range are treated in this mode in the flow diagram of the SRAC code.

As the PEACO routine solves the slowing-down equation by the collision probability method only in the resonance energy range, it is not available in the eigenvalue mode or in the fixed source mode by codes except PIJ. In order to use the effective cross-sections obtained by PEACO in the eigenvalue mode, the cross-sections have to be prepared in advance by PIJ with PEACO in the fixed source mode.

1.8 Definition of Spatial Division

In the SRAC code, several spatial divisions called as Sub-Region, T-Region, R-Region, X-Region and M-Region are used. Particularly for cell calculations, various space regions and meshes are defined to enhance the calculation accuracy or to save the computer time, as the needs of the case demand. They are defined as follows;

1.8.1 Sub-Region

The concept of Sub-Region is used only for the PIJ code. The Sub-Region is the purely geometrical sub-division that is bounded by the lines or circles used to identify the location of sub-division under consideration for the collision probability method. The rule of numbering of S-Regions is fixed by geometry model. S-Region is defined for convenience and does not have direct relation with the accuracy of flux calculation.

1.8.2 T-Region

In the fixed source mode, the fast energy range and the thermal energy range are separately solved. Thermal neutron fluxes have steeper gradient than fast neutron fluxes. Therefore, the flux calculation in the thermal energy range requires finer spatial mesh division than in the fast energy range. A unit of spatial division used in thermal flux calculation is called as a T-Region. A T-Region is composed by one or more S-Region(s) taking into account of geometrical symmetry. Some adjacent S-Regions with thin optical thickness can make a T-Region. In the S_N or diffusion codes, the finest spatial mesh is treated as a T-Region.

1.8.3 R-Region

Since the neutron distribution in the fission or resonance energy range is rather flat than in the thermal range, it is not always necessary to sub-divide the geometry into so many meshes as in the

thermal energy range. In the fixed source mode, a unit of spatial division used in fast and resonance flux calculation is called as an R-Region. The user forms an R-Region by collecting several T-Regions estimating the flatness of flux distribution. When the eigenvalue mode is chosen, R-Region is the spatial division in the whole energy range. A material is allocated to each R-Region.

1.8.4 X-Region

A core calculation requires homogenized cross-sections in a lattice cell. Therefore, one or more cell calculations on heterogeneous cell(s) are necessary beforehand the core calculation. Usually the homogenized cross-sections are obtained by the flux-volume weight of cross-sections of constituent materials. An X-region is the range of spatial integration. It is formed by gathering some of the R-regions. The homogenized cross-sections and fluxes used are stored in PDS files.

For usual cases, one X-Region corresponds to whole unit cell of which homogenized cross-sections are provided to the core calculation. An example to use plural X-Regions is the case to calculate the cross-sections of a control rod. As output of a heterogeneous cell calculation of the system including fuel and control rod, one can obtain the cross-sections of the control rod region and those of the neighboring fuel region by allocating these two regions to two separate X-Regions. Another kind of specification is that some of the R-Regions may be excluded from any of the X-regions when they are added as extra regions to an isolated cell to simulate the surrounding boundary condition by allocating zero value to these R-Regions.

1.8.5 M-Region

M-Region is used for allocation of materials. An M-Region is formed by one or more R-Regions which have the same composition. On the calculation of the background cross-section σ_0 based on the NR or IR approximation, the collision probabilities are calculated to the M-Region. Effective microscopic cross-sections are transferred to the burn-up routine by M-Region.

1.9 Cell Burn-up Calculation

In the cell burn-up calculation, burn-up changes of atomic number densities of nuclides in the burn-up chain model is obtained by solving the depletion equation with the reaction rates for fission, capture and (n,2n) reactions. Details on data and method are written in Sect.3.3 and Sect.7.7. SRAC provides several burn-up chain modes, and user can choose the most appropriate model by considering reactor type and his purpose.

The following optional treatments are available in the cell burn-up calculation:

- Option to consider cooling time during burn-up (e.g. analysis of post irradiation examination)
- Option to calculate instantaneous or integrated conversion ratio by user definition
- Burn-up calculation with constant flux level (e.g. burn-up of blanket fuel)
- Branch-off calculation (e.g. Doppler or void reactivity in each burn-up step)
- Burn-up calculation to start by reading the initial composition from a burn-up calculation result in different condition.
- Burn-up calculation with fixed number densities for specified nuclides (e.g. zero Xe in branch-off calculation, or on-line decontamination)
- Restart option to recover a burn-up calculation terminated for any reasons. It is available as far as the MACRO file is preserved.

As well as the atomic number densities along burn-up, the following items are edited for each M-Region and X-Region on the text file allocated to the 98-th logical device.

DAYS	Accumulated burn-up period in days
MWD/T	Exposure (MWt*days per metric-ton of initial heavy metal inventory)
U05-%	Fraction of depleted U-235 (changeable by user) atomic number density to the fresh one (0-100%)
K-EFF	Effective neutron multiplication factor
K-INF	Infinite neutron multiplication factor
INST. C.R.	Instantaneous conversion ratio defined by user
INTE. C.R.	Integrated conversion ratio defined by user
MWD	Exposure (MWt*days)
POWER (MW)	Thermal power over the cell
TON-HM	Heavy metal inventory in metric-ton ($=10^3$kg)
FLUX LEVEL	Absolute one-group flux level (n/cm^2-sec)
FIS. ABSOR.	Macroscopic absorption rate of fissile nuclides defined by user (sec^{-1})
FIS. DECAY	Decay rate of fissile nuclides defined by user (sec^{-1})
FER. CAPT.	Macroscopic capture rate of fertile nuclides defined by user (sec^{-1})
POW (MW/CC)	Power density (MW/cm^3)
ENERGY/FIS.	Average energy release per fission (Joule/fission) weighted by nuclide-wise fission rate
XE-135 YD.	Average fission yield of X-135 weighted by nuclide-wise fission rate
I-135 YD.	Average fission yield of I-135 weighted by nuclide-wise fission rate
SM-149 YD.	Average fission yield of Sm-149 weighted by nuclide-wise fission rate
PM-149 YD.	Average fission yield of Pm-149 weighted by nuclide-wise fission rate

The above data are stored in MACRO file together with few-group macroscopic cross-sections to be used in the COREBN code[8].

1.10 Calculation Scheme

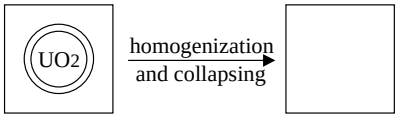
In Fig.1.10-1, a flow diagram of the SRAC code is shown. The number in the brackets '[ ]' in this figure denotes the step number printed on the standard output. The diamond-shaped mark denotes a branching point of the calculation by user options. In this flow, a set of flux calculation named by 4 characters (case name) is repeated until a blank case name is entered. The user can compose his own calculation scheme by combining several cases required for his purpose. The cases can be repeated as far as the computation cost allows. Here, we shall follow the following assuming a typical example.

---------- Specification of the example ----------

First case : UO2F

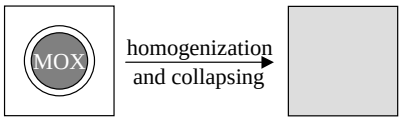
Cell calculation for a pin rod lattice of UO_2 fuel,

- with the JENDL-3.3 library,
- in fine-energy-group structure (e.g. 90 groups),
- in fixed source mode,
- by PIJ with PEACO



Second case : MOXF

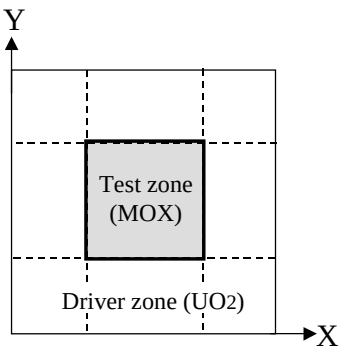
Cell calculation for a pin rod lattice of MOX fuel by the method same as the previous case.



Third case : CORE

Core calculation for a critical assembly where a central test zone of the MOX fuel is surrounded by a driver zone of the UO_2 fuel.

- with the homogenized cross-sections provided by the first and second cases,
- in few-energy-group structure (e.g. 4 groups),
- in eigenvalue mode,
- by CITATION with two-dimensional X-Y model.



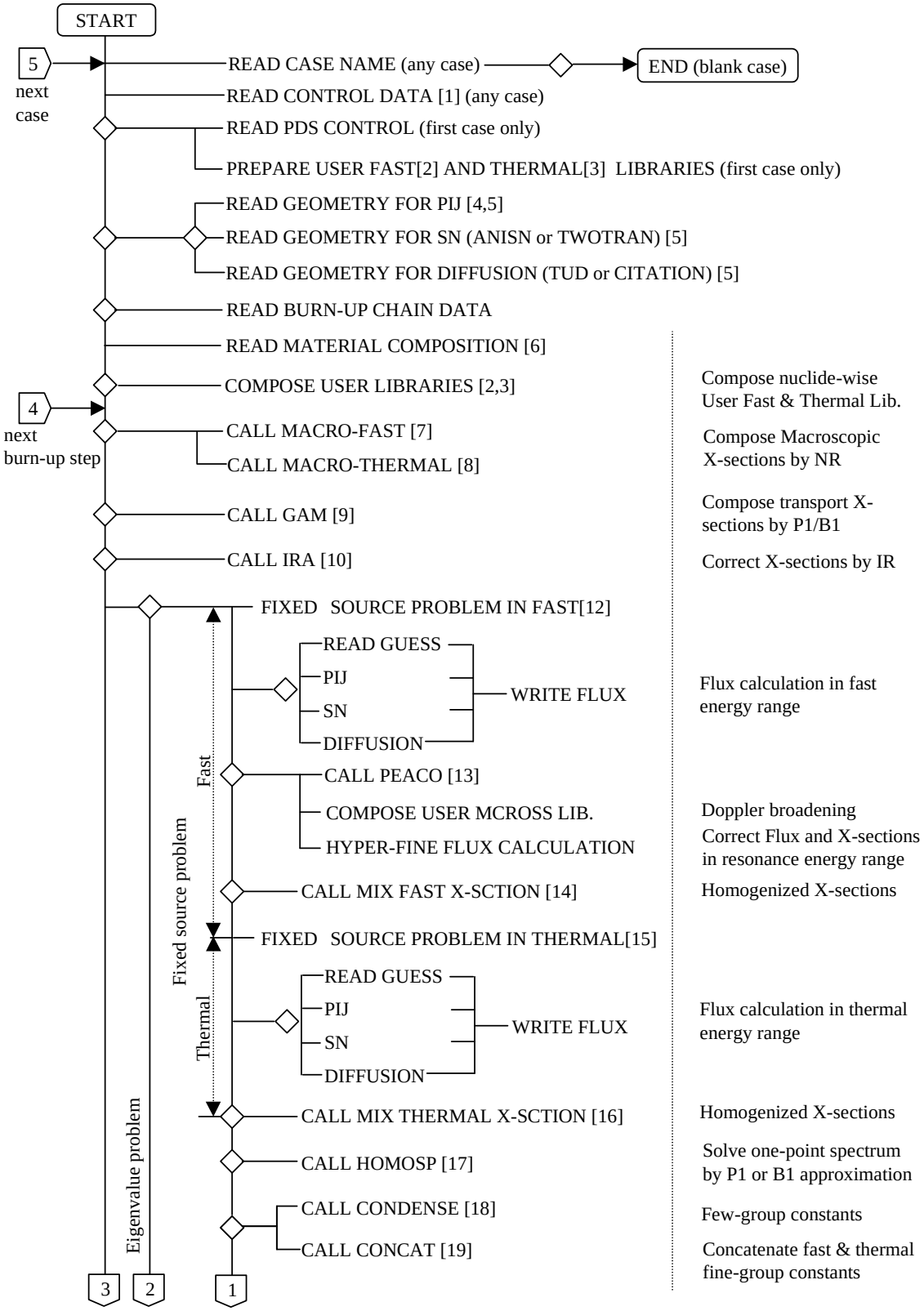


Fig.1.10-1 (1/2) Flow daigram of the SRAC code

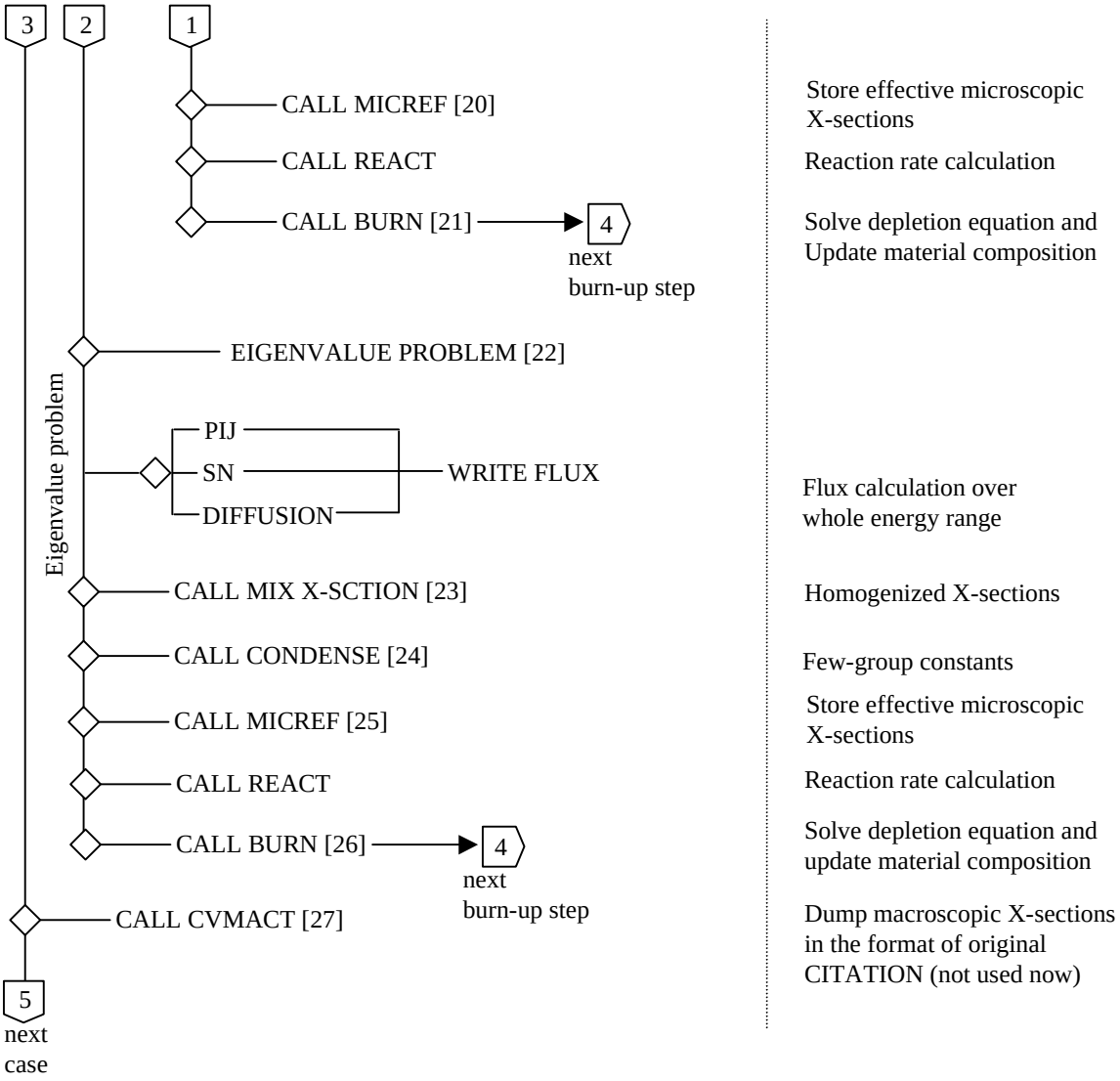


Fig.1.10-1 (2/2)　Flow daigram of the SRAC code

[Flow of the SRAC calculation for the sample problem]

UO2F ----------

READ CASE NAME

Read case name from the standard input in ‘A4’ format.

Some members to be stored in PDS files are named for this case name.

READ OPTION CONTROL

Read input data to control calculation flow. (cf. Sect.2.2 from Block-1 to -4)

READ FILE CONTROL

Read input data on PDS files and energy group structure.(cf. Sect.2.2, from Block-5 to -10)

PREPARE USER FAST AND THERMAL LIBRARY

Almost no action in this sample. (cf. Sect.2.3)

READ GEOMETRY FOR PIJ

Read input data for PIJ. (cf. Sect.2.4)

READ MATERIAL COMPOSITION

Read material specifications such as isotope composition and temperature. (cf. Sect.2.9)

COMPOSE USER LIBRARY

Compose the User Fast and Thermal Libraries by extracting and compiling the cross-section data of required nuclides from the Public Fast and Thermal Libraries. The 90-group cross-sections in the User Libraries are produced by collapsing 107-group ones in the Public Libraries with an asymptotic neutron spectrum (χ + 1/E + Maxwellian).

CALL MACRO-FAST

Compose effective microscopic and macroscopic cross-sections of each material in the fast energy range by the NR approximation, and store them in the MICREF and MACROWRK file, respectively.

CALL MACRO-THERMAL

Compose effective microscopic and macroscopic cross-sections of each material in the thermal energy range by the NR approximation, and store them in the MICREF and MACROWRK file, respectively.

CALL GAM

Form the macroscopic transport corrected cross-sections of each material. By choice of the option (IC16 in Sect.2.2), the P_1 or B_1 equation with an appropriate input buckling is solved for the cell homogenized by simple smearing of atomic number densities. Then, using the

homogenized P_1 spectrum obtained and assuming the flat flux, the transport correction is done for each material, and the MACROWRK file is updated.

FIXED SOURCE PROBLEM IN FAST

Enter into the process of the fixed source mode in the fast energy range

PIJ

Calculate collision probability in the fast energy range, then calculate fast neutron flux distribution on R-Region. The obtained flux is stored in the FLUX file.

CALL PEACO

Enter into the PEACO process

COMPOSE USER MCROSS LIB.

Compose the User MCROSS Library for the required nuclides and temperatures from the Public MCROSS Library.

HYPER-FINE FLUX CALCULATION

Calculate hyper-fine neutron spectra in the multi-region cell composed by R-Regions in the resonance energy range. Then, modify the effective absorption and fission cross-sections in MICREF and MACROWRK and the fine-group flux distribution in FLUX.

CALL MIX FAST X-SECTION

Homogenize the macroscopic cross-sections by X-Region

FIXED SOURCE PROBLEM IN THERMAL

Enter into the process of the fixed source mode in the thermal energy range

PIJ

Calculate collision probability in the thermal energy range, then calculate thermal neutron flux distribution on T-Region. The volume-averaged flux in each R-Region is stored in the FLUX file.

CALL MIX THERMAL X-SECTION

Homogenize the macroscopic cross-sections by X-Region

CALL HOMOSP

Solve a one-point (bare) reactor equation in whole energy range by P_1 or B_1 approximation with the input buckling to consider leakage effect. The k-infinity and k-effective together with the homogenized spectrum are obtained. The spectrum is stored in the FLUX file.

CALL CONDENSE

Condense the fine-group macroscopic cross-sections into few-group ones using the spectrum obtained by the above cell calculation. The few-group cross-sections are stored in the MACRO file.

Note: For the isolated material which does not appear in the cell, an asymptotic spectrum is used to condense the fine-group cross-sections. This treatment is used to make few-group cross-sections which is not so important for the core calculation. (e.g. radial water reflector). Otherwise, an appropriate cell or core calculation including the material have to be done to prepare a fine-group spectrum.

CALL MICREF

Print material-wise power distribution and conversion ratio

Note: The primary function of MICREF is to write the effective microscopic cross-sections in a scratch file for the succeeding reaction rate or burn-up calculation options.

MOXF ----------

READ CASE NAME

Read case name from the standard input in ‘A4’ format.

READ OPTION CONTROL

Read input data to control calculation flow.

READ GEOMETRY FOR PIJ

Read input data for PIJ.

:

the same as above case

:

CORE ----------

READ CASE NAME

Read case name from the standard input in ’A4’ format.

READ OPTION CONTROL

Read input data to control calculation flow.

READ GEOMETRY FOR DIFFUSION

Read input data for CITATION. (cf. Sect.2.8)

READ MATERIAL COMPOSITION

Read material specifications.

COMPOSE USER LIBRARY

Compose the User Fast and Thermal Libraries

Note: No action in this sample because of no new nuclides in the material specifications.

CALL MACRO-FAST

Compose effective microscopic and macroscopic cross-sections

Note: No action in this sample, because of no new nuclides in the material specifications.

Consequently next step 'CALL MACRO-THERMAL' is skipped.

CALL GAM

Form the macroscopic transport corrected cross-sections

Note : No action in this sample because of no new nuclides in the material specifications.

EIGENVALUE PROBLEM

Enter into the process of the eigenvalue mode

DIFFUSION(CITATION)

Compute k-effective and flux distribution by the whole energy calculation.

In this sample, CITATION is executed with few-group macroscopic cross-sections in the MACRO file by the choice of IC12=5 and IC10=1 (cf. Sect.2.2).

Note: As well as an eigenvalue calculation, an extra-source problem of CITATION (or other codes) is treated in this step.

READ CASE NAME

Read case name from the standard input in 'A4' format.

Terminate job by the specification of a blank case name.

Figure 1.10-2 shows the input data corresponding to the above sample problem, although details are omitted to emphasize the input data structure. As mentioned above, the first case (case name UO2F) requires to calculate the fine-group spectrum of the UO_2 cell by using PIJ and to obtain the homogenized and collapsed few-group cross-sections. The second case (MOXF) requires the same process as the first case for the MOX cell. The third case (case name CORE) requires a two-dimensional full core calculation by CITATION by using the few-group cross-sections provided by the first and second cases to yield the effective multiplication factor and the flux (or power) distribution. The cases can be repeated as far as the computation cost allows.

In this problem, the homogenized collapsed cross-sections are written in the few-group macroscopic cross-section file (MACRO) by the member names UO2FA010 and MOXFA010. The member name consists of the first four characters for the case name, the energy range by the fifth character, the burn-up step number by the sixth character, the homogenized region number by the seventh character and the group structure whether fine-group or few-group by the eighth character. The material specifications for the third case can be specified by only the names of members produced in the first and second cases. The PDS files take a role of an interface among the codes in the SRAC system.

```
UO2F  ← Case name for UO2 cell calculation
Macro-XS for UO2 CELL BY PIJ  ← Comment for this case
1 1 1 1 2   1 4 3 -2 1   0 0 0 0 2   0 1 0 0 0  ← Option control
1.0E-3 / BUCKLING FOR P1/B1
/home/okumura/SRACLIB-JDL33/pds/pfast      Old       File
/home/okumura/SRACLIB-JDL33/pds/pthml      O         F
/home/okumura/SRACLIB-JDL33/pds/pmcrs      O         F
/home/okumura/MyPDS/UFAST                  Scratch   Core
/home/okumura/MyPDS/UTHERMAL               S         C
/home/okumura/MyPDS/UMCROSS                S         C
/home/okumura/MyPDS/MACROWRK               S         C
/home/okumura/MyPDS/MACRO                  New       C
/home/okumura/MyPDS/FLUX                   New       C
/home/okumura/MyPDS/MICREF                 S         C
                                                          } PDS file control (first case only)
60 30   3 1 / Fast(60g)+Thermal(30g) => Fast(3G)+Thermal(1G)
          :
          :     { Energy Group Structure }
          :
          :     { Geometry for PIJ }
          :
3 / Number of Materials
FUE1X01X  0 3  300.  0.84  0.0  / 1 : UO2 FUEL
XU050001  2 0  6.086E-4
XU080001  2 0  2.255E-2
XO060001  0 0  4.725E-2
CLADX02X  0 1  300.  0.11  0.0  / 2 : CLADDING
XZRN0001  0 0  4.311E-2
MODEX031  0 2  300.  0.00  0.0  / 3 : MODERATOR
XH01H001  0 0  6.676E-2
XO060001  0 0  3.338E-2
                                                          } material specification
          :
          :
MOXF  ← Case name for MOX cell calculation
Macro-XS for MOX CELL BY PIJ  ← Comment for this case
1 1 1 1 2   1 4 3 -2 1   0 0 0 0 2   0 1 0 0 0  ← Option control
1.0E-3 / BUCKLING FOR P1/B1
          :
          :     { Geometry for PIJ }
          :
          :     { material specification for MOX fuel }
          :
CORE  ← Case name for Core calculation
2-dimensional Core calculation by CITATION (4-group)  ← Comment for this case
0 0 0 1 0   0 0 0 0 1   0 5 0 0 2   0 1 0 0 0  ← Option control
1.0E-20 / dummy BUCKLING (not effective)
          :
          :
          :     { Control and Geometry data for CITATION }
          :
005
  1  1  1
  1  2  1   ← Zone map
  1  1  1
          :
999

1 2  /  Material No. by Zone
2    / Number of Materials
UO2FA010 0  0  0.  0.  /  ← Homogenized X-section provided by the first case
MOXFA010 0  0  0.  0.  /  ← Homogenized X-section provided by the second case
     / End job  ← Blank case name to terminate job
                                                          } Input for CITATION
```

Fig.1.10-2 Sample input data structure of the SRAC code

1.11 Output Information

Major calculated results of the SRAC code are edited on a text-formatted file allocated to the 99th logical device. On the standard output file of the 6th device, information is written to check whether a series of calculations has completed appropriately or not, for instance, echo of user's input, status of calculation progress, record of PDS file access, warning or error message. When the calculation finished normally, the following message will be appeared at the last of the above two files.

```
'============================== END OF SRAC CALCULATION ======================='
```

Otherwise, a user has to check the standard output carefully.

For PIJ or PEACO, plotting options are available to confirm cell geometry under consideration or to draw hyper-fine neutron spectra obtained by PEACO. The plot data is written as a text-formatted Postscript file allocated to the 89th device. The user can see the figures of a Postscript file on a screen or printed matter, by using a free software on the market. On the UNIX operating system, a command 'lpr' is usually available to print out the figures.

In the case of the burn-up calculation, editing of the calculated results in each burn-up step is repeated up to the final burn-up step on the 99th file. Its contents may be enormous to extract necessary data. Therefore, major burn-up parameters are summarized and tabulated to the burn-up step on the 98th text-formatted file.

The binary data of fluxes and effective microscopic or macroscopic cross-sections are written in their own PDS files (cf. Sect.3.1). Although some of them can be printed on the 99th file by options, their printed format may not be convenient for plotting them or editing reaction rates defined by each user. In order to support editing or managing contents of PDS files, the SRAC system is equipped with several utility programs as described in Chapter 6.

2. Input Data Requirements

The input data requirements of the SRAC code consist of the following eleven input sections for a calculation case (cf. Sect. 1.10) in a job.

- General control and specification of group structure (always required)
- Specification of User library (always required)
- PIJ: Collision probability calculation
- ANISN: one-dimensional SN transport calculation
- TWOTRAN: two-dimensional SN transport calculation
- TUD: one-dimensional diffusion calculation
- CITATION: multi-dimensional diffusion calculation
- Material specification (always required)
- Reaction rate calculation
- Cell burn-up calculation
- PEACO: hyperfine resonance calculation

First elementary codes and functions to be used in a case are specified. After that, detailed input data for each code or function are specified if necessary. For a job with multiple-cases, a set of the above input sections are repeated necessary times.

2.1 SRAC Free Format

All input data for the SRAC system except for CITATION are read in a free format peculiar to SRAC. The features and usage are as follows.

(1) Three types of data array (character string of four bytes, integer, and floating point number of single precision) can be read.

e.g. TEST 1 2 1.00 2.00 3.00

(2) Columns 1 to 72 of a line record is used as data field. Data out of the field is neglected.

(3) A word (integer or floating number) is separated by a blank, a comma, or sign codes ‘+’ or ‘-‘ from the next word.

e.g. 1,2 3+4-5 is accepted as 1 2 3 4 -5

(4) A floating number may be entered by *F*-type or *E*-type; the latter needs the exponent code ‘E’ or ‘e’ at the beginning of exponent. *D*-type is not accepted.

e.g. -12.543 00.00125 1.0E-4 -.4E12 2.9e-2

(5) A word must be completed in a line record.

A wrong example: -12.543 0.00125 1.0E
-4 -.4E12

(6) Any blank column should not be inserted between sign code and digit code.

A wrong example: 1 2 - 3 4 - 5

(7) For *E*-type, any blank column should not be inserted between the exponent code ‘E’ or ‘e’ and the succeeding character.

A wrong example: 1.000E -5

(8) For character type, the style for the free format is not applied. Column position of character type variables is, in general, organized to start at the first column of a line record.

A wrong example: ABCD EFGH 4(IJKL)

(9) Repetition function is available. An integer before the code ‘(‘ is taken as the repetition number of a data or a series of data which are enclosed by ‘( )’.

e.g. 1 3(2) 2 (1.E-4) is accepted as 1 2 2 2 1.0E-04 1.0E-04

The data string enclosed by ‘( )’ can be written on more than one records. The closing ‘) ‘ may not be written on the first column.

e.g. 10 (1 2 3 4 5 4 3 2 1
5 4 3 2 1 2 3 4 5)

A wrong example: 2 (1 2 3 4
) 5 6 7 8

The duplicate use of ‘( )’ like 2(1 2(3 4)) is not allowed.

(10) Accumulation function is also available. An integer before ‘ * ‘ is taken as the number of times of accumulation, and the data value after ’ * ‘ is taken as increment to be added to the previous data. That is to say, ‘a b*c’ means ‘a a+c a+2c a+3c ..... a+bc’.

e.g. 0.0 4*1.0 2*-2.0 is accepted as 0.0 1.0 2.0 3.0 4.0 2.0 0.0

The coupling of ‘ ( )’ and ‘ * ‘ is not allowed.

A wrong example: 10(0 5*1)

(11) A series of strings for repetition or accumulation function must close within each type of array.

A wrong example: 10(1 1.0E-4)

(12) The character ' / ' is taken as the termination code of required data. The ' / ' is not necessarily required. If the termination code character is encountered, a check whether or not the array length

meets with one required by the program. However the character ‘ / ‘ on the new record after entering required data on the previous record causes error because the read-in is finished on the previous record without the termination code, then the code ‘ / ‘ is read at the beginning of the next call. The columns after ‘ / ‘ can be used as comment.

e.g. 5(0) 5(1) / Input data for Block-1

(13) The character ‘&’ is taken as the end-of-record code character. The columns after the ‘&’ can be used for comment. If the entries are not yet finished at this code, the remaining data follow on the next record.

An example when ten integers are required:

```
1  2  3  4  5  &  Input for Block-1(1-5)
& Comment 1
& Comment 2
6  7  8  9  10  /  End of Block-1
```

Although data type (character, integer or floating) of variable or array in the following description is not always mentioned, the user can recognize character type data by finding Hollerith count before the variable name as ‘/A8/’. Concerning to numerical data, the user can discriminate integer type or floating type by the first character of the variable name whether it is one of characters from I to N or not.

The term Block appearing in the descriptions denotes one or a series of data required by one FORTRAN read statement which may be entered on any number of lines. The use of the termination code ’ / ‘ is recommended to have suitable message if the data length is mismatched. The number of data required in a Block is shown as /20/ or /NRR/. If mixed types of data are required in a Block, they are read in the order of character, integer, then floating type, and the data requirement is expressed by /A8,3,2/ for 8 characters, 3 integers and 2 floating numbers, respectively.

2.2 General Control and Energy Structure Specification

Block-1 /A4/

CASENAME Case identification (*case*-tag)

It is used as the former half names of the members in the PDS files which store the macroscopic cross-sections (MACRO or MACROWRK) and fluxes (FLUX) homogenized in the X-Region.

As plural cases can be run in one job, enter a blank line after the last case to terminate the job.

[cf.] Sect.1.10, Sect.3.1

Block-2 Case description /A72/

TITLE Comments for the problem

Block-3 Integers to specify the options to control calculation flow /20/

IC1 Indicator to use the collision probability method routine (CPM) in any usage.

= 0 Skip

= 1 Use CPM

Note:

Enter IC1=1, if Dancoff correction factor is calculated automatically by CPM (IC3=1,2), or if PIJ is used for flux calculation (IC2=1, or IC12=±1), or if the PEACO routine is used (IC5=±2)

IC2 Selection of the routine for the fixed source mode (cf. Sect.1.7)

The problem is solved first in fast energy range where a uniform thermal flux distribution is assumed for providing the fast neutron source, then in thermal range.

= 0 None of routines is used. (Specify the routine for the eigenvalue mode by IC12.)

= 1 PIJ (CPM)

= 2 ANISN (one-dimensional S_N transport)

= 3 TWOTRAN (two-dimensional S_N transport)

= 4 TUD (one-dimensional diffusion)

= 5 CITATION (multi-dimensional diffusion)

Note:

Either IC2 or IC12 must be non-zero value. Enter IC2=0 and select the routine

by IC12, if the eigenvalue problem or the external neutron source problem in the whole energy range is solved. (e.g. shell source or distributed source in ANISN, inhomogeneous source or boundary source in TWOTRAN, point source in CITATION)

Enter IC2=1 if the PEACO routine is used by IC5=2 or =-2 for the resonance absorption process.

[cf.] Sect.1.7, Sect.1.10

IC3 Selection of the process to get the Dancoff correction factor

The Dancoff correction factor is used in the two steps; first for the heterogeneous effect on the admixture cross-sections in the interpolation of resonance shielding factors upon NR approximation, second for the IR approximation of absorption calculations of resolved resonance levels.

= 0 Use the input value specified in the material specification (cf. Sect.2.9)

= 1 Calculate by CPM

= 2 Calculate by the Tone's method[12)]

Note:

The Tone's method is recommended for a plate type cell with neighboring different fuels, but it is not recommended for a pin type cell.

When the double heterogeneity is solved by the PEACO routine by specifying a negative value of MAR (Block-6 in Sect. 2.4), the Dancoff correction factor of the microscopic heterogeneity in the material specification is used in spite of any IC3 value while that of the macroscopic heterogeneity is controlled by the IC3 value.

[cf.] Sect.1.6, Sect.2.4

IC4 Indicator for the energy range solved

= 0 Thermal range is excluded (for fast neutron reactors)

= 1 Thermal range is included (for thermal neutron reactors)

IC5 Selection of the process for resonance absorption in the resonance energy range

= 0 Interpolation of Bondarenko type table by NR approximation(NRA).

= 1 Interpolation of Bondarenko type table by IR approximation (IRA).
The IRA routine works for only one resonant R-Region (which contains at least one nuclide(s) with IRES=2 in the material specification) in a

cell.

= 2 The PEACO routine (hyperfine group calculation by the CPM)
The PEACO routine runs only on the fixed source mode by PIJ (IC2=1).
The number of resonant materials (which contains at least one nuclide(s) with the MCROSS library data) is limited one or two.

= -2 The PEACO routine to treat more than two resonant materials by an approximation to assume two pseudo resonant materials.
Additional input (in Sect.2.12) is required to assign the materials to which resonant material belongs.

Note:

The PEACO routine generally does not work for more than two resonant mixtures in a cell because the two-dimensional interpolation of collision probabilities is done for completely different resonant materials. When a depletion problem is solved for a multi-region cell, several compositions which have been uniform at the clean stage have to be considered in a cell. The similarity of cross-sections can permit the above-mentioned approximation.

[cf.] Sect.1.5, Sect.1.6, Sect.2.12

IC6 Indicator to get the flux-volume averaged cross-sections in the fixed source mode (IC2>0). Enter 0 in the eigenvalue mode.

= 0 Skip the averaging process

= 1 Call the averaging process specified by IC7 following

IC7 Selection of the process to get the spatial distribution of flux in each energy range.

= 0 for the eigenvalue problem mode (IC2=0, IC12 $\neq$ 0)

= 4 for the fixed source problem mode (IC2>0, IC12=0)

Note:

This option was originally prepared for computer time saving by skipping (if IC7=1~3) the calculation of spatially flat and nearly asymptotic neutron spectrum foreseen by the user in the fixed source problem. Enter IC7=4 in the fixed source problem. Otherwise enter IC7=0, because the other selections (IC7=1~3) are obsolete and not recommended.

IC8 Selection of the energy range and mesh of the hyperfine group structure of the

user's MCROSS library, required if the PEACO routine is used by IC5=±2. The selection IC8=3 is usually recommended.

= 0 between 130.07 eV and the thermal-cut-off energy with lethargy interval of Δu=0.00125

= 1 between 130.07 eV and the thermal-cut-off energy with lethargy interval of Δu=0.00125 and between 961.12 eV and 130.07 eV with lethargy interval of Δu=0.000625

= 2 between 961.12 eV and the thermal-cut-off energy with uniform lethargy interval of Δu=0.0005

= 3 between 130.07 eV and the thermal-cut-off energy with lethargy interval of Δu=0.0005 and between 961.12 eV and 130.07 eV with lethargy interval of Δu=0.00025

[cf.] Sect.1.3, Sect.1.6, Sect.1.10

IC9 Indicator to call the HOMOSP routine to calculate the one point (bare) reactor neutron spectrum and k_∞, k_{eff} in the fixed source problem (IC2>0). Enter IC9=0 in the eigenvalue problem mode.

= 0 Skip

= ±1 P_1 approximation

= ±2 B_1 approximation

= ±11 Critical buckling search by P_1 approximation

= ±12 Critical buckling search by B_1 approximation

Note:

If negative value is entered, P_0 components of the solution of P_1 or B_1 equations are used as the weight to collapse the homogenized cross-sections, i.e. the leakage effect is reflected on the spectrum by the geometrical buckling value. If positive value is entered, the spectrum obtained by the cell calculation is used for collapsing.

The CPM is carried out upon infinite cell approximation. The geometrical buckling is used to reflect the leakage effect on the spectrum by use of the HOMOSP routine.

If IC9=±1 or =±2 is entered, the geometrical buckling given in Block-4 is used in P_1/B_1 equations. If IC9=±11 or =±12 is entered, the geometrical buckling is obtained so that the k_{eff} is unity. The use of the critical buckling search option

should be avoided for the core where the large excess reactivity is mainly suppressed by using control absorber.

[cf.] Sect.1.7, Sect.1.10

IC10 Indicator to call CONDENSE routine to collapse the energy structure of the macroscopic cross-sections in the MACROWRK file to put into the MACRO file before the eigenvalue mode calculation specified by IC12.

= 0 Skip the collapsing

= 1 Collapse before the eigenvalue mode calculation (if any)

Note:

If the user wants to execute the fixed source mode by the routine specified by IC2 on the fine-group and then the eigenvalue problem by the routine specified by IC12 on the collapsed group structure, enter IC10=1, IC13=0 for the first case, and enter also IC10=1, IC13=0 for the second case.

If the user wants to execute a cell calculation by the fixed source mode on the fine-group structure to provide the fine-group homogenized cross-sections, and then to execute a super-cell calculation on the fine-group structure to provide the collapsed group cross-sections for the succeeding core calculation, enter IC10=0, IC13=1 in the first case, and IC10=1, IC13=0 for the second case.

Thus, if the collapsing is required in a job, any of IC10 or IC13 must be 1 at the first case. The entries IC10=1 and IC13=1 in a case are not accepted.

IC11 Indicator whether to enter or not the geometrical information required in Sect. 2.4 through 2.7 for this case.

= 0 Read the new geometry.

= 1 Skip reading and use the same as the previous case. Ineffective for CITATION.

IC12 Selection of the routine for the eigenvalue mode (whole energy range calculation).

= 0 None of routines is used. (Specify the routine for the separate energy calculation by IC2.)

= ± 1 PIJ (CPM)

= ± 2 ANISN (one-dimensional S_N)

= 3 TWOTRAN (two-dimensional S_N)

= 4 TUD (one-dimensional diffusion)

= 5 CITATION (multi-dimensional diffusion)

Note:

If IC12=-1 is entered, the incident current at the outer boundary is read from the FLUX file by the member *case*A*b*S*p* (cf. Sect.3.1.7) so that a fixed boundary source problem in the whole energy group will be solved.

If IC12=-2 is entered, the collapsing of P_1 components is carried out for the succeeding few-group transport calculation. (See IC16)

[cf.] Sect.1.7, Sect.1.10

IC13 Indicator whether or not to call CONDENSE to collapse the energy group structure of the macroscopic cross-sections in the MAROWRK file to put into the MACRO file after the eigenvalue mode calculation specified by IC12.

= 0 Skip the collapsing

= 1 Collapse after the eigenvalue mode calculation (if any)

Note:

For example, to execute an eigenvalue calculation by using the cross-sections of the fine-group structure stored in the MACROWRK file and to obtain the few-group cross-sections by using the flux solved by the above calculation, enter IC10=0, IC13=1.

[cf.] Sect.1.7, Sect.1.10, IC10 in this Section

IC14 = 0 (not used)

IC15 Selection of the process to compose (or define) the microscopic total cross-sections in the resonance energy range. (out of energy range of PEACO, if IC5=2 or -2)

= 1 Form the cross-sections by using the self-shielding factor of the total cross-sections. The in-group scattering cross-sections are adjusted to hold the neutron balance.

$$\sigma_{t,g} = \sigma^{\infty}_{t,g} f_{t,g}$$

= 2 Form the cross-sections by summation of all partial reactions

$$\sigma_{t,g} = \sum_{x} \sigma^{\infty}_{x,g} f_{x,g}$$

Note:

Usually IC15=1 is used in FBR analysis, while any selection does not make difference in thermal reactor analysis.

IC16 Indicator how to form the macroscopic transport (collision) cross-sections of each mixture which are required in the isotropic transport routine.

= 0 The extended transport approximation[23)]

$$\Sigma_{tr,g} = \Sigma_{0,g} - \sum_{g'} \Sigma_{1,g'\to g}$$

However, in the resonance shielding calculation $\Sigma_{tr,g}=\Sigma_{0,g}$ is always assumed.

= 1 Use the components (J) obtained by the P_1 approximation[24)]

$$\Sigma_{tr,g} = \Sigma_{0,g} - \sum_{g'} \Sigma_{1,g'\to g} J_{g'} / J_g$$

= 2 Use the current component (J) obtained by the B_1 approximation[24)]

$$\Sigma_{tr,g} = \Sigma_{0,g} - \sum_{g'} \Sigma_{1,g'\to g} J_{g'} / J_g$$

= 3 Use the current component (P_1 flux) obtained by the ANISN calculation

$$\Sigma_{tr,g} = \Sigma_{0,g} - \sum_{g'} \Sigma_{1,g'\to g} J_{g'} / J_g$$

An ANISN calculation in the fine-group structure is required in the previous case with IC12=-2 so that the corresponding members have to be stored in the FLUX file.

Note:

For the fixed source mode (IC2>0), a fixed source problem by one-point fine-group equations with P_1 or B_1 approximation selected is solved for an imaginary media made by the homogenized cross-sections averaged in the whole system where a flat flux approximation and the fission spectrum of U-235 are assumed.

For the eigenvalue mode (IC2=0 and IC12>0), a fixed source problem is solved to obtain the current components at each constituent material. In the above equations, the geometrical buckling given in Block-4 is used in the leakage term, and the source is assumed to be same as the fission neutron spectrum of U-235.

When the P_1 or B_1 option is used for a material which is a strong absorber such as a control rod material or a highly enriched plutonium, or an optically transparent

material such as an aluminum metal, the iterative process to obtain the spectrum may fail to converge.
[cf.] Sect.1.10

IC17 Indicator how to compose and to collapse the averaged diffusion coefficients

The absolute value of this item defines the way of spatial average of the diffusion coefficients in the fine-energy group stage, and the sign of IC17 defines how to collapse the diffusion coefficients and the total (transport) cross-sections into the few group constants.

If IC17>0

$$D_G = \sum_{g\in G} D_g \varphi_g \,/\, \sum_{g\in G} \varphi_g \quad , \quad \frac{1}{\Sigma_{t,G}} = \sum_{g\in G} \frac{1}{\Sigma_{t,g}} \varphi_g \,/\, \sum_{g\in G} \varphi_g$$

If IC17<0

$$\Sigma_{t,G} = \sum_{g\in G} \Sigma_{t,g} \varphi_g \,/\, \sum_{g\in G} \varphi_g \quad , \quad D_G = \sum_{g\in G} D_g \varphi_g \,/\, \sum_{g\in G} \varphi_g$$

It is recommended that for the succeeding diffusion calculation, enter positive value, and for the succeeding transport calculation enter negative value.

Note that only in case of IC17=±1, the few-group diffusion coefficients are made from the inverse of the few-group transport cross-sections as $D_G = 1/3\Sigma_{tr,G}$.

After obtaining the few-group total cross-sections, the self-scattering (in-group scattering) cross-sections are adjusted to keep the neutron balance.

Two kinds of diffusion coefficients D1 and D2 are stored in the MACRO and the MACROWRK files to allow a CITATION calculation with direction dependent diffusion coefficient.

= ±1 The fine group diffusion coefficients are made from the inverse of the fine group transport cross-sections.

$$D_g = 1/3\Sigma_{tr,g}$$

The calculated values are stored in the D1 position. (cf. Sect.3.1)

= ±2 The diffusion coefficients are formed by the isotropic components of

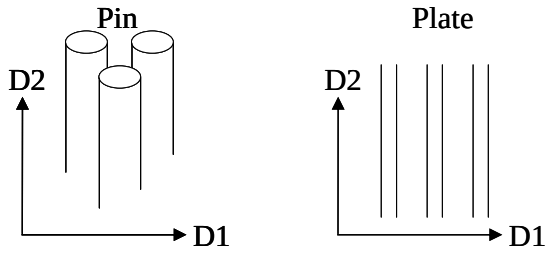
Behrens' term of the Benoist model[25] which are written into D1 positions in the MACROWRK file.

$$D_g = \left\{ \sum_i \varphi_{i,g} \sum_j P_{i->j,g} / \Sigma_{tr,j,g} \right\} / 3 \sum_i \varphi_{i,g}$$

= ±3 The anisotropic components of the Behrens' term of the Benoist model.

$$D_{k,g} = \left\{ \sum_i \varphi_{i,g} \sum_j P_{i->j,k,g} / \Sigma_{tr,j,g} \right\} / 3 \sum_i \varphi_{i,g}$$

The radial components in the cylindrical coordinate or the perpendicular components in the plate geometry are written into D1, and the axial components in the cylindrical or the parallel components in the plate are written into the D2 position.



Note:

Unless IC17=±3, the values stored in D2 position are made as if the options IC16=0 and IC17=1 are specified.

IC18 Indicator to call the reaction rate calculation.

= 0 Skip

= 1 Call reaction routine.

The input described in Sect.2.10 is required.

IC19 Print control in the routines for forming the macroscopic cross-sections (MACROF, MACROT, P1B1, HOMOSP, IRA, PEACO)

= 0 The most brief edit

> 0 The larger value prints the more fine information, (usually up to 2)

IC20 Indicator to call the cell burn-up calculation

= 0 Skip

= 1 Execute burn-up calculation

Note:

If the system contains a homogenized region which occurs in a super-cell calculation, the cell burn-up calculation is not available.

[cf.] Sect.1.9

Block-4 Geometrical buckling B^2 (cm^{-2}) /1/

BSQ Buckling value commonly used in the P_1 or B_1 approximation in one-point reactor calculation specified by IC9 (HOMOSP routine) and/or IC16 (GAM routine).

The negative value is accepted while zero value is rejected. Set a value about 1.0E-20 instead of 0.0, as an extremely small value less than 1.0E-20 may cause a numerical overflow.

Even if the buckling search is specified by IC9, the input value is used in the process specified by IC16.

<u>The succeeding input Block-5 through Block-10 are required only in the first case.</u>

Block-5 Data set specification for PDS files /A72/

One file is specified by PATHNAM, KPMODE, IOMODE on 72 columns. They are separated by one or more blank(s). This type input must be repeated 10 times : the total number of PDS files in the order of 1)PFAST, 2)PTHERMAL, 3)PMCROSS, 4)UFAST, 5)UTHERMAL, 6)UMCROSS, 7)MACROWRK, 8)MACRO, 9)FLUX and 10)MICREF files.

PATHNAM(*i*) path name to a PDS file

Specify the directory in which members are stored by the absolute path or by the relative path. Enter from the 1st column.

An example of an absolute path:

/home/okumura/SRACLIB-JDL33/pds/pfast

An example of a relative path:

../../SRACLIB-JDL33/pds/pfast

KPMODE(*i*) the preservation mode of a PDS file

Only the first character (capital letter) is effective.

=New New file, there is no practical difference with old file.

=Old Old file

=Scratch Scratch file, ineffective for the Public Libraries (read only files)

Note:

When ’New’ or ‘Old’ is specified, all the members produced are preserved after the job. If ’Scratch’ is specified, the members are deleted.

The preservation or deletion of the PDS directory is controlled by the description of shell-script. Even if ‘Scratch’ is specified here, an empty directory remains when the directory is not deleted by the shell-script. The ’New’ specification requires that the directory of the same name of PATHNAM should be prepared by shell-script beforehand.

IOMODE(*i*) Access mode to file

Only the first character (capital letter) is effective.

=File Direct I/O access to file

=Core I/O access on image PDS file on core memory

Note:

If ‘Core’ is specified, all the information on a PDS file is read into the core memory at the first access. After this, I/O is carried out from/into the core. A new member is also written on the actual file.

When the overflow of memory occurs on any PDS file, the Core specifications to all the PDS files are switched to File mode automatically. The core specification is effective for the job which takes much I/O time.

The IOMODE specifications to the Public Library files are compulsorily set to ‘File’ mode as they are used only to make User’s Library files and a large amount of data is stored.

When a series of burn-up calculation is executed, as a lot of members are written, a sufficient amount of memory has to be reserved. The memory capacity for PDS files is defined by a parameter statement in an include file.

An example of Block-5 input:

```
/home/okumura/SRACLIB-JDL33/pds/pfast      Old     File
/home/okumura/SRACLIB-JDL33/pds/pthml      O       F
```

```
/home/okumura/SRACLIB-JDL33/pds/pmcrs      O       F
/home/okumura/MyPDS/Test/UFAST             Scratch Core
/home/okumura/MyPDS/Test/UTHERMAL          S       C
/home/okumura/MyPDS/Test/UMCROSS           S       C
/home/okumura/MyPDS/Test/MACROWRK          S       C
/home/okumura/MyPDS/Test/MACRO             New     C
/home/okumura/MyPDS/Test/FLUX              New     C
/home/okumura/MyPDS/Test/MICREF            S       C
```

Block-6 Specification for energy group structures /4/

1 NEF Number of the fast neutron groups of the User Fast Library (NEF $\leq$ 74)

2 NET Number of the thermal neutron groups of the User Thermal Library;
(NET $\leq$ 48, and NEF+NET $\leq$ 107).
Enter 0, if IC4 = 0 (no thermal group calculation) in Block-3

3 NERF Number of the fast few-groups
If no collapsing is required (IC10=0 and IC13=0), enter NERF=0.

4 NERT Number of the thermal few-groups
If no collapsing is required (IC10=0 and IC13=0) or no thermal group calculation (IC4=0), enter NERT=0.

Block-7 Collapsing from PFAST into UFAST /NEF/

NEGF(i) Number of the public fast groups in each user fast group (i)
See the table of energy group structure in Sect. 8.3.

$\sum_{i=1}^{\mathrm{NEF}} \mathrm{NEGF}(i)$ =(Total number of public fast groups included between 10 MeV and the thermal-cut-off energy). By this item, the thermal-cut-off energy is decided.

As the thermal-cut-off energy has to be any of lower energy boundaries of Public energy group structure between 3.9278 eV and 0.41399 eV, set NEGFs so as to satisfy $59 \leq \sum_{i=1}^{\mathrm{NEF}} \mathrm{NEGF}(i) \leq 74$.

The recommended cut-off-energy in the SRAC code is about 2.0 eV (cf. Sect.1.3)

Block-8 Collapsing from PTHERMAL into UTHERMAL, Required if NET $\neq 0$ /NET/

NEGT(i) Number of the public thermal groups in each user thermal group (i)
See the table of energy group structure in Sect. 8.3.

$\sum_{i=1}^{NET}$ NEGT(i) =(Total number of public thermal groups below the thermal-cut-off energy).

The relation $\sum_{i=1}^{NEF}$ NEGF(i) + $\sum_{i=1}^{NET}$ NEGT(i) = 107 must be satisfied.

Block-9 Required if NERF $\neq 0$ is specified /NERF/

NECF(i) Number of the user fast groups in each condensed fast group (i)

The relation $\sum_{i=1}^{NERF}$ NECF(i) = NEF must be satisfied.

Block10 Required if NERT $\neq 0$ is specified /NERT/

NECT(i) Number of the user thermal groups in each condensed thermal group (i)

The relation $\sum_{i=1}^{NERT}$ NECT(i) = NET must be satisfied.

An example of the Block-6 through Block-10

```
-------------------------------------------------------------------------------------------------------
62 45  2 1     /  107(=62+45) fine-group => 3(=2+1) few-group
62(1)          /  No collapsing from PFAST to UFAST (cut-off=1.85eV)
45(1)          /  No collapsing from PTHERM to UTHERM
28 34          /  Block-9
45             /  Block-10
-------------------------------------------------------------------------------------------------------
```

2.3 User's Library Specification

Formally all of the nuclides used in the succeeding calculations had to be specified in this section to transfer the necessary cross section data from the Public Library to User's Library. In the current version, the requirements are automatically judged from the material specifications in Sect.2.9 and the burn-up chain library in Sect.3.3. Thus, the user completes the section by feeding one blank line.

A special option is provided for the case where a job was terminated with the following error message:

```
 ------------------------------------------------------------------------------------------
 NUCLIDE(xxxxxxxx) HAS DOUBLE TEMPERATURE DEFINITION.
 ONE TEMPERATURE IS xxx.xx KELVIN AND ANOTHER IS yyy.yy KELVIN.
 PLEASE RESET STATNDARD TEMPERATURE ARRAY BY YOUR INPUT DATA
 ------------------------------------------------------------
```

This message appears when a resonant nuclide with the MCROSS library data is included in two or more mixtures of different temperatures, and the PEACO routine is used for the resonance absorption calculation. To avoid this, the following Blocks are required before a blank line.

Block-1	Keyword to call the input requirement	/A8/
NMTEMP	Enter 'TEMPSET '	
	Keyword to call input requirement	
Block-2	Required if Block-1 is specified	/35/
STND(*i*)	The temperatures (K) appearing in the material specifications in ascending order. Fill 0.0 for residual array of the input data.	

An example of Block-1 and Block-2 (bold parts):

```
------------------------------------------------------------------------------------------------------
62 45  2 1     /  Block-6 in Sect.2.2 (107 group => 3 group)
62(1)          /  No collapsing from PFAST to UFAST
45(1)          /  No collapsing from PTHERM to UTHERM
28 34          /
45             /
TEMPSET
581.  600.  900.  1000.0   31(0.0) / STNDTMP(35)
                                   ←( one blank line to terminate input of this section.)
4 6 6 4 1   1 6 0 0 0   5 0 6 15 0   0 45 0    / Pij Input
          :
          :
4 / Material Specification
FUE1X01X  0 3  1000.  0.557    0.0  / 1 : FUEL-1
XU050009  2 0  7.0908E-4       /1
XU080009  2 0  2.1179E-2       /2
XO060009  0 0  4.3777E-2       /3
FUE2X02X  0 3  900.   0.278    0.0  / 2 : FUEL-2
XU050009  2 0  7.0908E-4       /1
XU080009  2 0  2.1179E-2       /2
XO060009  0 0  4.3777E-2       /3
CLADX03X  0 1  600.   0.114    0.0  / 3 : CLADDING
XZRN0008  2 0  4.2507E-2       /1
MODEX04X  0 7  581.   1.000    0.0  / 4 : MODERATOR
XH01H008  0 0  4.5869E-2       /1
XO060008  0 0  2.2934E-2       /2
          :
------------------------------------------------------------------------------------------------------
```

2.4 PIJ ; Collision Probability Method (CPM)

The input of this section is required if IC1=1 and IC11=0 to specify the control variables, geometry model, computation accuracy, and options used in the calculation of collision probabilities.

Block-1 Control integers /18/

1 IGT Geometry type (See Fig.2.4-1 through 2.4-6)

= 1 One-dimensional sphere of multi-shells with the isotropically reflective condition at the outer boundary.

= 2 One-dimensional slab of multi-layers.

Care should be taken of the boundary condition. If IBOUND=1 is specified, not the perfect reflective (mirror) boundary condition but the periodic condition is applied for this geometry so as to treat an asymmetric cell. On the other hand, if a symmetric lattice is considered, the full geometry must be given.

= 3 One-dimensional circular cylindrical divided by concentric annuli.

= 4 Square cylinder divided by concentric annuli.

A square cell is divided by the concentric circles into several regions. It is to be noticed that the cell can be divided by the circle of which radius exceeds the distance from the center to the flat.

= 5 Square cylinder of two-dimensional division.

A square cell sub-divided by the concentric circles and further by four lines crossing the central axis. Each line makes an angle of 67.5° with a flat of the square. While an annular ring is divided into eight pieces, because of the octant symmetry assumed, two adjacent pieces per annular division are left as independent regions.

= 6 Hexagonal cylinder divided by concentric annuli.

= 7 Hexagonal cylinder of two-dimensional division.

A hexagonal cell is divided by the concentric circles and also by six lines crossing the central axis. Each line makes an angle of 75° with a flat of the hexagon. While an annular ring is divided into twelve pieces, because the 60° rotational symmetry is assumed, two adjacent pieces on an annular division remain as independent regions.

= 8 Octant symmetric square pillar divided by X-Y coordinates.

= 9 Octant symmetric square pillar divided by X-Y coordinates with square array of pin rods.

A pin rod can not lie on the grid line specified by RX(*i*). Different

radius by pin is accepted.

S-Regions are numbered by the rules 1) coolant regions ahead of pin rod regions, 2) lower to upper, 3) left to right, 4) inner to outer in a pin rod.

= 10 Annular assembly with annular array of pin rods.

A circular cylindrical assembly is divided by concentric annuli specified by RX(*i*). A certain number NPIN(*j*) of pin rods are placed on circular annuli specified by RPP(*j*). They must be placed with equal spacing on their azimuthal angles because the pin rods on a circle are assumed equivalent. A pin rod is sub-divided into several concentric layers by RDP. All the pin rods have the same geometry. The pin rods may, together with the coolant, be divided further radially into inner and outer by the circles denoted by RPP(*j*) by an option indicator IDIVP.

S-Region is numbered first to the inner-most pin rod starting from inner to outer of a pin rod if IDIVP<2, and from inner to outer measured from the cell center if IDIVP=2, then to the pin rod on the outer ring. After the outer-most pin rod, the coolant region follows from the inner to the outer.

Note that the cylindrical approximation is made for the outer boundary of a unit assembly.

= 11 Annular assembly with asymmetric array of pin rods.

The model IGT=10 is extended to permit an asymmetric disposition of pin rods. Any size of pin rod can be mounted at an arbitrary position as far as pin rods do not intersect each other. The coolant regions can be subdivided two-dimensionally by the concentric circles and by the radiating lines.

The numbering of S-Regions obeys principally the same rule as IGT=10. In view of azimuthal angle, the region positioned at smaller angle comes ahead.

Care should be taken in applying the isotropically reflective boundary condition at the outer surface where the neutron flux is assumed uniform and isotropic even if the fluxes in the segment regions adjacent to the surface are not uniform in the rotational direction. It is suggested to use this model in the so-called super-cell structure in which an actual

asymmetric cell is surrounded by enough thick symmetric material and the isotropic boundary condition is applied at the outer boundary of this external material.

= 12 Hexagonal assembly with asymmetric array of pin rods.

A model is provided to permit a hexagonal block with asymmetrical array of pin rods. Except the shape of the outer surface, the input requirements and the rule of S-Region numbering are same as those of IGT=11.

= 13 Rectangular pillar divided by X-Y coordinates with pin rods on grid points.

This type permits the placement of pin rods on any grid point of an X-Y division of a rectangular lattice cell. Every pin rod has its own radius with annular sub-division.

When IBOUND=1 is specified as the outer boundary condition, not the perfect reflective but the periodic condition is supposed in x- and y-direction. As S-Region numbers are purely geometrical, the user is requested to allocate T- and R-Region numbers so as to satisfy the periodic condition. For example, the region number allocated to a fuel pin located on the left edge must be coincide to that on the right edge.

S-Regions are numbered by the rules 1) coolant regions ahead of pin rod regions, 2) small Y-abscissa to large abscissa, 3) small X-abscissa to large abscissa, 4) inner to outer in a pin rod.

= 14 Concentric layer of hexagons with pin rod array of 60° symmetry.

A hexagonal assembly is divided by several concentric hexagons. On the flat of the arbitrary hexagon, pin rods of the uniform size can be mounted. Number of pin rods on a hexagon must be a multiple of six, since the 60° rotational symmetry is assumed. They are placed with equal interval starting at a corner of a hexagon. Pin rods on a hexagon are treated to have the same fluxes.

S-Regions are numbered by the rules 1) pin rod regions ahead of coolant regions, 2) inner to outer in an assembly, 3) inner to outer in a pin rod. But in case of IDIVP=2, pin rod regions are numbered by the distance from the central axis of the assembly.

= 15 Hexagonal assembly of 60° rotational symmetry with pin rods on

triangular grid points .

Difference from IGT=14 is that 1) coolant regions are divided by triangular meshes, 2) each pin rod can have the particular size, and 3). trapezoidal shape regions near the outer boundary of the assembly can simulate the wrapper tube and inter-assembly gap.

As the perfect reflective boundary condition is not supported, the isotropically reflective condition is applied.

S-Regions are numbered by the rules: 1) coolant regions ahead of pin rod regions. For coolant regions, 2.1) from inner to outer measured from the central axis, 2.2) small Y-abscissa to large Y-abscissa, For pin rod regions, 3.1) inner to outer in a pin rod, 3.2) small Y-abscissa to large Y-abscissa, 3.3) inner to outer measured from the central axis.

= 16 Rectangular pillar divided by X-Y coordinates of quadrant symmetry with pin rods on grid points.

This type permits the placement of pin rods on any grid point of an x-y division of a rectangular lattice cell. Every pin rod has its own radius with annular sub-division. This model differs from the model IGT=13 by applying the perfect reflective boundary conditions always on the left surface and on the lower surface.

When IBOUND=1 is specified as the outer boundary condition, the perfect reflective condition is applied on the right and the upper surfaces.

S-Regions are numbered by the rules 1) coolant regions ahead of pin rod regions, 2) small Y-abscissa to large abscissa, 3) small X-abscissa to large abscissa, 4) inner to outer in a pin rod.

2 NZ Total number of Sub-Regions

3 NR Total number of T-Regions

4 NRR Total number of R-Regions

5 NXR Total number of X-Regions

6 IBOUND Outer boundary condition of the cell calculation

= 0 Isotropic (white) reflection

= 1 Perfect reflection (mirror)

For IGT=2 (1D slab) or IGT=13 (2D X-Y pillar) periodic condition is applied. For IGT=15, IBOUND=1 is ineffective.

= 2 Isolated (black)

= -1 60° rotational (applicable only for IGT=12)

Note:

It is recommended that reflective boundary condition at the outer surface for sphere (IGT=1) or cylinder (IGT=3, 10, 11) should be not perfect but white reflection.

If the fixed boundary source problem is solved by the specification of IC12=-1, IBOUND is automatically set to black.

For the optically large assembly, IBOUND=0 is recommended to avoid much computation time.

7 NX Number of mesh intervals for X division (IGT=2,8,9,13,15,16)
Number of mesh intervals for R division (IGT=1,3,4,5,6,7,10,11,12,14)

8 NY Effective for IGT=11,12,13,15,16
Number of mesh intervals for Y division (IGT=13,16)
Number of mesh intervals for angular division (IGT=11,12)
Number of mesh intervals for the division along the flat of outer trapezoidal regions (IGT=15)

9 NTPIN Total number of pin rods (effective for IGT=10,11,12,13,14,15,16)
This item is calculated internally for IGT=9 by NAPIN.

For IGT=10,11,12, the pin rod on the central axis is not counted as a pin rod, then, the central pin has to be entered by RXs. For IGT=14,15, the pin rod on the central axis is counted as a pin rod. For IGT=15, although 60° rotational symmetry is assumed, enter total number of pin rods in an (6/6) assembly.

10 NAPIN Effective for IGT=9,10,14,15
Number of pin rods in an array on X-direction (for IGT=9).
Number of circles on which the pin rods are located (for IGT=10). The central axis

is not counted for NAPIN.

Number of hexagons on which the pin rods are located (for IGT=14). The central axis is counted for NAPIN.

Number of triangular meshes on X-axis (for IGT=15) where (NX-NAPIN) are number of layers of outer trapezoidal regions.

11 NCELL Minimum number of lattice cells traced by a neutron path

This item is effective only for IBOUND=1 for geometries of non-circular outer shape. This is used to cut off a neutron path without knowing the actual optical path length. It is desirable to trace a neutron beyond an optical length of 6.0 if the computer time allows. Recommended value to this item is NCELL=2 for a cell enough large in the sense of optical path, or NCELL=5 for a transparent or small cell. The larger value causes the longer computer time. The user should not be afraid of the short cut of a path by insufficient number of NCELL while a certain amount of neutrons reach the end of the path and loose the contribution. It will be recovered by the later process of normalization and redistribution of collision probabilities.

If the negative value is entered, the new algorithms for vectorized calculation for the numerical integration of collision probabilities is applied. As the computing time depends on the geometry and the boundary condition, the comparison of CPU time by both algorithms is recommended before repetitive calculation of same geometry.

12 IEDPIJ Edit control for collision probabilities

= 0 Skip print

= 1 Print collision probabilities

13 NGR Order of Gaussian integration for the numerical radial integration

This item is ineffective for one-dimensional slab (IGT=2). Recommended value is from 6 to 10. The computer time for the integration of collision probabilities is proportional to this item. For the geometries IGT=8,9,13,15 and 16 the Gaussian integration is replaced by the trapezoidal rule.

14 NDA Number of division of the range IBETM (described below) entered by the unit of

degree for the numerical angular integration of the collision probabilities.

Required for two-dimensional integration for IGT 4 through 16. Sufficient accuracy will be attained if approximately IBETM/2 is entered as NDA.

Total amount of NX*NGR*NDA neutron paths are traced for the two-dimensional integration. After storing the path information and before the actual time-consuming integration, the ratios of the numerically integrated volumes to the exact ones are printed out. The deviations of the ratios from unity (should be less than a few percent) predict the accuracy of the integration. The user should adjust the values of NGR and NDA so as to be accurate but not time-consuming.

15 NDPIN Number of annular division of a pin rod (effective for IGT=9 through 16)

16 IDIVP Control of sub-division by RPP (effective for IGT= 9, 10, 11,12,14)

= 0 RPP indicate the radial positions of pin rods.

= 1 RPP also play the role of RX. i.e. positions of annular division.

= 2 RPP further divide the pin rod regions into inner and outer regions.

Control of sub-division by RX, TY(effective for IGT=13, and 16)

= 0 with NTPIN $\neq 0$, RXs and TYs do not divide coolant region, then only one coolant region is allocated to the region except pin rod regions

= 1 Division by RXs and TYs is effective. Usually enter IDIVP=1.

17 IBETM Range of angular integration in degree. (Effective for IGT=4 through 16)

Enter =45 in octant symmetric square geometry, =30 in hexagonal symmetry, Set double value if IBOUND=1 is specified. Enter =360 if symmetric only on left and right planes. Inefficient for one-dimensional geometry.

18 IPLOT Indicator to call plotter routine for geometry display

Plot data is stored as a PostScript file (cf. Sect.1.11)

= 0 Skip plotting

= 1 Call plotter routine (not effective for IGT=13,15,16)

Requirement of the following input Blocks are depending on geometries (IGT) specified in Block-1. It is summarized in Table 2.4-1.

Block-2 Iteration control parameters /7,6/

Parameters for the iterative solution of linear equations for neutron fluxes by the CPM. The value in < > shows defaulted value used when ITMINN ≤ 0 is specified. (cf. Sect.7.4)

1 IEDIT Edit control

= 0 No edit

plus 1 Print reaction balance and flux distribution

plus 2 Print macroscopic cross-sections

plus 4 Print collision probabilities

plus 8 Print fixed source distribution

Note:

If the user wants to print out macroscopic cross-sections and collision probabilities, IEDIT=2+4=6.

2 ITMINN Maximum number of inner iterations per an outer iteration

<20> for the eigenvalue problem, but <200> for the fixed source problem in thermal energy range

3 ITMOUT Maximum number of outer iterations for the eigenvalue problem <60>

4 ITBG Minimum number of iterations before extrapolation <5>

5 LCMX Number of iterations for testing over-relaxation factor <5>

6 ITDM Minimum delay between extrapolation <5>

7 IPT Control of monitor print at each iteration <0>

= 0 suppress print

= 1 print record

= -1 print detailed record

1 EPSI Convergence criterion for inner iterations <0.0001>

2 EPSO Convergence criterion for outer iterations <0.00001>

3 EPSG Extrapolation criterion <0.001>

4 RELC Initial over-relaxation factor <1.2>

5 OVERX Maximum extrapolation <100.>

6 FACTOR Under extrapolation factor <0.8>

Block-3 Required if NR<NZ /NZ/
NREG(*i*) T-Region number by Sub-Region (*i*)

Block-4 Required if NRR<NR /NR/
IRR(*i*) R-Region number by T-Region (*i*)

Block-5 Required if NXR<NRR /NRR/
IXR(*i*) X-Region number by R-Region (*i*).
If entered =0, this R-Region is excluded from the average in X-Region.

Block-6 /NRR/
MAR(*i*) Material number by R-Region (*i*)
Sequential order of a material appearing in the material specification in Sect.2.9 is used as material number.

=== Double heterogeneous problem option ===

Negative value of the material number indicates that this material is heterogeneous in the sense of the double heterogeneity[26]. For example, the coated particles dispersed in graphite matrix in the fuel compact of high temperature reactors compose the double heterogeneity. It is supposed that two composite materials of this material are specified in the preceding positions. That is, if the number -3 of an R-Region appears in MAR's, the first and second materials specified in Sect.2.9 are the composites of the microscopic cell. The relevant input data are required in Block-14. By this specification, both of microscopic and macroscopic heterogeneities are treated. The microscopic heterogeneity treated in this option is restricted to be two-region problem expressed by any of one-dimensional geometries (sphere, slab and cylinder) where the inner region is resonant and the outer is non-resonant. The double heterogeneous problem which

does not satisfy this condition must be treated in two-step process (cf. IXMICR in Sect. 2.9).

Block-7 Required only if IGT=10 or 14 and NAPIN $\neq 0$ /NAPIN/

NPIN(*i*) Number of pin rods on a circular ring (IGT=10) or on a hexagon (IGT=14).

If IGT=10, the pin rod on the central axis is not counted in NPIN. If IGT=14, the center pin rod is counted by NPIN. Defaulted values are prepared if NPIN(1)=0 is entered for IGT=14 as 1,6,12,18,....

Block-8 /NX+1/

RX(*i*) X-abscissa, radii, or the distances from the center to the flat of hexagon or square in unit of cm. Enter RX(1)=0 always.

Block-9 Required if IGT=11 or 12 and if NY>0 /NY/

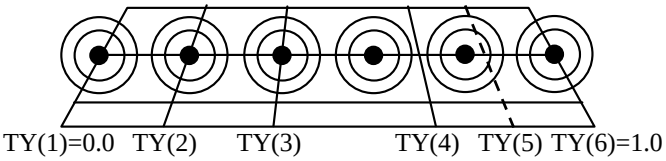
TY(*i*) Angular division by θ in degree

Block-9' Required if IGT=13 or 16 and if NY>1 /NY+1/

TY(*i*) Y-abscissa in cm. Enter TY(1)=0 always.

Block-9" Required if IGT=15 /NY+1/

TY(*i*) Division in anti-clockwise direction along the flat of outer trapezoidal regions by fraction. The region boundary line is drawn from the point expressed by the fraction to the center of hexagonal assembly. TY(1)=0.0 and TY(NY+1)=1.0 always. If the user wants to divide the flat into four equal pieces, enter 0.0, 0.25, 0.5, 0.75, 1.0. If a line crosses a pin rod, the line has to pass through the center of the pin rod. In the figure below, the line specified by TY(5) is not proper.



Block-10 Required if IGT=9,10 or 14 and NAPIN $\neq 0$ /NAPIN/

RPP(*i*) Positions (cm) of pin rods on X-direction for IGT=9.

Radii (cm) of the circles on which pin rods are located for IGT=10.

Distances (cm) from the center to the flats of hexagons for IGT=14.

Block-10’ Required if IGT=11, or 12 and NTPIN $\neq 0$ /NTPIN/

RPP(i) Radial position (cm) of each pin rod for IGT=11 or 12

Block-10” Required if IGT=13, 15, or 16 and NTPIN $\neq 0$ /NTPIN/

IXP(i) X-position of each pin rod on RX. Enter integers ranging from 1 to NX+1 for IGT=13, and =16, i.e. the lower left corner has the grid coordinate (1,1).

For IGT=15, the center of the assembly has the coordinate (0,0), then IXPs range from 0 to NX. While the input requires NTPIN entries, the entries for the first one-sixth part of a hexagon must be proper and others are dummy numbers because the 60° rotational symmetry is assumed.

Block-11 Required if IGT=10,11, or 12 and NTPIN $\neq 0$ /NTPIN/

THETA(i) Angular position of each pin rod by θ in degree

Block-11” Required if IGT=13, 15, or 16 and NTPIN $\neq 0$ /NTPIN/

IYP(i) Y-position of each pin rod on TY. Enter integers ranging from 1 to NY+1 for IGT=13 and 16, from 0 to NY for IGT=15. While the input requires NTPIN entries, the entries for the first one-sixth part of a hexagon must be proper and others are dummy numbers because the 60° rotational symmetry is assumed.

Block-12 Required if IGT=10 or 14 /NDPIN+1/

RDP(i) Radii (cm) for annular sub-division in a pin rod; where RDP(1)=0. The radii are common through all pin rods.

Block-12’ Required if IGT=9,11,12, 13, 15 or 16 and NTPIN $\neq 0$ /(NDPIN+1)*NTPIN/

RDP(i) Radii (cm) for annular sub-division of individual pin rod, where (RDP(1,j), j=1, NTPIN) =0 always.

For IGT=9, the input is required for an octant (1/8), then NTPIN= NAPIN*(NAPIN+1)/2.

For IGT=15, the entries for the first one-sixth part of a hexagon must be proper and others are dummy numbers because the 60° rotational symmetry is assumed.

Block-13 Plotter control integers, required if IPLOT $\neq 0$ in Block-1 is specified /3/

1 IG Signed integer to specify the combination of required region map; the integer is made of the summation of following integers corresponding to the kind of map.

= 0 None

plus 1 Sub-Region

plus 2 T-Region

plus 4 R-Region

plus 8 Material number

plus 16 X-Region

Note:

Positive value indicates printing of assignment of region numbers in the figure, and negative value requires only figure.

2 ISCAL Indicator of the scale of figures

= 1 One figure of diameter of 20 cm in a screen

= 2 Two figures of each diameter of 15 cm in a screen

= 3 Five figures of each diameter of 10 cm in a screen

3 ICONT Continuation indicator

= 0 Followed by the next Block-13

= 1 The last plotting

Block-14 Required if any negative MAR in Block-6 is entered /0,3,2/

Control integers for the treatment of the double heterogeneity

1 IDB Energy range indicator

= 1 Resonance range by the PEACO routine

= 2 Thermal range (not yet available)

= 3 Resonance and thermal range (not yet available)

2 IGEOM Geometry indicator of the microscopic heterogeneity

Restricted to two-region problem where the inner region is resonant and the outer is non-resonant.

= 1 Slab

= 2 Cylinder

= 3 Sphere

3 MODEL Model indicator for the definition of the collision rate ratio in the two-region microscopic cell.

= 1 Transmission (recommended)

= 2 Neutron from moderator

= 3 Neutron escaping from absorber lump

= 4 Simplified transmission

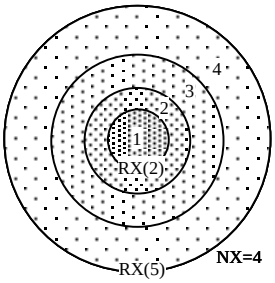
4 RF The thickness (cm) of absorber plate for IGEOM=1, and the outer radius (cm) of absorber lump for IGEOM=2,3.

5 RM The outer radius of microscopic cell. As the escape probability is evaluated by the analytical expression by Case *et al.*,[27] the Dancoff correction factor must be fed in the material specification in Sect.2.9 even if any is specified by IC3 in Sect.2.2.

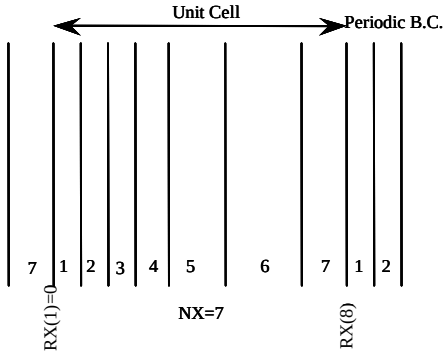
Table 2.4-1　List of input requirements for CPM routines by geometry model (IGT)

		IGT=1	IGT=2	IGT=3	IGT=4	IGT=5	IGT=6	IGT=7	IGT=8	IGT=9	IGT=10	IGT=11	IGT=12	IGT=13	IGT=14	IGT=15	IGT=16
B-1	IGT	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
	NZ	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
	NR	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
	NRR	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
	NRX	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
	IBOUND	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
	NX	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
	NY	●	●	●	●	●	●	●	●	●	●	○	○	○	●	○	○
	NTPIN	●	●	●	●	●	●	●	●	●	○	○	○	○	○	○	○
	NAPIN	●	●	●	●	●	●	●	●	○	○	●	●	●	○	○	●
	NCELL	●	○	●	○	○	○	○	○	○	●	●	○	●	○	●	○
	IEDPIJ	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
	NGR	○	●	○	○	○	○	○	○	○	○	○	○	○	○	○	○
	NDA	●	●	●	○	○	○	○	○	○	○	○	○	○	○	○	○
	NDPIN	●	●	●	●	●	●	●	●	○	○	○	○	○	○	○	○
	IDIVP	●	●	●	●	●	●	●	●	○	○	○	○	○	○	●	○
	IBETM	●	●	●	○	○	○	○	○	○	○	○	○	○	○	○	○
	IPLOT	○	○	○	○	○	○	○	○	○	○	○	○	○	○	●	○
B-2	IEDIT～FACTOR	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
B-3	NREG	△	△	△	△	△	△	△	△	△	△	△	△	△	△	△	△
B-4	IRR	△	△	△	△	△	△	△	△	△	△	△	△	△	△	△	△
B-5	IXR	△	△	△	△	△	△	△	△	△	△	△	△	△	△	△	△
B-6	MAR	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
B-7	NPIN	×	×	×	×	×	×	×	×	×	△	×	×	×	△	×	×
B-8	RX	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
B-9	TY	×	×	×	×	×	×	×	×	×	×	△	△	×	×	×	×
B-9'	TY	×	×	×	×	×	×	×	×	×	×	×	×	○	×	×	○
B-9''	TY	×	×	×	×	×	×	×	×	×	×	×	×	×	×	○	×
B-10	RPP	×	×	×	×	×	×	×	×	△	△	×	×	×	△	×	×
B-10'	RPP	×	×	×	×	×	×	×	×	×	×	△	△	×	×	×	×
B-10'	IXP	×	×	×	×	×	×	×	×	×	×	×	×	△	×	△	△
B-11	THETA	×	×	×	×	×	×	×	×	×	△	△	△	×	×	×	×
B-11'	IYP	×	×	×	×	×	×	×	×	×	×	×	×	△	×	△	△
B-12	RDP	×	×	×	×	×	×	×	×	×	△	×	×	×	△	×	×
B-12'	RDP	×	×	×	×	×	×	×	×	△	×	△	△	△	×	△	△
B-13	IG～ICONT	△	△	△	△	△	△	△	△	△	△	△	△	△	△	△	△
B-14	IDB～RM	△	△	△	△	△	△	△	△	△	△	△	△	△	△	△	△

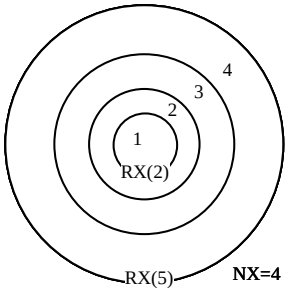
○: always required, ●: always required but ineffective, △: conditionally required, ×: not required



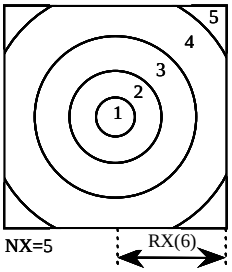
IGT=1 (Spherical cell)



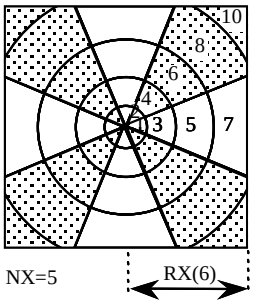
IGT=2 (Infinite plane cell)



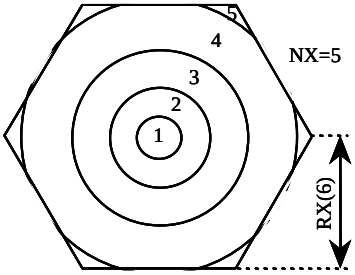
IGT=3 (Cylindrical cell)



IGT=4 (Square cell)

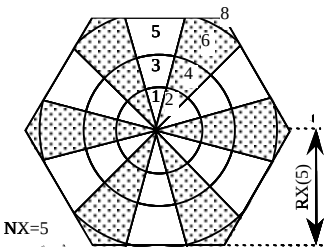


IGT=5 (2D square cell)

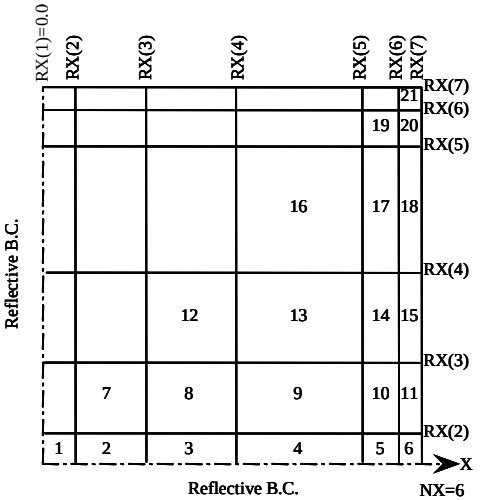


IGT=6 (Hexagonal cell)

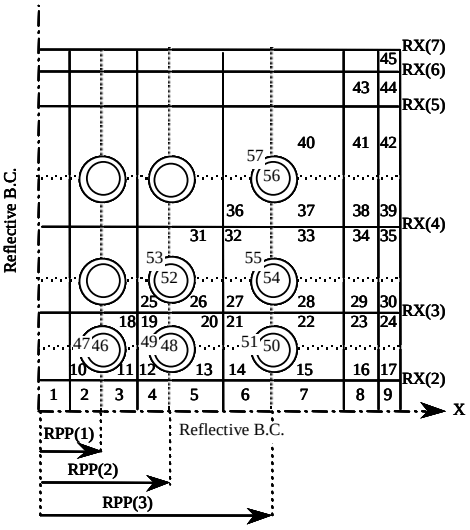
Fig.2.4-1 Geometries for PIJ (IGT=1~6)



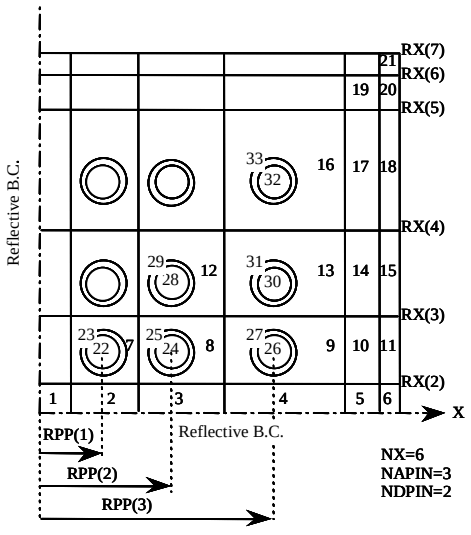
IGT=7 (2D hexagonal cell)



IGT=8 (Quadrant of an octant symmetric assembly)

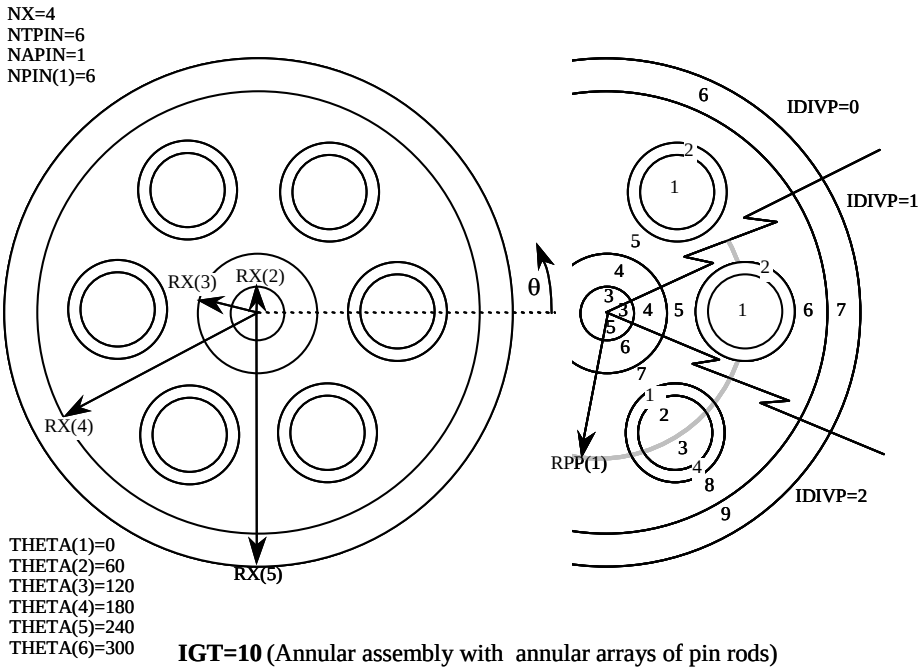


IGT=9 (Octant symmetric square assembly with pin rods)
IDIVP=1

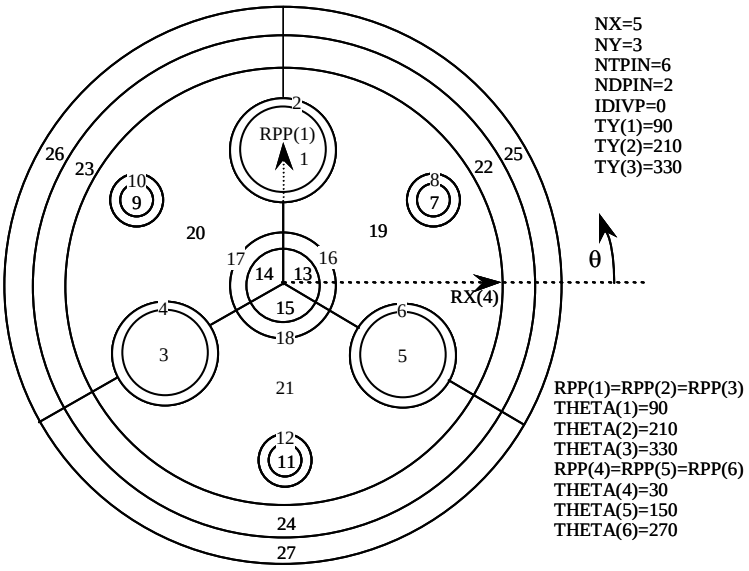


IGT=9 (Octant symmetric square assembly with pin rods)
IDIVP=0

Fig.2.4-2 Geometries for PIJ (IGT=7~9)

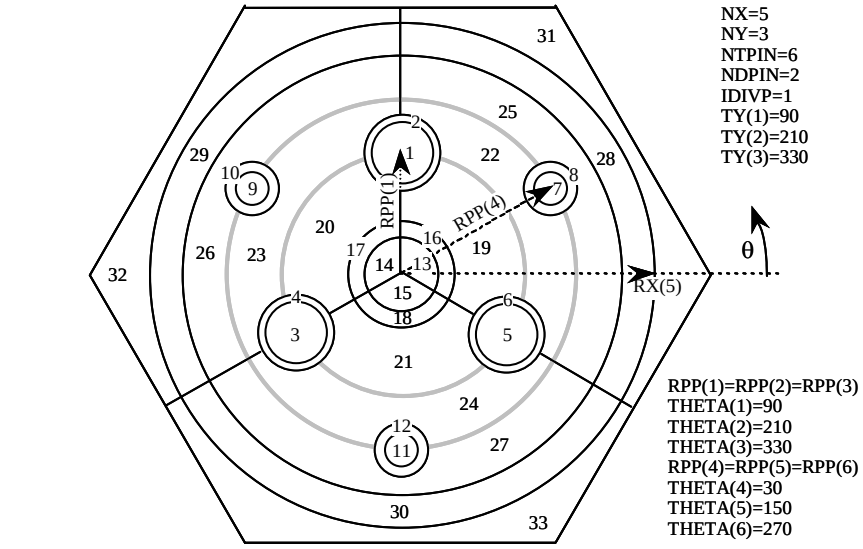


IGT=10 (Annular assembly with annular arrays of pin rods)



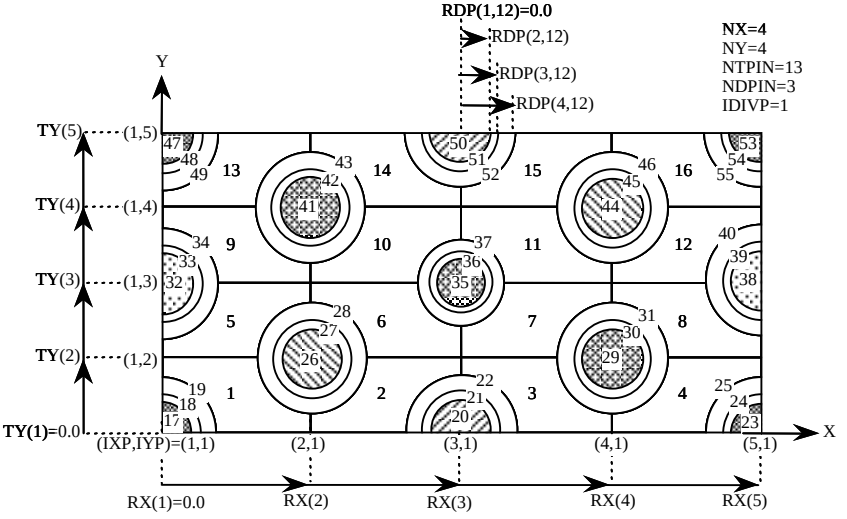
IGT=11 (Annular assembly with asymmetric pin rods)

Fig.2.4-3 Geometries for PIJ (IGT=10, 11)



If IDIVP=1, RPP(i) must not accross the pin rods on RPP(j) different from RPP(i).

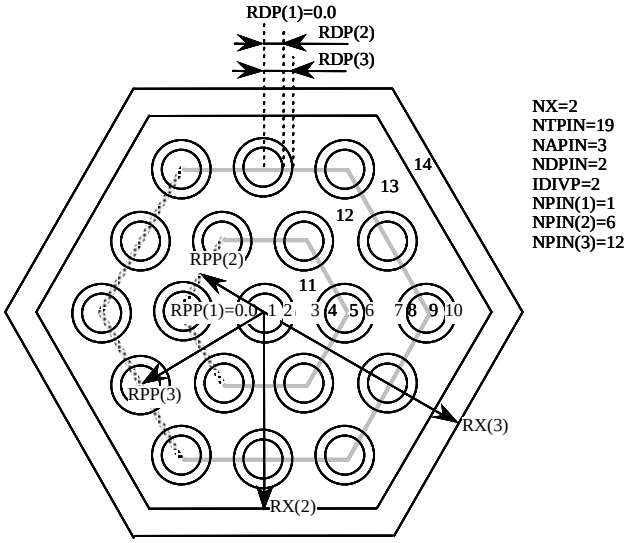
IGT=12 (Hexagonal assembly with asymmetric pin rods)



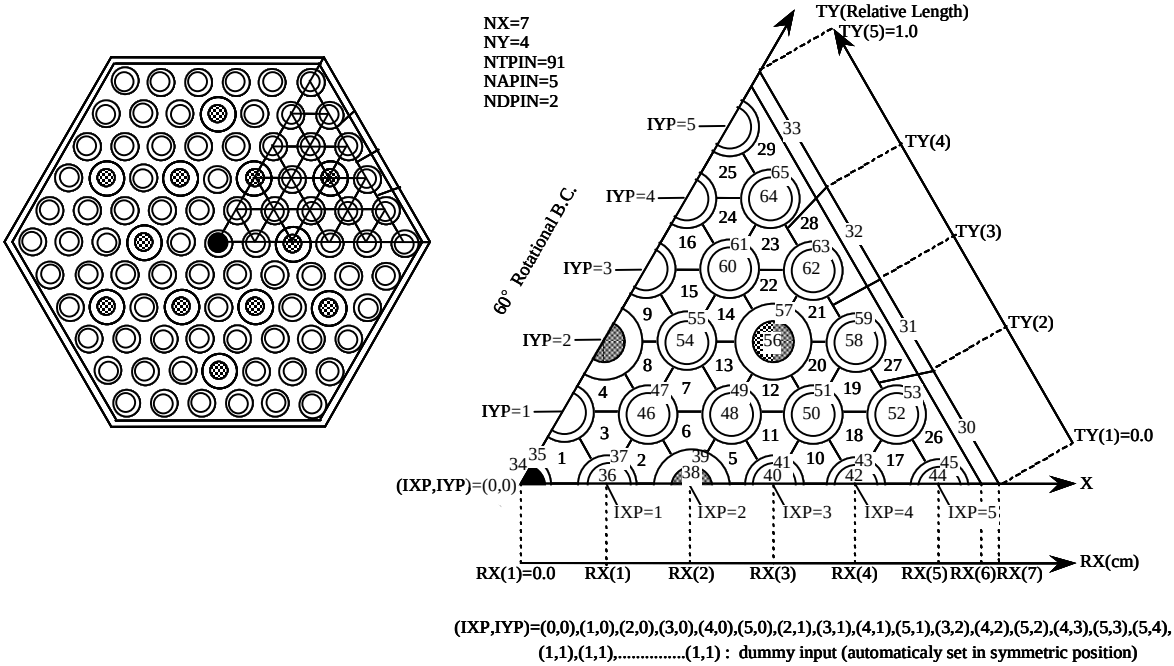
Sub-Region number for each pin rod is in order of (IXP,IYP).
(IXP,IYP)=(1,1), (3,1),(5,1),(2,2),(4,2),(1,3),(3,3),(5,3),(2,4),(4,4),(1,5),(3,5),(5,5)

IGT=13 (X-Y 2D cell with pin rods on arbitrary grid points)

Fig.2.4-4 Geometries for PIJ (IGT=12, 13)

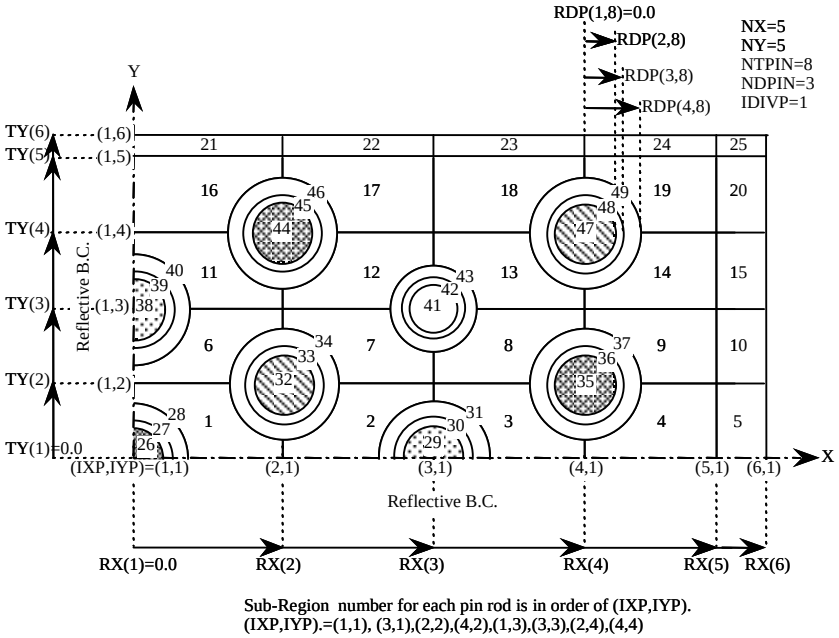


IGT=14 (Concentric layers of hexagons with equi-distant pin rod arrays)



IGT=15 (Hexagonal assembly with triangular pin rod arrangement)

Fig.2.4-5 Geometries for PIJ (IGT=14, 15)



IGT=16 (X-Y 2D symmetric cell with pin rods on arbitrary grid points)

Fig.2.4-6 Geometries for PIJ (IGT=16)