

GNOMER - Multigroup 3-Dimensional  
Neutron Diffusion Nodal Code with  
Thermohydraulic Feedbacks

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## 1 Introduction

In reactor core calculations the codes solving the neutron diffusion equation are the most frequently used tools. The diffusion solution is used for cross section homogenization to obtain larger equivalent homogeneous zones for coarse discretization of the core, it is used to obtain the global core neutron flux distribution and it also appears inside iterations to determine the power distribution including the thermohydraulic feedbacks and in the analysis of more complex transients. Due to the importance of the neutron diffusion solution, a lot of work has been invested to obtain very efficient and numerically accurate algorithms. At present, the most successful algorithms are based on the Nodal approach [1], whereby the multidimensional diffusion equation is converted into a set of coupled one-dimensional equations. These features are included in the GNOMER code which is described in this document.

## 2 Program description

The main calculational module is the one for solving the multigroup neutron diffusion equation. Using a variant of the Green's function method for the one-dimensional equations and applying the Nodal approach for extension to multidimensional cases, a very efficient algorithm was obtained [2]. After some further optimization of the iteration schemes this GNOME0 diffusion module was incorporated into the main GNOMER code.

For global core power distribution calculations the program includes a rather simple thermohydraulics module CHNTMP to calculate the temperature distributions. When the reactivity coefficient library RCFLib is available, a correction to the cross sections is made by the reactivity coefficient method, to compensate for feedback effects. The principle of the method is to calculate the change in reactivity due to the changes in the core parameters (i.e. boron concentration, moderator and fuel temperature, xenon level etc.). The change in reactivity is calculated from the reactivity coefficients and assuming that the effects are linear and mutually independent. A correction to the thermal cross section in a particular region is made such that the change in  $k_\infty$  of the cross sections for that region reflects the change in reactivity. Such corrections are valid when the core conditions at which the cross sections are calculated do not differ significantly from the actual core conditions. For global core calculations, two-group cross sections are usually adequate, so the calculations with thermohydraulic feedbacks are limited to two-group cases at present. The format of the RCFLib library is given in Appendix B.

To calculate homogenized cross sections over a fuel assembly a number of options are available, ranging from the simple flux-volume weighting, criticality search, to the more refined EDH method [4]. For the assembly calculations it is recommended to use 6 to 10 energy groups.

Precision control of the diffusion solution can be achieved through the choice of the mesh densification factors. A different value  $m_i$  may be stated in each direction and it means that the number of nodes in that direction is internally increased  $m_i$  times, without any other changes in input. Precision can also be controlled through the choice of the polynomial order of the flux expansion for integration purposes. The method of solution is most efficient for coarse mesh problems (for example, one node per assembly for global power distribution over a PWR core). In such cases the accuracy of the solution is limited by the usual, second order polynomial approximation for the

transverse leakage. If fine mesh calculations are required, the requested polynomial order for the flux expansion can be reduced.

The **GNOMER** code consists of the main driver program **GNOMER** and a number of modules which currently include the following:

**RESTRT** to dump the contents of the work arrays and common blocks to a dump file and to restart execution from a dump file,

**FILENM** to assign explicit filenames from input,

**GNOMEX** to generate reduced driver FORTRAN source for solving the diffusion equation for a fixed geometry problems,

**DATOPT** to process the input data options,

**PRTOUT** to print out the results according to the selected printout options,

**POWERD** to solve the diffusion equation and to perform iterations for self-consistent power distribution with thermohydraulic feedbacks and a criticality search (if requested). This module includes the **GNOME0** module to solve the diffusion equation and the **CHNTMP** module to calculate the temperature distributions corresponding to a particular power distribution.

### 3 Prerequisites

The coding is standard FORTRAN-77 so it is practically machine-independent. Exceptions are found in the **CPTIME** routine which measures the execution time of individual modules, and in some routines where data files are opened explicitly.

Different machines allow a different upper limit to the size of the internally declared arrays. This limits the size of the problems that may be tackled. Feasibility of accurate 3D calculations have been demonstrated even on an IBM-PC/XT compatible [2]. Depending on the compiler, three memory allocation options for the real scratch array have been suggested, as described below.

Alternate coding, reflecting the above requirements is provided in the FORTRAN source so that relevant code can be activated or deactivated automatically with the **CNVRTF** code, which is supplied with the package. The **CNVRTF** code identifies special coding in the source which is to be processed, when it is enclosed in statements of the form

```
C*****nnnn
```

where "nnn" is a 4-character keyword (any subsequent characters are ignored and may be used for comments). At present the following keywords were defined:

" **VAX**"            relevant to **CPTIME** routine and **OPEN** statements for carriagecontrol and write protection, available on **VAX**,

" **STANDARD**"    relevant to **OPEN** statements,

" **CDC**"            relevant to **CPTIME** routine,

" **LARGE**"         for 240K real scratch array allocation,

" MEDIUM" for 80K real scratch array allocation,  
" SMALL" for 20K real scratch array allocation,

The package is distributed with " VAX" and " LARGE" options active.

The program has been tested on various VAX machines, compiled with standard options, and on a PC with the MicroWay NDP Fortran-486 Ver.4.4.0 , with the Lahey Fortran Version 5.20 and with the MicroSoft FORTRAN Version 5.10. Procedures for automatic generation of the executable code on any of the above configurations is supplied with the package. On a PC the " STANDARD" and " PC " options must be active. In addition, the " LARGE" memory allocation option may be used with the NDP Fortran-486, but " MEDIUM" option must be selected with the MicroSoft FORTRAN due to the limitation in the module size to 640K-bytes.

The source code on a PC has been generated with 540 Kbytes of memory available. Problems may be encountered if less memory is available.

## 4 Module description and input instructions

The most recent documentation on individual modules can be found in the source code in comments following the module declaration. Such comments begin with "C-M" in the first three columns. Further information is also available in a similar way, as evident from the list below:

- C-T Title (i.e. name) of the program, function or subroutine,
- C-P Purpose of the routine, stated in a few words,
- C-D Description, usually stated for routines of more general interest and importance,
- C-M Manual of user instructions for the programs and main modules,
- C-A Author(s) names and affiliation,
- C-V Version stated as "yy/mm" with a brief description of the changes to keep track of the revisions.

On VAX such information can be extracted very conveniently by the system search utility as shown in the example below:

```
"$ SEARCH GNOMER.FUL/OUT=GNOMER.TXT "C-T",C-M", "C-V"
```

On pages that follow the users' guide to individual modules has been extracted directly from the source code and reflects the status of the code at the time when this document was prepared. There may be changes in the source code introduced subsequently. Any changes observed in the source code supersede those in this document.

## 4.1 Manual for GNOMER Program (Driver Module)

=====

The Driver program reserves the integer and real scratch arrays which are subdivided as necessary in individual modules and passed down to subroutines as formal parameters. It also assigns the main input file and controls the activation of other modules (selected by the appropriate keywords on input) which are the following:

'\$\* FILENM ' Assign files to logical units,  
'\$\* COMMENT' Transfer comments from input to output file,  
'\$\* DATOPT ' Process the input data options,  
'\$\* POWERD ' Activate the flux and power distribution calculation,  
'\$\* PRTOUT ' Activate the printout options,  
'\$\* GNOMEX ' Write the simplified GNOME0 Driver Source code,  
'\$\* IDXINI ' Re-initialize work-field indices INDEXI and INDEXR,  
'\$\* DUMPBIN' Dump the COMMONs and work fields to a binary file.  
The name of the binary dump file FLNM is read from columns 11-50. The logical file unit LBI is 3. It is automatically flagged negative to instruct the RESTRT module to write the Dump file.  
'\$\* RCVRBIN' Recover the COMMONs and work fields from a binary file. The name of the of the binary dump file FLNM is read from columns 11-50. The logical file unit LBI is 3. It is positive to instruct the RESTRT module to write the Dump file.  
'\$\* LOOP ' Define Do-loops of input instructions. Additional parameters are defined in columns:  
11-20 LBL - The Do-loop label LBL.  
21-30 NLOOP- The number of times the loop of instructions is to be executed.  
31-40 STME1- The final time when the loop defines time stepping instructions (such as Xenon transients). The format is either absolute time (minutes), or given in the format "d hh:mm" where "d" is the day, "hh" is the hour and "mm" are minutes. The time incement DTME is calculated (STME1-STME)/NLOOP where STME is the current time.  
See also ' XENON ' command of DATOPT.  
The LOOPIN module prepares an auxilliary input file and redefines the input logical file unit accordingly  
A Do-loop is terminated with a record ' ENDLLOOP' containing the label LBL in columns 11-20.  
input logical file unit accordingly.  
'\$\* END ' Calculations completed, terminate execution.  
See individual modules for further input instructions.

For compatibility with the CORD-2 system, some additional input commands are defined as an alternative to those which appear in the DATOPT and FILENM modules. These are

'\$\* CORPWR ' to define and open the CORlib file on unit 9.  
By default, the new output is appended to any existing content, unless the qualifier "NEW" is encountered in columns 51-60. In this case the output is overwritten.  
The filename is read from columns 11-50.  
'\$\* DIMLIB ' to define the DIMlib filename.  
The filename is read from columns 11-50.  
The file is opened and scanned for '\$\* BUCSQ' keyword from which the global buckling-squared is defined as an alternative to the '\$\* BUCKLSQ' main input option

or the ' BUCKLSQ' option in DATOPT.

'\$\* RCFLIB ' to define the RCFlib filename.  
The filename is read from columns 11-50.

'\$\* BUCKLSQ' to define the global buckling. In contrast to the DATOPT command ' BUCKLSQ', the '\$\* BUCKLSQ' command defines group-independent buckling and must be defined BEFORE the cross sections are read.

'\$\* POWERP ' to define the relative power level [%]. The requested percent power level is read from columns 11-20.  
NOTE:  
This command presets the relative power, but is not exactly equivalent to the ' POWERD ' option in DATOPT, since it does not initialize other thermohydraulic parameters of the core. The ' POWERD ' command must therefore ALWAYS be present, if feedback corrections are to be made. For the power level from the '\$\* POWERP ' declaration to remain active, the corresponding entry in columns 11-20 of ' POWERD ' in the '\$\* DATOPT ' options must be blank.

'\$\* ZEROPWR' to set the relative power level to 0.1 %. One additional parameter may be specified to redefine the coolant inlet temperature.  
NOTE: the same note applies as for '\$\* POWERP '.

'\$\* BORON ' to define the boron concentration.  
The concentration [ppm] is read from columns 11-20.

'\$\* XENON ' to specify the xenon condition.  
One additional parameter XEN can take the value:  
0 - for No-Xenon condition,  
1 - for Equilibrium Xenon condition.  
NOTE: This command can not be used to define Xenon transients (see DATOPT for details).

'\$\* BURNUP ' to define the current burnup.  
The burnup [Mwd/tU] is read from columns 11-20.

'\$\* PINBRN ' keyword indicates that pin burnups are considered in the fuel assembly calculations and that the input cross sections include burnup gradients.  
Additional parameters are:  
Name Col. Description  
FNBG 11-50 Not used  
NBG 51-60 For GNOMER it is sufficient that NBG is non-negative.  
If '\$\* PINBRN ' keyword is found and NBG.ge.0 then IZP1 is set to 2 (see ' MATERIA' input request of DATOPT), implying that P1 components of the fission yield in the cross sections is present.

'\$\* TMODINL' to re-define the coolant inlet temperature.  
The input value overrides the one read from the DIMlib library and represents the actual inlet coolant temperature, without adjustment for the power level. To restore the default inlet temperature processing, enter a negative value.  
The coolant inlet temperature value [K] is read from columns 11-20.

'\$\* CYCLE ' to define the cycle number. This affects the CORlib header labels when writing data to a CORlib and triggers a check in the Reactivity Coefficient library RCFlib for the correct cycle number. In this case a cycle-dependent RCFlib file must be provided.

Note, that the last seven commands are relevant only in connection with thermohydraulic feedbacks when the ' POWERD ' command is specified in DATOPT.

#### Instructions:

One record from Unit-5 is read as a character string. It is assumed to be the filename containing the input data in which case

this input file is opened as Unit-1 and all other input commands are read from it. If the first record begins with "\$\*", the input commands are expected from Unit-5 until the '\$\* END ' command is encountered or until input is re-routed with the '\$\* FILENM ' command.

Since the input commands are identified by keywords, the selected input file may be freely documented with comments, beginning from column 11 (i.e.: blank columns 1-10 imply comments). The keywords which are not recognized are ignored. This feature may be used to prepare a single input file for different programs which are executed in sequence, if they are compatible with these conventions.

Module description:

DATOPT: is the input instructions processing module. Full details on the currently available options are given in the Description comments in the module.

PRTOUT: is the output processing module which allows full control of the quantities that are printed on the output file. Full details on the currently available options are given in the Description comments in the module.

POWERD: calculates the neutron flux and fission density distributions in the diffusion approximation in 1D, 2D and 3D rectangular geometry. When nuclear heating is in effect, temperature distributions are calculated and their feedback on the cross sections is considered. Iterations on power due to feedbacks are performed till convergence. Special criticality search options are available for buckling, albedo, control rod position and boron concentration. A search for a prescribed axial flux difference (axial offset) can also be requested, in which case the control rod position is adjusted at critical boron concentration.

GNOMEX: writes the simplified GNOME0 Driver Source code.

RESTRT: Dump/Recover all COMMONs and work fields onto/from a binary dump file.

LOOPIN: Creates input data Do-loops, writing an auxiliary input file which is executed a specified number of times.

## 4.2 Manual for LOOPIN Module of GNOMER

-----

The module is activated by the '\$\* LOOPIN ' input statement. A scratch file is opened for the auxiliary input file. The records from the main input file are copied to the auxiliary file, until a record beginning with the string ' ENDLOOP' is encountered. The label in columns 11-20 must match LBL, the label, defined when initializing the loop, to protect against errors. The logical unit number of the auxiliary input LIN is one higher than the original input unit number LINO. The auxiliary input file is then rewound and control is returned to the main program to execute the instructions from the auxiliary input several times in sequence (but at least once), as requested in the statement initiating the loop.

Generally, the data within a loop are copied to the auxiliary input file as is, but there are special cases:

' DELPWR ' By default, the first parameter DPW in columns 11-20 defines the percent power increment. If the second parameter PW2 in columns 21-30 is present, it represents the final percent power level at the last pass through the loop. The power increment is redefined in terms of the current relative power PWN

and the loop counter NLOOP as follows:

$$DPW = (PW2-PWR)/NLOOP$$

This makes the final power level more evident from the input and thus less susceptible to errors.

- ' DELCBO ' By analogy with ' DELPWR ', the boron concentration can be changed incrementally to simulate continuous boration or dilution. The parameter in columns 21-30 defines the final boron concentration [ppm].
- ' DELAXO ' Similarly, the prescribed axial offset can be changed incrementally. In columns 21-30 the target axial offset at the end of the total time increment is specified [%].

### 4.3 Manual for RESTRT Module of GNOMER

-----  
The contents of the COMMON blocks and the Work-fields can be dumped onto a scratch file, which serves as a restart file to resume calculations from a point at which the dump file was created. The arrays MM and AA are the work arrays in which all the variables are stored.

#### Instructions

-----  
The file FLNM is opened. The logical unit number is Abs(LBI). If LBI<0 then the file is opened as new and all the data are dumped onto it in binary form. Alternately, if LBI>0 the data are retrieved from the dump file and calculations may resume from the point where the dump file was created.

### 4.4 Manual for FILENM Module of GNOMER

-----  
The 10-character sting KEY contains either the unit number or the file type to be open. The string FLNM contains the actual filename (up to 40 characters).

When the unit number is specified, a file is opened with the assigned filename and the UNKNOWN status, what means that the file is overwritten if it exists. If the unit number is negative, the file unit ABS(KEY) is closed and no further action is taken.

The string KEY may also take one of the following forms, with appropriate meaning:

- INPUT a new input filename is opened. The unit number is set to 20 if the default keyboard input was used previously. It is incremented by 1 every time a new input file is requested. The unit number is decreased in the main program when an E-O-F is encountered. This allows nested input files to be used.
- OUTPUT if the output unit is not the default one (i.e. the terminal screen or the log-file in batch mode on VAX), the previously declared output file is closed. A new output file with the specified filename is opened.
- RCFLIB The reactivity coefficient library filename is redefined. The actual file is opened in POWERD subroutine if needed.
- DIMLIB The core dimensions library filename is redefined. The actual file is opened in POWERD subroutine if needed.
- CORLIB The CORlib file to which the results are to be written is opened with the UNKNOWN status (and the LIST carriagecontrol on VAX). If the file already exists, the records are skipped till the E-O-F filemark so that

new results are appended to the old ones.

Currently used default file units are the following:

- 3 Core dump file for restart.
- 5 Keyboard input.
- 6 Terminal screen.
- 8 Main output.
- 9 Output CORLIB file.
- 17 Fortran source GNOMEX output.
- 18 RCFLIB reactivity coefficient library file.
- 19 DIMLIB library file.
- 20+n Auxilliary input files.

These unit numbers should be avoided, unless the user is certain that they will not interfere with the options used in the program.

## 4.5 Manual for DATOPT Module of GNOMER

-----  
Diffusion module input data options are selected by the "\$\* DATOPT" keyword on input. Additional data are then read, identified by the following keywords:

' MATERIA' Enter material cross section data. Additional parameters are:

Col.	Symbol	Description
11-20	NMT	Number of materials,
21-30	NG	Number of groups in cross sect. data.
31-40	IEDH	Flag to indicate the presence of the EDH flux normalization factor.
41-50	IZP1	Number of P1 cross section components for the x, y and z-direction if IZP1 equals 1, 2 or 3, respectively. If IZP1<0, it is assumed that Abs(IZP1) P1 cross section components are present in the cross sectins, but they are not used in the calculations. If columns 41-50 are blank, the IZP1 value is left unchanged.

Cross section data follow. They are formatted 8 values per record, 10 characters per value. For group (i) the cross sections are given in order:

- DC(i) - diffusion constant
- ZA(i) - Absorption cross section(capture+fission)
- VF(i) - Neutron fission yield (nu\*SigmaFission)
- HI(i) - Group fission spectrum fraction,
- ZF(i) - Fission cross section,
- ZT(i->j) - Cross section for scattering from group (i) into group (j).

Units for the diffusion constant are [cm] and for the cross sections [1/cm].

For a particular group there are (NG+5) values given. If (NG>3) then the group cross sections occupy more than one record. There are NG such cross section sets for each material.

SPECIAL CASE:

(NMT<0) implies that columns 1-40 of the record following the ' MATERIA' card are interpreted as: either:

FLN1,FLN2 filenames from which Abs(NMT) cross sections and core conditions at which the cross sections are calculated are

read. The format for the filenames is (2A40). The format of the cross sections is the same as described above. The format for the core conditions specifications is defined below. The files are opened and closed explicitly,

or:

LUN,LU2 integer unit numbers from which the data are read.

In both cases, Abs(NMT) materials are processed. If an End-of-file is encountered, another record is read from the main input and interpreted in the same way as filenames or unit numbers and the procedure is repeated. If a read error occurs, a message is issued and program terminated.

If columns 41-80 of the main input file are non-blank, they are also interpreted as a filename from which the specific core conditions at which the cross sections were calculated are read. There are five columns of data, each of them 10 characters long. They are:

Col. 1 - 10	Burnup	[Mwd/tU],
11 - 20	Boron concentration Cb	[ppm],
21 - 30	Xenon level relative to the equill. concentration at relative power level defined in columns 51 - 60 (0=No Xe, 1=Eq. Xe)	[rel.units],
31 - 40	Fuel temperature Tf	[K],
41 - 50	Moderator temperature Tm	[K],
51 - 60	Relative power expressed as fraction of the nominal full power.	

If core conditions are specified, they must be given for all fuel-bearing regions.

NOTE: core conditions can only be specified if the cross sections are given on separate files and not on the main input file.

' BUCKLSQ' Buckling-squared (BSQ) is specified in columns 11-20. If blank is entered, buckling is assumed group-dependent. NG values are read from the following record(s) (10 characters per value, up to 8 values per record).

' BCOND ' Boundary conditions (albedo values) are read for the East,West,North,South,Bottom,Top faces, respectively. They appear in columns 11-70, 10 characters per value. IF albedo=-1, zero-flux boundary condition is implied. Always, there are 6 values read but in 2D and 1D problems the unnecessary values are ignored.

Blank entries are allowed. They are interpreted as a request to retain the previous group-1 albedo and impose its value on all other groups.

Albedo boundary conditions are internally processed to define the relation

$$J = b \cdot \Phi$$

where

$$b = \frac{1 - (1 - \text{albedo})}{a + (1 + \text{albedo})}$$

In the diffusion approximation, parameter (a=2). A transport approximation (a=2.131338) as proposed in FINELM is used by default in GNOMER. To redefine, a new value for "a" can be specified in columns 71-80.

SPECIAL CASE: If in columns 11-20 the albedo is less than -10, boundary conditions are assumed to be group

dependent. NG records of albedo values are read (6 values per record, 10 characters each)

' ZONES ' six integer values are read: NX,NY,NZ,MX,MY,MZ from columns 11-70 (10 characters per value) where:

- NX = Max.No. of nodes in the x-direction,
- NY = Max.No. of nodes in the y-direction,
- NZ = Max.No. of nodes in the z-direction,
- MX = Mesh densification factor in the x-direction,
- MY = Mesh densification factor in the y-direction,
- MZ = Mesh densification factor in the z-direction,

If not specified, mesh densification factors are assumed equal to 1. Superfluous values (in the case of 2D and 1D problems are ignored).

SPECIAL CASES:

- If NZ=0 , 2D problem is implied.
- If NZ=NY=0, 1D problem is implied.
- If NX=0 , octant symmetry is implied.
- If NX<0 , cyclic quadrant symmetry is implied.  
In this case the right-half of the core must be specified to define the core geometry.

WARNING: it is illegal to enter NX=NY=0 for 1D cases.

Additional records are expected, depending on the values of NX,NY,NZ

- If NX>0 Read NX indices of node thicknesses, 5-char. per index, up to 16 indices per record (actual thicknesses are given under the ' ZONTHIC' input option).
- If NY>0 Read NY indices of node thicknesses, 5-char. per index, up to 16 indices per record.
- If NZ>0 Read NZ indices of node thicknesses, 5-char. per index, up to 16 indices per record.

' ZONTHIC' Define all different node thicknesses that appear in the geometry definition of the problem. Number of thickness values in the x-, y- and z- direction is given in columns 11-20, 21-30 and 31-40, respectively. If mesh densification is the same in all directions, the thicknesses need not be specified for each directions, if they are the same.

The actual thicknesses are given on the next record(s), 10 characters per value, up to 8 values per record. Dimensions are [cm].

NOTE: when mesh densification is requested, the ' ZONES ' command must precede ' ZONTHIC'.

' CRODMAT' Material assignment for core location when they are rodded (See ' ZONMAT' and ' CRODPOS' for additional information). The header card contains additional parameters:

- Col. 11-20 - control rod designation (2 characters),
- 21-30 - No. of rodded assemblies of this type,
- 31-40 - No. of regions in the axial direction KZ1 (including axial reflector). This value may be omitted if ' ZONES ' command has been issued beforehand.  
If KZ1<0 the multiregion option is in effect (see description below).

For each rodded assembly, KZ1+1 parameters follow, each 5 characters long (up to 16 integer parameters per record). The first parameter defines the rodded assembly location given as 100.IY+IX where indices IY and IX correspond y- and x- coordinate numbers (with reference to the MSS array defined by the ' ZONMAT ' command. (NOTE: since the "null" edit

is specified in the READ format, location at IY=3, IX=2 must be entered as ' 302' and not ' 3 2'). Then follow NZ1 material indices for control rod material assignment, given in top-to-bottom order, including the axial reflector.

NOTE: this input option has not been tested for 1D applications. For 2D cases a single axial region is assumed (NZ1=1).

MULTI-REGION INPUT OPTION: the format of the input data is the same and Abs(KZ1) is used. From columns 41-80, KZ1 pairs of values are read MTG(i), NRG(i) each occupying 5 characters. The i-th multiregion slice means NRGi actual slices. Material indices ABS(MTj) correspond to the top slice of the multiple region. Subsequent regions are the same on locations where MTj>0. On locations where MTj<0, the material index ABS(MTj) is incremented by MTG(j). The procedure is repeated for each of the KZ1 multiple regions.

' ZONMAT ' Material assignment to nodes: this data type is a matrix MSS of NX.NY values, repeated NZ times. The entries are material indices which correspond to the sequence in which the cross section data are entered.

First NX indices are entered, 5-characters per index, up to 16 indices per record. The indices are read for each of the NY rows of nodes. The procedure is repeated NZ times for each axial slice of nodes.

Octant symmetry: it is sufficient to specify the bottom-bottom-right octant.

Cyclic quadrant symmetry: the right half of the core must be specified. Care must be taken to correctly define symmetry, since automatic checking is not available.

MULTI-REGION INPUT OPTION: the format of the input data is the same except that only NRZ axial slices of MTj values need to be specified on input. The No. of slices NRZ is read from the header record from columns 11-20. From columns 21-80, NRZ pairs of values are read MTG(i), NRG(i) each occupying 5 characters. The i-th multiregion slice means NRGi actual slices. Material indices ABS(MTj) correspond to the top slice of the multiple region. Subsequent regions are the same on locations where MTj>0. On locations where MTj<0, the material index ABS(MTj) is incremented by MTG(j). The procedure is repeated for each of the NRZ multiple regions.

NOTE: In the case of octant symmetry the format is the same as if NX=NY on entry.

WARNING: This command defines the geometry and finalizes array reservation. If ' ZONMAT ' is called several times, all information stored into the work arrays after the first call will be lost. As a rule, all commands listed above should be issued before ' ZONMAT '.

' CRODPOS ' redefines material assignment to nodes by replacing material indices in the array MSS with those that correspond to fuel assemblies with control rods.

Additional parameters define:

Col. 11-20 Control rod designation (this must match one of the entries in ' CRODMAT '), or else it may be balnk or contain the ' OVERLAP ' string. This means that the

control rods are in fixed overlap and the control rod position refers to the first control rod on the list, while other control rods are positioned according to the previously defined overlap. Note that in this case the control rod position is "effective" and may lie outside the reactor volume. WARNING: this option works correctly when control rod position is given in "steps" (see ' STEPS ' command).

21-30 No. of rodded regions in the axial To simulate control rod position where the tip of the rod is somewhere inside a region, non-integer values may be specified, but only when core conditions are specified with the cross section data. Intermediate control rod positions are simulated by mixing the rodded and unrodded cross sections in appropriate volume ratios.

A warning is printed when core conditions are not specified or when control rod regions are assigned before the cross section data are read.

31-40 Alternatively, control rod position can be expressed in terms of the depth inserted into the core, in units of length (including the reflector) or other units (steps) when conversion parameters are specified (see the ' STEPS ' command below).

WARNING: This command has the same effect as the ' ZONMAT ' command and must be issued after it.

' STEPS ' Control rod axial position conversion parameters.  
Col. Var. Description:

11-20 XRF Offset thickness (top of the core, including the reflector) at which the reference control rod position ST0 is defined.

21-30 ST0 Reference control rod position (usually the control rod position in steps at the top of the active core).

31-40 STX Scaling factor in units of "steps" per unit length. Note that this factor is negative if the "step" units decrease with control rod insertion.

' CROVRLP' Define automatic control rods overlap. It is assumed that control rods enter the core in the same sequence in which their cross section data are defined with the ' CRODMAT' command. The reference position is with the first control rod at ST0 (for definitions see the ' STEPS ' command).

Subsequent rods position ST(i) is given by  
 $ST(i) = ST(i-1) + ST0 - OVL$

where OVL is an additional parameter read from columns 11-20. The Overlap units depend on the parameters of the ' STEPS ' command. If omitted, they imply the height [cm] of a control rod above the tip of the previously inserted control rod.

At present the C.R. overlap is only accounted for when the control rod position is defined by the criticality search ICR option 3.

WARNINGS:

- Control rod material data assignment with the ' CRODMAT' and the parameters for converting control rod position to "steps" with the ' STEPS ' command must be issued before the ' CROVRLP' command.
  - The ' CROVRLP' command should be issued when no control rods are positioned in the core.
- ' PARINT ' Cross section interpolation parameters. The ordering is the same as for the ' ZONMAT ' command, except that the entries are read as real (16F5.0). The units are arbitrary and correspond to those defined in the complementary ' MATINT ' command.
- NOTE: Since the interpolation parameter is to define the difference from the 'nominal' conditions and since the units are arbitrary (i.e. can be scaled if necessary), five digits are considered sufficient to represent the interpolation parameters.

- ' MATINT ' Auxilliary cross section data for interpolation according to the value of parameters defined in the ' PARINT ' command. Additional parameters are:
- | Col.  | Var. | Description  |
|-------|------|--|
| 11-20 | MT1  | MAT. number of the cross section set at nominal conditions (defined by ' ZONMAT ' and read in the ' MATERIA' command). |
|       | NM1  | Number of additional cross section sets.   |
|       | Xnom | Nominal value of the interpolation parameter.  |
|       | Xj   | NM1 additional values of the interpolation parameter which correspond to the cross sections to be read.                |

The records that follow define the cross sections as in the ' MATERIA' command. For any region with material MT1 assigned in the ' ZONMAT ' comand the interpolation parameter (defined in ' PARINT ') is checked and the cross sections interpolated accordingly. The cross section table is extended and the corresponding MAT number is modified to point to the new cross section set.

WARNINGS:

- The cross sections table length on the first call to ' MATERIA' must be sufficiently large to accomodate the new interpolated cross sections.
  - Commands ' MATERIA', ' ZONMAT ' and ' PARINT ' must be issued before ' MATINT ' is called.
  - The ' PARINT ' and ' MATINT ' commands must be defined in the same '\$\* DATOPT ' sequence.
- ' ZP1INT ' Define region-wise average cross sections from the P1 components (if specified) by specifying the effective local region coordinates. Parameter JDM in columns 11-20 defines the number of directions, for which the local coordinates are given and is normally equal to the IZP1 parameter, defining the cross sections. Then follow NX1 values of local coordinates for the x-direction, NY1 values for the y-direction (starting on a new record), and similarly NZ1 values for the z-direction, depending on the value of JDM. The format is (16F5.0) and the local coordinate values lie within the range [-1, 1].

This option is used to simulate mesh densification when cross sections with P1 cross section components are specified, since mesh densification factors from the ' ZONES ' command can not be used in such cases. The correct procedure is to specify an

explicitly densified mesh and define the local coordinates of the subregions to modify the fission yield and the fission cross section accordingly.

Since this command explicitly generates space-dependent cross sections, the IZP1 parameter is flagged -ve to suppress the use of the P1 cross section components in the calculations.

- ' ERROR ' Iteration limits and convergence criteria:
- | Col.  | Symbol | Description:  |
|-------|--------|---|
| 11-20 | MXIT   | Max. No. of outer iterations,                                 |
| 21-30 | ERK    | Convergence crit. on K-eff [pcm],                             |
| 31-40 | ERF    | Convergence criterion on fission source distribution [%],     |
| 41-50 | NCO    | Order of Legendre polynomial flux expansion for integration,  |
| 51-60 | IPRT   | Iteration printout control:                                   |
|       |        | 0 - criticality search iterations are printed on log-file,    |
|       |        | 1 - iterations on power distribution are printed,             |
|       |        | >1 - iterations on fission source and k-eff are printed.      |
| 61-70 | MXIN   | Max.No. of inner iter. (for leakage), default 5.              |
| 71-80 | MPW    | Max.No. of iterations for power (with feedbacks), default 20. |
- ' LEBEDEV ' Define the cycle length for the Lebedev ordering of the Chebishev acceleration scheme for outer iterations. Valid entries are (column 11-20)
- NLB = 0 - No acceleration performed (default)
- 6 - Cycle length is 6
- ' SOURCE ' External source definition: NE records follow, each containing NCO+1 values (10 characters each) of the Legendre polynomial coefficients of the external neutron source for the NE nodes.
- ' CRITICL ' Criticality search is requested. The flag ICR is read from columns 11-20 and can take the following values:
- ICR = 0 - No criticality search (default=0, except when NG=6, then ICR=4 for backward compatibility),
- 1 - Critical buckling search,
  - 2 - Critical boron concentration search (applicable at non-zero power only).
  - 3 - Critical control rod position (non-zero power, control rods in overlap only).
  - 4 - Critical albedo search.
  - 5 - Critical power level.
  - 8 - Critical boron concentration at prescribed axial offset
  - 9 - Critical power level at prescribed axial offset.
- In columns 21-30 the reference "critical" K-eff may be specified if different from 1.
- If ICR=8, the prescribed axial offset [%] is defined in columns 31-40 and the convergence criterion [%] for the axial offset in columns 41-50.
- If ICR=9, additional parameters are the same as for the previous case but note that the "prescribed" axial offset will change with the corresponding power level changes such that the axial flux difference (i.e. axial offset times power) is preserved.
- ' POWERD ' Nuclear heating is in effect so additional parameters need to be specified from input.
- | Col.  | Description                                 |
|-------|---|
| 11-20 | Rel. power level [ % of nominal full power] |

21-30 boron concentration [ppm]  
 31-40 Xenon level [frac.of equill. concentration]  
 (0=NoXe, 1=Equil.Xe),  
 41-80 DIMlib filename.

If balnk, previous definitions apply. Note that power, boron conc., xenon level and DIMlib filename may be defined by alternative commands '\$\* BORON', '\$\* XENON' and '\$\* DIMLIB' from the main module. For Xenon transients the required parameters must be defined with the ' XENON ' option of DATOPT.

DIMlib is the CORD-2 library file containing relevant core parameters. Alternately, if DIMlib filename remains undefined, the required parameters can be specified on additional records from input:

Col.	Description (Record-1)	
11-20	NFP - number of fuel pins in the core	-
21-30	CFL - total core coolant mass flow rate	[kg/s]
31-40	TMIF- coolant inlet temperature at HFP	[K]
41-50	THZP- temperature at HZP	[K]
51-60	PSP - primary system pressure	[bar]
	PSD - not used	
61-70	PCH - fuel pin pitch	[cm]
71-80	RFP - fuel pellet radius	[cm]
Col.	Description (Record-2)	
11-20	DGA - gap thickness	[cm]
21-30	DCL - cladding thickness	[cm]
31-40	CMX - inter-assembly coolant mixing factor	-
41-50	RCL - active core height	[cm]
51-60	PWN - nominal core power	[W]

- ' DELPWR ' Define relative power increment. This is useful for simulating linear power ramps, in combination with the '\$\* LOOP' option of the main program. One additional parameter DPW in Col. 11-20 defines the relative power change [%].  
 For and extension of this input option see the LOOPIN module instructions.
- ' DELCBO ' Define Boron concentration increment. This is useful for constant boration/dilution rates, in combination with the '\$\* LOOP' option of the main program. One additional parameter DCB in Col. 11-20 defines the Boron concentration change [ppm].  
 For and extension of this input option see the LOOPIN module instructions.
- ' DELAXO ' Define axial offset increment. This is used in a similar way like ' DELPWR ' to define continuous changes in the axial offset, in combination with the '\$\* LOOP' option of the main program. One additional parameter DAX in Col. 11-20 defines the axial offset change [%].  
 For and extension of this input option see the LOOPIN module instructions.
- ' XENON ' Define Xenon-related parameters parameters:  
 Col. Description  
 11-20 XEN - Main Xenon flag which can take the following values:  
     1 Force equilibrium xenon,  
     0 No Xenon,  
    <0 Freeze Xenon distribution or initiate a Xenon transient (see description of DTME below).  
 21-30 DTME- Time increment [minutes] for Xenon transient calculations. Starting from the last calculated Xenon distribution a new distribution is calculated (relative to the equilibrium xenon

concentration at average nominal power) corresponding to a given power distribution (assumed constant in the time interval).

If DTME is omitted or zero, the Xenon concentration from the previous calculation is adopted.

31-40 STME- Current time. The is specified either as absolute time (minutes), or given in the format "d hh:mm" where "d" is the day, "hh" is the hour and "mm" are minutes.

41-50 NDYS- Number of days from the reference day. The user may specify the days relative to some arbitrarily chosen reference date.

- ' FLUXINI' Initialize the neutron flux distribution. One additional parameter may be specified on the command line. If it equals to one, the flux is initialized according to the default routine FGUESO. If zero, the flux values are read from input on the following records. For each group (from 1 to NG), there are NE records read, each containing NCO+1 direction-dependent neutron flux Legendre coefficients (where NE is the total number of nodes).
- ' IDXINI ' Re-initialize all indices in INDEXT and INDEXR for the work-fields MM and AA.
- ' ENDDAT ' Data processing terminated, complete data initialization and return control to the driver program.

Data are packed into integer MM and real AA work arrays. The indices of specific variables contained in the work array are stored in the common blocks INDEXT and INDEXR for arrays MM and AA, respectively. For a more detailed description of these indices see the main module.

## 4.6 Manual for PRTOU Module of GNOMER

-----  
 From the data and the results in the work field print the results to output according to the keywords specified from input:

- ' NODEDAT' Print node data, depending on the value of parameter in columns 21-30 which has the format 10\*IN + IT and the following meaning:
 

IN	IT	Requested printout (direction dependent)
0	0	Node numbering,
	1	Node types,
	2	First complement of each node,
	3	Second complement of each node,
1	1	Node materials (on fine mesh),
	2	Node size index.
- ' REGMAT ' Print node material indices.
- ' CONDENS' Perform group condensation. By default, input NG-group data are condensed to 2-groups where Coarse Group-1 boundary includes fine group (NG/2+1). Alternately, coarse group definitions (in terms of the last fine group number that belongs to a particular coarse group) are read from columns 11-80 (10 characters per value). If more than 7 coarse groups are required, another record is read. Again, columns 11-80 are processed (columns 1-10 are ignored). The values must be entered in ascending order, the last value must be equal to NG or else an error

message is issued and no condensation is activated.

' COARSE ' Specify coarse mesh over which parameter averaging is performed (power, flux, leakage, cross sections, etc). By default, mesh homogenization factor is equal to the mesh densification factor so that the results are presented on the original (coarse) mesh, given on input. Alternately, homogenization instructions can be defined explicitly by specifying for each direction three additional sets of parameters Ku1, Ku0 Ku where u implies the x, y and z direction, respectively. Each parameter set is read from a string 'aaabbbmmm' in the format (1X,3I3) so that 'aaa'=Ku1, 'bbb'=Ku0 and 'mmm'=Ku. The parameters are read from input record columns 11-20, 21-30 and 31-40 for the x, y, and z-directions, respectively, with the following meaning:

Ku1 number of coarse (i.e. homogenized) groups of nodes over which averaging is performed (each group of nodes spans over Ku nodes in direction u). By default all nodes in a row are processed.

Ku0 number of nodes in a row (or column) to skip before averageing starts (by default Ku0=0). The nodes are normally counted on the input mesh. This convention is overruled if Ku<0 in which case nodes are counted on the fine mesh (which may be denser than the input mesh if mesh densification is requested in the ' ZONES ' option in DATOPT).

The value of Ku0 may be negative to allow for symmetric quarter core configurations in which the first coarse mesh node spans only over half the normal fine mesh intervals. In such cases it is recommended to enter  $Ku0 = -|Ku|/2$  where Ku is negative to imply fine mesh node counting.

Ku mesh homogenization factor (i.e.: Ku nodes at a time are taken for averaging in that direction). The value refers to the coarse (input) mesh and any densification factors are accounted for automatically. This convention is overruled if Ku<0, in which case Abs(Ku) fine mesh nodes are considered for homogenization.

By default Ku is 1. The upper limit of Ku is truncated to the total number of nodes in that direction.

NOTE: This command can be conveniently used to extract a region of nodes for printout even when no homogenization is required.

' FINE ' Specify fine mesh over which the original solution is expanded (flux, power, neutron fission source etc). General comments and input format for the ' COARSE ' option are applicable, as well as the description for non-negative entries of Ku0 and Ku1. Parameter Ku is the fine mesh densification factor, meaning that every node is subdivided into Ku intervals in the respective direction. The printed value on output corresponds to the centre of that interval.

If Ku0<0, the first node in the corresponding direction is assumed to be a half-node (due to core symmetry). The printed results are expanded symmetrically to a full node geometry.

' POWERLG ' Print power distribution Legendre polynomial expansion coefficients, given node-wise.

' NFLUXLG ' Print neutron flux Legendre polynomial expansion coefficients, given node-wise.

' VOLUMXY ' Print node volumes ordered in the x-y direction.

' POWERXY ' Print power distribution ordered in the x-y direction.

A factor SCF may be defined in columns 11-20 by which the output quantities are multiplied before printing.

By specifying parameter LWR in columns 21-30, the power distribution may also be printed on unit Abs(LWR) in CORlib format under keyword '\$\* PWRXY'. The following conventions are observed:

LWR = 0 - Print on default output only,  
> 0 - Print on default output and unit LWR,  
< 0 - Print only on unit Abs(LWR).

NOTE: In cyclic quadrant symmetry the normalisation of the power distribution is over all assemblies included in the calculation, not taking into account the split by the symmetry lines on the core diagonal when the number of the elements across the core diameter is odd.

- ' FISSNXY' Print fission neutron source distribution ordered in the x-y direction. Parameters SCF and LWR may be specified with same conventions as for ' POWERXY'. The corresponding CORlib keyword is '\$\* PWRXY'.
- ' NFLUXXY' Print neutron flux distribution for each group ordered in the x-y direction. Parameters SCF and LWR may be specified with same conventions as for ' POWERXY'. The corresponding CORlib keyword is '\$\* FLXXY'.
- ' TLEAKXY' Print transverse leakage distribution defined by  $L = [ (Jb) - (Ja) ] / (h)$ . The corresponding CORlib keyword is '\$\* TRLXY'.
- ' TFUELXY' Print the fuel temperature distribution ordered in the x-y direction. Parameter LWR may be specified with same conventions as for ' POWERXY'. The corresponding CORlib keyword is '\$\* TFUXY'.  
NOTE: All temperature distributions are available only when cross section data with associated core parameters are given on input. These temperatures are updated when non-zero power calculation is requested  
WARNING: when region-dependent data are homogenized and mesh densification factor > 1 for the diffusion calculation, mesh homogenization factors for node are different from those for the region data. An appropriate ' COARSE ' command must be issued before such data types are printed.  
In general, mesh densification is not recommended when thermohydraulic feedbacks are considered in the calculations.
- ' TCLADXY' Print the cladding temperature distribution ordered in the x-y direction. Parameter LWR may be specified with same conventions as for ' POWERXY'. The corresponding CORlib keyword is '\$\* TCLXY'. See also the NOTE and the WARNING for the ' TFUELXY' command.
- ' TMODEXY' Print the moderator temperature distribution ordered in the x-y direction. Parameter LWR may be specified with same conventions as for ' POWERXY'. The corresponding CORlib keyword is '\$\* TMOXY'. See also the NOTE and the WARNING for the ' TFUELXY' command.  
An additional parameter 'G' may be defined in column 11 to average moderator temperature by mass and not by volume.
- ' GMODEXY' Print the moderator density distribution ordered in the x-y direction. Parameter LWR may be specified with same conventions as for ' POWERXY'. The corresponding CORlib keyword is '\$\* GMOXY'. See also the NOTE and the WARNING for the ' TFUELXY' command.
- ' BURNX Y' Print the region burnup distribution ordered in

the x-y direction. Parameter LWR may be specified with same conventions as for ' POWERXY'. The corresponding CORlib keyword is '\$\* BRNXY'. See also the NOTE and the WARNING for the ' TFUELXY' command.

' XENONXY' Print the relative Xenon distribution in the x-y direction. Parameter LWR may be specified with same conventions as for ' POWERXY'. The corresponding CORlib keyword is '\$\* XENXY'.  
NOTE: Xenon distribution data are primarily intended for Xenon transients and are available only after such a transient is activated.

' IODINXY' Print the relative Iodine distribution in the x-y direction. Parameter LWR may be specified with same conventions as for ' POWERXY'. The corresponding CORlib keyword is '\$\* IODXY'. The same note applies as for the ' XENONXY' command.

' POWERAX' Print power distribution ordered in the z-direction. The x-y coordinates of the fuel channel are given and a vector of power distributions (bottom-to-top) follows. Parameters LWR and SCF may be specified with same conventions as for ' POWERXY'. The corresponding CORlib keyword is '\$\* PWRAX'.  
NOTE: See also the ' POWERXY' command.

' NFLUXAX' Same as ' NFLUXXY', but with different printout sequence. See comments on ' POWERAX'.

' TLEAKAX' Same as ' TLEAKXY', but with different printout sequence. See comments on ' POWERAX'.

' TFUELAX' Same as ' TFUELXY', but with different printout sequence. See comments on ' POWERAX'.

' TCLADAX' Same as ' TCLADXY', but with different printout sequence. See comments on ' POWERAX'.

' TMODEAX' Same as ' TMODEXY', but with different printout sequence. See comments on ' POWERAX'.  
The additional parameter 'G' in column 11 has the same meaning as for ' TMODEXY'.

' BURNAX' Same as ' BURNX', but with different printout sequence. See comments on ' POWERAX'.

' XENONAX' Print the relative Xenon distribution in the axial direction. Parameter LWR may be specified with same conventions as for ' POWERXY'. The corresponding CORlib keyword is '\$\* XENAX'. The same note applies as for the ' XENONXY' command.

' IODINAX' Print the relative Iodine distribution in the axial direction. Parameter LWR may be specified with same conventions as for ' POWERXY'. The corresponding CORlib keyword is '\$\* IODAX'. The same note applies as for the ' XENONXY' command.

' GMODEAX' Same as ' GMODEXY', but with different printout sequence. See comments on ' POWERAX'.

' XSMATER' Print the cross sections to output  
Four additional parameters are defined in columns:  
11-20 output unit number for the core region conditions file (i.e. the \*.XSP file),  
21-30 output unit number for the cross sections,  
31-40 index of the first material to be printed (default=1)  
41-50 index of the last material to be printed (default - all materials)  
NOTE:  
Do not attempt to use the printed cross sections with xenon in transient in calculations with thermohydraulic feedbacks because in such case the information on the samarium concentration is lacking and the results are unpredictable (i.e. the 3-rd entry in the XSP file must be >=0).

' XSAVER' Print homogenized/condensed cross sections to output

and to cross section library on specified output unit.  
Two additional parameters are defined in columns:

11-20 entered as an integer 'cchh' where 'cc' is interpreted as the condensation flag IC and 'hh' as the homogenization flag IH with the following options:

IC=1 flux weighting (default),  
2 |B\*\*2|Phi weighting,  
3 not used,  
4 1/D (Transport x-sect.) condensation for the diffusion constant.

IH=1 flux weighting (default),  
2 not used,  
3 EDH method (Effective Diffusion Homog.) conserving reaction rates and partial currents, but relaxing the condition on average flux conservation.

NOTE: this option is applicable only if  
- the entire solution domain is to be homogenized (net current is calculated from the neutron balance and boundary flux from the albedo b.c. It is highly recommended that the same albedo is specified on all sides),  
- the output cross sections are 2-group.

4 Transport x-sect. (1/D) homogenization for the diffusion constant.

21-30 LWR to define the cross section printout unit with the same convention as for 'POWERXY'. An implied extension of the format is also available where any characters in the respective columns are right-justified and unit numbers LW2, LW1, LWR are read from columns 22-24, 25-27, 28-30, respectively. The cross sections are written to all units which are non-zero.

31-40 LXQ to define the unit number from which the pre-calculated cross sections are read for each quadrant of each cross section averaging regions in turn. A non-zero LXQ is required only when the P1 components of the spatial variation of the fission yield are to be calculated (currently limited to the x-y direction).

41-50 NQ By default, quadrants are ordered in the usual sequence (left>right, top>bottom). Entering NQ=2, averages over half-intervals are expected (left-right half planes for the x-component and top-bottom half planes for the y-component).

- ' BURNUP ' Print the current cycle burnup.
- ' BUCKLSQ' Print the group dependent buckling.
- ' BCOND ' Print the boundary conditions.
- ' BORON ' Print boron concentration.
- ' TMODINL' Print core coolant inlet temperature.  
The print parameter LWR in columns 21-30 can be specified, with the same meaning as described for the ' PWRXY' keyword.
- ' CRODPOS' Print control rod position to output.
- ' TIME ' Print the transient time to output and to log file.
- ' K-EFF ' Print the effective multiplication factor and the excess reactivity.  
The print parameter LWR in columns 21-30 can be specified, with the same meaning as described for the ' PWRXY' keyword.
- ' K-INF ' Print the infinite medium multiplication factor of

- the active core and the excess reactivity. The multiplication factor is calculated as the ratio of the fission yield and absorption reaction rates, integrated over zones containing fissile material. The print parameter LWR in columns 21-30 can be specified, with the same meaning as described for the ' PWRXY' keyword.
- ' REFSOLN' Compare the results to reference solution (for test purposes only).
  - ' REWIND ' Rewind a file where the unit number LWR is read from columns 11-20.
  - ' ENDPRT ' Results printout completed. This card must be present to return control to the main program in case any further data or calculational options are to be processed.

#### 4.7 Manual for Module GNOMEX

-----  
 This is a preliminary version of the module for generating a simple driver for the GNOME0 routine which solves the neutron diffusion equation. It uses the information stored in the variables and the work arrays as set by the regular input options of GNOMER. The FORTRAN source code, which is written on Unit-17 serves as an example of how to use GNOME0 as a stand-alone module for use in other codes. It is also useful when repetitive calculations are required in which only the cross sections change while geometry definition and other constants remain the same.

Note that with this reduced code no criticality search or power distributions with thermohydraulic feedbacks may be calculated.

## 5 References

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- [4] A.Trkov, M.Ravnik: *Effective Diffusion Homogenization of Cross Sections for Pressurized Water Reactor Core Calculations*, Nucl.Sci.Enging., 116, 2, pp.86-95, (1994).
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# APPENDIX

## A Test case specifications

### A.1 IAEA-2D Benchmark

The test is one of the most widely applied benchmarks [3] for neutron diffusion codes. It demonstrates a simple 2D calculation of the multiplication factor and the core power distribution. The default units (Unit-5 and 6) are used to assign the input and output filenames (note that the input file must begin with a valid command, namely with the "\$\* " string in the first record). The cross sections are read from a separate file IAEA2D.XSR. The neutron fission source distribution is compared to the benchmark reference results on IAEA2D.REF.

Supplement to Test case-1 is the generation of the GNOMEX code Fortran source on GNOMEX.FOR for the IAEA2D benchmark problem geometry. GNOMEX is a simple driver for the GNOME0 diffusion solution module for the geometry as defined in the regular GNOMER input commands (IAEA-2D benchmark geometry in this case). The only required input then are the cross sections. Note that GNOMEX must be linked with the GNOME0, XKEFFZ, FORLIB, CORLIB and CPTIME decks of GNOMER.

Input instructions for the Test case-1 are listed below.

```

$* COMMENT IAEA-2D Benchmark problem

                                Main input data (geometry and cross section specifications)
$* DATOPT
MATERIA      -4      2      0
IAEA2D.XSR
BUCKLSQ     0.8E-4
BCOND       1.      0.      1.      0.
ZONES       0      9      0      1      1      1
  1  2      2  2  2  2  2  2  2
ZONTHIC     2      0
  10.      20.
ZONMAT
  3  2      2  2  3  2  2  1  4
  2  2      2  2  2  2  2  1  4
  2  2      2  2  2  2  1  1  4
  2  2      2  2  2  2  1  4  4
  3  2      2  2  3  1  1  4
  2  2      2  2  1  1  1  4  4
  2  2      1  1  1  4  4
  1  1      1  4  4  4
  4  4      4  4
ERROR       90      0.05      0.002      3
LEBEDEV     6
ENDDAT

                                Solve the diffusion equation
$* POWERD
                                Generate GNOMEX source for this problem
$* FILENM      21GNOMEX.FOR
$* GNOMEX

                                Printout options
$* PRTOUT
FISSNXY
REFSOLN IAEA2D.REF
K-EFF
ENDPRT
$* END
```



```

4 4 4 4 4 4 4 4
4 4 4 4 4 4 4
4 4 4 4 4 4
4 4 4 4
CRODPOS A 5
ERROR 170 0.05 0.002 3
LEBEDEV 6
ENDDAT
Solve the diffusion equation
$* POWERD
Printout options
$* PRTOUT
K-EFF
Print the radially averaged axial power distribution
COARSE 99 99 0
FISSNXY
Print the axially averaged assembly power distribution
COARSE 0 0 99
FISSNXY
Compare the results with the reference solution.
NOTE: The solution is given for all nodes in the core
but for the simplicity of output, only the axial
average is considered. The above defined COARSE
option applies to the reference solution also.
REFSOLN IAEA3D.REF
Print the multiplication factor
K-EFF
ENDPRT
$* END

```

### A.3 Fuel Assembly Cross Section Homogenization

The test demonstrates the calculation of fuel assembly effective diffusion homogenized cross sections by the EDH method and with a critical albedo search. Cell cross sections and the corresponding diffusion solution are given in 10 energy groups. Condensation to 2-groups is performed. As an example, only a sequence of three assemblies is given: an unrodded assembly, one containing burnable poison rods and a rodded assembly. In real calculation, homogenization may be performed for a sequence including all axial regions of all assemblies in the core.

```

$* FILENM      OUTPUT  FASXSA.OUT
$* FILENM      7      FASXSA.XSR
  
```

CORD-2 fuel assembly homogenization input by FASXSA  
Input instructions for GNOMER - General parameters

```

$* DATOPT
MATERIA      4      10      -1
BCOND        1      1      1      1
ERROR        8      1.000000  0.010000  2
LEBEDEV      6
CRITICL      4
ENDDAT
  
```

Assembly: G0701  
Case : Krsko Cy01 Quarter core 10 Reg. Axial

```

$* DATOPT
MATERIA      -3      10
FG0701.XSC
WG0701.XSC
CG0701.XSC
BUCKLSQ 7.3775E-5
ZONES        16      16      0      1      1      0
  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1
  2  2  2  2  2  2  2  2  2  2  2  2  2  2  2
ZONTHIC      1      1
1.243278  1.243278
ZONMAT
  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1
  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1
  1  1  1  1  1  2  1  1  1  1  2  1  1  1  1
  1  1  1  2  1  1  1  2  1  1  1  1  2  1  1
  1  1  2  1  1  2  1  1  1  1  2  1  1  2  1
  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1
  1  1  1  1  1  1  1  2  1  1  1  2  1  1  1
  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1
  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1
  1  1  1  2  1  1  1  1  2  1  1  1  2  1  1
  1  1  1  1  1  1  2  1  1  1  2  1  1  1  1
  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1
  1  1  1  1  1  1  1  1  1  1  1  1  1  1  1
ENDDAT
$* POWERD
$* PRTOUT
K-EFF
COARSE      16      16
CONDENSE    6      10
XSAVER      3      7
ENDPRT
  
```

Assembly: G0801  
Case : Krsko Cy01 Quarter core 10 Reg. Axial

```

$* DATOPT
MATERIA      -3      10
FG0801.XSC
WG0801.XSC
  
```

```

BG0801.XSC
ZONMAT
 1  1  1  1  1  1  1  1  1  1  1  1  1  1  1
 1  1  1  1  1  1  1  1  1  1  1  1  1  1  1
 1  1  1  1  1  3  1  1  1  1  3  1  1  1  1
 1  1  1  2  1  1  1  2  1  1  1  1  2  1  1
 1  1  1  1  1  1  1  1  1  1  1  1  1  1  1
 1  1  3  1  1  2  1  1  1  1  2  1  1  3  1
 1  1  1  1  1  1  1  1  1  1  1  1  1  1  1
 1  1  1  1  1  1  1  2  1  1  1  1  2  1  1
 1  1  1  2  1  1  1  1  1  1  1  1  1  1  1
 1  1  1  1  1  1  1  1  1  1  1  1  1  1  1
 1  1  3  1  1  2  1  1  1  1  2  1  1  3  1
 1  1  1  1  1  1  1  1  1  1  1  1  1  1  1
 1  1  1  2  1  1  1  1  2  1  1  1  2  1  1
 1  1  1  1  1  3  1  1  1  1  3  1  1  1  1
 1  1  1  1  1  1  1  1  1  1  1  1  1  1  1
 1  1  1  1  1  1  1  1  1  1  1  1  1  1  1
ENDDAT
$* POWERD
$* PRTOUT
K-EFF
COARSE      16      16
CONDENSE    6      10
XSAVER      3      7
ENDPRT

```

```

Assembly:      G0901
Case :      Krsko Cy01 Quarter core 10 Reg. Axial

```

```

$* DATOPT
MATERIA      -3      10
FG0901.XSC
WG0901.XSC
CG0901.XSC
ZONMAT
 1  1  1  1  1  1  1  1  1  1  1  1  1  1  1
 1  1  1  1  1  1  1  1  1  1  1  1  1  1  1
 1  1  1  1  1  3  1  1  1  1  3  1  1  1  1
 1  1  1  3  1  1  1  3  1  1  1  1  3  1  1
 1  1  1  1  1  1  1  1  1  1  1  1  1  1  1
 1  1  3  1  1  3  1  1  1  1  3  1  1  3  1
 1  1  1  1  1  1  1  2  1  1  1  1  3  1  1
 1  1  1  3  1  1  1  1  1  1  1  1  1  1  1
 1  1  1  1  1  1  1  1  1  1  1  1  1  1  1
 1  1  3  1  1  3  1  1  1  1  3  1  1  3  1
 1  1  1  1  1  1  1  1  1  1  1  1  1  1  1
 1  1  1  3  1  1  1  1  3  1  1  1  3  1  1
 1  1  1  1  1  3  1  1  1  1  3  1  1  1  1
 1  1  1  1  1  1  1  1  1  1  1  1  1  1  1
 1  1  1  1  1  1  1  1  1  1  1  1  1  1  1
ENDDAT
$* POWERD
$* PRTOUT
K-EFF
COARSE      16      16
CONDENSE    6      10
XSAVER      3      7
ENDPRT

```

```

$* END

```

#### A.4 PWR core 3D power distribution with feedbacks

Given cross sections for 10 axial regions of each assembly in a core quadrant of a PWR, the  $k_{eff}$  and the power distribution at a particular boron concentration is calculated at hot-zero-power (HZP) conditions. In the next calculational step the power is raised to 4% and the D-bank of control rods is partly inserted into the core. Output parameters are the  $k_{eff}$ , axial offset core average axial power distribution and assembly average power distribution. A comparison with the measured assembly averaged power distribution is presented. The main input file contains only the general input instructions. The input is internally re-directed to two auxiliary input files which define the geometry and control the calculations. The auxiliary inputs describe a calculation of power distribution over a core quadrant. They are essentially the same, except for the assumed core symmetry. They are designed to demonstrate the differences in input for reflective quadrant and for cyclic quadrant symmetry. Since the assumed core loading scheme is nearly octant-symmetric, the differences in the results are practically negligible.

##### Main input file:

```

$* FILENM OUTPUT      CORXSA.OUT

                Reactivity coefficient library and output CORlib file
$* RCFLIB RCFLIB.DAT
$* CORPWR HZP3DQS.COR                      NEW

                Boron conc. at which x-sect. are tabulated
$* BORON          1435.

                Power distribution calculation (reflective quadrant symmetry)
$* FILENM INPUT      HZP3DQS.INP

                Re-initialize the work fields
$* IDXINI

                Power distribution calculation (cyclic quadrant symmetry)
$* FILENM 9          HZP3DQC.COR
$* FILENM INPUT      HZP3DQC.INP

$* END
$* FILENM          OUTPUT CORXSA.OUT
```

First auxiliary input file:

```

$* COMMENT
$* COMMENT *****
$* COMMENT * PWR Reactor Power distribution      *
$* COMMENT * HZP ARO Cb(crit)                   *
$* COMMENT * Reflective quadrant symmetry        *
$* COMMENT *****

$* DATOPT
MATERIA      -483      2      0
CORE.XSR                                CORE.XSP
REFL.XSR
CROD.XSR                                CROD.XSP
  BCOND      1.      0      1.      0      0      0
  ZONES      8      8      12      1      1      1
    1  2  2  2  2  2  2  2  2
    1  2  2  2  2  2  2  2  2
    4  3  3  4  5  5  5  5  4  3  3  4
  ZONTHIC    2      0      3
9.946224 19.89245 15.24 30.48 60.96
Control rod material assignment - ling representation
CRODMAT      D      2      12
105 371 403 402 401 400 399 398 397 396 395 394 371
501 371 463 462 461 460 459 458 457 456 455 454 371
CRODMAT      C      2      12
101 371 383 382 381 380 379 378 377 376 375 374 371
404 371 453 452 451 450 449 448 447 446 445 444 371
CRODMAT      B      2      12
103 371 393 392 391 390 389 388 387 386 385 384 371
301 371 433 432 431 430 429 428 427 426 425 424 371
CRODMAT      A      2      12
206 371 423 422 421 420 419 418 417 416 415 414 371
602 371 483 482 481 480 479 478 477 476 475 474 371
CRODMAT      SA     2      12
305 371 443 442 441 440 439 438 437 436 435 434 371
503 371 473 472 471 470 469 468 467 466 465 464 371
CRODMAT      SB     1      12
202 371 413 412 411 410 409 408 407 406 405 404 371
Core geometry and material assignment
ZONMAT      3      1  -1  10      1
371 371 371 371 371 371 371 371
371 371 371 371 371 371 371 371
371 371 371 371 371 371 371
371 371 371 371 371 371 371
371 371 371 371 371 371
371 371 371 371 371
371 371 371
-10 -20 -30 -40 -50 -60 -70 371
-80 -90 -100 -110 -120 -130 -140 371
-150 -160 -170 -180 -190 -200 373 372
-210 -220 -230 -240 -250 -260 371
-270 -280 -290 -300 -310 373 372
-320 -330 -340 -350 373 372
-360 -370 373 371 372
371 371 372
371 371 371 371 371 371 371 371
371 371 371 371 371 371 371 371
371 371 371 371 371 371 371 371
371 371 371 371 371 371 371
371 371 371 371 371 371 371
371 371 371 371 371 371
371 371 371 371 371
371 371 371 371 371
371 371 371
ERROR      220 0.2000 0.0050 3
LEBEDEV    6
POWERD     .1
CRITICL    2
ENDDAT

$* POWERD

```

```

$* PRTOUT
    Print boron conc., K-eff and Ax.offset
BORON
K-EFF          9
COARSE   1000007  1000007  2001005
POWERXY
    Print radial power distribution (axially averaged)
COARSE   7000000  7000000  1001010
POWERXY          9
    Print average axial power distributions (to output only)
COARSE   1000007  1000007  10001000
POWERAX
    Print axial power distributions for each channel (to CORlib only)
COARSE   7000000  7000000  10001000
POWERAX          -9
ENDPRT

```

```

$* COMMENT

```

```

$* COMMENT *****
$* COMMENT * PWR Reactor Power distribution *
$* COMMENT * Power 4%, D-bank 45.72 cm inserted *
$* COMMENT *****

```

```

$* DATOPT
CRITICL      0
CRODPOS      D      4
POWERD       4
ENDDAT

```

```

$* POWERD

```

```

$* PRTOUT
$* PRTOUT

```

```

    Print boron conc., K-eff and Ax.offset
BORON
K-EFF          9
COARSE   1000007  1000007  2001005
POWERXY
    Print radial power distribution (axially averaged)
COARSE   7000000  7000000  1001010
POWERXY          9
    Compare with "reference" solution
REFSOLN CORXSA.REF
    Print average axial power distributions (to output only)
COARSE   1000007  1000007  10001000
POWERAX
    Print axial power distributions for each channel (to CORlib only)
COARSE   7000000  7000000  10001000
POWERAX          -9
ENDPRT

```

Second auxiliary input file:

```

$* COMMENT
$* COMMENT *****
$* COMMENT * PWR Reactor Power distribution      *
$* COMMENT * HZP ARO Cb(crit)                    *
$* COMMENT * Cyclic quadrant symmetry            *
$* COMMENT *****

$* DATOPT
MATERIA      -483      2      0
CORE.XSR                                CORE.XSP
REFL.XSR
CROD.XSR                                CROD.XSP
BCOND        1.        0        0        0        0        0
ZONES        -1        15       12       1        1        1
  2          2          2          2          2          2          2          2
  4          3          4          5          5          4          3          4
ZONTHIC      2          0          3
9.946224    19.89245    15.24    30.48    60.96
Control rod material assignment - short representation
CRODMAT      D          3        -3        1        -1       10        1
401 371 -463 371
805 371 -463 371
1201 371 -463 371
CRODMAT      C          3        -3        1        -1       10        1
504 371 -453 371
801 371 -383 371
1104 371 -453 371
CRODMAT      B          3        -3        1        -1       10        1
601 371 -433 371
803 371 -433 371
1001 371 -433 371
CRODMAT      A          4        -3        1        -1       10        1
302 371 -483 371
706 371 -423 371
906 371 -423 371
1302 371 -483 371
CRODMAT      SA         4        -3        1        -1       10        1
403 371 -473 371
605 371 -443 371
1005 371 -443 371
1203 371 -473 371
CRODMAT      SB         2        -3        1        -1       10        1
702 371 -413 371
902 371 -413 371
Core geometry and material assignment - short representation
ZONMAT       3         1        -1       10        1
371 371 371
371 371 371 371 371
371 371 371 371 371 371 371
371 371 371 371 371 371 371 371
371 371 371 371 371 371 371 371 371
371 371 371 371 371 371 371 371 371
371 371 371 371 371 371 371 371 371
371 371 371 371 371 371 371 371
371 371 371 371 371 371
371 371 371 371 371
371 371 371
-360 -140 373 371 372
-320 -130 -200 -260 373 372
-270 -120 -190 -250 -310 373 372
-210 -110 -180 -240 -300 -350 371
-150 -100 -170 -230 -290 -340 373 372
-80 -90 -160 -220 -280 -330 -370 371
-10 -80 -150 -210 -270 -320 -360 371
-80 -90 -100 -110 -120 -130 -140 371

```



```
REFSOLN CORXSA.REF
      Print average axial power distributions (to output only)
COARSE  1000007  1007007  10001000
POWERAX
      Print axial power distributions for each channel (to CORlib only)
COARSE  7000000  7007000  10001000
POWERAX                -9
ENDPRT
```

## A.5 Henry-Worley benchmark heterogeneous solution

The test demonstrates a heterogeneous calculation where due to the simplicity of the hypothetical core geometry [5], the heterogeneities can be modelled explicitly. The core is a 5 by 5 array of assemblies, surrounded by a reflector. Due to symmetry only the bottom-right-right octant needs to be considered. An assembly can be represented by a mesh of 5 by 5 homogeneous regions. In addition, the mesh densification factor is employed so that 10 by 10 nodes per assembly are actually used in the calculation. The test also demonstrates how the coarse mesh can be defined such that the printed average power values correspond to the fuel assembly mesh, spanning over 3 assemblies, each including 10 fine mesh nodes (Note that the coarse mesh is defined on the fine mesh including mesh densification, flagged by the negative number of nodes. The coarse mesh definition would change if the mesh densification factor would change). The symmetry lines (top and left) split the assemblies along these lines into half and the central assembly into a quarter. For this reason in defining the coarse mesh options for printout, the number of nodes to be skipped is negative (half-elements span over 6 fine mesh nodes only).

```

$* FILENM      OUTPUT HWFINE.OUT
$* FILENM      9 HWM2L3.COR

$* COMMENT Henry-Worley Homogenization Benchmark (Fine-mesh M2L3)

$* DATOPT
MATERIA      3      2      0
1.4360 0.010510 0.007293 1.0      0      0 0.01596 Fuel
0.3868 0.101800 0.153100 0.      0.
1.0920 0.003185 0.      1.0      0.      Rod
0.3507 0.402100 0.      0.
1.5450 0.000444 0.      1.0      0.02838 Water
0.3126 0.008736 0.      0.
BCOND      1.      0.      1.      0.      2.0
ZONES      0      15     0      2      2      2
1 3 4 4 3 2 3 4 4 3 2 3 4 5 5
ZONTHIC      5
0.5      1.0      1.5      2.0      4.0
ZONMAT
2 2 1 1 3 3 3 1 1 2 2 2 1 3 3
2 1 1 1 1 1 3 1 1 1 2 1 1 3 3
1 1 1 1 1 1 1 1 1 1 1 1 1 3 3
1 1 1 1 1 1 1 1 1 1 1 1 1 3 3
3 1 1 1 1 2 1 1 1 1 3 1 1 3 3
3 3 1 1 2 2 2 1 1 3 3 3 1 3 3
3 1 1 1 2 1 1 1 1 3 1 1 3 3
1 1 1 1 1 1 1 1 1 1 1 1 1 3 3
1 1 1 1 1 1 1 1 1 1 1 1 1 3 3
2 1 1 1 1 3 1 1 1 2 1 1 1 3 3
2 2 1 1 3 3 3 1 1 2 2 2 1 3 3
2 1 1 1 1 3 1 1 1 2 1 1 1 3 3
1 1 1 1 1 1 1 1 1 1 1 1 1 3 3
3 3 3 3 3 3 3 3 3 3 3 3 3 3 3
3 3 3 3 3 3 3 3 3 3 3 3 3 3 3
ERROR      120     0.05     0.002     3     2     10
LEBEDEV      0
ENDDAT
$* POWERD
$* PRTOU
K-EFF      9
COARSE      3 -4-10 3 -4-10
POWERXY      9
REFSOLN HW.REF
FLUXDS      9
ENDPRT
$* END

```

## B RCFlib library format

Reactivity coefficient library RCFlib is formatted according to the conventions usually applied in the CORD-2 package. The data are given as 8-column words, 10 words per record. Each data set begins with a header record which contains a unique keyword to identify a data type. The fifth word (col.33-40) of the form " nnnTmm" defines the format. In the present case nnn is the number of rows and mm is the number of entries per row in a data set. The first entry in a row is the first argument (usually temperature or power). When coefficients are tabulated as a function of two parameters, the first row is the second argument (usually the boron concentration or the burnup). At present the following keywords are defined:

- \$\* RHOCB Boron integral worth [*pcm*], tabulated as a function of the moderator temperature [*K*] and boron concentration [*ppm*]. Note:  $1\text{ pcm} = 10^5 \Delta k/k$ .
- \$\* RHOTM Moderator temperature coefficient [*pcm/K*] tabulated as a function of the moderator temperature [*K*] and boron concentration [*ppm*].
- \$\* RHOTF Doppler coefficient [*pcm/K*] tabulated as a function of the fuel temperature [*K*] and assembly burnup [*MWd/tU*].
- \$\* RHOXE Xenon integral worth [*pcm*] tabulated as a function of the fraction of the nominal full power.

The format is best evident from the example below

```

RCFlib reactivity coefficient library (Generic data)
=====

Integral boron worth(pcm) vs. [ temp.(K) \ boron conc.(ppm) ]
$* RHOCB
          3T07
          0.   400.   700.  1000.  1500.  2000.
564.82   0.  3186.  5453.  7643. 11176. 14525.
581.87   0.  2912.  4974.  6959. 10150. 13157.

Moderator temp. coeff.(pcm/K) vs. [ Temp.(K) \ Boron conc. (ppm) ]
$* RHOTM
          6T07
          0.00  400.   700.  1000.  1500.  2000.
564.82 -49.21 -37.86 -30.89 -22.44 -12.40 -3.31
570.00 -55.28 -43.26 -35.88 -26.83 -16.15 -6.41
575.00 -62.09 -49.35 -41.58 -31.73 -20.40 -10.00
578.00 -66.61 -53.42 -45.43 -34.97 -23.26 -12.45
581.87 -72.95 -59.14 -50.86 -39.49 -27.28 -15.91

Doppler temp. coeff.(pcm/K) vs. [ Temp.(K) \ burnup(MWd/tU)]
$* RHOTF
          7T03
          0  36000
569.00 -3.51 -3.68
707.00 -3.29 -3.46
822.00 -3.10 -3.28
937.00 -2.91 -3.10
1029.00 -2.75 -2.96
1100.00 -2.63 -2.85

Integral Xe-worth(col.2:pcm) vs. Nominal power(col.1:fract.)
$* RHOXE
          14T02
          0.00  000.0
          0.10 -837.8

```

0.20	-1365.4
0.40	-1994.4
0.60	-2357.3
0.80	-2593.7
1.00	-2759.6
1.20	-2882.7
1.40	-2977.3
1.60	-3052.4
1.80	-3113.3
2.00	-3163.8
2.20	-3206.1
2.40	-3242.3