A USER GUIDE FOR DONJON VERSION5

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64-bit

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1 INTRODUCTION

DONJON is a full-core modelization code designed around solution techniques of the neutron diffusion or simplified P_n equation.[1] The current DONJON package is an evolution version, released as an attempt to introduce the innovative capabilities for the full-core modeling and simulations of different types of nuclear reactors sush as Pressurized Water Reactors (PWRs), legacy CANDU reactors, and Advanced CANDU Reactors (ACRs). The computer code DONJON (Release 4.0) is part of Version4 distribution[2], built around the GAN generalized driver[3]. The current DONJON package (DONJON Version5) is a rewrite of the code around the GANLIB5 kernel[4], intended to be 64-bit clean.

DONJON execution depends on other computer codes, components of Version4, namely: GANLIB, UTILIB, DRAGON[5], and TRIVAC[6] codes. The DRAGON modules are used with DONJON code to define the reactor geometry, to provide the macroscopic cross-section libraries and to perform micro-depletion calculations. The TRIVAC solver modules are used to perform a spatial discretization of the reactor geometry and to provide the numerical solution according to the user-selected numerical procedure[7–12]. The UTILIB library provides the utility and linear algebra libraries. Finally, the GANLIB computer code provides CLE-2000 capabilities to control data flows and to implement *computational schemes*. GANLIB also provide LCM data structures to exchange information between modules.

The DONJON code is divided into several modules, each module is designed to perform some particular tasks. The transfer of information between the modules is achieved by means of well defined data structure. Several design features, data structure and computing algorithms were recovered, revised and adapted from the previous DONJON version[13, 14]. One of the main concerns of the DONJON developers is to ensure the code reliability and extensibility.

The DONJON modules are first designed for the reactor full-core modeling in *3-D* Cartesian geometry. These modules are built around the reactor fuel lattice specification corresponding to the common design features of CANDU reactors. The modules related to the modeling of reactivity mechanisms, which are normally presented in the reactor core, also constitute an important part of code. The DONJON code can perform several full-core calculations and can be used to determine some important core characteristics, such as the power and normalized flux distributions over the reactor core. All full-core calculations using current version of DONJON correspond to the reactor static conditions.

The modeling of the reactor fuel lattice using DONJON is made in considering that the fuel lattice is composed of a well defined number of fuel channels and bundles. All reactor channels contain the same number of fuel bundles and are identified by their specific names. The fuel bundles have a distinct set of properties that are recovered and interpolated according to the specified global and local parameters. The interpolation of fuel properties with respect to burnup distribution can be performed according to the time-average or instantaneous models[15]. The time-average calculation is performed in considering the bidirectional refuelling scheme of reactor channels and assuming that all channels have the same bundle-shift.

The modeling of the reactivity mechanisms is based on their specified parameters, which include the devices position, rods insertion level, water filling level, direction of movement, etc. The rod-devices insertion level can be set according to their nominal positions or they can be displaced in and out of core. The devices can also be divided into several groups so that they can be manipulated, displaced or moved simultaneously. The time-dependent behaviour of the moving devices can be modeled and used for the transient simulations or reactor control studies. The reactivity worth of devices can also be studied and predicted using DONJON.

The reactor material properties are essentially recovered from the reactor database, obtained from the lattice calculations using DRAGON code. The two distinct macroscopic cross-section libraries can be constructed using DONJON. The first MACROLIB is constructed only for the material properties which are evolution-independent, such as reflector and devices properties. The second MACROLIB is constructed only for the fuel properties, defined per each fuel bundle over the fuel lattice. The two libraries are next combined and updated, according to the devices insertion level. The produced extended MACROLIB is subsequently used to obtain the numerical solution, using TRIVAC modules.

Finally, it should be noted that the DONJON code development is permanently in progress. The

future updates will provide several extended capabilities for the reactor design and calculations; they will be gradually added to the subsequent DONJON versions.

2 GENERAL SPECIFICATION OF DONJON

2.1 Modules

Reactor calculations using DONJON are performed by means of sequential execution of several user-selected modules, according to the user-defined computing scheme. Each module is designed to perform some particular tasks. The detailed description of DONJON modules is given in Section 3 to Section 6. In order to perform the reactor calculations, it is also required to use some DRAGON and TRIVAC modules. For more details on DRAGON modules specification, refer to its user guide[5]; for more details on TRIVAC modules specification, refer to its user guide[6]. Because the code execution is controlled by the GAN generalized driver, it is also possible to use its utility modules[3, 5]. A brief description of each module that can be executed using DONJON is given below. A short description of each data structure that can be used in DONJON is given in Section 2.2.

- The following DRAGON modules can be executed using DONJON:

GEO: module used to create or modify a reactor geometry. The spatial locations of the reactor material mixtures must also be defined using the GEO: module. Only *3-D* Cartesian reactor geometries are allowed with DONJON.

MAC: module used to create or modify a MACROLIB containing the material properties, by directly specifying the group-ordered macroscopic cross-sections for each selected material mixture.

- The following TRIVAC modules can be executed using DONJON:

TRIVAT: module used to perform a *3-D* numerical discretization or "tracking" of the reactor geometry.

TRIVAA: module used to compute the set of system matrices with respect to the previously obtained "tracking" information.

FLUD: module used to compute the numerical solution to an eigenvalue problem, corresponding to a previously obtained set of system matrices.

- The following are short descriptions of utility modules that can be executed using DONJON:

UTL: module used to perform several utility actions on a data structure.

DELETE: module used to delete one or many data structures.

GREP: module used to extract a single value from a data structure.

END: module used to delete all the local linked lists, to close all the remaining local files and to return from a procedure; or to terminate the overall DONJON execution controlled by the GAN generalized driver.

- The following are short descriptions of DONJON modules:

CRE: module used to create a MACROLIB containing the material properties, by interpolating the nuclear properties from a mono-parameter database, previously generated in the lattice code.

NCR: module used to create a MICROLIB or a MACROLIB containing the material properties, by interpolating the nuclear properties from a multi-parameter database, previously generated in the lattice code.

AFM: module used to create a MACROLIB containing the material properties, by interpolating the nuclear properties from a multi-parameter feedback model database, previously generated in the lattice code.

USPLIT: module used to create an extended reactor material index over the whole mesh-splitted reactor geometry.

RESINI: module used to define the fuel lattice, to create the fuel-map geometry and to specify the global and local parameters.

MACINI: module used to create an extended MACROLIB, in which the properties are stored per each material region, over the whole mesh-splitted reactor geometry.

DEVINI: module used for *3-D* modeling of rod-type devices in the reactor core.

DETINI: module used to read and store detector information.

LZC: module used for *3-D* modeling of liquid zone controllers in the reactor core.

DSET: module used to set the new devices parameters, that can be used for the reactivity worth studies.

MCC: module used to modify the fuel map in order to compute a Doppler or general reactivity coefficient.

MOVDEV: module used to compute the time-dependent positions of the moving rod-type devices.

NEWMAC: module used to create an extended MACROLIB, that will contain the updated material properties, computed with respect to the actual devices positions.

FLPOW: module used to compute and print powers and normalized fluxes over the reactor core.

TAVG: module used to perform burnups calculation according to the time-average model, compute burnups integration limits, core-average exit burnup, axial power-shapes and channel refuelling rates.

TINST: module used to perform burnups calculation according to the time-linear model and compute instantaneous burnups values. This module is specific to Candu reactor refuelling.

SIM: module used to perform burnups calculation according to the time-linear model and compute instantaneous burnups values. This module is specific to PWR reactor refuelling.

DETECT: module used to compute the mean flux at each detector site and the response of each detector according to different types of interpolation.

CVR: module used for the core-voiding simulations.

HST: module used to manage a full reactor execution in DONJON using explicit DRAGON calculations for each cell (see Section 3.18).[19]

NAP: pin power reconstruction module.[47, 48]

2.2 Data structures

The transfer of information between the modules is performed by means of well defined data structures, also called objects. The objects can be defined in either create, read-only or modification mode. Each object has its own specific signature that can be easily recognized by a module. A detailed description of DONJON data structures is given in Section 9. For more details on DRAGON and TRIVAC data structures, refer to their guide[18]. A brief description of all data structures that can be used in DONJON is given below.

GEOMETRY   data structure containing the geometry information. This object has a signature L_GEOM; it is created using DRAGON module GEO:.

MACROLIB   data structure containing the multigroup macroscopic properties; it has a signature L_MACROLIB. This object can be created in several modules, namely: using DRAGON modules MAC: and NCR:; or using DONJON modules CRE:, MACINI:, and NEWMAC:.

COMPO   data structure containing the mono-parameter database, generated by the lattice code. This object has a signature L_COMPO; it is created using DRAGON module CPO:.

MULTICOMPO data structure containing the multi-parameter database, generated by the lattice code. This object has a signature L_MULTICOMPO; it is created using DRAGON module COMPO:.

SAPHYB   data structure containing the multi-parameter database, generated by the lattice code. This object has a signature L_SAPHYB; it is created using the APOLLO2 lattice code or the DRAGON module SAP:.

FMAP   data structure containing the fuel-lattice specification. This object has a signature L_MAP; it is created using DONJON module RESINI:.

MATEX   data structure containing the extended reactor material index. This object has a signature L_MATEX; it is created using DONJON module USPLIT:.

DEVICE   data structure containing the devices specification. This object has a signature L_DEVICE; it is created using DONJON module DEVINI:.

DETECT   data structure containing detector positions and responses. This object has a signature L_DETECT; it is created using DONJON module DETINI:, and can be modified by the modules DETINI: and DETECT: .

TRACK   data structure containing a "tracking" information of the reactor geometry. This object has a signature L_TRACK; it is created using TRIVAC module TRIVAT:.

SYSTEM   data structure containing a set of system matrices. This object has a signature L_SYSTEM; it is created using TRIVAC module TRIVAA:.

FLUX   data structure containing the numerical solution to an eigenvalue problem. This object has a signature L_FLUX; it is created using TRIVAC module FLUD:.

POWER   data structure containing the powers and normalized fluxes over the reactor core. This object has a signature L_POWER; it is created using DONJON module FLPOW:.

HISTORY   This data structure contains the information required to ensure a smooth coupling of DRAGON with DONJON when an history based full reactor calculation is to be performed. It is used only by the HST: module.

2.3 Syntactic rules for input specification

The input data to any module is read in free format using the subroutine `REDGET`. CLE-2000 variables[22, 23] are also allowed. The user guide for DONJON is written using the following convention:

- the parameters surrounded by single square brackets '[ ]' denote an optional input;

- the parameters surrounded by double square brackets '[[ ]]' denote an input which may be repeated as many times as needed;

- the parameters in braces separated by vertical bars '{ | | }' denote a choice where one and *only* one input is mandatory;

- the parameters in **bold face** and in brackets '( )' denote an input structure;

- the parameters in italics and in brackets with an index '($data$(i) , i = 1, n)' denote a set of n inputs;

- the words using the typewriter font `KEYWORD` are character constants used as keywords;

- the words in italics denote the user-defined variables: they are lower-case and of integer type (when starting from i to n), or of real type (when starting from a to h or from o to z); or they are upper-case and of character type *CHARACTER*.

2.4 General input structure

DONJON is built around the GAN generalized driver[3, 23]. Accordingly, all the modules that will be used during the current execution must be first identified. It is also necessary to define the format of each object (data structure) that will be processed by these modules. Then, the modules required for the specific DONJON calculation are called successively, information being transferred from one module to the next via the objects. Finally, the execution of DONJON is terminated when it encounters the `END:` module, even if it is followed by additional data records in the input data stream. The general input data structure therefore follows the calling specifications given below:

Table 1: Structure (**DONJON**)

```
[ MODULE [[ MODNAME ]] ; ]
[ LINKED_LIST [[ STRNAME ]] ; ]
[ XSM_FILE [[ STRNAME ]] ; ]
[ SEQ_BINARY [[ STRNAME ]] ; ]
[ SEQ_ASCII [[ STRNAME ]] ; ]
[[ (module) ; ]]
END: ;
```

where

MODULE	keyword used to specify the names of all modules that will be used in the current DONJON execution.
MODNAME	`character*12` name of a DONJON, or DRAGON, or TRIVAC, or utility module. The list of modules that can be executed using DONJON code is provided in Section 2.1.

LINKED␣LIST   keyword used to specify the names of data structure that will be stored as linked lists.

XSM␣FILE   keyword used to specify the names of all data structure that will be stored on XSM format files.

SEQ␣BINARY   keyword used to specify the names of all data structure that will be stored on sequential binary files.

SEQ␣ASCII   keyword used to specify the names of all data structures that will be stored on sequential ASCII files.

STRNAME   `character*12` name of a data structure. The list of data structure that can be used in DONJON is presented in Section 2.2.

(module)   input specification for a module that will be executed. For DONJON specific modules, these input structures are described in Section 3 to Section 6.

END: keyword to call the normal end-of-execution utility module.

;   keyword to specify the end of record. This keyword is used to delimit the part of the input data stream associated with each module.

Generally, the user has the choice to declare the most of data structure in the format of a linked list to reduce CPU times or as a XSM file to reduce memory resources. In general, the data structure are stored on the sequential ASCII files only for the backup purposes.

The input data normally ends with a call to the END: module. However, the GAN driver will insert automatically the END: module, even if it was not provided, upon reaching an end-of-file in the input stream.

Each **(module)** calling specification contains a module execution description and its associated input structure. All these modules, except the END: module may be called more than once.

3 GENERAL CORE-DESCRIPTION MODULES

3.1 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*. In `RESINI:` terminology, a *fuel bundle* can be a CANDU fuel cluster or an axial slice of a PWR or FBR assembly with homogeneous cross sections. 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 3.14).

- 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 9.1).
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 2: 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.

3.1.1 Main input data to the `RESINI:` module

Note that the input order must be respected.

Table 3: Structure **(descresini1)**

```
[ EDIT iprint ]
::: [ SPLIT-NAP: ] GEO: (descgeo)
[ ::: NAP: (descnap3) ]
[ 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)
        | NHNAME (HNAME(i) , i = 1, nh) }
[ SIM lx ly (naval(i) , i = 1, nch) ]
[ FOLLOW nis (HISOT(i) , i = 1, nis) ]
NCOMB { ncomb B-ZONE (icz(i) , i = 1, nch) | ALL | ASBLY }
(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 DRAGON5 user guide[5]). 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 8.1.3 for important note on the coarse geometry requirement.

(descnap3)
: structure describing the input data to the `NAP:` module to automatically define the core geometry with heterogeneous assembly (See Section 8.1.3).

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* for *3-D* Cartesian geometry case.
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* for *3-D* Cartesian geometry case.
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.
NHNAME	keyword used to specify *XHAME* for *3-D* hexagonal geometry case.
HNAME	`character*8` array of horizontal channel names. A radial channel name can be identified by the following scheme: The core is divided into 6 60-degree sectors; the sectors are labeled "A", "B", "C", "D", "E", and "F"

- Rings of channels are numbered starting at ring 0 for the central channel
- Each channel is now identified as a string 'RRSAA', with RR the ring number, S the sector, and AA the assembly number in the ring.

For example:

Ring 0: `C00A01`

Ring 1: `C01A01, C01B01, C01C01, C01D01, C01E01, C01F01`

Ring 2: `C02A01, C02A02, C02B01, C02B02, C02C01, C02C02, C02D01, C02D02, C02E01, C02E02, C02F01, C02F02`.

All non-fuel regions are to be assigned a single character '-'. This option is not available for *3-D* Cartesian geometry.

nh	integer total number of subdivisions along the hexagonal plane in the fuel-map geometry. Not used for *3-D* Cartesian 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_{ch}: number of fuel channels in the radial plane.
nb	N_{b}: number of fuel bundles (or assembly slices) 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 3.14).
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.
FOLLOW	keyword used to set the particularized isotopes that will be saved in each fuel cycle information directory.
nis	number of particularized isotopes that will be saved in each fuel cycle information directory.
HISOT	character*8 array of particularized isotope names.

3.1.2 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 4: 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 pwvalue | CHAN (pwvalue(i) , i = 1, nch ) | BUND (pwvalue(i) , i = 1, nch·nb ) } ]
[ REACTOR-POW pwtot AXIAL-PFORM (fvalue(i) , i = 1, 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 |
```

Structure (**descresini2**)

```
   CHAN (pvalue(i) , i = 1, nch ) | BUND (pvalue(i) , i = 1, nch·nb ) |
   LEVEL [ { H+ | H- } ] { SAME lvalue | CHAN (lvalue(i) , i = 1, nch ) } } } ]]
[[ 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 3.12). 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 values, given in *MW·day per tonne*/MW of initial heavy elements. The fuel burnup is considered as a global parameter.

pwvalue	real array containing the powers values, given in kW.
`REACTOR-POW`	keyword used to specify the full reactor power. This information is not required if `BUNDLE-POW` data is provided.
pwtot	power value, given in MW.
`AXIAL-PFORM`	keyword used to specify the axial form factors. They are assumed identical in all channels.
fvalue	axial form factor value.
`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 9.1.5.
`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 pro-
            vided. 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*.

LEVEL   keyword to specify that parameter *PNAME* (declared as `LOCAL`) is a control rod in-
            sertion parameter computed as a function of variable *lvalue* set between 0.0 (rod out
            of the core) and 1.0 (rod fully inserted). The variable *lvalue* can be a core-averaged
            value (with keyword `SAME`) or a set of channel-defined values (with keyword `CHAN`).

H+   keyword used to specify that a rod will be inserted into reactor core from the highest
            position (e.g. from the top for vertically moving rod-device). This is the default option.

H−   keyword used to specify that a rod will be inserted into reactor core from the lowest
            position (e.g. from the bottom for vertically moving rod-device).

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 initial heavy metal content 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 3.2.1).

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. 20.

3.2 The `USPLIT:` module

The `USPLIT:` module is used to create a `MATEX` object that will provide a link between the reactor geometry and material index. The *3-D* Cartesian or *3-D* Hexagonal reactor geometry, which is previously produced in the `GEO:` module, is analyzed and the material mixture indices are recomputed in order to provide a unique mixture number for each material sub-volume. Such renumbering permits a complex reactor core modeling. A `MATEX` object is also used to store some additional information that will be required and updated by other DONJON modules (see Section 9.2).

The `USPLIT:` module specification is:

Table 5: Structure `USPLIT:`

GEOM MATEX := `USPLIT:` { *GEOM* | *GEOMOLD* } :: **(desclink)**

---

where

GEOM	`character*12` name of a GEOMETRY object. This object is defined in creation (appears only on LHS) or modification (appears on both LHS and RHS) mode. An existing geometry previously created in the `GEO:` module is modified. Only *3-D* Cartesian or *3-D* Hexagonal reactor geometries are allowed.
MATEX	`character*12` name of a MATEX object to be created by the module.
GEOMOLD	`character*12` name of a GEOMETRY object previously created in the `GEO:` module. This object must be specified in read-only mode (appears only on RHS). It is copied into *GEOM* at the beginning of `USPLIT:` module. Only *3-D* Cartesian or *3-D* Hexagonal reactor geometries are allowed.
(desclink)	structure describing the input data to the `USPLIT:` module.

3.2.1 Input data to the USPLIT: module

Note that the fuel-type and reflector-type mixture indices are need to be specified explicitly and the input order must be respected.

Table 6: Structure **(desclink)**

```
[ EDIT iprint ]
NGRP ngrp
MAXR maxreg
NMIX nmixt
[ NREFL nrefl RMIX ( mixr(i) , i = 1, nrefl ) ]
[ NFUEL { nfuel FMIX ( mixf(i) , i = 1, nfuel ) | ASBLY } ]
;
```

---

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.
NGRP	keyword used to specify *ngrp*.
ngrp	integer total number of energy groups. This value must be greater than 0.
MAXR	keyword used to specify *maxreg*.
maxreg	integer maximum number of mesh-splitted regions in the reactor geometry. In *3-D* Hezagonal geometry, it corresponds to the total number of prismatic blocks $l_h * l_z$.
NMIX	keyword used to extend number of material mixtures in case new fuels are going to be inserted in the fuel map in upcoming fuel cycles. By default, *nmixt* is set to the maximum mixture index in RHS geometry *GEOM* or *GEOMOLD*.
nmixt	the maximum fuel mixture index in the complete life of the reactor. This number must be greater than the maximum mixture index in RHS geometry *GEOM* or *GEOMOLD*.
NREFL	keyword used to specify *nrefl*.
nrefl	integer total number of reflector types. A reactor should have at least one reflector material.
RMIX	keyword used to specify *mixr*.
mixr	integer array of the reflector-type mixture indices. Each reflector type is assigned a distinct mixture number as previously defined in the GEOMETRY object.
NFUEL	keyword used to specify *nfuel*.
nfuel	integer total number of fuel types. A reactor should have at least one fuel type.
FMIX	keyword used to specify *mixf*.
mixf	integer array of the fuel-type mixture indices. Each fuel type is assigned a distinct mixture number as previously defined in the GEOMETRY object.
ASBLY	keyword used to compute automatically *nfuel* and *mixf*(i). This option is only available when the geometry has been split by the NAP: module.

3.3 The `MACINI:` module

The `MACINI:` module is used to construct an extended MACROLIB, in which the properties are stored per each material region over the whole mesh-splitted reactor geometry. This MACROLIB is obtained by combining the material properties which are contained in the two distinct MACROLIB objects:

- The first MACROLIB contains the material properties which are evolution-independent, such as reflector and device properties. It is created using either `MAC:`, `CRE:`, `NCR:` or `AFM:` module.

- The second is a fuel-map MACROLIB created using either `CRE:`, `NCR:` or `AFM:` module. It must contain the interpolated fuel properties per each fuel bundle.

The resulting MACROLIB will contain the properties that are stored for each reactor material and per each mesh-splitted volume. When the devices are not present in the reactor core, then the resulting MACROLIB can be considered as a complete reactor MACROLIB and it can be directly used for the numerical solving. However, when the devices are inserted into the reactor core, the resulting MACROLIB is not yet complete; it must be subsequently updated with respect to the device properties, using the `NEWMAC:` module (see Section 3.10).

The `MACINI:` module specification is:

Table 7: Structure `MACINI:`

MACRO2 MATEX := `MACINI:` *MATEX MACRO* [*MACFL*] :: [`EDIT` *iprint*] [`FUEL`] ;

---

where

MACRO2	`character*12` name of the extended MACROLIB to be created by the module.
MATEX	`character*12` name of the MATEX object containing an extended material index over the reactor geometry. *MATEX* must be specified in the modification mode; it will store the recovered h-factors per each fuel region.
MACRO	`character*12` name of a MACROLIB, created using either `MAC:`, `CRE:`, `NCR:` or `AFM:` module, for the evolution-independent material properties (see structure **(desccre1)** or refer to the user guide[5]).
MACFL	`character*12` name of a fuel-map MACROLIB, created using either `CRE:`, `NCR:` or `AFM:` module, for the interpolated fuel properties (see structure **(desccre2)** or refer to the user guide[5]).
`EDIT`	keyword used to set *iprint*.
iprint	integer index used to control the printing on screen: $= 0$ for no print; $= 1$ for minimum printing; larger values produce increasing amounts of output. The default value is *iprint* $= 1$.
`FUEL`	keyword used to indicate that *MACRO* is a fuel-map MACROLIB in case where only two RHS objects are defined. By default, *MACRO* contains evolution-independent cross sections.

3.4 The `DEVINI:` module

The `DEVINI:` module is used for the modeling of reactivity mecanisms, based on the devices specifications which are read from the input data file. The module will create a new DEVICE object that will store the devices specifications and parameters (see Section 9.3). Note that only the rod-type (i.e. solid) devices are considered using the `DEVINI:` module; the liquid zone controllers can be added subsequently, using the `LZC:` module (see Section 3.6). A rod-type device is a reactivity controller rod (or plate), such as: a zone control rod (ZCR), a shutoff rod (SOR), etc. Several devices parameters can be modified using the `DSET:` module (see Section 3.7).

A device specification includes several controller rod parameters, such as: a rod position, rod insertion level, direction of movement, etc. The devices positions can not overlap in the reactor core; they are referred using *3-D*-Cartesian coordinates. The insertion level of rods can be set according to their nominal positions or they can be displaced *in* or *out* of core. The rods can also be divided into the several user-defined groups so that they can be manipulated, displaced or moved simultaneously.

The `DEVINI:` module specification is:

Table 8: Structure `DEVINI:`

DEVICE MATEX := `DEVINI:` *MATEX* :: **(descdev)**

---

where

DEVICE   `character*12` name of the DEVICE object that will be created by the module; it will contain the devices information.

MATEX   `character*12` name of the MATEX object that will be updated by the module. The rod-devices material mixtures are appended to the previous material index and the rod-devices indices are also modified, accordingly.

(descdev)   structure describing the input data to the `DEVINI:` module.

3.4.1 Input data to the `DEVINI:` module

The `DEVINI:` module allows the definition of rod-type devices made of one or many (up to 10) parts, as depicted in Fig. 1.

Table 9: Structure **(descdev)**

```
[ EDIT iprint ]
NUM-ROD nrod [ { FADE | MOVE } ]
( (dev-rod), i = 1, nrod )
[ CREATE ROD-GR ngrp ( (rod-group), i = 1, ngrp ) ]
;
```
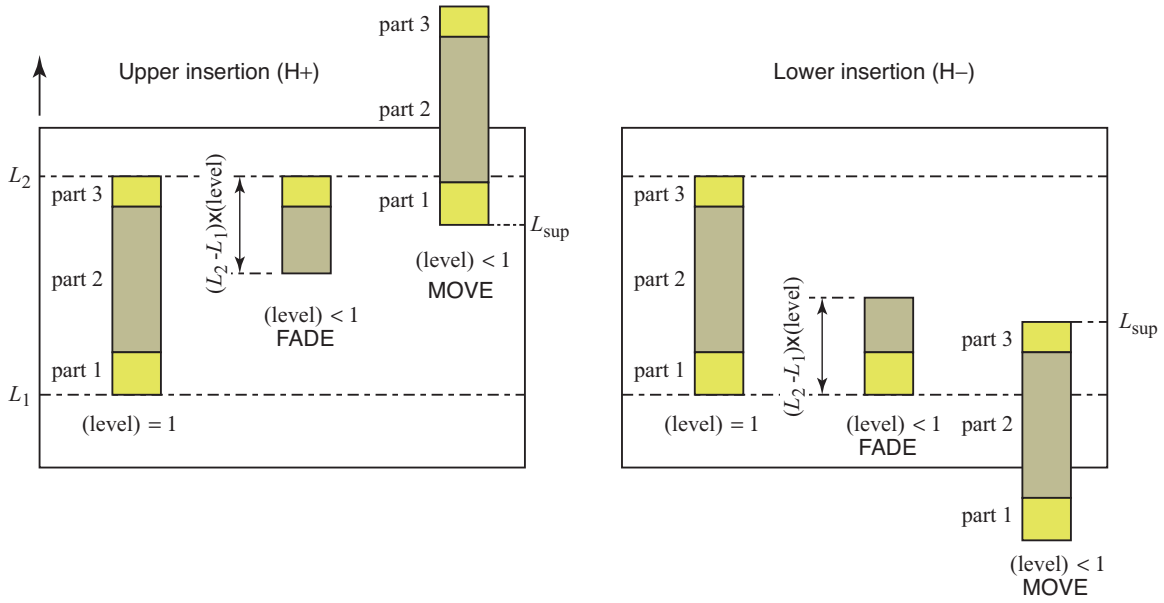
Figure 1: Presentation of fully- and partially-inserted 3-part control rods.

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.
NUM-ROD	keyword used to specify *nrod*.
nrod	integer total number of the reactor rod-type devices. This number must be greater than 0.
FADE	fading rod keyword. A fraction of the fully inserted rod vanishes (default option).
MOVE	moving rod keyword. The complete rod is moving (DONJON3-type movement).
CREATE	keyword used to create the rod-groups of devices. The creation of groups is optional.
ROD-GR	keyword used to set *ngrp*.
ngrp	integer total number of the rod groups to be created. This number must be greater than 0.
(dev-rod)	structure describing the input data for each individual rod.
(rod-group)	structure describing the input data for each group of rods.

3.4.2 Description of dev-rod input structure

A rod position is referred by its *3-D* Cartesian coordinates only. Note that the devices positions can not overlap. The input order of data must be respected.

Table 10: Structure **(dev-rod)**

```
ROD id
  ROD-NAME NAME
  AXIS { X | Y | Z }
  FROM { H+ | H- }
  [ LEVEL value ]
  [ SPEED speed ]
  [ TIME time ]
  [[ MAXPOS (pos(i), i = 1, 6) DMIX mix1 mix2 ]]
ENDROD
```

where

ROD   keyword used to specify the rod *id* number.

id   integer identification number of the current rod. Each rod-type device must be assigned a unique *id* number, given in an ascending order ranging from 1 to *nrod*.

ROD-NAME   keyword used to specify the rod *NAME*.

NAME   `character*12` name of the current rod. In general, this name is composed by the rod specific type (e.g. SOR, ZCR, etc.) followed by its sequential number (e.g. 01, 02, etc.).

AXIS   keyword used to specify the rod movement axis. A rod can be displaced along only one of the axis.

X   keyword used to specify that a rod is displaced along X axis.

Y   keyword used to specify that a rod is displaced along Y axis.

Z   keyword used to specify that a rod is displaced along Z axis.

FROM   keyword used to specify the insertion side of geometry. The rod-devices can be inserted into the reactor core from only one side of geometry. For example, some vertically moving devices can be inserted only from the top, whereas other only from the bottom.

H+   keyword used to specify that a rod will be inserted into reactor core from the highest position (e.g. from the top for vertically moving rod-device).

H-   keyword used to specify that a rod will be inserted into reactor core from the lowest position (e.g. from the bottom for vertically moving rod-device).

LEVEL   keyword used to specify the actual rod insertion level *value*. By default, the rod insertion level is left undefined.

value   real positive value of the rod insertion level. This value is used to compute the actual rod position in the reactor core. The rod insertion level is minimal (*value* = 0.0) when the rod is completely withdrawn, and it is maximal (*value* = 1.0) when the rod is fully inserted. For the partially inserted rod the insertion level must be: $0.0 < value < 1.0$

SPEED   keyword used to specify *speed*. By default, the speed is left undefined.

speed   real positive value of the rod movement speed, given in cm/s. This value is needed only for the reactor regulating purpose.

TIME	keyword used to specify *time*. By default, the insertion time is left undefined.
time	real value of time for the rod insertion (or extraction), given in sec. This value is needed only for the reactor regulating purpose.
MAXPOS	keyword used to specify the full-inserted coordinates of a rod part. The sequence of MAXPOS and DMIX data structures is repeated for each part making the rod.
pos	real array containing 3-D Cartesian coordinates of the full-inserted rod. This is the limiting rod position in the reactor core, which may or may not be the same as the actual rod position. These coordinates must be given in the order: X−, X+, Y−, Y+, Z−, and Z+.
DMIX	keyword used to specify *mix1* and *mix2*.
mix1	first of two integer rod mixture indices. Index *mix1* corresponds to the perturbed cross sections.
mix2	second of two integer rod mixture indices. Index *mix2* corresponds to the reference cross sections. Indices *mix1* and *mix2* will be used to compute the incremental cross sections in the NEWMAC: module.
ENDROD	keyword used to end the rod description.

3.4.3 Description of rod-group input structure

The partition of devices into groups is very useful when the same action is to be applied to several rods, e.g. setting of new parameters (using the DSET: module) or rods moving (using the MOVDEV: module).

Table 11: Structure **(rod-group)**

GROUP-ID *igrp* { ROD-ID [[*id*]] | ALL }

where

GROUP-ID	keyword used to set *igrp* number.
igrp	integer identification number of a group to be created. Each rods group must be assigned a unique identification number, given in ascending order ranging from 1 to *ngrp*.
ROD-ID	keyword used to set the rod *id* numbers.
id	integer identification numbers of rods which belong to the same group *igrp*. A particular rod (or several rods) may belong to different groups, but it could not be repeated inside the same group. The total number of rods in any group must be between 1 and *nrod*.
ALL	keyword used to specify that all rods will belong to the same group *igrp*.

3.5   The `DETINI:` **module**

The `DETINI:` module is used to read and store detector information. A detector is represented by a 2-D or 3-D Cartesian/Hexagonal geometry.

The `DETINI:` module specification is:

Table 12: Structure `DETINI:`

DETECT := `DETINI:` [*DETECT*] :: **(descdet)**

---

where

DETECT   `character*12` name of the DETECT object that will be created by the module; it will contain the detector informations. If DETECT appear on RHS, it is updated, otherwise, it is created.

(descdev)   structure describing the input data to the `DETINI:` module.

3.5.1 Input data to the `DETINI:` module

Note that the input order must be respected.

Table 13: Structure **(descinidet)**

[`EDIT` *iprt*] [`HEXZ`] `NGRP` *ngrp*
[[`TYPE` *NAMTYP*
`INFO` *ndetect* *nrep* { `SPECTRAL` (*spec*(i), i=1,*ngrp*) | `DEFAULT` }
[`INVCONST` (*tinv*(i), i=1,*nrep*−2)] [`FRACTION` (*fract*(i), i=1,*nrep*−1)]
(**(descdet)**, i=1,*ndetect*)]]
;

---

where

`EDIT`   keyword used to set *iprt*.

iprt   index used to control the printing in module `INIDET:`. =1,2 for no print(default value); =3 for printing the contents of the output DETECT.

`HEXZ`   keyword to specify that only hexagonal detectors will be defined. If this keyword is absent, Cartesian detectors will be defined.

`NGRP`   keyword used to set *ngrp*.

ngrp   number of energy groups in the calculation. It must be equal to the number set in the `MACD:` module or by the COMPO files.

TYPE   keyword to specify the detector type.

NAMTYP   `character*12` name of the detector type. To correspond to the actual detector response model encoded, the type of detector must be in this list:

- `PLATN_REGUL`
- `PLATN_SAU`
- `VANAD_REGUL`
- `CHION_SAU`
- `CHION_REGUL`

For other type names, only a fixed normalisation can be performed.

INFO   keyword to specify the information associated with the detector type.

ndetect   number of detectors of the specified type.

nrep   number of detector response components for the specified type. It must be greater or equal to 2, corresponding to a response in fraction and the reference flux value.

SPECTRAL   keyword to specify the energy spectral of a detector type.

spec   array containing the energy spectral of a detector type.

DEFAULT   keyword to specify the energy spectral will be initialized as 1.0 for the highest energy group and 0.0 for other groups.

INVCONST   keyword to specify the inverse time constants of the detector type model. This option is only valid for platinum, ($NAMTYP(1:5) = $'PLATN'), detector type.

tinv   array containing the inverse time constants of the detector model.

FRACTION   keyword to specify the fractions corresponding to each delayed or prompt reponse of the detector type model. This option is only valid for platinum, ($NAMTYP(1:5) = $'PLATN'), detector type.

frac   array containing the detector type model fractions.

(descdet)   structure describing the format used to read detector information.

3.5.2 Description of the detector data

Note that the information input order must be respected.

Table 14: Structure **(descdet)**

```
NAME NAMDET
[ NHEX nhex HEX ( ihex(i), i=1,nhex ) ]
POSITION ( pos(i), i=1,6 )
RESP ( rep(i), i=1,nrep )
ENDN
```

where

NAME   keyword to specify the detector name.

NAMDET   `character*12` name of the detector. The different names in alphabetical order must fit their usual numbering in the core.(Ex: PLATN01, CHION01C)

NHEX   keyword to set the number of hexagons where the detector is placed.

nhex   number of hexagons.

HEX   keyword to set the hexagon numbers corresponding to the detector position.

ihex   array containing the hexagon numbers where the detector is present, as ordered in the geometry definition.

POSITION   keyword to specify the detector coordinates.

pos   array containing the positions of the specified detector. The positions must be read as X− X+ Y− Y+ Z− Z+ . For 2-D geometry, Z coordinates must be 0.0 and a value greater than 1.0. For hexagonal geometry, only Z coordinates are used in 3-D representation.

RESP   keyword to specify the detector initial responses.

rep   array containing the initial responses of the detector. To use the current detector models in DONJON, responses are given as

- For vanadium detectors: current response, last response.
- For platinum detectors: current response, reference flux, last detector slow responses.
- For ion chamber detectors: current logarithmic response, current log rate response, reference flux.

ENDN   keyword to specify the end of the detector informations.

3.6 The `LZC:` module

The `LZC:` module is used for the modeling of liquid zone controllers, which are normally presented in the CANDU6-type reactor core. The liquid zone controllers specifications are read from the input data file. Note that this modeling can be made after the rod-type devices have been previously defined using the `DEVINI:` module (see Section 3.4). In this case, the previously created DEVICE object will be updated by the `LZC:` module; it will store the additional and separate information with respect to the liquid controllers (see Section 9.3).

The liquid zone controller specification includes several device parameters, such as: the whole device position, water filling level, direction of filling, etc. Note that a liquid zone controller is normally composed of two parts: one part is empty and the second part is full-filled. The water level can be adjusted according to the control reactivity requirements. The controllers positions are referred using *3-D*-Cartesian coordinates. Several devices parameters can be modified using the `DSET:` module (see Section 3.7). The liquid controllers can also be divided into the several user-defined groups so that they can be manipulated simultaneously.

The `LZC:` module specification is:

Table 15: Structure `LZC:`

DEVICE MATEX := `LZC:` [*DEVICE*] *MATEX* :: **(desclzc)**

---

where

DEVICE   `character*12` name of the DEVICE object. Note, if the rod-type devices are not present in the reactor core, then *DEVICE* object must appear only on the LHS (i.e. in create mode), it will contain the information only with respect to the liquid zone controllers. However, if the rod-type devices are present in the reactor core, then they must be specified first (i.e. before the liquid controllers) using the `DEVINI:` module (see Section 3.4). In the last case, the *DEVICE* object must also appear on the RHS (i.e. in modification mode), it will contain the additional and separate information with respect to the liquid zone controllers.

MATEX   `character*12` name of the MATEX object that will be updated by the module. The lzc-devices material mixtures are appended to the previous material index and the lzc-devices indices are also modified, accordingly.

(desclzc)   structure describing the input data to the `LZC:` module.

3.6.1 Input data to the `LZC:` module

Note that the input order must be respected.

Table 16: Structure **(desclzc)**

```
[ EDIT iprint ]
NUM-LZC nlzc
((dev-lzc), i = 1, nlzc)
[ CREATE LZC-GR ngrp ((lzc-group), i = 1, ngrp) ]
;
```

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.

NUM-LZC   keyword used to specify *nlzc*.

nlzc   integer total number of liquid zone controllers. This number must be greater than 0.

CREATE   keyword used to create the lzc-groups of devices. The creation of groups is optional.

LZC-GR   keyword used to set *ngrp*.

ngrp   integer total number of the lzc groups to be created. This number must be greater
                than 0.

(dev-lzc)   structure describing the input data for each individual liquid controller.

(lzc-group)   structure describing the input data for each group of liquid controllers.

3.6.2 Description of dev-lzc input structure

Note that the devices positions can not overlap in the reactor core. The input order of data must be
respected.

Table 17: Structure **(dev-lzc)**

```
LZC id
MAXPOS ( pos(i) , i = 1, 6 )
MAX-FULL fmax
AXIS { X | Y | Z }
LEVEL value
[ RATE rate ]
[ TIME time ]
EMPTY-MIX ( mixE(n), n = 1, 2 )
FULL-MIX ( mixF(n), n = 1, 2 )
```

where

`LZC`	keyword used to specify the liquid controller *id* number.
id	integer identification number of the current liquid controller. Each controller must be assigned a unique *id* number, given in an ascending order ranging from 1 to *nlzc*.
`MAXPOS`	keyword used to specify the entire position of a liquid zone controller, including its empty and full parts.
pos	real array containing 3-D Cartesian coordinates of the liquid zone controller position in the reactor core. These coordinates must be given in the order: X− X+ Y− Y+ Z− Z+
`MAX-FULL`	keyword used to specify *fmax*.
fmax	real value of the limiting coordinate along the controller filling axis, which corresponds to the maximum full-filling level for the current liquid controller.
`AXIS`	keyword used to specify the controller filling axis. A liquid controller can be filled along only one (vertical) axis.
`X`	keyword used to specify that a liquid controller is filled along X axis.
`Y`	keyword used to specify that a liquid controller is filled along Y axis.
`Z`	keyword used to specify that a liquid controller is filled along Z axis.
`LEVEL`	keyword used to specify the actual filling level.
value	real positive value of the water level. This value is minimal (*value* = 0.0) when the controller is empty, and it is maximal (*value* = 1.0) when the controller is full-filled. For the partially filled controller the water level must be: 0.0 < *value* < 1.0
`RATE`	keyword used to specify *rate*.
rate	real positive value of the water filling rate, given in m^3/s. This value is needed only for the reactor regulating purpose.
`TIME`	keyword used to specify *time*.
time	real value of the filling time, given in sec. This value is needed only for the reactor regulating purpose.
`EMPTY-MIX`	keyword used to specify *mixE*.
mixE	two integer mixture indices, specified for the empty-part of liquid controller. The first and the second mixture indices correspond to the perturbed and the reference cross sections, respectively. These indices will be used to compute the incremental cross sections in the `NEWMAC:` module.
`FULL-MIX`	keyword used to specify *mixF*.
mixF	two integer mixture indices, specified for the full-part of liquid controller. The first and the second mixture indices correspond to the perturbed and the reference cross sections, respectively. These indices will be used to compute the incremental cross sections in the `NEWMAC:` module.

3.6.3 Description of lzc-group input structure

The partition of lzc-devices into groups is similar to that of rod-devices.

Table 18: Structure **(lzc-group)**

`GROUP-ID` *igrp* { `LZC-ID` [[*id*]] | `ALL` }

---

where

`GROUP-ID`	keyword used to set *igrp* number.
igrp	integer identification number of a group to be created. Each controllers group must be assigned a unique identification number, given in ascending order ranging from 1 to *ngrp*.
`LZC-ID`	keyword used to set the controllers *id* numbers.
id	integer identification numbers of the liquid controllers which belong to the same group *igrp*. A particular controller (or several devices) may belong to different groups, but it could not be repeated inside the same group. The total number of liquid controllers in any group must be between 1 and *nlzc*.
`ALL`	keyword used to specify that all liquid controllers will belong to the same group *igrp*.

3.7   The `DSET:` module

The `DSET:` module is used to set or to update some of the devices parameters. The new parameters can be applied for the rod-type devices and/or for the liquid zone controllers, such as: the new insertion level for the rods or water filling level for the lzc-type devices, etc. It is possible to apply the new parameters to the individual user-selected devices as well as to the user-selected groups of devices. If the device (rod-insertion or lzc-filling) level is selected for the modification, then a new device position is recomputed accordingly. The `DSET:` module can be used to perform the device reactivity studies and also to predict the reactivity worth of the rod-devices.

The `DSET:` module specification is:

Table 19: Structure `DSET:`

DEVICE := `DSET:` *DEVICE* :: **(descdset)**

---

where

DEVICE   `character*12` name of the DEVICE object that will be updated by the module.

(descdset)   structure describing the input data to the `DSET:` module.

3.7.1 Input data to the `DSET:` *module*

It is possible to set or to modify the parameters for several individual devices and/or for several groups of devices simultaneously.

Table 20: Structure **(descdset)**

```
EDIT iprint
[[ { ROD irod | ROD-GROUP irgrp | LZC ilzc | LZC-GROUP ilgrp }
[ LEVEL value ] [ SPEED speed ] [ TIME time ]
END ]]
;
```

---

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; larger values produce increasing amounts of output.

`ROD`   keyword used to specify the rod *irod* number.

irod   integer identification number of a rod to be modified. Each rod-type device has a

	unique *irod* number, ranging from 1 to *nrod*, as been defined in the `DEVINI:` module (see Section 3.4.2).
`ROD-GROUP`	keyword used to specify the rod-group *irgrp* number.
irgrp	integer identification number of a rod-group of devices that will be modifed with the same parameters. Each rod-group has a unique *irgrp* number, ranging from 1 to *ngrp*, as been defined in the `DEVINI:` module (see Section 3.4.3).
`LZC`	keyword used to specify the liquid controller *ilzc* number.
ilzc	integer identification number of a liquid controller to be modified. Each lzc-type device has a unique *ilzc* number, ranging from 1 to *nlzc*, as been defined in the `LZC:` module (see Section 3.6.2).
`LZC-GROUP`	keyword used to specify the lzc-group *ilgrp* number.
ilgrp	integer identification number of a lzc-group of devices that will be modifed with the same parameters. Each lzc-group has a unique *ilgrp* number, ranging from 1 to *ngrp*, as been defined in the `LZC:` module (see Section 3.6.3).
`LEVEL`	keyword used to specify a new level *value*.
value	real positive value of the new device level. For the rod-type devices this *value* must correspond to the new rod insertion level (see Section 3.4.3). For the lzc-type devices this *value* must correspond to the new water filling level (see Section 3.6.2). In any case, the new level value must be: $0.0 \leq value \leq 1.0$
`SPEED`	keyword used to specify a new value for *speed*.
speed	real positive value of the device speed. For the rod-type devices this value must correspond to the speed of rod movement (insertion or extraction), given in cm/s. For the lzc-type devices this value must correspond to the water filling rate, given in m^3/s. The value of *speed* is required only for the reactor regulating purpose.
`TIME`	keyword used to specify a new value for *time*.
time	real value of time either for the rod insertion (or extraction) *or* for the liquid controller filling, given in sec. The value of *time* is required only for the reactor regulating purpose.
`END`	keyword used to indicate the end of input of the new parameters for the current device or group of devices.

3.8 The `MCC:` module

The `MCC:` module supplies tools to edit selectively one or several parameters of a fuel map object. These parameters are the ones defined when the fuel map is created, according to the calculation grid chosen to compute the macroscopic cross-sections libraries. Their selective edition is useful to study their impact on the core reactivity. For instance, this module enables to increase uniformly the fuel temperature in each cell, without modifying any other parameter such as the moderator temperature. It grants access to the Doppler coefficient, even at hot full power when the fuel temperature is different in every cell of the core.

This module enables the computation of (non-exhausive list) : the Doppler coefficient, the power Doppler coefficient (Doppler during a power transient), the moderator temperature coefficient, the boron concentration coefficient, the reactivity with the fuel temperature set to the moderator one, etc.

Note that this module does not perform any reactivity calculation (only fuel map edition).

The `MCC:` module specifications are:

Table 21: Structure `MCC:`

[*FLMAP1*] := `MCC:` *FLMAP1* [*FLMAP2*] :: **(descmcc1)**

where

FLMAP1   `character*12` name of the MAP object that will contain the updated fuel-lattice information. If *FLMAP1* appears on both LHS and RHS, it will be updated; if it only appears on RHS, it will only be read to display its contents.

FLMAP2   `character*12` name of the MAP object that contains information to be recovered to update *FLMAP1*. If *FLMAP2* exists, data to update *FLMAP1* will be taken in it. If not, data to update *FLMAP1* will be taken in *FLMAP1*.

(descmcc1)   structure describing the main input data to the `MCC:` module. Note that this input data is mandatory and must be specified either if *FLMAP1* is updated or only read.

3.8.1 Main input data to the `MCC:` module

Table 22: Structure **(descmcc1)**

```
[ EDIT iprint ]
[[ REC rec1 { UNI value1 | ADD value2 | { SAME | READ } rec2 } ]]
[ TTD pcore ]
;
```

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. A value of 5 or higher will display the contents of *FLMAP1* object after edition, and a value of 6 or higher will display the contents before edition.
REC	keyword used to indicate that the name of the record to be updated will follow.
rec1	name of the record to be updated. The authorised values are defined in the table 9.1.5, page 166 (P-NAME variable). To be allowed, these values have to be previously defined in the fuel map before calling MCC.
UNI	keyword to specify that an uniform and absolute value is to be set. With this parameter, the *rec1* of every region will have the same value.
value1	absolute value (in Kelvin if it is a temperature) that will be set for *rec1* in every region.
ADD	keyword to specify that an uniform variation of *rec1* value is to be applied. With this parameter, the value of *rec1* will be altered in every region.
value2	value of *rec1* variation (in Kelvin if it is a temperature) that will be applied to every region.
SAME	keyword used to indicate that the values to edit *rec1* are to be recovered from *rec2* in the same fuel map, *FLMAP1*. For instance, it enables the user to set the fuel temperature with the moderator temperature.
READ	keyword used to indicate that the values to edit *rec1* are to be recovered from *rec2* in an other fuel map, *FLMAP2*. For instance, it enables the user to set the fuel temperature in *FLMAP1* with the fuel temperature of *FLMAP2*.
rec2	name of the record where the data to perform the update of *FLMAP1* is to be recovered. The authorised values are defined in the table 9.1.5, page 166 (P-NAME variable). To be allowed, these values have to be previously defined in the fuel map before calling MCC.
TTD	keyword used to indicate that the values of the 'D-COOL' record are to be updated. They will be computed from the moderator temperature stored in the 'T-COOL' folder and the core pressure, using the water tables. Note that the position of the TTD keyword matters, the density being calculated when TTD is called and not at the end of MCC: execution.
pcore	core pressure (in Pa).

3.9   The `MOVDEV:` **module**

The `MOVDEV:` module can be used for the transient simulations and reactor control studies, which are related to the time-dependent rod-devices displacement in the reactor core. The rods can be inserted into or extracted from the reactor core, at constant or at variable speed of movement. The rod positions are recomputed at every given time step of movement. The new rod positions can be computed in several ways, based on either: current time increment and movement speed; relative change in rod positions; *or* current rod insertion level. The `MOVDEV:` module allows the rod-devices to be displaced individually or simultaneously in groups.

The `MOVDEV:` module specification is:

Table 23: Structure `MOVDEV:`

DEVICE := `MOVDEV:` *DEVICE* :: **(descmove)**

---

where

DEVICE   `character*12` name of the DEVICE object that will be modified by the module. The rods positions are updated according to the current time step of movement.

(descmove)   structure describing the input data to the `MOVDEV:` module.

3.9.1 Input data to the `MOVDEV:` module

It is possible to move several individual rods and/or several groups of rods simultaneously. A user must be aware that a particular device will not be displaced more than once during the same time step. Note that the input order of data to the module must be respected.

Table 24: Structure **(descmove)**

```
[ EDIT iprint ]
DELT delt
[[ { ROD id | GROUP igrp }
{ INSR | EXTR }
{ LEVEL value | DELH delh | SPEED speed } ]]
;
```

---

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.

`DELT`	keyword used to set *delt*.
delt	real value of the time increment for the current time step, given in sec.
`ROD`	keyword used to specify the rod *id* number.
id	integer identification number of a rod-type device to be displaced. Each rod has a unique *id* number, ranging from 1 to *nrod*, as been defined in the `DEVINI:` module (see Section 3.4.2).
`GROUP`	keyword used to specify a rod-group *igrp* number.
igrp	integer number of a group of rods that will be displaced simultaneously, with the same parameters of movement. Each group of rod-devices has a unique *igrp* number, ranging from 1 to *ngrp*, as been defined in the `DEVINI:` module (see Section 3.4.3).
`INSR`	keyword used to specify that a particular rod or a group of rods will be inserted into the reactor core during the period of time *delt*.
`EXTR`	keyword used to specify that a particular rod or a group of rods will be extracted from the reactor core during the period of time *delt*.
`LEVEL`	keyword used to specify the new level *value*.
value	real positive value of the rod insertion level at current time step. This value will be used to compute the new rod position in the reactor core. The insertion level is minimal (*value* = 0.0) when the rod is completely withdrawn, and it is maximal (*value* = 1.0) when the rod is fully inserted. For the partially inserted rod the insertion level must be: $0.0 < value < 1.0$
`DELH`	keyword used to specify the value *delh*.
delh	real positive (absolute) value of the relative change in the rod position during the period of time *delt*. This is a time-dependent rod displacement along the rod movement axis, which must be given in cm.
`SPEED`	keyword used to set the current value of *speed*.
speed	real positive (absolute) value of the rod movement speed, given in cm/s. The rod speed can be kept constant or it can be modified at any time step *delt*. The devices could also have the different speeds of movement.

3.10 The `NEWMAC:` module

The `NEWMAC:` module is used to create a complete MACROLIB with respect to the devices parameters. The resulting MACROLIB will contain the exact properties for every material region, over the whole mesh-splitted reactor geometry. The material properties of each region are recomputed with respect to the actual position of each rod-type and if present lzc-type device. The computing algorithm is based on the determination of the volumic fraction occupied by each device; the incremental cross sections are then adjusted, accordingly. Note that the `NEWMAC:` module must be executed each time the devices positions are modified from the previously computed ones.

The `NEWMAC:` module specification is:

Table 25: Structure `NEWMAC:`

MACRO3 MATEX := `NEWMAC:` *MATEX MACRO2 DEVICE* :: [`EDIT` *iprint*] [`XFAC` *xfac*] ;

where

MACRO3   **character*12** name of the MACROLIB to be created by the module. It will contain the updated properties of each material region with respect to the current position of each device.

MATEX   **character*12** name of the MATEX object, containing the complete reactor material index including devices. *MATEX* must be specified in the modification mode; it will store the updated h-factors, computed per each fuel region with respect to the devices positions.

MACRO2   **character*12** name of the read-only extended MACROLIB, previously created by the `MACINI:` module.

DEVICE   **character*12** name of the read-only DEVICE object containing the devices information and parameters.

`EDIT`   keyword used to set *iprint*.

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

`XFAC`   keyword used to specify the number of cells on which incremental cross sections were computed in the supercell code.

xfac   corrective factor for delta sigmas (real number). For DRAGON code, *xfac* is generally set to 2.0 and, for MULTICELL code, set to 1.0 . The default value is 2.0.

3.11   The `FLPOW:` module

The `FLPOW:` module is used to compute and print the flux and power distributions over the reactor core. It also computes and prints some additional information, for example: the fluxes ratios with respect to the thermal energy-group fluxes; the mean power density; the power- and flux-form factors; etc. The computed fluxes and powers are printed either on files or on the screen. Note that the calculation using the `FLPOW:` module can be performed once the numerical solution has been previously established using the `FLUD:` or `KINSOL:` module.

According to the user-selected module specification, the average fluxes and powers can be computed per each fuel region over the fuel lattice *and/or* per each material region over the whole reactor geometry. In either case, all fluxes are normalized to the given total reactor power corresponding to the reactor nominal conditions at core equilibrium. If the reactor is perturbed from its initial state, then a new total reactor power can be recomputed and, accordingly, the flux and power distributions will be updated using the previously computed normalization factor.

The `FLPOW:` module will create a new POWER object that will store the information related to the reactor fluxes and powers (see Section 9.5). In addition, the POWER object will store several parameters that can be used as power and criticity constraints for the optimization and fuel management purposes, namely: the maximum channel and bundle powers; the channel and bundle power-form factors; the effective multiplication factor (recovered from the FLUX or KINET data structure).

The `FLPOW:` module specifications are:

Table 26: Structure `FLPOW:`

```
{
  POWER [ NRMFLUX ] [ FMAP ]
      := FLPOW: [ POWOLD ] FMAP { FLUX | KINET } TRACK MATEX [ MACRO ]
      :: (descflpow)
|
  POWER := FLPOW: [ POWOLD ] { FLUX | KINET } TRACK MACRO
      :: (descflpow)
}
```

where

POWER   **character*12** name of the POWER object that will be created by the module. It will contain the information related to the reactor fluxes and powers.

NRMFLUX   **character*12** name of the FLUX object, in creation mode. According to the chosen option, this object contains either the fluxes normalized to the given total reactor power or the fluxes per bundle. Is it useful if you want to compute the detectors readings with the `DETECT:` module.

POWOLD   **character*12** name of the read-only POWER object. It must contain the previously computed flux normalization factor, which corresponds to the reactor nominal or equilibrium conditions.

FMAP   **character*12** name of the FMAP object containing the fuel lattice specification. When *FMAP* is specified on the RHS, the fluxes and powers calculations are performed over

the fuel lattice as well as over the whole reactor geometry. If *FMAP* is specified on the LHS, its records `'BUND-PW'` and `'FLUX-AV'` will be set according to the information present in *POWER*.

FLUX   `character*12` name of the FLUX object, previously created by the `FLUD:` module. The numerical flux solution contained in *FLUX* is recovered and all flux are normalized to the given total reactor power.

KINET   `character*12` name of the KINET object, previously created by the `KINSOL:` module. The numerical flux solution contained in *KINET* is recovered.

TRACK   `character*12` name of the TRACK object, created by the `TRIVAT:` module. The information stored in *TRACK* is recovered and used for the average flux calculation.

MATEX   `character*12` name of the MATEX object, containing the reactor material index and the h-factors that will be recovered and used for the power calculation.

MACRO   `character*12` name of the MACROLIB object, containing the h-factors that will be recovered and used for the power calculation.

(descflpow) structure describing the input data to the `FLPOW:` module .

3.11.1 Input data to the `FLPOW:` *module*

Note that the fuel-lattice power distribution can be printed only on the screen.

Table 27: Structure **(descflpow)**

```
[ EDIT iprint ]
[ { PTOT power | P-NEW } ]
[ FSTH fsth ] [ INIT ]
[ { NORM | BUND } ]
[ PRINT { MAP | DISTR [ FLUX ] [ RATIO ] [ POWER ] | ALL } ]
;
```

where

`EDIT`   keyword used to set *iprint*.

iprint   integer index used to control the printing on screen: $= 0$ for no print; $= 1$ for minimum editing (default value); $= 2$ only channel powers in radial plane are printed; $= 3$ only bundle powers per each radial plane are printed; $= 10$ only bundle powers per each channel are printed. Any combination of the values 2, 3 and 10 is possible, for example $5 = 2+3$. Note that any other value of *iprint* behaves as the first lower possible value, for example 7 gives the same output as 5. Moreover channel and bundle powers can be printed only if the *FMAP* object was provided in the calling specification.

`PTOT`   keyword used to specify the input of *power*. By default, a power is recovered from the *KINET* object.

power   real total reactor power, given in MW. This value must correspond to the reactor nominal conditions.

`FSTH`   keyword to specify the thermal to fission power ratio.

fsth   thermal to fission power ratio. By default this value is not used, and the total power is the one given after the `PTOT` keyword.

`INIT`   keyword used to save the actual power distribution in the `BUND-PW-INI` record of the fuel map object *FMAP*. It is used by the `AFM:` module to apply power feedback during a fast transient using the initial power distribution instead of the actual power.

`P-NEW`   keyword used to indicate that a new total reactor power is to be recomputed, based on the previously calculated flux normalization factor. The flux and power distributions over the reactor core are updated, accordingly. Note that this option is valid only if a read-only *POWOLD* object is provided.

`PRINT`   keyword used to indicate the printing on files. Note that all produced files will have the same extension "`.res`".

`MAP`   keyword used to specify the printing of the average fluxes and flux ratios per fuel bundle. The normalized bundle fluxes are computed and printed for each reactor channel and per each energy group. The flux ratios are computed with respect to the thermal energy-group fluxes; they are printed on the same file.

`DISTR`   keyword used to indicate the printing of data computed over the whole reactor geometry.

`FLUX`   keyword used to specify the printing of flux distribution. The normalized fluxes are printed in separated files, one file per energy group; the number of produced files will then equal to the total number of energy groups. The flux values are printed for each mesh-splitted volume, in X, Y and Z planes; the virtual regions will have the fluxes values set to 0.

`RATIO`   keyword used to specify the printing of flux-ratio distribution. The flux ratios are computed with respect to the thermal energy-group fluxes per each mesh-splitted volume. They are printed in separated files; the number of produced files will equal to the total number of energy groups less one.

`POWER`   keyword used to specify the printing of power distribution. The power values are printed for each mesh-splitted volume, in X, Y, and Z planes; the non-fuel regions will have the power values set to 0.

`ALL`   keyword used to indicate the printing of all available information, i.e. without particular selection of data.

`NORM`   keyword to specify that the output flux object will contain a value per mesh-splitted element, normalized to the given power, as required by the `DETECT:` module. This is the default option.

`BUND`   keyword to specify that the output flux object will contain a value per bundle, normalized to the given power.

3.12   The `TAVG:` module

The `TAVG:` module is used to compute the burnup integration limits for each fuel bundle, the axial power-shape over the fuel lattice, the channel refuelling rates and the reactor core-average exit burnup. All calculations using the `TAVG:` module are performed according to the time-average model for the equilibrium-core conditions. The computing algorithm is based on bidirectional refuelling schemes of channels and average exit burnups specified over the fuel lattice, which should be recorded in the fuel map using the `RESINI:` module.

Note that the complete time-average calculation is a complex and iterative procedure, requiring of several full-core calculations (external iterations) to be performed. The main steps of the time-average calculation using DONJON are briefly described at the end of this section. The `TAVG:` module can also be used to compute the instantaneous fuel burnups according to the channel patterned-age-model, for the fuel management and optimization purposes.

The `TAVG:` module specification is:

Table 28: Structure `TAVG:`

FMAP := `TAVG:` *FMAP POWER* :: **(desctavg)**

---

where

FMAP   `character*12` name of a FMAP object, that will be updated by the `TAVG:` module. The *FMAP* object must contain the average exit burnups and refuelling schemes of channels.

POWER   `character*12` name of a POWER object containing the channel and bundle powers, previously computed by the `FLPOW:` module. The channel and bundle powers are used by the `TAVG:` module to compute the normalized axial power-shape over each channel.

(desctavg)   structure describing the input data to the `TAVG:` module.

3.12.1 Input data to the `TAVG:` module

Note that the input order must be respected.

Table 29: Structure **(desctavg)**

```
[ EDIT iprint ]
[ AX-SHAPE [ RELAX relval ] ]
[ B-EXIT ]
;
```

---

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); $= 2$ only the burnup limits over each channel are printed; $= 3$ only the axial power-shape values over each channel are printed; $= 4$ only the channel refuelling rates are printed; for larger values of *iprint* everything will be printed.

AX-SHAPE   keyword used to indicate the calculation of the new axial power-shape and corresponding burnups limits over each reactor channel.

RELAX   keyword used to set the relaxation parameter *relval*.

relval   real value of the relaxation parameter, generally used to control the axial-shape convergence over the external time-average iterations. The optimal value, which corresponds to the minimal total number of such iterations, can be found by performing several runs at different *relval*. The default value of the relaxation parameter is set to 0.5

B-EXIT   keyword used to indicate the calculation of the core-average exit burnup and the channel refuelling rates.

3.12.2 Time-average calculation using DONJON

When the average exit burnups are provided for each channel, the exact burnup integration limits for each fuel bundle are unknown and need to be determined. The burnups integration limits are function of the normalized axial power-shape, which in turn depends on the flux solution over the fuel lattice. Moreover, the flux solution depends on the fuel-map macrolib (i.e. fuel properties), which in turn depends on the burnups integration limits for each fuel bundle. Consequently, the time-average calculation is an iterative procedure that consists to repeat all the steps required for the axial power-shape computation. This repetition is to be made until the relative error between the two (successives) axial power-shape calculations becomes as small as required for the precision.

The axial power-shape computing scheme is composed of several steps, each step is performed using an appropriate DONJON or TRIVAC module:

1. An initial axial power-shape is set as a flat distribution over the fuel lattice and the first burnup integration limits are calculated approximately, using the RESINI: module.

2. A time-average integration is performed and a new fuel-map MACROLIB is created, using either NCR:, CRE: or AFM: module.

3. An extended MACROLIB over the whole reactor geometry is created, using the MACINI: module.

4. If the devices are inserted into the reactor core, then the previously created MACROLIB is to be updated for the devices properties using the NEWMAC: module.

5. The complete MACROLIB is subsequently used by the TRIVAA: module in order to create a matrix SYSTEM.

6. The full-core numerical solution (i.e. fluxes and effective multiplication factor) is computed, using the FLUD: module.

7. The channel and bundle powers are next calculated, using the FLPOW: module.

8. Finally, the new axial power-shape and burnup limits are computed, using the TAVG: module.

Note that the steps from 2 to 8 are to be repeated until the required precision for the axial power-shape convergence is satisfied.

3.13   The `TINST:` module

The `TINST:` module is used to compute the instantaneous burnup for each fuel bundle. You can also use `TINST:` to refuel your reactor, according to a refueling-scheme. The scheme can be either specified with `RESINI:`, or directly in `TINST:`.

The `TINST:` module specification is:

Table 30: Structure `TINST:`

```
{ FMAP := TINST: FMAP [ POWER ] |
   MICLIB3 FMAP := TINST: FMAP MICLIB2 MICLIB }
:: (desctinst)
```

where

FMAP   `character*12` name of a FMAP object, that will be updated by the `TINST:` module. The *FMAP* object must contain the instantaneous burnups for each fuel bundle and the weight of each fuel mixture.

POWER   `character*12` name of a POWER object containing the channel and bundle powers, previously computed by the `FLPOW:` module. The channel and bundle powers are used by the `TINST:` module to compute the new burn-up of each bundle. If bundle-powers are previously specified with the module `RESINI:`, you can refuel your core without a *POWER* object.

MICLIB3   `character*12` name of a LIBRARY object, that will be created by the `TINST:` module. This MICROLIB contains the fuel properties after refueling when keyword MICRO is used in **(desctinst)**.

MICLIB2   `character*12` name of a LIBRARY object, that will be read by the `TINST:` module. This must be a fuel-map *LIBRARY* created either created by the `NCR:` or the `EVO:` module.

MICLIB   `character*12` name of a LIBRARY object, that will be read by the `TINST:` module. This MICROLIB contains the new fuel properties, that should be used for the refueling.

(desctinst)   structure describing the input data to the `TINST:` module.

3.13.1 Input data to the `TINST:` *module*

Note that the input order must be respected.

Table 31: Structure **(desctinst)**

```
[ EDIT iprint ]
[ BURN-STEP rburn | TIME rtime { DAY | HOUR | MINUTE | SECOND } ]
[[ REFUEL [ MICRO ] CHAN NAMCHA nsh ]]
[[ NEWFUEL [ MICRO ] CHAN NAMCHA nsh { SOME ( imix(i), i=1,ABS(nsh) ) | ALL imix } ]]
[[ SHUFF CHAN NMCHA1 TO { NMCHA2 | POOL } ]]
[ PICK >> burnup << ]
;
```

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); $= 2$ only the burnup limits over each channel are printed; $= 3$ only the axial power-shape values over each channel are printed; $= 4$ only the channel refueling rates are printed; for larger values of *iprint* everything will be printed.
`BURN-STEP`	keyword used to indicate an increase of core average burn-up.
rburn	keyword used to indicate in MWd/t the average increase of burn-up in the core.
`TIME`	keyword used to indicate the time of combustion at the power specified in *POWER* structure.
rtime	keyword used to set the time combustion value in `DAY` or `HOUR` or `MINUTE` or `SECOND`.
`DAY`	keyword used to specify that *rtime* is a number of days.
`HOUR`	keyword used to specify that *rtime* is a number of hours.
`MINUTE`	keyword used to specify that *rtime* is a number of minutes.
`SECOND`	keyword used to specify that *rtime* is a number of seconds.
`REFUEL`	key word to specify a channel refueling.
`MICRO`	keyword used to perform a microscopic refueling. In this case, three libraries have to be provided when `TINST:` is called.
`CHAN`	key word to specify the refueled channel information.
NAMCHA	channel name. In Cartesian geometry, *NAMCHA* is a character*4 variable defined by *NXNAME* and *NYNAME* and constructed as `WRITE(NAMCHA,'(A1,A3)')` *NYNAME*(1:1),*NXNAME*(1:2).

nsh   refueling scheme. The absolute value of *nsh* is the number of fuel bundles inserted in the channel *NAMCHA*. The sign of *nsh* define the refueling direction: positive direction is from the first to the *nk*-th bundle and negative is from the *nk*-th to the first bundle.

NEWFUEL   key word to specify that a channel will be refueled with a different type of fuel.

SOME   key word to specify that the *nsh* values of fuel types can be different.

imix(i)   index number of a fuel type with respect to the values defined in module NCR:, CRE: or AFM:.

ALL   key word to specify that the *nsh* values of fuel types will be identical to *imix*.

SHUFF   key word to specify that a specified channel will move into an other one or discharge into the pool.

CHAN   key word to specify the moved channel name.

NMCHA1   channel name as defined by *NXNAME* and *NYNAME*. It is constructed as *NAMCHA*.

TO   key word to specify the bundle destination.

NMCHA2   channel name as defined by *NXNAME* and *NYNAME*. It is constructed as *NAMCHA*.

POOL   key word to specify that the channel referenced by *NMCHA1* is discharged into the pool.

PICK   keyword used to recover the final burnup value (in MW-day/tonne) in a CLE-2000 variable.

burnup   character*12 CLE-2000 variable name in which the extracted burnup value will be placed.

3.14   The `SIM:` module

The `SIM:` module can perform a sequence of operations related to fuel management in PWRs:

- simulate a refuelling and shuffling scheme and update the burnup distribution accordingly. The refuelling scheme is specified directly in `SIM:`.

- increase the burnup using the power available in the *POWER* object and compute the final instantaneous burnup of each assembly subdivision

- modify a local parameter such as the Boron concentration in the coolant.

The `SIM:` module specification is:

Table 32: Structure `SIM:`

FMAP [*MLIB*] := `SIM:` *FMAP* [*MLIB*] [*POWER*]
:: **(descsim)**

---

where

FMAP   `character*12` name of a FMAP object, that will be updated by the `SIM:` module. The *FMAP* object must contain the instantaneous burnups for each assembly subdivision, a basic naval-coordinate assembly layout and the weight of each assembly subdivision.

MLIB   `character*12` name of a MICROLIB (type `L_LIBRARY`) containing particularized isotope data. If this object also appears on the RHS, it is open in modification mode and updated. Number densities of isotopes present in list *HISOT* (see Sect. 3.1.1) are recovered from a fuel cycle information directory of *FMAP* and saved in *MLIB* or recovered from *MLIB* and saved in a fuel cycle information directory of *FMAP*.

POWER   `character*12` name of a POWER object containing the channel and powers of the assembly subdivisions, previously computed by the `FLPOW:` module. The channel and powers of the assembly subdivisions are used by the `SIM:` module to compute the new burn-up of each assembly subdivision. If the powers of the assembly subdivisions are previously specified with the module `RESINI:`, you can burn your core without a *POWER* object.

(descsim)   structure describing the input data to the `SIM:` module.

3.14.1 Input data to the `SIM:` module

Note that the input order must be respected.

Table 33: Structure **(descsim)**

```
[ EDIT iprint ]
[ CYCLE hcnew [ FROM hcold [ BURN { indcycle | burncycle } ] ]
    [ { MAP (hx(i), i=1, lx )
            (hy(j), (hcase(i,j), i=1, lx ), j=1,ly ) |
       QMAP (hx(i), i=lx/2+1, lx )
            (hy(j), (hcase(i,j), i=lx/2+1, lx ), j=ly/2+1,ly ) } ]
    [ SPEC [[ [[ asmb1 ]]
       { SET AVGB avburn | SET FUEL ifuel | FROM hcold2 AT asmb2 [ BURN { indcycle | burncycle } ] }
            ]] ]
    [ DIST-AX [[ [[ asmb1 ]]
       { SET (axn(i), i=1,nb) | FROM hcold2 AT asmb2 [ BURN { indcycle | burncycle } ] }
                ]] ]
    [ BURN-STEP rburn | TIME rtime { DAY | HOUR | MINUTE | SECOND } ]
    [ SET-FOLLOW [ BURN { indcycle | burncycle } ] ]
ENDCYCLE ]
[[ COMPARE hc1 [ BURN { indcycle1 | burncycle1 } ] hc2 [ BURN { indcycle2 | burncycle2 } ]
      { DIST-BURN >> epsburn << | DIST-POWR >> epspowr << } ]]
[[ SET-PARAM PNAME pvalue ]]
;
```

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); for larger values of *iprint* everything will be printed.
CYCLE	keyword defining operations based on the actual fuel cycle.
hcnew	`character*12` identification name of the specific fuel cycle.
FROM	keyword defining the previous fuel cycle in case that some information needs to be transmitted to the actual fuel cycle.
hcold	`character*12` identification name of the previous fuel cycle.
BURN	keyword defining the burnup at which the assembly is recycled in the previous fuel cycle. By default, the last burnup step is used.
indcycle	integer index of the burnup step in the previous fuel cycle.
burncycle	real value of the burnup in the previous fuel cycle.
MAP	keyword defining the assembly layout in naval-coordinate positions in the actual fuel cycle. Here, *lx* and *ly* values are those defined in the fuel map (see Section 3.1.2).
QMAP	keyword defining the assembly layout in naval-coordinate positions using quarter-core symmetry conditions. Here, the lower-right quarter is defined. The full map is reconstructed through rotations around the center.
hx	ordered list of available `character*1` prefixes for the X-oriented naval-coordinate positions. Values are generally chosen between `A` and `T`.

hy	ordered list of available `character*2` suffixes for the *Y*-oriented naval-coordinate positions. Values are generally chosen between `01` and `17`.
hcase	`character*4` or integer identification value for the (i,j) position. Accepted values are:

- `|`, `-` or `-|-` for a position outside the core,
- `NEW` for a new assembly (at zero burnup) selected according to the fuel map specified in Sect. 3.1,
- `SPC` for an assembly described later in the dataset using a `SPEC` specification,
- or a naval-coordinate position referring to the position of an assembly in cycle *hcold* that is recycled in the current cycle,
- *imix* for an assembly (at zero burnup) made of fuel mixture *imix*. The fuel mixture should be selected among integer values defined in the fuel map `GEO:/MIX` data of Table 3.

`SPEC`	keyword defining specifications related to all assemblies previously identified with the `SPC` keyword. If `QMAP` keyword has been used with `SPC` values, the 4 equivalent assemblies must be specified (i.e. not only the lower-right quarter assembly).
asmb1	`character*3` naval-coordinate position of an assembly identified with a `SPC` keyword. Up to 30 coordinates can be set aside if many assemblies have the same specification.
`SET`	keyword indicating that a user-defined value will be assigned to the assembly.
`AVGB`	keyword indicating that an averaged burnup will be assigned to the assembly.
avburn	real value of the average burnup in MWd/t.
`FUEL`	keyword indicating that a new fuel assembly will be used.
fuel	integer index of the fuel type corresponding to the new fuel assembly. Fuel type indices are those used in the `RESINI: PLANE` descriptions of Sect. 3.1.
`FROM`	keyword indicating that a value recovered from another assembly will be assigned to the current assembly.
hcold2	`character*12` identification name of a previous fuel cycle.
`AT`	keyword indicating that the naval-coordinate position of the other assembly will be given.
asmb2	`character*3` naval-coordinate position of the other assembly in cycle *hcold2*.
`DIST-AX`	keyword used to impose an axial burnup distribution to the assembly. The burnup distribution is recovered from an existing assembly or is set to user-suppled values.
axn	real values of the axial burnup distribution.
`BURN-STEP`	keyword used to indicate an increase of core average burn-up.
rburn	keyword used to indicate in MWd/t the average increase of burn-up in the core.
`TIME`	keyword used to indicate the time of combustion at the power specified in *POWER* structure.
rtime	keyword used to set the time combustion value in `DAY` or `HOUR` or `MINUTE` or `SECOND`.
`DAY`	keyword used to specify that *rtime* is a number of days.

HOUR	keyword used to specify that *rtime* is a number of hours.
MINUTE	keyword used to specify that *rtime* is a number of minutes.
SECOND	keyword used to specify that *rtime* is a number of seconds.
SET-FOLLOW	keyword used to reset the number densities of particularized isotopes in the *hcnew* fuel cycle information directory of the fuel map. The burnup step indicated by BURN structure is used to store the particularized isotopes. By default, the last burnup step is used. The MICROLIB *MLIB* must be defined in read-only mode in Table 32.
ENDCYCLE	keyword indicating the end of data specific to the actual fuel cycle.
COMPARE	keyword for obtaining a CLE-2000 variable that is a measure of the discrepancy between two cycles.
hc1	character*12 identification name of the first fuel cycle to compare.
hc2	character*12 identification name of the second fuel cycle to compare.
DIST-BURN	keyword used to recover the discrepancy on burnup distribution in a CLE-2000 variable.
epsburn	character*12 CLE-2000 variable name in which the extracted burnup discrepancy (expressed in MW-day/tonne) will be placed.
DIST-POWR	keyword used to recover the relative error on power distribution in a CLE-2000 variable.
epspowr	character*12 CLE-2000 variable name in which the extracted power relative error will be placed.
SET-PARAM	keyword used to indicate the input (or modification) of the actual values for a parameter specified using its *PNAME*.
PNAME	keyword used to specify *PNAME*.
PNAME	character*12 name of a parameter.
pvalue	single real value containing the actual parameter's values. Note that this value will not be checked for consistency by the module. It is the user responsibility to provide the valid parameter's value which should be consistent with those recorded in the multicompo or Saphyb database.

3.15   The XENON: module

The XENON: module is used to correct the Xenon distribution coming from an interpolation calculation. This module computes the new densities according to the bundle flux, and the equation providing the balance concentration of Xenon-135 :

$$N_{X_{eq}} = \frac{(Y_I + Y_X)\Sigma_f \phi}{\lambda_X + \sigma_X \phi}$$ (3.1)

where

- Y_I is the fission yield of I135

- Y_X is the fission yield of Xe135

- σ_X is the capture cross section of Xe135

- λ_X is the decay constant of Xe135

- Σ_f is the total fission cross section

- ϕ is the bundle flux

The XENON: module specification is:

Table 34: Structure XENON:

MICROLIB := XENON: *MICROLIB* [*POWER*]
:: **(descxenon)**

---

where

MICROLIB   `character*12` name of a LIBRARY object, that will be updated by the XENON: module. The Xenon should be extracted in this library for the use of this module.

POWER   `character*12` name of a POWER object containing the bundle fluxes, previously computed by the FLPOW: module. The fluxes should be normalized to the reactor power.

(descxenon)   structure describing the input data to the XENON: module.

3.15.1 Input data to the XENON: module

Note that the input order must be respected.

Table 35: Structure **(descxenon)**

```
[ EDIT iprint ]
[ INIT ]
;
```

where

EDIT   keyword used to set *iprint*.

iprint   integer index used to control the printing on screen.

INIT   keyword used to indicate the initialization of the library for a recursive calculation
                using the `XENON:` module. The Xenon concentration is set to zero for all the bundles.

3.16   The `DETECT:` **module**

The `DETECT:` module is used to compute the mean flux at each detector site and the response of each detector.
The `DETECT:` module specifications are:

Table 36: Structure `DETECT:`

DETEC := `DETECT:` *DETEC FLUX TRACK GEOM* :: **(descdetect)** ;

---

where

DETEC   `character*12` name of the DETECT containing the detector positions and responses.

FLUX   `character*12` name of the FLUX containing the flux solution computed by the `FLUD:` or `FLPOW:` modules. To obtain a correct result, the best is to use a normalized flux, coming from the `FLPOW:` module. In this case, the fluxes are normalized to the reactor power.

TRACK   `character*12` name of the TRACK containing the TRIVAC tracking.

GEOM   `character*12` name of the GEOMETRY containing the mesh-splitting geometry created by the `USPLIT:` or `GEO:` modules.

(descdetect)   structure containing the data to module `DETECT:`.

3.16.1 Input data to the `DETECT:` module

Note that the fuel-lattice power distribution can be printed only on the screen.

Table 37: Structure **(descdetect)**

[`EDIT` *iprt*] `TIME` *dt* `REF` *kc*
[`NORM` *vnorm*]
[`SIMEX` { `SPLINE` | `PARAB` }]
;

---

where

`EDIT`   key word used to set *iprt*.

iprt   index used to control the printing in module `DETECT:`. =0 for no print; =1 for minimum printing(default value); =4 for printing each detector name; =5 for finite element numbers and total number of finite elements for each detector.

`TIME`	key word used to set *dt*.
dt	time step between two calls to the `DETECT:` module.
`REF`	key word used to set *kc*.
kc	index used to control the type of calculation, =0 for reference calculation; =1 normal calculation. The reference responses are used to obtain detector current responses in full power fractions.
`NORM`	key word used to set *vnorm*.
vnorm	value used to normalized responses of all the detectors present in DETECT.
`SIMEX`	key word used to specify that a polynomial interpolation of detector fluxes according to HQSIMEX method. This interpolation will be applied only for vanadium detectors, under *NAMTYP* of value `VANAD_REGUL`.
`SPLINE`	key word to specify that the flux at detector site will be computed with a spline method.
`PARAB`	key word to specify that the flux at detector site will be computed with a parabolic method.

3.17   The `CVR:` module

The `CVR:` module is used to update the fuel-type index and the coolant densities throughout the reactor core as required for the voiding simulations. A particular core-voiding pattern is either selected from the several pre-defined patterns *or* directly defined by the user in an arbitrary fashion. In the last case, the user may specify the individual voided channels by indicating their identification names. The `CVR:` module will create a new (perturbed) FMAP object, in which the fuel-type mixtures indices are modified according to the specified core-voiding pattern. The information with respect to the relative coolant densities is required only for the subsequent interpolation of fuel properties using the `NCR:` module. These data will also be reordered by the `CVR:` module according to the specified voiding pattern and recorded as local parameter in the perturbed fuel-map object (see Section 3.1.2).

The `CVR:` module specification is:

Table 38: Structure `CVR:`

FMAPV := `CVR:` *FMAP* :: **(descrcvr)**

where

FMAP   `character*12` name of a read-only FMAP object, created in the `RESINI:` module. This object must contain the non-perturbed fuel-cell properties.

FMAPV   `character*12` name of a new FMAP object, that will contain the modified fuel-type indices and reordered coolant densities according to the specified core-voiding pattern.

(descrcvr)   structure describing the input data to the `CVR:` module.

3.17.1 Input data to the CVR: module

Note that the input order must be respected.

Table 39: Structure **(descrcvr)**

```
 EDIT iprint
( MIX-FUEL mixF(i)  MIX-VOID mixV(i) , i = 1, nfuel )
[ DENS-COOL PNAME  SET dcoolV ]
 VOID-PATTERN { FULL | HALF | QUARTER | CHECKER | CHECKER-1/2 | CHECKER-1/4 |
 CHAN-VOID nvoid ( YNAME(i) XNAME(i) , i = 1, nvoid ) }
 ;
```

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; $= 2$ modified fuel indices and coolant densities are printed per bundle over each channel; $= 3$ modified fuel indices are printed per each radial plane; for larger values of *iprint* everything will be printed.
`MIX-FUEL`	keyword used to specify *mixF*.
mixF	integer fuel-type mixture number of the non-perturbed fuel cell. This number must be specified for each fuel type as been recorded in the MATEX object (see Section 3.2.1).
`MIX-VOID`	keyword used to specify *mixV*.
mixV	integer new mixture number assigned to the voided fuel cell. Note that this number must be specified for each fuel type and it must be different from any other reactor material mixtures.
`DENS-COOL`	keyword used to specify *PNAME*. This information is required only for the interpolation of fuel properties using the `NCR:` module.
PNAME	`character*12` user-defined identification name of local parameter associated with the relative coolant density. The recommended name is `D-COOL`. This parameter name and the unperturbed densities values should be previously recorded in the *FMAP* object (see Section 3.1.2). The same *PNAME* will be set for the coolant density in the perturbed *FMAPV*, but the actual values of coolant densities throughout the core will be reordered by the `CVR:` module according to the specified voiding pattern.
`SET`	keyword used to specify the value *dcoolV*.
dcoolV	real value of the relative coolant density (with respect to the nominal or unperturbed conditions) associated with the voided reactor channels. In general, this value equals to 0.0 for the complete voiding of a channel and to 1.0 for an unperturbed channel. Intermediate values of *dcoolV* will then correspond to the partially voided channels. It is supposed that all voided channels will have the same *dcoolV* value.
`VOID-PATTERN`	keyword used to specify the core voiding pattern, which will be used for a particular voiding simulation.
`FULL`	keyword used to specify the full-core voiding pattern. According to this pattern, the fuel mixtures will be modified for all reactor channels.
`HALF`	keyword used to specify the half-core voiding pattern. According to this pattern, the fuel mixtures will be modified only for the upper-half of reactor channels.
`QUARTER`	keyword used to specify the quarter-core voiding pattern. According to this pattern, the fuel mixtures will be modified only for the upper-left quarter of reactor channels.
`CHECKER`	keyword used to specify the checkerboard-full voiding pattern. According to this pattern, the fuel mixtures will be modified for all reactor channels in which the direction of coolant flow is positive.
`CHECKER-1/2`	keyword used to specify the checkerboard-half voiding pattern. According to this pattern, the fuel mixtures will be modified only for the upper-half of reactor channels in which the direction of coolant flow is positive.
`CHECKER-1/4`	keyword used to specify the checkerboard-quarter voiding pattern. According to this pattern, the fuel mixtures will be modified only for the upper-left quarter of reactor channels in which the direction of coolant flow is positive.

CHAN-VOID   keyword used to specify the user-defined voiding pattern. Each voided channel must
                    be identified by its *YNAME* name followed by its *XNAME*.

nvoid   integer total number of the voided channels. This number must be greater than 0 and
                    less than (or equal to) the total number of reactor channels.

YNAME   `character*2` vertical name of the voided channel. A vertical channel name is identified
                    by the channel row using an alphabetical letter ('A', 'B', 'C', etc). The total number
                    of the specified Y-names must equal to the total number of voided channels *nvoid*.

XNAME   `character*2` horizontal name of the voided channel. A horizontal channel name is
                    identified by the channel column using a numerical character ('1', '2', '3', etc.). The to-
                    tal number of the specified X-names must equal to the total number of voided channels
                    nvoid.

3.18   The `HST:` module

The `HST:` module has been designed to manage a full reactor execution in DONJON using explicit DRAGON calculations for each cell.[19] This module saves in an HISTORY data structure the information available in BURNUP data structures generated by DRAGON. It can also read MAP data structure generated by DONJON to prepare the HISTORY data structure for a new series of cell calculations in DRAGON. The HISTORY data structure can also be used to update the MAP data structure. Finally, the module `HST:` can be used to create an initial BURNUP data structure that can be used to evolve the cell another time step in DRAGON.

The `HST:` module can be used to create or update an HISTORY data structure. The possible options are:

Table 40: Updating an HISTORY structure using a MAP structure

HISTORY := `HST:` [HISTORY] MAP [`::` [**(hstdim)**] [`GET` **(hstpar)**]]

Table 41: Updating an HISTORY structure using a BURNUP structure

HISTORY := `HST:` [HISTORY] [BURNUP] [`::` [**(hstdim)**]
   [`GET` **(hstpar)**] [`CELLID` *icha ibun* [*idfuel*] [`GET` **(hstpar)**]]]

It can also be used to create a BURNUP data structure from the information available on an HISTORY data structure:

Table 42: Updating a BURNUP structure using an HISTORY structure

BURNUP := `HST:` HISTORY [`::` [**(hstdim)**]
   [`PUT` **(hstpar)**]
   `CELLID` *icha ibun*
   [`PUT` { `BREFL` **(hstbrn)** **(hstpar)** `AREFL` **(hstbrn)** **(hstpar)** | [`AREFL`] **(hstbrn)** **(hstpar)**
}]]

It can also be used to update a MAP data structure from the information available on an HISTORY data structure:

Table 43: Updating an HISTORY structure using a MAP structure

MAP := `HST:` MAP HISTORY

where

HISTORY   character*12 name of an HISTORY data structure.

BURNUP   character*12 name of a BURNUP data structure.

MAP   character*12 name of a MAP data structure.

(hstdim)   structure containing the dimensions for the HISTORY data structure.

CELLID   keyword to identify the cell for which history information is to be processed.

icha   channel number for which history information is to be processed.

ibun   bundle number for which history information is to be processed.

idfuel   fuel type number associated with this cell. One can associate to each fuel cell a different fuel type. By default a single fuel type is defined and it fills every fuel cell. Only the initial properties of each fuel type are saved. These properties are used for refueling.

GET   keyword to specify that the values of the parameters selected in **(brnpar)** will be read from the input stream or CLE-2000 local variables and stored on the HISTORY data structure.

PUT   keyword to specify that the values of the parameters selected in **(brnpar)** will be read from the HISTORY data structure and transferred to local CLE-2000 variables.

BREFL   to specify that the information to extract from the HISTORY data structure is related to the properties of the cell before refueling takes place.

AREFL   to specify that the information to extract from the HISTORY data base is related to the properties of the cell after refueling took place.

(hstbrn)   structure containing the burnup options.

(hstpar)   structure containing the local parameters options.

The **(hstdim)** input structure is required for general dimensioning purpose. It is generally used only when creating the HISTORY data structure. However, the number of global and local parameters used in a HISTORY data structure can be increased at all time. The number of channels, bundles and the refueling scheme must be defined at the creation of the HISTORY data structure. This information can be provided manually or extracted from a MAP data structure. The general form of the **(hstdim)** input structure follows:

<div align="center">Table 44: Structure **(hstdim)**</div>

```
[ EDIT iprint ]
[ DIMENSIONS [ GLOBAL nglo ] [ LOCAL nloc ] [ BUNDLES nbun bunl ] [ CHANNELS ncha ] ]
```

where

EDIT   keyword used to modify the print level *iprint*.

iprint   index used to control the printing in this module. It must be set to 0 if no printing on the output file is required.

DIMENSIONS   keyword used to indicate that the general dimensioning of the HISTORY data structure will be modified.

GLOBAL	keyword used to modify the number of global parameters on the HISTORY data structure.
nglo	the number of global parameters. Note that the history module will use the maximum value between the current *nglob* and the value, if any, defined on the HISTORY data structure.
LOCAL	keyword used to modify the number of local parameters on the HISTORY data structure.
nloc	the number of local parameters. Note that the history module will use the maximum value between the current *nloc* and the value, if any, defined on the HISTORY data structure.
BUNBLES	keyword used to specify the number of bundles per channels for the reactor model considered in the HISTORY data structure.
nbun	the number of bundles per channels for the reactor model. Note that if *nbun* is different from the value already defined on the HISTORY data structure or the MAP data structure, the execution will be aborted.
bunl	bundle length in cm. This information is required to compute inital fuel weight.
CHANNELS	keyword used to specify the number of fuel channels for the reactor model considered in the HISTORY data structure.
ncha	the number of fuel channels for the reactor model. Note that if *ncha* is different from the value already defined on the HISTORY data structure or the MAP data structure, the execution will be aborted.

The **(hstbrn)** serves a unique purpose, mainly to extract from the HISTORY file the information required to process a burnup evaluation in DRAGON using the EVO: module. The information must be stored inside CLE-2000 variables. The general form of this output structure is:

Table 45: Structure **(hstbrn)**

BURN *period power*

where

BURN	keyword to indicate that burnup information follows.
period	the burnup period (in days) that will be transferred to a real CLE-2000 variable.
power	the power density (in kW/kg) that will be transferred to a real CLE-2000 variable.

The **(hstpar)** serves two purposes. First, it is used to define the names of the local and global parameters that may be used in our calculations as well as the values of these local parameters. In can also be used to extract from a HISTORY data structure the values of these parameters. The general form of this structure is:

Table 46: Structure **(hstpar)**

[[*NAMPAR valpar*]]

---

where

NAMPAR   name of a local or global parameter to process. The parameters specified before the keyword *CELLID* is read will be considered global otherwise they will be considered local.

valpar   real value for the local or global parameter to process. In the case where the `GET` option is activated, the history module will extract this parameter from the input data stream. In the case where the `PUT` option is activated, the history module will try to transfer this information into a real CLE-2000 variable.

3.18.1 Example

The history interface between the codes DRAGON and DONJON has been written as a new module in order to facilitate the access to the GANLIB utilities that manage the required hierarchical data structures. The resulting `HST:` module can be called both by DRAGON and DONJON.

The reactor model we will consider as an example is a 3–D model with an $x = 3$, $y = 3$ and $z = 3$ mesh. Here we will assume that the $x - y$ plane describes fuel channels. The z plane will be associated with the so-called fuel bundles. This choice is somewhat arbitrary, however it is useful if the refueling takes place in a specific direction as in a CANDU reactor. Here, a 2–bundle shift fueling strategy will be considered. To each fresh fuel cell introduced in the core the `HST:` module will associate a unique cell number between 1 and `Nc`, the maximum number of cells in the reactor. Most of the information associated with the fresh fuel cells will be extracted from a DRAGON BURNUP file or defined using variable local parameters. Each fresh fuel cell inserted in the core will also be associated with a specific fuel type. Each fuel type is defined as a unique initial fuel composition. The fuel management for the reactor, including burnup and refueling will be performed by the DONJON code. Here the `HST:` will interact with this code via the MAP data structure. Typically, each cell in the reactor will be burned inside DRAGON using the power provided in the `AX-SHAPE` record and the depletion time provided in the `BURNUP-BEG` record stored in the MAP structure. When refueling takes place some of the fuel cells will be extracted, other will be displaced from one position to another and finally new fresh fuel cells inserted. The fresh fuel cells properties will be extracted from the fuel types properties available on the HISTORY data structure.

In a coupled DRAGON/DONJON execution, the `HST:` module will be called at various points and for various reasons. The first call to `HST:` can be performed using:

```
MODULE HST: ;
*----
* Map data structure for initialization: MAPO
* History data structure : History
*----
SEQ_ASCII MAPO ;
XSM_FILE History ;
XSM_FILE Reseau ;
*----
* Reactor parameters
```

```
* ncha = nunber of channels = 9
* nbun = number of bundles = 3
* nevo = number of evolution = 3
* nglo = nunber of global parameters = 1
* nloc = nunber of local parameters = 2
* bunl = bundle length in cm = 49.53 cm
*----
INTEGER ncha nbun nevo nglo nloc :=
9 3 3 1 2 ;
REAL bunl := 49.53 ;
*----
* Initialize History using MAP0
*----
Reseau := MAP0 ;
History := HST: Reseau ::
DIMENSIONS GLOBAL <<nglo>> LOCAL <<nloc>>
BUNDLES <<nbun>> <<bunl>>
CHANNELS <<ncha>> ;
```

Here, the HISTORY data structure will be stored in the XSM file `History`. One global and two local parameters are considered. No information about the name or the value of the global and local parameters will be available. This initialization procedure stores information only on the main level of the HISTORY data structure if the MAP data structure is not available. In this case the HISTORY is updated using a MAP data structure (in sequential ASCII file `MAP0`). The number of channels and bundles per channel are stored and compared with the same information in the MAP structure. For each bundle in the MAP, cell type and fuel type directories are constructed. The bundle powers and burnups available in MAP are used to generate the power rates in kW/kg and the depletion time in days required to reach the specified burnups. These values are stored in the HISTORY in the `PARAMBURNTAR` record. The fuel mass is mandatory for such calculation, thus the fuel weight is recovered from the MAP. If the HISTORY is in modification mode, the fuel weight is computed using the bundle lenght and the initial fuel density. Now, let us assume that a DRAGON calculation was performed for the cell located in bundle $j = 1$ of channel $i = 1$. We will also assume that these cells contain a single type of fuel. Here the moderator temperature `TMod` is a global parameter while the fuel (`TComb`) and coolant (`TCalo`) temperatures are considered local parameters. We assume that after the cell flux calculation a BURNUP data structure was generated using the following instructions:

```
*----
* Procedures for cell calculation: CellCalc
*----
PROCEDURE CellCalc ;
*----
* Global parameter: Tmod for moderator temperature
* Local parameters: TComb for fuel temperature
* TCalo for coolant temperature
*----
REAL TMod := 345.66 ;
REAL TComb TCalo := 941.29 560.66 ;
*----
* Initial burnup options for cell calculation
*----
REAL Power DeltaT := 31.9713 5.0 ;
*----
* Local data structures
*----
```

```
LINKED_LIST Burnup Edition ;
*----
* Execution control parameters
* icha = channel number = 1
* ibun = bundle number = 1
*----
INTEGER icha ibun := 1 1 ;
*----
* Perform cell calculation
*----
Burnup Edition := CellCalc Burnup ::
<<TComb>> <<TCalo>> <<TMod>>
<<Power>> <<DeltaT>> ;
```

Then, assuming that the history structure `HistXSM` was created using the options above, we can use

```
*----
* Update history structure
*----
History := HST: History Burnup ::
GET TMod <<TMod>>
CELLID <<icha>> <<ibun>>
GET TComb <<TComb>> TCalo <<TCalo>> ;
```

where no `idfuel` is given (see Table 41), thus we have used the default value for `idfuel`= 1 to store in HISTORY the general information associated with fuel channel 1 and bundle 1. Here, the initial properties associated with fuel type 1 will be generated from the initial isotope densities in the BURNUP. For the `CELLID`, here `icha`= 1 and `ibun`= 1, the burnup information, isotope densities, depletion parameters and initial fuel density are stored in a /celldir/ directory. Moreover the power rate 31.9713 kW/kg and the depletion time 5.0 days are kept in the `PARAMBURNTAR` record.

A HISTORY data structure that contains the initial cell information can be updated using a MAP data structure:

```
*----
* Map data structure for refueling: MAP1
*----
SEQ_ASCII MAP1 ;
*----
* Refuel
*----
Reseau := MAP1 ;
History := HST: History Reseau ;
```

Here, new burnup power ratings will be stored in the HISTORY data structure reflecting the power distribution in the DONJON calculation. The refueling information available in the MAP structure will also be used to redistribute the fuel in the HISTORY structure at various cell location.

Finally the last option is to recover this information in DRAGON to perform a new series of cell calculations:

```
*----
* Local parameters
* Initial burnup options for cell calculation
* *A is after refueling
* *B is before refueling
*----
```

```
REAL TCombA TCaloA TCombB TCaloB ;
REAL PowerA DeltaTA PowerB DeltaTB ;
Burnup := HST: History ::
PUT TMod >>TMod<<
CELLID <<icha>> <<ibun>>
PUT BREFL BURN >>DeltaTB<< >>PowerB<<
TComb >>TCombB<< TCalo >>TCaloB<<
AREFL BURN >>DeltaTA<< >>PowerA<<
TComb >>TCombA<< TCalo >>TCaloA<< ;
IF DeltaTB 0.0 > THEN
*----
* Burn before refueling
*----
Burnup Edition := CellCalc Burnup ::
<<TCombB>> <<TCaloB>> <<TMod>>
<<PowerB>> <<DeltaTB>> ;
Edition := DELETE: Edition ;
ENDIF ;
*----
* Burn after refueling
*----
Burnup Edition := CellCalc Burnup ::
<<TCombA>> <<TCaloA>> <<TMod>>
<<PowerA>> <<DeltaTA>> ;
*----
* Update History
*----
History := HST: History Burnup ::
CELLID <<icha>> <<ibun>> ;
```

Note that here, there are two sets of local parameters that can be extracted from the history data structure, namely the before (**BREFL**) and the after (**AREFL**) refueling information. In the case of fresh fuel (single fuel description or a refueled bundle) extracting the before information is not required. However, if one uses the general procedure described above to extract the before and after information, one will be able to identify the new fuel bundles as well as the bundle that have not been moved in the core by the fact that $\Delta t = 0$ for burnup before refueling. For bundles that have been displaced in the core during refueling then $\Delta t > 0$.

3.19 The `ROD:` module

The `ROD:` module used for rod insertion gestion in PWR. This module creates a 3-D field for rod parameter in a fuel map. This local field contains, for each mesh, one coefficient describing the rod insertion for the considered mesh. These coefficients are chosen according to rod coefficients saved in the SAPHYB or MULTICOMPO object.

The `ROD:` module specifications are:

Table 47: Structure `ROD:`

FLMAP := `ROD:` *FLMAP* :: **(descrod1)**

where

FLMAP   `character*12` name of the MAP object that will contain the 3-D rod file. The *FLMAP* has to be modified for the module and must appear on both LHS and RHS.

(descrod1)   structure describing the main input data to the `ROD:` module. Note that this input data is mandatory and must be specified.

3.19.1 Main input data to the `ROD:` module

A *rod identification number* (RIN) is a local parameter (type real) assigned to each type of rod in the SAPHYB or MULTICOMPO object. Black bars of 900 MW PWRs in France are made of AICN material (Silver-Indium-Cadmium). Black bars of 1300 MW, N4 and EPR PWRs in France are made of a section of B4C followed by a section of AICN (in yellow), as depicted in Fig. 2.
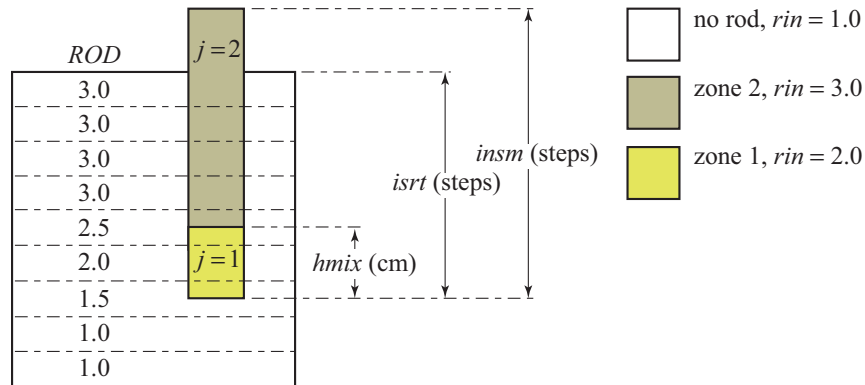
Figure 2: Presentation of a partially-inserted 2-part control rod.

Recommended values are:

RIN	type of bar
0	AICG (grey bar, generally out at nominal power)
1 (= *val1*)	rod extracted
2	AICN (black bar, generally out or partly inserted)
3	B4C (black bar, generally out or partly inserted)

The rod identification number is interpolated over each axial mesh of the fuel map. A local parameter name *par1* is defined and their distributed values are computed by the `ROD:` module as depicted in Fig. 2. Local parameters *par1* are identified as *ROD* in the figure. A local value of *ROD* = 2.5 corresponds to a mesh of the fuel map containing 50% of AICN material and 50% of B4C material.

Table 48: Structure **(descrod1)**

```
[ EDIT iprint ]
[ PARA par1 val1 ]
[ LINS insm ]
[ STEP step ]
[ NRFB nrfb ]
[ RGRP
   { ngrp maxmix
      ((hgrp(i) isrt(i) rin(i,1) [[ hmix(i,j) rin(i,j+1) ]]), i=1, ngrp, j=1, lmix-1)
   | nrmv
      ((hgrp(i) isrt(i)), i=1, nrmv) }
ENDRGRP ]
[ RMAP nass
   ((hrod(i,j)), i=1, lx, j=1,ly )
ENDRMAP ]
;
```

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.
PARA	keyword used to indicate that the name of the record to be contained the rod field will follow.
par1	name of the rod record and local parameter to be created. This name must correspond to the rod name of the SAPHYB or MULTICOMPO object.
val1	real value of the 3-D rod field *par1*. This value enables to initialise the field to a uniform value, corresponding to a core with no rod inserted.
LINS	keyword used to indicate the maximum number of insertion steps for all rods.
insm	integer value of maximum rod insertion step.
STEP	keyword used to indicate the length of one rod step.
step	real value of rod step length (in cm).
NRFB	keyword used to indicate the number of bottom-reflective meshes in the core.
nrfb	integer value of bottom-reflective meshes in the core.
RGRP	keyword used to define all rod groups present in the core.
ngrp	integer value of the number of rod groups present in the core.

maxmix	integer value of the maximum number of rod zones (for hybrid rods with many materials).
nrmv	integer value of the number of rod groups that rod insertion is modified.
hgrp	`character*3` identification value for the rod group i.
isrt	integer value for the number of inserted steps for the rod group i.
rin	real value for the rod identification number (RIN) considered from the SAPHYB or MULTICOMPO object.
hmix	real value for the height (in cm) of the RIN considered. If only one RIN is used to define the rod, *hmix* is not defined. If two or more RIN are used for one rod, the values of the lower rod sections with $1 \leq j < lmix$ should be defined, as depicted in Fig. 2.
lmix	integer value for the number of *rin* for each rod group.
`ENDRGRP`	keyword used to indicate the end of rod groups definition.
`RMAP`	keyword used to define the position of each rod group inside the core.
nass	integer value of number of assemblies inside the core.
hrod	`character*3` identification value for the (i,j) position. Accepted values are:

- |, – or –|– for an unrodded assembly,
- or a `character*3` identification value referring to the identification value of the rod group.

`ENDRMAP`	keyword used to indicate the end of rod group position map.

3.20 The `IDET:` module

The `IDET:` module can perform an evaluation of fission chamber response in a PWR by integrating the fission rate over the detector positions. This module is limited to Cartesian geometry.

The `IDET:` module specification is:

Table 49: Structure `IDET:`

```
IDETEC := IDET: [ IDETEC ] TRKNAM FLUNAM LIBNAM [ FMAP ]
:: (descidet)
```

where

IDETEC   `character*12` name of a IDETECT data structure, (`L_INTDETEC` signature) that will be created or updated by the `IDET:` module.

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

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

LIBNAM   `character*12` name of the read-only MACROLIB data structure (`L_LIBRARY` signature) that contains the interpolated microscopic cross sections.

FMAP   `character*12` name of the read-only FMAP data structure (`L_MAP` signature) containing renumbered mixture indices. This object is optionnal.

(descidet)   structure describing the input data to the `IDET:` module.

3.20.1 Input data to the `IDET:` module

Table 50: Structure **(descidet)**

```
[ EDIT iprint ]
[ DETNAME dname ] [ REANAME rname ]
DETECTOR
   [[ POSITION { valx | INTEG valx1 valx2 } { valy | INTEG valy1 valy2 }
               [ { valz | INTEG valz1 valz2 } ] ]]
ENDD
;
```

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 for more printouts.
DETNAME	keyword used to set *dname*, the alias name of the isotope used as detector. By default, *dname*=U235 is used.
dname	character*12 alias name of the isotope used as detector.
REANAME	keyword used to set *rname*, the name of the nuclear reaction used as detector. By default, *rname*=NFTOT is used.
rname	character*12 name of the nuclear reaction used as detector.
POSITION	keyword defining the position of a single detector.
INTEG	keyword indicating that the detector reading will be averaged between two Cartesian positions.
valx	position (real number) of the detector along X axis.
valx1	starting position (real number) of the detector along X axis.
valx2	ending position (real number) of the detector along X axis. We must have *valx1*<*valx2*.
valy	position (real number) of the detector along Y axis.
valy1	starting position (real number) of the detector along Y axis.
valy2	ending position (real number) of the detector along Y axis. We must have *valy1*<*valy2*.
valz	position (real number) of the detector along Z axis. Detector position along Z axis is given only for 3D geometries.
valz1	starting position (real number) of the detector along Z axis.
valz2	ending position (real number) of the detector along Z axis. We must have *valz1*<*valz2*.

4 CROSS-SECTION INTERPOLATION MODULES

4.1 The `CRE:` module

The `CRE:` module is used for the recovering and interpolation of nuclear properties from one or many COMPO objects, originated from the transport calculations using lattice code DRAGON. A resulting MACROLIB will be created (or updated) by the `CRE:` module, it will contain the nuclear properties of some selected reactor materials.

Two types of MACROLIB can be constructed using the `CRE:` module:

- A MACROLIB that will be constructed for the few reactor materials, namely for the devices and/or reflector properties. It can also be created for the few fuel regions defined in the reactor core. This MACROLIB is permitted to be updated for the new properties in the subsequent calls to the `CRE:` module.

- A fuel-map MACROLIB that will be constructed over the fuel lattice only. This MACROLIB will contain a set of interpolated fuel properties with respect to the burnup distribution over the fuel lattice and according to the interpolation option defined in the FMAP object. The total number of mixtures in the resulting MACROLIB will equal to the total number of fuel bundles.

Note that the `CRE:` module can be used only with the mono-parameter COMPO objects and the nuclear properties can be interpolated only with respect to the burnup data. In case of the MACROLIB construction from a multi-parameter database, the `NCR:` module should be used instead. In this case, the interpolation of nuclear properties can be made with respect to global and local parameters, if they were previously specified in the fuel-map (see Section 3.1.2).

The `CRE:` module specifications are:

Table 51: Structure `CRE:`

{ *MACRO* := `CRE:` [*MACRO*] [[*CPO*]] :: **(desccre1)** |
   MACFL := `CRE:` [[*CPO*]] *FMAP* :: **(desccre2)** }

---

where

MACRO	`character*12` name of the MACROLIB object to be created or updated for the few reactor material properties. Note that if *MACRO* appears on the RHS, the information previously stored in *MACRO* is kept.
CPO	`character*12` name of the COMPO object containing the mono-parameter database from transport calculations.
MACFL	`character*12` name of the fuel-map MACROLIB that will be created only for the fuel properties over the fuel lattice.
FMAP	`character*12` name of the FMAP object containing the fuel-map specification and burnup informations.
(desccre1)	structure describing the input data to the `CRE:` module when the FMAP object is not specified.

(desccre2)   structure describing the input data to the CRE: module for the fuel-map MACROLIB construction.

4.1.1 Input data for the CRE: module

Table 52: Structure **(desccre1)**

```
[ EDIT iprint ]
[ NMIX nmix ]
READ [[ COMPO CPO (descdata1) ]]
;
```

Table 53: Structure **(desccre2)**

```
[ EDIT iprint ]
READ [[ TABLE CPO (descdata2) ]]
;
```

where

EDIT   keyword used to set *iprint*.

iprint   integer index used to control the printing of information on screen: $= 0$ for no print; $= 1$ for minimum printing; larger values will produce increasing amounts of output.

NMIX   keyword used to define the number of material mixtures *nmix*. This data must be given only if *MACRO* is created and the FMAP object is not specified.

nmix   integer maximum number of reactor material mixtures, as defined in the reactor geometry.

READ   keyword used to read the MACROLIB specification from the input data file.

COMPO   keyword used to indicate a simple MACROLIB creation, i.e. according to the first calling specification when FMAP object is not specified.

TABLE   keyword used to indicate a fuel-map MACROLIB creation, i.e. according to the second calling specification with FMAP object specified.

CPO   `character*12` name of the selected COMPO object. This name must appear in the calling specification to the CRE: module.

(descdata1)   structure containing the interpolation specification if COMPO is the selected option.

(descdata2)   structure containing the interpolation specification if TABLE is the selected option.

Table 54: Structure **(descdata1)**

```
[[ MIX mix NAMDIR [ DERIV ] [ UPS ]
   [ { I-BURNUP burn | T-BURNUP burn0 burn1 } ]
   [ MICRO { [[ HISO { conc | * } ]] | ALL } ]
ENDMIX ]]
```

Table 55: Structure **(descdata2)**

```
[[ MIX mix NAMDIR [ DERIV ] [ UPS ]
   [ { TIMAV-BURN | INST-BURN | AVG-EX-BURN ivarty } ]
   [ MICRO { [[ HISO { conc | * } ]] | ALL } ]
ENDMIX ]]
```

where

MIX	keyword used to set the material mixture *mix*.
mix	integer identifier for the material mixture that will be included in the MACROLIB. The maximum number of identifiers permitted is *nmix* and the maximum value that *mix* may have is *nmix*. Note that if TABLE is the selected option, then *mix* identifies the fuel type as defined in the reactor geometry.
NAMDIR	`character*12` directory name in the *CPO* object from which the nuclear properties for material mixture *mix* are to be recovered.
DERIV	keyword used to compute the derivative of the MACROLIB information with respect to *burn* or *burn1* value. By default, the MACROLIB information is not differentiated.
UPS	keyword used to compute properties with no up-scattering contribution.
TIMAV-BURN	keyword used to compute time-averaged cross-section information. This option is available *only if* TABLE is the selected option. By default, the type of calculation (TIMAV-BURN or INST-BURN) is recovered from the *FMAP* object.
INST-BURN	keyword used to compute cross-section information at specific bundle burnups. This option is available *only if* TABLE is the selected option. By default, the type of calculation (TIMAV-BURN or INST-BURN) is recovered from the *FMAP* object.
AVG-EX-BURN	keyword used to compute the derivatives of cross-section information relative to the exit burnup of a single combustion zone. The derivatives are computed using Eq. (3.3) of Ref. 16, written as

$$\frac{\partial \bar{\Sigma}_x}{\partial B_j^{\mathrm{e}}} = \frac{1}{B_j^{\mathrm{e}} \left(B_{j,k}^{\mathrm{eoc}} - B_{j,k}^{\mathrm{boc}} \right)} \left[-\int_{B_{j,k}^{\mathrm{boc}}}^{B_{j,k}^{\mathrm{eoc}}} dB\, \Sigma_x(B) + B_{j,k}^{\mathrm{eoc}} \Sigma_x(B_{j,k}^{\mathrm{eoc}}) - B_{j,k}^{\mathrm{boc}} \Sigma_x(B_{j,k}^{\mathrm{boc}}) \right]$$

where $B_{j,k}^{\mathrm{boc}}$, $B_{j,k}^{\mathrm{eoc}}$, and B_j^{e} are the beginning of cycle burnup of bundle $\{j, k\}$, end of cycle burnup of bundle $\{j, k\}$ and exit burnup of channel j. This option is available *only if* TABLE is the selected option.

ivarty	index of the combustion zone for differentiation of cross-section information.
I-BURNUP	keyword used to perform a single interpolation and to set the burnup interpolation value *burn*.
burn	real interpolation value of the burnup, given in MW·day per tonne of initial heavy elements.
T-BURNUP	keyword used to perform a time-average MACROLIB evaluation between the burnup values *burn0* and *burn1*.
burn0	real initial value of the burnup, given in MW·day per tonne of initial heavy elements.
burn1	real final value of the burnup, given in MW·day per tonne of initial heavy elements.
MICRO	keyword used to set the number densities of the extracted isotopes present in the COMPO linked list or XSM file. By default, the extracted isotopes are not added to the resulting MACROLIB.
HISO	`character*12` name of an extracted isotope.
conc	user-defined real number density of the extracted isotope, given in 10^{24} particles per cm^3.
*	keyword used to indicate that the number density for the isotope *HISO* will be recovered from the COMPO object.
ALL	keyword used to indicate that all the number densities are to be recovered from the COMPO object.
ENDMIX	keyword used to indicate the end of data specification for the material mixture *mix*.

4.2   The `NCR:` module

This component of DONJON is dedicated to the interpolation of MICROLIB and MACROLIB data from a MULTICOMPO object, the reactor database produced by `COMPO:`. A set of *global* and/or *local parameters* are defined for each material mixture and used as multi-dimensional interpolation variables.

The calling specifications are:

Table 56: Structure **(NCR:)**

MLIB := `NCR:` [{ *MLIB* | *MLIB2* }] *CPONAM1* [[*CPONAM2*]] [*MAPFL*] :: **(ncr_data)**

---

where

MLIB   `character*12` name of a MICROLIB (type **L_LIBRARY**) or MACROLIB (type **L_MACROLIB**) containing the interpolated data. If this object also appears on the RHS of structure **(NCR:)**, it is open in modification mode and updated.

MLIB2   `character*12` name of an optional MICROLIB object whose content is copied on *MLIB*.

CPONAM1   `character*12` name of the LCM object containing the MULTICOMPO data structure (**L_MULTICOMPO** signature).

CPONAM2   `character*12` name of an additional LCM object containing an auxiliary MULTICOMPO data structure (**L_MULTICOMPO** signature). This object is optional.

MAPFL   `character*12` name of the MAP object containing fuel regions description, global and local parameter information (burnup, fuel/coolant temperatures, coolant density, etc). Keyword `TABLE` is expected in **(ncr_data)**.

ncr_data   input data structure containing interpolation information (see Section 4.2.1).

4.2.1 Interpolation data input for module `NCR:`

Table 57: Structure **(ncr_data)**

```
[ EDIT iprint ]
[ ALLX nbfuel ] [ RES ] [ PURE ]
[ { MACRO | MICRO } ] [ { LINEAR | CUBIC } ] [ LEAK b2 ]
[ NMIX nmixt ]
{ [[ COMPO CPONAM NAMDIR (descintf) ]]
 | [[ TABLE CPONAM NAMDIR [ namburn ] (descintf) ]] }
;
```

---

where

`EDIT`   keyword used to set *iprint*.

iprint	index used to control the printing in module `NCR:`. =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:` and `COMPO:` before.
nbfuel	number of fuel rings used for micro-depletion calculations.
`RES`	keyword indicating that the interpolation is done only for the microscopic cross sections and not for the isotopic densities. In this case, a RHS MICROLIB must be defined and the number densities are recovered from it. This option is useful for micro-depletion applications. **Important note:** It is possible to force interpolation of some isotopic densities with `RES` option if these isotopes are explicitly specified with a "`*`" flag after `MICRO` keyword in *descintf* input data structure (see Section 4.4.2).
`PURE`	keyword indicating that the interpolation is a pure linear combination of terp factors. The fission spectra are *not* renormalized. By default, non-linear effects are produced by renormalization operations.
`MACRO`	keyword indicating that *MLIB* is a MACROLIB.
`MICRO`	keyword indicating that *MLIB* is a MICROLIB (default option). Object *MLIB* contains an embedded MACROLIB, but the CPU time required to obtain it is longer.
`LINEAR`	keyword indicating that interpolation of the MULTICOMPO uses linear Lagrange polynomials (default option).
`CUBIC`	keyword indicating that interpolation of the MULTICOMPO uses the Ceschino method with cubic Hermite polynomials, as presented in Ref. 17.
`LEAK`	keyword used to introduce leakage in the embedded MACROLIB. This option should only be used for non-regression tests.
b2	the imposed buckling corresponding to the leakage.
`NMIX`	keyword used to define the maximum number of material mixtures. This information is required only if *MLIB* is created.
nmixt	the maximum number of mixtures (a mixture is characterized by a distinct set of macroscopic cross sections) the MACROLIB may contain. The default value is *nmixt* = 0 or the value recovered from *MLIB* if it appears on the RHS of structure **(NCR:)**.
`COMPO`	keyword used to set *CPONAM* and to define each global and local parameter.
`TABLE`	keyword used to set *CPONAM* and to recover some global and local parameter from a MAP object named *MAPFL*.
CPONAM	`character*12` name of the LCM object containing the MULTICOMPO data structure where the interpolation is performed. This name must be set in the RHS of structure **(NCR:)**.
NAMDIR	access the MULTICOMPO structure of *CPONAM* from the sub-directory named *NAMDIR*. This value must be set equal to `'default'` if not previously defined by a `STEP UP` keyword in module `COMPO`.
namburn	name of the parameter for burnup (or irradiation) in the sub-directory named *NAMDIR*. This value is defined if option `TABLE` is set *and* if burnup (or irradiation) is to be considered as parameter.

descintf   input data structure containing interpolation information relative to the MULTICOMPO
                   data structure named *CPONAM* (see Section 4.4.2).

4.2.2 Defining local and global parameters

If a MAP object is defined on the RHS of structure **(NCR:)**, and if the TABLE keyword is set, some information required to set the interpolation points is found in this object. In this case, the NCR: operator search the MULTICOMPO object for global or local parameters having an arbitrary name specified in the MAP object or set directly in this module. Note that any parameter's value set directly in this module prevails on a value stored in the *MAPFL* object.

Each instance of *descintf* is a data structure specified as

Table 58: Structure **(descintf)**

```
[[ MIX imix [ { FROM imixold | USE } ]
    [ { TIMAV-BURN | INST-BURN | AVG-EX-BURN ivarty } ]
    [[ { SET | DELTA | ADD } } ] [ { LINEAR | CUBIC } ] PARKEY { val1 | MAP } [ { val2 | MAP } ]
        [ REF [[ PARKEY { valref | SAMEASREF } ]] ENDREF ] ]]
    [ MICRO { ALL | ONLY } [[ HISO { conc | * } ]] ] ]
ENDMIX ]]
```

where

MIX   keyword used to set *imix*. Discontinuity factor information present in the Multicompo
                   is interpolated as mixture 1 values.

imix   index of the mixture that is to be created in the MICROLIB and MACROLIB.

FROM   keyword used to set the index of the mixture in the MULTICOMPO object.

imixold   index of the mixture that is recovered in the MULTICOMPO object. By default, *imixold*=
                   1.

USE   keyword used to set the index of the mixture in the MULTICOMPO object equal to *imix*.

TIMAV-BURN   keyword used to compute time-averaged cross-section information. This option is avail-
                   able *only if* a *MAPFL* object is set. By default, the type of calculation (TIMAV-BURN
                   or INST-BURN) is recovered from the *MAPFL* object.

INST-BURN   keyword used to compute cross-section information at specific bundle burnups. This
                   option is available *only if* a *MAPFL* object is set. By default, the type of calculation
                   (TIMAV-BURN or INST-BURN) is recovered from the *MAPFL* object.

AVG-EX-BURN   keyword used to compute the derivatives of cross-section information relative to the
                   exit burnup of a single combustion zone. The derivatives are computed using Eq. (3.3)
                   of Ref. 16, written as

$$\frac{\partial \bar{\Sigma}_x}{\partial B_j^{\mathrm{e}}} = \frac{1}{B_j^{\mathrm{e}}\left(B_{j,k}^{\mathrm{eoc}} - B_{j,k}^{\mathrm{boc}}\right)} \left[-\int_{B_{j,k}^{\mathrm{boc}}}^{B_{j,k}^{\mathrm{eoc}}} dB\, \Sigma_x(B) + B_{j,k}^{\mathrm{eoc}} \Sigma_x(B_{j,k}^{\mathrm{eoc}}) - B_{j,k}^{\mathrm{boc}} \Sigma_x(B_{j,k}^{\mathrm{boc}}) \right]$$

where $B_{j,k}^{\mathrm{boc}}$, $B_{j,k}^{\mathrm{eoc}}$, and B_j^{e} are the beginning of cycle burnup of bundle $\{j,k\}$, end of cycle burnup of bundle $\{j,k\}$ and exit burnup of channel j. This option is available

	only if a *MAPFL* object is set. By default, the type of calculation (`TIMAV-BURN` or `INST-BURN`) is recovered from the *MAPFL* object.
ivarty	index of the combustion zone for differentiation of cross-section information.
SET	keyword used to indicate a simple interpolation at *val1* or an averaging between *val1* and *val2*. The result σ_{ref} is also used as the reference value when the `ADD` is used. Note: see at the ending note of this section for a detailed description and examples.
DELTA	keyword used to indicate a delta-sigma calculation between *val2* and *val1* (i.e., $\Delta\sigma_{\mathrm{ref}} = \sigma_{\mathrm{val2}} - \sigma_{\mathrm{val1}}$ is computed). This keyword can be used only once in each mixture data block (initiated with a `MIX` keyword). Note: see at the ending note of this section for a detailed description and examples.
ADD	keyword used to indicate a delta-sigma calculation between *val2* and *val1* is added to the reference value (i.e., $\Delta\sigma = \sigma_{\mathrm{val2}} - \sigma_{\mathrm{val1}}$ is used as contribution, $\sigma_{\mathrm{ref}} + \Delta\sigma$ or $\Delta\sigma_{\mathrm{ref}} + \Delta\sigma$ is returned). Note: see at the ending note of this section for a detailed description and examples.
LINEAR	keyword indicating that interpolation of the MULTICOMPO for parameter *PARKEY* uses linear Lagrange polynomials. It is possible to set different interpolation modes to different parameters. By default, the interpolation mode is set in Sect. 4.2.1.
CUBIC	keyword indicating that interpolation of the MULTICOMPO for parameter *PARKEY* uses the Ceschino method with cubic Hermite polynomials, as presented in Ref. 17. By default, the interpolation mode is set in Sect. 4.2.1.
PARKEY	`character*12` user-defined keyword associated to a global or local parameter to be set.
val1	value of a global or local parameter used to interpolate. *val1* is the initial value of this parameter in case an average is required. *val1* can be an integer, real or string value.
val2	value of the final global or local parameter. By default, a simple interpolation is performed, so that *val2*=*val1*. *val2* is always a real value with *val2*≥*val1*.
MAP	keyword used to indicate that the value of parameter *val1* or the second value for the $\Delta\sigma$ calculation is recovered from *MAPFL*, i.e. the MAP object containing fuel regions description.
REF	keyword only available together with the `ADD` option. It is used to set all the other variable values when a Δ contribution is performed for one variable.
valref	value of the reference parameter, when it is directly given by the user. Note that there is no default value.
SAMEASREF	keyword used to specify that the reference value will be the same as in the refence case, i.e. for the σ_{ref} computation.
ENDREF	keyword only available together with the `ADD` option. It is used to specify that all the other variable values which are required are given.
MICRO	keyword used to set the number densities of some isotopes present in the MULTICOMPO object. The data statement "`MICRO ALL`" is used by default.
ALL	keyword to indicate that all the isotopes present in the MULTICOMPO object will be used in the MICROLIB and MACROLIB objects. Concentrations of these isotopes will be recovered from the MULTICOMPO object or set using the "*HISO conc*" data statement.

ONLY	keyword to indicate that only the isotopes set using the *"HISO conc"* data statement will be used in the MICROLIB and MACROLIB objects.
HISO	`character*8` name of an isotope.
conc	user-defined value of the number density (in 10^{24} particles per cm^3) of the isotope.
*	the value of the number density for isotope *HISO* is recovered from the MULTICOMPO object.
ENDMIX	end of specification keyword for the material mixture.

4.2.3 Interpolation in the parameter grid

The following example corresponds to a delta-sigma computation in mixture 1 corresponding to a perturbation. Note that in this case, the MACROLIB object may content negative cross-section.

```
MACROLIB := NCR: CPO ::
   EDIT 40 NMIX 1 MACRO COMPO CPO default
   MIX 1  !(* delta sigma contribution *)
          SET 'CELL' '3D'
          DELTA 'PITCH' 0.0 1.0
   ENDMIX
;
```

When the number of parameters used for the interpolation is increased, all the lattice computations corresponding to all the combinations of parameters may not be done for computation time reasons. In this case, some approximations may be required. The choice for the SET, DELTA and ADD is then dependent of the structure of the database (i.e. how the database grid of possibilities is filled). When a MAP object containing fuel regions description is used, the problem become even more complex, because values have to be automatically changed for all bundles. In order to clarify all the different possibilities and limitations dependently of the database structure, we will use a 3 parameter case. The paramaters are referenced by 'A', 'B' and 'C'. But before we explain the different cases, we want to remind that the interpolation factors are computed on each axis seperatly.

The first case corresponds to a complete grid, represented by a gray paralepiped on Fig. 3 and 4. The figure 3 shows that the interpolated value in point V can be obtained directly without MAP object. For time-average (TA) computation, lets assume that the parameter 'B' represents the burnup (and keep this convention for other database structure also). In this case the figure 4 shows also that the direct interpolation can be done to compute an average value between the points V' and V. Note that the TA burnups are stored in the MAP object, and are then recovered automatically.

The second case corresponds to a partial grid where all the lattice computations have been perfomed for several pairs of parameters, which are represented as the gray rectangles on Fig. 5 and 6. If we use the notations of Fig. 5 and 6, the best estimate interpolated values, f, we can get are given by:
$f = f(V) \approx f(V_B) + (f(V_{BA}) - f(V_B)) + (f(V_{BC}) - f(V_B)) = f(V_{BC}) + (f(V_{BA}) - f(V_B)) = f(V_{BA}) + (f(V_{BC}) - f(V_B))$ for instataneous
$f = f(V', V) \approx f(V'_B, V_B) + (f(V'_{BA}, V_{BA}) - f(V'_B, V_B)) + (f(V'_{BC}, V_{BC}) - f(V'_B, V_B)) = f(V'_{BC}, V_{BC}) + (f(V'_{BA}, V_{BA}) - f(V'_B, V_B)) = f(V'_{BA}, V_{BA}) + (f(V'_{BC}, V_{BC}) - f(V'_B, V_B))$ for TA
where $f(.,.)$ represents the average value between two points.

The third case corresponds to a minimal grid, where the lattice computations have been perfomed only for one parameter variation at a time. In this case, the grid is represented by the thick gray lines on the axis on Fig. 7 and 8. If we use the notations of Fig. 7 and 8, the best estimate interpolated values, f, we can get are given by:
$f = f(V) \approx f(V_0) + (f(V_A) - f(V_0)) + (f(V_B) - f(V_0)) + (f(V_C) - f(V_0)) = f(V_B) + (f(V_A) - f(V_0)) +$

$(f(V_C) - f(V_0))$ for instataneous
$f = f(V', V) \approx f(V'_B, V_B) + (f(V_A) - f(V_0)) + (f(V_C) - f(V_0))$ for TA
Note that the reference point (V_0 in the example) does not have to be the same for all parameters. Database structures such as represented on Fig 9 can also been used. In this case, we even have two choices for the Δf computation on axis 'A'.

The last case is in fact a mix of cases 2 and 3. The gray rectangle and the gray line on Fig. 10 and 11 reprensent where all the lattice computations have been performed. With the notations used on those figures, one can write that the best estimate interpolated values, f, we can get are given by:
$f = f(V) \approx f(V_B) + (f(V_{BC}) - f(V_B)) + (f(V_A) - f(V_0)) = f(V_{BC}) + (f(V_A) - f(V_0))$ for instataneous
$f = f(V', V) \approx f(V'_B, V_B) + (f(V'_{BC}, V_{BC}) - f(V'_B, V_B)) + (f(V_A) - f(V_0)) = f(V'_{BC}, V_{BC}) + (f(V_A) - f(V_0))$ for TA
Note once again that the reference point (V_0 in the example) does not have to be the same for all parameters. Database structures such as represented on Fig 12 can also been used.

The input files will actually reflect the previous equations. However, they are different if the parameters are stored in a MAP object, *MAPFL*, or provided directly by the user. For the case of one point interpolation (i.e. instantaneous), the input files will be:

case	all parameters explicitly set	all parameters in MAP

GRID (Fig. 3)	<pre>MACROLIB := NCR: CPO ::
	    NMIX 1 MACRO
	    COMPO CPO default
	    MIX 1
	        SET 'A' <<va>>
	        SET 'B' <<vb>>
	        SET 'C' <<vc>>
	    ENDMIX
	;</pre>
		<pre>MACROLIB := NCR: CPO FMAP ::
		    NMIX 1 MACRO
		    TABLE CPO default 'B'
		    MIX 1
		    ENDMIX
		;</pre>

PLANE (Fig. 5)	<pre>MACROLIB := NCR: CPO ::
	    NMIX 1 MACRO
	    COMPO CPO default
	    MIX 1
	        SET 'A' <<va>>
	        SET 'B' <<vb>>
	        SET 'C' <<vc0>>
	        ADD 'C' <<vc0>> <<vc>>
	            REF 'A' <<va0>>
	                 'B' <<vb>> ENDREF
	!or 'B' SAMEASREF ENDREF
	    ENDMIX
	;</pre>
		<pre>MACROLIB := NCR: CPO FMAP ::
		    NMIX 1 MACRO
		    TABLE CPO default 'B'
		    MIX 1
		        SET 'C' <<vc0>>
		        ADD 'C' <<vc0>> MAP
		            REF 'A' <<va0>>
		                 'B' SAMEASREF ENDREF
		!or SET 'A' <<va0>>
		!or ADD 'A' <<va0>> MAP
		!or REF 'C' <<vc0>>
		!or 'B' SAMEASREF ENDREF
		    ENDMIX
		;</pre>

AXE (Fig. 7)	<pre>MACROLIB := NCR: CPO ::
	    NMIX 1 MACRO
	    COMPO CPO default
	    MIX 1
	        SET 'A' <<va0>>
	        SET 'B' <<vb>>
	        SET 'C' <<vc0>>
	        ADD 'A' <<va0>> <<va>>
	            REF 'C' <<vc0>>
	                 'B' <<vb0>> ENDREF
	        ADD 'C' <<vc0>> <<vc>>
	            REF 'A' <<va0>>
	                 'B' <<vb0>> ENDREF
	    ENDMIX
	;</pre>
		<pre>MACROLIB := NCR: CPO FMAP ::
		    NMIX 1 MACRO
		    TABLE CPO default 'B'
		    MIX 1
		        SET 'A' <<va0>>
		        SET 'C' <<vc0>>
		        ADD 'A' <<va0>> MAP
		            REF 'C' <<vc0>>
		                 'B' <<vb0>> ENDREF
		        ADD 'C' <<vc0>> MAP
		            REF 'A' <<va0>>
		                 'B' <<vb0>> ENDREF
		    ENDMIX
		;</pre>

		continued on next page

case	all parameters explicitly set	all parameters in MAP

PLANE + AXE (Fig. 10)	<pre>MACROLIB := NCR: CPO ::
	   NMIX 1 MACRO
	   COMPO CPO default
	   MIX 1
	      SET 'A' <<va0>>
	      SET 'B' <<vb>>
	      SET 'C' <<vc>>
	      ADD 'A' <<va0>> <<va>>
	         REF 'C' <<vc0>>
	               'B' <<vb0>> ENDREF
	      ENDMIX
	   ;</pre>
		<pre>MACROLIB := NCR: CPO FMAP ::
		   NMIX 1 MACRO
		   TABLE CPO default 'B'
		   MIX 1
		      SET 'A' <<va0>>
		      ADD 'A' <<va0>> MAP
		         REF 'C' <<vc0>>
		                'B' <<vb0>> ENDREF
		   ENDMIX
		;</pre>

Table 59: NCR inputs for instantaneous cases

For the TA, the burnup variable has no other choice than to be stored in the MAP object, *MAPFL*. Then the input files will be:

case	only the burnup in MAP	all parameters in MAP

GRID (Fig. 4)	<pre>MACROLIB := NCR: CPO FMAP ::
	   NMIX 1 MACRO
	   TABLE CPO default 'B'
	   MIX 1
	      SET 'A' <<va>>
	      SET 'C' <<vc>>
	   ENDMIX
	;</pre>
		<pre>MACROLIB := NCR: CPO FMAP ::
		   NMIX 1 MACRO
		   TABLE CPO default 'B'
		   MIX 1
		   ENDMIX
		;</pre>

PLANE (Fig. 6)	<pre>MACROLIB := NCR: CPO FMAP ::
	   NMIX 1 MACRO
	   TABLE CPO default 'B'
	   MIX 1
	      SET 'A' <<va>>
	      SET 'C' <<vc0>>
	      ADD 'C' <<vc0>> <<vc>>
	         REF 'A' <<va0>>
	               'B' SAMEASREF ENDREF
	   ENDMIX
	;</pre>
		<pre>MACROLIB := NCR: CPO FMAP ::
		   NMIX 1 MACRO
		   TABLE CPO default 'B'
		   MIX 1
		      SET 'C' <<vc0>>
		      ADD 'C' <<vc0>> MAP
		         REF 'A' <<va0>>
		                'B' SAMEASREF ENDREF
		!or SET 'A' <<va0>>
		!or ADD 'A' <<va0>> MAP
		!or REF 'C' <<vc0>>
		!or 'B' SAMEASREF ENDREF
		   ENDMIX
		;</pre>

		continued on next page

case	only the burnup in MAP	all param. in MAP
| AXE (Fig. 8) | ```
MACROLIB := NCR: CPO FMAP ::
   NMIX 1 MACRO
   TABLE CPO default 'B'
   MIX 1
      SET 'A' <<va0>>
      SET 'C' <<vc0>>
      ADD 'A' <<va0>> <<va>>
         REF  'C' <<vc0>>
              'B' <<vb0>> ENDREF
      ADD 'C' <<vc0>> <<vc>>
         REF  'A' <<va0>>
              'B' <<vb0>> ENDREF
   ENDMIX
;
``` | ```
MACROLIB := NCR: CPO FMAP ::
   NMIX 1 MACRO
   TABLE CPO default 'B'
   MIX 1
      SET 'A' <<va0>>
      SET 'C' <<vc0>>
      ADD 'A' <<va0>> MAP
         REF  'C' <<vc0>>
              'B' <<vb0>> ENDREF
      ADD 'C' <<vc0>> MAP
         REF  'A' <<va0>>
              'B' <<vb0>> ENDREF
   ENDMIX
;
``` |
| PLANE + AXE (Fig. 11) | ```
MACROLIB := NCR: CPO FMAP ::
   NMIX 1 MACRO
   TABLE CPO default 'B'
   MIX 1
      SET 'A' <<va0>>
      SET 'C' <<vc>>
      ADD 'A' <<va0>> <<va>>
         REF  'C' <<vc0>>
              'B' <<vb0>> ENDREF
   ENDMIX
;
``` | ```
MACROLIB := NCR: CPO FMAP ::
   NMIX 1 MACRO
   TABLE CPO default 'B'
   MIX 1
      SET 'A' <<va0>>
      ADD 'A' <<va0>> MAP
         REF  'C' <<vc0>>
              'B' <<vb0>> ENDREF
   ENDMIX
;
``` |

Table 60: NCR inputs for TA cases

The following pictures correspond to the previous different examples:

Figure 3: Complete grid, one point case

Figure 6: Partial grid, complete planes, TA case

Figure 4: Complete grid, TA case

Figure 7: Partial grid, complete axis, one point case

Figure 5: Partial grid, complete planes, one point case

Figure 8: Partial grid, complete axis, TA case

Figure 9: Partial grid, complete axis with another configuration, one point case

Figure 11: Partial grid, one complete plane and one complete axis, TA case

Figure 10: Partial grid, one complete plane and one complete axis, one point case

Figure 12: Partial grid, one complete plane and one complete axis with another configuration, one point case

4.3 The `SCR:` module

This component of DONJON is dedicated to the interpolation of MACROLIB data from a SAPHYB object, the reactor database produced by module `SAP:` in DRAGON or by module `SAPHYB:` in APOLLO2.[25] A set of *global parameters* are defined for each material mixture and used as multi-dimensional interpolation variables.

The calling specifications are:

Table 61: Structure **(SCR:)**

MLIB := SCR: [{ *MLIB* | *MLIB2* }] *SAPNAM1* [[*SAPNAM2*]] [*MAPFL*] :: **(scr_data)**

---

where

MLIB   `character*12` name of a MICROLIB (type `L_LIBRARY`) or MACROLIB (type `L_MACROLIB`) containing the interpolated data. If this object also appears on the RHS of structure **(SCR:)**, it is open in modification mode and updated.

MLIB2   `character*12` name of an optional MICROLIB object whose content is copied on *MLIB*.

SAPNAM1   `character*12` name of the LCM object containing the SAPHYB data structure (`L_SAPHYB` signature).

SAPNAM2   `character*12` name of an additional LCM object containing an auxiliary SAPHYB data structure (`L_SAPHYB` signature). This object is optional.

MAPFL   `character*12` name of the MAP object containing fuel regions description, global parameter information (burnup, fuel/coolant temperatures, coolant density, etc). Keyword `TABLE` is expected in **(scr_data)**.

scr_data   input data structure containing interpolation information (see Section 4.3.1).

Note: SAPHYB files generated by APOLLO2 don't have a signature. If such a SAPHYB is given as input to module `SCR:`, a signature must be included before using it. The following instruction can do the job:

```
Saphyb := UTL: Saphyb :: CREA SIGNATURE 3 = 'L_SA' 'PHYB' ' ' ;
```

4.3.1 Interpolation data input for module `SCR:`

Table 62: Structure **(scr_data)**

```
[ EDIT iprint ]
[ RES ] [ PURE ]
[ { MACRO | MICRO } ] [ { LINEAR | CUBIC } ] [ LEAK b2 ] [ EQUI TEXT4 ] [ MASL TEXT4 ]
[ NMIX nmixt ]
{ [[ SAPHYB SAPNAM (descints) ]] | [[ TABLE SAPNAM [ namburn ] (descints)  ]] }
[ (descdepl) ]
;
```

---

where

EDIT	keyword used to set *iprint*.
iprint	index used to control the printing in module SCR:. =0 for no print; =1 for minimum printing (default value).
RES	keyword indicating that the interpolation is done only for the microscopic cross sections and not for the isotopic densities. In this case, a RHS MICROLIB must be defined and the number densities are recovered from it. This option is useful for micro-depletion applications. **Important note:** It is possible to force interpolation of some isotopic densities with RES option if these isotopes are explicitly specified with a "*" flag after MICRO keyword in *descints* input data structure (see Section 4.3.2).
PURE	keyword indicating that the interpolation is a pure linear combination of terp factors. The fission spectra are *not* renormalized. By default, non-linear effects are produced by renormalization operations.
MACRO	keyword indicating that *MLIB* is a MACROLIB (default option).
MICRO	keyword indicating that *MLIB* is a MICROLIB. Object *MLIB* contains an embedded MACROLIB, but the CPU time required to obtain it is longer.
LINEAR	keyword indicating that interpolation of the SAPHYB uses linear Lagrange polynomials (default option).
CUBIC	keyword indicating that interpolation of the SAPHYB uses the Ceschino method with cubic Hermite polynomials, as presented in Ref. 17.
LEAK	keyword used to introduce leakage in the embedded MACROLIB. This option should only be used for non-regression tests.
b2	the imposed buckling corresponding to the leakage.
EQUI	keyword used to select a SPH factor set in the Saphyb. By default, the cross sections and diffusion coefficients are not SPH-corrected.
MASL	keyword used to recover the heavy metal density in the local parameter data of the Saphyb.
TEXT4	character*4 user-defined keyword of the SPH factor set or heavy metal density selected in the Saphyb. These sets are stored as local parameter information in the Saphyb.
NMIX	keyword used to define the maximum number of material mixtures. This information is required only if *MLIB* is created.
nmixt	the maximum number of mixtures (a mixture is characterized by a distinct set of macroscopic cross sections) the MACROLIB may contain. The default value is *nmixt* = 0 or the value recovered from *MLIB* if it appears on the RHS of structure **(scr_data)**.
SAPHYB	keyword used to set *SAPNAM* and to define each global parameter.
TABLE	keyword used to set *SAPNAM* and to recover some global parameter from a MAP object named *MAPFL*.
SAPNAM	character*12 name of the LCM object containing the SAPHYB data structure where the interpolation is performed. This name must be set in the RHS of structure **(SCR:)**.
namburn	name of the parameter for burnup (or irradiation). This value is defined if option TABLE is set *and* if burnup (or irradiation) is to be considered as parameter.

descints	input data structure containing interpolation information relative to the SAPHYB data structure named *SAPNAM* (see Section 4.3.2).
(descdepl)	input structure describing the depletion chain (see Section 4.4.3). This input structure requires option `MICRO`. By default, the depletion chain data is not written in the output MICROLIB.

4.3.2 Defining global parameters

If a MAP object is defined on the RHS of structure **(SCR:)**, and if the `TABLE` keyword is set, some information required to set the interpolation points is found in this object. In this case, the `SCR:` operator search the SAPHYB object for global parameters having an arbitrary name specified in the MAP object or set directly in this module. Note that any parameter's value set directly in this module prevails on a value stored in the *MAPFL* object.

Each instance of *descints* is a data structure specified as

Table 63: Structure **(descints)**

```
[[ MIX imix [ { FROM imixold | USE } ]
    [ { TIMAV-BURN | INST-BURN | AVG-EX-BURN ivarty } ]
    [[ { SET | DELTA | ADD } } [ { LINEAR | CUBIC } ] PARKEY { val1 | MAP } [ { val2 | MAP } ]
        [ REF [[ PARKEY { valref | SAMEASREF } ]] ENDREF ] ]]
    [ MICRO { ALL | ONLY } [[ HISO { conc | * } [ NOEV ] ]] ] ]
ENDMIX ]]
```

where

MIX	keyword used to set *imix*. Discontinuity factor information present in the Saphyb is interpolated as mixture 1 values.
imix	index of the mixture that is to be created in the MICROLIB and MACROLIB.
FROM	keyword used to set the index of the mixture in the SAPHYB object.
imixold	index of the mixture that is recovered in the SAPHYB object. By default, *imixold*= 1.
USE	keyword used to set the index of the mixture in the SAPHYB object equal to *imix*.
TIMAV-BURN	keyword used to compute time-averaged cross-section information. This option is available *only if* a *MAPFL* object is set. By default, the type of calculation (`TIMAV-BURN` or `INST-BURN`) is recovered from the *MAPFL* object.
INST-BURN	keyword used to compute cross-section information at specific bundle burnups. This option is available *only if* a *MAPFL* object is set. By default, the type of calculation (`TIMAV-BURN` or `INST-BURN`) is recovered from the *MAPFL* object.
AVG-EX-BURN	keyword used to compute the derivatives of cross-section information relative to the exit burnup of a single combustion zone. The derivatives are computed using Eq. (3.3) of Ref. 16, written as

$$\frac{\partial \bar{\Sigma}_x}{\partial B_j^{\mathrm{e}}} = \frac{1}{B_j^{\mathrm{e}} \left(B_{j,k}^{\mathrm{eoc}} - B_{j,k}^{\mathrm{boc}} \right)} \left[-\int_{B_{j,k}^{\mathrm{boc}}}^{B_{j,k}^{\mathrm{eoc}}} dB\, \Sigma_x(B) + B_{j,k}^{\mathrm{eoc}}\, \Sigma_x(B_{j,k}^{\mathrm{eoc}}) - B_{j,k}^{\mathrm{boc}}\, \Sigma_x(B_{j,k}^{\mathrm{boc}}) \right]$$

	where $B_{j,k}^{\text{boc}}$, $B_{j,k}^{\text{eoc}}$, and B_j^{e} are the beginning of cycle burnup of bundle $\{j,k\}$, end of cycle burnup of bundle $\{j,k\}$ and exit burnup of channel j. This option is available *only if* a *MAPFL* object is set. By default, the type of calculation (`TIMAV-BURN` or `INST-BURN`) is recovered from the *MAPFL* object.
ivarty	index of the combustion zone for differentiation of cross-section information.
`SET`	keyword used to indicate a simple interpolation at *val1* or an averaging between *val1* and *val2*. The result σ_{ref} is also used as the reference value when the `ADD` is used. Note: see at the ending note of this section for a detailed description and examples.
`DELTA`	keyword used to indicate a delta-sigma calculation between *val2* and *val1* (i.e., $\Delta\sigma_{\text{ref}} = \sigma_{\text{val2}} - \sigma_{\text{val1}}$ is computed). This keyword can be used only once in each mixture data block (initiated with a `MIX` keyword). Note: see at the ending note of this section for a detailed description and examples.
`ADD`	keyword used to indicate a delta-sigma calculation between *val2* and *val1* is added to the reference value (i.e., $\Delta\sigma = \sigma_{\text{val2}} - \sigma_{\text{val1}}$ is used as contribution, $\sigma_{\text{ref}} + \Delta\sigma$ or $\Delta\sigma_{\text{ref}} + \Delta\sigma$ is returned). Note: see at the ending note of this section for a detailed description and examples.
`LINEAR`	keyword indicating that interpolation of the SAPHYB for parameter *PARKEY* uses linear Lagrange polynomials. It is possible to set different interpolation modes to different parameters. By default, the interpolation mode is set in Sect. 4.3.1.
`CUBIC`	keyword indicating that interpolation of the SAPHYB for parameter *PARKEY* uses the Ceschino method with cubic Hermite polynomials, as presented in Ref. 17. By default, the interpolation mode is set in Sect. 4.3.1.
PARKEY	`character*12` user-defined keyword associated to a global parameter to be set.
val1	value of a global parameter used to interpolate. *val1* is the initial value of this parameter in case an average is required. *val1* can be an integer, real or string value.
val2	value of the final global parameter. By default, a simple interpolation is performed, so that *val2*=*val1*. *val2* is always a real value with *val2*≥*val1*.
`MAP`	keyword used to indicate that the value of parameter *val1* or the second value for the $\Delta\sigma$ calculation is recovered from *MAPFL*, i.e. the MAP object containing fuel regions description.
`REF`	keyword only available together with the `ADD` option. It is used to set all the other variable values when a Δ contribution is performed for one variable.
valref	value of the reference parameter, when it is directly given by the user. Note that there is no default value.
`SAMEASREF`	keyword used to specify that the reference value will be the same as in the refence case, i.e. for the σ_{ref} computation.
`ENDREF`	keyword only available together with the `ADD` option. It is used to specify that all the other variable values which are required are given.
`MICRO`	keyword used to set the number densities of some isotopes present in the SAPHYB object. The data statement "`MICRO ALL`" is used by default.
`ALL`	keyword to indicate that all the isotopes present in the SAPHYB object will be used in the MICROLIB and MACROLIB objects. Concentrations of these isotopes will be recovered from the SAPHYB object or set using the "*HISO conc*" data statement.

`ONLY`	keyword to indicate that only the isotopes set using the "*HISO conc*" data statement will be used in the MICROLIB and MACROLIB objects.
HISO	`character*8` name of an isotope.
conc	user-defined value of the number density (in 10^{24} particles per cm^3) of the isotope.
`*`	the value of the number density for isotope *HISO* is recovered from the SAPHYB object.
`NOEV`	keyword to force the isotope *HISO* to be non-depleting.
`ENDMIX`	end of specification keyword for the material mixture.

4.3.3 Depletion data structure

Part of the depletion data used in the isotopic depletion calculation (the fission yields and the radioactive decay constants) is recovered from the Saphyb file. Remaining depletion data is recovered from the input data structure **(descdepl)**. This data describes the heredity of the radioactive decay and the neutron activation chain.

Table 64: Structure **(descdepl)**

```
CHAIN
  [[ NAMDPL [ izae ]
    [[ reaction [ energy ] ]]
    [ { STABLE | FROM [[ { DECAY | reaction } [[ yield NAMPAR ]] ]] } ] ]]
ENDCHAIN
```

with:

`CHAIN`	keyword to specify the beginning of the depletion chain.
NAMDPL	`character*12` name of an isotope (or isomer) of the depletion chain that appears as a particularized isotope of the Saphyb.
izae	optional six digit integer representing the isotope. The first two digits represent the atomic number of the isotope; the next three indicate its mass number and the last digit indicates the excitation level of the nucleus (0 for a nucleus in its ground state, 1 for an isomer in its first exited state, etc.). For example, ^{238}U in its ground state will be represented by *izae*=922380.
reaction	`character*6` identification of a neutron-induced reaction that takes place either for production of this isotope, its depletion, or for producing energy. Example of reactions are following:

	`NG`	indicates that a radiative capture reaction takes place either for production of this isotope, its depletion or for producing energy.
	`N2N`	indicates that the following reaction is taking place:

$$n +^A X_Z \rightarrow 2n +^{A-1} X_Z$$

| N3N | indicates that the following reaction is taking place: |

$$n +^A X_Z \rightarrow 3n +^{A-2} X_Z$$

| N4N | indicates that the following reaction is taking place: |

$$n +^A X_Z \rightarrow 4n +^{A-3} X_Z$$

| NP | indicates that the following reaction is taking place: |

$$n +^A X_Z \rightarrow p +^A Y_{Z-1}$$

| NA | indicates that the following reaction is taking place: |

$$n +^A X_Z \rightarrow^4 He_2 +^{A-3} X_{Z-2}$$

| NFTOT | indicates that a fission is taking place. |

energy   energy (in MeV) recoverable per neutron-induced reaction of type *reaction*. If the energy associated to radiative capture is not explicitely given, it should be added to the energy released per fission. By default, *energy*=0.0 MeV.

STABLE   non depleting isotope. Such an isotope may produces energy by neutron-induced reactions (such as radiative capture).

FROM   indicates that this isotope is produced from decay or neutron-induced reactions.

DECAY   indicates that a decay reaction takes place for its production.

yield   branching ratio or production yield expressed in fraction.

NAMPAR   `character*12` name of the a parent isotope (or isomer) that appears as a particularized isotope of the Saphyb.

ENDCHAIN   keyword to specify the end of the depletion chain.

4.3.4 Interpolation in the parameter grid

The following example corresponds to a delta-sigma computation in mixture 1 corresponding to a perturbation. Note that in this case, the MACROLIB object may content negative cross-section.

```
MACROLIB := SCR: SAP ::
   EDIT 40 NMIX 1 SAPHYB SAP
   MIX 1  !(* delta sigma contribution *)
         SET 'CELL' '3D'
         DELTA 'PITCH' 0.0 1.0
   ENDMIX
;
```

When the number of parameters used for the interpolation is increased, all the lattice computations corresponding to all the combinations of parameters may not be done for computation time reasons. In this case, some approximations may be required. The choice for the SET, DELTA and ADD is then dependent of the structure of the database (i.e. how the database grid of possibilities is filled). When a MAP object containing fuel regions description is used, the problem become even more complex, because values have to be automatically changed for all bundles. In order to clarify all the different possibilities

and limitations dependently of the database structure, we will use a 3 parameter case. The paramaters are referenced by 'A', 'B' and 'C'. But before we explain the different cases, we want to remind that the interpolation factors are computed on each axis seperatly.

The first case corresponds to a complete grid, represented by a gray paralepiped on Fig. 3 and 4. The figure 3 shows that the interpolated value in point V can be obtained directly without MAP object. For time-average (TA) computation, lets assume that the parameter 'B' represents the burnup (and keep this convention for other database structure also). In this case the figure 4 shows also that the direct interpolation can be done to compute an average value between the points V' and V. Note that the TA burnups are stored in the MAP object, and are then recovered automatically.

The second case corresponds to a partial grid where all the lattice computations have been perfomed for several pairs of parameters, which are represented as the gray rectangles on Fig. 5 and 6. If we use the notations of Fig. 5 and 6, the best estimate interpolated values, f, we can get are given by:

$f = f(V) \approx f(V_B) + (f(V_{BA}) - f(V_B)) + (f(V_{BC}) - f(V_B)) = f(V_{BC}) + (f(V_{BA}) - f(V_B)) = f(V_{BA}) + (f(V_{BC}) - f(V_B))$ for instataneous

$f = f(V', V) \approx f(V'_B, V_B) + (f(V'_{BA}, V_{BA}) - f(V'_B, V_B)) + (f(V'_{BC}, V_{BC}) - f(V'_B, V_B)) = f(V'_{BC}, V_{BC}) + (f(V'_{BA}, V_{BA}) - f(V'_B, V_B)) = f(V'_{BA}, V_{BA}) + (f(V'_{BC}, V_{BC}) - f(V'_B, V_B))$ for TA

where $f(.,.)$ represents the average value between two points.

The third case corresponds to a minimal grid, where the lattice computations have been perfomed only for one parameter variation at a time. In this case, the grid is represented by the thick gray lines on the axis on Fig. 7 and 8. If we use the notations of Fig. 7 and 8, the best estimate interpolated values, f, we can get are given by:

$f = f(V) \approx f(V_0) + (f(V_A) - f(V_0)) + (f(V_B) - f(V_0)) + (f(V_C) - f(V_0)) = f(V_B) + (f(V_A) - f(V_0)) + (f(V_C) - f(V_0))$ for instataneous

$f = f(V', V) \approx f(V'_B, V_B) + (f(V_A) - f(V_0)) + (f(V_C) - f(V_0))$ for TA

Note that the reference point (V_0 in the example) does not have to be the same for all parameters. Database structures such as represented on Fig 9 can also been used. In this case, we even have two choices for the Δf computation on axis 'A'.

The last case is in fact a mix of cases 2 and 3. The gray rectangle and the gray line on Fig. 10 and 11 reprensent where all the lattice computations have been performed. With the notations used on those figures, one can write that the best estimate interpolated values, f, we can get are given by:

$f = f(V) \approx f(V_B) + (f(V_{BC}) - f(V_B)) + (f(V_A) - f(V_0)) = f(V_{BC}) + (f(V_A) - f(V_0))$ for instataneous

$f = f(V', V) \approx f(V'_B, V_B) + (f(V'_{BC}, V_{BC}) - f(V'_B, V_B)) + (f(V_A) - f(V_0)) = f(V'_{BC}, V_{BC}) + (f(V_A) - f(V_0))$ for TA

Note once again that the reference point (V_0 in the example) does not have to be the same for all parameters. Database structures such as represented on Fig 12 can also been used.

The input files will actually reflect the previous equations. However, they are different if the parameters are stored in a MAP object, *MAPFL*, or provided directly by the user. For the case of one point interpolation (i.e. instantaneous), the input files will be:

case	all parameters explicitly set	all parameters in MAP
| GRID (Fig. 3) | ```
MACROLIB := SCR: SAP ::
    NMIX 1
    SAPHYB SAP
    MIX 1
        SET 'A' <<va>>
        SET 'B' <<vb>>
        SET 'C' <<vc>>
    ENDMIX
;
``` | ```
MACROLIB := SCR: SAP FMAP ::
    NMIX 1
    TABLE SAP 'B'
    MIX 1
    ENDMIX
;
``` |
| PLANE (Fig. 5) | ```
MACROLIB := SCR: SAP ::
    NMIX 1
    SAPHYB SAP
    MIX 1
        SET 'A' <<va>>
        SET 'B' <<vb>>
        SET 'C' <<vc0>>
        ADD 'C' <<vc0>> <<vc>>
            REF  'A' <<va0>>
                 'B' <<vb>> ENDREF
!or              'B' SAMEASREF ENDREF
    ENDMIX
;
``` | ```
MACROLIB := SCR: SAP FMAP ::
    NMIX 1
    TABLE SAP 'B'
    MIX 1
        SET 'C' <<vc0>>
        ADD 'C' <<vc0>> MAP
            REF  'A' <<va0>>
                 'B' SAMEASREF ENDREF
!or     SET 'A' <<va0>>
!or     ADD 'A' <<va0>> MAP
!or         REF  'C' <<vc0>>
!or              'B' SAMEASREF ENDREF
    ENDMIX
;
``` |
| AXE (Fig. 7) | ```
MACROLIB := SCR: SAP ::
    NMIX 1
    SAPHYB SAP
    MIX 1
        SET 'A' <<va0>>
        SET 'B' <<vb>>
        SET 'C' <<vc0>>
        ADD 'A' <<va0>> <<va>>
            REF  'C' <<vc0>>
                 'B' <<vb0>> ENDREF
        ADD 'C' <<vc0>> <<vc>>
            REF  'A' <<va0>>
                 'B' <<vb0>> ENDREF
    ENDMIX
;
``` | ```
MACROLIB := SCR: SAP FMAP ::
    NMIX 1
    TABLE SAP 'B'
    MIX 1
        SET 'A' <<va0>>
        SET 'C' <<vc0>>
        ADD 'A' <<va0>> MAP
            REF  'C' <<vc0>>
                 'B' <<vb0>> ENDREF
        ADD 'C' <<vc0>> MAP
            REF  'A' <<va0>>
                 'B' <<vb0>> ENDREF
    ENDMIX
;
``` |
| | | *continued on next page* |

case	all parameters explicitly set	all parameters in MAP
PLANE + AXE (Fig. 10)	```MACROLIB := SCR: SAP ::
NMIX
SAPHYB SAP
MIX 1
SET 'A' <<va0>>
SET 'B' <<vb>>
SET 'C' <<vc>>
ADD 'A' <<va0>> <<va>>
REF 'C' <<vc0>>
'B' <<vb0>> ENDREF
ENDMIX
;```	```MACROLIB := SCR: SAP FMAP ::
NMIX 1
TABLE SAP 'B'
MIX 1
SET 'A' <<va0>>
ADD 'A' <<va0>> MAP
REF 'C' <<vc0>>
'B' <<vb0>> ENDREF
ENDMIX
;```

Table 65: SCR inputs for instantaneous cases

For the TA, the burnup variable has no other choice than to be stored in the MAP object, *MAPFL*. Then the input files will be:

case	only the burnup in MAP	all parameters in MAP
GRID (Fig. 4)	```MACROLIB := SCR: SAP FMAP ::
NMIX 1
TABLE SAP 'B'
MIX 1
SET 'A' <<va>>
SET 'C' <<vc>>
ENDMIX
;```	```MACROLIB := SCR: SAP FMAP ::
NMIX 1
TABLE SAP 'B'
MIX 1
ENDMIX
;```
PLANE (Fig. 6)	```MACROLIB := SCR: SAP FMAP ::
NMIX 1
TABLE SAP 'B'
MIX 1
SET 'A' <<va>>
SET 'C' <<vc0>>
ADD 'C' <<vc0>> <<vc>>
REF 'A' <<va0>>
'B' SAMEASREF ENDREF
ENDMIX
;```	```MACROLIB := SCR: SAP FMAP ::
NMIX 1
TABLE SAP 'B'
MIX 1
SET 'C' <<vc0>>
ADD 'C' <<vc0>> MAP
REF 'A' <<va0>>
'B' SAMEASREF ENDREF
!or   SET 'A' <<va0>>
!or   ADD 'A' <<va0>> MAP
!or   REF 'C' <<vc0>>
!or   'B' SAMEASREF ENDREF
ENDMIX
;```
		continued on next page

case	only the burnup in MAP	all param. in MAP
| AXE (Fig. 8) | ```
MACROLIB := SCR: SAP FMAP ::
   NMIX 1
   TABLE SAP 'B'
   MIX 1
      SET 'A' <<va0>>
      SET 'C' <<vc0>>
      ADD 'A' <<va0>> <<va>>
         REF  'C' <<vc0>>
               'B' <<vb0>> ENDREF
      ADD 'C' <<vc0>> <<vc>>
         REF  'A' <<va0>>
               'B' <<vb0>> ENDREF
   ENDMIX
;
``` | ```
MACROLIB := SCR: SAP FMAP ::
   NMIX 1
   TABLE SAP 'B'
   MIX 1
      SET 'A' <<va0>>
      SET 'C' <<vc0>>
      ADD 'A' <<va0>> MAP
         REF  'C' <<vc0>>
               'B' <<vb0>> ENDREF
      ADD 'C' <<vc0>> MAP
         REF  'A' <<va0>>
               'B' <<vb0>> ENDREF
   ENDMIX
;
``` |
| PLANE + AXE (Fig. 11) | ```
MACROLIB := SCR: SAP FMAP ::
   NMIX 1
   TABLE SAP 'B'
   MIX 1
      SET 'A' <<va0>>
      SET 'C' <<vc>>
      ADD 'A' <<va0>> <<va>>
         REF  'C' <<vc0>>
               'B' <<vb0>> ENDREF
   ENDMIX
;
``` | ```
MACROLIB := SCR: SAP FMAP ::
   NMIX 1
   TABLE SAP 'B'
   MIX 1
      SET 'A' <<va0>>
      ADD 'A' <<va0>> MAP
         REF  'C' <<vc0>>
               'B' <<vb0>> ENDREF
   ENDMIX
;
``` |

Table 66: SCR inputs for TA cases

4.4 The `PCR:` module

This component of DONJON is dedicated to the interpolation of MICROLIB and MACROLIB data from a PMAXS file, the reactor database produced by the GenPMAXS utility.[51] A set of *parameters* are defined for each material mixture and used as multi-dimensional interpolation variables.

The calling specifications are:

Table 67: Structure **(PCR:)**

MLIB := PCR: [{ *MLIB* | *MLIB2* }] *PMAX1* [[*PMAX2*]] [*MAPFL*] :: **(PCR_data)**

---

where

MLIB   character*12 name of a MICROLIB (type L_LIBRARY) or MACROLIB (type L_MACROLIB) containing the interpolated data. If this object also appears on the RHS of structure **(PCR:)**, it is open in modification mode and updated.

MLIB2   character*12 name of an optional MICROLIB object whose content is copied on *MLIB*.

PMAX1   character*12 name of the PMAXS file.

PMAX2   character*12 name of an additional PMAXS file. This file is optional.

MAPFL   character*12 name of the MAP object containing fuel regions description, parameter information (burnup, fuel/coolant temperatures, coolant density, etc). Keyword TABLE is expected in **(PCR_data)**.

PCR_data   input data structure containing interpolation information (see Section 4.4.1).

4.4.1 Interpolation data input for module `PCR:`

Table 68: Structure **(PCR_data)**

```
[ EDIT iprint ]
[ { MACRO | MICRO } ] [ { LINEAR | CUBIC } ] [ LEAK b2 ]
[ NMIX nmixt ]
{ [[ PMAXS PMAX (descintf) ]]
 | [[ TABLE PMAX (descintf) ]] }
[ (descdepl) ]
;
```

---

where

EDIT   keyword used to set *iprint*.

iprint   index used to control the printing in module `PCR:`. =0 for no print; =1 for minimum

printing (default value).

MACRO	keyword indicating that *MLIB* is a macrolib (default option).
MICRO	keyword indicating that *MLIB* is a microlib. Object *MLIB* contains an embedded macrolib, but the CPU time required to obtain it is longer.
LINEAR	keyword indicating that interpolation of the PMAXS file uses linear Lagrange polynomials (default option).
CUBIC	keyword indicating that interpolation of the PMAXS file uses the Ceschino method with cubic Hermite polynomials, as presented in Ref. [17].
LEAK	keyword used to introduce leakage in the embedded macrolib. This option should only be used for non-regression tests.
b2	the imposed buckling corresponding to the leakage.
NMIX	keyword used to define the maximum number of material mixtures. This information is required only if *MLIB* is created.
nmixt	the maximum number of mixtures (a mixture is characterized by a distinct set of macroscopic cross sections) the macrolib may contain. The default value is *nmixt* = 0 or the value recovered from *MLIB* if it appears on the RHS of structure **(PCR:)**.
PMAXS	keyword used to set *PMAX* and to define each parameter.
TABLE	keyword used to set *PMAX* and to recover some parameter from a map object named *MAPFL*.
PMAX	`character*12` name of the PMAXS file where the interpolation is performed. This name must be set in the RHS of structure **(PCR:)**.
descintf	input data structure containing interpolation information relative to the PMAXS file named *PMAX* (see Section 4.4.2).
(descdepl)	input structure describing the depletion chain (see Section 4.4.3). This input structure requires option MICRO. By default, the depletion chain data is not written in the output microlib.

4.4.2 Defining parameters

If a map object is defined on the RHS of structure **(PCR:)**, and if the TABLE keyword is set, some information required to set the interpolation points is found in this object. In this case, the PCR: operator search the PMAXS file for parameters having an arbitrary name specified in the map object or set directly in this module. Note that any parameter's value set directly in this module prevails on a value stored in the *MAPFL* object.

Each instance of *descintf* is a data structure specified as

Table 69: Structure **(descintf)**

[[MIX *imix*

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

```
    [ { TIMAV-BURN | INST-BURN | AVG-EX-BURN ivarty } ]
    [[ { SET | DELTA | ADD } } [ { LINEAR | CUBIC } ] PARKEY { val1 | MAP } [ { val2 | MAP } ]
        [ REF [[ PARKEY { valref | SAMEASREF } ]] ENDREF ] ]]
    [ MICRO [[ HISO conc ]] ]
ENDMIX ]]
```

where

MIX   keyword used to set *imix*.

imix   index of the mixture that is to be created in the MICROLIB and MACROLIB.

TIMAV-BURN   keyword used to compute time-averaged cross-section information. This option is avail-
                        able *only if* a *MAPFL* object is set. By default, the type of calculation (TIMAV-BURN
                        or INST-BURN) is recovered from the *MAPFL* object.

INST-BURN   keyword used to compute cross-section information at specific bundle burnups. This
                        option is available *only if* a *MAPFL* object is set. By default, the type of calculation
                        (TIMAV-BURN or INST-BURN) is recovered from the *MAPFL* object.

AVG-EX-BURN   keyword used to compute the derivatives of cross-section information relative to the
                        exit burnup of a single combustion zone. The derivatives are computed using Eq. (3.3)
                        of Ref. [16], written as

$$\frac{\partial \bar{\Sigma}_x}{\partial B_j^{\mathrm{e}}} = \frac{1}{B_j^{\mathrm{e}} \left(B_{j,k}^{\mathrm{eoc}} - B_{j,k}^{\mathrm{boc}}\right)} \left[-\int_{B_{j,k}^{\mathrm{boc}}}^{B_{j,k}^{\mathrm{eoc}}} dB \, \Sigma_x(B) + B_{j,k}^{\mathrm{eoc}} \, \Sigma_x(B_{j,k}^{\mathrm{eoc}}) - B_{j,k}^{\mathrm{boc}} \, \Sigma_x(B_{j,k}^{\mathrm{boc}}) \right]$$

                        where $B_{j,k}^{\mathrm{boc}}$, $B_{j,k}^{\mathrm{eoc}}$, and B_j^{e} are the beginning of cycle burnup of bundle $\{j, k\}$, end of
                        cycle burnup of bundle $\{j, k\}$ and exit burnup of channel j. This option is available
                        only if a *MAPFL* object is set. By default, the type of calculation (TIMAV-BURN or
                        INST-BURN) is recovered from the *MAPFL* object.

ivarty   index of the combustion zone for differentiation of cross-section information.

SET   keyword used to indicate a simple interpolation at *val1* or an averaging between *val1*
                        and *val2*. The result σ_{ref} is also used as the reference value when the ADD is used.
                        Note: see at the ending note of this section for a detailed description and examples.

DELTA   keyword used to indicate a delta-sigma calculation between *val2* and *val1* (i.e., $\Delta\sigma_{\mathrm{ref}} = \sigma_{\mathrm{val2}} - \sigma_{\mathrm{val1}}$ is computed). This keyword can be used only once in each mixture data
                        block (initiated with a MIX keyword). Note: see at the ending note of this section for
                        a detailed description and examples.

ADD   keyword used to indicate a delta-sigma calculation between *val2* and *val1* is added
                        to the reference value (i.e., $\Delta\sigma = \sigma_{\mathrm{val2}} - \sigma_{\mathrm{val1}}$ is used as contribution, $\sigma_{\mathrm{ref}} + \Delta\sigma$ or
                        $\Delta\sigma_{\mathrm{ref}} + \Delta\sigma$ is returned). Note: see at the ending note of this section for a detailed
                        description and examples.

LINEAR   keyword indicating that interpolation of the PMAXS file for parameter *PARKEY*
                        uses linear Lagrange polynomials. It is possible to set different interpolation modes to
                        different parameters. By default, the interpolation mode is set in Sect. 4.4.1.

CUBIC   keyword indicating that interpolation of the PMAXS file for parameter *PARKEY* uses the Ceschino method with cubic Hermite polynomials, as presented in Ref. [17]. By default, the interpolation mode is set in Sect. 4.4.1.

PARKEY   `character*12` user-defined keyword associated to a parameter to be set.

val1   value of a parameter used to interpolate. *val1* is the initial value of this parameter in case an average is required. *val1* can be an integer, real or string value.

val2   value of the final parameter. By default, a simple interpolation is performed, so that *val2=val1*. *val2* is always a real value with *val2≥val1*.

MAP   keyword used to indicate that the value of parameter *val1* or the second value for the $\Delta\sigma$ calculation is recovered from *MAPFL*, i.e. the MAP object containing fuel regions description.

REF   keyword only available together with the `ADD` option. It is used to set all the other variable values when a Δ contribution is performed for one variable.

valref   value of the reference parameter, when it is directly given by the user. Note that there is no default value.

SAMEASREF   keyword used to specify that the reference value will be the same as in the refence case, i.e. for the σ_{ref} computation.

ENDREF   keyword only available together with the `ADD` option. It is used to specify that all the other variable values which are required are given.

MICRO   keyword used to set the number densities of some isotopes present in the PMAXS file.

HISO   `character*8` name of an isotope (namely `'Xe135'` or `'Sm149'`).

conc   user-defined value of the number density (in 10^{24} particles per cm^3) of the isotope.

ENDMIX   end of specification keyword for the material mixture.

4.4.3 Depletion data structure

   Depletion data is recovered from the input data structure **(descdepl)**. This data describes the heredity of the radioactive decay and the neutron activation chain.

Table 70: Structure **(descdepl)**

```
CHAIN nel
  [[ NAMDPL [ izae ]
      [[ { DECAY dcr | reaction [ energy ] } ]]
    [ { STABLE | FROM [[ { DECAY | reaction } [[ yield NAMPAR ]] ]] } ] ]]
ENDCHAIN
```

with:

CHAIN   keyword to specify the beginning of the depletion chain.

nel   number of depleting isotopes in the chain.

NAMDPL   `character*12` name of an isotope (or isomer) of the depletion chain that appears as a particularized isotope of the PMAXS file.

izae   optional six digit integer representing the isotope. The first two digits represent the atomic number of the isotope; the next three indicate its mass number and the last digit indicates the excitation level of the nucleus (0 for a nucleus in its ground state, 1 for an isomer in its first exited state, etc.). For example, ^{238}U in its ground state will be represented by *izae*=922380.

DECAY   indicates that a decay reaction takes place either for production of this isotope or its depletion.

dcr   radioactive decay constant (in 10^{-8} s^{-1}) of the isotope. By default, *dcr*=0.0.

reaction   `character*6` identification of a neutron-induced reaction that takes place either for production of this isotope, its depletion, or for producing energy. Example of reactions are following:

    NG   indicates that a radiative capture reaction takes place either for production of this isotope, its depletion or for producing energy.

    N2N   indicates that the following reaction is taking place:
$$n +^A X_Z \rightarrow 2n +^{A-1} X_Z$$

    N3N   indicates that the following reaction is taking place:
$$n +^A X_Z \rightarrow 3n +^{A-2} X_Z$$

    N4N   indicates that the following reaction is taking place:
$$n +^A X_Z \rightarrow 4n +^{A-3} X_Z$$

    NP   indicates that the following reaction is taking place:
$$n +^A X_Z \rightarrow p +^A Y_{Z-1}$$

    NA   indicates that the following reaction is taking place:
$$n +^A X_Z \rightarrow^4 He_2 +^{A-3} X_{Z-2}$$

    NFTOT   indicates that a fission is taking place.

energy   energy (in MeV) recoverable per neutron-induced reaction of type *reaction*. If the energy associated to radiative capture is not explicitly given, it should be added to the energy released per fission. By default, *energy*=0.0 MeV.

STABLE   non depleting isotope. Such an isotope may produces energy by neutron-induced reactions (such as radiative capture).

FROM   indicates that this isotope is produced from decay or neutron-induced reactions.

DECAY   indicates that a decay reaction takes place for its production.

yield   branching ratio or production yield expressed in fraction.

NAMPAR   `character*12` name of the a parent isotope (or isomer) that appears as a particularized isotope of the PMAXS file.

ENDCHAIN   keyword to specify the end of the depletion chain.

4.5   The `AFM:` module

The `AFM:` module is used to create an extended MACROLIB containing set of interpolated nuclear properties from a feedback model database.[21] The DATABASE information are obtained by previous DRAGON calculations using module `CFC:`.[18]

There are two possible utilizations:

- Construction of an extended MACROLIB for fuel properties directly from DATABASE information with respect to local parameters contained in the fuel map object or directly input.

- Construction of an extended MACROLIB containing only one set of cross sections derivated from the DATABASE information. Properties can be obtained for fuel or reflector.

The calling specifications are:

Table 71: Structure `AFM:`

MACRO := `AFM:` [*MACRO*] *DBASE* [*MAPFL*] :: **(descafm)**

where

MACRO   `character*12` name of the extended MACROLIB. The MACROLIB can be in modification mode.

DBASE   `character*12` name of the DATABASE object containing fuel properties with respect to local parameters.

MAPFL   `character*12` name of the MAP object containing fuel regions description and burnup informations. This file is only required when a MACRO is created for fuel area.

(descafm)   structure containing the data to module `AFM:`.

4.5.1 Input data to the `AFM:` module

Table 72: Structure **(descafm)**

```
{ MAP | MCR mmix } INFOR NAMDB
DNAME ntyp ( NAMTYP(i), i=1,ntyp )
REFT ( imix(i) NAMTYP(i), i=1,ntyp )
[ EDIT iprint ]
[ FIXP { INIT | pow } ]
[ { PWF | NPWF } ]
[ TFUEL tfuel ]
[ TCOOL tcool ]
[ TMOD tmod ]
```

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

```
[ BORON nB ]
[ RDCL dcool ]
[ RDMD dmod ]
[ PUR purity ]
[ BURN bval ]
[ { XENON nXe | XEREF } ]
[ { NEP nNp | NREF } ]
[ SAM nSm ]
[ IMET imet ]
[ BLIN ]
;
```

where

MAP	keyword to specify that a MACROLIB for fuel properties will be computed.
MCR	keyword to specify that a MACROLIB containing only one non-zero mixture will be created.
mmix	maximum number of mixtures in the MACROLIB.
INFOR	keyword to specify the data base name.
NAMDB	`character*72` title of the database as it has been created.
DNAME	keyword to specify the number of fuel types and their names as stored in the data base.
ntyp	number of fuel types. For MCR option, *ntyp* must be 1.
NAMTYP(i)	`character*12` name of the directory where each fuel type information has been stored.
REFT	keyword to specify a number associated with a fuel type name.
imix(i)	fuel type index as specified for the fuel map or a non-zero mixture number for the single-property sc macrolib.
EDIT	keyword used to set *iprint*.
iprint	index used to control the printing in module AFM:. =0 for no print(default value); =1 for minimum printing; larger values produce increasing amounts of output.
FIXP	keyword used to set the power used for cross-section interpolation.
INIT	a distributed beginning-of-transient bundle power in kW is used. This power distribution has to be pre-calculated in the FLPOW: module using the INIT keyword.
pow	uniform bundle power in kW. If this data is omitted, the reference value in the data base is used or the bundle powers present in a MAP. The reference value is 615 kW if none were provided at the database computation time.
PWF	keyword used to activate power bundle feedback on fuel properties using powers recovered from 'BUND-PW' record in *MAPFL*. This is the default option if MAP is selected.
NPWF	keyword used to desactivate PWF feedback. This is the only possible option if MCR is selected.

TFUEL	keyword used to set *tfuel*.
tfuel	fuel temperature in K. If this data is omitted and the bundle powers present in a MAP, fuel temperatures are computed with respect to powers. If this data is omitted and there is no bundle power, the reference value in the data base is used, where it is 941.29 K if none were provided at the database computation time.
TCOOL	keyword used to set *tcool*.
tcool	coolant temperature in K. If this data is omitted, the reference value in the data base is used. The reference value is 560.66 K if none were provided at the database computation time.
TMOD	keyword used to set *tmod*.
tmod	moderator temperature in K. If this data is omitted, the reference value in the data base is used. The reference value is 345.66 K if none were provided at the database computation time.
BORON	keyword used to set nB.
nB	Boron concentration in ppm. If this data is omitted, the reference value in the data base is used. The reference value is 0.0 ppm. See note below for inside equations.
RDCL	keyword used to set *dcool*.
dcool	coolant density in g/cm^3. If this data is omitted, the reference value in the data base is used. The reference value is 0.81212 g/cm^3 if none were provided at the database computation time.
RDMD	keyword used to set *dmod*.
dmod	moderator density in g/cm^3. If this data is omitted, the reference value in the data base is used. The reference value is 1.082885 g/cm^3 if none were provided at the database computation time.
PUR	keyword used to set *purity*.
purity	moderator purity in atm%. If this data is omitted, the reference value in the data base is used. The reference value is 99.911 atm% if none were provided at the database computation time.
BURN	keyword used to set *bval*. This option is valid only when MCR is used and can not be omitted.
bval	fuel burnup in MWd/t. This value must be positive.
XENON	keyword used to set nXe.
nXe	Xenon concentration in $10^{24}at/cm^3$. This concentration will be applied to every bundle.
XEREF	keyword used to specify that the Xenon concentrations as computed with DRAGON will be taken. If this option is omitted and MAP contains bundle fluxes, new Xenon concentrations will be computed and used.
NEP	keyword used to set nNp.
nNp	Neptunium concentration in $10^{24}at/cm^3$.

XEREF   keyword used to specify that the Neptunium concentrations as computed with DRAGON will be taken. If this option is omitted and MAP contains bundle fluxes, new Neptunium concentrations will be computed and used.

SAM   keyword used to set *nSm*.

nSm   Samarium concentration in $10^{24} at/cm^3$. If this data is omitted, bundle concentrations as computed by DRAGON is used.

IMET   keyword used to set *imet*.

imet   interpolation type for time-average calculations. $imet = 1$: using Lagrange approximations; $imet = 2$: using spline approximations; $imet = 3$: using Hermite approximations (default value).

BLIN   keyword used to linear interpolation for burnup instead of the Lagrangian interpolation method.

Note: The concentration of boron is provided in terms of $10^{24} at/cm^3$ in the database. However, the usual units are $ppm(wt)$ of Boron. Thus, the input asks for ppm of Boron (n_B), and automatically transform the units into $10^{24} at/cm^3$ using the following equations:

$$\rho_B(g/cm^3) \quad = \quad n_B \cdot \rho_{\text{water}}(g/cm^3)$$

and

$$\rho_{\text{water}}(at/cm^3) \quad = \quad 3\rho_{\text{water}}(molecule/cm^3) = \frac{3.N}{M_{\text{water}}}\rho_{\text{water}}(g/cm^3)$$

$$\rho_B(at/cm^3) \quad = \quad \rho_B(molecule/cm^3) = \frac{N}{M_B}\rho(g/cm^3)$$

thus

$$\rho_B(10^{24} at/cm^3) \quad = \quad n_B \cdot \frac{M_{\text{water}}}{3.M_B}\rho_{\text{water}}(10^{24} at/cm^3)$$

where M molar mass and N the Avogadro number.

They are many options on how to use the module AFM: for its different purposes. A compact summary is presented on Tab. 73.

The Rozon correlation for fuel temperature as a function of bundle power is:

$$T_{\text{fuel}} = T_{\text{cool}} + 0.476\, P + 2.267\, P^2 \times 10^{-4}$$

where P is in kW and temperatures are in Kelvin.

Table 73: AFM options summary

Option	Keywords	Parameter values
MCR	REFT	Nominal values
	REFT + {TFUEL, TCOOL, ...}	Nominal values except for specified parameters
TAB	REFT	Nominal values except for TFUEL parameter which is computed according to the Rozon correlation using nominal power
	REFT + {TFUEL, TCOOL, ...}	Same as above except for specified parameters which will have a constant value
MAP with local parameters	REFT	Nominal values except for local parameters included in MAP
	REFT + {TFUEL, TCOOL, ...}	Same as above except for specified parameters which will have a constant value
MAP without local parameters	REFT	Nominal values except for TFUEL parameter which is computed according to the Rozon correlation if power distribution is available
	REFT + {TFUEL, TCOOL, ...}	Same as above except for specified parameters which will have a constant value

4.6 The `T16CPO:` module

The WIMS–AECL `Tape16` file is a FORTRAN sequential binary file which is used to transfer the results of a WIMS–AECL calculation to other applications.[26] The explicit contents of this file may vary from application to application since the output of most records to this file is controlled by the user who can activate specific keywords in the WIMS–AECL input file.

The standard CPO data structure used by the code DONJON is generally generated by the cell code DRAGON. This data structure can be stored on a FORTRAN direct access binary file in the form of a hierarchical data base. There is also the possibility to keep the contents of this data structure in memory (with the same hierarchical structure) for faster access. The structure of the data base is in the form of a list of material directories which contain burnup sub-directories. Inside each of these burnup sub-directories the isotopic contents of a mixture is described and the multigroup cross sections associated with a specific isotope are stored in individual sub-directories. Note that in this database the macroscopic cross sections associated with a mixture are stored in a default isotopic sub-directory.

The interface between the `Tape16` file and the CPO data structure should be written as a new module of the code DONJON in order to facilitate the access to the GANLIB utilities which manage the hierarchical data structures. This module will be called `T16CPO:`. The transfer of information from a `Tape16` format file to a CPO data structure will require the following DONJON instructions:

The `T16CPO:` module specifications for creating or updating a CPO data structure from a `Tape16` file are:

Table 74: Structure `T16CPO:`

DONCPO := T16CPO: [DONCPO] WIMS16 :: **(desct16cpo)** ;

where

DONCPO   name of data structure where the output CPO is stored. This can be a new data structure or an old data structure which will be updated.

(desct16cpo)   input specifications for the execution of the `T16CPO:` module.

;   end of record keyword. This keyword is used to delimit the part of the input data stream associated the current module.

In the following dataset

```
MODULE T16CPO: ;
SEQ_BINARY WIMS16 ;
LINKED_LIST DONCPO ;

DONCPO :=  T16CPO: WIMS16 ::
...
;
```

means that that the module will read the sequential binary file `WIMS16` file (in readonly mode) and create the CPO data structure `DONCPO` while the dataset

```
MODULE T16CPO: ;
SEQ_BINARY WIMS16 ;
LINKED_LIST DONCPO ;
```

```
DONCPO :=  T16CPO: DONCPO WIMS16 ::
...
;
```

means that the data structure `DONCPO` will be updated. The input instructions (replaced by ... here) should indicate what part of the information located on `WIMS16` should be transferred to `DONCPO` and in what order.

4.6.1 Input data for the `T16CPO:` module

The input data structure (**desct16cpo**) will take the form:

Table 75: Structure (**desct16cpo**)

```
[ EDIT iprint ]
[ NMIX nmixt ]
[ CONDG ngcond (igc(i) , i=1,ngcond ) ]
[ LIST ]
[ MIX [[ MIXNAM [ { CELLAV | REGION noreg } ]
      [ RC [ nburn ] frstrec ]
      [[ NAMPER valref npert (valper(i), frstrec(i) , i=1,npert ) ]]
      [ MTMD [ valreft valrefd ] npert (valpert(i), valperd(i), frstrec(i) , i=1,npert ) ]
      ]] ]
```

where

EDIT	optional keyword used to modify the print level *iprint*.
iprint	index used to control the printing in this module. It must be set to 0 if no printing on the output file is required while values <10 will print general information about each record requested on `Tape16` as well as other generic information pertinent to the `T16CPO:` module. Finally for values of *iprint*≥10, additional information required for debugging will be printed. The default value is *iprint*=1.
NMIX	optional keyword used to define the number of mixtures created on the CPO data structure.
nmixt	the maximum number of mixtures created. The default value is *nmixt*=1.
CONDG	optional keyword used to define the group structure for condensation. In the case where the CPO is to be updated, the information following CONDG must yield an energy group structure compatible with that already available on this data structure. If it is absent, the code will first try to use the CPO group structure (if available). Then, it will try to use the editing group structure corresponding to NGREAC on the following `Tape16` record:

        REACTION␣␣, FLUX␣␣␣␣␣␣, NEL

        Finally, if everything else fails, it will select the main transport group structure corresponding to NGMTR on the following `Tape16` record:

WIMS␣␣␣␣␣␣, CONSTANT␣␣, NEL

ngcond	the number of condensed groups required.
ilg	the last group number associated with each condensed group.
LIST	keyword to specify that the complete contents of `Tape16` must be listed on the output file.
MIX	keyword to specify that the remaining information will be associated with mixture properties definition.
MIXNAM	`character*6` name of the mixture to create or update on the CPO.
CELLAV	optional keyword to specify that cell averaged data will be taken from `Tape16`. This is the default option.
REGION	optional keyword to specify that regional data will be taken from `Tape16`. The default option is `CELLAV`.
noreg	region number associated with this material in `Tape16`.
RC	optional keyword to specify that the cross section taken from `Tape16` are at reference value. This information must be defined at least once for each mixture. It must also precede the definition of perturbation parameters.
nburn	number of consecutive burnup steps associated with mixture. The default value is *nburn*=1. We will assume that the same number of burnup steps is also available for the nuclear properties associated with the perturbed local parameters.
frstrec	first `Tape16` record number associated with this mixture.
NAMPER	`character*2` name of the perturbation. Each perturbation is associated with a single local parameter. The values permitted for *NAMPER* are the following:

  1. FT for fuel temperature
  2. MT for moderator temperature
  3. MD for moderator density
  4. MP for moderator purity
  5. MB for moderator boron
  6. CT for coolant temperature
  7. CD for coolant density
  8. CP for coolant purity
  9. RT for reflector temperature
  10. RD for reflector density
  11. RP for reflector purity

Note that these keywords are identical to those used in the Proc16 program.[27] Here the moderator, coolant and reflector can be D_2O, H_2O or any other mixture since DONJON is not aware of the compositions of these mixtures. In the case where many different `Tape16` files contains the reference and the individual perturbation effects, one must first define the reference case before updating the CPO using the `Tape16` files containing the perturbations.

valref	reference value of the associated local parameter.

npert	number of local parameter perturbations.
valper	perturbed values of the local parameter.
MTMD	`character*4` name of perturbation associated with combine temperature and density changes effects. Note that this keyword is equivalent to the `MTS` keyword used in the Proc16 program.[27] In principle, any combined perturbations effects could be built from the catenation of two individual perturbations given in *NAMPER*.
valreft	reference temperature. This is required if either the `MT` or the `MD` perturbation is not defined.
valrefd	reference density. This is required if either the `MT` or the `MD` perturbation is not defined.
npert	number of simultaneous perturbations in moderator temperature and density.
valpert	perturbed values of the moderator temperature.
valperd	perturbed value of the moderator density.

The explicit name of the mixtures MIXDIR that will be stored on the main CPO directory will correspond to a catenation of *MIXNAM* and a perturbation name and an index i describing the perturbation order. It is created using the following FORTRAN instructions for the reference mixture:

WRITE(MIXDIR,'(A6,A6)') *MIXNAM*, 'RC␣␣␣␣'

while for the ith perturbed state associated with *NAMPER*(J) we will use:

WRITE(MIXDIR,'(A6,A2,A2,I2)') *MIXNAM*, *NAMPER*(J),'␣␣', i

Finally, for the ith perturbed state associated with the `MTMD` perturbation we will use:

WRITE(MIXDIR,'(A6,A4,I2)') *MIXNAM*, 'MTMD', i

Typically if the **(desct16cpo)** structure takes the form:

```
EDIT 0
NMIX 2
MIX
    Candu  RC 15 1
           FT 900.0 2 1100.0 16 1300.0 46
    Maple  RC 70
           RP 1.0 1 0.5 71
```

Then the first 15 cases stored on the `Tape16` file will correspond to a reference CANDU fuel with burnup. The reference fuel temperature is 900.0 K. The next 15 cases are for a fuel temperature of 1100.0 K. Finally cases 46 to 60 are for a fuel temperature of 1300.0 K. The Maple mixture will have no burnup. The reference Maple cross sections correspond to case 70, while case 71 contains the effect on the Maple fuel mixture cross sections of a 50 % reduction in reflector purity . As a result we will end up with a CPO data structure which contains 5 mixtures called respectively

Candu␣RC␣␣␣␣

Candu␣FT␣␣␣1

Candu␣FT␣␣␣2

Maple␣RC␣␣␣␣

Maple␣RP␣␣␣1

The beginning of a new case on `Tape16` will be identified by the presence of the record:

CELLAV␣␣␣␣,MODERATOR

in a `Tape16` file. Accordingly, the keyword `CELLAV` should be used in the WIMS–AECL run creating this file. In addition, if the `REGION` option is used in the `T16CPO:` input data structure, then it should also be used in the WIMS–AECL run creating this file.

4.7 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 [50] 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.).

4.7.1 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*)[51]. 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 Σ 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 [51].

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 [51]. 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 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

4.7.2 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:` (or `NCR:`) 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 76: Structure `D2P:`

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

PROC   `ascii file` data set automoatically created by `:=D2P:` and used for execution of `PHASE=2` and `PHASE=3`.

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

NB : The complete sequence of execution of the `:=D2P:` module should be performed in two separate data files.The first execution is dedicated to `PHASE=1` and then, at the end of this step, a second data file is automatically generated by the module to run `PHASE=2` and `PHASE=3`.

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

Table 77: Structure (`descphase1`)

```
[ NAMDIR mixdir ] [ MIX imix ]
[ TEMP htemp ]
[ PKEY (refnam(i) sapnam(i), i=1, npkey) ENDPKEY ]
[ OTHER noth (othpk(i) othtyp(i) othval(i), i=1, noth) ]
[ ADF [ MERGE ] { DRA nadf  (hadf(i), i=1,nadf) | GET | SEL} ]
[ CDF DRA ncdf  (hcdf(i), i=1,ncdf) ]
[ GFF DRA ]
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 } } } ]
[ ISOTOPES { [ XE135 xenam ] [ SM149 smnam ] [ I135 inam ] [ PM147 pm47nam ] [ ND147 nd47nam ]
[ PM149 pmnam ] [ PM148 pm48nam ] [ PM148M pm48mnam ] [ PM149 pmam ] } ENDISOTOPES ]
[ DET hdet ]
[ YLD [ COR ] { REF | MAN (refnam(i),val(i), i=1,npkey) ENDMAN | FIX yldi yldxe yldpm } ]
}
| REFLECTOR
HELIOS [
  [ FILE_CONT_1 ncols nrows part hm_dens bypass ]
```

Structure (`descphase1`)

```
  [ 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 ]
  [ XESM xesmopt ] ]
PROC [
  [ MEMO ]
  [ MASL hmasl ]
  [ EQUI hequi ]
  [ ISOT { * | isotval } ] ]
```

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*.
TEMP	keyword used to set *htemp*
htemp	unit for the temperature variables used in the *SAP*. Two units are possible *htemp='C'* or *htemp='K'*. Default *htemp='C'*.
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.
OTHER	keyword used to associate a name of variable in the `SAP` object to a kind of state variable other than the ones defined in `PKEY`.

noth	number of variable wich are not defined in with PKEY but present in the SAP object (*'FLUE'* and *'TIME'* exepted). No default.
othpk	name of the other variable. No default.
othtyp	type of the other variable (REAL STRING or INTEGER). *othtyp=R,S or I*. No default.
othval	value of the other variable . This value is fixed for in the rest of the execution. No default.
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'*.
PM149	keyword used to indicate that the following record correponds to the name of Pm 149 in the SAP (or MCO) object .
pmnam	name of Pm 149 isotope in the SAP (or MCO) object. Default *pmnam = 'PM149PF'*.
PM147	keyword used to indicate that the following record correponds to the name of Pm 147 in the SAP (or MCO) object .
pm47nam	name of Pm 147 isotope in the SAP (or MCO) object. Default *pm47nam = 'PM147PF'*.
ND147	keyword used to indicate that the following record correponds to the name of Nd 147 in the SAP (or MCO) object .
nd47nam	name of Nd 147 isotope in the SAP (or MCO) object. Default *nd47nam = 'ND147PF'*.
PM148	keyword used to indicate that the following record correponds to the name of Pm 148 in the SAP (or MCO) object .
pm47nam	name of Pm 148 isotope in the SAP (or MCO) object. Default *pm48nam = 'PM148PF'*.

PM148M	keyword used to indicate that the following record correponds to the name of Pm 148m in the `SAP` (or `MCO`) object .
pm48mnam	name of Pm 148m isotope in the `SAP` (or `MCO`) object. Default *pm48nam = 'PM148MPF'*.
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.
MERGE	the Assembly Discontinuity Factors are inserted in the cross sections
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.

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

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 The-ory*. NB: This option is available with Saphyb produced by the *APOLLO2* lattice code using a 2-level flux calculation with the Method of Characteristics.

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

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.

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

where g is the energy group, f, the assembly surface, ϕ_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 ($part \geq 2$), the numbering is different with the PARCS version (numbering as for CASMO starting from v3.2m18).

DET keyword to set the name of the particularised isotope in which detector cross sections are to be recovered.

hdet name of the particularised isotopes containing detector information. No default.

YLD keyword used to set the type of fission yields to be recovered from the SAP (or MCO) object. NB : the *lyld* flag must be set to true.

COR	keyword used to correct the PM149 fission yield. The correction applied include the contribution of PM148 and PM148M in the production of SM149 (normally not taken into account in the PARCS depletion chain). The correction is :

$$\gamma_{PM} \Rightarrow \gamma_{PM} \times \left[1 + \left(\frac{\sum_g N^{PM148}\sigma_g^{PM148}\Phi_g + N^{PM148M}\sigma_g^{PM148M}\Phi_g}{\gamma_{PM}\sum_g \Sigma_g^f \Phi_g} \right) \right]$$

	This correction is recommended for comparison with other core codes or with expérimental data. The Pm148 adn Pm148M need to be particularized in the SAP | MCO object (`ISOTOPES` keyword to set isotopes names).
REF	keyword used to indicate that fission yields are recovered from the reference branch calculation.
MAN	keyword used to indicate that fission yields are fixed by the user according to the local conditions specified.
FIX	keyword used to indicate that fission yields are fixed for all local conditions including burnup.
yldi	value for the iodine fission yield. Default: *yldi*=0.06386.
yldxe	value for the xenon fission yield. Default: *yldxe*=0.00228.
yldpm	value for the promethium fission yield. Default: *yldpm*=0.0113.
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. 51.
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. The initial heavy metal density can be computed as follow :

$$hm\_dens = \left(\frac{d_{fuel} \times \pi \times r_{pellet} \times n_{pellet}}{(pitch \times nrows)^2} \right) \times \left(\frac{m_{hm}}{m_{fuel}} \right)$$

	where d_{fuel} is the fuel density, r_{pellet} the radius of fuel pellet, n_{pin} the number of fuel rods, *pitch* the rod lattice pitch, *nrows* the number of rows in whole assembly, m_{hm} the mass of heavy metal, and m_{fuel} the total mass of fuel.
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. 51.
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. 51.
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. 51.
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*≥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. 51, 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) 0: keep up scatter XS, 1: remove up scatter XS, modify down scatter XS with 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. 51.
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. 51.
bfac	the multiplier for betas. If *bfac* is different from 1, then the betas will be multiplied by *bfac*. Default: *bfac*=1.0.
XESM	keyword used to set *xesmopt*. See Ref. 51.
xesmopt	Compare k-inf in genpmaxs using 1:Pm/Sm data, 2: I/Xe data, 3: I/Xe/Pm/Sm data
PROC	keyword used to create automatically the second data set needed to the complete execution of the module.
MEMO	keyword used to store in the *SAP* object in memory. If the size of the object is important this option is recommended.
EQUI	keyword used to select a SPH factor set in the Saphyb. By default, the cross sections and diffusion coefficients are not SPH-corrected.

hequi user-defined keyword used in the saphyb for the SPH factor. This set is stored as local parameter information in the Saphyb.

MASL keyword used to select a heavy metal density in the Saphyb.

hmasl user-defined keyword used in the saphyb for the heavy metal density. This set is stored as local parameter information in the Saphyb.

ISOT keyword used to select a heavy metal density in the Saphyb.

* the value of the number density for all isotopes is recovered from the saphyb object.

isotval user-defined value of the number density (in 10^{24} particles per cm^{-3}). This value is fixed for all particularised isotopes other than Xenon-135 and Samarium-149.

5 THERMAL-HYDRAULICS MODULES

5.1   The `THM:` module

The `THM:` module is a simplified thermal-hydraulics module where the reactor is represented as a collection of independent channels with no cross-flow between them. Each channel is represented using 1D convection equations along the channel and 1D cylindrical equations for a single pin cell. A two-fluid homogeneous model is used. The `THM:` module is built around *freesteam*, an open source implementation of IAPWS-IF97 steam tables for light water.[29].

The simplified model used in `THM:` is based on the work of M. F. Fehri for CANDU clusters[42] and P. Gallet for PWR assemblies[43]. The `THM:` module works both in steady-state and in transient conditions and includes a subcooled flow boiling model based on the *Bowring* correlation[44] or on the *Saha-Zuber* correlation[45] for computing the temperature subcooling at the onset of fully developed boiling (OFDB).

The 1D thermal-hydraulics equations are solved in each channel as a fonction of two *fixed* inlet conditions for the coolant velocity and temperature and one *fixed* outlet condition for the pressure.

The `THM:` module specification is:

Table 78: Structure `THM:`

> *THERMO MAPFL* := `THM:` [*THERMO*] *MAPFL* :: **(descthm)**

where

THERMO	`character*12` name of the THERMO object that will be created or updated by the `THM:` module. Object THERMO contains thermal-hydraulics information set or computed by `THM:` in transient or in permanent conditions such as the distribution of the enthalpy, the pressure, the velocity, the density and the temperatures of the coolant for all the channels in the geometry. It also contains all the values of the fuel temperatures in transient or in permanent conditions according to the discretisation chosen for the fuel rods.
MAPFL	`character*12` name of the MAP object containing fuel regions description and local parameter informations.
(descthm)	structure describing the input data to the `THM:` module.

5.1.1 Input data to the `THM:` module

Table 79: Structure **(descthm)**

> [`EDIT` *iprint*]
> [`FLUID` { `H2O` | `D2O` }]

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

```
[ RELAX relax ]
[ TIME time [ timestep ] ]
[ FPUISS fract ] [ CRITFL cflux ]
INLET poutlet tinlet
{ CWSECT sect flow | INLET-Q sect qfluid | SPEED velocity }
{ ASSMB { nbf | CHAN (nbf(i), i = 1, nch ) } { nbg | CHAN (nbg(i), i = 1, nch ) }
   | CLUSTER pitch { nbf | CHAN (nbf(i), i = 1, nch ) } }
RADIUS r1 r2 r3 r4
[ POROS poros ] [ PUFR { pufr | CHAN (pufr(i), i = 1, nch ) } ]
[ CONDF ncond (kcond(k),k=0,ncond) [ INV inv ref ] unit ]
[ F-RUG epsr ] [ THETA theta ]
[ CONDC ncond (kcond(k),k=0,ncond) unit ]
[ HGAP hgap ] [ HCONV hconv ] [ TEFF wteff ]
[ CONV maxit1 maxit2 maxit3 ermaxt ermaxc ]
[ RODMESH nb1 nb2 ]
[ FORCEAVE ]
[ { MONO | BOWR | SAHA } ]
[ RAD-PROF [[ rprad fprad ]] ]
[ POWER-LAW tpow ntime (t(i) pow(i),i=1,ntime) ]
[[ SET-PARAM PNAME pvalue ]]
[ PICK >> ratio << ]
;
```

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; larger values produce increasing amounts of output.
FLUID	keyword used to set the fluid type. By default, light water (H_2O) is used.
H2O	use light water (H_2O).
D2O	use heavy water (D_2O).
RELAX	keyword used to set the relaxation parameter *relax*.
relax	relaxation parameter selected in the interval $0 <relax\leq 1$ and used to update the fuel (average and surface) temperature, coolant temperature and coolant density. The updated value is taken equal to $(1-relax)$ times the previous iteration value plus *relax* times the actual iteration value. The default value is *relax*$= 1$.
TIME	keyword used to specify the type of calculation (steady-state or transient) performed by the THM: module and the temporal parameters. By default, a steady-state calculation is performed.
time	real value of time in second. Equal to the current time in case of steady-state calculation. Equal to the time at beginning-of-step in case of transient calculation. The default value is 0.0.
timestep	real value (in second) set to the time step in case of a transient calculation. A steady-state/transient calculation is assumed depending if this value is not given/is given.

FPUISS   keyword used to specify the fraction of the power released in fuel. The remaining fraction is assumed to be released in coolant. The default value is 0.974.

fract   real value set to the fraction (f). Power densities released in coolant and fuel are computed as

$$Q_{\mathrm{cool}} = (1 - f)\,\frac{V_{\mathrm{cool}} + V_{\mathrm{fuel}}}{V_{\mathrm{cool}}}\,\frac{P_{\mathrm{mesh}}}{V_{\mathrm{mesh}}}$$

$$Q_{\mathrm{fuel}} = f\,\frac{V_{\mathrm{cool}} + V_{\mathrm{fuel}}}{V_{\mathrm{fuel}}}\,\frac{P_{\mathrm{mesh}}}{V_{\mathrm{mesh}}}$$

where V_{cool} and V_{fuel} are coolant and fuel area computed from *sass*, *nbf*, *nbg*, *r3* and *r4*. The mesh power P_{mesh} and volume V_{mesh} are recovered from *MAPFL* object.

CRITFL   keyword used to specify the critical heat flux.

cflux   real value set to the critical heat flux in W/m^2. The default value is 2.0×10^6 W/m^2.

INLET   keyword used to specify the outlet pressure and inlet absolute temperature.

poutlet   real value set to the outlet coolant pressure in Pa. The pressure along each channel is assumed to be constant and equal to *poutlet* in permanent conditions.

tinlet   real value set to the inlet coolant absolute temperature in K.

CWSECT   keyword used to specify the core coolant section and the coolant inlet flow.

sect   real value set to the core coolant section in m^2.

flow   real value set to the coolant flow in m^3/hr. This value doesn't include the by-pass flow. The inlet coolant velocity in m/s is computed as

$$V = \frac{flow}{3600\ sect}.$$

INLET-Q   keyword used to specify the core coolant section and the inlet mass flow rate.

qfluid   real value set to the inlet mass flow rate in kg/s. This value doesn't include the by-pass flow. The inlet coolant velocity in m/s is computed as

$$V = \frac{qfluid}{\rho_{\mathrm{cool}}\ sect}$$

where ρ_{cool} is the coolant density as obtained by the steam tables as a function of *poutlet* and *tinlet*.

SPEED   keyword used to specify the inlet coolant velocity.

velocity   real value set to the inlet coolant velocity in m/s.

ASSMB   keyword used to specify the assembly characteristics, used for PWR cases.

nbf   integer or real value set to the number of active fuel rods in a single assembly or number of active fuel pins in the cluster. This value can be zero (if a fuel channel is not processed in THM:), integer or real (if a fuel channel contains a fraction of a rod).

nbg   integer or real value set to the number of active guide tubes in a single assembly.

CLUSTER   keyword used to specify the cluster characteristics, used for CANDU reactor cases.
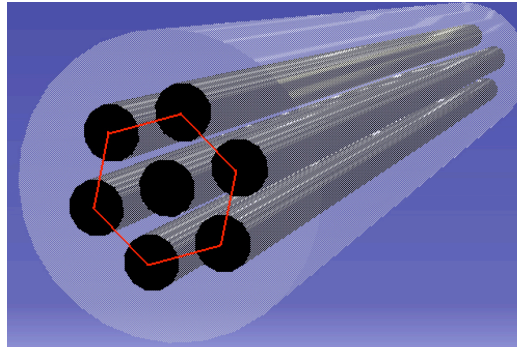
Figure 13: Simplified cluster geometry used for CANDU reactor cases.

pitch	real value set to the side of the hexagon in m for the simplified cluster geometry. This geometry is depicted in Fig. 13.
CHAN	keyword used to specify that a data is channel-dependent.
nch	number of fuel channels in the radial plane.
RADIUS	keyword used to set the pin-cell radii.
r1	real value set to the fuel pellet radius in m.
r2	real value set to the internal clad rod radius in m.
r3	real value set to the external clad rod radius in m.
r4	real value set to the guide tube radius in m.
POROS	keyword used to set the oxyde porosity of fuel. Porosity affects some built-in correlations used to represent the heat conduction phenomenon in fuel.
poros	real value set to the oxyde porosity. The default value is 0.05.
PUFR	keyword used to set the plutonium mass enrichment of fuel. Plutonium enrichment affects some built-in correlations used to represent the heat conduction phenomenon in fuel.
pufr	real value set to the plutonium mass enrichment. This value can be unique or channel-dependent. The default value is 0.0.
F-RUG	keyword used to set the rugosity of the fuel rod, used in Müller-Steinhagen correlation for coolant friction.
epsr	real value set to the rugosity of the fuel rod in m. The default value is 0.0.
THETA	keyword used to set the angle of the fuel channel, used in Müller-Steinhagen correlation for coolant friction.
theta	real value set to the angle of the fuel channel in radians. The default value is 0.0, corresponding to a vertical channel.
CONDF	keyword used to set the fuel thermal conductivity as a function of local fuel temperature T_{fuel}. Fuel conductivity is computed as

$$\lambda_{fuel} = \sum_{k=0}^{ncond} kcond(k) * (T_{fuel})^k + \frac{inv}{T_{fuel} - ref}$$

with λ_{fuel} in $W/m/K$ and T_{fuel} in the selected unit (Kelvin or Celsius).

By default, built-in models are used, taking into account oxide porosity and plutonium mass enrichment. Note that oxide porosity and plutonium mass enrichment are ignored if this keyword is used.

ncond integer value set to the degree of the conductivity polynomial.

kcond real value set to the coefficient of the conductivity polynomial. $ncond + 1$ coefficients are expected.

unit string value set to the unit of temperature T in the conductivity function. Can be either *CELSIUS* or *KELVIN*.

INV keyword used to add an inverse term in the fuel conductivity function.

inv real value set to the coefficient in the inverse term of fuel conductivity. The default value is 0.0 (i.e. no inverse term).

ref real value set to the reference in the inverse term of fuel conductivity.

CONDC keyword used to set the clad thermal conductivity as a function of local clad temperature T_{clad}. Clad conductivity is computed with the following polynomial

$$\lambda_{clad} = \sum_{k=0}^{ncond} kcond(k) * (T_{clad})^k$$

with λ_{clad} in $W/m/K$ and T_{clad} in the selected unit (Kelvin or Celsius).

By default, a built-in model is used.

HGAP keyword used to set the heat exchange coefficient of the gap as a constant. By default, a built-in model is used.

hgap real value set to the constant heat exchange coefficient of the gap in $W/m^2/K$.

HCONV keyword used to set the heat transfer coefficient between clad and fluid as a constant. By default, this coefficient is computed using a built-in correlation.

hconv real value set to the constant heat transfer coefficient between clad and fluid in $W/m^2/K$.

TEFF keyword used to set the weighting factor in the effective fuel temperature approximation. The effective fuel temperature is used for the cross sections interpolations on fuel temperature.

wteff real value W_{teff} set to the weighting factor in the effective fuel temperature. The effective fuel temperature is computed as

$$T_{\text{eff}}^{\text{fuel}} = W_{\text{teff}} * T_{\text{surface}}^{\text{fuel}} + (1 - W_{\text{teff}}) * T_{\text{center}}^{\text{fuel}}$$

where $0 \leq W_{\text{teff}} \leq 1$, $T_{\text{surface}}^{\text{fuel}}$ is the temperature at the surface of the fuel pellet (K), and $T_{\text{center}}^{\text{fuel}}$ is the temperature at the center of the fuel pellet (K).

By default, the Rowlands weighting factor $W_{\text{teff}} = \frac{5}{9}$ is used[49].

CONV	keyword used to set the convergence criteria for solving the conduction and the conservation equation.
maxit1	integer value set to the maximum number of iterations for computing the conduction integral. The default value is 50.
maxit2	integer value set to the maximum number of iterations for computing the center pellet temperature. The default value is 50.
maxit3	integer value set to the maximum number of iterations for computing the coolant parameters (mass flux, pressure, enthalpy and density) in case of a transient calculation. The default value is 50.
ermaxt	real value set to the maximum temperature error in K. The default value is 1 K.
ermaxc	real value set to the maximum relative error for parameters given by the resolution of flow conservation equations (pressure, velocity and enthalpy). The default value is 10^{-3}.
RODMESH	keyword used to set the radial discretization of pin-cells.
nb1	integer value set to the number of discretisation points in fuel. The default value is 5.
nb2	integer value set to the number of discretisation points in the whole pin-cell (fuel+cladding). The default value is 8.
FORCEAVE	keyword used to force the use of the average approximation during the fuel conductivity evaluation. By default, a rectangle quadrature approximation is used.
MONO	keyword used to set a one-phase flow model.
BOWR	keyword used to set a subcooling model based on the Bowring correlation[44] (default option).
SAHA	keyword used to set a subcooling model based on the Saha-Zuber correlation[46]. This option is recommended for BWR and CANDU applications.
RAD-PROF	keyword used to set radial power form factors. By default, these factors are set to 1.0.
rprad	radius corresponding to a form factor with $0 \leq rprad \leq r1$. This value doesn't need to correspond to a material limit in the fuel rod.
fprad	radial power form factor corresponding to radius *rprad*.
POWER-LAW	keyword used to define a time-dependent power law in the input. By default, the power is recovered from the fuelmap object *MAPFL*.
tpow	total power delivered in the reactor in W.
ntime	number of tabulation points for the power law.
t(i)	tabulation abscissa in time (s).
pow(i)	tabulation power factor corresponding to *t(i)*. The reactor power at time *t(i)* is given as *tpow*×*pow(i)*.
SET-PARAM	keyword used to indicate the input (or modification) of the actual values for a parameter specified using its *PNAME*.
PNAME	keyword used to specify *PNAME*.

PNAME   `character*12` name of a parameter.

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

PICK   keyword used to recover the temperature variation parameter R in a CLE-2000 variable. This parameter describes the variation of averaged fuel and coolant temperatures during a time step using the formula

$$R = \max \left\{ \frac{1}{\Delta T_{\text{fuel}}} \left| \bar{T}_{\text{fuel}}(n) - \bar{T}_{\text{fuel}}(n-1) \right|, \frac{1}{\Delta T_{\text{cool}}} \left| \bar{T}_{\text{cool}}(n) - \bar{T}_{\text{cool}}(n-1) \right| \right\}$$

where $\Delta T_{\text{fuel}} = 5$ K and $\Delta T_{\text{cool}} = 40$ K.

ratio   `character*12` CLE-2000 variable name in which the temperature variation parameter will be placed.

6 POINT KINETICS MODULES

6.1   The `PKINI:` module

The `PKINI:` module is used to initialize the point kinetics parameters, to define the delayed neutron information and to set the global feedback parameters. The point kinetics equations are solved for a *time stage* using module `PKINS:` (See Sect. 6.2) as a function of a fixed set of global parameters recovered from the MAP object *MAPFL*. Modules `PKINI:` and `PKINS:` are intended to be used with thermal-hydraulics module `THM:` (See Sect. 5.1) to simulate a single reactor channel.

The `PKINI:` module specification is:

Table 80: Structure `PKINI:`

$MAPFL$:= `PKINI:` $MAPFL$ :: **(descpkini)**

where

MAPFL   `character*12` name of the MAP object containing fuel regions description and global parameter informations.

(descpkini)   structure describing the input data to the `PKINI:` module.

6.1.1 Input data to the `PKINI:` module

Table 81: Structure **(descpkini)**

```
[ EDIT iprint ]
POWER power
[ EPSILON epsilon ]
TIME t0 dt
LAMBDA lambda
NGROUP ngroup
BETAI (beta(i),i=1,ngroup) LAMBDAI (dlambda(i),i=1,ngroup)
ALPHA [[ PNAME { DIRECT | DERIV | SQDERIV }
   [ { LINEAR | CUBIC } ] nalpha (x(i) y(i),i=1,nalpha) ]] ENDA
[ PTIME [[ PNAME [ { LINEAR | CUBIC } ] {ntime (t(i) x(i),i=1,ntime) |
   T-DELT [ nxy ] t1 t2 P-VALV gamma p1 p2 tb1 bval1 [ RESET p3 tb2 bval2 ] } ]] ENDP ]
;
```

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; larger values produce increasing amounts of output.
POWER	keyword used to set the initial reactor power.
power	reactor power in MW.
EPSILON	keyword used to set the epsilon of the Runge-Kutta solver used to adjust the internal time step. The default value is $\epsilon = 1.0 \times 10^{-2}$.
epsilon	user-selected epsilon.
TIME	keyword used to set the initial time and stage duration. It is possible to readjust the stage duration in module PKINS:.
t0	initial time (s).
dt	stage duration (s).
LAMBDA	keyword used to set the prompt neutron generation time.
lambda	prompt neutron generation time (s).
NGROUP	keyword used to set the number of delayed precursor groups.
ngroup	number of delayed precursor groups.
BETAI	keyword used to set the delayed neutron fraction vector.
betai	value of the delayed neutron fraction in a delayed precursor group.
LAMBDAI	keyword used to set the delayed neutron time constant vector.
lambdai	value of the delayed neutron time constant (s) in a delayed precursor group.
ALPHA	keyword used to set the feedback parameters.
PNAME	character*12 name of a feedback parameter. A feedback parameter should be a global parameter defined in the fuelmap.
DIRECT	keyword indicating that the reactivity is a direct function of the global parameter.
DERIV	keyword indicating that the reactivity is a function of the variation of the local parameter with respect to its initial value.
SQDERIV	keyword indicating that the reactivity is a function of the variation of the square root of the local parameter with respect to its initial value. This option is generally used to represent the Doppler effect due to the fuel temperature.
LINEAR	keyword indicating that interpolation of the reactivity effect uses linear Lagrange polynomials (default option).
CUBIC	keyword indicating that interpolation of the reactivity effect uses the Ceschino method with cubic Hermite polynomials, as presented in Ref. 17.
nalpha	number of values in the table describing reactivity effects for feedback parameter PNAME.
x	value of the global parameter.
y	corresponding reactivity coefficient.
PTIME	keyword used to set the time laws for some feedback parameters.

ntime	number of values in the time law for feedback parameter `PNAME`.
t	time (s)
x	corresponding value of the global parameter.
`T-DELT`	keyword used to set an analytical time law between two times.
nxy	number of points used to construct the discrete time law. The default value is *nxy* = 1001.
t1	initial time (s) for the analytical time law domain.
t2	final time (s) for the analytical time law domain.
`P-VALV`	keyword used to define a time law corresponding to the depressurization of a gas reservoir. The time-vatiation of the pressure $P(t)$ in a reservoir is given by a relation of the form

$$P(t) = \begin{cases} P_{\max} & \text{if } t \leq tb1 \\ \max\left(P_{\min}, \dfrac{P_{\max}}{(1 + Bt)^{\alpha}} \right) & \text{otherwise} \end{cases} \qquad (6.1)$$

where $P_{\max}$ is the pressure of the reservoir at time $t \leq tb1$, before depressurization and $P_{\min}$ is the final pressure after depressurization. B (s^{-1}) is the time constant of the exhaust pipe and α is given by relation

$$\alpha = \frac{2\gamma}{\gamma - 1} \qquad (6.2)$$

where γ is a constant related to the gas capacitance (= 1.66 for Helium).

gamma	value of γ parameter in Eq. (6.2).
p1	value of pressure $P_{\max}$ in Eq. (6.1).
p2	value of pressure $P_{\min}$ in Eq. (6.1).
tb1	time (s) when the exhaust pipe is open with value *bval1*. We must have $t1 \leq tb1 < t2$.
bval1	value of B parameter in Eq. (6.1) after time *tb1*.
`RESET`	optional keyword used to reset the opening of the exhaust pipe after a fixed period of time.
p3	value of pressure $P_{\min}$ in Eq. (6.1) after reset.
tb2	time (s) when the exhaust pipe is open with value *bval2*. We must have $tb1 < tb2 < t2$.
bval2	value of B parameter in Eq. (6.1) after time *tb2*.

6.2 The `PKINS:` module

The feedback parameters are responsible for the introduction of reactivity in the solution of the point-kinetics equations. Some feedback parameters have their time variation set by *time laws* defined in module `PKINI:` (See Sect. 6.1). Some other are assumed constant during a *time stage*, corresponding to a single call to module `PKINS:`. The `PKINS:` module is used to solve the point-kinetics equations over a single time stage.

The `PKINS:` module specification is:

Table 82: Structure `PKINS:`

[*MAPFL* :=] `PKINS:` *MAPFL* :: **(descpkins)**

---

where

MAPFL   `character*12` name of the MAP object containing fuel regions description and global parameter informations. This object is declared in read-only mode if and only if keyword `PICKR` is set.

(descpkins)   structure describing the input data to the `PKINS:` module.

6.2.1 Input data to the `PKINS:` module

Table 83: Structure **(descpkins)**

[`EDIT` *iprint*]
`TIME` *t0 dt*
{ [`POWER` *power* | `Y-INIT` (*y*(i),i=1,*ngroup+1*) }]
[{ `PICK >>` *power_out* `<<` | `PICKR >>` *rho* `<<` }]
;

---

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; larger values produce increasing amounts of output.

`TIME`   keyword used to set the beginning-of-stage and duration times.

t0   beginning-of-stage time (s).

dt   stage duration (s). $dt = 0.0$ if keyword `PICKR` is set.

`POWER`   keyword used to set the beginning-of-stage reactor power.

power	beginning-of-stage reactor power in MW.
`Y-INIT`	keyword used to set the beginning-of-stage solution of the point kinetics equations.
y	beginning-of-stage value of a component of the beginning-of-stage solution. *ngroup* is the number of delayed precursor groups.
`PICK`	keyword used to recover the end-of-stage power (in MW) in a CLE-2000 variable.
power_out	`character*12` CLE-2000 variable name in which the extracted power value will be placed.
`PICKR`	keyword used to recover the reactivity at time *t0* in a CLE-2000 variable.
rho	`character*12` CLE-2000 variable name in which the reactivity value will be placed.

7 OPTIMIZATION MODULES

This section is related to optimization capabilities available in Donjon and based on generalized perturbation theory.[30, 31] General information about the generalized perturbation theory can be found in Sect. 5.3 of Ref. 1.

7.1   The `DLEAK:` module

The `DLEAK:` module is used to create a delta MACROLIB (type **L_MACROLIB**) with respect to leakage information. Derivatives of leakage-related information (recovered from the input MACROLIB) are stored in the `STEP` heteroneneous list components present in the output MACROLIB. Derivatives can be taken with respect to a leakage parameter itself ($D_{g,i}$ or $\Sigma_{1,g,i}$) or relative to factor μ in $\mu D_{g,i}$ or $\mu\Sigma_{1,g,i}$. Note that factor μ is not a SPH factor because it multiplies only leakage-related parameters. One component of the `STEP` heteroneneous list is created for each value of energy group g and for each value of mixture i.

The calling specifications are:

Table 84: Structure (**DLEAK:**)

DMACRO OPTIM := `DLEAK:` *MACRO* :: (**dleak_data**)

where

DMACRO   `character*12` name of a LCM object (type **L_MACROLIB**) containing the delta MACROLIB information. *DMACRO* is created by the module. A `STEP` heteroneneous list is present in *DMACRO*.

OPTIM   `character*12` name of a second LCM object (type **L_OPTIMIZE**) created by the module. Leakage-related parameters are saved in the the control variable record `'VAR-VALUE'` of *OPTIM* object. Input data defined in Sect. 7.1.1 is also saved in *OPTIM* object.

MACRO   `character*12` name of the LCM object (type **L_MACROLIB**) containing the input MACROLIB.

(**dleak_data**) structure containing the data to module `DLEAK:` (see Sect. 7.1.1).

7.1.1 Data input for module `DLEAK:`

Table 85: Structure (**dleak_data**)

```
[ EDIT iprint ]
TYPE { DIFF | NTOT1 }
DELTA { VALUE | FACTOR }
[ MIXMIN ibm1 ] [ MIXMAX ibm2 ]
[ GRPMIN ngr1 ] [ GRPMAX ngr2 ]
;
```

where

EDIT   keyword used to set *iprint*.

iprint   index used to control the printing in module `DLEAK:`.

TYPE   keyword used to set the leakage parameter that is differentiated.

DIFF   differentiation with respect to diffusion coefficients.

NTOT1   differentiation with respect to P_1-weighted macroscopic total cross sections.

DELTA   keyword used to set the type of differentiation.

VALUE   differentiation with respect to the leakage parameter itself.

FACTOR   differentiation with respect to the correction factor μ.

MIXMIN   keyword used to set the first mixture where leakage parameters are differentiated. By default, the first mixture index is used.

ibm1   minimum mixture index where leakage parameters are differentiated.

MIXMAX   keyword used to set the last mixture where leakage parameters are differentiated. By default, the total number of mixtures in *MACRO* is used.

ibm2   maximum mixture index where leakage parameters are differentiated.

GRPMIN   keyword used to set the first energy group where leakage parameters are differentiated. By default, the first energy group index is used.

ngr1   minimum energy group index where leakage parameters are differentiated.

GRPMAX   keyword used to set the last energy group where leakage parameters are differentiated. By default, the total number of energy groups in *MACRO* is used.

ngr2   maximum energy group index where leakage parameters are differentiated.

7.2 The `DSPH:` module

The `DSPH:` module is used to create a delta MACROLIB (type **L_MACROLIB**) with respect to SPH factor variation. Derivatives of diffusion coefficient and cross-section information (recovered from the input MACROLIB) are stored in the **STEP** heteroneneous list components present in the output MACROLIB. One component of the **STEP** heteroneneous list is created for each value of energy group g and for each value of mixture i.

The calling specifications are:

Table 86: Structure **(DSPH:)**

DMACRO OPTIM := `DSPH:` *MACRO* :: **(dsph_data)**

---

where

DMACRO   `character*12` name of a LCM object (type **L_MACROLIB**) containing the delta MACROLIB information. *DMACRO* is created by the module. A **STEP** heteroneneous list is present in *DMACRO*.

OPTIM   `character*12` name of a second LCM object (type **L_OPTIMIZE**) created by the module. SPH factors are saved in the the control variable record `'VAR-VALUE'` of *OPTIM* object. Input data defined in Sect. 7.2.1 is also saved in *OPTIM* object.

MACRO   `character*12` name of the LCM object (type **L_MACROLIB**) containing the input MACROLIB.

(dsph_data)   structure containing the data to module `DSPH:` (see Sect. 7.2.1).

7.2.1 Data input for module `DSPH:`

Table 87: Structure **(dsph_data)**

```
[ EDIT iprint ]
[ SPH { PN | SN | ALBEDO } ]
[ GRPMIN ngr1 ] [ GRPMAX ngr2 ]
;
```

---

where

`EDIT`   keyword used to set *iprint*.

iprint   index used to control the printing in module `DSPH:`.

`PN`   keyword to activate the calculation of heterogeneous SPH factors of diffusion, PN or SPN type.

SN   keyword to activate the calculation of heterogeneous SPH factors of PIJ, IC, SN or MOC type. This is the default option.

ALBEDO   keyword to activate the calculation of a unique SPH factor assigned to the albedo function in each energy group.

GRPMIN   keyword used to set the first energy group where SPH correction is applied. By default, the first energy group index is used.

ngr1   minimum energy group index where SPH correction is applied.

GRPMAX   keyword used to set the last energy group where SPH correction is applied. By default, the total number of energy groups in *MACRO* is used.

ngr2   maximum energy group index where SPH correction is applied.

7.3   The `DREF:` module

This module is used to set fixed sources that can be used in the right hand term of an adjoint fixed source eigenvalue problem. This type of equation appears in generalized perturbation theory (GPT) applications. The fixed sources set in `DREF:` are corresponding to the gradient of the RMS functional which is a measure of the discrepancy between actual and reference (or target) reaction rate distributions. The actual reaction rate distribution is recovered from a *MICRO* or *MACRO* object. The reference reaction rate distribution is recovered from a *MICREF* or *MACREF* object.

7.3.1 Minimizing the RMS error of power distribution

The fixed sources are computed for the case where the OPTIMIZE object was initialized in module `DLEAK:`. This option is used with the *OPTEX reflector model*.[32]

Actual power values are defined as

$$P_i\{\phi(r)\} \equiv \langle H, \phi \rangle_i = \int_0^\infty dE \int_{V_i} d^3r \, H(\boldsymbol{r}, E) \, \phi(\boldsymbol{r}, E)$$

where the power factors $H(\boldsymbol{r}, E)$ and fluxes $\phi(\boldsymbol{r}, E)$ are recovered from `H-FACTOR` and `FLUX-INTG` records in a MACROLIB object.

The RMS error on power distribution is an homogeneous functional of the flux defined as

$$\mathcal{F}\{\phi(r)\} = \sum_i \left(\frac{\langle H, \phi \rangle_i}{\langle H, \phi \rangle} - \frac{P_i^*}{\sum_j P_j^*} \right)^2$$

where the reference (or target) powers P_i^* are obtained from the full-core reference transport calculation.

The gradient of functional $\mathcal{F}\{\phi(r)\}$ is a G-group function of space defined as

$$\boldsymbol{\nabla}\mathcal{F}\{\phi(\zeta); \boldsymbol{r}\} = \frac{2}{\langle H, \phi \rangle} \sum_i \left(\frac{\langle H, \phi \rangle_i}{\langle H, \phi \rangle} - \frac{P_i^*}{\sum_j P_j^*} \right) \left(\delta_i(\boldsymbol{r}) - \frac{\langle H, \phi \rangle_i}{\langle H, \phi \rangle} \right) \begin{bmatrix} H_1(\boldsymbol{r}) \\ H_2(\boldsymbol{r}) \\ \vdots \\ H_G(\boldsymbol{r}) \end{bmatrix}$$

where $\delta_i(\boldsymbol{r}) = 1$ if $\boldsymbol{r} \in V_i$ and $= 0$ otherwise.

Each fixed source $\boldsymbol{\nabla}\mathcal{F}\{\phi(\zeta); \boldsymbol{r}\}$ is orthogonal to the flux $\phi(\boldsymbol{r})$.

7.3.2 Minimizing the RMS error associated with SPH factor calculation

The fixed sources are computed for the case where the OPTIMIZE object was initialized in module `DSPH:`. Module `DREF` is call to compute the gradients required for computing SPH factors using an optimization algorithm (OPTEX in `PLQ:`, quasi-Newton in `LNSR:`, Newton in `FPSPH:`). Module `DREF` computes the direct gradients and the fixed sources to be used in a fixed-source eigenvalue problem originating from the generalized perturbation theory (GPT).

Fundamental mode conditions are the cases where no neutron is leaking due to the boundary conditions. In the case where the macro-calculation over macro-group g is done in non-fundamental mode conditions, it is proposed to apply a SPH correction on the *albedo functions* corresponding to boundaries with a non-conservative condition in the reference calculation.[37] If the macro calculation is performed in diffusion or P_1 approximation, the albedo function $\Lambda(\beta_g)$ corresponding to a non-conservative boundary is defined as

$$\Lambda(\beta_g) = \frac{1}{2} \frac{1 - \beta_g}{1 + \beta_g} \tag{7.1}$$

where β_g is the albedo in macro-group g. The net current $\boldsymbol{J}_g(\boldsymbol{r})$ escaping the domain at point $\boldsymbol{r}$ of the boundary is given by the *albedo boundary condition* as

$$-\boldsymbol{J}_g(\boldsymbol{r}) \cdot \boldsymbol{N}(\boldsymbol{r}) + \Lambda(\beta_g)\,\phi_g(\boldsymbol{r}) = 0 \quad \text{if } \boldsymbol{r} \in \partial V \tag{7.2}$$

where ∂V is the fraction of the domain where the non-conservative boundary condition is applied and $\boldsymbol{N}(\boldsymbol{r})$ is the outgoing normal unit vector.

The integrated flux are defined over the macro-region m and macro-group g as

$$F_{m,g} \equiv \langle\phi\rangle_{m,g} = \int_{V_m} d^3r\,\phi_g(\boldsymbol{r}) \tag{7.3}$$

The net leakage L_g over each macro group due to non conservative boundary conditions is defined as

$$L_g \equiv \langle\Lambda\phi\rangle_g = \int_{\partial V} d^2r\,\Lambda(\beta_g)\,\phi_g(\boldsymbol{r}) = \int_{\partial V} d^2r\,\boldsymbol{J}_g(\boldsymbol{r}) \cdot \boldsymbol{N}(\boldsymbol{r})\ . \tag{7.4}$$

In order to preserve the neutron balance in macro-group g, cross section data and albedo functions must all be SPH corrected. The correction specific to albedo functions is written

$$\tilde{\Lambda}_g = \mu_{M+1,g}\,\Lambda_g^* \tag{7.5}$$

where M is the total number of macro-regions and Λ_g^* is the albedo function of the reference calculation in macro-group g. This correction technique is proposed as an alternative to the discontinuity factor correction used by Ref. 38.

In fundamental mode conditions and in cases where Eq. (7.5) is used, an infinity of SPH factor sets can satisfy the reference reaction rates in each macro-group g. A unique set is selected with the application of an arbitrary normalization condition. The simplest option is to use the *flux-volume normalization condition* which consists to preserve the averaged flux in the lattice. This normalization condition, satisfied in each macro-group g, is written

$$\sum_{m=1}^{M} \int_{V_m} d^3r\,\widetilde{\phi}_g(\boldsymbol{r}) = \sum_{m=1}^{M} F_{m,g}^*\ , \quad g \leq G \tag{7.6}$$

where $F_{m,g}^*$ is the volume-integrated flux in macro-region V_m and macro-group g of the reference calculation.

Equation (7.6) can be rewritten as

$$\sum_{m=1}^{M} \frac{F_{m,g}^*}{\mu_{m,g}} = \sum_{m=1}^{M} F_{m,g}^*\ , \quad g \leq G. \tag{7.7}$$

The absorption rates are defined over the macro-region m and macro-group g as

$$P_{\mathrm{a},m,g} \equiv \langle\Sigma_{\mathrm{a}},\phi\rangle_{m,g} = \int_{V_m} d^3r\,\Sigma_{\mathrm{a},g}(\boldsymbol{r})\,\phi_g(\boldsymbol{r}) \tag{7.8}$$

where $i \leq I$ and $g \leq G$ and where

$$\Sigma_{\mathrm{a},g}(\boldsymbol{r}) = \Sigma_g(\boldsymbol{r}) - \Sigma_{\mathrm{s},g}(\boldsymbol{r}). \tag{7.9}$$

The ν-fission rates are defined over the macro-region m and macro-group g as

$$P_{\mathrm{f},m,g} \equiv \langle\nu\Sigma_{\mathrm{f}},\phi\rangle_{m,g} = \int_{V_m} d^3r\,\nu\Sigma_{\mathrm{f},g}(\boldsymbol{r})\,\phi_g(\boldsymbol{r}) \tag{7.10}$$

where $i \leq I$ and $g \leq G$ and where $\nu\Sigma_{\mathrm{f},g}(\boldsymbol{r})$ is the macroscopic fission cross section multiplied by the averaged number of neutrons emitted per fission.

The absorption and ν-fission cross sections are corrected according to

$$\Sigma_{\mathrm{a},m,g} = \mu_{m,g}\,\Sigma^*_{\mathrm{a},m,g} = \mu_{m,g}\,\frac{P^*_{\mathrm{a},m,g}}{F^*_{m,g}} \tag{7.11}$$

and

$$\nu\Sigma_{\mathrm{f},m,g} = \mu_{m,g}\,\nu\Sigma^*_{\mathrm{f},m,g} = \mu_{m,g}\,\frac{P^*_{\mathrm{f},m,g}}{F^*_{m,g}} \tag{7.12}$$

where the reference integrated fluxes $F^*_{m,g}$ are also obtained from the full-core reference transport calculation. The SPH factors are normalized in each macro energy group according to

$$\sum_{j=1}^{M} \frac{F^*_{j,g}}{\mu_{j,g}} = \sum_j F^*_{j,g}\ , \quad g \leq G. \tag{7.13}$$

The RMS error on absorption distribution is an homogeneous functional of the flux defined as

$$\mathcal{F}\{\phi(\boldsymbol{r})\} = \sum_{m=1}^{M+2} \sum_{g=1}^{G} \left(f_{m,g}\{\phi(\boldsymbol{r})\}\right)^2 \tag{7.14}$$

where the components $f_{m,g}\{\phi(\boldsymbol{r})\}$ are the $M+2$ conditions to satisfy in each macro-group. They are defined as

$$f_{m,g}\{\phi(\boldsymbol{r})\} = \begin{cases} \dfrac{\langle\Sigma_{\mathrm{a}},\phi\rangle_{m,g}}{\langle\Sigma_{\mathrm{a}},\phi\rangle}\dfrac{P^*_{\mathrm{a,tot}}}{\Delta_{\mathrm{a},m,g}} - \dfrac{P^*_{\mathrm{a},m,g}}{\Delta_{\mathrm{a},m,g}} & \text{if } m \leq M \\[2ex] \sqrt{M}\left(\dfrac{\langle\Lambda+\Sigma_{\mathrm{a}},\phi\rangle_g}{\langle\nu\Sigma_{\mathrm{f}},\phi\rangle}\dfrac{P^*_{\mathrm{f,tot}}}{\Delta_{\mathrm{L},g}} - \dfrac{L^*_g + P^*_{\mathrm{a},g}}{\Delta_{\mathrm{L},g}}\right) & \text{if } m = M+1 \\[2ex] \dfrac{1}{F^*_g}\sum\limits_{j=1}^{M} \dfrac{F^*_{j,g}}{\mu_{j,g}} - 1 & \text{if } m = M+2 \end{cases} \tag{7.15}$$

with

$P^*_{\mathrm{a},m,g}$ = reference (or target) absorption rates obtained from the full-core reference transport calculation

$P^*_{\mathrm{f},m,g}$ = reference (or target) ν-fission rates obtained from the full-core reference transport calculation

$\Delta_{\mathrm{a},m,g}$ = low limit absorption rates defined as $\max\left(10^{-4}P^*_{\mathrm{a,tot}}, P^*_{\mathrm{a},m,g}\right)$ in order to avoid division by small numbers.

L^*_g = reference leakage in macro-group g

$\Lambda(\boldsymbol{r})$ = albedo function defined on the non-conservative boundaries ∂V of the domain

$\Delta_{\mathrm{L},g}$ = low limit leakage defined as $\max\left(10^{-4}P^*_{\mathrm{f,tot}}, L^*_g + P^*_{\mathrm{a},g}\right)$ in order to avoid division by small numbers.

and where $P^*_{\mathrm{a},g} = \sum_m P^*_{\mathrm{a},m,g}$, $P^*_{\mathrm{a,tot}} = \sum_g P^*_{\mathrm{a},g}$, $P^*_{\mathrm{f,tot}} = \sum_m \sum_g P^*_{\mathrm{f},m,g}$ and $F^*_g = \sum_m F^*_{m,g}$.

The condition $m = M+1$ in Eq. (7.15) is based on the preservation of the effective multiplication factor of the core. The SPH normalization relations (7.7) are included in the RMS error in order to simplify the optimization process.

The gradient of functional (7.14) with respect to a variation of flux ϕ is a G-group function of space whose components are defined as

$$\nabla\mathcal{F}_g\{\phi(\boldsymbol{\zeta});\boldsymbol{r}\} = \left[\frac{d}{d\epsilon}\mathcal{F}\{\phi(\boldsymbol{\zeta}) + \epsilon\,\boldsymbol{\delta}_g(\boldsymbol{\zeta}-\boldsymbol{r})\}\right]_{\epsilon=0} ; \quad g = 1, G \tag{7.16}$$

where $\boldsymbol{\delta}_g(\boldsymbol{\zeta} - \boldsymbol{r})$ is a multidimensional Dirac delta distribution defined as

$$\boldsymbol{\delta}_g(\boldsymbol{\zeta} - \boldsymbol{r}) = \mathrm{col}\left[\delta_{g,h}\,\delta(\boldsymbol{\zeta} - \boldsymbol{r})\,,\ h = 1, G\right] \tag{7.17}$$

where $\delta_{g,h}$ is a Kronecker delta function and $\delta(\boldsymbol{\zeta} - \boldsymbol{r})$ is the classical Dirac delta distribution.

Next, we evaluate the gradient of each component $f_{m,g}\{\boldsymbol{\phi}(\boldsymbol{r})\}$ with respect to the SPH factors and we construct a rectangular matrix $\mathbb{A}$, of size $(M + 2)G \times (M + 1)G$, defined as

$$\mathbb{A} = \left\{\frac{\partial f_{m,g}}{\partial \mu_{n,h}};\ \ m \leq M + 2,\ n \leq M + 1,\ g \leq G,\ h \leq G\right\}. \tag{7.18}$$

We first evaluate the direct contribution of these derivatives for a variation of the SPH factors assigned to cross sections (i.e., for $n \leq M$). Direct contributions are the chain rule terms not involving a variation in flux. These direct gradients are

$$\left.\frac{\partial f_{m,g}}{\partial \mu_{n,h}}\right|^{\mathrm{direct}} = \frac{\langle \Sigma_{\mathrm{a}}, \phi \rangle_{m,g}}{\mu_{n,h}\,\langle \Sigma_{\mathrm{a}}, \phi \rangle}\frac{P^*_{\mathrm{a,tot}}}{\Delta_{\mathrm{a},m,g}}\left(\delta_{m,n}\delta_{g,h} - \frac{\langle \Sigma_{\mathrm{a}}, \phi \rangle_{n,h}}{\langle \Sigma_{\mathrm{a}}, \phi \rangle}\right) \quad \text{if } m \leq M \tag{7.19}$$

$$\left.\frac{\partial f_{M+1,g}}{\partial \mu_{n,h}}\right|^{\mathrm{direct}} = \frac{\sqrt{M}}{\mu_{n,h}\,\langle \nu\Sigma_{\mathrm{f}}, \phi \rangle}\frac{P^*_{\mathrm{f,tot}}}{\Delta_{\mathrm{L},g}}\left(\delta_{g,h}\,\langle \Sigma_{\mathrm{a}}, \phi \rangle_{n,h} - \langle \Lambda + \Sigma_{\mathrm{a}}, \phi \rangle_g\,\frac{\langle \nu\Sigma_{\mathrm{f}}, \phi \rangle_{n,h}}{\langle \nu\Sigma_{\mathrm{f}}, \phi \rangle}\right) \tag{7.20}$$

and

$$\left.\frac{\partial f_{M+2,g}}{\partial \mu_{n,h}}\right|^{\mathrm{direct}} = -\delta_{g,h}\,\frac{F^*_{n,g}}{\mu^2_{n,g}F^*_g}. \tag{7.21}$$

The SPH factors assigned to the albedo functions are not responsible for any direct contributions to the derivatives of component $f_{m,g}\{\boldsymbol{\phi}(\boldsymbol{r})\}$. Consequently,

$$\left.\frac{\partial f_{m,g}}{\partial \mu_{M+1,h}}\right|^{\mathrm{direct}} = 0. \tag{7.22}$$

The indirect gradient of each component $f_{m,g}\{\boldsymbol{\phi}(\boldsymbol{r})\}$ with respect to the SPH factors are an effect of *flux variation* and are obtained using *generalized perturbation theory* (GPT). The gradient of functional $f_{m,g}\{\boldsymbol{\phi}(\boldsymbol{r})\}$ with respect to a variation of flux is a G-group function of space defined as

$$\nabla f_{m,g}\{\boldsymbol{\phi}(\boldsymbol{\zeta}); \boldsymbol{r}\} = \begin{bmatrix} f_{m,g,1}\{\boldsymbol{\phi}(\boldsymbol{\zeta}); \boldsymbol{r}\} \\ f_{m,g,2}\{\boldsymbol{\phi}(\boldsymbol{\zeta}); \boldsymbol{r}\} \\ \vdots \\ f_{m,g,G}\{\boldsymbol{\phi}(\boldsymbol{\zeta}); \boldsymbol{r}\} \end{bmatrix} \tag{7.23}$$

where the group-h components are

$$\nabla f_{m,g,h}\{\boldsymbol{\phi}(\boldsymbol{\zeta}); \boldsymbol{r}\} = \frac{\Sigma_{\mathrm{a},h}(\boldsymbol{r})}{\langle \Sigma_{\mathrm{a}}, \phi \rangle}\frac{P^*_{\mathrm{a,tot}}}{\Delta_{\mathrm{a},m,g}}\left(\delta_m(\boldsymbol{r})\,\delta_{g,h} - \frac{\langle \Sigma_{\mathrm{a}}, \phi \rangle_{m,g}}{\langle \Sigma_{\mathrm{a}}, \phi \rangle}\right) \quad \text{if } m \leq M \tag{7.24}$$

where $\delta_m(\boldsymbol{r}) = 1$ if $\boldsymbol{r} \in V_m$ and $= 0$ otherwise,

$$\begin{aligned} \nabla f_{M+1,g,h}\{\boldsymbol{\phi}(\boldsymbol{\zeta}); \boldsymbol{r}\} &= \frac{\sqrt{M}}{\langle \nu\Sigma_{\mathrm{f}}, \phi \rangle}\frac{P^*_{\mathrm{f,tot}}}{\Delta_{\mathrm{L},g}}\left[\left(\Lambda_h(\boldsymbol{r}) + \Sigma_{\mathrm{a},h}(\boldsymbol{r})\right)\,\delta_{g,h}\right. \\ &\quad - \left.\nu\Sigma_{\mathrm{f},h}(\boldsymbol{r})\,\frac{\langle \Lambda + \Sigma_{\mathrm{a}}, \phi \rangle_g}{\langle \nu\Sigma_{\mathrm{f}}, \phi \rangle}\right] \end{aligned} \tag{7.25}$$

and

$$\nabla f_{M+2,g,h}\{\boldsymbol{\phi}(\boldsymbol{\zeta}); \boldsymbol{r}\} = 0. \tag{7.26}$$

We first compute the gradient $\boldsymbol{g}$ of the RMS error with respect to a variation of the SPH factors. We define three column vectors as

$$\boldsymbol{f} = \text{col}\{f_{m,g}\{\boldsymbol{\phi}(\boldsymbol{r})\} ; \quad m \leq M + 2, \ g \leq G\}, \tag{7.27}$$

$$\boldsymbol{\nabla} \boldsymbol{f} = \text{col}\{\boldsymbol{\nabla} f_{m,g}\{\boldsymbol{\phi}(\boldsymbol{\zeta}); \boldsymbol{r}\} ; \quad m \leq M + 2, \ g \leq G\} \tag{7.28}$$

and

$$\boldsymbol{g} = \text{col}\left\{\frac{\partial \mathcal{F}\{\boldsymbol{\phi}(\boldsymbol{r})\}}{\partial \mu_{n,h}}; \quad n \leq M + 1, \ h \leq G\right\}. \tag{7.29}$$

From Eqs. (7.14) and (7.16), we have

$$\mathcal{F}\{\boldsymbol{\phi}(\boldsymbol{r})\} = \boldsymbol{f}^{\top} \boldsymbol{f} \tag{7.30}$$

and

$$\boldsymbol{\nabla} \mathcal{F}\{\boldsymbol{\phi}(\boldsymbol{\zeta}); \boldsymbol{r}\} = 2 \boldsymbol{f}^{\top} \boldsymbol{\nabla} \boldsymbol{f} \tag{7.31}$$

so that

$$\frac{\partial \mathcal{F}}{\partial \mu_{n,h}} = 2 \sum_{m=1}^{M+2} \sum_{g=1}^{G} f_{m,g} \frac{\partial f_{m,g}}{\partial \mu_{n,h}} \tag{7.32}$$

where the derivatives of $f_{m,g}$ are computed taking into account both direct and indirect contributions:

$$\frac{\partial f_{m,g}}{\partial \mu_{n,h}} = \left.\frac{\partial f_{m,g}}{\partial \mu_{n,h}}\right|^{\text{direct}} + \left\langle \boldsymbol{\nabla} f_{m,g}\{\boldsymbol{\phi}(\boldsymbol{\zeta}); \boldsymbol{r}\}, \frac{\partial}{\partial \mu_{n,h}} \boldsymbol{\phi}(\boldsymbol{r}) \right\rangle \tag{7.33}$$

and where the bracket stands for a summation over the G energy groups and an integration over the domain. The flux derivatives $\partial \boldsymbol{\phi} / \partial \mu_{n,h}$ are G-group functions obtained using generalized perturbation theory.

Equation (7.32) can be rewritten in matrix form as

$$\boldsymbol{g} = 2 \, \mathbb{A}^{\top} \, \boldsymbol{f}. \tag{7.34}$$

The bracket term in Eq. (7.33) is computed by module `GRAD:`, outside module `DREF:`. Module `GRAD:` compute only the *direct contributions* of the gradients:

- By default, the objective function $\mathcal{F}\{\boldsymbol{\phi}(\boldsymbol{r})\}$ and direct components of vector $\boldsymbol{g}$ are computed.

- If keyword `NEWTON` is set, individual components $f_{m,g}\{\boldsymbol{\phi}(\boldsymbol{r})\}$ and direct components of matrix $\mathbb{A}$ are computed.

7.3.3 Calling specifications

The calling specifications for module `DREF:` are:

Table 88: Structure **(DREF:)**

```
SOURCE OPTIM := DREF: OPTIM FLUX TRACK { MICRO | MACRO }
    { MICREF | MACREF }
    [ :: [ EDIT iprint ] [ NODERIV ] [ NEWTON ] [ RMS >>RMS_VAL<< ] ] ;
```

where

SOURCE	`character*12` name of a FIXED SOURCES (type `L_SOURCE`) object open in creation mode. This object contains the adjoint fixed source corresponding to the RMS error on power distribution.
OPTIM	`character*12` name of the OPTIMIZE object (`L_OPTIMIZE` signature) containing the optimization informations. Object *OPTIM* must appear on both LHS and RHS to be able to update the previous values.
FLUX	`character*12` name of the actual FLUX (type `L_FLUX`) object open in read-only mode.
TRACK	`character*12` name of the actual TRACKING (type `L_TRACK`) object open in read-only mode.
MICRO	`character*12` name of the actual MICROLIB (type `L_LIBRARY`) object open in read-only mode. The information on the embedded macrolib is used.
MACRO	`character*12` name of the actual MACROLIB (type `L_MACROLIB`) object open in read-only mode.
MICREF	`character*12` name of reference (or target) MICROLIB (type `L_LIBRARY`) object open in read-only mode. The information contained in the embedded macrolib is used to compute P_i^* values.
MACREF	`character*12` name of reference (or target) MACROLIB (type `L_MACROLIB`) object open in read-only mode. This information is used to compute P_i^* values.
`EDIT`	keyword used to set *iprint*.
iprint	index used to control the printing in module `DREF:`. $=0$ for no print; $=1$ for minimum printing (default value).
`NODERIV`	keyword used to stop processing of `DREF:` module after calculation of objective function. By default, information related to the gradient of the RMS functional is also computed.
`NEWTON`	keyword used to enable the detailed calculation of gradient for all components of the objective function, as required by a full Newtonian approach. By default, only the gradient of the objective function is computed.
`RMS`	keyword used to recover the RMS error on power or absorption distribution in a CLE-2000 variable.
RMS_VAL	`character*12` CLE-2000 variable name in which the extracted RMS value will be placed. This variable should be declared real or double precision.

7.4 The `GRAD:` module

The `GRAD:` module is designed to perform the following tasks:

- compute the gradients of the *system characteristics* (i.e., objective function and constraints) using solutions of direct or adjoint fixed source eigenvalue problems. Here, we assume an optimization problem with *nvar* control variables and with *ncst* constraints. The total number of system characteristics is therefore equal to *ncst*+1.

- define options and parameters related to the optimization problem.

The calling specifications are:

Table 89: Structure `GRAD:`

OPTIM := `GRAD:` [*OPTIM*] *DFLUX GPT* :: **(grad_data)**

where

OPTIM   `character*12` name of the OPTIMIZE object (**L_OPTIMIZE** signature) containing the optimization informations. Object *OPTIM* must appear on the RHS to be able to updated the previous values.

DFLUX   `character*12` name of the FLUX object (**L_FLUX** signature) containing a set of solutions of fixed-source eigenvalue problems.

GPT   `character*12` name of the SOURCE object (**L_SOURCE** signature) containing a set of direct or adjoint sources.

(grad_data)   structure containing the data to the module `GRAD:` (see Sect. 7.4.1).

7.4.1 Data input for module `GRAD:`

Table 90: Structure `grad_data`

```
[ EDIT iprint ]
[ { MAXIMIZE | MINIMIZE } ]
[ OUT-STEP-LIM sr ]
[ VAR-VALUE ( control(i), i=1,nvar ) ] [ VAR-WEIGHT ( weight(i), i=1,nvar ) ]
[ VAR-VAL-MIN { ( vecmin(i), i=1,nvar ) | ALL varmin ]
[ VAR-VAL-MAX { ( vecmax(i), i=1,nvar ) | ALL varmax ]
[ FOBJ-CST-VAL ( funct(i), i=1,ncst+1 ) ]
[ CST-TYPE ( type(i), i=1,ncst ) ] [ CST-OBJ { ( cstval(i), i=1,ncst ) | KEEP } ]
[ CST-WEIGHT ( cstw(i), i=1,ncst ) ]
;
```

where

EDIT	keyword used to set *iprint*.
iprint	index used to control the printing in module.
MAXIMIZE	keyword used to specify that the optimization problem will be a maximization.
MINIMIZE	keyword used to specify that the optimization problem will be a minimization (default).
OUT-STEP-LIM	keyword used to set or reset the maximum steplength along the gradient (default value is $sr = 1.0$ or the value recovered from *OPTIM*).
sr	maximum steplength value (real).
VAR-VALUE	keyword to specify the values of the control variables. These values can also be set in a previous call to module GRAD: or set in another module.
control	array containing *nvar* real values.
VAR-WEIGHT	keyword to specify the values of the control variable weights in the quadratic constraint. All weights are set to 1.0 by default.
weight	array containing *nvar* real values.
VAR-VAL-MIN	keyword to specify the minimum values of the control variables. These values can also be set in a previous call to module GRAD:.
vecmin	array containing *nvar* real values.
varmin	single real value used for all control variables.
VAR-VAL-MAX	keyword to specify the maximum values of the control variables. These values can also be set in a previous call to module GRAD:.
vecmax	array containing *nvar* real values.
varmax	single real value used for all control variables.
FOBJ-CST-VAL	keyword to specify the value of the objective function followed by the actual values of the constraints. These values can also be set in a previous call to module GRAD: or set in another module.
funct	array containing *ncst*+1 real values.
CST-TYPE	keyword to specify the relation types of the constraints. These values can also be set in a previous call to module GRAD:.
type	array containing *ncst* integer values. These values are: $= -1$ for $\geq$, $= 0$ for equally and $= 1$ for $\leq$.
CST-OBJ	keyword to specify the RHS values of the constraints. These values can also be set in a previous call to module GRAD:.
cstval	array containing *ncst* real values.
KEEP	keyword to specify that the RHS values of the constraints are identical to the values of the previous iteration.
CST-WEIGHT	keyword to specify the weights (or penalties) of the constraints. These weights are not used with Lemke or MAP methods. These values can also be set in a previous call to module GRAD:.
cstw	array containing *ncst* real values.

7.5 The `PLQ:` module

The `PLQ:` module is used to solve a general non-linear optimization problem with constraints using the Optex method.[1, 30–32] The `PLQ:` module performs a single iteration of the Optex method where a linearized optimization problem is solved with a quadratic constraint. This quadratic constraint is of the form

$$\sum_{i=1}^{nvar} \omega_i \left(\Delta x_i^{(n)} \right)^2 \leq \left(S^{(n)} \right)^2$$

where ω_i is a weight defined after keyword `CST-WEIGHT` in module `GRAD:` and $\Delta x_i^{(n)}$ is a displacement for i–th control variable at iteration (n). The initial value of radius $S^{(1)}$ is defined after keyword `OUT-STEP-LIM`.

The gradients of the *system characteristics* can be calculated with module `GRAD:`. The `PLQ:` module is also used to define options and parameters for the different method to solve the optimization problem and to reduces the radius $S^{(n)}$ of the quadratic constraint.

The calling specifications are:

Table 91: Structure `PLQ:`

OPTIM := `PLQ:` *OPTIM* :: **(plq_data)**

where

OPTIM `character*12` name of the OPTIMIZE object (**L_OPTIMIZE** signature) containing the optimization informations. Object *OPTIM* must appear on both LHS and RHS to be able to update the previous values.

(plq_data) structure containing the data to the module `PLQ:` (see Sect. 7.5.1).

7.5.1 Data input for module `PLQ:`

Table 92: Structure `plq_data`

```
[ EDIT iprint ]
[ { MAXIMIZE | MINIMIZE } ]
[ METHOD { SIMPLEX | LEMKE | MAP | AUG-LAGRANG | PENAL-METH } ]
[ OUT-STEP-LIM sr ]
[ OUT-STEP-EPS ε_ext ] [ INN-STEP-EPS ε_inn ]
[ CST-QUAD-EPS ε_quad ]
[ STEP-REDUCT { HALF | PARABOLIC } ]
[ WARNING-ONLY ]
CALCUL-DX [ NO-STORE-OLD ]
[ COST-EXTRAP >> ecost << ]
[ OUT-CONV-TST >> l_conv << ]
;
```

where

`EDIT`	keyword used to set *iprint*.
iprint	index used to control the printing in module.
`MAXIMIZE`	keyword used to specify that the optimization problem will be a maximization.
`MINIMIZE`	keyword used to specify that the optimization problem will be a minimization (default).
`METHOD`	keyword used to define the quasi-linear programming method. **Note:** If the general Lemke method is used, the quadratic constraint must be active. The strategy consists to proceed in two steps:

- At first step, the linear programming problem (i. e., without the quadratic constraint) is solved and the control-variable displacement is computed. If this displacement is less than the radius of the quadratic constraint, the step one solution is accepted and step two is not performed. If this displacement is greater than the radius of the quadratic constraint, the step one solution is rejected and step two is performed. Step one can be solved with the SIMPLEX method or with the linear LEMKE method.
- At step two, the general LEMKE method is used to find the correct solution. The general Lemke method is based on a parametric linear complementarity principle, as explained in Ref. 41.

`SIMPLEX`	keyword used to specify that the SIMPLEX method will be used at step one and the general LEMKE method at step two.
`LEMKE`	keyword used to specify that the linear LEMKE method will be used at step one and the general LEMKE method at step two.
`MAP`	keyword used to specify that the MAP method will be used. The quadratic constraint is linearized and a converging sequence of SIMPLEX calculations is performed.
`AUG-LAGRANG`	keyword used to specify that the augmented Lagrangian method will be used.
`PENAL-METH`	keyword used to specify that the penalty method will be used.
`OUT-STEP-LIM`	keyword used to set or reset the initial radius of the quadratic constraint (default value is $sr = 1.0$ or the value recovered from *OPTIM*).
sr	initial radius of the quadratic constraint (real or double precision).
`OUT-STEP-EPS`	keyword used to set the tolerance of outer iteration convergence inside module `PLQ:` (default value is 1.0×10^{-4}).
ϵ_{ext}	tolerance value (real or double precision).
`INN-STEP-EPS`	keyword used to set the tolerance used within the SIMPLEX or LEMKE method (default value is 1.0×10^{-4}).
ϵ_{inn}	tolerance value (real or double precision).
`CST-QUAD-EPS`	keyword to set the convergence parameter *epsilon4* for the radius of the quadratic constraint inside module `GRAD:`.
ϵ_{quad}	tolerance for convergence of the radius of the quadratic constraint (real).
`STEP-REDUCT`	keyword used to define the method of the reduction of the outer step.

`HALF`	keyword used to specify that the step will be reduced by a factor of 2.
`PARABOLIC`	keyword used to specify that the step will be reduced with the parabolic method.
`WARNING-ONLY`	keyword used to specify that only a warning will be used when no valid previous decision vectors can be recall in case of error of the mathematical programming.
`CALCUL-DX`	keyword used to specify that the new step will be calculated.
`NO-STORE-OLD`	keyword used to specify that the old value of decision variables and gradients will not be stored in the `L_OPTIMIZE/'OLD-VALUE'` directory.
`COST-EXTRAP`	keyword used to calculate the extrapolated objective constant *ecost*.
ecost	extrapolated objective constant.
`OUT-CONV-TST`	keyword used to calculate if the external convergence has been reached.
l_{conv}	$= 1$ means that external convergence has been reached; $= 0$ otherwise.

7.6 The `LNSR:` module

The `LNSR:` module performs a single iteration of the line search algorithm, used as inner iteration of steepest descent, conjugate gradient or quasi-Newton optimization techniques.[33] The Armijo line search algorithm is used.[34] The `LNSR:` module is generally used inside an inner loop, as depicted in Fig 14.

Figure 14: Line search iterations.

The calling specifications are:

Table 93: Structure `LNSR:`

$OPTIM$:= `LNSR:` $OPTIM$ :: (**lnsr_data**)

where

$OPTIM$	`character*12` name of the OPTIMIZE object (`L_OPTIMIZE` signature) containing the optimization informations. Object $OPTIM$ must appear on both LHS and RHS to be able to update the previous values.
(**lnsr_data**)	structure containing the data to the module `LNSR:` (see Sect. 7.7.1).

7.6.1 Data input for module `LNSR`:

Table 94: Structure `lnsr_data`

```
[ EDIT iprint ]
[ { MAXIMIZE | MINIMIZE } ]
[ OUT-STEP-LIM sr ]
[ OUT-STEP-EPS ε_ext ] [ INN-STEP-EPS ε_inn ]
OUT-ITER-MAX maxE
[ OUT-RESTART nstart ]
[ { SD | CG | BFGS | LBFGS [ hist_nr ] | NEWT } ]
[ INN-CONV-TST >> l_convI << OUT-CONV-TST >> l_convE << ]
;
```

where

`EDIT`	keyword used to set *iprint*.
iprint	index used to control the printing in module.
`MAXIMIZE`	keyword used to specify that the optimization problem will be a maximization.
`MINIMIZE`	keyword used to specify that the optimization problem will be a minimization (default).
`OUT-STEP-LIM`	keyword used to set or reset the maximum stepsize for the line search (default value is $sr = 1.0$ or the value recovered from *OPTIM*).
sr	initial radius of the stepsize (real or double precision).
`OUT-STEP-EPS`	keyword used to set the tolerance of outer iteration convergence inside module `LNSR`: (default value is 1.0×10^{-4}).
ϵ_{ext}	tolerance value (real or double precision).
`INN-STEP-EPS`	keyword used to set the tolerance used for the line search algorithm (default value is 1.0×10^{-4}).
ϵ_{inn}	tolerance value (real or double precision).
`OUT-ITER-MAX`	keyword used to set the maximum number of external iterations.
maxE	maximum number of external iterations.
`OUT-RESTART`	keyword used to set the external iteration restart cycle. A new recursion cycle is restarted from the conjugate gradient method. By default, no restart is performed.
nstart	number of iterations in one external iteration restart cycle.
`SD`	steepest descent method (default option).
`CG`	conjugate gradient method.
`BFGS`	Broyden-Fletcher-Goldfarb-Shanno method.[33]

LBFGS   Memory limited Broyden-Fletcher-Goldfarb-Shanno method.[35]

hist_nr   number of corrections used in the memory limited Broyden-Fletcher-Goldfarb-Shanno method (default value is 10).

NEWT   Newton method for unconstrained optimization.[36]

INN-CONV-TST   keyword used to determine if the line search convergence has been reached.

l_{convI} = 1 means that line search convergence has been reached; = 0 otherwise.

OUT-CONV-TST   keyword used to determine if the external convergence has been reached.

l_{convI} = 1 means that external convergence has been reached; = 0 otherwise.

7.7   The `FPSPH:` module

The `FPSPH:` module performs a single fixed-point (aka. Picard) or Newton SPH iteration. This module is intended to be used in a `REPEAT UNTIL` loop, implemented in CLE-2000 macro-language, where the macro calculation is explicitly called, as depicted in Figs. 15 and 16.

Figure 15: Fixed point SPH iterations.

Figure 16: Newton SPH iterations.

The calling specifications are:

Table 95: Structure FPSPH:

OPTIM := FPSPH: [*OPTIM*] *MACROLIB MACROREF* :: **(fpsph_data)**

---

where

OPTIM	**character*12** name of the OPTIMIZE object (**L_OPTIMIZE** signature) containing the SPH factors. At the first call, object *OPTIM* must appear on LHS to receive its initial values. On subsequent calls, object *OPTIM* must appear on both LHS and RHS to be able to update the previous values.
MACROLIB	**character*12** name of the read-only extended MACROLIB object (**L_MACROLIB** signature) containing the macroscopic cross sections used by the macro-calculation and fluxes produced by the macro-calculation.
MACROREF	**character*12** name of the read-only extended MACROLIB object (**L_MACROLIB** signature) containing the reference macroscopic cross sections and fluxes.
(fpsph_data)	structure containing the data to the module FPSPH: (see Sect. 7.7.1).

7.7.1 Data input for module FPSPH:

Table 96: Structure fpsph_data

```
[ EDIT iprint ]
[ SPH { PN | SN } ]
[ GRPMIN ngr1 ] [ GRPMAX ngr2 ]
[ OUT-STEP-EPS ε_ext
[ VAR-VAL-MIN varmin ] [ VAR-VAL-MAX varmax ]
[ OUT-CONV-TST >> l_conv << ]
;
```

---

where

EDIT	keyword used to set *iprint*.
iprint	index used to control the printing in module.
PN	keyword to activate a calculation of heterogeneous SPH factors of diffusion, PN or SPN type.
SN	keyword to activate a calculation of heterogeneous SPH factors of PIJ, IC, SN or MOC type. This is the default option.

`GRPMIN`	keyword used to set the first energy group where SPH correction is applied. By default, the first energy group index is used.
ngr1	minimum energy group index where SPH correction is applied.
`GRPMAX`	keyword used to set the last energy group where SPH correction is applied. By default, the total number of energy groups in *MACROLIB* is used.
ngr2	maximum energy group index where SPH correction is applied.
`OUT-STEP-EPS`	keyword used to set the tolerance of SPH iteration convergence inside module `FPSPH:` (default value is 1.0×10^{-4}).
ϵ_{ext}	tolerance value (real or double precision).
`VAR-VAL-MIN`	keyword to specify the minimum values of the SPH factors. These values can also be set in a previous call to module `GRAD:`.
varmin	single real value used for all SPH factors.
`VAR-VAL-MAX`	keyword to specify the maximum values of the SPH factors. These values can also be set in a previous call to module `GRAD:`.
varmax	single real value used for all SPH factors.
`OUT-CONV-TST`	keyword used to determine if the SPH convergence has been reached.
l_{conv}	$= 1$ means that SPH convergence has been reached; $= 0$ otherwise.

8 PIN-POWER RECONSTRUCTION MODULES

This section is related to pin-power reconstruction capabilities available in Donjon. The corresponding theory is explained in [47, 48]

8.1 The `NAP:` module

The `NAP:` module supplies the main transport-diffusion equivalence options to DRAGON and DON-JON. It can be used to perform the pin power reconstruction.[47, 48] The calling specifications are:

Table 97: 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). A previous call to the `FLPOW:` module is highly recommended prior to the pin-power reconstruction to normalize the flux and compute the assembly power. If not, the pin-power reconstruction will be normalized using the whole core power instead of a normalization for each assembly. 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 8.1.1).

(descnap2)	structure containing the input data to this module to perform pin power reconstruction (see Section 8.1.2).
(descnap3)	structure containing the input data to this module to automatically define the core geometry with heterogeneous assembly (see Section 8.1.3).

8.1.1 Additional properties calculations

Table 98: 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" up to 5 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): WRITE(RECNAME,'5HFINF_,I3.3') IFX 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.

8.1.2 Pin power reconstruction

Table 99: Structure **(descnap2)**

```
[ EDIT iprint ]
PPR
NZASS nzass
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:

- *iprint*=0 results in no output;
- *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. 8.1.1 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 either previously by the FLPOW: module or by the user independently.

pow   power used to normalize the flux (MW).

8.1.3 Heterogeneous assembly geometry definition

Table 100: 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:

- *iprint*=0 results in no output;
- *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.

9 DONJON DATA STRUCTURES

A brief description of each DRAGON, DONJON and TRIVAC data structures, which can be used with DONJON code, is given in Section 2.2. In this section, a detailed description of the DONJON data structures is presented.

9.1 Contents of /fmap/ data structure

A /fmap/ data structure is used to store fuel assembly (or bundle) map and fuel information such as powers, average fluxes, control zones, burnup or refueling scheme. The fuel bundle location are given in an embedded sub-directory which contains the records as a /geometry/ data structure. This object has a signature L_MAP; it is created using the RESINI: module.

9.1.1 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 fuel bundles per channel $N_{\mathrm{b}} = \mathcal{S}_1$

- The number of fuel channels $N_{\mathrm{ch}} = \mathcal{S}_2$

- The number of combustion zones $N_{\mathrm{comb}} = \mathcal{S}_3$

- The number of energy groups $N_{\mathrm{gr}} = \mathcal{S}_4$

- The type of interpolation with respect to burnup $I_{\mathrm{btyp}} = \mathcal{S}_5$

$$
I_{\mathrm{btyp}} = \begin{cases} 0 & \text{interpolation type is not provided} \\ 1 & \text{according to the time-average model} \\ 2 & \text{according to the instantaneous model} \end{cases}
$$

- The number of bundle shift. $N_{\mathrm{sht}} = \mathcal{S}_6$

- The number of fuel types $N_{\mathrm{fuel}} = \mathcal{S}_7$

- The number of recorded parameters $N_{\mathrm{parm}} = \mathcal{S}_8$

- The total number of fuel bundles $N_{\mathrm{tot}} = \mathcal{S}_9$

- The number of voided reactor channels $N_{\mathrm{void}} = \mathcal{S}_{10}$

- The option with respect to the core-voiding pattern $I_{\mathrm{void}} = \mathcal{S}_{11}$

$$
I_{\mathrm{void}} = \begin{cases} 0 & \text{voiding pattern not provided} \\ 1 & \text{full-core voiding pattern} \\ 2 & \text{half-core voiding pattern} \\ 3 & \text{quarter-core voiding pattern} \\ 4 & \text{checkerboard-full voiding pattern} \\ 5 & \text{checkerboard-half voiding pattern} \\ 6 & \text{checkerboard-quarter voiding pattern} \\ 7 & \text{user-defined voiding pattern} \end{cases}
$$

- The type of the geometry $F_{\mathrm{t}} = \mathcal{S}_{12}$

$$F_{\mathrm{t}} = \left\{ \begin{array}{ll} 7 & \text{Cartesian } \textit{3-D} \text{ geometry} \\ 9 & \text{Hexagonal } \textit{3-D} \text{ geometry} \end{array} \right.$$

- The naval-coordinate layout used by the `SIM:` module $I_{\mathrm{sim}} = \mathcal{S}_{13}$.

  The number of assemblies along X and Y axis are given using

$$L_{\mathrm{x}} = \frac{I_{\mathrm{sim}}}{100} \quad \text{and} \quad L_{\mathrm{y}} = \mathrm{mod}(I_{\mathrm{sim}}, 100)$$

- The total number of assemblies $N_{\mathrm{ass}} = \mathcal{S}_{14}$

- The number of assemblies along X direction in Cartesian geometry. The number of assemblies in the radial plane in hexagonal geometry. $N_{\mathrm{xa}} = \mathcal{S}_{15}$

- The number of assemblies along Y direction in Cartesian geometry $N_{\mathrm{ya}} = \mathcal{S}_{16}$

- The number of plane of the mesh along Z direction where assemblies are located $N_{\mathrm{z,ass}} = \mathcal{S}_{17}$

- The number of particularized isotopes to store in {hcycle} sub-directories $N_{\mathrm{is}} = \mathcal{S}_{18}$

- The number of {hcycle} sub-directories $N_{\mathrm{cy}} = \mathcal{S}_{19}$

9.1.2 The main /fmap/ directory

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

Table 101: Records and sub-directories in /fmap/ data structure

Name	Type	Condition	Units	Comment
SIGNATURE␣␣␣	C*12			Signature of the /fmap/ data structure (SIGNA =L␣MAP␣␣␣␣␣␣␣).
STATE-VECTOR	I(40)			Vector describing the various parameters associated with this data structure $\mathcal{S}_i$
FLMIX␣␣␣␣␣␣␣	I($N_{\mathrm{ch}}, N_{\mathrm{b}}$)			Fuel type indices per bundle or assembly subdivisions for each reactor channel.
FLMIX-INI␣␣␣	I($N_{\mathrm{ch}}, N_{\mathrm{b}}$)	$I_{\mathrm{sim}} \neq 0$		Fuel type indices per bundle or assembly subdivisions for each reactor channel, as defined by user in RESINI: module.
S-ZONE␣␣␣␣␣␣	C(N_{ch}) * 4	$I_{\mathrm{sim}} \neq 0$		identification name corresponding to the basic naval-coordinate position of an assembly, as defined by user in RESINI: module..
BMIX␣␣␣␣␣␣␣␣	I(N_x, N_y, N_z)			Renumbered mixture indices per each fuel region over the fuel-map geometry; for the non-fuel regions these indices are set to 0.

Records and sub-directories in /fmap/ data structure

Name	Type	Condition	Units	Comment
XNAME␣␣␣␣␣␣␣	$C(N_x) * 4$	$F_t = 7$		Channel identification names with respect to their horizontal position in Cartesian geometry.
YNAME␣␣␣␣␣␣␣	$C(N_y) * 4$	$F_t = 7$		Channel identification names with respect to their vertical position in Cartesian geometry.
HNAME␣␣␣␣␣␣␣	$C(N_x) * 8$	$F_t = 9$		Channel identification names with respect to their radial position in hexagonal geometry.
AXNAME␣␣␣␣␣␣	$C(N_{xa}) * 4$	$F_t = 7$		Name of the assembly on X-direction (4 character name per assembly) in Cartesian geometry
AYNAME␣␣␣␣␣␣	$C(N_{ya}) * 4$	$F_t = 7$		Name of the assembly on Y-direction (4 character name per assembly) in Cartesian geometry
ASSEMBLY␣␣␣␣	$Dir(N_{ass})$			List of *assembly* directories. Each component of this list follows the specification presented in Section 9.1.7.
B-ZONE␣␣␣␣␣␣	$I(N_{ch})$	$N_{comb} \geq 1$		Combustion-zone indices per channel.
BURN-AVG␣␣␣␣	$R(N_{comb})$		MW d t^{-1}	Average exit burnups per combustion zone.
BURN-INST␣␣␣	$R(N_{ch}, N_b)$	$I_{btyp} = 2$	MW d t^{-1}	Instantaneous burnups per bundle or assembly subdivisions for each channel.
BURN-BEG␣␣␣␣	$R(N_{ch}, N_b)$	$I_{btyp} = 1$	MW d t^{-1}	Low burnup integration limits according to the time-average model.
BURN-END␣␣␣␣	$R(N_{ch}, N_b)$	$I_{btyp} = 1$	MW d t^{-1}	Upper burnup integration limits according to the time-average model.
BUND-PW␣␣␣␣␣	$R(N_{ch}, N_b)$	$*$	kW	Bundle-powers set in RESINI: module or recovered from L_POWER object.
BUND-PW-INI␣	$R(N_{ch}, N_b)$	$*$	kW	Beginning-of-transient bundle-powers recovered from L_POWER object.
FLUX-AV␣␣␣␣␣	$R(N_{ch}, N_b, N_{gr})$	$*$	cm^{-2} s^{-1}	The normalized average fluxes recorded per each fuel bundle and for each energy group, recovered from L_POWER object.
REACTOR-PW␣␣	$R(1)$	$*$	MW	Full reactor power set in RESINI: module or recovered from L_POWER object.
AXIAL-FPW␣␣␣	$R(N_b)$	$*$	1	Axial power form factor set in RESINI: module.
B-EXIT␣␣␣␣␣␣	$R(1)$		MW d t^{-1}	Core-average discharge burnup.
REF-SHIFT␣␣␣	$I(N_{comb})$			Bundle-shifts per combustion zone. A bundle-shift corresponds to the number of displaced fuel bundles during the refueling operation.
REF-VECTOR␣␣	$I(N_{comb}, N_b)$			Refueling pattern vector per combustion zone.
REF-SCHEME␣␣	$I(N_{ch})$			Refueling scheme of each channel; it corresponds to the positive or negative bundle-shift number according to the flow direction.
REF-RATE␣␣␣␣	$R(N_{ch})$		kg d^{-1}	Channel refueling rates.
REF-CHAN␣␣␣␣	$R(N_{ch})$		d	Time values at which channels are refueled inside a refueling time period.

Records and sub-directories in /fmap/ data structure

Name	Type	Condition	Units	Comment
`DEPL-TIME`	$R(1)$		d	Refueling time period in days.
$\{pshift\}$	$R(N_{\mathrm{ch}}, N_{\mathrm{b}})$	$N_{\mathrm{sht}} \geq 1$	kW	The power of the bundles shifted the i-th time.
$\{bshift\}$	$R(N_{\mathrm{ch}}, N_{\mathrm{b}})$	$N_{\mathrm{sht}} \geq 1$	$MWdT^{-1}$	The burnup of the bundles shifted the i-th time.
$\{ishift\}$	$I(N_{\mathrm{ch}}, N_{\mathrm{b}})$	$N_{\mathrm{sht}} \geq 1$		The number of shifts per bundle during refueling.
`AX-SHAPE`	$R(N_{\mathrm{ch}}, N_{\mathrm{b}})$	$I_{\mathrm{btyp}} = 1$		Normalized axial power-shape values over the fuel bundles. Equal to fuel-bundle powers divided by channel powers.
`EPS-AX`	$R(1)$	$I_{\mathrm{btyp}} = 1$		Convergence factor for the axial power-shape calculation; it is defined as a relative error between the two successives calculations.
`FQ`	$R(1)$			Hot spot factor: power of the hottest 3D Cartesian pin spot normalized to the mean power of a 3D Cartesian pin spot.

$$FQ = \frac{P_{\substack{\max \\ \text{x,y,z}}}(x, y, z)}{P_{\substack{\text{moy} \\ \text{x,y,z}}}(x, y, z)}$$

where P(x,y,z) is the power of an axial part of a pin located at the coordinates (x,y,z).

Name	Type	Condition	Units	Comment
`FXY`	$R(1)$			Radial hot spot factor: power of the hottest pin normalized to the mean power of a pin.

$$Fxy = \frac{P_{\substack{\max \\ \text{x,y}}}(x, y)}{P_{\substack{\text{moy} \\ \text{x,y}}}(x, y)}$$

with

$$P(x, y) = \int_0^{zmax} P(x, y, z)\, \mathrm{d}z$$

Name	Type	Condition	Units	Comment
`FXYZ`	$R(N_{\mathrm{z,ass}})$			For each axial mesh, power of the hottest 2D Cartesian pin spot normalized to the mean power of a 3D Cartesian pin spot.

$$Fxy(z) = \frac{P_{\substack{\max \\ \text{x,y}}}(x, y, z)}{P_{\substack{\text{moy} \\ \text{x,y,z}}}(x, y, z)}$$

Records and sub-directories in /fmap/ data structure

Name	Type	Condition	Units	Comment
FXYASS␣␣␣␣␣␣	$R(N_{\text{ass}})$			For each assembly, power of the hottest pin normalized to the mean power of a pin. $$Fxy(iass) = \frac{P_{\max}_{\text{x,y}}(x,y,iass)}{P_{\text{moy}}_{\text{x,y}}(x,y)}$$ with $$P(x,y,iass) = \int_0^{zmax} P(x,y,z,iass)\,\mathrm{d}z$$
HFOLLOW␣␣␣␣␣	$C(N_{\text{is}})*8$	$N_{\text{is}} > 0$		Name of the particularized isotopes to store in {hcycle} directory.
GEOMAP␣␣␣␣␣␣	Dir			Sub-directory containing the embedded *3D*-Cartesian /geometry/ of the fuel lattice.
FUEL␣␣␣␣␣␣␣␣	$\text{Dir}(N_{\text{fuel}})$			List of fuel–type sub-directories. Each component of the list is a directory containing the information relative to a single fuel type.
ROD-INFO␣␣␣␣	Dir	*		Sub-directory containing the information corresponding to the local rod insertion for PWR. This sub-directory follows the specification presented in Section 9.1.6.
{hcycle}	$\text{Dir}(N_{\text{burn}})$	$N_{\text{cy}} > 0$		Sub-directory containing information related to a fuel cycle in a PWR. N_{burn} is the number of burnup steps used during the simulation of the cycle. These burnup steps may not be of increasing values. If module TINST: was used to burn fuel, the name of the *hcycle* directory is "␣TINST".
CYCLE-NAMES␣	$C(N_{\text{cy}})*12$	$N_{\text{cy}} > 0$		Names of fuel cycle sub-directories {hcycle}.
PARAM␣␣␣␣␣␣␣	$\text{Dir}(N_{\text{parm}})$	$N_{\text{parm}} > 0$		List of parameter–type sub-directories corresponding to actual time. Each component of the list is a directory containing the information relative to a single parameter (see Sect. 9.1.5). The total number of sub-directories corresponds to the total number of recorded parameters N_{parm} (excluding burnups).

The contents of the GEOMAP sub-directory correspond to the typical contents of the /geometry/ data structure. The dimensioning parameters N_x, N_y, and N_z represent the number of volumes along the corresponding axis in the fuel-map geometry.

The shifting information records {pshift}, {bshift} and {ishift} will be composed using the following FORTRAN instructions, respectively, as

$$\text{WRITE(pshift,}' \text{(A6, I2)}') \text{ 'PSHIFT'}, ell$$

$$\text{WRITE(bshift,}' (\text{A6, I2})') \ '\text{BSHIFT}', ell$$

$$\text{WRITE(ishift,}' (\text{A6, I2})') \ '\text{ISHIFT}', ell$$

for $1 \leq ell \leq N_{\text{sht}}$.

Each time a bundle is shifted and stay in the reactor, its burnup and power will be saved in the records {bshift} and {pshift}. For example, {bshift i} and {pshift i} will contain all the burnups and powers of bundles that have been shifted i-th time.

9.1.3 The FUEL sub-directories

Each FUEL sub-directory contains the information corresponding to a single fuel type. Inside each sub-directory, the following records will be found:

Table 102: Records in FUEL sub-directories

Name	Type	Condition	Units	Comment
MIX␣␣␣␣␣␣␣␣␣	I(1)			Fuel-type mixture number.
TOT␣␣␣␣␣␣␣␣␣	I(1)			Total number of fuel bundles for this fuel type.
MIX-VOID␣␣␣␣	I(1)			Voided-cell mixture number for this fuel type.
WEIGHT␣␣␣␣␣␣	R(1)		kg	Fuel weight in a bundle for this fuel type.
ENRICH␣␣␣␣␣␣	R(1)		wt%	Fuel enrichment for this fuel type.
POISON␣␣␣␣␣␣	R(1)			Poison load for this fuel type.

9.1.4 The {hcycle} sub-directories

Each {hcycle} sub-directory contains the information corresponding to a single PWR fuel cycle. Inside each sub-directory, the following records will be found:

Table 103: Records in {hcycle} sub-directories

Name	Type	Condition	Units	Comment
ALIAS␣␣␣␣␣␣␣	C(*12			Name of the cycle sub-directory.
TIME␣␣␣␣␣␣␣␣	R(1)		d	Depletion time corresponding to instantaneous burnup values.

Name	Type	Condition	Units	Comment
PARAM␣␣␣␣␣␣␣	$\mathrm{Dir}(N_\mathrm{parm})$	$N_\mathrm{parm} > 0$		List of parameter–type sub-directories corresponding to refuelling time. Each component of the list is a directory containing the information relative to a single parameter (see Sect. 9.1.5). The total number of sub-directories corresponds to the total number of recorded parameters N_parm (excluding burnups).
BURNAVG␣␣␣␣␣	R(1)		MW d t^{-1}	Average burnup of the assembly.
NAME␣␣␣␣␣␣␣␣	$\mathrm{C}(N_\mathrm{ch}) * 12$			Names of each assembly or of each quart-of assembly during a refuelling cycle. All quart-of-assembly belonging to the same assembly have the same name.
CYCLE␣␣␣␣␣␣␣	$\mathrm{C}(L_\mathrm{x} \times L_\mathrm{y}) * 4$			Shuffling matrix for refuelling as provided by the plant operator. The name "|" is reserved for empty locations.
FLMIX␣␣␣␣␣␣␣	$\mathrm{I}(N_\mathrm{ch}, N_\mathrm{b})$			Fuel type indices per assembly subdivisions for each reactor channel.
BURN-INST␣␣␣	$\mathrm{R}(N_\mathrm{ch}, N_\mathrm{b})$		MW d t^{-1}	Instantaneous burnups per assembly subdivisions for each channel.
POWER-BUND␣␣	$\mathrm{R}(N_\mathrm{ch}, N_\mathrm{b})$		kW	Powers per assembly subdivisions for each channel.
K-EFFECTIVE␣	R(1)			Effective multiplication factor k_eff.
FOLLOW␣␣␣␣␣␣	$\mathrm{R}(N_\mathrm{ch}, N_\mathrm{b}, N_\mathrm{is})$	$N_\mathrm{is} > 0$	(cm b)$^{-1}$	Number densities of the particularized isotopes.

9.1.5 The `PARAM` *sub-directories*

Each `PARAM` sub-directory contains the information corresponding to a single local or global parameter (excluding burnups). Inside a such sub-directory, the following records will be found:

Table 104: Records in `PARAM` sub-directories

Name	Type	Condition	Units	Comment
`P-NAME⎵⎵⎵⎵⎵⎵`	C*12			Unique identification name of this parameter. This name is user-defined; however, 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

Name	Type	Condition	Units	Comment
`PARKEY⎵⎵⎵⎵⎵⎵`	C*12			Corresponding name of this parameter as recorded in a multi-parameter Compo file.
`P-TYPE⎵⎵⎵⎵⎵⎵`	I(1)			Number associated to the type of recorded parameter: $ptype = 1$ for global parameter; $ptype = 2$ for local parameter.
`P-VALUE⎵⎵⎵⎵⎵`	R(1)	$ptype = 1$		Recorded single value for global parameter. Temperatures are given in K and densities are given in g/cc.
	R($N_{\mathrm{ch}}, N_{\mathrm{b}}$)	$ptype = 2$		Recorded values for local parameter per each fuel bundle for every channel. Temperatures are given in K and densities are given in g/cc.

9.1.6 The `ROD-INFO` *sub-directory*

The `ROD-INFO` sub-directory contains the information corresponding to the local rod insertion for PWR. This sub-directory is created after the first calling to the `ROD:` module. Inside this sub-directory, the following records will be found:

Table 105: Records in `ROD-INFO` sub-directories

Name	Type	Condition	Units	Comment
ROD-INIT␣␣␣␣	R(1)			Default value for the rod field. This value corresponds to no rod inserted.
INS-MAX␣␣␣␣␣	I(1)			Number associated to the maximum of rod insertion steps possible.
STEP-CM␣␣␣␣␣	R(1)			Length of one rod insertion step (in cm).
REFL-BOTTOM␣	I(1)			Number of bottom reflective axial-planes.
NB-GROUP␣␣␣␣	I(1)			Number of rod groups.
MAX-MIX␣␣␣␣␣	I(1)			Maximum number of rod zones for all the rods defined.
ROD-NAME␣␣␣␣	$C(N_{\rm gr}) * 3$			Name of each rod group defined by user in `ROD:` module.
ROD-INSERT␣␣	$I(N_{gr})$			Insertion of each rod group defined by user in `ROD:` module.
ROD-RIN␣␣␣␣␣	$R(N_{gr}, N_{mmix})$			Rod identification numbers (RIN) for each rod group defined by user in `ROD:` module.
ROD-NBZONE␣␣	$I(N_{gr})$			Number of RIN zones for each rod group defined by user in `ROD:` module.
ROD-HEIGHT␣␣	$R(N_{gr}, N_{mmix})$			Height between the bottom of the rod and the beginning of the RIN zone for each rod group and each RIN zone defined by user in `ROD:` module.
ROD-MAP␣␣␣␣␣	$C(N_{\rm ch}) * 3$			Identification name corresponding to the rod map as defined by user in `ROD:` module.

9.1.7 The ASSEMBLY sub-directory

Table 106: Assembly type sub-directory

Name	Type	Condition	UnitsComment
LABEL␣␣␣␣␣␣␣	C*8		Label of the assembly. It consists a 8 character name composed of the AYNAME and AXNAME
PIN-POWER␣␣␣	$R(N_{pin}^2 * N_{\rm z,ass})$		array containing the pin power for each pin on each mesh plane of the assembly.
ASS-POWER␣␣␣	R(1)		total assembly power.

Name	Type	Condition	Units	Comment
`SIG_F*PHI␣␣␣`	$R(N_{pin}^2 * N_{z,ass})$			array containing the integral of Σ_f times the flux for each pin on each mesh plane of the assembly.
`FLUX␣␣␣␣␣␣␣␣`	$R(N_{pin}^2 * N_{z,ass} * N_g)$			array containing the flux of each group for each pin on each mesh plane of the assembly.

9.2   Contents of /matex/ data structure

A /matex/ data structure is used to store several information related to the reactor extended material index and geometry. This object has a signature L_MATEX; it is created using the USPLIT: module. The information contained in this data structure can be used and updated in other DONJON modules.

9.2.1 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 $N_{gr} = \mathcal{S}_1$

- The maximum number of material mixtures $N_m = \mathcal{S}_2$ (N_m equals to the total number of material regions plus the number of device mixtures)

- The number of reflector types $N_r = \mathcal{S}_3$

- The number of fuel types $N_f = \mathcal{S}_4$

- The total number of mixtures indices $N_{tot} = \mathcal{S}_5$ (N_{tot} equals to the total number of mesh-splitted volumes plus the number of device mixtures)

- The type of reactor geometry $I_g = \mathcal{S}_6$ (only $I_g = 7$ for *3D*-Cartesian geometry or $I_g = 9$ for *3D*-Hexagonal geometry are allowed)

- The total number of mesh-splitted volumes $N_{el} = \mathcal{S}_7$

- The number of mesh-splitted volumes along x-axis $L_x = \mathcal{S}_8$

- The number of mesh-splitted volumes along y-axis $L_y = \mathcal{S}_9$

- The number of mesh-splitted volumes along z-axis $L_z = \mathcal{S}_{10}$

9.2.2 The /matex/ directory

The following records will be found on the /matex/ directory:

Table 107: Records in /matex/ data structure

Name	Type	Condition	Units	Comment
SIGNATURE␣␣␣	C*12			Signature of the /matex/ data structure (SIGNA =L_MATEX␣␣␣␣␣).
STATE-VECTOR	I(40)			Vector describing the various parameters associated with this data structure $\mathcal{S}_i$
RMIX␣␣␣␣␣␣␣␣	I(N_r)			The reflector-type mixture indices, as defined in the reactor geometry.
RTOT␣␣␣␣␣␣␣␣	I(N_r)			The total number of reflector regions per each reflector type.

Records in /matex/ data structure

Name	Type	Condition	Units	Comment
FMIX␣␣␣␣␣␣␣␣	$I(N_f)$			The fuel-type mixture indices, as defined in the reactor geometry.
FTOT␣␣␣␣␣␣␣␣	$I(N_f)$			The total number of fuel regions per each fuel type.
MAT␣␣␣␣␣␣␣␣␣	$I(N_{tot})$			The material mixture indices per each region and including the device mixtures. The fuel-type indices are set negative; the device indices are appended at the end of vector; the virtual-region indices are set to 0.
INDEX␣␣␣␣␣␣␣	$I(N_{el})$			The renumbered mixture indices. A unique number is associated with each mesh-splitted volume. The device indices are not included; the virtual-region indices are set to 0.
MESHX␣␣␣␣␣␣␣	$R(L_x + 1)$			The mesh-splitted coordinates along x-axis of the reactor geometry.
MESHY␣␣␣␣␣␣␣	$R(L_y + 1)$			The mesh-splitted coordinates along y-axis of the reactor geometry.
MESHZ␣␣␣␣␣␣␣	$R(L_z + 1)$			The mesh-splitted coordinates along z-axis of the reactor geometry.
H-FACTOR␣␣␣␣	$R(N_m, N_{gr})$			The h-factors per each mixture and per each energy group, as recovered from the extended /macrolib/ data structure.

9.3 Contents of /device/ data structure

A /device/ data structure is used to store several information related to the reactor devices. This object has a signature L_DEVICE; it is created using the DEVINI: module. The information contained in this data structure can be used and updated in other DONJON modules which are related to the devices, namely: LZC:, DSET:, MOVDEV: and NEWMAC: modules.

9.3.1 The state-vector content

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

- The type of reactor geometry $I_g = \mathcal{S}_1$ (only $I_g = 7$ for *3D*-Cartesian geometry allowed)

- The total number of rod-type devices $N_{rod} = \mathcal{S}_2$

- The total number of the rod-type groups $N_{rgrp} = \mathcal{S}_3$

- The total number of lzc-type devices $N_{lzc} = \mathcal{S}_4$

- The total number of the lzc-type groups $N_{lgrp} = \mathcal{S}_5$

- Type of control rod movement $I_{mov} = \mathcal{S}_6$ where

$$I_{\mathrm{mov}} = \begin{cases} 1 & \text{Fading. A fraction of the fully inserted rod vanishes} \\ 2 & \text{Moving. The complete rod is moving (DONJON3-type movement).} \end{cases}$$

9.3.2 The main /device/ directory

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

Table 108: Records and sub-directories in /device/ data structure

Name	Type	Condition	Units	Comment
SIGNATURE␣␣␣	C*12			Signature of the /device/ data structure (SIGNA =L_DEVICE␣␣␣␣).
STATE−VECTOR	I(40)			Vector describing the various parameters associated with this data structure $\mathcal{S}_i$
DEV_ROD␣␣␣␣␣	Dir(N_{rod})			Sub-directories for each controller rod. A sub-directory is created for each controller rod according to the rod identification number.
ROD_GROUP␣␣␣	Dir(N_{rgrp})			Sub-directories for each group of rod-type devices. A sub-directory is created for each group of rod-type devices according to the rod-group identification number.

Records and sub-directories in /device/ data structure continued from last page

Name	Type	Condition	Units	Comment
DEV_LZC⎵⎵⎵⎵⎵	Dir(N_{lzc})			Sub-directories for each liquid zone controller. A sub-directory is created for each liquid controller according to the liquid controller identification number.
LZC_GROUP⎵⎵⎵	Dir(N_{lgrp})			Sub-directories for each group of lzc-type devices. A sub-directory is created for each group of lzc-type devices according to the lzc-group identification number.

9.3.3 The DEV-ROD sub-directories

Inside each DEV-ROD sub-directory, the following records will be found:

Table 109: Records in DEV-ROD sub-directories

Name	Type	Condition	Units	Comment
ROD-ID⎵⎵⎵⎵⎵⎵	I(1)			The identification number of the rod.
ROD-NAME⎵⎵⎵⎵	C∗12			The identification name of the rod.
ROD-PARTS⎵⎵⎵	I(1)			The number of parts in the rod ($N_{\text{part}} \geq 1$).
AXIS⎵⎵⎵⎵⎵⎵⎵⎵	I(1)			The number used to identify the rod mouvement direction: = 1 along x-axis; = 2 along y-axis; =3 along z-axis.
FROM⎵⎵⎵⎵⎵⎵⎵⎵	I(1)			The number used to identify the side of geometry, from which the controller rod is inserted into the reactor core along its direction of mouvement: = 1 if a rod is inserted from the highest position (e.g. from the top); = -1 if a rod is inserted from the lowest position (e.g. from the bottom).
LENGTH⎵⎵⎵⎵⎵⎵	R(2)		cm	The initial and final position coordinates of the full-inserted rod along its direction of movement. The rod length is the distance between these two coordinates.
CORE-LIMITS⎵	R(6)		cm	The initial and final position coordinates of the full core along each Cartesian direction.
MAX-POS⎵⎵⎵⎵⎵	R($6 \times N_{\text{part}}$)		cm	The limiting *3D*-Cartesian coordinates of the full-inserted rod. This data is given for each part of the rod.

Name	Type	Condition	Units	Comment
ROD-MIX␣␣␣␣␣	$I(2 \times N_{\text{part}})$			The rod-type mixture indices. The first number corresponds to the inserted rod position and the second to the withdrawn rod position. This data is given for each part of the rod.
LEVEL␣␣␣␣␣␣	$R(1)$	*		The actual insertion level of the controller rod. This value must be between 0.0 for the full-withdrawn rod and 1.0 for the full-inserted rod.
SPEED␣␣␣␣␣␣	$R(1)$	*	cm s^{-1}	The speed of rod movement (insertion or extraction).
TIME␣␣␣␣␣␣␣	$R(1)$	*	s	The time for the full rod insertion or extraction.
ROD-POS␣␣␣␣␣	$R(6 \times N_{\text{part}})$	*	cm	The actual *3D*-Cartesian coordinates of the rod. This data is given for each part of the rod.

9.3.4 The `ROD-GROUP` sub-directories

Inside each `ROD-GROUP` sub-directory, the following records will be found:

Table 110: Records in `ROD-GROUP` sub-directories

Name	Type	Condition	Units	Comment
GROUP-ID␣␣␣␣	$I(1)$			The identification number of the rod-group.
NUM-ROD␣␣␣␣␣	$I(1)$			The total number N_{rd} of rod-devices in the group.
ROD-ID␣␣␣␣␣␣	$I(N_{rd})$			An array of identification numbers of rods which belong to the same group.

9.3.5 The `DEV-LZC` sub-directories

Inside each `DEV-LZC` sub-directory, the following records will be found:

Table 111: Records in `DEV-LZC` sub-directories

Name	Type	Condition	Units	Comment
LZC-ID␣␣␣␣␣␣	I(1)			The identification number of the liquid zone controller.
MAX-POS␣␣␣␣␣	R(6)		cm	The limiting *3D*-Cartesian coordinates of the whole liquid controller, including its empty and full parts.
AXIS␣␣␣␣␣␣␣	I(1)			The number used to identify the water filling direction: = 1 along x-axis; = 2 along y-axis; =3 along z-axis.
HEIGHT␣␣␣␣␣	R(1)		cm	The water height of the full-filled controller along its direction of filling.
LEVEL␣␣␣␣␣␣	R(1)			The actual water level of the liquid controller device. This value must be between 0.0 for the empty state and 1.0 for the full-filled state.
EMPTY-POS␣␣␣	R(6)		cm	The actual *3D*-Cartesian coordinates of the empty-part of liquid contoller.
FULL-POS␣␣␣␣	R(6)		cm	The actual *3D*-Cartesian coordinates of the full-part of liquid contoller.
EMPTY-MIX␣␣␣	I(2)			The empty-part mixture number and the reference mixture number.
FULL-MIX␣␣␣␣	I(2)			The full-part mixture number and the reference mixture number.
RATE␣␣␣␣␣␣␣␣	R(1)		$m^3 s^{-1}$	The water filling rate.
TIME␣␣␣␣␣␣␣␣	R(1)		s	The water filling time.

9.3.6 The `LZC-GROUP` sub-directories

Inside each `LZC-GROUP` sub-directory, the following records will be found:

Table 112: Records in `LZC-GROUP` sub-directories

Name	Type	Condition	Units	Comment
GROUP-ID␣␣␣␣	I(1)			The identification number of the lzc-group.
NUM-LZC␣␣␣␣␣	I(1)			The total number N_{ld} of lzc-devices in the group.
LZC-ID␣␣␣␣␣␣	I(N_{ld})			An array of identification numbers of liquid controllers which belong to the same group.

9.4   Contents of a /detect/ data structure

The /detect/ data structure is used to store detector positions and responses. This object has a signature L_DETECT; it is created using the DETINI: module. The information contained in this data structure can be used and updated in other DONJON modules which are related to the detectors, namely: DETECT: and DETINI: modules.

9.4.1 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. $N_g = \mathcal{S}_1$

- The total number of detectors $\sum \mathcal{I}_1 = \mathcal{S}_2$.

- Flag for hexagonal detector definition $\mathcal{S}_3 = 1$ for hexagonal detector definition, $= 0$ otherwise.

The dimensioning parameters for a specific detector type, which are stored in the vector $\mathcal{I}_i$, represents:

- The number of detectors of type { name_type } $\mathcal{I}_1$.

- The number of delayed responses $+ \, 2$, $\mathcal{I}_2$.

9.4.2 The main /detect/ directory

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

Table 113: Records and sub-directories in /detect/ data structure

Name	Type	Condition	Units	Comment
SIGNATURE␣␣␣	C*12			Signature of the /detect/ data structure (SIGNA =L_DETECT␣␣␣␣).
STATE-VECTOR	I(40)			Vector describing the various parameters associated with this data structure $\mathcal{S}_i$
{/name_type/}	Dir			Detector type sub-directory contains informations for each detector of this type.

9.4.3 The /name_type/ sub-directories

Inside each /name_type/ sub-directory, the following records will be found:

Table 114: Records in /name_type/ sub-directories

Name	Type	Condition	Units	Comment
INFORMATIONS	I(2)			Record containing describing the various parameters associated with a detector type $\mathcal{I}_i$.
INV-CONST␣␣␣	R($\mathcal{I}_2 - 2$)		s^{-1}	The inverse time constant of the delayed detector responses.
FRACTION␣␣␣␣	R($\mathcal{I}_2 - 1$)			The delayed and prompt fractions of the detector responses.
SPECTRAL␣␣␣␣	R($\mathcal{I}_2 - 1$)			The energy spectrum of the detector.
{/name_detect/}	Dir			Detector information sub-directory

9.4.4 The /name_detect/ sub-directories

Inside each /name_detect/ sub-directory, the following records will be found:

Table 115: Records in /name_detect/ sub-directories

Name	Type	Condition	Units	Comment
NHEX␣␣␣␣␣␣␣␣	I($nhex$)	$hex = 1$		The numbers of affected hexagons in the first X-Y plane.
POSITION␣␣␣␣	R(6)		cm	The coordinates of the detector.
RESPON␣␣␣␣␣␣	R($\mathcal{I}_2$)			The responses of the detector.

9.5   Contents of /power/ data structure

A /power/ data structure is used to store the information related to the powers and fluxes over the reactor core. This object has a signature L POWER; it is created using the FLPOW: module. The reactor fluxes and powers are recorded using several data formats.

9.5.1 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 $N_{gr} = \mathcal{S}_1$

- The total number of mesh-splitted volumes $N_{el} = \mathcal{S}_2$

- The number of mesh-splitted volumes along x-axis $L_x = \mathcal{S}_3$

- The number of mesh-splitted volumes along y-axis $L_y = \mathcal{S}_4$

- The number of mesh-splitted volumes along z-axis $L_z = \mathcal{S}_5$

- The number of reactor channels $N_{ch} = \mathcal{S}_6$

- The number of bundles per channel $N_b = \mathcal{S}_7$

9.5.2 The /power/ directory

The following records will be found on the /power/ directory:

Table 116: Records in /power/ data structure

Name	Type	Condition	Units	Comment
SIGNATURE␣␣␣	C∗12			Signature of the /power/ data structure (SIGNA =L␣POWER␣␣␣␣␣␣).
STATE-VECTOR	I(40)			Vector describing the various parameters associated with this data structure $\mathcal{S}_i$
PTOT␣␣␣␣␣␣␣␣␣	D(1)		MW	The total reactor power.
VTOT␣␣␣␣␣␣␣␣␣	D(1)		cm^3	The total reactor volume.
NORM␣␣␣␣␣␣␣␣␣	D(1)			The flux normalization factor.
FLMIX␣␣␣␣␣␣␣	I(N_{ch}, N_b)			Fuel mixture indices per fuel bundle.
FLUX␣␣␣␣␣␣␣␣␣	R(N_{el}, N_{gr})		cm^{-2} s^{-1}	The normalized fluxes over the whole reactor geometry, recorded per each mesh-splitted volume and per each energy group. The flux values over the virtual regions are set to 0.
VOLU-BUND␣␣␣	R(N_{ch}, N_b)		cm^2	The volume of each fuel bundle.
FLUX-BUND␣␣␣	R(N_{ch}, N_b, N_{gr})		cm^{-2} s^{-1}	The normalized average fluxes recorded per each fuel bundle and per each energy group.

Records in /power/ data structure

Name	Type	Condition	Units	Comment
FLUX-DISTR␣␣	$R(L_x, L_y, L_z, N_{gr})$		$cm^{-2} \ s^{-1}$	The normalized flux distribution over the whole reactor geometry, recorded per each X-Y-Z planes and per each energy group.
FLUX-RATIO␣␣	$R(L_x, L_y, L_z, N_{gr} - 1)$			The fluxes ratios with respect to the thermal energy-group fluxes.
POWER-BUND␣␣	$R(N_{ch}, N_b)$		kW	The bundle powers.
POWER-CHAN␣␣	$R(N_{ch})$		kW	The channel powers.
POWER-DISTR␣	$R(L_x, L_y, L_z)$		W	The power distribution over the reactor core, recorded per each X-Y-Z planes. The power values over the non-fuel regions are set to 0.
PMAX-CHAN␣␣␣	$R(1)$		kW	The maximum channel power.
PMAX-BUND␣␣␣	$R(1)$		kW	The maximum bundle power.
FORM-CHAN␣␣␣	$R(1)$			The radial power-form factor, defined as maximum-to-average channel power in core.
FORM-BUND␣␣␣	$R(1)$			The overall power-form factor, defined as maximum-to-average bundle power in core.
K-EFFECTIVE␣	$R(1)$			The effective multiplication factor, recovered from the /flux/ data structure.

All stored fluxes are normalized either to the given total reactor power or using the previously recorded normalization factor. The recorded values of the maximum channel and bundle powers, the channel and bundle power-form factors, and the effective multiplication factor, can be used as power and criticity constraints for the optimization and fuel management purposes.

9.6 Contents of /history/ data structure

This data structure contains the information required to ensure a smooth coupling of DRAGON with DONJON when a history based full reactor calculation is to be performed.

9.6.1 The main directory

The following records and sub-directories will be found in the first level of a /history/ directory:

Table 117: Main records and sub-directories in /history/

Name	Type	Condition	Units	Comment
SIGNATURE␣␣␣	C*12			parameter SIGNA containing the signature of the data structure
STATE-VECTOR	I(40)			array $\mathcal{S}_i^h$ containing various parameters that are required to describe this data structure
BUNDLELENGTH	R(1)		cm	parameter L_z containing the fuel bundle length
NAMEGLOBAL␣␣	C($\mathcal{S}_1^h$)*12			array $\mathcal{G}_j$ containing the names of the global parameters
PARAMGLOBAL␣	R($\mathcal{S}_1^h$)			array G_j containing the value of the global parameters
NAMELOCAL␣␣␣	C($\mathcal{S}_2^h$)*12			array $\mathcal{L}_j$ containing the names of the local parameters
CELLID␣␣␣␣␣␣	I($\mathcal{S}_3^h, \mathcal{S}_4^h$)			array $C_{i,j}$ containing an identification number associated with bundle i and channel j
FUELID␣␣␣␣␣␣	I($\mathcal{S}_3^h, \mathcal{S}_4^h$)			array $F_{i,j}$ containing the fuel type associated with bundle i and channel j
{/FUELDIR/}	Dir			list of sub-directories FUEL$_{i,j}$ that contain the properties associated with the fuel type $F_{i,j}$
{/CELLDIR/}	Dir			list of sub-directories CELL$_{i,j}$ that contain the properties associated with the cell $C_{i,j}$

The signature for this data structure is SIGNA=L_HISTORY␣␣␣. The array $\mathcal{S}_i^h$ contains the following information:

- $\mathcal{S}_1^h = N_g$ contains the number of global parameters.

- $\mathcal{S}_2^h = N_l$ contains the number of local parameters.

- $\mathcal{S}_3^h = N_b$ contains the number of bundles per channel.

- $\mathcal{S}_4^h = N_c$ contains the number of channels in the core.

- $\mathcal{S}_5^h = N_s$ contains the number of bundle shift.

- $\mathcal{S}_6^h = T_s$ contains the type of depletion solution used.

- $\mathcal{S}_7^h = T_b$ contains the type of burnup considered.

- $\mathcal{S}_8^h = N_I$ contains the number of isotopes.

- $\mathcal{S}_9^h = G$ contains the number of transport groups.

- $\mathcal{S}_{10}^h = N_r$ contains the number of regions.

- $\mathcal{S}_{11}^h = N_F$ contains the number of fuel types.

The fuel directory name $\mathsf{FUEL}_{i,j}$ associated with fuel type $F_{i,j}$ is composed using the following FOR-TRAN instruction:

```
WRITE(FUEL,'(A4,I8.8)') 'FUEL', F_{i,j}
```

This directory will contain the initial isotopic content of this fuel type. The cell directory name $\mathsf{CELL}_{i,j}$ associated with $C_{i,j}$ is composed using the following FORTRAN instruction:

```
WRITE(CELL,'(A4,I8.8)') 'CELL', C_{i,j}
```

This directory will contain the value of the local parameters associated with cell $C_{i,j}$ as well as the current isotopic content of this cell.

The identification number $C_{i,j}$ associated with channel j and bundle i can be seen as the serial number of the bundle located at a position in space identified by (i, j). It is automatically managed by the $\mathsf{HST}\!:$ module.[?] For a fresh core $C_{i,j} = n$ where n represents the cell order definition in the input file. Upon refueling, some bundles in channel k of the core are displaced from region (l, k) to (m, k), new bundles are introduced at location (l, k) and old bundles removed from location (m, k). If one assumes that C^{NEW} and C^{OLD} represents the value of C after and before refueling then we will have:

$$
\begin{aligned}
C_{m.k}^{\mathrm{NEW}} &= C_{l,k}^{\mathrm{OLD}} \\
C_{l,k}^{\mathrm{NEW}} &= C_{m,k}^{\mathrm{FRESH}}
\end{aligned}
$$

where $C_{m,k}^{\mathrm{FRESH}}$ represent a fresh fuel cell. The local parameters and burnup power density of the fuel cell previously located at (m, k) are preserved and the fresh fuel isotopic densities is that provided in $F_{m,k}$, the fuel type associated with $C_{m,k}^{\mathrm{FRESH}}$.

9.6.2 The fuel type sub-directory

Each fuel sub-directory $\mathsf{FUEL}_{i,j}$ contains the following information

Table 118: Fuel type sub-directory

Name	Type	Condition	Units	Comment
FUELDEN-INIT	R(2)			array containing the initial density of heavy element in the fuel ρ_f in g/cm^3 and the initial linear density of heavy element in the fuel m_f in g/cm.
ISOTOPESUSED	C(N_I)*12			array containing the name of isotopes used in this fuel type
ISOTOPESMIX␣	I(N_I)			array containing the mixture associated with each isotopes in this fuel type
ISOTOPESDENS	R(N_I)		(cm b)$^{-1}$	array ρ_i containing the density of each isotopes

9.6.3 The cell type sub-directory

Each cell isotopic sub-directory $\mathsf{CELL}_{i,j}$ contains the following information

Table 119: Cell sub-directory

Name	Type	Condition	Units	Comment
FUELDEN-INIT	R(2)			array containing the initial density of heavy element in the fuel ρ_f in g/cm^3 and the initial linear density of heavy element in the fuel m_f in g/cm.
PARAMLOCALBR	R(N_l)			array V_l^B containing the value of the local parameters before refueling
PARAMLOCALAR	R(N_l)			array V_l^A containing the value of the local parameters after refueling
PARAMBURNTBR	R(2)			array containing the depletion time T^B in days and the burnup power rate P^B in kW/kg before refueling
PARAMBURNTAR	R(2)			array containing the depletion time T^A in days and the burnup power rate P^A in kW/kg after refueling
DEPL-PARAM␣␣	R(3)			array containing the time step T in days, the burnup B in kWd/kg and the irradiation w in n/kb currently reached by the fuel in this cell
ISOTOPESDENS	R(N_I)		(cm b)$^{-1}$	array ρ_i containing the density of each isotopes

9.7 Contents of /thm/ data structure

This data structure contains the thermal-hydraulics information required in a multi-physics calculation

9.7.1 The main /thm/ directory

The following records and sub-directories will be found in the first level of a /thm/ directory:

Table 120: Main records and sub-directories in /thm/

Name	Type	Condition	Units	Comment
SIGNATURE␣␣␣	C∗12			parameter SIGNA containing the signature of the data structure
STATE-VECTOR	I(40)			array $\mathcal{S}_i^{th}$ containing various integer parameters that are required to describe this data structure
REAL-PARAM␣␣	R(40)			array $\mathcal{R}_i^{th}$ containing various floating-point parameters that are required to describe this data structure
MESHZ␣␣␣␣␣␣␣	R($\mathcal{S}_1^{th}$)		m	initial axial meshes as recovered from the fuelmap
REF-RAD␣␣␣␣␣	R($(\mathcal{S}_7^{th} - 1) \times \mathcal{S}_1^{th}$)		m	initial radial meshes as recovered from the first call to THM: module
NB-FUEL␣␣␣␣␣	R($\mathcal{S}_2^{th}$)			number of active fuel rods in a single assembly or number of active fuel pins in the cluster
NB-TUBE␣␣␣␣␣	R($\mathcal{S}_2^{th}$)			number of active guide tubes in a single assembly
FRACT-PU␣␣␣␣	R($\mathcal{S}_2^{th}$)			plutonium mass enrichment
KCONDF␣␣␣␣␣␣	R($\mathcal{S}_{16}^{th} + 3$)	$\mathcal{S}_{12}^{th} \neq 0$		coefficients of the user-defined correlation for the fuel thermal conductivity
UCONDF␣␣␣␣␣␣	C12	$\mathcal{S}_{12}^{th} \neq 0$		string variable set to KELVIN or to CELSIUS
KCONDC␣␣␣␣␣␣	R($\mathcal{S}_{17}^{th} + 3$)	$\mathcal{S}_{13}^{th} \neq 0$		coefficients of the user-defined correlation for the clad thermal conductivity
UCONDC␣␣␣␣␣␣	C12	$\mathcal{S}_{13}^{th} \neq 0$		string variable set to KELVIN or to CELSIUS
ERROR-T-FUEL	R(1)		K	absolute error in fuel temperature
ERROR-D-COOL	R(1)		g/cc	absolute error in coolant density
ERROR-T-COOL	R(1)		K	absolute error in coolant temperature
MIN-T-FUEL␣␣	R(1)		K	minimum fuel temperature
MIN-D-COOL␣␣	R(1)		g/cc	minimum coolant density
MIN-T-COOL␣␣	R(1)		K	minimum coolant temperature
MAX-T-FUEL␣␣	R(1)		K	maximum fuel temperature
MAX-D-COOL␣␣	R(1)		g/cc	maximum coolant density
MAX-T-COOL␣␣	R(1)		K	maximum coolant temperature
HISTORY-DATA	Dir			sub-directory containing the historical values taken by the thermal-hydraulics parameters (mass flux, density, pressure, enthalpy, temperature) in the coolant and in the fuel rod for the whole geometry
RAD-PROF_R␣␣	R($\mathcal{S}_{18}^{th}$)	$\mathcal{S}_{18}^{th} \neq 0$	m	abscissas of the user-defined radial form factor table
RAD-PROF_F␣␣	R($\mathcal{S}_{18}^{th}$)	$\mathcal{S}_{18}^{th} \neq 0$		form-factor values of the user-defined radial form factor table
TIME-SR1␣␣	R($\mathcal{S}_{19}^{th}$)	$\mathcal{S}_{19}^{th} \neq 0$	s	tabulation abscissa in time

Main records and sub-directories in /thm/   continued from last page

Name	Type	Condition	UnitsComment
POWER-SR1␣␣	$R(\mathcal{S}_{19}^{th})$	$\mathcal{S}_{19}^{th} \neq 0$	tabulation power factor corresponding to each tabulation abscissa in time

The signature for this data structure is SIGNA=L_THM. The array $\mathcal{S}_i^h$ contains the following information:

- $\mathcal{S}_1^{th}$ contains the number of axial meshes N_z.

- $\mathcal{S}_2^{th}$ contains the number of channels in the radial plane N_{ch}.

- $\mathcal{S}_3^{th}$ contains the maximum number of iterations for computing the conduction integral.

- $\mathcal{S}_4^{th}$ contains the maximum number of iterations for computing the center pellet temperature.

- $\mathcal{S}_5^{th}$ contains the maximum number of iterations for computing the coolant parameters (velocity, pressure, enthapy, density) in case of a transient calculation.

- $\mathcal{S}_6^{th}$ contains the number of discretisation points in fuel.

- $\mathcal{S}_7^{th}$ contains the number of total discretisation points in the whole fuel rod (fuel+cladding) N_{dtot}.

- $\mathcal{S}_8^{th}$ contains the type of calculation performed by the THM: module:

$$\mathcal{S}_8^{th} = \begin{cases} 0 & \text{steady-state calculation} \\ 1 & \text{transient calculation.} \end{cases}$$

- $\mathcal{S}_9^{th}$ contains the current time index.

- $\mathcal{S}_{10}^{th}$ flag to set the gap correlation:

$$\mathcal{S}_{10}^{th} = \begin{cases} 0 & \text{built-in correlation is used} \\ 1 & \text{set the heat exchange coefficient of the gap as a user-defined constant.} \end{cases}$$

- $\mathcal{S}_{11}^{th}$ flag to set the heat transfer coefficient between the clad and fluid:

$$\mathcal{S}_{11}^{th} = \begin{cases} 0 & \text{built-in correlation is used} \\ 1 & \text{set the heat exchange coefficient between the clad and fluid as a user-defined constant.} \end{cases}$$

- $\mathcal{S}_{12}^{th}$ flag to set the fuel thermal conductivity:

$$\mathcal{S}_{12}^{th} = \begin{cases} 0 & \text{built-in correlation is used} \\ 1 & \text{set the fuel thermal conductivity as a function of a simple user-defined correlation.} \end{cases}$$

- $\mathcal{S}_{13}^{th}$ flag to set the clad thermal conductivity:

$$\mathcal{S}_{13}^{th} = \begin{cases} 0 & \text{built-in correlation is used} \\ 1 & \text{set the clad thermal conductivity as a function of a simple user-defined correlation.} \end{cases}$$

- $\mathcal{S}_{14}^{th}$ type of approximation used during the fuel conductivity evaluation:

$$\mathcal{S}_{14}^{th} = \begin{cases} 0 & \text{use a rectangle quadrature approximation} \\ 1 & \text{use an average approximation.} \end{cases}$$

- $\mathcal{S}_{15}^{th}$ type of subcooling model:

$$\mathcal{S}_{15}^{th} = \begin{cases} 0 & \text{use the Bowring correlation} \\ 1 & \text{use the Saha-Zuber correlation.} \end{cases}$$

- $\mathcal{S}_{16}^{th}$ contains the number of terms in the user-defined correlation for the fuel thermal conductivity (if $\mathcal{S}_{12}^{th} = 1$).

- $\mathcal{S}_{17}^{th}$ contains the number of terms in the user-defined correlation for the clad thermal conductivity (if $\mathcal{S}_{13}^{th} = 1$).

- $\mathcal{S}_{18}^{th}$ type of radial form factor for the power:

$$\mathcal{S}_{18}^{th} = \begin{cases} 0 & \text{flat radial form factor} \\ N_{\text{rad}} & \text{number of point in the radial form factor table.} \end{cases}$$

- $\mathcal{S}_{19}^{th}$ number of points in the user-defined time-power table.

- $\mathcal{S}_{20}^{th}$ type of fluid:
$$\mathcal{S}_{20}^{th} = \begin{cases} 0 & \text{light water } (\text{H}_2\text{O}) \\ 1 & \text{heavy water } (\text{D}_2\text{O}). \end{cases}$$

The array $\mathcal{R}_i^{th}$ contains the following information:

- $\mathcal{R}_1^{th}$ contains the current time step in s.

- $\mathcal{R}_2^{th}$ contains the fraction of reactor power released in fuel.

- $\mathcal{R}_3^{th}$ contains the critical heat flux in W/m^2.

- $\mathcal{R}_4^{th}$ contains the inlet coolant velocity in m/s.

- $\mathcal{R}_5^{th}$ contains the outlet coolant pressure in Pa.

- $\mathcal{R}_6^{th}$ contains the inlet coolant temperature in K.

- $\mathcal{R}_7^{th}$ contains the fuel porosity.

- $\mathcal{R}_8^{th}$ contains the fuel pellet radius

- $\mathcal{R}_9^{th}$ contains the internal clad rod radius in m.

- $\mathcal{R}_{10}^{th}$ contains the external clad rod radius in m.

- $\mathcal{R}_{11}^{th}$ contains the guide tube radius in m.

- $\mathcal{R}_{12}^{th}$ contains the hexagonal side in m. Used only for cluster geometries.

- $\mathcal{R}_{13}^{th}$ contains the temperature maximum absolute error (in K) allowed in the solution of the conduction equations.

- $\mathcal{R}_{14}^{th}$ contains the maximum relative error allowed in the matrix resolution of the conservation equations of the coolant.

- $\mathcal{R}_{15}^{th}$ contains the relaxation parameter for the multiphysics parameters (temperature of fuel and coolant and density of coolant).

- $\mathcal{R}_{16}^{th}$ contains the time in s.

- $\mathcal{R}_{17}^{th}$ contains the heat transfer coefficient of the gap (if $\mathcal{S}_{10}^{th} = 1$).

- $\mathcal{R}_{18}^{th}$ contains the heat transfer coefficient between the clad and fluid (if $\mathcal{S}_{11}^{th} = 1$).

- $\mathcal{R}_{19}^{th}$ contains the surface temperature weighting factor of effective fuel temperature for the Rowlands approximation.

- $\mathcal{R}_{20}^{th}$ reactor power, as defined after the `POWER-LAW` keyword.

- $\mathcal{R}_{21}^{th}$ maximum of variable variations in local parameters (used for time step adjustment strategy).

- $\mathcal{R}_{22}^{th}$ contains the rugosity of the fuel rod in m, used in Müller-Steinhagen correlation for coolant friction.

- $\mathcal{R}_{23}^{th}$ contains the angle in radians of the fuel channel with respect of the vertical axis.

9.7.2 The `HISTORY-DATA` sub-directory

In the `HISTORY-DATA` directory, the following sub-directories will be found:

Table 121: Sub-directories in `HISTORY-DATA` directory

Name	Type	Condition	Units	Comment
`TIMESTEP0000`	Dir			sub-directory containing all the values of the thermal-hydraulics parameters computed by the `THM:` module *in steady-state conditions.*
`TIMESTEPnumt`	Dir			sub-directories containing all the values of the thermal-hydraulics parameters computed by the `THM:` module in transient conditions at a given time index *numt*. *numt* can take values between 1 and 9999 in I4.4 format.

In the `TIMESTEP0000` and in each of the `TIMESTEPnumt` sub-directories, the following records will be found:

Table 122: Records in `TIMESTEP` directories

Name	Type	Condition	Units	Comment
TIME␣␣␣␣␣␣␣␣	R(1)		s	time
CHANNEL␣␣␣␣␣	Dir(N_{ch})			list of N_{ch} sub-directories containing all the values of the thermal-hydraulics parameters computed by the `THM:` module and sorted channel by channel.

In each of the `CHANNEL` sub-directories, the following records will be found:

Table 123: Records in each `CHANNEL` directory

Name	Type	Condition	Units	Comment
VINLET␣␣␣␣␣␣	R(1)		$m.s^{-1}$	inlet velocity
TINLET␣␣␣␣␣␣	R(1)		K	inlet temperature
PINLET␣␣␣␣␣␣	R(1)		Pa	inlet pressure
VELOCITIES␣␣	R(N_{z})		$m.s^{-1}$	velocity in each of the N_{z} bundles of the channel numbered *numc*
PRESSURE␣␣␣␣	R(N_{z})		Pa	pressure in each bundle of the channel
ENTHALPY␣␣␣␣	R(N_{z})		$J.kg^{-1}$	enthalpy in each bundle of the channel
DENSITY␣␣␣␣␣	R(N_{z})		$kg.m^{-3}$	density in each bundle of the channel
LIQUID-DENS␣	R(N_{z})		$kg.m^{-3}$	density of liquid phase in each bundle of the channel
TEMPERATURES	R($N_{\text{z}}, N_{\text{dtot}}$)		K	distribution of the temperature in the fuel-pin for each bundle of the channel
CENTER-TEMPS	R(N_{z})		K	center fuel pellet temperature in each bundle of the channel
RADII	R($N_{\text{z}}, N_{\text{dtot}} - 1$)		m	fuel and clad radii

9.8 Contents of a /optimize/ data structure

The /optimize/ specification is used to store the optimization variables and functions values and definitions, limits and options.

In any case, the signature variable for this data structure must be $\mathsf{SIGNA=L\_OPTIMIZE_{\sqcup\sqcup}}$. The dimensioning parameters for this data structure, which are stored in the state vector $\mathcal{S}_i^o$, represents:

- The number of decision variables $N_{var} = \mathcal{S}_1^o$.

- The number of constraints $N_{cst} = \mathcal{S}_2^o$.

- The type of optimization $\mathcal{S}_3^o$, where

$$\mathcal{S}_3^o = \left\{ \begin{array}{rl} 1 & \text{minimization} \\ -1 & \text{maximization} \end{array} \right.$$

- The result of a test for external convergence of the optimization problem $\mathcal{S}_4^o$, where

$$\mathcal{S}_4^o = \left\{ \begin{array}{ll} 0 & \text{not converged} \\ 1 & \text{converged} \end{array} \right.$$

- The index of external iteration (S_5^o). If module $\mathsf{PLQ{:}}$ is used, this is the iteration index relative to the solution of a new linear optimization problem with a quadratic constraint. If module $\mathsf{LNSR{:}}$ is used, this is the number of times the line search algorithm is called.

- The type of reduction for the radius if the quadratic constraint $(\mathcal{S}_6^o)$ used in module $\mathsf{PLQ{:}}$, where

$$\mathcal{S}_6^o = \left\{ \begin{array}{ll} 1 & \text{half} \\ 2 & \text{parabolic} \end{array} \right.$$

- The type of gradient search $\mathcal{S}_7^o$, where

$$\mathcal{S}_7^o = \left\{ \begin{array}{ll} 0 & \text{steepest descent} \\ 1 & \text{conjugate gradient} \\ 2 & \text{Broyden-Fletcher-Goldfarb-Shanno (BFGS)} \\ 3 & \text{memory limited Broyden-Fletcher-Goldfarb-Shanno (LBFGS)} \\ 4 & \text{Newton method for unconstrained optimization} \end{array} \right.$$

- The type of optimization method $\mathcal{S}_8^o$, where

$$\mathcal{S}_8^o = \left\{ \begin{array}{ll} 0 & \text{not set} \\ 1 & \text{OPTEX method with module } \mathsf{PLQ{:}} \\ 2 & \text{line search algorithm with module } \mathsf{LNSR{:}} \\ 3 & \text{fixed point SPH algorithm with module } \mathsf{FPSPH{:}} \\ 4 & \text{Newtonian SPH algorithm with module } \mathsf{FPSPH{:}} \end{array} \right.$$

- The resolution's method for the linear problem with quadratic constraint used in module $\mathsf{PLQ{:}}$ $(\mathcal{S}_9^o)$, where

$$\mathcal{S}_9^o = \left\{ \begin{array}{ll} 1 & \text{SIMPLEX/LEMKE} \\ 2 & \text{LEMKE/LEMKE} \\ 3 & \text{MAP} \\ 4 & \text{Augmented Lagragian} \\ 5 & \text{Penalty Method} \end{array} \right.$$

- The index of line search iteration in module `LNSR:` (S_{10}^o). The maximum number of line search iterations is fixed to 50 in module `LNSR:`.

- The result of a test for the convergence of the line search iterations $\mathcal{S}_{11}^o$ in module `LNSR:`, where

$$
\mathcal{S}_{11}^o = \left\{ \begin{array}{ll} 0 & \text{not converged} \\ 1 & \text{converged} \\ 2 & \text{maximum line search iteration reached} \end{array} \right.
$$

- The maximum number of external iterations in module `LNSR:` (S_{12}^o).

- The external iteration restart cycle in module `LNSR:` (S_{13}^o).

- A flag for unsuccessful resolution in module `PLQ:` S_{14}^o, where

$$
\mathcal{S}_{14}^o = \left\{ \begin{array}{ll} 0 & \text{successful at last iteration} \\ \geq 1 & \text{number of iteration with unsuccessful resolution.} \end{array} \right.
$$

Table 124: Main records and sub-directories in /optimize/

Name	Type	Condition	Units	Comment
SIGNATURE␣␣␣	C*12			Signature of the data structure (SIGNA)
STATE-VECTOR	I(40)			Vector describing the various parameters associated with data structure $\mathcal{S}_i^o$.
DEL-STATE␣␣␣	I(40)	*		Vector describing the various parameters associated with data structure $\mathcal{S}_i^g$. This array is available if the OPTIMIZE object has been created using module DLEAK: or DSPH:.
VAR-VALUE␣␣␣	D(N_{var})			The values of the decision variables
VAR-VAL-MAX␣	D(N_{var})			The maximum values of the decision variables can be.
VAR-VAL-MIN␣	D(N_{var})			The minimum values of the decision variables can be.
VAR-WEIGHT␣␣	D(N_{var})			The weight of the decision variables w_i in the quadratic constraint.
CST-OBJ␣␣␣␣␣	D(N_{cst})			The limit value of the contraints. The units depends with the type of the constraint type.
CST-TYPE␣␣␣␣	I(N_{cst})			The type of the contraints: =-1 for $\geq$; =0 for =; =1 for $\leq$.
CST-WEIGHT␣␣	D(N_{cst})			The weight of the constraint η_j and γ_j for the duals and meta-heuristic methods.
FOBJ-CST-VAL	D($N_{cst}+1$)			The actual values of the objective function (first value) and the contraints (the following values). The number of the constraints are assigned in the order they have been defined.
OPT-PARAM-R␣	D(40)			The different limits and values for the iterative calculations of the optimization problem.

Main records and sub-directories in /optimize/ continued from last page

Name	Type	Condition	UnitsComment
GRADIENT␣␣␣␣	$D(N_{var}, N_{cst} + 1)$		The gradients of the objective function and the constraints. The gradients of the objective for all the decision variables are in first position, then follow the gradients of the constraints.
GRADIENT-DIR	$D(N_{var}, N_{cst} + 1)$	*	The direct component (without the flux effect) for the gradients of the objective function and the constraints.
DIRECTION␣␣␣	$D(N_{var})$	$\mathcal{S}_8^o = 2$	Direction of the line search.
HESSIAN␣␣␣␣␣	$D(N_{var}, N_{var})$	$\mathcal{S}_7^o = 2$	The hessian matrix containing second derivatives of the objective function with respect to the decision variables.
LNSR-INFO␣␣␣	$D(9)$	$\mathcal{S}_8^o = 2$	Double precision values used by module LNSR:.
OLD-VALUE␣␣␣	Dir		Directory containing differents informations of the previous iterations. the values of the decision variables, the objective function, the constraints and the gradients of these functions for the previous external iteration. This repertory will be created by the module PLQ: (unless it is specified to not do) or by module LNSR:.

The array `OPT-PARAM-R` contains double precision values related with the different limits and values for the iterative calculations of the optimization problem:

1st	S	initial radius of the quadratic constraint in module PLQ: or maximum stepsize for the line search in module LNSR: (default: 1.0).
2nd	δ	initial size of the hypercube for MAP method. (default: 0.1).
3rd	ε_{ext}	limit for external convergence (default: 10^{-4}).
4th	ε_{int}	limit for internal convergence (default: 10^{-4}).
5th	$\varepsilon_{\text{quad}}$	limit for convergence of the quadratic constraint in module PLQ: (default: 10^{-4}).

The other value of the record are not used and set to 0.0.

The optional array `DEL-STATE` contains integer values related to the definition of mixture and group indices in module `DLEAK:`.

- The number of energy groups in macrolib $\mathcal{S}_1^g$.

- The number of mixtures in macrolib $\mathcal{S}_2^g$.

- The type of leakage parameters $\mathcal{S}_3^g$, where

$$\mathcal{S}_3^g = \begin{cases} 1 & \text{use diffusion coefficients} \\ 2 & \text{use } P_1\text{-weighted macroscopic total cross sections.} \end{cases}$$

- The type of control variables $\mathcal{S}_4^g$, where

$$\mathcal{S}_4^g = \begin{cases} 1 & \text{use leakage parameters} \\ 2 & \text{use correction factors on leakage parameters} \\ 3 & \text{use SPH factors compatible with diffusion theory, } P_n \text{ and } SP_n \text{ equations} \\ 4 & \text{use SPH factors compatible with other types of transport-theory macro-} \\ & \text{calculations} \\ 5 & \text{use one SPH factor assigned to the albedo function in each macro-group.} \end{cases}$$

- The minimum group index $\mathcal{S}_5^g$, with $1 \leq \mathcal{S}_5^g \leq \mathcal{S}_1^g$.

- The maximum group index $\mathcal{S}_6^g$, with $\mathcal{S}_5^g \leq \mathcal{S}_6^g \leq \mathcal{S}_2^g$.

- The minimum mixture index $\mathcal{S}_7^g$, with $1 \leq \mathcal{S}_7^g \leq \mathcal{S}_2^g$.

- The maximum mixture index $\mathcal{S}_8^g$, with $\mathcal{S}_7^g \leq \mathcal{S}_8^g \leq \mathcal{S}_2^g$.

- The number of physical albedos $\mathcal{S}_9^g$.

9.8.1 The sub-directory /OLD-VALUE/ in /optimize/

Table 125: Main records and sub-directories in //OLD-VALUE//

Name	Type	Condition	UnitsComment
VAR-VALUE␣␣␣	$D(N_{var})$		The values of the decision variables of the last valid iteration.
FOBJ-CST-VAL	$D(N_{cst}+1)$		The values of the objective function and the contraints of the last valid iteration.
GRADIENT␣␣␣␣	$D(N_{var}, N_{cst}+1)$		The gradients of the objective function and the constraints of the last valid iteration.
VAR-VALUE2␣␣	$D(N_{var})$	$\mathcal{S}_8^o = 1$	The values of the decision variables of the second-last valid iteration.
BEST-VAR␣␣␣␣	$D(N_{var})$	$\mathcal{S}_8^o = 1$	The values of the decision variables corresponding to the best valid solution ever found.
BEST-FCT␣␣␣␣	$D(1)$	$\mathcal{S}_8^o = 1$	The value of the objective function corresponding to the best valid solution ever found.

9.9   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.

9.9.1 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 $N_{\mathrm{gr}} = \mathcal{S}_1$

- The number of pkey for the generation of the PMAXS file $N_{\mathrm{pk}} = \mathcal{S}_2$

- The number of cross sections recovered using the SCR: module $N_{\mathrm{xs}} = \mathcal{S}_3$

- The number of points with respect to burnup $N_{\mathrm{bu}} = \mathcal{S}_4$

- The type of branching calculation requested for the generation of PMAXS tree $I_{\mathrm{grid}} = \mathcal{S}_5$

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

- The number of control rod composition $N_{\mathrm{comp}} = \mathcal{S}_6$

- The number of delay neutron groups $N_{\mathrm{del}} = \mathcal{S}_7$

- The number of columns in assembly $N_{\mathrm{cols}} = \mathcal{S}_8$

- The number of rows in assembly $N_{\mathrm{rows}} = \mathcal{S}_9$

- The computed part of asembly assembly $I_{\mathrm{part}} = \mathcal{S}_{10}$

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

- The number of sides in assembly. $N_{\mathrm{surf}} = \mathcal{S}_{11}$

- The number of corners in assembly $N_{\mathrm{corn}} = \mathcal{S}_{12}$

- The number of assembly discontinuity factors per energy groups $N_{\mathrm{adf}} = \mathcal{S}_{13}$

- The number of ADF-type boundary flux edits. $N_{\mathrm{type}} = \mathcal{S}_{14}$

- The number of corner discontinuity factors per energy groups. $N_{\mathrm{cdf}} = \mathcal{S}_{15}$

- The number of group-wise form functions per energy groups in compued part of assembly. $N_{\mathrm{gff}} = \mathcal{S}_{16}$

- The number of pin on each side of the assembly. $N_{\mathrm{pin}} = \mathcal{S}_{17}$

- The type of cross section library containing the cross sections. $I_{\mathrm{typ}} = \mathcal{S}_{18}$

$$I_{\mathrm{typ}} = \begin{cases} 0 & \text{saphyb} \\ 1 & \text{multicompo} \end{cases}$$

- The temperature unit for moderator and fuel. $I_{\text{temp}} = \mathcal{S}_{19}$

$$I_{\text{temp}} = \left\{ \begin{array}{ll} 0 & \text{celsius} \\ 1 & \text{kelvin} \end{array} \right.$$

- The number of additional parameters contained in the saphyb (other than state variables). $N_{\text{oth}} = \mathcal{S}_{20}$

- The treatment of Assembly Discontinuity Factors. $I_{\text{merge}} = \mathcal{S}_{21}$

$$I_{\text{merge}} = \left\{ \begin{array}{ll} 0 & \text{ADF are explicitly stored in the PMAXS} \\ 1 & \text{ADF are inserted in the cross sections} \end{array} \right.$$

- The correction on Pm 147 fission yield. $I_{\text{cor}} = \mathcal{S}_{22}$

$$I_{\text{cor}} = \left\{ \begin{array}{ll} 0 & \text{No correction of Pm 147 fission yield} \\ 1 & \text{Correction of Pm 147 fission yield} \end{array} \right.$$

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

Table 126: Records and sub-directories in /d2p_info/ data structure

Name	Type	Condition	Units	Comment
SIGNATURE␣␣␣	C*12			Signature of the /d2p_info/ data structure (SIGNA =L_INFO␣␣␣␣␣␣).
STATE-VECTOR	I(40)			Vector describing the various parameters associated with this data structure
BARR_INFO␣␣␣	I(N_{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␣	Dir	$iph \geq 1$		Information related to the saphyb content.
HELIOS_HEAD␣	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␣	Dir	$iph \geq 3$		Information related to the current branch calculation.
TH_DATA␣␣␣␣␣	Dir(N_{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 127: Records and sub-directories in /SAPHYB_INFO/

Name	Type	Condition	Units	Comment
PKEY_INFO␣␣␣	Dir(6)			Each component of the list is a directory containing information for all possible state variables.
OTHPK␣␣␣␣␣␣␣	C(N_{oth}) * 12			Name of other parameters .
OTHTYP␣␣␣␣␣␣	I((N_{oth}))			Type of other parameters (Integer=1, Real=2, String=3.
OTHVAC␣␣␣␣␣␣	C(N_{oth}) * 12			Value of other parameters of type characater.
OTHVAR␣␣␣␣␣␣	R((N_{oth}))			Value of other parameters of type real.
NTOT␣␣␣␣␣␣	I(1)			Total number of parameters in the SAP (or MCO) object. Exept *'FLUE'* and *'TIME'*
STATE_VAR␣␣␣	C(N_{pk}) * 12			Name of state variables (PKEY).

Records and sub-directories in /SAPHYB_INFO/

Name	Type	Condition	Units	Comment
ISOTOPES␣␣␣␣	$C(8) * 12$			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 4) Pm149 5)Pm148 6) Pm148m 7) Nd147 8)Pm147 .
/svname/	$R(N_k)$			Values for each state variable specified by PKEY$_k$, N_k is the number of value taken for the kth PKEY.
PKIDX␣␣␣␣␣␣␣	$I(N_{pk})$			Correspondance of indices between SAP/MCO and GenPMAXS state variables
ADF_TYPE␣␣␣␣	$C*3$	ladf		Type of ADF recovered (DRA, GET or SEL).
HADF␣␣␣␣␣␣␣␣	$C(N_{adf}) * 8$	ladf		Name of the ADF-type boundary flux edit to be recovered from Multicompo
CDF_TYPE␣␣␣␣	$C*3$	lcdf		Type of CDF recovered (only DRA).
HCDF␣␣␣␣␣␣␣␣	$C(N_{adf}) * 8$	lcdf		Name of the CDF-type boundary flux edit to be recovered from Multicompo.
GFF_TYPE␣␣␣␣	$C*3$	lgff		Type of GFF recovered (only DRA).
YLD_OPT␣␣␣␣␣	$C*3$	lyld		Type of fission yield to be recovered (FIX,MAN or DEF).
YLD_FIX␣␣␣␣␣	$R(3)$	lyld		User defined values for fission yields (1:I, 2:XE, 3:PM)
YLD_LOC␣␣␣␣␣	$R(6)$	lyld		Values for state parameter on which fission yields are calculated.

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 128: Records in /PKEY_INFO/

Name	Type	Condition	Units	Comment
LFLAG␣␣␣␣␣␣␣	$I(1)$			Indicates if the corresponding state variable can be found in the SAP (or MCO) object.
NAME␣␣␣␣␣␣␣␣	$C*12$	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 129: Records and sub-directories in /HELIOS_HEAD/

Name	Type	Condition	Units	Comment
`FILE_CONT_1`␣	R(2)			Set of data for `FILE_CONT_1` block in `DRA` file : Heavy metal Density(`HM_Dens`), Bypass Density(`ByPass`).
`FILE_CONT_2`␣	R(8)			Set of data for `FILE_CONT_2` block in `DRA` file : Lower Energy Limits of Neutron Groups.
`FILE_CONT_3`␣	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`␣	R(3)			Set of data for `FILE_CONT_4` block in `DRA` file : Cell Pitch and X,Y Position of First Cell.
`XS_CONT`␣␣␣␣␣␣	R(1)			Set of data for `XS_CONT` block in `DRA` file : (`VFCM`).

Table 130: 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 [51]).
`DAT_SRC`␣␣␣␣␣	R(5)			Data source information (see [51]).

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 131: Records in sub-directory /TH_DATA/

Name	Type	Condition	Units	Comment
CHI␣␣␣␣␣␣␣␣␣␣	$R(N_{gr})$	*lchi*		The steady-state energy spectrum of the neutron emitted by fission χ.
OVERV␣␣␣␣␣␣␣␣	$R(N_{gr})$	*linv*	s.cm^{-1}	The average of the inverse neutron velocity.
LAMBDA␣␣␣␣␣␣	$R(N_{del})$	*lamb*	s^{-1}	Decay constant of delayed neutron.
BETA␣␣␣␣␣␣␣␣	$R(N_{del})$	*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 132: 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.
BRANCH␣␣␣␣␣␣	$C*4$			Current BRANCH type calculation.
BRANCH_NB␣␣␣	$I(1)$			Number of branches to be created in PMAXS files.
REF_STATE␣␣␣	$R(N_{pk} - 1)$			Values of state variables for reference state, burnup excepted.
HST_STATE␣␣␣	$R(N_{pk} - 1)$			Values of state variables for history state, burnup excepted.
STATE_INDEX␣	$I(N_{pk})$			Current index value for each state variables.
BRANCH_INDEX	$I(N_{pk})$			Index of current branch calculation.
STATE␣␣␣␣␣␣␣	$R(N_{pk})$			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␣␣	$Dir(N_{bu})$			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␣␣␣␣␣␣	$Dir(N_{bu})$	$I_{grid} \leq 1$		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 133: 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 134: Records in the sub-directory /MACROLIB_XS/

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

Table 135: Records in the sub-directory /MICROLIB_XS/

Name	Type	Condition	Units	Comment
XENG␣␣␣␣␣␣␣␣␣	$R(N_{\mathrm{gr}})$		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␣␣␣␣␣␣␣␣␣	$R(N_{\mathrm{gr}})$		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␣␣␣␣␣␣␣␣␣	$R(N_{\mathrm{gr}})$		(b.cm)$^{-1}$	The Xenon number density: n_{Xe}.
SMND␣␣␣␣␣␣␣␣␣	$R(N_{\mathrm{gr}})$		(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 136: 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.

9.10 Contents of a /intdetec/ data structure

The /intdetec/ data structure is used to store integrated detector positions and responses in a PWR. This object has a signature L_INTDETEC; it is created using the IDET: module.

9.10.1 The state-vector content

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

- The first dimension of matrices COORD1, COORD2 and COORD3, representing the maximum number of interpolation points for a single detector. $N_{\max} = \mathcal{S}_1$.

- The total number of detectors. $N_{\det} = \mathcal{S}_2$.

9.10.2 The main /intdetec/ directory

The following records will be found on the first level of /intdetec/ directory:

Table 137: Records in /intdetec/ data structure

Name	Type	Condition	Units	Comment
SIGNATURE␣␣␣	C∗12			Signature of the /intdetec/ data structure (SIGNA =L_INTDETEC␣␣).
STATE-VECTOR	I(40)			Vector describing the various parameters associated with this data structure $\mathcal{S}_i$
NINX␣␣␣␣␣␣␣␣	I($\mathcal{S}_2$)			Number of interpolation point for the detector reading along X axis.
NINY␣␣␣␣␣␣␣␣	I($\mathcal{S}_2$)			Number of interpolation point for the detector reading along Y axis.
NINZ␣␣␣␣␣␣␣␣	I($\mathcal{S}_2$)			Number of interpolation point for the detector reading along Z axis.
COORD1␣␣␣␣␣␣	R($\mathcal{S}_1, \mathcal{S}_2$)		cm	Values of the interpolation coordinates along X axis.
COORD2␣␣␣␣␣␣	R($\mathcal{S}_1, \mathcal{S}_2$)		cm	Values of the interpolation coordinates along Y axis.
COORD3␣␣␣␣␣␣	R($\mathcal{S}_1, \mathcal{S}_2$)		cm	Values of the interpolation coordinates along Z axis.
DETNAM␣␣␣␣␣␣	C∗12			Alias name of the isotope used as detector.
REANAM␣␣␣␣␣␣	C∗12			Name of the nuclear reaction used as detector.
RESPON␣␣␣␣␣␣	R($\mathcal{S}_2$)			The integrated responses of the detectors.

10 EXAMPLES

The following examples of input files represent a typical core modeling using DONJON. The main characteristics of a simplified design for the ACR-700 benchmark core model are given below.

Figure 17: Face View of ACR Benchmark Core Model (292 Channels)

- Number of reactor channels 292

- Number of fuel bundles per channel 12

- Core radius 260 cm

- Core length 594.36 cm

- Lattice pitch 22 cm

- Reactor thermal power 1800 MW(th)

10.1 (Example1) – Compo related example

Input data for test case: **Example1.x2m**

```
*************************************************************
*                                                          *
* Input file :  Example1.x2m                               *
* Purpose    :  Test for non-regression using DONJON-4     *
* Author(s)  :  D. Sekki (2007/11)                         *
*                                                          *
*************************************************************
PROCEDURE    assertS Pgeom Pfmap Pburn Pdevc ;
MODULE       DELETE: GREP: END: CRE: MACINI: FLUD: USPLIT:
             DSET: TAVG: FLPOW: TRIVAT: TRIVAA: NEWMAC: ;
LINKED_LIST  GEOM TRACK MATEX FMAP FLUX POWER MACFL
             DEVICE MACRO1 MACRO2 MACRO SYSTEM ;
LINKED_LIST  LREFL1 LREFL2 LFUEL1 LFUEL2
             LZCRin LZCRot LSORin LSORot ;
*--
* variables:
*--
INTEGER   nbMix  := 8 ;
INTEGER   nbRefl nbFuel := 2 2 ;
INTEGER   mFuel1 mFuel2 := 1 2 ;
INTEGER   mRefl1 mRefl2 := 3 4 ;
INTEGER   mZCRin mZCRot := 5 6 ;
INTEGER   mSORin mSORot := 7 8 ;
INTEGER   MaxReg := 100000 ;
STRING    Method := "MCFD" ;
INTEGER   degree quadr := 1 1 ;
INTEGER   iter iEdit := 0 5 ;
REAL      Power := 1800. ;
REAL      epsil := 1.E-5 ;
REAL      Precf := 1.E-5 ;
REAL      Eps Keff Bexit ;
*--
* compo files:
*--
SEQ_ASCII  SFUEL1 :: FILE 'CpoFuel1' ;
SEQ_ASCII  SFUEL2 :: FILE 'CpoFuel2' ;
SEQ_ASCII  SREFL1 :: FILE 'CpoMode1' ;
SEQ_ASCII  SREFL2 :: FILE 'CpoMode2' ;
SEQ_ASCII  SZCRin :: FILE 'CpoZCRin' ;
SEQ_ASCII  SZCRot :: FILE 'CpoZCRot' ;
SEQ_ASCII  SSORin :: FILE 'CpoSORin' ;
SEQ_ASCII  SSORot :: FILE 'CpoSORot' ;
*--
* compo directories:
*--
STRING    NamFuel1 := "FUEL1     1" ;
STRING    NamFuel2 := "FUEL2     1" ;
STRING    NamRefl1 := "MODE1     1" ;
STRING    NamRefl2 := "MODE2     1" ;
```

```
STRING    NamZCRin := "ZCRIN      1" ;
STRING    NamZCRot := "ZCROT      1" ;
STRING    NamSORin := "SORIN      1" ;
STRING    NamSORot := "SOROT      1" ;
*------------------------------------------------------------
*
*                  FULL-CORE   CALCULATION
*                  =====================
*--
* geometry construction:
*--
GEOM := Pgeom ;
*--
* reactor material index:
*--
GEOM MATEX := USPLIT: GEOM :: EDIT 0 NGRP 2 MAXR <<MaxReg>>
              NREFL <<nbRefl>>  RMIX <<mRefl1>> <<mRefl2>>
              NFUEL <<nbFuel>>  FMIX <<mFuel1>> <<mFuel2>> ;
*--
* numerical discretization:
*--
IF Method "MCFD" = THEN
   TRACK := TRIVAT: GEOM :: EDIT 1
            MAXR <<MaxReg>> MCFD <<degree>> ;
ELSEIF Method "PRIM" = THEN
   TRACK := TRIVAT: GEOM :: EDIT 1
            MAXR <<MaxReg>> PRIM <<degree>> ;
ELSEIF Method "DUAL" = THEN
   TRACK := TRIVAT: GEOM :: EDIT 1
            MAXR <<MaxReg>> DUAL <<degree>> <<quadr>> ;
ENDIF ;
*--
* macrolib for reflector:
*--
LREFL1 := SREFL1 ;
LREFL2 := SREFL2 ;
MACRO1 := CRE: LREFL1 LREFL2 :: EDIT 1 NMIX <<nbMix>> READ
          COMPO LREFL1  MIX <<mRefl1>> <<NamRefl1>> ENDMIX
          COMPO LREFL2  MIX <<mRefl2>> <<NamRefl2>> ENDMIX ;
*--
* device specification:
*--
DEVICE MATEX := Pdevc MATEX ::
     <<mZCRin>> <<mZCRot>> <<mSORin>> <<mSORot>> ;
*--
* full insertion of ZCR-devices:
*--
DEVICE := DSET: DEVICE :: EDIT 1
          ROD-GROUP 1 LEVEL 1.0 END
          ROD-GROUP 2 LEVEL 1.0 END
          ROD-GROUP 3 LEVEL 1.0 END ;
*--
* update macrolib for devices:
```

```
*--
LZCRin := SZCRin ;
LZCRot := SZCRot ;
LSORin := SSORin ;
LSORot := SSORot ;
MACRO1 := CRE: MACRO1 LZCRin LZCRot LSORin LSORot :: EDIT 1
          READ
          COMPO LZCRin  MIX <<mZCRin>> <<NamZCRin>>  ENDMIX
          COMPO LZCRot  MIX <<mZCRot>> <<NamZCRot>>  ENDMIX
          COMPO LSORin  MIX <<mSORin>> <<NamSORin>>  ENDMIX
          COMPO LSORot  MIX <<mSORot>> <<NamSORot>>  ENDMIX ;
*--
* fuel-map specification:
*--
FMAP MATEX := Pfmap MATEX ;
*--
* average exit burnups:
*--
FMAP := Pburn FMAP ;
*--
* initialization:
*--
LFUEL1 := SFUEL1 ;
LFUEL2 := SFUEL2 ;
EVALUATE Eps := epsil 1. + ;
*----------------------------------------------------------
*                     TIME-AVERAGE CALCULATION
*----------------------------------------------------------
WHILE Eps epsil > iter 20 < * DO

   EVALUATE iter := iter 1 + ;
*--
* fuel-map macrolib:
*--
   MACFL := CRE: LFUEL1 LFUEL2 FMAP :: EDIT 0 READ
             TABLE LFUEL1
                MIX <<mFuel1>> <<NamFuel1>> ENDMIX
             TABLE LFUEL2
                MIX <<mFuel2>> <<NamFuel2>> ENDMIX ;
*--
* extended macrolib:
*--
   MACRO2 MATEX := MACINI: MATEX MACRO1 MACFL :: EDIT 0 ;
   MACFL := DELETE: MACFL ;
*--
* complete macrolib:
*--
   MACRO MATEX := NEWMAC: MATEX MACRO2 DEVICE :: EDIT 0 ;
   MACRO2 := DELETE: MACRO2 ;
*--
* numerical solution:
*--
   SYSTEM := TRIVAA: MACRO TRACK :: EDIT 0 ;
```

```
      MACRO   := DELETE: MACRO ;
      IF iter 1 = THEN
         FLUX := FLUD: SYSTEM TRACK :: EDIT 0
                   ACCE 3 3  ADI 4  EXTE 1000 <<Precf>>
                   THER 1000 ;
      ELSE
         FLUX := FLUD: FLUX SYSTEM TRACK :: EDIT 0
                   ACCE 3 3  ADI 4  EXTE 1000 <<Precf>>
                   THER 1000 ;
      ENDIF ;
      SYSTEM := DELETE: SYSTEM ;
   *--
   * flux and power:
   *--
      POWER := FLPOW: FMAP FLUX TRACK MATEX ::
               EDIT 0 PTOT <<Power>> ;
   *--
   * burnups integration limits:
   *--
      FMAP   := TAVG: FMAP POWER :: EDIT 0
               AX-SHAPE RELAX 0.5  B-EXIT ;
      POWER := DELETE: POWER ;
   *--
   * current parameters:
   *--
      GREP: FLUX :: GETVAL 'K-EFFECTIVE' 1 >>Keff<< ;
      GREP: FMAP :: GETVAL EPS-AX 1 >>Eps<< ;
      ECHO "Iteration No. " iter ;
      ECHO "AXIAL-SHAPE ERROR : " Eps  ;
      ECHO "RESULTING K-EFF   : " Keff ;

   ENDWHILE ;
   *---------------------------------------------------------
   *--
   * edit resulting fluxes and powers:
   *--
   POWER := FLPOW: FMAP FLUX TRACK MATEX ::
           EDIT <<iEdit>> PTOT <<Power>> ;
   *--
   * last parameters:
   *--
   GREP: FLUX :: GETVAL 'K-EFFECTIVE' 1 >>Keff<< ;
   GREP: FMAP :: GETVAL EPS-AX 1 >>Eps<< ;
   GREP: FMAP :: GETVAL B-EXIT 1 >>Bexit<< ;
   ECHO "Number of Iterations " iter ;
   ECHO "AXIAL-SHAPE ERROR        : " Eps   ;
   ECHO "CORE-AVERAGE EXIT BURNUP : " Bexit ;
   ECHO "RESULTING K-EFFECTIVE    : " Keff  ;
   assertS FLUX :: 'K-EFFECTIVE' 1 1.050128 ;
   END: ;
   QUIT .
```

10.2 (Example2) – Multicompo related example

Input data for test case: **Example2.x2m**

```
************************************************************
*                                                        *
* Input file :  Example2.x2m                             *
* Purpose    :  Test for non-regression using DONJON-4   *
* Author(s)  :  D. Sekki (2007/11)                       *
*                                                        *
************************************************************
PROCEDURE    assertS Pgeom Pfmap Pburn Pdevc ;
MODULE       DELETE: GREP: END: NCR: MACINI: FLUD: USPLIT:
             DSET: TAVG: FLPOW: TRIVAT: TRIVAA: NEWMAC: ;
LINKED_LIST  GEOM TRACK MATEX FMAP FLUX POWER MACFL
             DEVICE MACRO1 MACRO2 MACRO SYSTEM LCPO ;
*--
* variables:
*--
INTEGER   nbMix  := 8 ;
INTEGER   nbRefl nbFuel := 2 2 ;
INTEGER   mFuel1 mFuel2 := 1 2 ;
INTEGER   mRefl1 mRefl2 := 3 4 ;
INTEGER   mZCRin mZCRot := 5 6 ;
INTEGER   mSORin mSORot := 7 8 ;
INTEGER   MaxReg := 100000 ;
STRING    Method := "MCFD" ;
INTEGER   degree quadr := 1 1 ;
INTEGER   iter iEdit := 0 5 ;
REAL      Power := 1800. ;
REAL      epsil := 1.E-5 ;
REAL      Precf := 1.E-5 ;
REAL      Eps Keff Bexit ;
*--
* multi-compo file:
*--
SEQ_ASCII  SCPO :: FILE 'MultiCompo' ;
*----------------------------------------------------------
*
*                    FULL-CORE  CALCULATION
*                    ======================
*--
* geometry construction:
*--
GEOM := Pgeom ;
*--
* reactor material index:
*--
GEOM MATEX := USPLIT: GEOM :: EDIT 1 NGRP 2 MAXR <<MaxReg>>
              NREFL <<nbRefl>>  RMIX <<mRefl1>> <<mRefl2>>
              NFUEL <<nbFuel>>  FMIX <<mFuel1>> <<mFuel2>> ;
*--
* numerical discretization:
```

```
*--
IF Method "MCFD" = THEN
   TRACK := TRIVAT: GEOM :: EDIT 1
             MAXR <<MaxReg>> MCFD <<degree>> ;
ELSEIF Method "PRIM" = THEN
   TRACK := TRIVAT: GEOM :: EDIT 1
             MAXR <<MaxReg>> PRIM <<degree>> ;
ELSEIF Method "DUAL" = THEN
   TRACK := TRIVAT: GEOM :: EDIT 1
             MAXR <<MaxReg>> DUAL <<degree>> <<quadr>> ;
ENDIF ;
*--
* macrolib for reflector and devices:
*--
LCPO := SCPO ;
*
MACRO1 := NCR: LCPO :: EDIT 1 MACRO NMIX <<nbMix>>
           COMPO LCPO MODE
           MIX <<mRefl1>> SET MTYPE CELL20 ENDMIX
           MIX <<mRefl2>> SET MTYPE CELL18 ENDMIX
           COMPO LCPO FUEL
           MIX <<mZCRin>>
              SET FTYPE ZCU SET RDTPOS 1. SET RDDPOS 1.
           ENDMIX
           MIX <<mZCRot>>
              SET FTYPE ZCU SET RDTPOS 1. SET RDDPOS 0.
           ENDMIX
           MIX <<mSORin>>
              SET FTYPE SOR SET RDTPOS 1. SET RDDPOS 1.
           ENDMIX
           MIX <<mSORot>>
              SET FTYPE SOR SET RDTPOS 1. SET RDDPOS 0.
           ENDMIX ;
*--
* device specification:
*--
DEVICE MATEX := Pdevc MATEX ::
     <<mZCRin>> <<mZCRot>> <<mSORin>> <<mSORot>> ;
*--
* full insertion of ZCR-devices:
*--
DEVICE := DSET: DEVICE :: EDIT 1
           ROD-GROUP 1 LEVEL 1.0 END
           ROD-GROUP 2 LEVEL 1.0 END
           ROD-GROUP 3 LEVEL 1.0 END ;
*--
* fuel-map specification:
*--
FMAP MATEX := Pfmap MATEX ;
*--
* average exit burnups:
*--
FMAP := Pburn FMAP ;
```

```
EVALUATE Eps := epsil 1. + ;
*-----------------------------------------------------------
*                    TIME-AVERAGE CALCULATION
*-----------------------------------------------------------
WHILE Eps epsil > iter 10 < * DO

   EVALUATE iter := iter 1 + ;
*--
* fuel-map macrolib:
*--
   MACFL := NCR: LCPO FMAP :: EDIT 0 MACRO
             TABLE LCPO FUEL BURN
             MIX <<mFuel1>> SET FTYPE CELL20 ENDMIX
             TABLE LCPO FUEL BURN
             MIX <<mFuel2>> SET FTYPE CELL18 ENDMIX ;
*--
* extended macrolib:
*--
   MACRO2 MATEX := MACINI: MATEX MACRO1 MACFL :: EDIT 0 ;
   MACFL := DELETE: MACFL ;
*--
* complete macrolib:
*--
   MACRO MATEX := NEWMAC: MATEX MACRO2 DEVICE :: EDIT 0 ;
   MACRO2 := DELETE: MACRO2 ;
*--
* numerical solution:
*--
   SYSTEM := TRIVAA: MACRO TRACK :: EDIT 0 ;
   MACRO  := DELETE: MACRO ;
   IF iter 1 = THEN
      FLUX := FLUD: SYSTEM TRACK :: EDIT 0
               ACCE 3 3  ADI 4  EXTE 1000 <<Precf>>
               THER 1000 ;
   ELSE
      FLUX := FLUD: FLUX SYSTEM TRACK :: EDIT 0
               ACCE 3 3  ADI 4  EXTE 1000 <<Precf>>
               THER 1000 ;
   ENDIF ;
   SYSTEM := DELETE: SYSTEM ;
*--
* flux and power:
*--
   POWER := FLPOW: FMAP FLUX TRACK MATEX ::
            EDIT 0 PTOT <<Power>> ;
*--
* burnups integration limits:
*--
   FMAP  := TAVG: FMAP POWER :: EDIT 0
            AX-SHAPE RELAX 0.5  B-EXIT ;
   POWER := DELETE: POWER ;
*--
* current parameters:
```

```
*--
   GREP: FLUX :: GETVAL 'K-EFFECTIVE' 1 >>Keff<< ;
   GREP: FMAP :: GETVAL EPS-AX 1 >>Eps<< ;
   ECHO "Iteration No. " iter ;
   ECHO "AXIAL-SHAPE ERROR : " Eps  ;
   ECHO "RESULTING K-EFF   : " Keff ;

ENDWHILE ;
*------------------------------------------------------------
*--
* edit resulting fluxes and powers:
*--
POWER := FLPOW: FMAP FLUX TRACK MATEX ::
         EDIT <<iEdit>> PTOT <<Power>> ;
*--
* last parameters:
*--
GREP: FLUX :: GETVAL 'K-EFFECTIVE' 1 >>Keff<< ;
GREP: FMAP :: GETVAL EPS-AX 1 >>Eps<< ;
GREP: FMAP :: GETVAL B-EXIT 1 >>Bexit<< ;
ECHO "Number of Iterations " iter ;
ECHO "AXIAL-SHAPE ERROR          : " Eps   ;
ECHO "CORE-AVERAGE EXIT BURNUP  : " Bexit ;
ECHO "RESULTING K-EFFECTIVE     : " Keff  ;
assertS FLUX :: 'K-EFFECTIVE' 1 1.050102 ;
END: ;
QUIT .
```

10.3   Procedures

10.3.1 Input file for geometry

Input data for test case: **Pgeom.c2m**

```
*************************************************************
*                                                          *
* Procedure :  Pgeom.c2m                                   *
* Purpose   :  Reactor geometry definition                 *
* Author(s) :  D. Sekki   (2007/06)                        *
*                                                          *
* CALL      :  GEOM := Pgeom ;                             *
*                                                          *
*************************************************************

PARAMETER   GEOM :: ::: LINKED_LIST GEOM ; ;
MODULE      END: GEO: ;

  GEOM := GEO: :: CAR3D 24 24 12
```

Figure 18: Geometry definition (plane-1)

```
          EDIT 1
          X- VOID  X+ VOID
          Y- VOID  Y+ VOID
          Z- VOID  Z+ VOID
    MIX
    PLANE 1

*  -  -  -  1 2 3 4 5 6 7 8 9  0 1 2 3 4 5 6 7 8  -  -  -

    0 0 0 0 0 0 0 0 3 3 3 3  3 3 3 3 0 0 0 0 0 0 0 0   ! -
    0 0 0 0 0 0 3 3 3 3 3 3  3 3 3 3 3 3 0 0 0 0 0 0   ! -
    0 0 0 0 0 3 3 3 3 3 3 3  3 3 3 3 3 3 3 0 0 0 0 0   ! -
    0 0 0 3 3 3 3 1 1 1 1 1  1 1 1 1 3 3 3 3 0 0 0     ! A
    0 0 0 3 3 1 1 1 1 1 1 1  1 1 1 1 1 1 3 3 0 0 0     ! B
    0 0 3 3 1 1 1 1 1 1 1 1  1 1 1 1 1 1 1 3 3 0 0     ! C
    0 3 3 3 1 1 1 1 1 1 1 1  1 1 1 1 1 1 1 3 3 3 0     ! D
    0 3 3 1 1 1 1 1 1 1 1 1  1 1 1 1 1 1 1 1 3 3 0     ! E
    3 3 3 1 1 1 1 1 1 1 1 1  1 1 1 1 1 1 1 1 3 3 3     ! F
    3 3 3 1 1 1 1 1 1 1 1 1  1 1 1 1 1 1 1 1 3 3 3     ! G
    3 3 3 1 1 1 1 1 1 1 1 1  1 1 1 1 1 1 1 1 3 3 3     ! H
```

```
      3 3 3 1 1 1 1 1 1 1 1 1  1 1 1 1 1 1 1 1 1 1 3 3 3    ! J


      3 3 3 1 1 1 1 1 1 1 1 1  1 1 1 1 1 1 1 1 1 1 3 3 3    ! K
      3 3 3 1 1 1 1 1 1 1 1 1  1 1 1 1 1 1 1 1 1 1 3 3 3    ! L
      3 3 3 1 1 1 1 1 1 1 1 1  1 1 1 1 1 1 1 1 1 1 3 3 3    ! M
      3 3 3 1 1 1 1 1 1 1 1 1  1 1 1 1 1 1 1 1 1 1 3 3 3    ! N
      0 3 3 1 1 1 1 1 1 1 1 1  1 1 1 1 1 1 1 1 1 1 3 3 0    ! O
      0 3 3 3 1 1 1 1 1 1 1 1  1 1 1 1 1 1 1 1 1 3 3 3 0    ! P
      0 0 3 3 1 1 1 1 1 1 1 1  1 1 1 1 1 1 1 1 1 3 3 0 0    ! Q
      0 0 0 3 3 1 1 1 1 1 1 1  1 1 1 1 1 1 1 3 3 0 0 0      ! R
      0 0 0 3 3 3 3 1 1 1 1 1  1 1 1 1 1 3 3 3 3 0 0 0      ! S
      0 0 0 0 0 3 3 3 3 3 3 3  3 3 3 3 3 3 3 0 0 0 0 0      ! -
      0 0 0 0 0 0 3 3 3 3 3 3  3 3 3 3 3 3 0 0 0 0 0 0      ! -
      0 0 0 0 0 0 0 0 3 3 3 3  3 3 3 3 0 0 0 0 0 0 0 0      ! -

      PLANE 2   SAME 1
      PLANE 3   SAME 1
      PLANE 4   SAME 1

      PLANE 5

*  -  -  - 1 2 3 4 5 6 7 8 9  0 1 2 3 4 5 6 7 8 - - -

      0 0 0 0 0 0 0 0 4 4 4 4  4 4 4 4 0 0 0 0 0 0 0 0      ! -
      0 0 0 0 0 0 4 4 4 4 4 4  4 4 4 4 4 4 0 0 0 0 0 0      ! -
      0 0 0 0 0 4 4 4 4 4 4 4  4 4 4 4 4 4 4 0 0 0 0 0      ! -
      0 0 0 4 4 4 4 2 2 2 2 2  2 2 2 2 2 4 4 4 4 0 0 0      ! A
      0 0 0 4 4 2 2 2 2 2 2 2  2 2 2 2 2 2 2 4 4 0 0 0      ! B
      0 0 4 4 2 2 2 2 2 2 2 2  2 2 2 2 2 2 2 2 4 4 0 0      ! C
      0 4 4 4 2 2 2 2 2 2 2 2  2 2 2 2 2 2 2 2 4 4 4 0      ! D
      0 4 4 2 2 2 2 2 2 2 2 2  2 2 2 2 2 2 2 2 2 4 4 0      ! E
      4 4 4 2 2 2 2 2 2 2 2 2  2 2 2 2 2 2 2 2 2 4 4 4      ! F
      4 4 4 2 2 2 2 2 2 2 2 2  2 2 2 2 2 2 2 2 2 4 4 4      ! G
      4 4 4 2 2 2 2 2 2 2 2 2  2 2 2 2 2 2 2 2 2 4 4 4      ! H
      4 4 4 2 2 2 2 2 2 2 2 2  2 2 2 2 2 2 2 2 2 4 4 4      ! J


      4 4 4 2 2 2 2 2 2 2 2 2  2 2 2 2 2 2 2 2 2 4 4 4      ! K
      4 4 4 2 2 2 2 2 2 2 2 2  2 2 2 2 2 2 2 2 2 4 4 4      ! L
      4 4 4 2 2 2 2 2 2 2 2 2  2 2 2 2 2 2 2 2 2 4 4 4      ! M
      4 4 4 2 2 2 2 2 2 2 2 2  2 2 2 2 2 2 2 2 2 4 4 4      ! N
      0 4 4 2 2 2 2 2 2 2 2 2  2 2 2 2 2 2 2 2 2 4 4 0      ! O
      0 4 4 4 2 2 2 2 2 2 2 2  2 2 2 2 2 2 2 2 4 4 4 0      ! P
      0 0 4 4 2 2 2 2 2 2 2 2  2 2 2 2 2 2 2 2 4 4 0 0      ! Q
      0 0 0 4 4 2 2 2 2 2 2 2  2 2 2 2 2 2 4 4 0 0 0        ! R
      0 0 0 4 4 4 4 2 2 2 2 2  2 2 2 2 2 4 4 4 4 0 0 0      ! S
      0 0 0 0 0 4 4 4 4 4 4 4  4 4 4 4 4 4 4 0 0 0 0 0      ! -
      0 0 0 0 0 0 4 4 4 4 4 4  4 4 4 4 4 4 0 0 0 0 0 0      ! -
      0 0 0 0 0 0 0 0 4 4 4 4  4 4 4 4 0 0 0 0 0 0 0 0      ! -

      PLANE  6   SAME 5
      PLANE  7   SAME 5
      PLANE  8   SAME 5
```

```
   PLANE  9  SAME 1
   PLANE 10  SAME 1
   PLANE 11  SAME 1
   PLANE 12  SAME 1

   MESHX  0.0   20.  40.  62.  84. 106. 128. 150. 172.
          194. 216. 238. 260. 282. 304. 326. 348. 370.
          392. 414. 436. 458. 480. 500. 520.

   MESHY  0.0   20.  40.  62.  84. 106. 128. 150. 172.
          194. 216. 238. 260. 282. 304. 326. 348. 370.
          392. 414. 436. 458. 480. 500. 520.

   MESHZ  0.0 49.53 99.06 148.59 198.12 247.65 297.18
          346.71 396.24 445.77 495.30 544.83 594.36


   SPLITX 2 2 2 2 2 2 2 2 2 2 2 2
          2 2 2 2 2 2 2 2 2 2 2 2

   SPLITY 2 2 2 2 2 2 2 2 2 2 2 2
          2 2 2 2 2 2 2 2 2 2 2 2

   SPLITZ 2 2 2 2 2 2 2 2 2 2 2 2 ;

 END: ;
 QUIT .
```

10.3.2 Input file for devices

Input data for test case: **Pdevc.c2m**

```
   *************************************************************
   *                                                           *
   * Procedure :  Pdevc.c2m                                    *
   * Purpose   :  Reactor rod-devices specification            *
   * Author(s) :  D. Sekki (2007/06)                           *
   *                                                           *
   * CALL      :  DEVICE MATEX := Pdevc MATEX ::               *
   *          <<mZCRin>> <<mZCRout>> <<mSORin>> <<mSORout>> ;  *
   *                                                           *
   *************************************************************

   PARAMETER  DEVICE MATEX ::
                             ::: LINKED_LIST DEVICE MATEX ; ;
   MODULE     END: DEVINI: ;
   INTEGER    mZCRin mZCRout mSORin mSORout ;
   *--
   * Read arguments:
   *--
     :: >>mZCRin<< >>mZCRout<< >>mSORin<< >>mSORout<< ;
```

Figure 19: Top View of ACR Benchmark Core Model

```
  DEVICE MATEX := DEVINI: MATEX :: EDIT 1 NUM-ROD 56 FADE
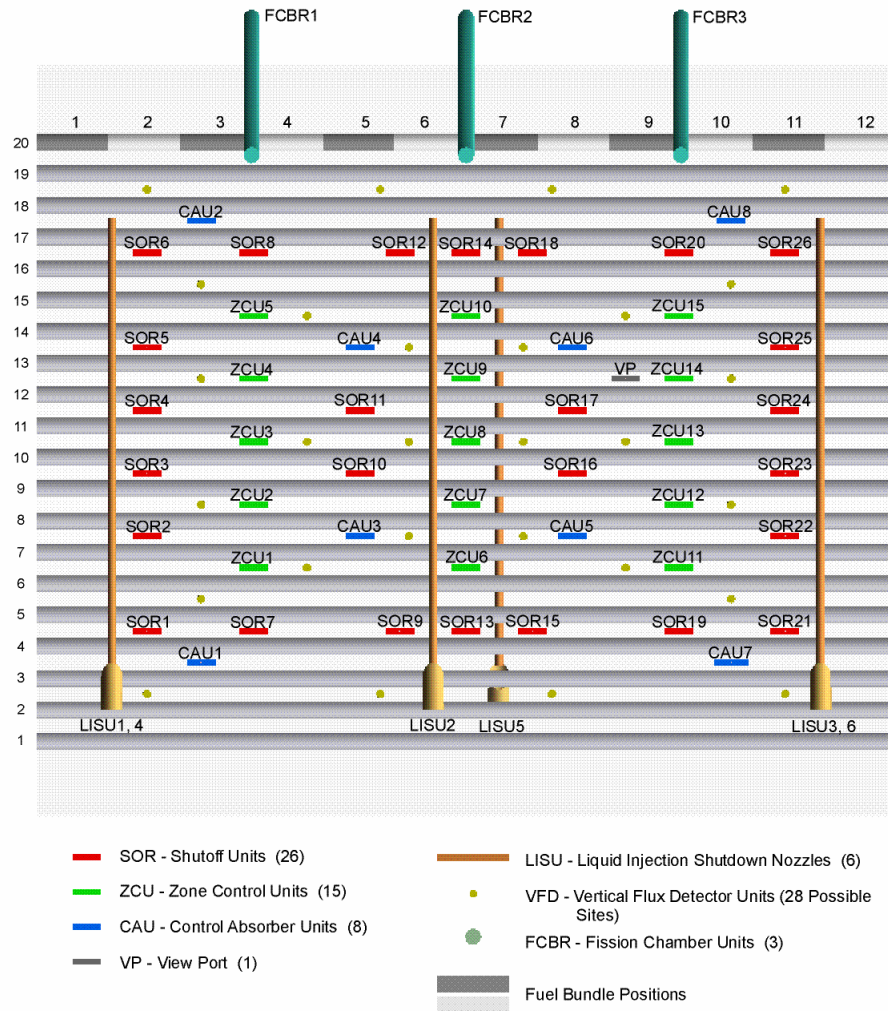
*--
* ZCR:
*--
    ROD 1
      ROD-NAME ZCR01A
      LEVEL 0.0   AXIS Y  FROM H-
      MAXPOS 161.0 183.0   0.0 260.0   123.825 173.355
      DMIX <<mZCRin>> <<mZCRout>>
    ENDROD
*
    ROD 2
```

```
        ROD-NAME ZCR01B
        LEVEL 0.0   AXIS Y  FROM H+
        MAXPOS 161.0 183.0   260.0 520.0   123.825 173.355
        DMIX <<mZCRin>> <<mZCRout>>
      ENDROD
*
      ROD 3
        ROD-NAME ZCR02A
        LEVEL 0.0   AXIS Y  FROM H-
        MAXPOS 205.0 227.0   0.0 260.0   123.825 173.355
        DMIX <<mZCRin>> <<mZCRout>>
      ENDROD
*
      ROD 4
        ROD-NAME ZCR02B
        LEVEL 0.0   AXIS Y  FROM H+
        MAXPOS 205.0 227.0   260.0 520.0   123.825 173.355
        DMIX <<mZCRin>> <<mZCRout>>
      ENDROD
*
      ROD 5
        ROD-NAME ZCR03A
        LEVEL 0.0   AXIS Y  FROM H-
        MAXPOS 249.0 271.0   0.0 260.0   123.825 173.355
        DMIX <<mZCRin>> <<mZCRout>>
      ENDROD
*
      ROD 6
        ROD-NAME ZCR03B
        LEVEL 0.0   AXIS Y  FROM H+
        MAXPOS 249.0 271.0   260.0 520.0   123.825 173.355
        DMIX <<mZCRin>> <<mZCRout>>
      ENDROD
*
      ROD 7
        ROD-NAME ZCR04A
        LEVEL 0.0   AXIS Y  FROM H-
        MAXPOS 293.0 315.0   0.0 260.0   123.825 173.355
        DMIX <<mZCRin>> <<mZCRout>>
      ENDROD
*
      ROD 8
        ROD-NAME ZCR04B
        LEVEL 0.0   AXIS Y  FROM H+
        MAXPOS 293.0 315.0   260.0 520.0   123.825 173.355
        DMIX <<mZCRin>> <<mZCRout>>
      ENDROD
*
      ROD 9
        ROD-NAME ZCR05A
        LEVEL 0.0   AXIS Y  FROM H-
        MAXPOS 337.0 359.0   0.0 260.0   123.825 173.355
        DMIX <<mZCRin>> <<mZCRout>>
```

```
      ENDROD
 *
      ROD 10
        ROD-NAME ZCR05B
        LEVEL 0.0    AXIS Y   FROM H+
        MAXPOS 337.0 359.0   260.0 520.0   123.825 173.355
        DMIX <<mZCRin>> <<mZCRout>>
      ENDROD
 *
      ROD 11
        ROD-NAME ZCR06A
        LEVEL 0.0    AXIS Y   FROM H-
        MAXPOS 161.0 183.0   0.0 260.0   272.415 321.945
        DMIX <<mZCRin>> <<mZCRout>>
      ENDROD
 *
      ROD 12
        ROD-NAME ZCR06B
        LEVEL 0.0    AXIS Y   FROM H+
        MAXPOS 161.0 183.0   260.0 520.0   272.415 321.945
        DMIX <<mZCRin>> <<mZCRout>>
      ENDROD
 *
      ROD 13
        ROD-NAME ZCR07A
        LEVEL 0.0    AXIS Y   FROM H-
        MAXPOS 205.0 227.0   0.0 260.0   272.415 321.945
        DMIX <<mZCRin>> <<mZCRout>>
      ENDROD
 *
      ROD 14
        ROD-NAME ZCR07B
        LEVEL 0.0    AXIS Y   FROM H+
        MAXPOS 205.0 227.0   260.0 520.0   272.415 321.945
        DMIX <<mZCRin>> <<mZCRout>>
      ENDROD
 *
      ROD 15
        ROD-NAME ZCR08A
        LEVEL 0.0    AXIS Y   FROM H-
        MAXPOS 249.0 271.0   0.0 260.0   272.415 321.945
        DMIX <<mZCRin>> <<mZCRout>>
      ENDROD
 *
      ROD 16
        ROD-NAME ZCR08B
        LEVEL 0.0    AXIS Y   FROM H+
        MAXPOS 249.0 271.0   260.0 520.0   272.415 321.945
        DMIX <<mZCRin>> <<mZCRout>>
      ENDROD
 *
      ROD 17
        ROD-NAME ZCR09A
```

```
             LEVEL 0.0   AXIS Y  FROM H-
             MAXPOS 293.0 315.0   0.0 260.0   272.415 321.945
             DMIX <<mZCRin>> <<mZCRout>>
           ENDROD
      *
           ROD 18
             ROD-NAME ZCR09B
             LEVEL 0.0   AXIS Y  FROM H+
             MAXPOS 293.0 315.0   260.0 520.0   272.415 321.945
             DMIX <<mZCRin>> <<mZCRout>>
           ENDROD
      *
           ROD 19
             ROD-NAME ZCR10A
             LEVEL 0.0   AXIS Y  FROM H-
             MAXPOS 337.0 359.0   0.0   260.0   272.415 321.945
             DMIX <<mZCRin>> <<mZCRout>>
           ENDROD
      *
           ROD 20
             ROD-NAME ZCR10B
             LEVEL 0.0   AXIS Y  FROM H+
             MAXPOS 337.0 359.0   260.0 520.0   272.415 321.945
             DMIX <<mZCRin>> <<mZCRout>>
           ENDROD
      *
           ROD 21
             ROD-NAME ZCR11A
             LEVEL 0.0   AXIS Y  FROM H-
             MAXPOS 161.0 183.0   0.0 260.0   421.005 470.535
             DMIX <<mZCRin>> <<mZCRout>>
           ENDROD
      *
           ROD 22
             ROD-NAME ZCR11B
             LEVEL 0.0   AXIS Y  FROM H+
             MAXPOS 161.0 183.0   260.0 520.0   421.005 470.535
             DMIX <<mZCRin>> <<mZCRout>>
           ENDROD
      *
           ROD 23
             ROD-NAME ZCR12A
             LEVEL 0.0   AXIS Y  FROM H-
             MAXPOS 205.0 227.0   0.0 260.0   421.005 470.535
             DMIX <<mZCRin>> <<mZCRout>>
           ENDROD
      *
           ROD 24
             ROD-NAME ZCR12B
             LEVEL 0.0   AXIS Y  FROM H+
             MAXPOS 205.0 227.0   260.0 520.0   421.005 470.535
             DMIX <<mZCRin>> <<mZCRout>>
           ENDROD
```

```
*
    ROD 25
      ROD-NAME ZCR13A
      LEVEL 0.0   AXIS Y  FROM H-
      MAXPOS 249.0 271.0   0.0 260.0   421.005 470.535
      DMIX <<mZCRin>> <<mZCRout>>
    ENDROD
*
    ROD 26
      ROD-NAME ZCR13B
      LEVEL 0.0   AXIS Y  FROM H+
      MAXPOS 249.0 271.0   260.0 520.0   421.005 470.535
      DMIX <<mZCRin>> <<mZCRout>>
    ENDROD
*
    ROD 27
      ROD-NAME ZCR14A
      LEVEL 0.0   AXIS Y  FROM H-
      MAXPOS 293.0 315.0   0.0 260.0   421.005 470.535
      DMIX <<mZCRin>> <<mZCRout>>
    ENDROD
*
    ROD 28
      ROD-NAME ZCR14B
      LEVEL 0.0   AXIS Y  FROM H+
      MAXPOS 293.0 315.0   260.0 520.0   421.005 470.535
      DMIX <<mZCRin>> <<mZCRout>>
    ENDROD
*
    ROD 29
      ROD-NAME ZCR15A
      LEVEL 0.0   AXIS Y  FROM H-
      MAXPOS 337.0 359.0   0.0 260.0   421.005 470.535
      DMIX <<mZCRin>> <<mZCRout>>
    ENDROD
*
    ROD 30
      ROD-NAME ZCR15B
      LEVEL 0.0   AXIS Y  FROM H+
      MAXPOS 337.0 359.0   260.0 520.0   421.005 470.535
      DMIX <<mZCRin>> <<mZCRout>>
    ENDROD

*--
* SOR:
*--
    ROD 31
      ROD-NAME SOR01
      LEVEL 0.0   AXIS Y  FROM H+
      MAXPOS 117.0 139.0   53.75 466.25   49.53 99.06
      DMIX <<mSORin>> <<mSORout>>
    ENDROD
*
```

```
      ROD 32
        ROD-NAME SOR02
        LEVEL 0.0    AXIS Y   FROM H+
        MAXPOS 183.0 205.0    24.5 495.5    49.53 99.06
        DMIX <<mSORin>> <<mSORout>>
      ENDROD
*
      ROD 33
        ROD-NAME SOR03
        LEVEL 0.0    AXIS Y   FROM H+
        MAXPOS 227.0 249.0    24.5 495.5    49.53 99.06
        DMIX <<mSORin>> <<mSORout>>
      ENDROD
*
      ROD 34
        ROD-NAME SOR04
        LEVEL 0.0    AXIS Y   FROM H+
        MAXPOS 271.0 293.0    24.5 495.5    49.53 99.06
        DMIX <<mSORin>> <<mSORout>>
      ENDROD
*
      ROD 35
        ROD-NAME SOR05
        LEVEL 0.0    AXIS Y   FROM H+
        MAXPOS 315.0 337.0    24.5 495.5    49.53 99.06
        DMIX <<mSORin>> <<mSORout>>
      ENDROD
*
      ROD 36
        ROD-NAME SOR06
        LEVEL 0.0    AXIS Y   FROM H+
        MAXPOS 381.0 403.0    53.75 466.25    49.53 99.06
        DMIX <<mSORin>> <<mSORout>>
      ENDROD
*
      ROD 37
        ROD-NAME SOR07
        LEVEL 0.0    AXIS Y   FROM H+
        MAXPOS 117.0 139.0    53.75 466.25    123.825 173.355
        DMIX <<mSORin>> <<mSORout>>
      ENDROD
*
      ROD 38
        ROD-NAME SOR08
        LEVEL 0.0    AXIS Y   FROM H+
        MAXPOS 381.0 403.0    53.75 466.25    123.825 173.355
        DMIX <<mSORin>> <<mSORout>>
      ENDROD
*
      ROD 39
        ROD-NAME SOR09
        LEVEL 0.0    AXIS Y   FROM H+
        MAXPOS 117.0 139.0    53.75 466.25    222.885 272.415
```

```
         DMIX <<mSORin>> <<mSORout>>
       ENDROD
  *
       ROD 40
         ROD-NAME SOR10
         LEVEL 0.0    AXIS Y   FROM H+
         MAXPOS 227.0 249.0    24.5 495.5    198.12 247.65
         DMIX <<mSORin>> <<mSORout>>
       ENDROD
  *
       ROD 41
         ROD-NAME SOR11
         LEVEL 0.0    AXIS Y   FROM H+
         MAXPOS 271.0 293.0    24.5 495.5    198.12 247.65
         DMIX <<mSORin>> <<mSORout>>
       ENDROD
  *
       ROD 42
         ROD-NAME SOR12
         LEVEL 0.0    AXIS Y   FROM H+
         MAXPOS 381.0 403.0    53.75 466.25    222.885 272.415
         DMIX <<mSORin>> <<mSORout>>
       ENDROD
  *
       ROD 43
         ROD-NAME SOR13
         LEVEL 0.0    AXIS Y   FROM H+
         MAXPOS 117.0 139.0    53.75 466.25    272.415 321.945
         DMIX <<mSORin>> <<mSORout>>
       ENDROD
  *
       ROD 44
         ROD-NAME SOR14
         LEVEL 0.0    AXIS Y   FROM H+
         MAXPOS 381.0 403.0    53.75 466.25    272.415 321.945
         DMIX <<mSORin>> <<mSORout>>
       ENDROD
  *
       ROD 45
         ROD-NAME SOR15
         LEVEL 0.0    AXIS Y   FROM H+
         MAXPOS 117.0 139.0    53.75 466.25    321.945 371.475
         DMIX <<mSORin>> <<mSORout>>
       ENDROD
  *
       ROD 46
         ROD-NAME SOR16
         LEVEL 0.0    AXIS Y   FROM H+
         MAXPOS 227.0 249.0    24.5 495.5    346.71 396.24
         DMIX <<mSORin>> <<mSORout>>
       ENDROD
  *
       ROD 47
```

```
      ROD-NAME SOR17
      LEVEL 0.0   AXIS Y  FROM H+
      MAXPOS 271.0 293.0   24.5 495.5   346.71 396.24
      DMIX <<mSORin>> <<mSORout>>
    ENDROD
*
    ROD 48
      ROD-NAME SOR18
      LEVEL 0.0   AXIS Y  FROM H+
      MAXPOS 381.0 403.0   53.75 466.25   321.945 371.475
      DMIX <<mSORin>> <<mSORout>>
    ENDROD
*
    ROD 49
      ROD-NAME SOR19
      LEVEL 0.0   AXIS Y  FROM H+
      MAXPOS 117.0 139.0   53.75 466.25   421.005 470.535
      DMIX <<mSORin>> <<mSORout>>
    ENDROD
*
    ROD 50
      ROD-NAME SOR20
      LEVEL 0.0   AXIS Y  FROM H+
      MAXPOS 381.0 403.0   53.75 466.25   421.005 470.535
      DMIX <<mSORin>> <<mSORout>>
    ENDROD
*
    ROD 51
      ROD-NAME SOR21
      LEVEL 0.0   AXIS Y  FROM H+
      MAXPOS 117.0 139.0   53.75 466.25   495.3 544.83
      DMIX <<mSORin>> <<mSORout>>
    ENDROD
*
    ROD 52
      ROD-NAME SOR22
      LEVEL 0.0   AXIS Y  FROM H+
      MAXPOS 183.0 205.0   24.5 495.5   495.3 544.83
      DMIX <<mSORin>> <<mSORout>>
    ENDROD
*
    ROD 53
      ROD-NAME SOR23
      LEVEL 0.0   AXIS Y  FROM H+
      MAXPOS 227.0 249.0   24.5 495.5   495.3 544.83
      DMIX <<mSORin>> <<mSORout>>
    ENDROD
*
    ROD 54
      ROD-NAME SOR24
      LEVEL 0.0   AXIS Y  FROM H+
      MAXPOS 271.0 293.0   24.5 495.5   495.3 544.83
      DMIX <<mSORin>> <<mSORout>>
```

```
      ENDROD
  *
      ROD 55
        ROD-NAME SOR25
        LEVEL 0.0    AXIS Y   FROM H+
        MAXPOS 315.0 337.0    24.5 495.5    495.3 544.83
        DMIX <<mSORin>> <<mSORout>>
      ENDROD
  *
      ROD 56
        ROD-NAME SOR26
        LEVEL 0.0    AXIS Y   FROM H+
        MAXPOS 381.0 403.0    53.75 466.25    495.3 544.83
        DMIX <<mSORin>> <<mSORout>>
      ENDROD

  *--
  * create rod-devices groups:
  *--
      CREATE ROD-GR 5

      GROUP-ID 1
      ROD-ID 1 2 15 16 19 20 23 24 27 28

      GROUP-ID 2
      ROD-ID 3 4 7 8 9 10 13 14

      GROUP-ID 3
      ROD-ID 5 6 11 12 17 18 21 22 25 26 29 30

      GROUP-ID 4
      ROD-ID 31 36 37 38 39 42 43 44 45 48 49 50 51 52 53 54 55

      GROUP-ID 5
      ROD-ID 32 33 34 35 40 41 46 47 53 56 ;

  END: ;
  QUIT .
```

10.3.3 Input file for fuel map

Input data for test case: **Pfmap.c2m**

```
  ************************************************************
  *                                                        *
  * Procedure :  Pfmap.c2m                                 *
  * Purpose   :  Reactor fuel-map specification            *
  * Author(s) :  D. Sekki (2007/11)                        *
  *                                                        *
  * CALL      :  FMAP MATEX := Pfmap MATEX ;               *
  *                                                        *
```

```
    ***********************************************************
    PARAMETER  FMAP MATEX :: ::: LINKED_LIST FMAP MATEX ; ;
    MODULE     END: RESINI: ;

    FMAP MATEX := RESINI: MATEX :: EDIT 0

        ::: GEO: CAR3D 20 20 12

            EDIT 0
            X- VOID  X+ VOID
            Y- VOID  Y+ VOID
            Z- VOID  Z+ VOID

        MIX

        PLANE 1

    *   - 1 2 3 4 5 6 7 8 9  0 1 2 3 4 5 6 7 8 -

        0 0 0 0 0 0 0 0 0 0  0 0 0 0 0 0 0 0 0 0   ! -
        0 0 0 0 0 1 1 1 1 1  1 1 1 1 1 0 0 0 0 0   ! A
        0 0 0 1 1 1 1 1 1 1  1 1 1 1 1 1 1 0 0 0   ! B
        0 0 1 1 1 1 1 1 1 1  1 1 1 1 1 1 1 1 0 0   ! C
        0 0 1 1 1 1 1 1 1 1  1 1 1 1 1 1 1 1 0 0   ! D
        0 1 1 1 1 1 1 1 1 1  1 1 1 1 1 1 1 1 1 0   ! E
        0 1 1 1 1 1 1 1 1 1  1 1 1 1 1 1 1 1 1 0   ! F
        0 1 1 1 1 1 1 1 1 1  1 1 1 1 1 1 1 1 1 0   ! G
        0 1 1 1 1 1 1 1 1 1  1 1 1 1 1 1 1 1 1 0   ! H
        0 1 1 1 1 1 1 1 1 1  1 1 1 1 1 1 1 1 1 0   ! J

        0 1 1 1 1 1 1 1 1 1  1 1 1 1 1 1 1 1 1 0   ! K
        0 1 1 1 1 1 1 1 1 1  1 1 1 1 1 1 1 1 1 0   ! L
        0 1 1 1 1 1 1 1 1 1  1 1 1 1 1 1 1 1 1 0   ! M
        0 1 1 1 1 1 1 1 1 1  1 1 1 1 1 1 1 1 1 0   ! N
        0 1 1 1 1 1 1 1 1 1  1 1 1 1 1 1 1 1 1 0   ! O
        0 0 1 1 1 1 1 1 1 1  1 1 1 1 1 1 1 1 0 0   ! P
        0 0 1 1 1 1 1 1 1 1  1 1 1 1 1 1 1 1 0 0   ! Q
        0 0 0 1 1 1 1 1 1 1  1 1 1 1 1 1 1 0 0 0   ! R
        0 0 0 0 0 1 1 1 1 1  1 1 1 1 1 0 0 0 0 0   ! S
        0 0 0 0 0 0 0 0 0 0  0 0 0 0 0 0 0 0 0 0   ! -

        PLANE 2  SAME 1
        PLANE 3  SAME 1
        PLANE 4  SAME 1

        PLANE 5

    *   - 1 2 3 4 5 6 7 8 9  0 1 2 3 4 5 6 7 8 -

        0 0 0 0 0 0 0 0 0 0  0 0 0 0 0 0 0 0 0 0   ! -
        0 0 0 0 0 2 2 2 2 2  2 2 2 2 2 0 0 0 0 0   ! A
        0 0 0 2 2 2 2 2 2 2  2 2 2 2 2 2 2 0 0 0   ! B
        0 0 2 2 2 2 2 2 2 2  2 2 2 2 2 2 2 2 0 0   ! C
```

```
   0 0 2 2 2 2 2 2 2 2   2 2 2 2 2 2 2 2 0 0    ! D
   0 2 2 2 2 2 2 2 2 2   2 2 2 2 2 2 2 2 2 0    ! E
   0 2 2 2 2 2 2 2 2 2   2 2 2 2 2 2 2 2 2 0    ! F
   0 2 2 2 2 2 2 2 2 2   2 2 2 2 2 2 2 2 2 0    ! G
   0 2 2 2 2 2 2 2 2 2   2 2 2 2 2 2 2 2 2 0    ! H
   0 2 2 2 2 2 2 2 2 2   2 2 2 2 2 2 2 2 2 0    ! J

   0 2 2 2 2 2 2 2 2 2   2 2 2 2 2 2 2 2 2 0    ! K
   0 2 2 2 2 2 2 2 2 2   2 2 2 2 2 2 2 2 2 0    ! L
   0 2 2 2 2 2 2 2 2 2   2 2 2 2 2 2 2 2 2 0    ! M
   0 2 2 2 2 2 2 2 2 2   2 2 2 2 2 2 2 2 2 0    ! N
   0 2 2 2 2 2 2 2 2 2   2 2 2 2 2 2 2 2 2 0    ! O
   0 0 2 2 2 2 2 2 2 2   2 2 2 2 2 2 2 2 0 0    ! P
   0 0 2 2 2 2 2 2 2 2   2 2 2 2 2 2 2 2 0 0    ! Q
   0 0 0 2 2 2 2 2 2 2   2 2 2 2 2 2 2 0 0 0    ! R
   0 0 0 0 0 2 2 2 2 2   2 2 2 2 2 0 0 0 0 0    ! S
   0 0 0 0 0 0 0 0 0 0   0 0 0 0 0 0 0 0 0 0    ! -

   PLANE  6   SAME 5
   PLANE  7   SAME 5
   PLANE  8   SAME 5

   PLANE  9   SAME 1
   PLANE 10   SAME 1
   PLANE 11   SAME 1
   PLANE 12   SAME 1

   MESHX  0.0    62.  84. 106. 128. 150. 172.
          194. 216. 238. 260. 282. 304. 326.
          348. 370. 392. 414. 436. 458. 520.

   MESHY  0.0    62.  84. 106. 128. 150. 172.
          194. 216. 238. 260. 282. 304. 326.
          348. 370. 392. 414. 436. 458. 520.

   MESHZ  0.0  49.53  99.06  148.59  198.12  247.65
   297.18 346.71 396.24 445.77 495.30 544.83 594.36
 ;

 NXNAME  '-' '1' '2' '3' '4' '5' '6' '7' '8' '9' '10'
         '11' '12' '13' '14' '15' '16' '17' '18' '-'

 NYNAME  '-' 'A' 'B' 'C' 'D' 'E' 'F' 'G' 'H' 'J'
         'K' 'L' 'M' 'N' 'O' 'P' 'Q' 'R' 'S' '-'

 NCOMB 73  B-ZONE

  1   2   3   4   5   5   4   3   2   1   6   7   8   9
 10  11  12  12  11  10   9   8   7   6  13  14  15  16
 17  18  19  20  20  19  18  17  16  15  14  13  21  22
 23  24  25  26  27  28  28  27  26  25  24  23  22  21
 29  30  31  32  33  34  35  36  37  37  36  35  34  33
 32  31  30  29  38  39  40  41  42  43  44  45  46  46
```

```
   45   44   43   42   41   40   39   38   47   48   49   50   51   52
   53   54   55   55   54   53   52   51   50   49   48   47   56   57
   58   59   60   61   62   63   64   64   63   62   61   60   59   58
   57   56   65   66   67   68   69   70   71   72   73   73   72   71
   70   69   68   67   66   65   65   66   67   68   69   70   71   72
   73   73   72   71   70   69   68   67   66   65   56   57   58   59
   60   61   62   63   64   64   63   62   61   60   59   58   57   56
   47   48   49   50   51   52   53   54   55   55   54   53   52   51
   50   49   48   47   38   39   40   41   42   43   44   45   46   46
   45   44   43   42   41   40   39   38   29   30   31   32   33   34
   35   36   37   37   36   35   34   33   32   31   30   29   21   22
   23   24   25   26   27   28   28   27   26   25   24   23   22   21
   13   14   15   16   17   18   19   20   20   19   18   17   16   15
   14   13    6    7    8    9   10   11   12   12   11   10    9    8
    7    6    1    2    3    4    5    5    4    3    2    1
 ;

 END:  ;
 QUIT .
```

10.3.4 Input file for exit burnups

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
A					1	2	3	4	5	5	4	3	2	1				
B			6	7	8	9	10	11	12	12	11	10	9	8	7	6		
C		13	14	15	16	17	18	19	20	20	19	18	17	16	15	14	13	
D		21	22	23	24	25	26	27	28	28	27	26	25	24	23	22	21	
E	29	30	31	32	33	34	35	36	37	37	36	35	34	33	32	31	30	29
F	38	39	40	41	42	43	44	45	46	46	45	44	43	42	41	40	39	38
G	47	48	49	50	51	52	53	54	55	55	54	53	52	51	50	49	48	47
H	56	57	58	59	60	61	62	63	64	64	63	62	61	60	59	58	57	56
J	65	66	67	68	69	70	71	72	73	73	72	71	70	69	68	67	66	65
K	65	66	67	68	69	70	71	72	73	73	72	71	70	69	68	67	66	65
L	56	57	58	59	60	61	62	63	64	64	63	62	61	60	59	58	57	56
M	47	48	49	50	51	52	53	54	55	55	54	53	52	51	50	49	48	47
N	38	39	40	41	42	43	44	45	46	46	45	44	43	42	41	40	39	38
O	29	30	31	32	33	34	35	36	37	37	36	35	34	33	32	31	30	29
P		21	22	23	24	25	26	27	28	28	27	26	25	24	23	22	21	
Q		13	14	15	16	17	18	19	20	20	19	18	17	16	15	14	13	
R			6	7	8	9	10	11	12	12	11	10	9	8	7	6		
S					1	2	3	4	5	5	4	3	2	1				

Figure 20: Combustion zones definition

Input data for test case: **Pburn.c2m**

```
****************************************************************
*                                                              *
* Procedure :  Pburn.c2m                                       *
* Purpose   :  Provide average exit burnups                    *
* Author(s) :  D. Sekki (2007/11)                              *
*                                                              *
* CALL      :  FMAP := Pburn FMAP ;                            *
*                                                              *
****************************************************************
PARAMETER  FMAP :: ::: LINKED_LIST FMAP ; ;
MODULE     END: RESINI: ;

  FMAP := RESINI: FMAP :: EDIT 2  REF-SHIFT 8

    BTYPE TIMAV-BURN
    TIMAV-BVAL

  *A
     1008.98  1057.69  1071.61  1095.41  1137.92

  *B
     1365.60  1586.43  1643.79  1656.34  1756.62
     2014.25  2364.85

  *C
     1806.72  2019.33  2425.27  2556.62  2822.28
     3250.93  3391.85  3761.47

  *D
     2279.49  2267.03  2563.72  2898.28  3261.49
     3409.15  3715.98  4136.73

  *E
     2258.14  2345.30  3173.47  3111.80  3212.21
     3456.56  3705.48  3801.69  3953.67

  *F
     2678.92  3263.24  3614.41  3764.97  3813.93
     3857.62  3925.74  4046.12  4119.31

  *G
     2792.21  3087.13  3705.48  3960.65  4030.43
     4025.20  3978.10  3990.31  4037.40

  *H
     1693.96  2811.67  3666.96  4115.83  4241.15
     4134.99  4025.20  3910.02  3915.26

  *J
     2268.81  3065.97  3826.17  4232.46  4380.19
     4121.05  3995.54  3889.07  3890.81
   ;
```

```
    END: ;
    QUIT .
```

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