
BURNUPS    1
   1  35 0.00000 0.00900 0.01900 0.07500 0.15000 0.50000 1.00000 2.00000 3.00000
         4.00000 6.00000 8.00000 10.0000 12.0000 14.0000 16.0000 18.0000 20.0000
         24.0000 28.0000 32.0000 36.0000 40.0000 44.0000 48.0000 52.0000 56.0000
         60.0000 64.0000 68.0000 72.0000 76.0000 80.0000 84.0000 86.0000
```

In the above example, one can observe a set of 35 burnup points from 0 to 86 GWd/t.

**Block** `XS SET identification (mandatory)`

In this block, the geometrical configuration of core reactor is specified and also the number of ADF in each group, the number of rod rows and columns in whole assembly, the rod lattice pitch etc. Some of these parameters have default values

```
XS_SET  00000001  1 1 1 17 17 3 1.44270 0.72135 0.72135 2.78613 0.73659 0.00016
        0.00000   0.00000
```

**Block** `HISTORY CASE identification (mandatory)`

This block describes the state variables values for all histories contained in the PMAXS file. The first parameter refers to the burnup set.

```
HISTORYC   1     0.00000     0.71100  1000.00000   900.00000
```

**Block** `T/H invariant variables (mandatory)`

It contains invariant variables, if the corresponding logical flag in block `XS CONTROL` is set to 'T'. The list of invariant variables, repeated for each burnup points, is :

- Chi spectra
- Yield of I, Xe, and Sm
- Beta of delayed neutron
- Lambda of delayed neutron
- Decay heat data

```
1.00000E+00 0.00000E+00 5.13949E-08 2.17697E-06
8.87406E-14 1.13375E-13 4.25558E-15
2.68628E-04 1.43419E-03 1.39641E-03 3.23740E-03 1.43931E-03 5.99082E-04
1.33535E-02 3.26045E-02 1.21056E-01 3.05531E-01 8.60559E-01 2.89034E+00
...
```

This block contains the necessary information for 1 burnup point and for each energy group `Chi,inV/YLD/Bet/Lam/`.

**Block** `XS data (mandatory)`

Cross sections in PMAXS file are listed for each burnup point and for each neutron energy group. Some cross sections are optional (see table below)

| **XS data block** | | |
|---|---|---|
| `STR` | *Transport cross section* | mandatory |
| `SAB` | *Absorption cross section* | mandatory |
| `SNF` | *Nu-fission cross section* | mandatory |
| `SKF` | *Kappa-fission cross section* | mandatory |
| `XENG` | *Microscopic capture cross section of Xenon* | optional |
| `SMNG` | *Microscopic capture cross section of Samarium* | optional |
| `SFI` | *Fission cross section* | optional |
| `DET` | *Detector response parameter* | optional |
| `SCT` | *Scattering cross section* | mandatory |
| `ADF` | *Assembly discontinuity factor* | optional |
| `DED` | *Direct energy deposition* | optional |
| `J1` | *J1 factors* | optional |
| `CDF` | *Corner discontinuity factor* | optional |
| `GFF` | *Group-Wise form function* | optional |

### *B.2.2 General format of the module*

The `D2P:` module can perform a sequence of phases related to the generation of a cross section format readable by GenPMAXS :

- PHASE 1 : recover input data from Saphyb and create output files
  1. recover information from a Saphyb file,
  2. store general information in output file,
  3. generate the GenPMAXS input file

– PHASE 2 : recover crosss section from microlib thanks to the `SCR:` module and store in memory,
– PHASE 3 : store cross sections in output file.

The general format of the data for the `D2P:` module is the following :

TABLE 21: Structure `D2P:`

{ *HEL GEN INF* `:=D2P:` *INF* { *SAP* | *MCO* } `::` `PHASE` *1* [`EDIT` *iprint*] `(descphase1)`
| *GEN INF* `:=D2P:` *MIC INF GEN* { *SAP* | *MCO* } `::` `PHASE` *2* [`EDIT` *iprint*]
| *HEL GEN INF* `:=D2P:` *INF GEN HEL* `::` `PHASE` *3* [`EDIT` *iprint*]
}

In the DRAGON formalism, the Left-Hand-Side (LHS) is dedicated to the objects created or modified by the module, the Right-Hand-Side (RHS) is used for input objects, all parameters are passed to the module after the " : :" delimiter .
where

| | |
|---|---|
| *HEL* | `ascii file` Output file with HELIOS-like format, compulsory if *iphase*= 1 (in creation mode) or if *iphase*=3 (in modification mode). |
| *GEN* | `ascii file` Input file for running GenPMAXS, compulsory if *iphase*= 1 (in creation mode) or if *iphase*=2 or 3 (in modification mode) |
| *INF* | `LCM object` Block of data for the dialogue between different sequence of operations. |
| *SAP* | Saphyb object with cross sections to be extracted,compulsory if *iphase*= 1 or 2. |
| *MCO* | Multicompo object with cross sections to be extracted,compulsory if *iphase*= 1 or 2. |
| *MIC* | microlib object with cross sections for one burnup point,compulsory if *iphase*= 2. |
| `PHASE` | keyword used to set *iphase*. |
| *iph* | integer index used to control the current phase of `D2P:` module |
| `EDIT` | keyword used to set *iprint*. |
| *iprint* | integer index used to control the printing on screen : = 0 for no print (default value) ; = 1 for minimum printing ; for larger values of *iprint* everything will be printed. |
| `(descphase1)` | input data structure for PHASE 1 of this module |

In the case where the current PHASE of the `D2P:` module is *iphase=1*, the (`descphase1`) takes the form :

TABLE 22: Structure (`descphase1`)

[`NAMDIR` *mixdir* ] [`MIX` *imix* ]
[`PKEY` (*refnam(i) sapnam(i)*, i=1, npkey) `ENDPKEY` ]
`FUEL` {
`BARR` { `DEF` *unrodded aicg aicn* | `USER` *unrodded (compo(i),i=1,ncompo)* `ENDBARR` }
[`GRID`{`SAP`|`DEF`|
`USER` { `GLOBAL` *(pkey(i),nval(i), i=1,npkey)* `ENDGLOBAL` |
[`NEW`] `ADD` *(pkey(i),nval(i),(val(j),j=1,nval(i)),i=1,npkey)* `ENDADD` } } } ]
[`ADF` { `DRA` *nadf (hadf(i), i=1,nadf)* | `GET` | `SEL`} ]
[`CDF DRA` *ncdf (hcdf(i), i=1,ncdf)* ]
[`GFF DRA` ]
[`ISOTOPES` { [`XE135` *xenam* ] [`SM149` *smnam* ] [`I135` *inam* ] } `ENDISOTOPES` ]

continued on next page

Structure (`descphase1`) continued from last page

```
}
|REFLECTOR
HELIOS [
 [FILE_CONT_1 ncols nrows part hm_dens bypass ]
 [FILE_CONT_2 (emin(g), g=1,ngroup) ]
 [FILE_CONT_3 vcool vwatr vmodr vcnrd vfuel vclad vchan ]
 [FILE_CONT_4 pitch xbe ybe ]
 [XS_CONT nside ncorner vfcm ] ]
GENPMAXS [
 [JOB_TIT jobtit ]
 [FILE_NAME fname ]
 [DERIVATIVE der ]
 [VERSION vers ]
 [COMMENT comment ]
 [JOB_OPT ladf lxes lded lj1f lchi lchd linv ldet lyld lcdf lgff lbet lamb ldec ]
 [IUPS iups ]
 [SFAC sfac ]
 [BFAC bfac ] ]
```

where

| | |
|---|---|
| `NAMDIR` | keyword used to set *mixdir* . |
| *mixdir* | name of sub-directory in Multicompo containing information to be recovered. Default *mixdir = 'default'*. |
| `MIX` | keyword used to set *imix* |
| *imix* | index of the mixture in the *SAP* object which will be considered by the module. Default *imix*=1. |
| `PKEY` | keyword used to associate a name of PKEY in the `SAP` object to a type of state variable. |
| *refnam* | type of state variable. The possible *refnam* are : `BARR` for the control rod (-), `DMOD` for the density of coolant (g/cc), `CBOR` for the boron concentration (ppm), `TCOM` for the fuel temperature (C), `TMOD` for the moderator temperature (C), `BURN` for the burnup exposure (MWd/T). It is not necessary to specify all state variable names, only state variables with a different name compared to *refnam* are expected. |
| *sapnam* | name of state variable in the `SAP` object associated to *refnam* . Default values are *sapnam=refnam*. NB : If a state variable name is not correctly associated, an error will occur during processing. |
| `FUEL` | keyword used to indicate that the input *SAP* object contains cross sections for fuel assembly . |
| `BARR` | keyword used to associate an index of control rod in the *SAP* object to an index composition in PMAXS. |
| *unrodded* | index of control rod in the `SAP` object for the unrodded cross section. No default. |
| *aicg* | index of control rod in the `SAP` object for the aicg cross section. No default. |
| *aicn* | index of control rod in the `SAP` object for the aicn cross section. No default. |
| *compo* | index of control rod in the `SAP` object for the composition i.No default. |
| `ISOTOPES` | keyword used to associate a name of isotope in the `SAP` object to a specific isotope. |
| `XE135` | keyword used to indicate that the following record correponds to the name of Xe 135 in the `SAP` object . |
| *xenam* | name of Xe 135 isotope in the `SAP` (or `MCO`) object. Default *xenam = 'XE135PF'*. |

`SM149` keyword used to indicate that the following record correponds to the name of Sm 149 in the `SAP` (or `MCO`) object .

*smnam* name of Xe 135 isotope in the `SAP` (or `MCO`) object. Default *smnam = 'SM149PF'*.

`I135` keyword used to indicate that the following record correponds to the name of I 135 in the `SAP` (or `MCO`) object .

*inam* name of Xe 135 isotope in the `SAP` (or `MCO`) object. Default *inam = 'I135PF'*.

`GRID` keyword used to select the grid of state variables used for the branching generation of the `PMAXS` file.

`SAP` keyword used to indicate that the meshing is the one used in the `SAP` (or `MCO`) object. Default option.

`USER` keyword used to indicate that the meshing is defined by the user.

`GLOBAL` keyword used to set a global meshing by defining for each desired state variables a number of points for the branching calculation.

`ADD` keyword used to add a set of new points for the branching calculation. The new points are added to the meshing contained in the `SAP` (or `MCO`) object.

`NEW` keyword used to indicate that the points contained in the `SAP` (or `MCO`) object are ignored, consequently only the set of points indicated using `ADD` will be considered for the branching calculation.

*pkey* name of the state variable. If *pkey* does not correpond to any name in the `SAP` (or `MCO`) object, it will be ignored. It is not necessary to set all state variable contained in `SAP` (or `MCO`) , if a state variable is missing, the `SAP` (or `MCO`) meshing for this state variable will be considered. NB : the BARR parameter cannot be modified by the user.

*nval* number of points for the state variable *pkey*. In the case `GLOBAL`, the *nval* points are obtained by splitting the pkey range from the first to the last values contained in the `SAP` (or `MCO`) object, otherwise it corresponds to the number of new points to be introduced in the meshing.

*val* value to be added in the branching calculation corresponding to the *pkey(i)*. In the case where *pkey(i)* is `TCOM` or `TMOD`, the temperature must be in Celsius.

`DEF` keyword used to call a default meshing : the values for `BARR` and `BURN` are extracted from Saphyb, four default values are considered for `DMOD`,`CBOR`, `TCOM` and `TMOD` (if exists). These values correspond to the first, mid and last values of the initial `SAP` (or `MCO`) meshing. This otpion is used if the number of banches in the Saphyb or defined by the user exceeds 1000.

`ADF` keyword used to set the type of Assembly Discontonuity Factor to be recovered from the `SAP` (or `MCO`) object. NB : the *ladf* flag must be set to true.

`DRA` Discontinuity factors are generated using the *DRAGON V5* procedure. Discontinuity factors could be Assembly Discontinuity Factors (ADF), Corner Discontinuity Factors (CDF) or Group-wise Form Function (GFF). Default option. NB : This option is available with Multicompo produced by the *DRAGON V5* lattice code using a 2-level flux calculation with the Method Of Characteristics.

$$\mathrm{ADF}_{g,f} = \frac{\phi_g^{Het}}{\phi_g^{Hom}},$$

where $g$ is the energy group, $f$, the assembly surface and $\phi_g^{Het}$,$\phi_g^{Hom}$ are the average surfacic homogene and heterogene fluxes in asssembly.

`GET` Assembly discontinuity factors are generated using the *Generalized Equivalence Theory*. NB : This option is available with Saphyb produced by the *APOLLO2* lattice code using a 2-level flux calculation with the Method of Characteristics.

$$\mathrm{ADF}_{g,f} = \frac{\phi_g^{Het}}{\left(\frac{\pm J_g^{Net} \times h}{2 \times D_g}\right) + \phi_g^{Hom}},$$

where $g$ is the energy group, $f$, the assembly surface, $\phi_g^{Het}$,$\phi_g^{Hom}$ are the homogene and heterogene fluxes in asssembly,$D_g$ , the diffusion coefficient, $h$ the mesh dimension and $J_g^{Net}$ the net average surfacic current.

`SEL` Assembly discontinuity factors are generated using the *Selengut* normalization. This option is available with Saphyb prduced by the *APOLLO2* lattice code using a 2-level flux calculation with the Method of Characteristics.

$$\mathrm{ADF}_{g,f} = \frac{2 \times \left(J_g^+ + J_g^-\right)}{\left(\frac{\pm J_g^{Net} \times h}{2 \times D_g}\right) + \phi_g^{Hom}},$$

where $g$ is the energy group, $f$, the assembly surface,$\phi_g^{Hom}$ is the homogene fluxe in asssembly, $D_g$ , the diffusion coefficient,$h$ the mesh dimension and $J_g^+$, $J_g^-$, $J_g^{Net}$ the incoming, outgoing, and net average surfacic currents.

*nadf* number of the ADF-type boundary flux edit to be recovered from Multicompo. Allowed values $nadf = 1$ or 4.

*hadf* name of the ADF-type boundary flux edit to be recovered from Multicompo. Default all $hadf = 'FD\_B'$. In case *nadf*=4, the ADF values correspond to the following sides of the assembly : #1 for North , #2 for East, #3 for South and #4 for West. (same order as the SAPHYB)

`CDF` keyword used to set the type of Assembly Discontonuity Factor to be recovered from the `SAP` (or `MCO`) object. NB : the *ladf* flag must be set to true.

*ncdf* number of the CDF-type boundary flux edit to be recovered from Multicompo. Allowed values $nadf = 1$ or 4.

*hcdf* name of the CDF-type boundary flux edit to be recovered from Multicompo. Default all $hadf = 'FD\_C'$. In case *ncdf*=4, the CDF values correspond to the following corner of the assembly : #1 for North-West, #2 for South-West, #3 for South-East and #4 for North-East.

`GFF` keyword used to set the type of Group Form Factor to be recovered from the `MCO` object. NB : the *lgff* flag must be set to true. In case of symmetry (*part*≥2), the numbering is different with the PARCS version (numbering as for CASMO starting from PARCS v3.2m18).

`REFLECTOR` keyword used to indicate that the input *SAP* object contains cross sections for reflector .

`HELIOS` keyword used to indicate that the input data for the *HEL* file will be set by the user.

`FILE_CONT_1` keyword used to set the `FILE_CONT_1` block. See Ref. 14.

*ncols* number of rod columns. Default : *ncols*=17.

*nrows* number of rod rows. Default : *nrows*=17.

*part* index for computed part of assembly (0/1/2/3 : whole/half/quarter/eight). By default, *part*=3.

*hm_dens* initial heavy metal density ($g.cm^{-3}$). By default, *hm_dens*=2.78613 .

*bypass* the saturated moderator density ($g.cm^{-3}$). By default, *bypass*=0.73659.

`FILE_CONT_2` keyword used to set the lower energy limits of neutron groups.

*emin* lower energy limits of neutron groups. Default : *emin*={ 6.2506E-01,1E-04 }

`FILE_CONT_3` keyword used to set the `FILE_CONT_3` block (volume of regions). See Ref. 14.

*vcool* volume of coolant. Default : *vcool*=2.4921E+02.

*vwatr* volume of water. By default, *vwatr*=0.0000E+00.

*vmodr* volume of moderator. Default : *vmodr*=2.4921E+02.

*vcnrd* volume of control rods. By default, *vcnrd*=2.3020E+01.

*vfuel* volume of fuel. By default, *vfuel*=1.4407E+02 .

*vclad* volume of cladding. By default, *vclad*=4.5099E+01.

*vchan* volume of channel. By default, *vchan*=4.5099E+01.

`FILE_CONT_4` keyword used to set the `FILE_CONT_4` block. See Ref. 14.

*pitch* rod lattice pitch (cm). Default : *pitch*=1.44270E+00.

*xbe* starting position of first column rods (cm), i.e. water gap thickness. By default, *xbe*=7.21350E-01.

*ybe* starting position of first row rods (cm), i.e. water gap thickness. By default, *ybe*=7.21350E-01.

`XS_CONT` keyword used to set the `XS_CONT` block. See Ref. 14.

*nside* number of sides in assembly. Default : *nside*=1.

*ncorner* number of corners in assembly. By default, *ncorner*=1.

*vfcm* value of vfcm . By default, *vfcm*=5.32151E-01.

`GENPMAXS` keyword used to indicate that the input data for the *GEN* file will be set by the user.

`JOB_TIT` keyword used to set *jobtit*

*jobtit* `character*16` name of the PMAXS file created by the `D2P:` module. Default : *jobtit*='`D2P.PMAX`'

`FILE_NAME` keyword used to set *fname* .

*fname* `character*12` name of the HELIOS-like file (*HEL*) created by the `D2P:` module. Default : *fname*='`HELIOS.dra`'

`DERIVATIVE` keyword used to set *der*.

*der* `character` (T/F) type of data in non-reference branches of output PMAXS file. If *der*='`T`', data are partial derivatives, otherwise it is raw cross sections. Default : *der*='`T`'.

`VERSION` keyword used to set *vers*.

*vers* the version of PARCS which will be used. If *vers*$\geq$2.705, generate PMAXS for PARCS 2.71 or later versions, otherwise it is for PARCS 2.7 or earlier versions. Default : *vers*=3.0. The version number is as follows : v3.2m17 *vers*=3.217

`COMMENT` keyword used to set a comment line.

*comment* `character*40` Comment line for the user. Default : *comment*='`PWR CASE : UOX/MOX CORE FUEL`'.

`JOB_OPT` keyword use to set logical flags, it indicates write or not write correponding data into PMAXS file. If the flag is '`F`', default values given in Ref. 14, will be used in PARCS. For reflector case, all flags will be forced to '`F`', except for *ladf* and *linv*.

*ladf* `character` (T/F) assembly discontinuity factor. Default : *ladf*='`F`'.

*lxes* `character` (T/F) microscopic cross section of Xe and Sm. Default : *lxes*='`F`'.

*lded* `character` (T/F) direct energy deposition fraction. Default : *lded*='`F`'.

*lj1f* `character` (T/F) J1 factor for minimal critical power ratio. Default : *lj1f*='`F`'.

*lchi* `character` (T/F) fission spectrum. Default : *lchi*='`F`'.

*lchid* `character` (T/F) delay neutron fission spectrum. Default : *lchid*='`F`'.

*linv* `character` (T/F) inverse neutron velocity. Must be '`T`' for transient. Default : *linv*='`F`'.

*ldet* `character` (T/F) Detector response. Default : *ldet*='`F`'.

*lyld* `character` (T/F) yield values of I, Xe,and Pm. Default : *lyld*='`F`'.

*lcdf* `character` (T/F) corner discontinuity factor. Default : *lcdf*='`F`'.

*lgff* `character` (T/F) group wise power form function. Default : *lgff*='`F`'.

*lbet* `character` (T/F) Beta of delayed neutron. Default : *lbet*='`F`'.

*lamb* `character` (T/F) Lambda of delayed neutron. Default : *lamb*='`F`'.

*ldec* `character` (T/F) Decay heat beta and lambda. Default : *ldec*='`F`'.

`IUPS` keyword used to set the treatment for up-scattering.

*iups* (0/1/2) 0 : keep up scatter XS, 1 : remove up scatter XS, modify down scatter XS with DRAGON spectrum, 2 : remove up scatter XS, modify down scatter with infinite medium spectrum. Default :*iups*=0.

$$\Sigma'_{s,g\longleftarrow g'} = \Sigma'_{s,g\longleftarrow g'} - \Sigma'_{s,g'\longleftarrow g} \times \frac{\phi_g}{\phi_{g'}}$$

for $g' < g$

where $\phi_g, \phi_{g'}$ are the spectra flux either provided by DRAGON or infinite spectra computed in GenPMAXS.

`SFAC` keyword used to set *sfac*. See Ref. 14.

*sfac* the scattering cross section factor. If *sfac* is different from 1, then the scattering cross section will be multiplied by *sfac*. Default : *sfac*=1.0.

`BFAC` keyword used to set *bfac*. See Ref. 14.

*bfac* the multiplier for betas. If *bfac* is different from 1, then the betas will be multiplied by *bfac*. Default : *bfac*=1.0.

### B.3 The NAP: module

The NAP: module supplies the main transport-diffusion equivalence options to DRAGON and DONJON. It can be used to perform the pin power reconstruction.[?,7] The calling specifications are :

TABLE 23: Structure **(NAP :)**

*COMPO* := NAP: *COMPO TRKNAM FLUNAM* :: **(descnap1)**
*MAP* := NAP: *MAP TRKNAM FLUNAM MATEX MACRES* :: **(descnap2)**
*GEONEW* := NAP: *GEOOLD COMPO* :: **(descnap3)**

where

*COMPO* character*12 name of the MULTICOMPO data structure (L_COMPO signature) where the detailed subregion properties will be stored.

*TRKNAM* character*12 name of the read-only TRACKING data structure (L_TRACK signature) containing the tracking.

*FLUNAM* character*12 name of the read-only FLUXUNK data structure (L_FLUX signature) containing a transport solution.

*MAP* character*12 name of the MAP data structure (L_MAP signature) containing fuel regions description, global and local parameter information (burnup, fuel/coolant temperatures, coolant density, etc). Keyword PPR is expected in **(descnap2)**.

*MATEX* character*12 name of the read-only MATEX data structure (L_MATEX signature). The object corresponds to the heterogeneously splited geometry. Keyword PPR is expected in **(descnap2)**.

*MACRES* character*12 name of the read-only MACROLIB data structure (L_MACROLIB signature) containing a cross section for the fuel. The MACROLIB data structure must have been created with a MULTICOMPO data structure with pin level properties (transport flux, H-factor, infinite domain diffusion flux). Keyword PPR is expected in **(descnap2)**.

*GEONEW* character*12 name of the created GEOMETRY data structure (L_GEOM signature) containing the detailed core geometry definition at heterogeneous assembly level.

*GEOOLD* character*12 name of the read-only GEOMETRY data structure (L_GEOM signature) containing the core geometry definition with homogeneous assembly (only 1 mesh per assembly mandatory).

**(descnap1)** structure containing the input data to this module to compute additional properties for subregions (see Section B.3.1).

**(descnap2)** structure containing the input data to this module to perform pin power reconstruction (see Section B.3.2).

**(descnap3)** structure containing the input data to this module to automatically define the core geometry with heterogeneous assembly (see Section B.3.3).

#### *B.3.1 Additional properties calculations*

TABLE 24: Structure **(descnap1)**

```
[ EDIT iprint ]
PROJECTION
STEP namedir
[ IFX ifx ]
{ [[ SET pname pvalue ]] }
;
```

where

| | |
|---|---|
| `EDIT` | keyword used to modify the print level *iprint*. |
| *iprint* | integer index used to control the printing in module `NAP:`. =0 for no print ; =1 for minimum printing (default value) ; larger values of *iprint* will produce increasing amounts of output. |
| `PROJECTION` | keyword to specify that additional properties for subregions will be computed and stored in the MULTICOMPO data-structure *COMPO*. |
| `STEP` | keyword to specify *namedir*. |
| *namedir* | name of the directory containing the homogenized cross sections (homogeneous or heterogeneous). |
| `IFX` | keyword to specify *ifx*. |
| *ifx* | number used to create the name of the flux record representing $\psi_{m,p}^{d,\infty}$. This flux represents the results of calculation in an infinite domain computed in diffusion with cross sections homogenized either homogeneously or heterogeneously. One record is associated with each type of homogenization when the MULTICOMPO is created. Thus MULTICOMPO can be "enriched" several times, each time using a different homogenization of the assembly at the end of the transport calculations. The following format is used for the flux record name (`RECNAME`) :<br>`WRITE(RECNAME,'5HFINF_,I3.3') IFX`<br>Thus, for example for *ifx*=2, `RECNAME` would be `FINF_002`. |
| `SET` | keyword to specify assembly calculations at which $\psi_{m,p}^{d,\infty}$ have been calculated. Repeated as many times as there are parameters in the MULTICOMPO. |
| *pname* | name of the parameter in the MULTICOMPO. |
| *pvalue* | value of the parameter in the MULTICOMPO. |

Note that in the case of heterogeneously homogenized assembly, the pin-wise projected diffusion flux is stored in mixture 1.

*B.3.2 Pin power reconstruction*

TABLE 25: Structure **(descnap2)**

```
[ EDIT iprint ]
PPR
NZASS nzass
```

continued on next page

Structure **(descnap2)** continued from last page

```
METH GPPR ifx
[ POWER pow ]
;
```

where

| | |
|---|---|
| `EDIT` | keyword used to modify the print level *iprint*. |
| *iprint* | index used to control the printing of this module. The *iprint* parameter is important for adjusting the amount of data that is printed by this calculation step :<br>– *iprint*=0 results in no output ;<br>– *iprint*=1 ... |
| `PPR` | keyword to perform pin power reconstruction and stored results in the MAP data-structure *MAP*. |
| `NZASS` | keyword to specify *nzass*. |
| *nzass* | number of mesh in Z direction along assemblies. |
| `METH` | keyword to select the type of methodology used for pin power reconstruction. |
| `GPPR` | keyword to select the generalized pin power reconstruction from an heterogeneous assembly definition (several mixtures per assembly). Note that if there is only one mixture (homogeneous assembly) this method is actually the regular pin power reconstruction. |
| *ifx* | number used to create the named of the flux record representing $\psi_{m,p}^{d,\infty}$. See Sect. B.3.1 for more details. |
| `POWER` | keyword used to normalize the flux. If this keyword is not used, the flux directly computed by the `FLUD:` is used to perform the pin-power reconstruction, then normalization has to be performed by the user indepently. |
| *pow* | power used to normalize the flux (MW). |

*B.3.3 Heterogeneous assembly geometry definition*

TABLE 26: Structure **(descnap3)**

```
[ EDIT iprint ]
DIRGEO namedir [ MACGEO ]
MIXASS nmix (imix(i), i=1,nmix)
[ SLPITX-ASS (ispx(i), i=1,nxass) ]
[ SLPITY-ASS (ispy(i), i=1,nyass) ]
[ MAX-MIX-GEO nmxgeo ]
;
```

where

| | |
|---|---|
| `EDIT` | keyword used to modify the print level *iprint*. |
| *iprint* | index used to control the printing of this module. The *iprint* parameter is important for adjusting the amount of data that is printed by this calculation step :<br>– *iprint*=0 results in no output ;<br>– *iprint*=1 ... |
| `DIRGEO` | keyword to specify *namedir*. |
| *namedir* | name of the directory containing the heterogeneously or homogeneously homogenized cross sections. |
| `MACGEO` | keyword to specify that the macro-geometry stored in the *GFF* record of the macrolib will be used instead of the macro-geometry of the heterogeneously or homogeneously homogenized cross sections. Usually this other macro-geometry of the assembly corresponds to the pin-by-pin geometry. Note that another multicompo with all pin-wise properties is needed to be able to use the automatically generated geometry. |
| `MIXASS` | keyword to specify mixtures corresponding to assembly in the coarse geometry. |
| *nmix* | number of type of assembly. |
| *imix* | mixture number of the assemblies. |
| `SLPITX-ASS` | keyword to specify the mesh splitting at assembly level. |
| *ispx* | split along x-direction for each mesh of the heterogeneous assembly. |
| *nxass* | number of mesh of the heterogeneous assembly along x-direction. |
| `SLPITY-ASS` | keyword to specify the mesh splitting at assembly level. |
| *ispy* | split along y-direction for each mesh of the heterogeneous assembly. |
| *nyass* | number of mesh of the heterogeneous assembly along y-direction. |
| `MAX-MIX-GEO` | keyword to specify the number of mixtures in the original core geometry (i.e. before the core geometry is splited by the `NAP:` module). This keyword is mandatory if there is a reflector in the geometry otherwise the numbers for fuel mixtures will not match between the split core geometry (GEOMETRY) and the split fuel geometry (GEOMETRY embedded in MAP). |
| *nmxgeo* | number of mixtures in the original core geometry. |

**Note : The included geometry in the *COMPO* has to be unfolded, even if the transport calculations are done on a 1/8th assembly. Moreover no split can be defined in the geometry, one mesh ONLY per heterogeneous mixture is mandatory.**

### B.4 The `RESINI:` module

The `RESINI:` module is used for modeling of the reactor fuel lattice in *3-D* Cartesian geometry or *3-D* Hexagonal geometry. This modeling is based on the following considerations :

- For *3-D* Cartesian geometry, the reactor fuel lattice is composed of a well defined number of fuel channels. Each channel is composed of a well defined number of fuel bundles or assembly subdivisions. All channels contain the same number of fuel bundles or assembly subdivisions. Each reactor channel is identified by its specific name which corresponds to its position in the fuel lattice.

  In a Candu reactor, the channels are refuelled according to the bidirectional refuelling scheme. The refuelling scheme of a channel corresponds to the number of displaced fuel bundles (bundle-shift) during each channel refuelling. The direction of refuelling corresponds to the direction of coolant flow along the channel.

  In a PWR, a basic assembly layout can be projected over the fuel map using a naval-coordinate position system. Assembly refuelling and shuffling will be possible using the ad hoc module `SIM:` (see Section **??**).
- For *3-D* Hexagonal geometry, the reactor fuel lattice is composed of a well defined number of fuel channels and each channel is composed of a well defined number of fuel bundle. All fuel bundles have the same volume. All channels contain the same number of fuel bundles. Refuelling is not available during the calculation. The lattice indexation is kept to identify the hexagons.
- The fuel regions generally have a different set of global and local parameters. For example, the fuel bundles have a different evolution of the fuel properties according to the given burnup distribution, which is a global parameter. Consequently, the homogenized cell properties will differ from one fuel region to another, i.e., they are not uniform over the fuel lattice. Thus, the realistic modeling of a reactor core requires the fuel properties to be interpolated with respect to global and local parameters, which must be specified in the fuel map.

Note that the above considerations correspond to the typical core modeling of CANDU or PWR reactors. The `RESINI:` module will create a new `FMAP` object that will store the information related to the fuel lattice specification and properties (see Section **??**).
In PWR cases, each channel correspond to an assembly. Using heterogeneous mixtures in one assembly increases the complexity of the geometry. However, two levels geometries (embedded geometry) are not possible in the DONJON code. The general idea is then to define one channel per mixture for all assemblies. All these channels have then to be regrouped by assembly to impose the same burnup. This process could be done manually, but if the heterogeneity of the cross-section is large (ex. one mixture per pin within a complete core), the geometry definition may be too complex. This task can be performed automatically by the module `NAP:`.
The `RESINI:` module specifications are :

TABLE 27: Structure `RESINI:`

{ *FLMAP MATEX* `:=` `RESINI:` *MATEX* [*COMPO*] `::` **(descresini1)** |
*FLMAP* `:=` `RESINI:` *FLMAP* [*FLMAP2*] `::` **(descresini2)** }

where

| | |
|---|---|
| *FLMAP* | `character*12` name of the RESINI object that will contain the fuel-lattice information. If *FLMAP* appears on both LHS and RHS, it will be updated ; otherwise, it is created. |
| *MATEX* | `character*12` name of the MATEX object specified in the modification mode. *MATEX* is required only when *FLMAP* is created. |
| *COMPO* | `character*12` name of the MULTICOMPO data structure (`L_COMPO` signature) where the detailed subregion geometry at assembly level is stored. |
| *FLMAP2* | `character*12` name of the RESINI object that contains the fuel-lattice information to recover from. |

**(descresini1)** structure describing the main input data to the `RESINI:` module. Note that this input data is mandatory and must be specified only when *FLMAP* is created.

**(descresini2)** structure describing the input data for global and local parameters. This data is permitted to be modified in the subsequent calls to the `RESINI:` module.

### *B.4.1 Main input data to the `RESINI:` module*

Note that the input order must be respected.

TABLE 28: Structure **(descresini1)**

[ `EDIT` *iprint* ]
`:::` [ `SPLIT-NAP:` ] `GEO:` **(descgeo)**
[ `:::` `NAP:` **(descnap)** ]
[ `ASSEMBLY` *na nax nay*
`A-ZONE` { (*iza*(i) , i = 1, *nch*) `A-NX` (*nbax*(i) , i = 1, *nay*) `A-IBX` (*ibax*(i) , i = 1, *nay*) | `ASBLY` }
`AXNAME` (*XNAMEA*(i) , i = 1, *nax*)
`AYNAME` (*YNAMEA*(i) , i = 1, *nay*) ]
`NXNAME` (*XNAME*(i) , i = 1, *nx*)
`NYNAME` (*YNAME*(i) , i = 1, *ny*)
`NCOMB` { *ncomb* `B-ZONE` (*icz*(i) , i = 1, *nch*) | `ALL` | `ASBLY` }
[ `SIM` *lx ly* (*naval*(i) , i = 1, *nch*) ]
**(descresini2)**

where

`EDIT` keyword used to set *iprint*.

*iprint* integer index used to control the printing on screen : = 0 for no print ; = 1 for minimum printing (default value) ; larger values produce increasing amounts of output.

`:::` keyword used to indicate the call to an embedded module.

`SPLIT-NAP:` keyword to specify that the embedded geometry will be split by the embedded `NAP:` module .

`GEO:` keyword used to call the `GEO:` module. The fuel-map geometry differs from the complete reactor geometry in the sense that it must be defined as a coarse geometry, i.e. without mesh-splitting over the fuel bundles. Consequently, the mesh-spacings over the fuel regions must correspond to the bundle dimensions (e.g. $h_x$=*width* ; $h_y$=*height* ; $h_z$=*length* or in *3-D* Hexagonal geometry $h_x$=*side* ; $h_z$=*height*). Note that the total number of non-virtual regions in the embedded geometry must equal to the number of fuel channels *times* the number of fuel bundles per channel. This means that only the fuel-type mixture indices are to be provided in the data input to the `GEO:` module for `MIX` record. Other material regions (e.g. reflector) must be declared as virtual, i.e. with the mixtures indices set to 0.

**(descgeo)** structure describing the input data to the `GEO:` module (see the user guide[?]). Only *3-D* Cartesian or *3-D* Hexagonal fuel-map geometry is allowed.

`NAP:` keyword used to call the `NAP:` module. The heterogeneous assembly geometry definition will be called using the geometry defined previously with the embedded module `GEO:` and the *COMPO* data structure. See section B.3.3 for important note on the coarse geometry requirement.

`ASSEMBLY` keyword to specify that assembly related information are provided.

*na* number of assemblies.

*nax* number of assemblies along x-direction.

*nay* number of assemblies along y-direction.

`A-ZONE` keyword to specify the assembly number *iza* of each channels.

*iza* assembly belonging number.

`A-NX` keyword to specify the number of assembly *nbax* per row.

*nbax* number of assembly for each row.

`A-IBX` keyword to specify the column for the first assembly *ibax* on each row.

*ibax* column number for the first assembly on each row.

`ASBLY` (after `A-ZONE`) keyword to automatically compute the assembly number of each channel. A call to the embedded module `NAP:` is required previously.

`AXNAME` keyword to specify the assembly position names along x-direction *XNAMEA*.

*XNAMEA* `character*2` array of horizontal channel names. A horizontal channel name is identified by the channel column using numerical characters '1', '2', '3', and so on. Note that the total number of X-names must equal to *nxa*.

`AYNAME` keyword to specify the assembly position names along y-direction *YNAMEA*.

*YNAMEA* `character*2` array of horizontal channel names. A horizontal channel name is identified by the channel column using numerical characters 'A', 'B', 'C', and so on. Note that the total number of Y-names must equal to *nya*.

`NXNAME` keyword used to specify *XNAME*. Not used for *3-D* Hexagonal geometry.

*XNAME* `character*2` array of horizontal channel names. A horizontal channel name is identified by the channel column using numerical characters '1', '2', '3', and so on. Note that the total number of X-names must equal to the total number of subdivisions along the X-direction in the fuel-map geometry. All non-fuel regions are to be assigned a single character '-'. This option is not available for *3-D* Hexagonal geometry. When assembly are defined and split, several names can be the same.

*nx* integer total number of subdivisions along the X-direction in the fuel-map geometry. Not used for *3-D* Hexagonal geometry.

`NYNAME` keyword used to specify *YNAME*. Not used for *3-D* Hexagonal geometry.

*YNAME* `character*2` array of vertical channel names. A vertical channel name is identified by the channel row using alphabetical letters 'A' (from the top), 'B', 'C', and so on. The total number of Y-names must equal to the total number of subdivisions along the Y-direction in the fuel-map geometry. All non-fuel regions are to be assigned a single character '-'. This option is not available for *3-D* Hexagonal geometry. When assembly are defined and split, several names can be the same.

*ny* integer total number of subdivisions along the Y-direction in the fuel-map geometry. Not used for *3-D* Hexagonal geometry.

`NCOMB` keyword used to specify the number of combustion zones.

*ncomb* integer total number of combustion zones. This value must be greater than (or equal to) 1 and less than (or equal to) the total number of reactor channels.

`B-ZONE` keyword used to specify *icz*.

*icz* integer array of combustion-zone indices, specified for every channel. A reactor channel can belong to only one combustion zone, however a combustion zone can be specified for several channels.

`ALL` keyword used to indicate that the total number of combustion zones equals to the number of reactor channels. In this particular case, each channel will have a unique combustion-zone number. Hence, an explicit specification of the combustion-zone indices can be omitted.

*nch* $N_{\text{ch}}$ : number of fuel channels in the radial plane.

*nb* $N_{\text{b}}$ : number of fuel bundles or assembly subdivisions in the axial plane.

`ASBLY` (after `NCOMB`) keyword to specify that one combustion zone per assembly is to be defined.

`SIM` keyword used to specify a basic assembly layout for the `SIM:` PWR refuelling module (see Section **??**).

*lx* number of assemblies along the $X$ axis. Typical values are 15 or 17.

*ly* number of assemblies along the $Y$ axis.

*naval* `character*3` identification name corresponding to the basic naval-coordinate position of an assembly. *naval*(i) is the concatenation of a letter (generally chosen between `A` and `T`) and of an integer (generally chosen between `01` and `17`). An assembly may occupies four positions in the fuel map in order to be represented by four radial burnups. In this case, the same naval-coordinate value will appear at four different (i) indices.

### *B.4.2 Input of global and local parameters*

The information with respect to the fuel burnup is required for the fuel-map MACROLIB construction, using either the `CRE:`, `NCR:` or `AFM:` module. The fuel-region properties related to other local or global parameters can be interpolated only using the `NCR:` module.

TABLE 29: Structure **(descresini2)**

```
[ EDIT iprint ]
[ BTYPE { TIMAV-BURN | INST-BURN } ]
[ TIMAV-BVAL (bvalue(i) , i = 1, ncomb ) ]
[ INST-BVAL { SAME bvalue | CHAN (bvalue(i) , i = 1, nch ) | BUND (bvalue(i) , i = 1, nch·nb ) |
  SMOOTH } | ASBLY (bvalue(i) , i = 1, na ) | OLDMAP ]
[ BUNDLE-POW { SAME bvalue | CHAN (bvalue(i) , i = 1, nch ) | BUND (bvalue(i) , i = 1, nch·nb ) } ]
[ REF-SHIFT { ishift | COMB (ishift(i) , i = 1, ncomb ) } ]
[[ ADD-PARAM PNAME PNAME PARKEY PARKEY { GLOBAL | LOCAL } ]]
[[ SET-PARAM PNAME { pvalue | OLDMAP | { [ TIMES PNAMEREF ] SAME pvalue |
   CHAN (pvalue(i) , i = 1, nch ) | BUND (pvalue(i) , i = 1, nch·nb ) } } ]]
[[ FUEL { WEIGHT | ENRICH | POISON } (fvalue(i) , i = 1, nfuel ) ]]
[ CELL (ialch(i) , i = 1, nch ) ]
;
```

where

`EDIT` keyword used to set *iprint*.

*iprint* integer index used to control the printing on screen : = 0 for no print ; = 1 for minimum printing (default value) ; = 2 to print the channels refuelling schemes (if they are new or modified) ; = 3 initial burnup limits per each channel are also printed (if the axial power-shape has been reinitialized).

`BTYPE` keyword used to specify the type of interpolation with respect to burnup data. This information will be used during the execution of `CRE:`, `NCR:` or `AFM:` module.

`TIMAV-BURN` keyword used to indicate the burnups interpolation according to the time-average model. This option is not available in *3-D* Hexagonal geometry.

`INST-BURN` keyword used to indicate the burnups interpolation according to the instantaneous model.

`TIMAV-BVAL` keyword used to indicate the input of average exit burnup values per each combustion zone. Note that the axial power-shape and the first burnup limits will be reinitialized each time the average exit burnups are modified by the user. These data are required for the time-average calculation (see Section **??**). This option is not available with *3-D* Hexagonal geometry.

`INST-BVAL` keyword used to specify the instantaneous burnup values for each fuel bundle.

`SMOOTH` keyword used to level fuel mixtures burnup. If the burnup is supposed to be the same at each occurence of every fuel mixture (for symetry reasons), `SMOOTH` will make sure they share the exact same value (the first one in the burnup map). Purpose is only to correct calculation noise in historic calculation.

`ASBLY` keyword to specify that one burnup value per assembly is to be defined.

`OLDMAP` keyword to specify that the burnup value is recovered from *FLMAP2*. The recovered burnup distribution is either from a previous calculation :
- with the same geometry but different initialization values. Example : homogeneous calculation followed by a pin power reconstruction where assemblies were not defined in the first place.
- with a different geometry. In this case, the assembly geometry of the new *FLMAP* and the geometry of the *FLMAP2* must match. Example : homogeneous calculation followed by a heterogeneous calculation or pin power reconstruction

`BUNDLE-POW` keyword used to specify the power values for each fuel bundle. This option is not available in *3-D* Hexagonal geometry.

*bvalue* real array containing the burnups/powers values, given in *MW·day per tonne*/MW of initial heavy elements. The fuel burnup is considered as a global parameter.

`REF-SHIFT` keyword used to specify *ishift*. Note that the axial power-shape and the first burnup limits will be reinitialized each time the channel refuelling schemes are modified by the user. This option is not avaialble in *3-D* Hexagonal geometry.

`COMB` keyword used to indicate the input of bundle-shift numbers per combustion zone.

*ishift* integer array (or single value) of the bundle-shift numbers. A single *ishift* value means that the same bundle-shift will be applied for all combustion zones. Note that the bundle-shift value must be positive, it corresponds to the number of displaced fuel bundles during each channel refuelling.

`ADD-PARAM` keyword used to indicate the input of information for a new global or local parameter. For more information about the parameter data organization on `FMAP` data structure see Section **??**.

`PNAME` keyword used to specify *PNAME*.

*PNAME* `character*12` identification name of a given parameter. This name is user-defined so that it is arbitrary, however it must be unique so that it can be used for the search of parameter information and interpolation purpose. Moreover, it is recommended to use the following pre-defined values :

| | |
|---|---|
| `C-BORE` | Boron concentration |
| `T-FUEL` | Averaged fuel temperature |
| `T-SURF` | Surfacic fuel temperature |
| `T-COOL` | Averaged coolant temperature |
| `D-COOL` | Averaged coolant density |
| CANDU-only parameters : | |
| `T-MODE` | Averaged moderator temperature |
| `D-MODE` | Averaged moderator density |

`PARKEY` keyword used to specify *PARKEY*.

*PARKEY* `character*12` corresponding name of a given parameter as it is recorded in the particular multi-parameter compo file. The *PARKEY* name of a parameter may not be same as its *PNAME* and can also differ from one multi-compo file to another.

`GLOBAL` keyword used to indicate that a given parameter is global, which will have a single and constant parameter's value.

`LOCAL` keyword used to indicate that a given parameter is local. In this case, the total number of recorded parameter's values will be set to $N_{\rm ch} \times N_{\rm b}$.

`SET-PARAM` keyword used to indicate the input (or modification) of the actual values for a parameter specified using its *PNAME*.

`SAME` keyword used to indicate that a core-average value of a local parameter will be provided. If the keyword `SAME` is specified, then this average value will be set for all fuel bundles for every reactor channel.

`CHAN` keyword used to indicate that the values of a local parameter will be provided per each reactor channel. If the keyword `CHAN` is specified, then the channel-averaged parameter's value will be set for all fuel bundles containing in the same reactor channel.

`BUND` keyword used to indicate that the values of a local parameter will be specified per each fuel bundle for every channel.

`TIMES` keyword used to indicate that the values of the local parameter *PNAME* is a translation of the local parameter *PNAMEREF* via a multiplication of the constant indicated by `SAME`.

*PNAMEREF* `character*12` identification name of a given parameter.

*pvalue* real array (or a single value) containing the actual parameter's values. Note that these values will not be checked for consistency by the module. It is the user responsibility to provide the valid parameter's values which should be consistent with those recorded in the multicompo database.

`OLDMAP` keyword to specify that the *pvalue* value(s) is (are) recovered from *FLMAP2*.

`FUEL` keyword used to indicate the input of data which will be specified for each fuel type.

`WEIGHT` keyword used to indicate the input of fuel weight in a bundle, given in *kg*.

`ENRICH` keyword used to indicate the input of fuel enrichment values, given in *wt%*.

`POISON` keyword used to indicate the input of poison load in a fuel.

*fvalue* real value of the fuel-type parameter, specified for each fuel type in the same order as the fuel mixture indices have been recorded in the MATEX object (see Section **??**).

*nfuel* integer total number of the fuel types, as been defined in the `USPLIT:` module.

`CELL` keyword used to specify that a patterned age distribution will be input and used to compute instantaneous bundle burnup.

*ialch* real array containing the refueling sequence numbers. This channel is refueled the *ialch(i)*th one. The channels are ordering from the top left to the bottom right of the core. The expression of the resulting bundle burnups are given in Ref. **?**.

### B.5 Modification of the MACROLIB data structure in the MULTICOMPO data structure

The pin-wise information is stored for each calculation (one set of parameter and one burnup) in the MACROLIB included in the MULTICOMPO. The group form factors, the energy release factors and the volume are stored in a folder named 'GFF' as described further below. Note that the same directory is used to store the pin-flux computed in an infinite domain with diffusion theory. This value is required by the PPR using the `NAP:` module.

The state vector of the MACROLIB is changed to include if 'GFF' information is available :

– Group form factor index $I_{\text{gff}} = \mathcal{S}_{16}^{M}$ :

$$I_{\text{gff}} = \begin{cases} 0 & \text{no group form factor information} \\ > 0 & \text{number of form factors per mixture and per energy group (see below).} \end{cases}$$

The additional sub-directory `/GFF/` contains group form factor information. This information can be used to perform *fine power reconstruction* over a fuel assembly. The specifications are as follows :

TABLE 30: Records in the `/GFF/` sub-directory

| Name | Type | Condition | Units | Comment |
|---|---|---|---|---|
| `GFF-GEOM`␣␣␣␣ | Dir | | | Macro–geometry directory. This geometry corresponds to an unfolded fuel assembly and is compatible for a discretization with TRIVAC. This directory follows the specification presented in Section **??**. |
| `VOLUME`␣␣␣␣␣␣ | R($N_m, I_{\text{gff}}$) | | $\text{cm}^3$ | Volumes of homogenized cells $V_m$ |
| `NWTO`␣␣␣␣␣␣␣␣ | R($N_m, I_{\text{gff}}, G$) | | $\text{s}^{-1}\text{cm}^{-2}$ | The multigroup neutron flux spectrum $\phi_w^g$ |
| `H-FACTOR`␣␣␣␣ | R($N_m, I_{\text{gff}}, G$) | | J $\text{cm}^{-1}$ | Energy production coefficients $H_m^g$ (product of each macroscopic cross section times the energy emitted by this reaction). |
| `FINF_NUMBER`␣ | I($N_{\text{ifx}}$) | | | Array containing the $N_{\text{ifx}}$ $ifx$ indices used by the user every time the multicompo were "enriched" with different options. |
| {/FINF/} | R($N_m, I_{\text{gff}}, G$) | | $\text{s}^{-1}\text{cm}^{-2}$ | The diffusion multigroup neutron flux spectrum in an infinite domain $\psi_{m,p}^{d,\infty}$. See `NAP:` module description in IGE344 user guide for details. |

The set of diffusion multigroup neutron flux spectrum records {/FINF/} will be composed, using the following FORTRAN instructions as HVECT,

$$\texttt{WRITE}(\texttt{HVECT},'(\texttt{5HFINF\_},\texttt{I3.3})')\ '\texttt{ifx}'$$

where `ifx` is a value chosen by the user (default value is 0). A different value can be chosen every time the multicompo are "enriched" with different options (homogeneous/heterogeneous, tracking options, etc.).

### B.6 The `D2P:` module

The objective of the `D2P:` module is to produce a file containing the macroscopic cross sections generated by the DRAGON5 lattice code and readable by the GenPMAXS software. This module makes possible the use of DRAGON5-integrated XS into the PARCS core code. PARCS (*Purdue Advanced Reactor Core Simulator*) from the U.S. NRC[5] is a full 3D core code for the simulation of nuclear reactor steady state and transient behavior, at a specific burnup state. The missing features for the PPR with PARCS are :

– to be able to compute the relative flux value *adf* and *cdf* from the absolute flux value stored with the homogenized cross-section. Capability related to *adf* information is already implemented but remains to be validated.
– to extract the relative flux value *gff* stored with the homogenized cross-section (computed previously by the `COMPO:` module).

The new specifications added to general format of the data for the `D2P:` module are all included in the phase 1. The additions to (`descphase1`) are as follows :

TABLE 31: Structure (`descphase1`)

```
[ADF { DRA | GET | SEL } ]
[CDF { DRA } ]
[GFF { DRA } ]
```

where

`GFF` keyword used to extract the group form factors *gff*.

`DRA` the group form factors *gff* are generated by DRAGON5.

`ADF` keyword used to set the type of Assembly Discontonuity Factor to be recovered from the `SAP` or `MCO` object. NB : the *ladf* flag must be set to true.

`DRA` Assembly discontinuity factors are generated using the *DRAGON5* procedure. Default option. NB : This option is available with Saphyb and Multicompo produced by the *DRAGON5* lattice code using a 2-level flux calculation with the Method Of Characteristics.

$$\mathrm{ADF}_{g,f} = \frac{\phi_g^{Het}}{\phi_g^{Hom}},$$

where $g$ is the energy group, $f$, the assembly surface and $\phi_g^{Het}$,$\phi_g^{Hom}$ are the average surfacic homogene and heterogene fluxes in asssembly.

`CDF` keyword used to set the type of Corner Discontonuity Factor to be recovered from the `SAP` or `MCO` object. NB : the *lcdf* flag must be set to true.

`DRA` Corner discontinuity factors are generated using the *DRAGON5* procedure. Default option. NB : This option is available with Multicompo produced by the *DRAGON5* lattice code using a 2-level flux calculation with the Method Of Characteristics.

$$\mathrm{CDF}_{g,f} = \frac{\phi_g^{Het,c}}{\phi_g^{Hom}},$$

where $g$ is the energy group, $f$, the assembly surface and $\phi_g^{Het,c}$,$\phi_g^{Hom}$ are the average corner homogene and heterogene fluxes in asssembly.

## B.7 Contents of /d2p_info/ data structure

A /d2p_info/ data structure is used to store cross sections and Saphyb information such as keff, kinf, assembly discontinuity factors. This object has a signature `L_INFO`; it is created using the `D2P:` module.

### *B.7.1 The state-vector content*

The dimensioning parameters $\mathcal{S}_i$, which are stored in the state vector for this data structure, represent :

- The number of energy groups $N_{\text{gr}} = \mathcal{S}_1$
- The number of pkey for the generation of the PMAXS file $N_{\text{pk}} = \mathcal{S}_2$
- The number of cross sections recovered using the `SCR:` module $N_{\text{xs}} = \mathcal{S}_3$
- The number of points with respect to burnup $N_{\text{bu}} = \mathcal{S}_4$
- The type of branching calculation requested for the generation of PMAXS tree $I_{\text{grid}} = \mathcal{S}_5$

$$I_{\text{grid}} = \begin{cases} 0 & \text{default meshing} \\ 1 & \text{according to the saphyb content} \\ 2 & \text{user defined with global otpion} \\ 3 & \text{user defined with add otpion} \\ 4 & \text{user defined with add new otpion} \end{cases}$$

- The number of control rod composition $N_{\text{comp}} = \mathcal{S}_6$
- The number of delay neutron groups $N_{\text{del}} = \mathcal{S}_7$
- The number of columns in assembly $N_{\text{cols}} = \mathcal{S}_8$
- The number of rows in assembly $N_{\text{rows}} = \mathcal{S}_9$
- The computed part of asembly assembly $I_{\text{part}} = \mathcal{S}_{10}$

$$I_{\text{part}} = \begin{cases} 0 & \text{whole} \\ 1 & \text{half} \\ 2 & \text{quarter} \\ 3 & \text{eighth} \end{cases}$$

- The number of sides in assembly. $N_{\text{surf}} = \mathcal{S}_{11}$
- The number of corners in assembly $N_{\text{corn}} = \mathcal{S}_{12}$
- The number of assembly discontinuity factors per energy groups $N_{\text{adf}} = \mathcal{S}_{13}$
- The number of ADF-type boundary flux edits. $N_{\text{type}} = \mathcal{S}_{14}$
- The number of corner discontinuity factors per energy groups. $N_{\text{cdf}} = \mathcal{S}_{15}$
- The number of group-wise form functions per energy groups in compued part of assembly. $N_{\text{gff}} = \mathcal{S}_{16}$
- The number of pin on each side of the assembly. $N_{\text{pin}} = \mathcal{S}_{17}$

The following records and sub-directories will be found on the first level of /d2p_info/ directory :

TABLE 32: Records and sub-directories in /d2p_info/ data structure

| Name | Type | Condition | Units | Comment |
|---|---|---|---|---|
| SIGNATURE$_{\sqcup\sqcup\sqcup}$ | C∗12 | | | Signature of the /d2p_info/ data structure (SIGNA =L_INFO$_{\sqcup\sqcup\sqcup\sqcup\sqcup\sqcup}$). |
| STATE-VECTOR | I(40) | | | Vector describing the various parameters associated with this data structure |
| BARR_INFO$_{\sqcup\sqcup\sqcup}$ | I($N_{\text{comp}}$) | | | Meaning of control rod in the saphyb object. $N_{comp}$ is the number of composition for control rods (including the unrodded case) |
| SAPHYB_INFO$_{\sqcup}$ | Dir | $iph \geq 1$ | | Information related to the saphyb content. |
| HELIOS_HEAD$_{\sqcup}$ | Dir | $iph \geq 1$ | | Information related to the header of output .DRA file |
| GENPMAXS_INP | Dir | $iph \geq 2$ | | Information related to the GenPMAXS input file. |
| BRANCH_INFO$_{\sqcup}$ | Dir | $iph \geq 3$ | | Information related to the current branch calculation. |
| TH_DATA$_{\sqcup\sqcup\sqcup\sqcup\sqcup}$ | Dir($N_{\text{bu}}$) | $iph \geq 2$ | | Information related to the invariant T/H data block. Each componant of the list is a directory containing TH data for a single burnup point. |

TABLE 33: Records and sub-directories in /SAPHYB_INFO/

| Name | Type | Condition | Units | Comment |
|---|---|---|---|---|
| PKEY_INFO$_{\sqcup\sqcup\sqcup}$ | Dir(6) | | | Each component of the list is a directory containing information for all possible state variables. |
| STATE_VAR$_{\sqcup\sqcup\sqcup}$ | C($N_{\text{pk}}$) ∗ 12 | | | Name of state variables (PKEY). |
| ISOTOPES$_{\sqcup\sqcup\sqcup\sqcup}$ | C(3) ∗ 12 | | | Reference name of isotopes in the saphyb object for depletion chain, recovery of fission yield and number densities. 1) Xe135 2) I135 3) Sm 149. |
| */svname/* | R($N_k$) | | | Values for each state variable specified by PKEY$_k$, $N_k$ is the number of value taken for the k$^{th}$ PKEY. |
| PKIDX$_{\sqcup\sqcup\sqcup\sqcup\sqcup\sqcup\sqcup}$ | I($N_{\text{pk}}$) | | | Correspondance of indices between SAP/MCO and GenPMAXS state variables |
| ADF_TYPE$_{\sqcup\sqcup\sqcup\sqcup}$ | C∗3 | | | Type of ADF recovered (DRA, GET or SEL). |
| HADF$_{\sqcup\sqcup\sqcup\sqcup\sqcup\sqcup\sqcup}$ | C($N_{\text{adf}}$) ∗ 8 | | | Name of the ADF-type boundary flux edit to be recovered from Multicompo |

continued on next page

Records and sub-directories in /SAPHYB_INFO/ continued from last page

| Name | Type | Condition | Units | Comment |
|---|---|---|---|---|
| CDF_TYPE$_{\sqcup\sqcup\sqcup\sqcup}$ | C∗3 | | | Type of CDF recovered (only DRA). |
| HCDF$_{\sqcup\sqcup\sqcup\sqcup\sqcup\sqcup\sqcup\sqcup}$ | C($N_{\rm adf}$) ∗ 8 | | | Name of the CDF-type boundary flux edit to be recovered from Multicompo. |
| GFF_TYPE$_{\sqcup\sqcup\sqcup\sqcup}$ | C∗3 | | | Type of GFF recovered (only DRA). |

Each component of the list PKEY_INFO is a directory containing for all possible state variables ( 1=BARR, 2=DMOD, 3=CBOR, 4=TCOM, 5=TMOD, 6=BURN). Inside each groupwise directory, the following records will be found :

Table 34: Records in /PKEY_INFO/

| Name | Type | Condition | Units | Comment |
|---|---|---|---|---|
| LFLAG$_{\sqcup\sqcup\sqcup\sqcup\sqcup\sqcup\sqcup}$ | I(1) | | | Indicates if the corresponding state variable can be found in the SAP (or MCO) object. |
| NAME$_{\sqcup\sqcup\sqcup\sqcup\sqcup\sqcup\sqcup\sqcup}$ | C*12 | lflag | | Name of the state parameter in the SAP (or MCO) object. For BARR and BURN state variables, this record exists even if LFLAG is *false*. |

Table 35: Records and sub-directories in /HELIOS_HEAD/

| Name | Type | Condition | Units | Comment |
|---|---|---|---|---|
| FILE_CONT_1$_{\sqcup}$ | R(2) | | | Set of data for FILE_CONT_1 block in DRA file : Heavy metal Density(HM_Dens), Bypass Density(ByPass). |
| FILE_CONT_2$_{\sqcup}$ | R(8) | | | Set of data for FILE_CONT_2 block in DRA file : Lower Energy Limits of Neutron Groups. |
| FILE_CONT_3$_{\sqcup}$ | R(7) | | | Set of data for FILE_CONT_3 block in DRA file : Volume of coolant (VCool), moderator (VModr), control rods (VCnRd), fuel(VFuel), cladding (VClad), channels (VChan), water (VWatR). |
| FILE_CONT_4$_{\sqcup}$ | R(3) | | | Set of data for FILE_CONT_4 block in DRA file : Cell Pitch and X,Y Position of First Cell. |
| XS_CONT$_{\sqcup\sqcup\sqcup\sqcup\sqcup\sqcup}$ | R(1) | | | Set of data for XS_CONT block in DRA file : (VFCM). |

TABLE 36: Records and sub-directories in /GENPMAXS_INP/

| Name | Type | Condition | Units | Comment |
|---|---|---|---|---|
| FLAG | I(1) | | | Indicates the end of a branch calculation. |
| JOB_TIT | C∗16 | | | Name of final PMAXS file. |
| FILE_NAME | C∗12 | | | Name of output DRA file |
| DERIVATIVE | C∗4 | | | Set of data for FILE_CONT_3 block in DRA file : Volume of coolant (VCool), moderator (VModr), control rods (VCnRd), fuel(VFuel), cladding (VClad), channels (VChan), water (VWatR). |
| VERSION | R(1) | | | Version of PARCS used. |
| COMMENT | C∗40 | | | Free comment. |
| JOB_OPT | C(14) ∗ 1 | | | Options for GenPMAXS running (see [14]). |
| DAT_SRC | R(5) | | | Data source information (see [14]). |

Each component of the list TH_DATA is a directory containing TH data for a single burnup point. Inside each groupwise directory, the following records associated will be found :

TABLE 37: Records in sub-directory /TH_DATA/

| Name | Type | Condition | Units | Comment |
|---|---|---|---|---|
| CHI | R($N_{\text{gr}}$) | *lchi* | | The steady-state energy spectrum of the neutron emitted by fission $\chi$. |
| OVERV | R($N_{\text{gr}}$) | *linv* | s.cm$^{-1}$ | The average of the inverse neutron velocity. |
| LAMBDA | R($N_{\text{del}}$) | *lamb* | s$^{-1}$ | Decay constant of delayed neutron. |
| BETA | R($N_{\text{del}}$) | *lbet* | | Effective delayed neutron fraction. |
| YLDPm | R(1) | *lyld* | | Effective yield value of Pm-149 |
| YLDXe | R(1) | *lyld* | | Effective yield value of Xe-135 |
| YLDI | R(1) | *lyld* | | Effective yield value of I-135 |

TABLE 38: Records and sub-directories in sub-directory /BRANCH_INFO/

| Name | Type | Condition | Units | Comment |
|---|---|---|---|---|
| BRANCH_IT | I(1) | | | Index of the current branch type calculation. |

continued on next page

Records and sub-directories in sub-directory /BRANCH_INFO/ continued from last page

| Name | Type | Condition | Units | Comment |
|---|---|---|---|---|
| `BRANCH␣␣␣␣␣␣` | C∗4 | | | Current BRANCH type calculation. |
| `BRANCH_NB␣␣␣` | I(1) | | | Number of branches to be created in PMAXS files. |
| `REF_STATE␣␣␣` | R($N_{\text{pk}}-1$) | | | Values of state variables for reference state, burnup excepted. |
| `HST_STATE␣␣␣` | R($N_{\text{pk}}-1$) | | | Values of state variables for history state, burnup excepted. |
| `STATE_INDEX␣` | I($N_{\text{pk}}$) | | | Current index value for each state variables. |
| `BRANCH_INDEX` | I($N_{\text{pk}}$) | | | Index of current branch calculation. |
| `STATE␣␣␣␣␣␣␣` | R($N_{\text{pk}}$) | | | State variable values for the current branch calculation. |
| `REWIND␣␣␣␣␣␣` | I(1) | | | Indicates the end of a branch calculation (`REWIND`=1). |
| `STOP␣␣␣␣␣␣␣␣` | I(1) | | | Indicates the end of calculation (`STOP`=1). |
| `CROSS_SECT␣␣` | Dir($N_{\text{bu}}$) | | | Each component of the list is a directory containing cross sections for all burnup point of a specific branch(cross sections are overwrited after each branch calcualtion). |
| `DIVERS␣␣␣␣␣␣` | Dir($N_{\text{bu}}$) | $I_{grid} \leq 1$ | | Each component of the list is a directory containing the `DIVERS` data block recovered from the saphyb object(inforamtions are overwrited after each branch calcualtion). |

Each component of the list `CROSS_SECT` is a directory containing cross sections for all burnup point of a specific branch. Cross sections for a single burnup points are filled seqentially during the branching calculation. Inside each groupwise directory, the following sub-directories will be found :

Table 39: Sub-directories in /CROSS_SECT/

| Name | Type | Condition | Units | Comment |
|---|---|---|---|---|
| `MACROLIB_XS␣` | Dir | | | Directory for macroscopic cross sections for a given calculated branch (cross sections are overwrited after each branch calculation). |
| `MICROLIB_XS␣` | Dir() | *lxes* | | Directory for microscopic cross sections for a given calculated branch (cross sections are overwrited after each branch calculation). |

TABLE 40: Records in the sub-directory /MACROLIB_XS/

| Name | Type | Condition | Units | Comment |
|---|---|---|---|---|
| XTR␣␣␣␣␣␣␣␣␣ | R($N_{\rm gr}$) | | $\rm cm^{-1}$ | The transport cross section $\Sigma_f^g : \Sigma_t^g = 1/(3 \cdot D_g)$. |
| ABSORPTION␣␣ | R($N_{\rm gr}$) | | $\rm cm^{-1}$ | The absorption cross section $\Sigma_a^g : \Sigma_a^g = \Sigma_{tot}^g - \sum_{g'} \Sigma_s^{g \to g'}$. |
| KAPPA_FI␣␣␣␣ | R($N_{\rm gr}$) | | $\rm cm^{-1}$ | The product of $\Sigma_f^g$, the fission cross section with the energy emitted by this reaction $\kappa$ : $\kappa\Sigma_f^g$. |
| X_NU_FI␣␣␣␣␣ | R($N_{\rm gr}$) | | $\rm cm^{-1}$ | The product of $\Sigma_f^g$, the fission cross section with the averaged number of fissionemitted delayed neutron $\nu$ : $\nu\Sigma_f^g$. |
| SCAT␣␣␣␣␣␣␣␣ | R($N_{\rm gr} * N_{\rm gr}$) | | $\rm cm^{-1}$ | Scattering cross section elements from group g to g' : $\Sigma_s^{g \to g'}$. |
| DET␣␣␣␣␣␣␣␣␣ | R($N_{\rm gr}$) | *ldet* | | The detector response parameter, it is product of cross section and local flux ratio. |
| SFI␣␣␣␣␣␣␣␣␣ | R($N_{\rm gr}$) | *lxes* | $\rm cm^{-1}$ | The fission cross section : $\Sigma_f^g$. |
| ADF␣␣␣␣␣␣␣␣␣ | R($N_{\rm adf}, N_{\rm gr}$) | *ladf* | | Assembly Discontinuity Factors. |
| CDF␣␣␣␣␣␣␣␣␣ | R($N_{\rm cdf}, N_{\rm gr}$) | *lcdf* | | Corner Discontinuity Factors. |
| GFF␣␣␣␣␣␣␣␣␣ | R($N_{\rm pin} * N_{\rm pin}, N_{\rm gr}$) | *lgff* | | Group-wise Form Function. |

TABLE 41: Records in the sub-directory /MICROLIB_XS/

| Name | Type | Condition | Units | Comment |
|---|---|---|---|---|
| XENG␣␣␣␣␣␣␣␣ | R($N_{\rm gr}$) | | $\rm cm^{-2}$ | The microscopic absorption cross section of Xenon : $\sigma_{a,Xe}^g = \sigma_{tot,Xe}^g - \sum_{g'} \Sigma_{s,Xe}^{g \to g'}$. |
| SMNG␣␣␣␣␣␣␣␣ | R($N_{\rm gr}$) | | $\rm cm^{-2}$ | The microscopic absorption cross section of Samarium : $\sigma_{a,Sm}^g = \sigma_{tot,Sm}^g - \sum_{g'} \Sigma_{s,Sm}^{g \to g'}$. |
| XEND␣␣␣␣␣␣␣␣ | R($N_{\rm gr}$) | | $(\rm b.cm)^{-1}$ | The Xenon number density : $n_{Xe}$. |
| SMND␣␣␣␣␣␣␣␣ | R($N_{\rm gr}$) | | $(\rm b.cm)^{-1}$ | The Samarium number density : $n_{Sm}$. |

Each component of the list DIVERS is a directory containing informations for all burnup points of a specific branch recovered from the DIVERS block of the saphyb object. Inside each groupwise directory, the following records will be found :

TABLE 42: Records in the sub-directory /DIVERS/

| Name | Type | Condition | Units | Comment |
|---|---|---|---|---|
| B2␣␣␣␣␣␣␣␣␣␣ | R(1) | | $cm^{-2}$ | Critical buckling. |
| KEFF␣␣␣␣␣␣␣␣ | R(1) | | | Effective multiplication factor. |
| KINF␣␣␣␣␣␣␣␣ | R(1) | | | Infinite multiplication factor. |

# C Description of input files used as examples and validation tests

Several input files have been generated for the different steps of calculations :
- Step #1 : '*rep900_het_gff.x2m*' set is used to generate the *multicompo* files.
- Step #2 : '*D2P_mco.x2m*' set is used to generate the HELIOS output-like and the associated GenPMAXS file.
- Step #3 : '*GENPMAXS_MOX.inp*' + '*HEL_MOX.dra*' and '*GENPMAXS_UOX.inp*' + '*HEL_UOX.dra*' are used to generate the PMAXS files.
- Step #4 : '*clus3x3gff.inp*' and '*clus3x3burn.dep*' sets, one for each case. They are the main PARCS input file and the burnup distribution file.

## C.1 rep900_het_gff.x2m

The main characteristics are the following :
- UOX or MOX assembly,
- self-shielding geometry + two levels of geometry for 281 groups and 26 groups,
- burnup until 60GW/t :
  1. 71 steps for MOX :
     0.0 9.37499 18.7500 37.5000 74.9999 150.000 325.000 500.000 750.000 1000.00 1500.00 2000.00 2500.00 3000.00 4000.00 5000.00 6000.00 7000.00 8000.00 9000.00 10000.0 11000.0 12000.0 13000.0 14000.0 15000.0 16000.0 17000.0 18000.0 19000.0 20000.0 21000.0 22000.0 23000.0 24000.0 25000.0 26000.0 27000.0 28000.0 29000.0 30000.0 31000.0 32000.0 33000.0 34000.0 35000.0 36000.0 37000.0 38000.0 39000.0 40000.0 41000.0 42000.0 43000.0 44000.0 45000.0 46000.0 47000.0 48000.0 49000.0 50000.0 51000.0 52000.0 53000.0 54000.0 55000.0 56000.0 57000.0 58000.0 59000.0 60000.0
  2. 73 steps for UOX :
     0.0 9.37498 18.7500 37.4999 74.9999 150.000 237.500 325.000 412.500 500.000 625.000 750.000 1000.00 1250.00 1500.00 1750.00 2000.00 2500.00 3000.00 3500.00 4000.00 4500.00 5000.00 5500.00 6000.00 6500.00 7000.00 7500.00 8000.00 8500.00 9000.00 9500.00 10000.0 10500.0 11000.0 11500.0 12000.0 12500.0 13000.0 13500.0 14000.0 14500.0 15000.0 15500.0 16000.0 16500.0 17000.0 17500.0 18000.0 18500.0 19000.0 19500.0 20000.0 22000.0 24000.0 26000.0 28000.0 30000.0 32000.0 34000.0 36000.0 38000.0 40000.0 42000.0 44000.0 46000.0 48000.0 50000.0 52000.0 54000.0 56000.0 58000.0 60000.0
- 5 boron steps :
  0.0 600.0 1200.0 1800.0 2400.0
- 1 fuel temperature : 800.0
- 1 coolant temperature : 600.0
- 1 coolant density : 0.659
- Several choices of homogenization :
  1. 'Assembly' : homogeneous. Saved in record 'EDI2A'.
  2. 'PinByPin' : pin by pin mixtures (45). The water gap is included in the outer pin mixtures. Saved in record 'EDI2B'.
  3. 'Heter1' : heterogeneous with 3 mixtures (corner, side and inner parts). The width of the outer mixtures is 1 pin plus the water gap. Saved in record 'EDI2C'.
  4. 'Heter2' : Same as 'Heter1', except that the width of the outer mixtures is 2 pins plus the water gap. Saved in record 'EDI2D'.
  5. 'All' : all of the above are performed.
- Include GFF generation if selected

## C.2 D2P_mco.x2m

The main characteristics are the following :

– Several choices of volume selection for ADF calculation :

1. case 'No_ADF' : all ADF values are equal to default value of 1.
2. case 'FD_B' : the water gap
3. case 'FD_H' : the first row of pin around the assembly and its surrounding water gap

– Several choices of volume selection for CDF calculation :

1. case 'No_CDF' : all CDF values are equal to default value of 1.
2. case 'FD_C' : the water gap in the corner
3. case 'FDCG' : the water gap in corner and along the corner pin
4. case 'FDCP' : the whole corner pin and the surrounding water gap
5. case 'FDCP+FCDM' : one value for the whole corner pin and the surrounding water gap and one value for the pin and water gap in the middle of the assembly surface
6. case 'FD_C+FCDW' : one value for the water gap in the corner and one value for the pin and water gap in the middle of the assembly surface
7. any other combination of corner and side value.

Note : the *xbe* and *ybe* represent the thickness of the gap. Their value is very important to make sure that the flux interpolation is perform at the exact position of the pins.

### C.3 clus3x3gff.inp

The main characteristics are the following :
– Several choices for neutronic solver
– Flag to use the ADF, CDF and GFF
– link to the burnup distribution file
– link to the PMAXS files
These files were automatically generated for each cases by the *'allclus3x3.run.sh'* script from a template file stored in the *clus3x3template* folder.

### C.4 clus3x3burn.dep

The main characteristics are the following :
– burnup distribution for each assembly position
These files were automatically generated for each cases by the *'allclus3x3.run.sh'* script from a template file stored in the *clus3x3template* folder.

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