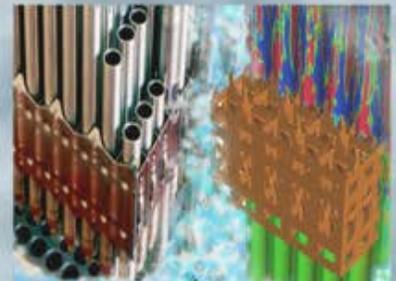
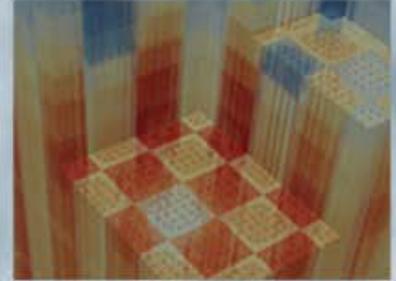


CTF – A Thermal- Hydraulic Subchannel Code for LWRs Transient Analyses

Users' Manual, Revision 0

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March 10, 2015



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Technical Report

**CTF - A Thermal-Hydraulic Subchannel Code for LWRs Transient
Analyses**

Users' Manual

Prepared by

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1 Input Manual

1.1 General remarks to input files

1.1.1 Standard CTF input file

- Input files must have the name '**deck.inp**'.
- Input files are read in a **free-formatted** way only.
- Because of the free-formatted input structure **each** of the parameters described below has to be specified in the input file (as **dummy** parameters, in case they are not used in the code).
- Lines must **not** be longer than **200** characters. Otherwise the remaining characters are truncated, which could cause reading errors.

1.2 MAIN PROBLEM CONTROL DATA (read by subroutines INPUT and COBRAI)

UNITS OF PHYSICAL QUANTITIES IN INPUT AND OUTPUT (read by subroutine INPUT)

CARD INPUT.1: ICOBRA

<u>Variable</u>	<u>Description</u>	<u>US units</u>	<u>SI units</u>
ICOBRA	Units in input and output files:	-	-
	0 - US input / SI output		
	1 - SI input / SI output		
	2 - US input / US output		
	3 - SI input / US output		

RESTART DATA (read by subroutine INPUT)

CARD INPUT.2: INITIAL, DUMPF

<u>Variable</u>	<u>Description</u>	<u>US units</u>	<u>SI units</u>
INITIAL	Vessel initialization option:	-	-
	1 - initial start Initial values are specified in Card 1.2.		
	2 - full restart (not currently working) Variable arrays are filled with data obtained from the restart file 'deck.crs'. Operating conditions, boundary conditions, and time domain data can be changed for the restart run.		

The input file for restart

- must contain CARDS INPUT.1, INPUT.2, INPUT.3, COBRA.1, and CARD GROUP 15;
- can contain CARD GROUP 1, CARD GROUP 11, CARD GROUP 12, CARD GROUP 13, CARD GROUP 14;
- must not contain CARD GROUP 2, CARD GROUP 3, CARD GROUP 4, CARD GROUP 5, CARD GROUP 6, CARD GROUP 7, CARD GROUP 8, CARD GROUP 9, CARD GROUP 10.

- 3 - Simple restart (not currently working)**
Variable arrays are filled with data obtained from the restart file 'deck.crs'. Only time domain data can be changed for the restart run.

4 - Start from External Power File

The Input file for restart

- must contain CARDS INPUT.1, INPUT.2, INPUT.3, COBRA.1, and CARD GROUP 15;
- must not contain CARD GROUP 1, ..., CARD GROUP 14.

DUMPF	Flag for restart file generation:	-	-
-------	-----------------------------------	---	---

- 0 - No restart file is generated.
- 1 - Restart file '**deck.cdm**'¹ is generated in time intervals of DMPINT (see Card 15.1) and independently from this intervals also at the end of the calculation.

The input file for this option:

- Be sure to enter the name of the external power file on the following line
- Otherwise, nothing special is done with the deck.inp file. It will look the same as if you had selected INITIAL=1.
- The format of the external power file is as follows:
 - The first line is reserved for a header. It is disposed of when read in, so don't put anything meaningful on this line.
 - The first column should be an index specifying the axial level
 - The second column should be an index specifying the rod index (Note that Rod index 1 starts at the top-left of the model and increases from left-to-right, then top-to-bottom).
 - The third column is the heat flux for that rod cell.
 - The heat fluxes have to be provided in the CTF native units of BTU/ft²-sec
 - This also means that you must consider the meshing of CTF because no interpolation is done when this file is read.
 - Note that the rod mesh will be identical to the fluid mesh at the beginning of the solution except for one difference; the rods get an extra top and bottom level of cells (see the CTF programmer guide for more details on rod meshing). DO NOT supply power for the bottom and top rod levels. The bottom rod level will automatically be set to the J=2 level in the rod, which is the first one you should supply. Likewise, the top level will be set to the J=N-1 level values, which should be the last level you supply.

CARD INPUT.2.1: POW_NAME (only read if INITIAL=4)

<u>Variable</u>	<u>Description</u>
POW_NAME	Name of the external power file

ITERATION CONTROL (read by subroutine INPUT)

WARNING: THE FOLLOWING ITERATION CONTROLS: EPSO, OITMAX, AND IITMAX, HAVE NO EFFECT ON THE SOLUTION UNLESS YOU MODEL MULTIPLE SIMULATION GROUPS (NSIM IN CARD GROUP 4). IN THAT CASE, IITMAX WILL HAVE AN EFFECT ON THE INNER ITERATION SOLUTION, BUT EPSO AND OITMAX WILL STILL HAVE NO EFFECT.

CARD INPUT.3: EPSO, OITMAX, IITMAX, COURANT

<u>Variable</u>	<u>Description</u>	<u>US units</u>	<u>SI units</u>
EPSO	Outer iteration convergence criterion: No effect on the solution, enter whatever.	-	-
OITMAX	Maximum number of outer iterations: No effect on the solution, enter whatever.	-	-
IITMAX	Maximum number of vessel iterations: Effects the solution only if NSIM>1. Suggested value of 40 in that case.	-	-

¹ During a calculation the restart file '**deck.cdm**' is **written**. For a restart calculation the file '**deck.crs**' is **read**. Therefore '**deck.cdm**' has to be copied to '**deck.crs**' before the new calculation.

COURANT	<p>The Courant number to be used in setting the timestep size. If you leave this blank, it will default to the traditional CTF value of 0.8. A suggested value for steady-state simulations is 3.0, but check the 'deck.run' file for numerical stability issues associated with the timestep becoming too large. The proper Courant value will be highly dependent on the particular case being modeled. You can also limit the timestep size using controls in Group 15.</p>	-	-
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TITLE CARD (read by subroutine COBRAI)

CARD COBRA.1 TEXT

<u>Variable</u>	<u>Description</u>	<u>US units</u>	<u>SI units</u>
TEXT	Alphanumeric information to identify the simulation (maximum 30 characters)	-	-

1.3 CARD GROUP 1: Selection of the Physical Models, Global Boundary Conditions, and Initial Conditions (read by subroutine READ_CARD_1)

CARD GROUP 1

<u>Variable</u>	<u>Description</u>	<u>US units</u>	<u>SI units</u>
NGROUP	1	-	-

SELECTION OF PHYSICAL MODELS

CARD 1.1 NGAS, IRFC, EDMOD, IMIX, ISOL, GINIT, NOTRANS, MESH, MAPS, IPROPS, MFLX, IBTM, NDUM13, NDUM14

<u>Variable</u>	<u>Description</u>	<u>US units</u>	<u>SI units</u>
NGAS	Number of non-condensable gases: 1 - minimum input value 8 - maximum number	-	-
IRFC	Rod friction factor correlation: 1 - original correlation 2 - $\lambda = 0.204 Re^{-0.2}$ 3 - $\lambda = 0.390 Re^{-0.249}$	-	-
EDMOD	Entrainment and deposition model: 0 - neither entrainment nor deposition 1 - original model	-	-
IMIX	Mixing and void drift model: 0 - neither mixing nor void drift 1 - user specified constant (two-phase) turbulent mixing coefficient 2 - single-phase mixing coefficient according to <i>Rogers and Rosehart (1972)</i> , two-phase multiplier according to <i>Beus (1970)</i> 3 - user specified constant single-phase turbulent mixing coefficient, two-phase multiplier according to <i>Beus (1970)</i>	-	-
ISOL	Solver for pressure equation: 0 - Direct Gaussian elimination <u>or</u> Iterative Gauss-Seidel solver (for pressure equation, selection by means of parameter NSIM in CARD 4.1) 3 - Iterative Krylov solver: BCGS (Bi-Conjugate Gradient Method Stabilized) 5 - Parallel iterative solver using PETSc. You must use this option if you are doing a parallel run. If you don't, CTF will set ISOL to 5 for you.	-	-
** NOTE: Solution Options 1, 2 and 4 were removed because it was discovered there were memory issues with Option 1. Since we do not test Options 2 or 4, we cannot guarantee they work right either.			
GINIT	Value of the mass flow rate to initialize mass flow rate in the entire CTF mesh. The cross-sectional area used to calculate the mass flux will be the Section 1 inlet cross-sectional area, as is done for GTOT. Enter 0.0 if you will be specifying the mass flux for initialization.	lbm/s	kg/s

NOTRANS	Flag to specify whether CTF should use TEND from Card 15 to end the simulation or if convergence criteria should instead be used to end the simulation.	-	-
	0 - Use the Card 15 transient information		
	1 - Use internal code convergence criteria		
	2 - Same as 0 except that the VTK files will be printed at each EDINT interval of the transient. If this is selected, the files will be named according to the convention, "filename.rods.vtk.N", where "N" is the number of the file.		
MESH	Flag to specify whether the deck was built with the pre-processor (deck includes meshing information) or if it wasn't (no meshing information). To output VTK files, it is necessary to provide the meshing information to the code.	-	-
	0 - No meshing information		
	1 - Meshing information provided on Cards 2.2 and new card, Card 3.3.5	-	-
MAPS	Flag to specify if Card Group 17, containing rod and channel map information necessary for writing HDF5 edits, should be read in.	-	-
	0 - Do not look for Group 17 or print HDF5 edits		
	1 - Group 17 is present, read it and produce HDF5 edit file		
IPROPS	Fluid property tables to use:		
	0 - Original CTF property tables (mix of different sources)		
	1 - IAPWS IF97 tables		
MFLX	Option to set the inlet boundary condition and the mass flow initialization using a mass flux rather than mass flow rate. If you use this option, you must set GTOT and GINIT to 0.0. CTF will use the mass flux you end up supplying to calculate GTOT and GINIT based on the channel flow areas.		
	0 - Do not specify mass flow BC as mass flux		
	1 - Specify the mass flow BC as mass flux		
IBTM	Flag to specify if Card Group 13, containing boron information necessary for applying the boron tracking and precipitation model, is read in. Additional initial data are included in Card Group 1.		
	0 - No boron tracking/precipitation model		
	1 - First order accurate upwind boron tracking model and boron precipitation model (<i>Kim's</i> correlation)		
	2 - Second order accurate Modified Godunov boron tracking model and boron precipitation model (<i>Kim's</i> correlation)		
	Boron information provided on Card Group 13 (Card 13.1 specifies the total number of vertical mesh cell boundary conditions, and Cards 13.2 and 13.3 specify the boron forcing functions; and a new Card, Card 13.11, to introduce the boron concentration as a BC). Initial boron model parameters are provided on Card 1.3		
NDUM13	Not used, but entry is obligatory:	-	-
	0 - suggested value		
NDUM14	Not used, but entry is obligatory:	-	-
	0 - suggested value		

GLOBAL BOUNDARY CONDITIONS

CARD1.2 GTOT, AFLUX, DHFRAC

<u>Variable</u>	<u>Description</u>	<u>US units</u>	<u>SI units</u>
GTOT	Total inlet mass flow rate	lbm/s	kg/s

If $GTOT \neq 0$ and the inlet boundary condition type (see CARD 13.4) is inlet mass flow rate and inlet enthalpy (BC type 2), the code will calculate subchannel mass flow rates according to the subchannels flow areas as specified in CARD 2.1 and will ignore the subchannel mass flow rates in CARD 13.4.

If $GTOT = 0$ and the inlet boundary condition type is inlet mass flow rate and inlet enthalpy (BC type 2), the user must specify subchannel mass flow rates in CARD 13.4.

Enter 0.0 if you set MFLX=1.

AFLUX	Average linear heat rate per rod To calculate AFLUX the total bundle power is divided by the total rod length multiplied by the total number of rods.	kW/ft	kW/m
DHFRAC	Fraction of local heat rate generated by the heater rods which is released directly into the coolant (As a coarse approach, the direct heat is added to the <i>liquid</i> only – not to the vapor.)	-	-
MFLUX	The inlet and initialization mass flux. Only read if MFLX=1.	lbm/s-ft ²	kg/s-m ²

INITIAL CONDITIONS

CARD1.3 PUF, HIN or TIN, HGIN, VFRAC (1), VFRAC (2), BRIN, RDIF

<u>Variable</u>	<u>Description</u>	<u>US units</u>	<u>SI units</u>
PREF	Initial pressure in the fluid domain	psi	bar
HIN	Initial enthalpy in the fluid domain	btu/lbm	kJ/kg
	or		
TIN	Initial temperature in the fluid domain If you wish to use temperature, enter it as a negative number e.g. To specify 300°C, enter -300 for TIN	°F	°C
HGIN	Enthalpy of non-condensable gas mixture	btu/lbm	kJ/kg
VFRAC (1)	Initial liquid volume fraction in the liquid-vapor-gas mixture	-	-
VFRAC (2)	Initial volume fraction of vapor in the vapor-gas mixture	-	-
BRIN	Initial boron concentration (uniform distribution)	ppm	ppm
RDIF	Boron physical diffusion coefficient	-	-
	0.0 - suggested value (First Order Upwind Scheme, IBTM=1)		
	1.0 - suggested value (Modified Goudonov Scheme, IBTM=2)		

CARD1.4 (GTYPE (I), VFRAC (I+2), I=1, NGAS)

<u>Variable</u>	<u>Description</u>	<u>US units</u>	<u>SI units</u>
GTYPE(I)	Name of non-condensable gas Available gas names: air, argo, heli, hydr, kryp, nitr, oxyg, xeno	-	-
VFRAC(I+2)	Initial volume fraction of non-condensable gas I in the vapor-gas mixture	-	-

Note 1: The initial mass flow rate is set to 0.0 by default. Therefore, a time-dependent “ramp” for the inlet mass flow rate should be applied (see description in CARD GROUP 13).

Note 2: Variables $PREF$ and HIN are used to determine the initial properties of the fluid in computational domain.

Note 3: Because the mass conservation equation for non-condensable gases is not actively solved in this version of CTF the volume fraction of vapor in the vapor-gas mixture should not be less than 0.9999!)

Note 4: Variables $BRIN$ and $RDIF$ are only read if the boron tracking/precipitation model is activated ($IBTM \neq 0$). $RDIF$ is only used when $IBTM = 2$.

1.4 CARD GROUP 2: Channel Description (read by subroutine READ_CARD_2)

CARD GROUP 2

<u>Variable</u>	<u>Description</u>	<u>US units</u>	<u>SI units</u>
NGROUP	2	-	-

CARD 2.1 NCHANL, NDUM2, NDUM3, NDUM4, NDUM5, NDUM6, NDUM7, NDUM8, NDUM9, NDUM10, NDUM11, NDUM12, NDUM13, NDUM14

<u>Variable</u>	<u>Description</u>	<u>US units</u>	<u>SI unit</u>
NCHANL	Total number of subchannels	-	-
NDUM2	Not used, but entry is obligatory: 0 - suggested value	-	-
NDUM3	Not used, but entry is obligatory: 0 - suggested value	-	-
NDUM4	Not used, but entry is obligatory: 0 - suggested value	-	-
NDUM5	Not used, but entry is obligatory: 0 - suggested value	-	-
NDUM6	Not used, but entry is obligatory: 0 - suggested value	-	-
NDUM7	Not used, but entry is obligatory: 0 - suggested value	-	-
NDUM8	Not used, but entry is obligatory: 0 - suggested value	-	-
NDUM9	Not used, but entry is obligatory: 0 - suggested value	-	-
NDUM10	Not used, but entry is obligatory: 0 - suggested value	-	-
NDUM11	Not used, but entry is obligatory: 0 - suggested value	-	-
NDUM12	Not used, but entry is obligatory: 0 - suggested value	-	-
NDUM13	Not used, but entry is obligatory: 0 - suggested value	-	-
NDUM14	Not used, but entry is obligatory: 0 - suggested value	-	-

Cards CARD 2.2 and CARD 2.3 are read in pairs NCHANL times.

CARD 2.2 I, AN(I), PW(I), ABOT(I), ATOP(I), NAMGAP (I)

<u>Variable</u>	<u>Description</u>	<u>US units</u>	<u>SI units</u>
I	Index of subchannel	-	-
AN (I)	Nominal channel area	in ²	m ²
PW (I)	Channel wetted perimeter	in	m

ABOT (I)	Area of the bottom of the channel for use in the momentum equation If ABOT (I) is entered as zero, it is set to AN (I).	in ²	m ²
ATOP (I)	Area on the top of the channel for use in the momentum equation If ATOP (I) is entered as zero, it is set to AN (I).	in ²	m ²
NAMGAP (I)	Number of gaps for which the vertical velocity of channel I convects transverse momentum between sections	-	-
*** The following data is only entered if MESH=1 (see Card 1.1)			
X(I)	The x location of the center of channel I	in	m
Y(I)	The y location of the center of channel I	in	m
XSIZ(I)	The size of channel I in the x direction	in	m
YSIZ(I)	The size of channel I in the y direction	in	m

Note 1: Do not enter PW(I) equal to zero, because in that case the calculated hydraulic diameter of the channel becomes infinite.

Note2: In case of more than one axial sections, NAMGAP(I) has to be specified different from zero and CARD 2.3 has to be specified, too, in order to get a correct momentum transfer in the last axial cell of each section. In case of only one axial section, the input values of CARD 2.3 are ignored. They are created automatically by the code. That means, NAMGAP(I) can be set to zero and CARD 2.3 can be omitted. (The procedure was not yet tested for reverse flow conditions!)

Note 3: For the meshing information, the x and y positions of the channel center are with respect to the lower left corner of the assembly (if looking from above). See Figure 1 for the definition of these terms in a graphical way. A group of 9 subchannels is shown, setup as a single assembly. The zero location is in the lower left. The four parameters are defined for channel 5. Similarly, for a core configuration, the (0,0) location will be at the lower left of the model where there may be no assemblies directly located (see Figure 2).

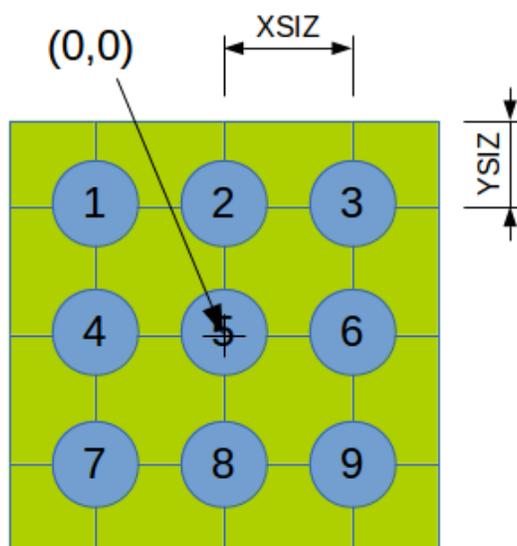


Figure 1: Definition of the X, Y, XSIZ, and YSIZ terms for Card 2.2 for a single odd assembly plus a suggestion of where the origin can be placed

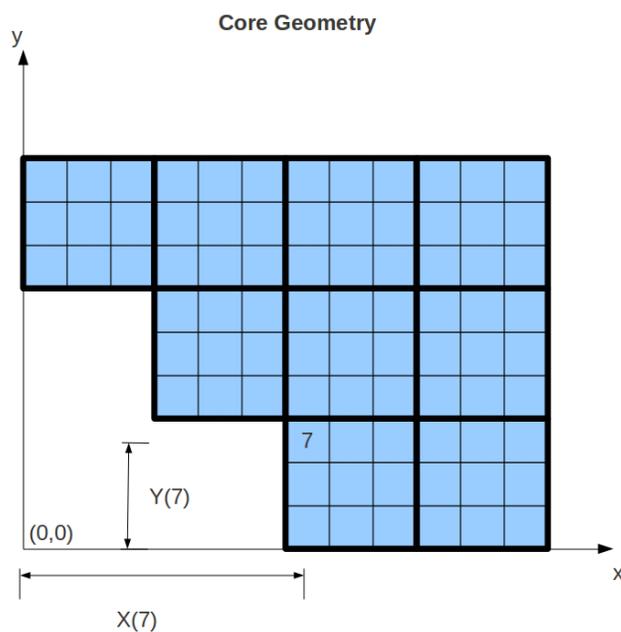


Figure 2: Definition of the (0,0) location and X and Y for core geometry

CARD 2.3 is read only, if $NAMGAP(I) > 0$ for channel I.

CARD 2.3 (INODE (I, N), KGAPB (I, N), KGAPA (I, N), N = 1, NAMGAP(I))

<u>Variable</u>	<u>Description</u>	<u>US units</u>	<u>SI units</u>
INODE (I, N)	The index number of the node where the vertical velocity of channel I convects transverse momentum across a section boundary <i>Note: INODE will be either at the bottom of the channel (INODE(I,N)=1), or the top of the channel, INODE(I,N)=NONODE+1, where NONODE is the number of axial levels in the section containing channel I. INODE is defined in the section where the vertical momentum equation is solved.</i>	-	-
KGAPB (I, N)	Index number of the gap below the section boundary: 0 - if there is no gap below the section boundary <i>Note: If KGAPB \neq 0, the positive velocity of channel I at INODE (I, N) convects transverse momentum from KGAPB into KGAPA. The negative velocity of channel I at INODE (I, N) convects transverse momentum from KGAPA into KGAPB.</i> If KGAPB = 0, this momentum is dissipated.	-	-
KGAPA (I, N)	Index number of the gap above the section boundary: 0 - if there is no gap above the section boundary <i>Note: If KGAPA \neq 0, the positive velocity of channel I at INODE(I,N) convects transverse momentum from KGAPB (if KGAPB \neq 0) into KGAPA. The negative velocity of channel I at INODE(I,N) convects transverse</i>	-	-

momentum from KGAPA to KGAPB.

If $KGAPA = 0$, this momentum is dissipated.

1.5 CARD GROUP 3: Transverse Channel Connection Data (Gap definition) (read by subroutine READ_CARD_3)

This group is omitted if there are no transverse connections between channels.

CARD GROUP 3

<u>Variable</u>	<u>Description</u>	<u>US units</u>	<u>SI units</u>
NGROUP	3	-	-

CARD 3.1 NK, NDUM2, NDUM3, NDUM4, NDUM5, NDUM6, NDUM7, NDUM8, NDUM9, NDUM10, NDUM11, NDUM12, NDUM13, NDUM14

<u>Variable</u>	<u>Description</u>	<u>US units</u>	<u>SI units</u>
NK	Total number of gaps (transverse connections between subchannels)	-	-
NDUM2	Not used, but entry is obligatory: 0 - suggested value	-	-
NDUM3	Not used, but entry is obligatory: 0 - suggested value	-	-
NDUM4	Not used, but entry is obligatory: 0 - suggested value	-	-
NDUM5	Not used, but entry is obligatory: 0 - suggested value	-	-
NDUM6	Not used, but entry is obligatory: 0 - suggested value	-	-
NDUM7	Not used, but entry is obligatory: 0 - suggested value	-	-
NDUM8	Not used, but entry is obligatory: 0 - suggested value	-	-
NDUM9	Not used, but entry is obligatory: 0 - suggested value	-	-
NDUM10	Not used, but entry is obligatory: 0 - suggested value	-	-
NDUM11	Not used, but entry is obligatory: 0 - suggested value	-	-
NDUM12	Not used, but entry is obligatory: 0 - suggested value	-	-
NDUM13	Not used, but entry is obligatory: 0 - suggested value	-	-
NDUM14	Not used, but entry is obligatory: 0 - suggested value	-	-

Cards CARD 3.2 and CARD 3.3 are read in pairs NK times.

CARD 3.2 K, IK (K), JK (K), GAPN (K), LENGTH (K), WKR (K), FWALL (K), IGAPB (K), IGAPA (K), FACTOR (K), (IGAP (K,N), JGAP (K,N), N=1,3)

<u>Variable</u>	<u>Description</u>	<u>US units</u>	<u>SI units</u>
K	Index of gap <i>Note: Gap indices must be entered sequentially, from 1 to NK. Skipping numbers is not permitted</i>	-	-
IK (K)	Identification number of the <i>lower</i> -numbered subchannel of the pair connected to gap K.	-	-
JK (K)	Identification number of the <i>higher</i> -numbered subchannel of the pair connected to gap K.	-	-
GAPN (K)	Nominal gap width	in	m
LENGTH (K)	Distance between the center of channel IK(K) and the center of subchannel JK(K)	in	m
WKR (K)	Horizontal pressure loss coefficient (velocity head) for gap K <i>Note: This ζ value can be specified for the whole gap only, i.e., not node-wise in the axial direction.</i>	-	-
FWALL (K)	Wall friction factor for the gap: 0.0 - no walls 0.5 - one wall 1.0 - two walls <i>Note: A rod bordering a gap is no wall. If one wall is determined, a wall with the surface area of $LENGTH(K)*DXS$ is assumed to be perpendicular to the gap.</i>	-	-
IGAPB (K)	Index number of the gap in the section below gap K 0 - if there is no gap below gap K The velocity of IGAPB(K) convects vertical momentum at node 1 into (or out of) channel IK(K) out of (or into) channel JK(K).	-	-
IGAPA (K)	Index number of the gap in the section above gap K 0 - if there is no gap above gap K The velocity of IGAPA(K) convects vertical momentum at the top node of the section into (or out of) channel IK(K) out of (or into) JK(K).	-	-
FACTOR (K)	Gap orientation flag: 1.0 - if gap positive flow (from channel IK(K) to channel JK(K)) is in the same direction as positive flow for the global coordinate system (default) -1.0 - if gap positive flow is opposite to positive flow for the global coordinate system	-	-
IGAP (K, N)	Gap numbers facing the IK(K) side of gap K -1 - if the gap faces a wall -(50+IK(K)) - for gaps facing a pressure source boundary condition, enter the negative sum of 50 plus the channel that has the pressure source boundary condition. -(40+IK(K)) - for gaps facing a mass source boundary condition, enter the negative of the sum of 40 and the channel that has the mass source boundary condition (note that since the value can only be between 40 and 50, this means you can only apply mass flow boundary conditions to channels 1 through 10)	-	-
JGAP (K, N)	Gap numbers facing the JK(K) side of gap K -1 - if the gap faces a wall -(50+JK(K)) - for gaps facing a pressure source boundary condition, enter the negative of 50 plus the channel that has the pressure source boundary condition. -(40+JK(K)) - for gaps facing a mass source boundary condition, enter the negative of the sum of 40 and the channel that has the mass source boundary condition (note	-	-

that since the value can only be between 40 and 50, this means you can only apply mass flow boundary conditions to channels 1 through 10)

Three sets of (IGAP, JGAP) are obligatory ($N = 1, \dots, 3$). If there are not so many gaps to specify, enter 0.

Note: The input for FACTOR, IGAP and JGAP is required only if the three-dimensional form of the transverse momentum equation is desired.

CARD 3.3 GMULT(K), ETANR(K)

<u>Variable</u>	<u>Description</u>	<u>US units</u>	<u>SI units</u>
GMULT (K)	Number of actual gaps modeled by gap K There are no internal gaps in a lumped subchannel. Only gaps lying on the interface to the neighboring lumped subchannel are regarded.	-	-
ETANR (K)	Cross-flow de-entrainment (deposition) fraction	-	-

CARD 3.3.5 is read only if meshing information is being provided (MESH=1 from CARD 1.1). It is read NK times (once for each gap in the model).

CARD 3.3.5 Gap Location Information

<u>Variable</u>	<u>Description</u>		
K	Gap number	-	-
X(K)	X location of the center of the momentum cell that makes up the gap (it will be on the face between subchannels that are connected by the gap). See Figure 1 for how the global coordinate system is setup.	in	m
Y(K)	Y location of the center of the momentum cell that makes up gap K.	in	m
NORM	The direction that flow through the gap travels (it will be either 'x' or 'y' and the orientation is with regards to the x and y directions that were shown in Figure 1)	-	-

CARD 3.4 NLMGAP

<u>Variable</u>	<u>Description</u>	<u>US units</u>	<u>SI units</u>
NLMGAP	Number of gaps that convect orthogonal transverse momentum This is required only for the three-dimensional formulation of the transverse momentum equation. 0 - if the three-dimensional form of the transverse momentum equation is not desired	-	-

CARD 3.5 is read NLMGAP times. (That means, only in case the three-dimensional form of the transverse momentum equation is applied.)

CARD 3.5 (KGAP1 (N), KGAP2 (N), KGAP3 (N), N=1, NLMGAP)

<u>Variable</u>	<u>Description</u>	<u>US units</u>	<u>SI units</u>
KGAP1 (N)	Index number of the gap whose velocity transports transverse momentum from one gap to another	-	-
KGAP2 (N)	Index number of the gap that receives the transverse momentum convected by the positive velocity of gap	-	-

	KGAP1		
	A number $\neq 0$ must be entered.		
KGAP3 (N)	Index number of the gap that the positive velocity of KGAP1 transports transverse momentum out of (The positive velocity of KGAP1 transports momentum from KGAP3 to KGAP2. Note: The negative velocity of KGAP1 will transport transverse momentum in the opposite direction; i.e., from KGAP2 into KGAP3.)	-	-
	A number $\neq 0$ must be entered.		

One set of (KGAP1, KGAP2, KGAP3) entries are specified per line. Enter a new line for each set of KGAP1, KGAP2, and KGAP3.

1.6 CARD GROUP 4: Vertical Channel Connection Data (read by subroutine SETIN)

CARD GROUP 4

<u>Variable</u>	<u>Description</u>	<u>US units</u>	<u>SI units</u>
NGROUP	4	-	-

CARD 4.1 NSECTS, NSIM, IREBAL, NDUM4, NDUM5, NDUM6, NDUM7, NDUM8, NDUM9, NDUM10, NDUM11, NDUM12, NDUM13, NDUM14

<u>Variable</u>	<u>Description</u>	<u>US units</u>	<u>SI units</u>
NSECTS	Number of sections	-	-
NSIM	Number of simultaneous solution groups	-	-
	1 - Direct Gaussian elimination (for pressure equation)		
	>1 - Iterative Gauss-Seidel solver (for pressure equation)		
IREBAL	Rebalancing option for iteration control (acceleration of convergence):	-	-
	0 - no rebalancing		
	1 - rebalancing		
	(If NSIM = 1, IREBAL will be set to 0.)		
NDUM4	Not used, but entry is obligatory:	-	-
	0 - suggested value		
NDUM5	Not used, but entry is obligatory:	-	-
	0 - suggested value		
NDUM6	Not used, but entry is obligatory:	-	-
	0 - suggested value		
NDUM7	Not used, but entry is obligatory:	-	-
	0 - suggested value		
NDUM8	Not used, but entry is obligatory:	-	-
	0 - suggested value		
NDUM9	Not used, but entry is obligatory:	-	-
	0 - suggested value		
NDUM10	Not used, but entry is obligatory:	-	-
	0 - suggested value		
NDUM11	Not used, but entry is obligatory:	-	-
	0 - suggested value		
NDUM12	Not used, but entry is obligatory:	-	-
	0 - suggested value		
NDUM13	Not used, but entry is obligatory:	-	-
	0 - suggested value		
NDUM14	Not used, but entry is obligatory:	-	-
	0 - suggested value		

Note: Within a simultaneous solution group, different solvers can be selected by means of parameter ISOL in CARD 1.1. But in case of Krylov solver (ISOL=1) it is **not** recommended to divide the computational domain into more than one simultaneous solution group.

Cards CARD 4.2, CARD 4.3, and CARD 4.4 are read in a group NSECTS times.

<u>CARD 4.2</u>	ISEC, NCHN, NONODE, DXS (ISEC,1), IVARDX		
<u>Variable</u>	<u>Description</u>	<u>US units</u>	<u>SI units</u>
ISEC	Section number Begin with section number 1 on the bottom of the vessel and proceed toward the top, incrementing ISEC by 1.	-	-
NCHN	Number of channels in section ISEC	-	-
NONODE	Number of vertical levels (continuity mesh cells <i>without</i> auxiliary lower or upper boundary cells) in section ISEC	-	-
DXS (ISEC,1)	Vertical mesh cell length in section ISEC	in	m
IVARDX	Flag for variable node length in section ISEC 0 - constant mesh cell length (default) > 0 - read IVARDX pairs in variable ΔX table (see CARD 4.3)	-	-

CARD 4.3 is read only, if IVARDX > 0.

CARD 4.3 (JLEV (I), VARDX (I), I=1, IVARDX)

<u>Variable</u>	<u>Description</u>	<u>US units</u>	<u>SI units</u>
JLEV (I)	Last axial level in section ISEC to have a node length of VARDX (I) JLEV (IVARDX) must be greater than or equal to NONODE+1.	-	-
VARDX (I)	Axial mesh cell length	in	m

Up to 5 sets of (JLEV, VARDX) may be entered. If IVARDX is greater than 5, repeat CARD 4.3 until IVARDX pairs has been entered. If IVARDX is less than 5 enter (0; 0.0) until 5 sets of (JLEV, VARDX) have been entered.

CARD 4.4 is read NCHN times for section ISEC.

CARD 4.4 I, (KCHANA (I, J), J=2,7), (KCHANB (I,J), J=2,7)

<u>Variable</u>	<u>Description</u>	<u>US units</u>	<u>SI units</u>
I	Identification number of a channel in section ISEC	-	-
KCHANA (I, J)	Indices of channels in the section above ISEC that connect to channel I. If channel I does not connect to any channels above, enter I in KCHANA (I,2). A maximum of 6 channels can be connected to channel I. If number of channels connected to channel I is less than 6, enter 0 until 6 KCHANA values have been entered.	-	-
KCHANB (I, J)	Indices of channels in the section below ISEC that connect to channel I. If channel I does not connect to any channels below, enter I in KCHANB (I,2). A maximum of 6 channels can be connected to channel I. If number of channels connected to channel I is less than 6, enter 0 until 6 KCHANB values have been entered.	-	-

CARD 4.5 IWIDE

<u>Variable</u>	<u>Description</u>	<u>US units</u>	<u>SI units</u>
IWIDE	Maximum difference between the index numbers of adjacent cells (vertical or transversal, resp.) in a simultaneous solution group (For the simplest case of only one simultaneous solution group, one section, and no sub-divided subchannels – i.e. only one mesh cell per subchannel radial direction – IWIDE is equal to the number of subchannels.)	-	-

CARD 4.6 (MSIM(I), I = 1, NSIM)

<u>Variable</u>	<u>Description</u>	<u>US units</u>	<u>SI units</u>
MSIM (I)	Last cell number in each simultaneous solution group This is the total number of continuity mesh cells within the simultaneous solution group I (number of subchannels times the number of vertical layers NONODE).	-	-

Twelve values are entered per card. If NSIM is greater than 12, repeat CARD 4.6 until NSIM values have been entered.

1.7 CARD GROUP 5: Geometry Variation Data (read by subroutine SETIN)

The input for this group allows the user to specify vertical variations in the *continuity area*, *momentum area*, or *wetted perimeter* for channels, and in the *transverse width* for gaps. It can be omitted, if such variations are not needed.

CARD GROUP 5

<u>Variable</u>	<u>Description</u>	<u>US units</u>	<u>SI units</u>
NGROUP	5	-	-

CARD 5.1 NAFACT, NAXL, NDUM3, NDUM4, NDUM5, NDUM6, NDUM7, NDUM8, NDUM9, NDUM10, NDUM11, NDUM12, NDUM13, NDUM14

<u>Variable</u>	<u>Description</u>	<u>US units</u>	<u>SI units</u>
NAFACT	Total number of geometry variation tables	-	-
NAXL	Maximum number of pairs of entries in the vertical variation tables (see CARD 5.2)	-	-
NDUM3	Not used, but entry is obligatory: 0 - suggested value	-	-
NDUM4	Not used, but entry is obligatory: 0 - suggested value	-	-
NDUM5	Not used, but entry is obligatory: 0 - suggested value	-	-
NDUM6	Not used, but entry is obligatory: 0 - suggested value	-	-
NDUM7	Not used, but entry is obligatory: 0 - suggested value	-	-
NDUM8	Not used, but entry is obligatory: 0 - suggested value	-	-
NDUM9	Not used, but entry is obligatory: 0 - suggested value	-	-
NDUM10	Not used, but entry is obligatory: 0 - suggested value	-	-
NDUM11	Not used, but entry is obligatory: 0 - suggested value	-	-
NDUM12	Not used, but entry is obligatory: 0 - suggested value	-	-
NDUM13	Not used, but entry is obligatory: 0 - suggested value	-	-
NDUM14	Not used, but entry is obligatory: 0 - suggested value	-	-

CARD 5.2 is read NAFAC T times. The tables are numbered sequentially in the code.

CARD 5.2 (JAXL (I, N), AFACT (I, N), N=1, NAXL (I))

<u>Variable</u>	<u>Description</u>	<u>US units</u>	<u>SI units</u>
JAXL (I, N)	Axial node number at which to apply the geometry variation factor for table I, point N	-	-
AFACT (I, N)	Geometry variation factor for table I, point N Whether AFACT (I, N) is applied to channel areas, wetted perimeter, or gap width, is specified in CARD 6.2.	-	-

Eight pairs of (JAXL, AFACT) are entered per card. The tables are numbered sequentially in the code. All entered tables must have a full set of NAXL pairs of (JAXL, AFACT) data.

1.8 CARD GROUP 6: Channels and Gaps Affected by Variation Tables (read by subroutine SETIN)

This group is read only if vertical variation tables have been specified in CARD GROUP 5 (with NAFAC).

CARD GROUP 6

<u>Variable</u>	<u>Description</u>	<u>US units</u>	<u>SI units</u>
NGROUP	6	-	-

CARD 6.1 N1, NDUM2, NDUM3, NDUM4, NDUM5, NDUM6, NDUM7, NDUM8, NDUM9, NDUM10, NDUM11, NDUM12, NDUM13, NDUM14

<u>Variable</u>	<u>Description</u>	<u>US units</u>	<u>SI units</u>
N1	Total number of channel and gap variation table cards to be read in CARD 6.2	-	-
NDUM2	Not used, but entry is obligatory: 0 - suggested value	-	-
NDUM3	Not used, but entry is obligatory: 0 - suggested value	-	-
NDUM4	Not used, but entry is obligatory: 0 - suggested value	-	-
NDUM5	Not used, but entry is obligatory: 0 - suggested value	-	-
NDUM6	Not used, but entry is obligatory: 0 - suggested value	-	-
NDUM7	Not used, but entry is obligatory: 0 - suggested value	-	-
NDUM8	Not used, but entry is obligatory: 0 - suggested value	-	-
NDUM9	Not used, but entry is obligatory: 0 - suggested value	-	-
NDUM10	Not used, but entry is obligatory: 0 - suggested value	-	-
NDUM11	Not used, but entry is obligatory: 0 - suggested value	-	-
NDUM12	Not used, but entry is obligatory: 0 - suggested value	-	-
NDUM13	Not used, but entry is obligatory: 0 - suggested value	-	-
NDUM14	Not used, but entry is obligatory: 0 - suggested value	-	-

CARD 6.2 is read N1 times.

CARD 6.2 IACT, IAMT, IPWT, (ICRG (M), M=1, 12)

<u>Variable</u>	<u>Description</u>	<u>US units</u>	<u>SI units</u>
IACT	Table number for geometry variation: > 0 - for subchannel <i>continuity area</i> variation < 0 - for <i>gap width</i> variation	-	-
IAMT	Table number for subchannel <i>momentum area</i> variation: 0 - if IACT < 0	-	-
IPWT	Table number for subchannel <i>wetted perimeter</i> variation:- 0 - if IACT < 0	-	-
ICRG (M)	Index numbers of the <u>subchannels</u> (if IACT > 0) <u>or gaps</u> (if IACT < 0) that the tables specified in IACT, IAMT ,and IPWT are to be applied to. Up to 12 channels or gaps may be specified per card. If the number of specified channels or gaps is greater than 12, repeat CARD 6.2 until all values have been entered. If the number of specified channels or gaps is less than 12, enter 0 until 12 values have been entered.	-	-

1.9 CARD GROUP 7: Local Pressure Loss Coefficient and Grid Spacer Data (read by subroutine READ_CARD_7)

This card group may be omitted if there are no spacers.

CARD GROUP 7

<u>Variable</u>	<u>Description</u>	<u>US units</u>	<u>SI units</u>
NGROUP	7	-	-

CARD 7.1 NCD, NGT, IFGQF, IFSDRP, IFESPV, IFTPE, IGTEMP, NFBS, IFCD, IXFLOW, NDUM11, NDUM12, NDUM13, NDUM14

<u>Variable</u>	<u>Description</u>	<u>US units</u>	<u>SI units</u>
NCD	Number of lines in CARD 7.2 specifying local spacer pressure loss coefficients. These include <i>vertical</i> pressure losses only. Transverse pressure losses are specified in CARD GROUP 3.	-	-
NGT	Number of grid types with special geometrical specification 0 - if spacers are defined via pressure loss coefficients CDL in CARD 7.2 only . >0 - if spacers are defined via geometrically modeled blockages in cards CARD 7.3 to CARD 7.9 or if spacers are modeled as heat transfer enhancements on Card 7.1.6.	-	-
IFGQF	Flag for grid quench front model: ≥1 - on <1 - off	-	-
IFSDRP	Flag for small drop model: ≥1 - on <1 - off	-	-
IFESPV	Flag for grid convective enhancement: =0 - off =1 - on for single phase vapor only =2 - on for both single-phase vapor and liquid (multiplied by the HTC calculated by Dittus-Boelter only). =3 - Simple grid modeling option with grid enhancement for both phases. If you choose this option, you do not enter Cards 7.3 through 7.5. Instead, you specify the grid enhancement locations on Card 7.1.6.	-	-
IFTPE	Flag for two-phase enhancement of dispersed flow heat transfer: ≥1 - on <1 - off	-	-
IGTEMP	Flag for grid quench calculations (see CARD 7.8): =Total number of obstructions in model (NGAL*NGCL from Card 73) =0 - off	-	- on
NFBS	Number of flow blockages	-	-
IFCD	Flag for internal calculation of grid pressure loss coefficients	-	-

	≥ 1	- on		
	< 1	- off		
IXFLOW	Flag for modeling lateral-exchange cross-flow effects caused by the spacer grids (see CARD 7.9)		-	-
	0	- no special modeling		
	1	- directed cross-flow model		
	2	- enhanced turbulence mixing model		
	3	- both models included		
NDUM11	Not used, but entry is obligatory:		-	-
	0	- suggested value		
NDUM12	Not used, but entry is obligatory:		-	-
	0	- suggested value		
NDUM13	Not used, but entry is obligatory:		-	-
	0	- suggested value		
NDUM14	Not used, but entry is obligatory:		-	-
	0	- suggested value		

CARD7.1.5 is read only if IFESPV=1, 2, or 3. It is read NGT times. All terms in this entry refer to those shown in Equation 5 below, which represents the mixing-vane form of the Yao-Hochreiter-Leech formula. The correlation values which were presented in the original Yao-Hochreiter-Leech paper are given in parentheses; however, it has been observed that the mixing-vane component of the equation does not produce accurate results. Therefore, it is suggested that the C3, C4, A, and PHI terms be set to 0.0 to disable that portion of the correlation.

SIMPLE GRID MODELING: If you do not require the advanced models offered by Cards 7.3 through 7.5, you can use the simple grid modeling option by setting IFESPV to 3 on Card 7.1, setting grid type parameters on Card 7.1.5, setting grid enhancement locations on Card 7.1.6, and entering grid loss coefficients on Card 7.2.

CARD7.1.5 is read NGT times if IFESPV>0. Enter parameters for each grid on a separate line. Line 1 will be Grid ID 1, line 2 will be Grid ID 2, and so on.

CARD7.1.5 C1(N), C2(N), C3(N), C4(N), A(N), PHI(N)

<u>Variable</u>	<u>Description</u>	<u>US units</u>	<u>SI units</u>
C1	Coefficient in Yao-Hochreiter-Leech (paper gives 5.55)	-	-
C2	Coefficient in Yao-Hochreiter-Leech (paper gives -0.13)	-	-
C3	Coefficient in Yao-Hochreiter-Leech (paper gives -0.034)	-	-
C4	Coefficient in Yao-Hochreiter-Leech (paper gives 0.4)	-	-
A	The blockage ratio normal to the flow caused by the mixing vanes	-	-
PHI	Angle of the vanes with respect to the flow direction	degrees	degrees

IF IFESPV=3, YOU ALSO MUST ENTER:

ABLOC Blockage ratio of the grid straps
 SPBLOC Blockage ratio of the grid springs

$$\frac{Nu}{Nu_0} = [1 + C_1 \varepsilon^2 e^{C_2(z/D)}][1 + A^2 \tan^2(\phi) e^{C_3(z/D)}]^{C_4} \quad (5)$$

CARD 7.1.6 is entered only if IFESPV=3. It specifies the location of each enhancement in the model. CTF will continue reading lines of Card 7.1.6 until it encounters a negative number on a new line.

<u>CARD 7.1.6</u>	GRIDTYPE	J	(CHANNEL(M), M=1,12)
<u>Variable</u>	<u>Description</u>		
GRIDTYPE	The grid type ID of this grid. Data for each grid type was entered on Card 7.1.5.		
J	The axial momentum cell that this grid type is located in.		
CHANNEL	The channel that this grid type is located in. Enter 12 channels on one line. If the grid resides in less than 12 channels for one axial level, enter 0's until 12 entries have been made.		

****NOTE:** You must enter a negative number on a new line to terminate Card 7.1.6.

CARD 7.2 is read NCD times. Do not enter this card if IFESPV=1 or 2. Enter it if IFESPV=0 or 3. Note that if you are using IFESPV, you **MUST** enter a loss coefficient for each location in the model that contains a grid type that will cause a mixing enhancement in the flow. For example, if you place Grid ID 1 at axial level 5 in channel 3, you must also enter a loss coefficient in axial level 5 and channel 3 that corresponds to that grid type. While you cannot enter fewer loss coefficients than there are enhancements to the flow, it is permissible to enter more loss coefficients than there are enhancements.

CARD7.2 CDL, J, (ICDUM (I), I=1, 12)

<u>Variable</u>	<u>Description</u>	<u>US units</u>	<u>SI units</u>
CDL	Pressure loss coefficient (vertical) of spacer	-	-
J	Node number at which the pressure loss coefficient is applied <i>Note: The vertical node number is relative to the beginning of the section containing the channel(s) listed in ICDUM (I).</i>	-	-
ICDUM (I)	Index number of channel the pressure loss coefficient will be applied to at axial node J Up to 12 channels may use the specified pressure loss coefficient CDL at vertical node J. If the number of channels is less than 12, enter 0 until 12 values have been entered.	-	-

Note: If pressure loss coefficients CDL are specified in CARD 7.2, cards CARD 7.3 to CARD 7.9 have to be omitted. (Pressure losses are specified either by ζ values or by geometrically modeled flow blockages.)

Cards CARD 7.3, CARD 7.4, and CARD 7.5 are read in groups NG = 1, NGT times. Only enter if IFESPV=1 or 2.

CARD 7.3 (ING, NGAL (NG), NGCL (NG), IGMAT (NG), GLOSS (NG), GABLOC (NG), GLONG (NG), GPERIM (NG), SPBLOC (NG), TPROBE (NG))

<u>Variable</u>	<u>Description</u>	<u>US units</u>	<u>SI units</u>
ING	Grid type number (must be sequential starting with 1)	-	-
NGAL(NG)	Number of axial locations for grid type ING (maximum = 16)	-	-
NGCL(NG)	Number of channels containing grid ING at levels NGAL	-	-
IGMAT(NG)	Grid material type index corresponding to material types in CARD GROUP 10	-	-
GLOSS(NG)	Pressure loss coefficient multiplier: 1.0 - suggested for round edge grids	-	-

1.4 - suggested for square edge grids

GABLOC(NG)	Fraction of channel area blocked by grid	-	-
GLONG(NG)	Grid length	in	m
GPERIM(NG)	Grid perimeter	in	m
SPBLOC(NG)	Ratio of the area blocked by the grid springs to the channel flow area	-	-
TPROBE(NG)	Time scale for grid quench	s	s
GTHICK(NG)	Thickness of the straps	in	m

CARD 7.4 (NNGL (NG,NN), NN=1, NGAL)

<u>Variable</u>	<u>Description</u>	<u>US units</u>	<u>SI units</u>
NNGL (NG, NN)	Axial node number of momentum cells containing grid type ING	-	-

CARD 7.5 is read NGCL (NG) times.

CARD 7.5 (NCNGL(NG,M), GMULT(NG,M), (NGROD(NG,M,L), NGSURF(NG,M,L), L = 1, 6), M = 1, NGCL(NG))

<u>Variable</u>	<u>Description</u>	<u>US units</u>	<u>SI units</u>
NCNGL (NG, M)	Channel ID number with grid type ING at axial levels NNGL (NG, NN) (specified above)	-	-
GMULT (NG, M)	Number of grids contained in channel NCNGL (NG, M)	-	-
NGROD (NG, M, L)	Whole rod number with surface surrounding grid (maximum of six)	-	-
NGSURF (NG, M, L)	Rod surface index of whole rod NGROD (NG, M, L) surrounding grid ING. Note: The average temperature of all surfaces surrounding grid is used to transport heat between grid and heater rods.	-	-

Up to 6 sets of (NGROD, NGSURF) may be entered. If the number of rods with surfaces surrounding a grid is less than 6, enter (0; 0) until 6 sets have been entered.

Cards CARD 7.6 and CARD 7.7 are read NFBS times.

CARD 7.6 IBS, IFB (IBS), JSFB (IBS), NRFB (IBS), SPOINT (IBS), DSEP (IBS), THROAT (IBS), AFLBLK (IBS), CDFB (IBS), ABLOCK (IBS) (IBS=1, ..., NFBS)

<u>Variable</u>	<u>Description</u>	<u>US units</u>	<u>SI units</u>
IBS	Flow blockage index number (Must be sequential from 1 to NFBS.)	-	-
IFB (IBS)	Channel index number	-	-
JSFB (IBS)	Axial node index number	-	-
NRFB (IBS)	Number of rods that block this channel	-	-
SPOINT (IBS)	Axial position of the flow separation point	in	m
DSEP (IBS)	Channel diameter at separation point	in	m

$$D = \sqrt{\frac{4A}{\pi}}$$

THROAT(IBS)	Diffuser diameter at exit	in	m
AFLBLK(IBS)	Area for DBM (fraction of channel) x 0.25	-	-
CDFB (IBS)	Pressure loss coefficient (Rehme multiplier)	-	-
ABLOCK(IBS)	Blockage area ratio	-	-

CARD 7.7 (NRODFB(IBS,N), KRODFB(IBS,N), ANGIHT(IBS,N), ARAIHT(IBS,N), N = 1, NRFB)

<u>Variable</u>	<u>Description</u>	<u>US units</u>	<u>SI units</u>
NRODFB (IBS, N)	Index number of rod	-	-
KRODFB (IBS, N)	Surface number	-	-
ANGIHT (IBS, N)	Angle for impact heat transfer	degrees	degrees
ARAIHT (IBS, N)	Area for impact heat transfer (per rod)	in ²	m ²

CARD 7.8 is read only if IGTEMP ≠ 0. This option bypasses the original TGRID calculation.

CARD 7.8 TGRID (I), QFGRID (I) (I= 1, IGTEMP)

<u>Variable</u>	<u>Description</u>	<u>US units</u>	<u>SI units</u>
TGRID (I)	Grid temperature	°F	°C
QFGRID (I)	Length of the quenched portion of the grid	in	m

CARD 7.9 is read only if IXFLOW ≠ 0. This is for the spacer grid induced crossflow effects.

CARD 7.9 VALUE_ANGLE, NSETS_XFLOW, NSETS_SG_MULT

<u>Variable</u>	<u>Description</u>	<u>US units</u>	<u>SI units</u>
VALUE_ANGLE	Vane angle	degrees	degrees
NSETS_XFLOW	Number of data sets in input file 'xflow_data'	-	-
NSETS_SG_MULT	Number of data sets in input file 'sg_mult_data'	-	-

If NSETS_XFLOW > 0, then external files 'xflow_data' and 'dirct_data.inp' must be placed in the current directory.

If NSETS_SG_MULT > 0, then external file 'sg_mult_data' must be placed in the current directory.

If IXFLOW (from CARD 7.1) = 1 or 3, then NSETS_XFLOW should be > 0.

If IXFLOW (from CARD 7.1) = 2 or 3, then NSETS_SG_MULT should be > 0.

Files 'xflow_data', 'dirct_data.inp', and 'sg_mult_data' are explained in the next section of this CTF Users' Manual.

1.10 CARD GROUP 8: Rod and Unheated Conductor Data (read by subroutine SETIN)

Even if not modeling any conductors, you must enter at least the Card Group number (8) and Card 8.1, specifying zero rods and zero unheated conductors.

CARD GROUP 8

<u>Variable</u>	<u>Description</u>	<u>US units</u>	<u>SI units</u>
NGROUP	8	-	-

CARD 8.1 NRROD, NSROD, NC, NRTAB, NRAD, NLTYP, NSTATE, NXF, NCAN, RADFLG, W3CF, NDUM12, NDUM13, NDUM14

<u>Variable</u>	<u>Description</u>	<u>US units</u>	<u>SI units</u>
NRROD	Number of rods	-	-
NSROD	Number of unheated conductors	-	-
NC	Conduction model flag: 0 - no conduction 1 - radial conduction only 2 - radial and axial conduction 3 - radial, axial, and azimuthal conduction Note: For unheated conductors, radial conduction is regarded at most.	-	-
NRTAB	Number of temperature initialization tables to be read in cards CARD 8.6 through CARD 8.9 ≥1 - mandatory	-	-
NRAD	Number of radiation channels 0 - if no radiation is modeled at all (in case RADFLG = 0)	-	-
NLTYP	Number of geometry types for the radiation calculations 0 - if no radiation is modeled at all (in case RADFLG = 0)	-	-
NSTATE	Flag for steady state calculation of rod temperatures 0 - full transient calculation (default) >0 - steady state solution of rod temperatures at the beginning of a calculation	-	-
NXF	Number of time steps between radiation calculations: 1 - default	-	-
NCAN	Flag for the Yamanouchi canister quench model (spray cooling after LOCA): <0 - off >0 - on	-	-
RADFLG	Flag for the radiation heat transfer calculations only: 0 - off ≠ 0 - on 2 - on, excluding fluid	-	-
W3CF	Critical heat flux (CHF) calculation option: < 0 - no correlation 0 - standard correlation (Biasi)	-	-

	1	- W3 correlation		
IHTC		Choice for the nucleate boiling model. Whichever is chosen will be used in both sub-cooled and saturated boiling regions.	-	-
	0	- Chen		
	1	- Thom		
NDUM13		Not used, but entry is obligatory:	-	-
	0	- suggested value		
NDUM14		Not used, but entry is obligatory:	-	-
	0	- suggested value		

ROD GEOMETRY DATA

Cards CARD 8.2, CARD 8.3, and CARD 8.4 are read NRROD times.

CARD 8.2 N, IFTYP (N), IAXP (N), NRENODE (N), DAXMIN (N), RMULT (N), HGAP (N), ISECR(N), HTAMB (N), TAMB (N)

<u>Variable</u>	<u>Description</u>	<u>US units</u>	<u>SI units</u>
N	Index of rod <i>Note: Rod indices must be entered sequentially, from 1 to NRROD. Skipping numbers is not permitted.</i>	-	-
IFTYP (N)	Geometry type identification number (refers to CARD GROUP 9 for geometry type input data)	-	-
IAXP (N)	Axial power profile table identification number (refers to cards CARD 11.3 and CARD 11.4 for axial power profile input data)	-	-
NRENODE (N)	Re-noding flag for heat transfer solution for rod N 0 - no fine mesh re-noding > 0 - re-noding every NRENODE (N) time steps < 0 - re-noding every NRENODE (N) time steps, based on inside surface temperatures	-	-
DAXMIN (N)	Minimum axial node size This is used only in case NRENODE \neq 0 (fine mesh re-noding).	in	m
RMULT (N)	Rod multiplication factor (number of rods modeled by the single rod N) <i>Note: This number can contain fractional parts.</i>	-	-
HGAP (N)	Constant gap conductance 0 - if rod N does not model a nuclear fuel rod <i>Note: This parameter is used only for nuclear fuel rods that do not have the dynamic gap conductance model specified by their geometry type.</i>	btu/(h ft ² °F)	W/(m ² K)
ISECR (N)	Total number of sections containing rod N	-	-
HTAMB (N)	Heat transfer coefficient for heat loss to the ambience from a surface not connected to a coolant channel <i>Note: This option is normally not related to the real fuel rod simulation. It is used in some simulations of experiments when the user wants to account for the heat loss from a non water-cooled rod to the ambience or to the medium inside the tube.</i>	btu/(h ft ² °F)	W/(m ² K)
TAMB (N)	Sink temperature for heat loss to ambience	°F	°C

Cards CARD 8.3 and CARD 8.4 are read in pairs IS = 1, ... , ISECR (N) times.

CARD 8.3 (NSCHC (IS, K), PIE (N, K), K = 1, 8)

<u>Variable</u>	<u>Description</u>	<u>US units</u>	<u>SI units</u>
NSCHC(IS,K)	Channel number with thermal connections to rod N	-	-
PIE(N, K)	Azimuthal fraction of rod N thermally connected to channel NSCHC(K)	-	-

Up to 8 sets of (NSCHC, PIE) may be entered. If the rod N is thermally connected to fewer than 8 channels, enter (0; 0.0) until 8 sets of (NSCHC, PIE) have been entered.

CARD 8.4 is read only if an inside surface for rod N exists, i.e. if NSCHC(IS,1) < 0.

NOTE: This feature does not work. If you try to utilize it, CTF will raise an exception and kill the simulation.

CARD 8.4 (NISCHC (N, IS, K), K = 1, 8)

<u>Variable</u>	<u>Description</u>	<u>US units</u>	<u>SI units</u>
NISCHC (N,IS,K)	Negative of channel number connected to the inside of azimuthal section K of rod N	-	-

UNHEATED CONDUCTOR DATA

CARD 8.5 is read NSROD times for all unheated conductors (also called “heat slabs”).

CARD 8.5 N, ISTYP (N), HPERIM (N), HPERIMI (N), RMULS (N), NOSLCH, NSLCHC, HTAMBS (N), TAMBS (N)

<u>Variable</u>	<u>Description</u>	<u>US units</u>	<u>SI units</u>
N	Index of unheated conductor <i>Note:</i> Unheated conductor indices must be entered sequentially, from 1 to NSROD. Skipping numbers is <i>not</i> permitted.	-	-
ISTYP (N)	Geometry type identification number (Refer to CARD GROUP 9 for geometry type input data.)	-	-
HPERIM (N)	Wetted perimeter on <i>outside</i> surface ² of unheated conductor N (perimeter which is applied to calculate heat transfer from the adjacent subchannel NOSLCH (see below) to the unheated conductor N) 0.0 - if no subchannels are connected to <i>outside</i> surface (NOSLCH = 0)	in	m
HPERIMI (N)	Wetted perimeter on <i>inside</i> surface of unheated conductor N (perimeter which is applied to calculate heat transfer from the adjacent subchannel NSLCHC (see below) to the unheated conductor N) 0.0 - if no subchannels are connected to <i>inside</i> surface (NSLCHC = 0)	in	m

² What the *inside* and the *outside* surface of an unheated conductor are, is only a question of definition. This is done via the specification of the adjacent subchannels (see NSLCHC and NOSLCH).

RMULS (N)	Unheated conductor multiplication factor (number of unheated conductors modeled by the single one unheated conductor N) This number can contain fractional parts.	-	-
NOSLCH	Channel number adjacent to <i>outside</i> surface of unheated conductor N 0 - if no subchannels are connected to <i>outside</i> surface	-	-
NSLCHC	Channel number adjacent to <i>inside</i> surface of unheated conductor N 0 - if no subchannels are connected to <i>inside</i> surface	-	-
HTAMBS (N)	Heat transfer coefficient for heat loss to the ambience This is used in some simulations of experiments when the user wants to account for the heat loss from the unheated conductor surfaces (tubes, walls) which are not connected to a coolant channel (not water-cooled) to the ambience (outside of the bundle, inside a water channel, inside a guide tube).	btu/(h ft ² °F)	W/(m ² K)
TAMBS (N)	Sink temperature for heat loss to the ambience	°F	°C

ROD TEMPERATURE INITIALIZATION TABLES

Cards CARD 8.6 through CARD 8.9 are read to specify which temperature tables apply to which rods and unheated conductors. The sequence is repeated NRTAB times, and all rods and conductors must be accounted for.

CARD 8.6 I, NRT1, NST1, NRAX1

<u>Variable</u>	<u>Description</u>	<u>US units</u>	<u>SI units</u>
I	Identification number of temperature table	-	-
NRT1	Number of rods using table I	-	-
NST1	Number of unheated conductors using table I	-	-
NRAX1	Number of pairs of elements in table I	-	-

CARD 8.7 is read only if NRT1 > 0.

CARD 8.7 (IRTAB (I, L), L=1, NRT1)

<u>Variable</u>	<u>Description</u>	<u>US units</u>	<u>SI units</u>
IRTAB (I, L)	Identification numbers of rods using table I for temperature initialization Enter the negative of the rod identification number if the temperature boundary is to be applied to the inside surface of the rod. <i>Note: The steady-state conduction equation is solved for these rods using the temperatures from table I as a boundary condition on the rod surface.</i>	-	-

CARD 8.8 is read only if NST1 > 0.

CARD 8.8 (ISTAB (I,L), L=1, NST1)

<u>Variable</u>	<u>Description</u>	<u>US units</u>	<u>SI units</u>
ISTAB (I, L)	Identification numbers of unheated conductors using table I for temperature initialization <i>Note: A flat radial temperature profile is assumed initially in unheated conductors.</i>	-	-

CARD 8.9 (AXIALT(I,L), TRINIT(I,L), L=1, NRAX1)

<u>Variable</u>	<u>Description</u>	<u>US units</u>	<u>SI units</u>
AXIALT(I, L)	Vertical location	in	m
TRINIT (I, L)	Temperature to be applied at AXIALT (I, L) <i>Note: The vertical locations of the bottom and top of each rod or unheated conductor using table I must be contained within the range AXIALT (I, 1) to AXIALT (I, NRAX1).</i>	°F	°C

RADIATION INITIALIZATION TABLES

Cards CARD 8.10 through CARD 8.11.5 are read in to specify orientation and which location type tables apply to which fluid channels, rods, and unheated conductors.

Channel Orientation and Location Type Card

CARD 8.10 is read NRAD times, if NRAD > 0.

CARD 8.10 IRAD, NSIDR (IRAD), LOCATE (IRAD), NRRAD (IRAD), NSYMF (IRAD), MLTF (1, IRAD), MLTF (2, IRAD), MLTF (3, IRAD), MLTF (4, IRAD), VDMLT (IRAD)

<u>Variable</u>	<u>Description</u>	<u>US units</u>	<u>SI units</u>
IRAD	Index of radiation subchannel <i>Note: Radiation subchannel indices must be entered sequentially, from 1 to NRAD. Skipping numbers is not permitted.</i>	-	-
NSIDR (IRAD)	Index of fluid subchannel which contains radiation subchannel IRAD	-	-
LOCATE (IRAD)	Location type for radiation channel IRAD: < 0 - contains no unheated conductors > 0 - has both rods and unheated conductors	-	-
NRRAD (IRAD)	Number of contributing radiation surfaces for 20 - location types 1 and 10 19 - location type 2 18 - location type 3 14 - location type 12 13 - location type 4 12 - location types 5, 13, 14, 15, 16, and 17 8 - location type 6	-	-
NSYMF	Flag for fluid channel or rod lumping.	-	-

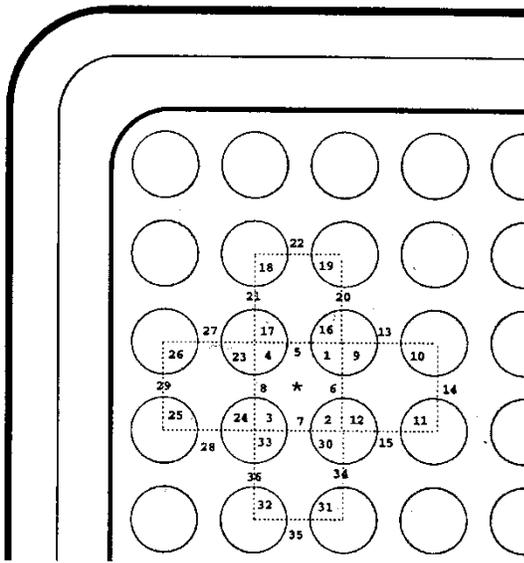
(IRAD)	0	- no lumping		
	1	- lumped fluid channels		
MLTF (1, IRAD)		Surface lumping factor for surface position 1 Ratio of total calculated to actually modelled surface areas of this rod type contained in location type IRAD times the ratio of total surface areas in all channels of this rod type to this surface area: 1.0 - default	-	-
MLTF (2, IRAD)		Surface lumping factor for surface position 2 Ratio of total calculated to actually modelled surface areas of this rod type contained in location type IRAD times the ratio of total surface areas in all channels of this rod type to this surface area: 1.0 - default	-	-
MLTF (3, IRAD)		Surface lumping factor for surface position 3 Ratio of total calculated to actually modelled surface areas of this rod type contained in location type IRAD times the ratio of total surface areas in all channels of this rod type to this surface area: 1.0 - default	-	-
MLTF (4, IRAD)		Surface lumping factor for surface position 4 Ratio of total calculated to actually modelled surface areas of this rod type contained in location type IRAD times the ratio of total surface areas in all channels of this rod type to this surface area: 1.0 - default	-	-
VDMLT (IRAD)		Vapor / droplet multiplication factor Total number of radiation channels being modeled by this location type: 1.0 - default	-	-

RADIATION CHANNEL ORIENTATION ARRAY

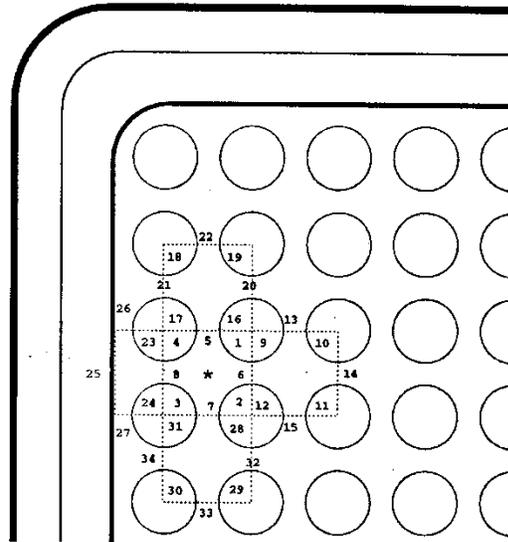
CARD 8.10.1 (LRAD (IRAD, J), J=1, NRRAD (IRAD))

<u>Variable</u>	<u>Description</u>	<u>US units</u>	<u>SI units</u>
LRAD (IRAD, J)	Surface number in position "J" for appropriate radiation subchannel IRAD corresponding to location type LOCATE (IRAD). Negative for inside surface.	-	-

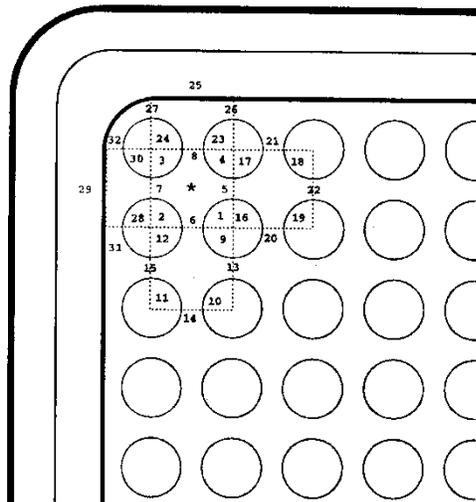
Geometry Type Summary



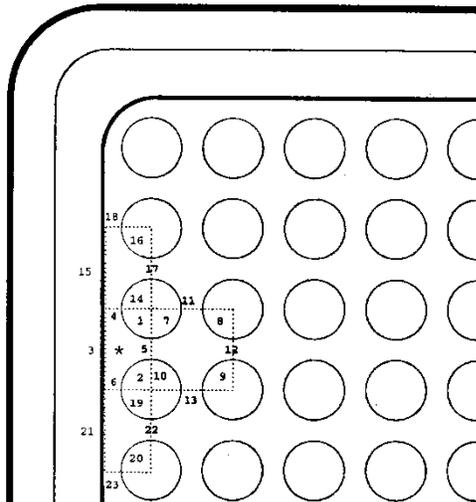
Radiation Geometry Type 1



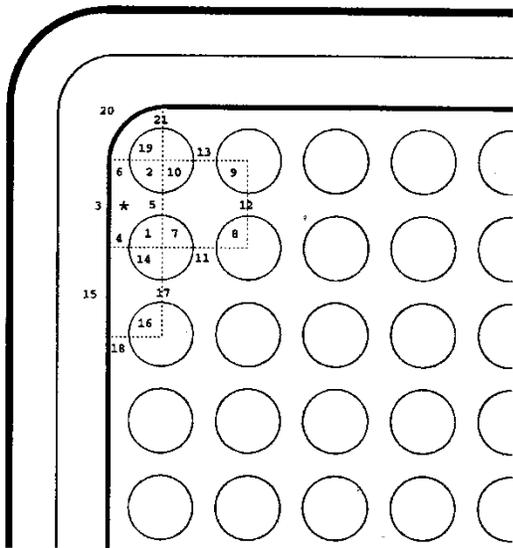
Radiation Geometry Type 2



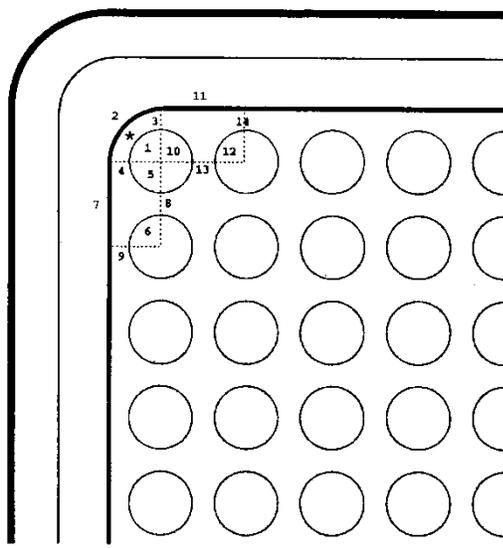
Radiation Geometry Type 3



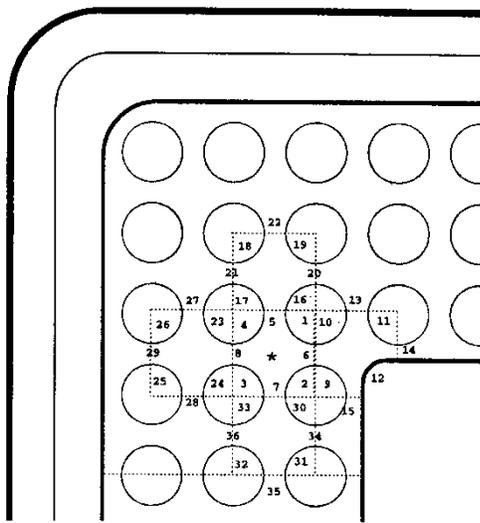
Radiation Geometry Type 4



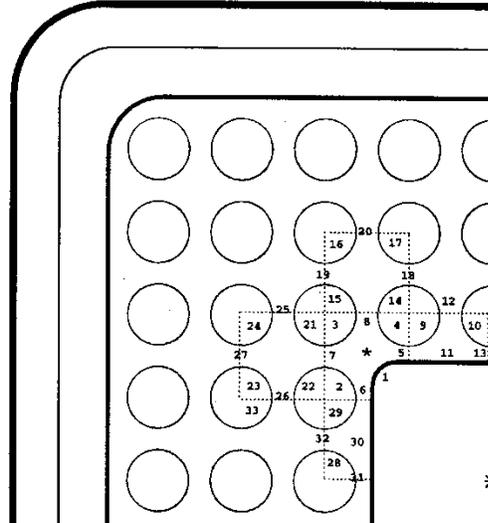
Radiation Geometry Type 5



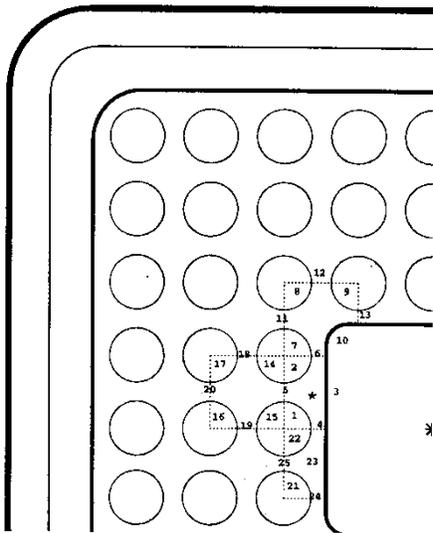
Radiation Geometry Type 6



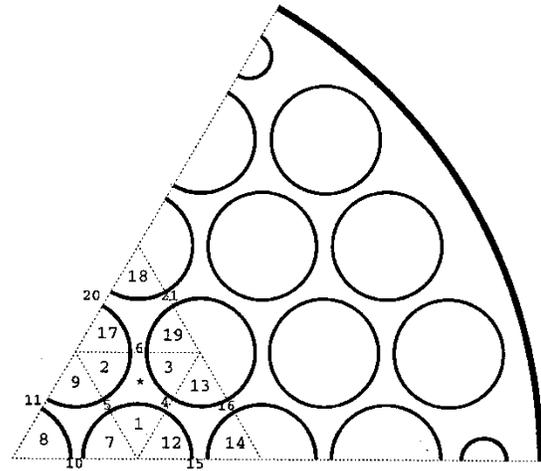
Radiation Geometry Type 10



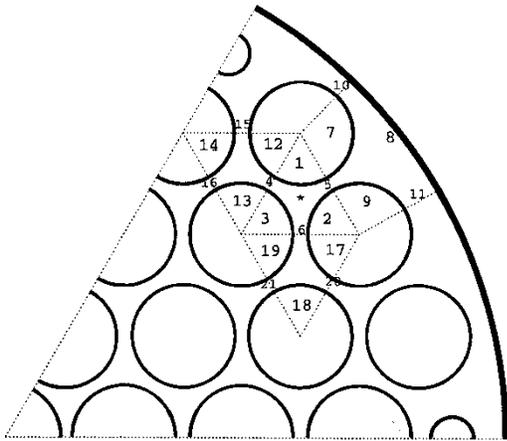
Radiation Geometry Type 11



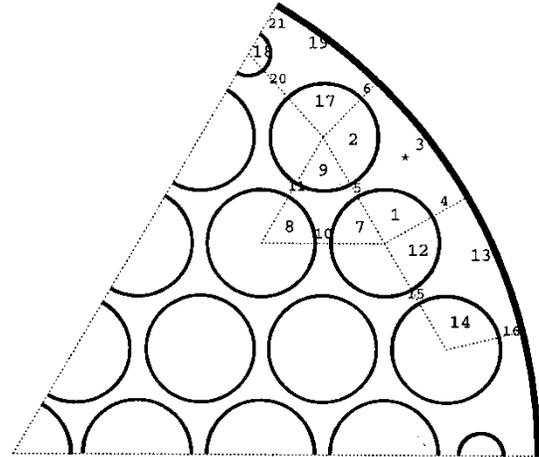
Radiation Geometry Type 12



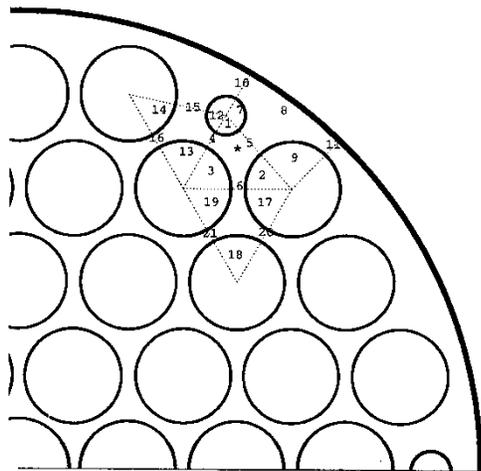
Radiation Geometry Type 13



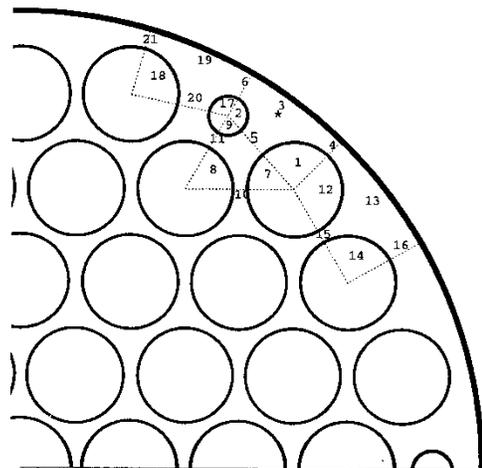
Radiation Geometry Type 14



Radiation Geometry Type 15



Radiation Geometry Type 16



Radiation Geometry Type 17

CAVITY TO CAVITY RADIATION WEIGHTING FACTOR**CARD 8.10.2** (CAVSM (IRAD, J), J=1,4)

<u>Variable</u>	<u>Description</u>	<u>US units</u>	<u>SI units</u>
CAVSM (IRAD, J)	Weighting factor to be applied to cavity to cavity radiation 1.0 - suggested value	-	-

Four records per card are required.

Repeat CARD 8.10.1 and CARD 8.10.2 until all radiation channels have been input.

RADIATION LOCATION TYPE INFORMATION**CARD 8.11** (IDTYP (I), I=1, NLTYP)

<u>Variable</u>	<u>Description</u>	<u>US units</u>	<u>SI units</u>
IDTYP (I)	Location type to be input >0 - manual input to follow <0 - auto view factor routine to be used	-	-

Manual Location Type Input

If IDTYP (I) < 0, skip cards CARD 8.11.1 through CARD 8.11.4

Area Input**CARD 8.11.1** (ARAD (J), J=1, JTOT)

JTOT is the total number of surfaces for location type IDTYP (I).

<u>Variable</u>	<u>Description</u>	<u>US units</u>	<u>SI units</u>
ARAD (J) IDTYP (I)	Surface area of position "J" for location type IDTYP (I)	in ²	cm ²

Emissivity Input**CARD 8.11.2** (ERAD (J), J=1, JTOT)

JTOT is the total number of radiant surfaces in location type IDTYP (I).

<u>Variable</u>	<u>Description</u>	<u>US units</u>	<u>SI units</u>
ERAD (J)	Emissivity of position "J" for location type IDTYP (I)	-	-

View Factor Input**CARD 8.11.3** ((FRAD(J,K), J=1, JL), K=J, JL)

JL is the total number of radiant surfaces in location type IDTYP (I).

<u>Variable</u>	<u>Description</u>	<u>US units</u>	<u>SI units</u>
Card Set 1 FRAD (1, K) Card Set 2	Radiation view factor between surface 1 and surface "K"	-	-

FRAD (2, K) Card Set "J"	Radiation view factor between surface 2 and surface "K".	-	-
FRAD (J, K)	Radiation view factor between surface "J" and surface "K", where "J" > "K"	-	-

Continue until all "J" surfaces have been input, starting each "J" surface group with a new card set. Eight records are required per card set.

Beam Length Input

CARD 8.11.4 ((DRAD (J, K), J=1, JL), K=J, JL)
JL is the total number of radiant surfaces in location type IDTYP (I).

<u>Variable</u>	<u>Description</u>	<u>US units</u>	<u>SI units</u>
Card Set 1			
DRAD (1, K) Card Set 2	Beam length between surface 1 and surface "K"	in	cm
DRAD (2, K) Card Set "J"	Beam length between surface 2 and surface "K"	in	cm
DRAD (J, K)	Beam length between surface "J" and surface "K" where "J" > "K"	in	cm

Continue until all "J" surfaces have been input, starting each "J" surface group with a new card set.

Repeat CARD 8.11 through CARD 8.11.4 until all IDTYP (I)s are input for IDTYP(I) > 0.

Auto View Factor Input

Omit if IDTYP (I) > 0.

CARD 8.11.5 (APAR (III), III = 1,10)

<u>Variable</u>	<u>Description</u>	<u>US units</u>	<u>SI units</u>
APAR (1)	First parameter for auto view factor input according to location type. See following Table.	-	-
APAR (2)	Second parameter for auto view factor input according to location type. See following Table.	-	-
APAR (3)	Third parameter for auto view factor input according to location type. See following Table.	-	-
APAR (4)	Fourth parameter for auto view factor input according to location type. See following Table.	-	-
APAR (5)	Fifth parameter for auto view factor input according to location type. See following Table.	-	-
APAR (6)	Sixth parameter for auto view factor input according to location type. See following Table.	-	-
APAR (7)	Seventh parameter for auto view factor input according to location type. See following Table.	-	-
APAR (8)	Eighth parameter for auto view factor input according to location type. See following Table.	-	-
APAR (9)	Ninth parameter for auto view factor input according to location type. See following Table.	-	-
APAR (10)	Tenth parameter for auto view factor input according to location type. See following Table.	-	-

SUMMARY OF VIEW FACTOR INPUTS**Radiation**

Channel Type	Apar1	Apar2	Apar3	Apar4	Apar5
Type 1	Rod Dia.	Rod Emiss.	Large Rod Dia.	Rod Pitch	
Type 2	Rod Dia.	Rod Emiss.	Gap between Rod & Wall	Rod Pitch	0
Type 3	Rod Dia.	Rod Emiss.		Rod Pitch	0
Type 4	Rod Dia.	Rod Emiss.		Rod Pitch	0
Type 5	Rod Dia.	Rod Emiss.		Rod Pitch	0
Type 6	Rod Dia.	Rod Emiss.		Rod Pitch	0
Type 10	Rod Dia.	Rod Emiss.	Water Ch. Corner Rad.	Rod Pitch	Half Width Water Ch.
Type 11	Rod Dia.	Rod Emiss.		Rod Pitch	
Type 12	Rod Dia.	Rod Emiss.		Rod Pitch	
Type 13	Rod 1 Dia.	Rod 1 Emiss.	Rod 2 Dia.	Rod 2 Emiss.	Rod 3 Dia.
Type 14	Rod 1 Dia.	Rod 1 Emiss.	Rod 2 Dia.	Rod 2 Emiss.	Rod 3 Dia.
Type 15	Rod 1 Dia.	Rod 1 Emiss.	Rod 2 Dia.	Rod 2 Emiss.	Rod 3 Dia.

	Apar6	Apar7	Apar8	Apar9	Apar10
Type 1					
Type 2	0	Wall Emiss.	Large Rod. Dia.		
Type 3	0	Wall Emiss.	Large Rod. Dia.		
Type 4	0	Wall Emiss.			
Type 5	0	Wall Emiss.			
Type 6	0	Wall Emiss.			
Type 10	Distance from Water Ch. Centerline to Rad. Ch. Boundary	Water Ch. Emiss.			
Type 11					
Type 12					
Type 13	Rod 3 Emiss.	Pitch 1-2	Pitch 1-3	Pitch 2-3	
Type 14	Rod 3 Emiss.	Pitch 1-3	Pitch 1-3	Pitch 2-3	
Type 15	Rod 3 Emiss.	Dist. from Tube CL to Rod 1 CL	Dist. from Tube CL to Rod 2 CL	Gap Length from Rod 1 to Tube Wall	Gap Length from Rod 2 to Tube Wall

CARD 8.12 is read only if $NCAN > 0$.

CARD 8.12 QNINIT, TLIDEN, EWET

<u>Variable</u>	<u>Description</u>	<u>US units</u>	<u>SI units</u>
QNINIT	Time at which canister quench is initiated	s	s
TLIDEN	Temperature at Leidenfrost point, at which $\frac{dq''}{d(T_{wall} - T_{sat})} = 0$	°F	°C
EWET	Emissivity of the canister	in	cm

1.11 CARD GROUP 9: Conductor Geometry Description (read by subroutine READ_CARD_9)

The geometry types are read in this group. The geometry types are numbered sequentially in the order they are read in. Nuclear rod geometry types are read using cards CARD 9.2 through CARD 9.5. All other geometry types are read using cards CARD 9.6 and CARD 9.7.

CARD GROUP 9

<u>Variable</u>	<u>Description</u>	<u>US units</u>	<u>SI units</u>
NGROUP	9	-	-

CARD 9.1 NFUEL, IRELF, ICONF, IMWR, NDUM5, NDUM6, NDUM7, NDUM8, NDUM9, NDUM10, NDUM11, NDUM12, NDUM13, NDUM14

<u>Variable</u>	<u>Description</u>	<u>US units</u>	<u>SI units</u>
NFUEL	Number of geometry types to be read Note: A geometry type may be used by both, rods and unheated conductors, but for the unheated conductor, any heat generation specified for the type will be ignored.	-	-
IRELF	Fuel relocation flag: 1 - on 0 - off This is used only for nuclear fuel rods using the dynamic gap conductance model.	-	-
ICONF	Fuel degradation flag: 1 - on 0 - off Note: If IRELF = 1, then ICONF = 1.	-	-
IMWR	Flag for metal-water reaction (zirconium dioxide only) 0 - off 1 - Cathcart (for best-estimate analysis) 2 - Baker-Just (for evaluation model analysis)	-	-
NDUM5	Not used, but entry is obligatory: 0 - suggested value	-	-
NDUM6	Not used, but entry is obligatory: 0 - suggested value	-	-
NDUM7	Not used, but entry is obligatory: 0 - suggested value	-	-
NDUM8	Not used, but entry is obligatory: 0 - suggested value	-	-
NDUM9	Not used, but entry is obligatory: 0 - suggested value	-	-
NDUM10	Not used, but entry is obligatory: 0 - suggested value	-	-
NDUM11	Not used, but entry is obligatory: 0 - suggested value	-	-
NDUM12	Not used, but entry is obligatory: 0 - suggested value	-	-
NDUM13	Not used, but entry is obligatory:	-	-

	0	- suggested value		
NDUM14	Not used, but entry is obligatory:		-	-
	0	- suggested value		

NUCLEAR FUEL GEOMETRY TYPES

Cards CARD 9.2 to CARD 9.5 are read only for nuclear fuel geometry types. If FTYPE(I) ≠ NUCL, the geometry data are interpreted by cards CARD 9.6 and CARD 9.7.

CARD 9.2 I, FTYPE (I), DROD, DFUEL (I), NFUEL, IMATF, IMATC, IMATOX (I), DCORE, TCLAD, FTDENS (I), IGPC, IGFORC, IRADP

<u>Variable</u>	<u>Description</u>	<u>US units</u>	<u>SI units</u>
I	Geometry type identification number Note: Geometry type index numbers must be entered sequentially, from 1 to NFUEL. Skipping numbers is not permitted.	-	-
FTYPE (I)	Alphanumeric geometry type flag: nucl - nuclear fuel rod	-	-
DROD	Outside rod diameter	in	m
DFUEL (I)	Fuel pellet diameter	in	m
NFUEL	Number of radial nodes in fuel pellet	-	-
IMATF	Fuel material properties flag: 0 - built-in UO ₂ properties > 0 - number of material properties table (see CARD GROUP 10)	-	-
IMATC	Clad material properties flag: 0 - built-in zirconium dioxide properties > 0 - number of material properties table (see CARD GROUP 10)	-	-
IMATOX (I)	Clad oxide property flag: 0 - built-in zirconium dioxide properties > 0 - number of material properties table (see CARD GROUP 10)	-	-
DCORE	Diameter of central void for cored fuel 0 - uncored fuel	in	m
TCLAD	Clad thickness	in	m
FTDENS (I)	Fuel theoretical density as a fraction (used only if built-in UO ₂ properties have been flagged; i.e., if IMATF = 0). <i>Note: Do not enter zero.</i>	-	-
IGPC	Gap conductance option flag: 0 - for constant gap conductance (as specified by HGAP(N) on CARD 8.2) Enter a positive integer for user-specified non-uniform gap conductance (entered on CARD 9.4 in a table of IGPC elements). Enter a negative integer for the dynamic gap conductance model. IGPC is the number of entries in the cold gap width vs axial location table, read on CARD 9.4).	-	-
IGFORC	Flag for temporal forcing function on gap conductance (valid only if IGPC > 0): 0 - constant gap conductance	-	-

	Enter a positive integer for a temporal forcing function with IGFORC table entries.		
IRADP	Number of entries in radial power profile table for the fuel pellet: 0 - uniform radial power profile	-	-

CARD 9.3 is read only if FTYPE (I) = NUCL and IGPC < 0.

CARD 9.3 PGAS (I), VPLEN (I), ROUFF (I), ROUFC (I), (GSFRAC (L), L = 1, 6), OXIDET

<u>Variable</u>	<u>Description</u>	<u>US units</u>	<u>SI units</u>
PGAS (I)	Cold pin gas pressure for nuclear fuel rod geometry type I	psia	bar
VPLEN (I)	Gas plenum volume	in ³	m ³
ROUFF (I)	Fuel pellet surface roughness	in	m
ROUFC (I)	Surface roughness of clad inner surface	in	m
	Note: Fuel and clad surface roughness should correspond to those suggested in Thurgood (1983) since the correlation is empirical: fuel surface ROUFF = 0.000085 inches clad surface ROUFC = 0.000045 inches		
GSFRAC (1)	Molar fraction of helium gas present	-	-
GSFRAC (2)	Molar fraction of xenon gas present	-	-
GSFRAC (3)	Molar fraction of argon gas present	-	-
GSFRAC (4)	Molar fraction of krypton gas present	-	-
GSFRAC (5)	Molar fraction of hydrogen gas present	-	-
GSFRAC (6)	Molar fraction of nitrogen gas present	-	-
	Note: $\sum_{L=1}^6 \text{GSFRAC (L)} = 1.000$		
OXIDET	Initial oxide thickness for the zircaloy metal-water reaction rate equation (used only if IMWR > 0)	in	m

CARD 9.4 is read only if FTYPE (I) = NUCL and |IGPC| > 0.

CARD 9.4 (AXJ (I, L), AGFACT (I, L), L = 1, |IGPC|)

<u>Variable</u>	<u>Description</u>	<u>US units</u>	<u>SI units</u>
AXJ (I, L)	Top-most vertical position, measured from the bottom of the rod, at which the cold gap width <u>or</u> the gap conductance AGFACT(I,L) is applied. (All vertical levels below AXJ(I,L) also get that value for gap width <u>or</u> gap conductance.)	in	m
AGFACT (I, L)	Cold gap width (if IGPC < 0) <u>or</u> Gap conductance (if IGPC > 0)	in btu/(h ft ² °F) W/(m ² K)	m

CARD 9.5 is read only if FTYPE (I) = NUCL and IRADP > 0.

CARD 9.5 (RADP (L), POWR (L), L = 1, IRADP) FORMAT (8F10.0)

<u>Variable</u>	<u>Description</u>	<u>US units</u>	<u>SI units</u>
RADP (L)	The relative radial location (r/r_o) where the	-	-

corresponding power factor (POWR(L)) is applied:

$$\frac{r}{r_0} = \frac{(\text{radius} - \text{DCORE}/2)}{\frac{1}{2}(\text{DFUEL} (l) - \text{DCORE})}$$

POWR (L) Relative power factor (i.e., the ratio of local power at location RADP(L) to total rod power) - -

NON-NUCLEAR GEOMETRY TYPES

Cards CARD 9.6 and CARD 9.7 are read in pairs for all geometry types that do *not* describe nuclear fuel (i.e. FTYPE(I) = HROD, TUBE, WALL).

CARD 9.6 is read only, if FTYPE (I) ≠ NUCL.

CARD 9.6 I, FTYPE (I), DROD, DIN, NFUEL, IMATOX (I), IMATIX (I), NDUM8, NDUM9, NDUM10, NDUM11, NDUM12, NDUM13, NDUM14

<u>Variable</u>	<u>Description</u>	<u>US units</u>	<u>SI units</u>
I	Geometry type identification number	-	-
FTYPE (I)	Alphanumeric geometry type flag: hrod - solid cylinder tube - hollow tube wall - flat plate	-	-
DROD	Outside diameter for HROD or TUBE geometries <u>or</u> Wetted perimeter for WALL geometries	in in	m m
DIN	Inside diameter for TUBE geometries <u>or</u> Thickness for WALL geometries <u>or</u> Entry "0.0" for HROD geometries	in in -	m m -
NFUEL	Number of radial regions within the conductor Each region has a uniform power profile and consists of one material.	-	-
IMATOX (I)	Material property table identification number for oxide on <i>outside</i> surface: 0 - built-in zirconium dioxide properties (default) > 0 - number of the material property table for material in region NFUEL if there is no oxide present (see CARD GROUP 10)	-	-
IMATIX (I)	Material property table identification number for oxide on <i>inside</i> surface (applies only to TUBE or WALL geometries, ignored for HROD and TUBEs and WALLs with fluid contact only on the outside surface): 0 - built-in zirconium dioxide properties (default) > 0 - number of the material property table for material in region 1 if there is no oxide present (see CARD GROUP 10)	-	-
NDUM8	Not used, but entry is obligatory: 0 - suggested value	-	-
NDUM9	Not used, but entry is obligatory: 0 - suggested value	-	-
NDUM10	Not used, but entry is obligatory: 0 - suggested value	-	-

NDUM11	Not used, but entry is obligatory: 0 - suggested value	-	-
NDUM12	Not used, but entry is obligatory: 0 - suggested value	-	-
NDUM13	Not used, but entry is obligatory: 0 - suggested value	-	-
NDUM14	Not used, but entry is obligatory: 0 - suggested value	-	-

The dummy values NDUM8 to NDUM14 are necessary, because CARD 9.6 uses the same read statement as CARD 9.2.

CARD 9.7 is read only if FTYPE (I) \neq NUCL. Data sets for the NFUEL regions of geometry type I are entered starting at the centerline for HROD types and at the inside surface for TUBE and WALL types. Data sets are entered in sequence moving radially toward the outside surface.

CARD 9.7 (NODER (L), MATR (L), TREG (L), QREG (L), L=1, NFUEL)

<u>Variable</u>	<u>Description</u>	<u>US units</u>	<u>SI units</u>
NODER (L)	Number of radial heat transfer nodes in region L Note: Because of special data handling inside the code, the following restrictions hold: $2 \leq \text{NODER}(L) \leq \text{NFUEL}$. (NFUEL = number of radial regions in CARD 9.6)	-	-
MATR (L)	Index of material properties table for region L In case of FTYPE = TUBE a material properties table has to be specified necessarily, i.e. $\text{MATR}(L) \geq 1$.	-	-
TREG (L)	Thickness of region L Note: For the different geometry types it must hold: $\sum_{L=1}^{\text{NFUEL}} \text{TREG}(L) = 0.5 \text{ DROD} \text{ , for HROD}$ $\sum_{L=1}^{\text{NFUEL}} \text{TREG}(L) = 0.5 (\text{DROD} - \text{DIN}) \text{ , for TUBE}$ $\sum_{L=1}^{\text{NFUEL}} \text{TREG}(L) = \text{DIN} \text{ , for WALL}$	in	m
QREG (L)	Radial power generation factor for region L This radial power profile is automatically normalized to unity.	-	-

1.12 CARD GROUP 10: Material Properties Tables (read by subroutine READ_CARD_10)

This input group is required only if user-supplied material properties were flagged by input in CARD GROUP 9 (i.e., with nonzero values for IMATF, IMATC, IMATOX (I), or MATR (L) for any geometry type). If only default material properties are used, (i.e., zircaloy and UO₂), this group is omitted. In case of FTYPE = TUBE a material properties table has to be specified necessarily, i.e. MATR(L) ≥ 1.

CARD GROUP 10

<u>Variable</u>	<u>Description</u>	<u>US units</u>	<u>SI units</u>
NGROUP	10	-	-

CARD 10.1 NMAT, NDUM2, NDUM3, NDUM4, NDUM5, NDUM6, NDUM7, NDUM8, NDUM9, NDUM10, NDUM11, NDUM12, NDUM13, NDUM14

<u>Variable</u>	<u>Description</u>	<u>US units</u>	<u>SI units</u>
NMAT	Total number of material properties tables	-	-
NDUM2	Not used, but entry is obligatory: 0 - suggested value	-	-
NDUM3	Not used, but entry is obligatory: 0 - suggested value	-	-
NDUM4	Not used, but entry is obligatory: 0 - suggested value	-	-
NDUM5	Not used, but entry is obligatory: 0 - suggested value	-	-
NDUM6	Not used, but entry is obligatory: 0 - suggested value	-	-
NDUM7	Not used, but entry is obligatory: 0 - suggested value	-	-
NDUM8	Not used, but entry is obligatory: 0 - suggested value	-	-
NDUM9	Not used, but entry is obligatory: 0 - suggested value	-	-
NDUM10	Not used, but entry is obligatory: 0 - suggested value	-	-
NDUM11	Not used, but entry is obligatory: 0 - suggested value	-	-
NDUM12	Not used, but entry is obligatory: 0 - suggested value	-	-
NDUM13	Not used, but entry is obligatory: 0 - suggested value	-	-
NDUM14	Not used, but entry is obligatory: 0 - suggested value	-	-

Cards CARD 10.2 and CARD 10.3 are read in pairs NMAT times.

CARD 10.2 N, NNTDP, RCOLD(N), IMATAN (N)

<u>Variable</u>	<u>Description</u>	<u>US units</u>	<u>SI units</u>
N	Material properties table identification number	-	-
NNTDP	Number of entries in material properties table N (must not exceed 100!)	-	-
RCOLD (N)	Cold density for material N <i>Note: This value is used to define the mass in the heat transfer nodes composed of material type N.</i>	lbm/ft ³	kg/m ³
IMATAN (N)	Alphanumeric label for material Example: Stainless steel, Inconel 600	-	-

CARD 10.3 (TPROP (I, N), CPF1 (I, N), THCF (I, N), I=1, NNTDP)

<u>Variable</u>	<u>Description</u>	<u>US units</u>	<u>SI units</u>
TPROP (I, N)	Temperature for entry I in material properties table N	°F	°C
CPF1 (I, N)	Specific heat capacity at temperature TPROP(I,N)	btu/(lbm °F)	kJ/(kg K)
THCF (I, N)	Thermal conductivity at temperature TPROP(I,N)	btu/(h ft °F)	W/(m K)

1.13 CARD GROUP 11: Axial Power Distribution Tables, Radial Power Distribution, and Transient Forcing Functions (read by subroutine READ_CARD_11)

CARD GROUP 11

<u>Variable</u>	<u>Description</u>	<u>US units</u>	<u>SI units</u>
NGROUP	11	-	-

CARD 11.1 NQA, NAXP, MNXN, NQ, NGPFF, NQR, NDUM7, NDUM8, NDUM9, NDUM10, NDUM11, NDUM12, NDUM13, NDUM14

<u>Variable</u>	<u>Description</u>	<u>US units</u>	<u>SI units</u>
NQA**	Number of transient changes of the axial power profile: 1 - if axial power profile is not transient	-	-
NAXP	Number of axial power profile tables to be read for each transient time point (≥ 1)	-	-
MNXN	Maximum number of pairs of elements in any axial power profile table The minimum value is 2 (top and bottom of the rod) for the uniform power distribution.	-	-
NQ	Number of pairs of elements in the total power forcing function table: 0 - if total power is constant	-	-
NGPFF	Number of pairs of elements in gap conductance forcing function table: 0 - if there is no forcing function on gap conductance	-	-
NQR	Number of radial power profile tables (for different transient points of time): 1 - if radial power profile is <i>not</i> transient	-	-
NDUM7	Not used, but entry is obligatory: 0 - suggested value	-	-
NDUM8	Not used, but entry is obligatory: 0 - suggested value	-	-
NDUM9	Not used, but entry is obligatory: 0 - suggested value	-	-
NDUM10	Not used, but entry is obligatory: 0 - suggested value	-	-
NDUM11	Not used, but entry is obligatory: 0 - suggested value	-	-
NDUM12	Not used, but entry is obligatory: 0 - suggested value	-	-
NDUM13	Not used, but entry is obligatory: 0 - suggested value	-	-
NDUM14	Not used, but entry is obligatory: 0 - suggested value	-	-

**NOTE: When you specify different power factor tables (be they axial, radial, or total power), you need to make sure you cover the entire transient you intend to model or else you will get error messages in 'deck.out'

that “tabular lookup failed”. For example, if your transient will end at 1 second, your last set of transient power factor tables should be for a little over 1 second. The interpolation functions need to have that “end cap” with which to interpolate when determining the current-time power factors.

Cards CARD 11.2, CARD 11.3, and CARD 11.4 are read in groups NQA times.

CARD 11.2 YQA

<u>Variable</u>	<u>Description</u>	<u>US units</u>	<u>SI units</u>
YQA	Transient time for each axial power profile change	s	s

Cards CARD 11.3 and CARD 11.4 are read in pairs NAXP times for each transient time YQA (M = 1, NQA).

CARD 11.3 I, NAXN (I)

<u>Variable</u>	<u>Description</u>	<u>US units</u>	<u>SI units</u>
I	Axial power profile table identification number (refer to CARD 8.2: Each rod can have its own axial power profile table).	-	-
NAXN (I)	Number of pairs of elements in axial power profile table I	-	-

CARD 11.4 (Y(I,N), AXIALZ(M,I,N) ,N = 1, NAXN(I))

<u>Variable</u>	<u>Description</u>	<u>US units</u>	<u>SI units</u>
Y (I, N)	Vertical location	in	m
AXIALZ (M, I, N)	Relative axial power factor (ratio of local power to average power) at vertical location Y (I, N)	-	-

All rods using the same table should start and end at the same vertical locations. In the table, Y(I,1) must be the vertical location of the beginning of the rods, and Y(I, NAXN(I)) must be the vertical location of the end of the rods.

TOTAL POWER FORCING FUNCTION

CARD 11.5 is read only if NQ > 0.

CARD 11.5 (YQ (N), FQ (N), N = 1, NQ)

<u>Variable</u>	<u>Description</u>	<u>US units</u>	<u>SI units</u>
YQ (N)	Transient time	s	s
FQ (N)	Power factor:	-	-

$$FQ(N) = \frac{\text{power at time } YQ(N)}{\text{initial power}}$$

GAP CONDUCTANCE FORCING FUNCTION

CARD 11.6 is read only if NGPFF > 0.

CARD 11.6 (YGPF (N), FGPF (N), N = 1, NGPFF)

<u>Variable</u>	<u>Description</u>	<u>US units</u>	<u>SI units</u>
YGPF (N)	Transient time	s	s
FGPF (N)	Conductance factor:	-	-
	$FGPF (N) = \frac{\text{conductance at time } YGPF (N)}{\text{initial conductance}}$		

RADIAL POWER PROFILE FORCING FUNCTION

Cards CARD 11.7 and CARD 11.8 are read in pairs NQR times.

CARD 11.7 YQR

<u>Variable</u>	<u>Description</u>	<u>US units</u>	<u>SI units</u>
YQR	Transient time for each radial power profile change	s	s

CARD 11.8 (FQR (N), N=1, NRROD)

<u>Variable</u>	<u>Description</u>	<u>US units</u>	<u>SI units</u>
FQR (N)	Radial power factors for all rods (normalized to average power) starting from rod no. 1. Skipped rod numbers are <i>not</i> permitted.	-	-

Eight values are entered per card. If NRROD is greater than 8, repeat CARD 11.8 until NRROD values for FQR have been entered.

1.14 CARD GROUP 12: Turbulent Mixing and Void Drift Data (read by subroutine SETIN)**CARD GROUP 12**

<u>Variable</u>	<u>Description</u>	<u>US units</u>	<u>SI units</u>
NGROUP	12	-	-

MODEL PARAMETERS FOR IMIX = 1:

CARD 12.1 is read if IMIX = 1 (see CARD 1.1).

CARD 12.1 AAAK, BETA

<u>Variable</u>	<u>Description</u>	<u>US units</u>	<u>SI units</u>
AAAK	Equilibrium distribution weighting factor K_M in void drift model: 0.0 - void drift <i>inactive</i> (turbulent mixing only) 1.4 - suggested value	-	-
BETA	Constant (<i>two-phase</i>) turbulent mixing coefficient	-	-

MODEL PARAMETERS FOR IMIX = 2:

CARD 12.2 is read if IMIX = 2 (see CARD 1.1).

CARD 12.2 AAAK, DFROD, THETM

<u>Variable</u>	<u>Description</u>	<u>US units</u>	<u>SI units</u>
AAAK	Equilibrium distribution weighting factor K_M in void drift model: 0.0 - void drift <i>inactive</i> (turbulent mixing only) 1.4 - suggested value	-	-
DFROD	Outside rod diameter (should be consistent with DROD in CARD 9.2 or CARD 9.6!)	in	m
THETM	Ratio between maximum two-phase turbulent mixing coefficient (near the transition between slug and annular flow) and single-phase turbulent mixing coefficient (in single phase liquid).	-	-

MODEL PARAMETERS FOR IMIX = 3:

CARD 12.2 is read if IMIX = 3 (see CARD 1.1).

CARD 12.3 AAAK, BETA, THETM

<u>Variable</u>	<u>Description</u>	<u>US units</u>	<u>SI units</u>
AAAK	Equilibrium distribution weighting factor K_M in void drift	-	-

	model:		
	0.0	- void drift <i>inactive</i> (turbulent mixing only)	
	1.4	- suggested value	
BETA	Single-phase mixing coefficient	-	-
THETM	Ratio between maximum two-phase turbulent mixing coefficient (near the transition between slug and annular flow) and single-phase turbulent mixing coefficient (in single phase liquid).	-	-

1.15 CARD GROUP 13: Boundary Condition Data (read by subroutine READ_CARD_13)**CARD GROUP 13**

<u>Variable</u>	<u>Description</u>	<u>US units</u>	<u>SI units</u>
NGROUP	13	-	-

CARD 13.1 NIBND, NKBND, NFUNCT, NGBND, NIBNDB, NDUM6, NDUM7, NDUM8, NDUM9, NDUM10, NDUM11, NDUM12, NDUM13, NDUM14

<u>Variable</u>	<u>Description</u>	<u>US units</u>	<u>SI units</u>
NIBND	Total number of vertical mesh cell boundary conditions (including inlet, outlet, and internal mesh cells)	-	-
NKBND	Total number of transverse momentum cells for which cross flow will be set to zero	-	-
NFUNCT	Total number of forcing functions for the boundary conditions (It is possible to vary each boundary value: BCVALUE1, BCVALUE2, BCVALUE3, DROPS, FDROPS, HMGA, GVALUE.)	-	-
NGBND	Number of groups of adjacent transverse momentum cells for which cross flows will be set to zero	-	-
NIBNDB	Total number of vertical mesh cell boundary conditions to apply the boron tracking/precipitation model (number of inlet boron boundary conditions)	-	-
NDUM6	Not used, but entry is obligatory: 0 - suggested value	-	-
NDUM7	Not used, but entry is obligatory: 0 - suggested value	-	-
NDUM8	Not used, but entry is obligatory: 0 - suggested value	-	-
NDUM9	Not used, but entry is obligatory: 0 - suggested value	-	-
NDUM10	Not used, but entry is obligatory: 0 - suggested value	-	-
NDUM11	Not used, but entry is obligatory: 0 - suggested value	-	-
NDUM12	Not used, but entry is obligatory: 0 - suggested value	-	-
NDUM13	Not used, but entry is obligatory: 0 - suggested value	-	-
NDUM14	Not used, but entry is obligatory: 0 - suggested value	-	-

CARD 13.2 is read only if NFUNCT > 0.

CARD 13.2 (NPTS (K), K=1, NFUNCT)

<u>Variable</u>	<u>Description</u>	<u>US units</u>	<u>SI units</u>
NPTS (K)	Number of pairs of values in forcing function table K	-	-

Sixteen values are entered per card. Repeat CARD 13.2 until NFUNCT values have been entered.

CARD 13.3 is read NFUNCT times.

CARD 13.3 ((ABSCIS (K, I), ORDINT (K, I), I=1, NPTS (K)), K=1, NFUNCT)

<u>Variable</u>	<u>Description</u>	<u>US units</u>	<u>SI units</u>
ABSCIS (K,I)	Transient time	s	s
ORDINT (K,I)	Forcing function factor to be applied at time ABSCIS (K, I)	-	-

Five pairs of (ABSCIS, ORDINT) are entered per card. Repeat CARD 13.3 until NPTS (K) points have been entered for forcing function table K. Continue entering data until NFUNCT tables have been specified.

CARD 13.4, CARD 13.5, CARD 13.6, and CARD 13.7 are read NIBND times.

CARD 13.4 ((IBOUND (L, N), L = 1, 2), ISPEC (N), N1FN (N), N2FN (N), N3FN (N), BCVALUE1 (N), BCVALUE2 (N), BCVALUE3 (N), INITGAS, N = 1, NIBND)

<u>Variable</u>	<u>Description</u>	<u>US units</u>	<u>SI units</u>
IBOUND (1, N)	Index number of the channel at which boundary condition N is applied	-	-
IBOUND (2, N)	Vertical node number at which boundary condition N is applied Note: The node number counts relatively to the first node of the section that the channel identified in IBOUND (1, N) resides in. The auxiliary (boundary) cells are counted as well. <u>Example:</u> 1 section with NONODE = 80 continuity mesh cells → Inlet: IBOUND(2,N) = 1 → Outlet: IBOUND(2,N) = 82	-	-
ISPEC (N)	Boundary condition type: 1 - pressure and enthalpy (or temperature) 2 - mass flow rate and enthalpy (or temperature) 3 - mass flow rate only 4 - mass source (mass flow rate and enthalpy) 5 - pressure sink (pressure and enthalpy) (See also description table at the end of CARD GROUP 13.)	-	-
N1FN (N)	Index number of the forcing function table by which the first parameter of the boundary condition (BCVALUE1) will be varied 0 - if the boundary condition is constant <u>Note:</u> The forcing function tables are numbered sequentially in the order they are read in CARD 13.3. For example: If ISPEC (N) = 3 and N1FN (N) = 3, the specified mass flow rate will be adjusted according to the 3 rd forcing function table entered in CARD 13.3.	-	-

N2FN (N)	Index number of the forcing function table by which the second parameter of the boundary condition (BCVALUE2) will be varied: 0 - if the boundary condition is constant For example: If ISPEC (N) = 1 and N2FN(N) = 6, the specified enthalpy will be adjusted according to the 6 th forcing function table specified in CARD 13.3.	-	-
N3FN (N)	Index number of the forcing function table by which the third parameter of the boundary condition (BCVALUE3) will be varied: 0 - if the boundary condition is constant	-	-
BCVALUE1 (N)	First boundary value: flow rate - if ISPEC(N) = 2, 3, or 4 (If ISPEC(N) = 2 and GTOT \neq 0 or MFLUX.ne.0.0 in CARD 1.2 the subchannel mass flow rates are calculated automatically and BCVALUE1(N) is ignored.) 0.0 - if ISPEC (N) = 1 or 5 (See also description table at the end of CARD GROUP 13.)	lbm/s	kg/s
BCVALUE2 (N)	Second boundary value: enthalpy - if ISPEC(N) = 1, 2, 4, or 5 or temperature - enter as negative of the number e.g. for 300°C, enter -300 here 0.0 - if ISPEC(N) = 3 (See also description table at the end of CARD GROUP 13.) note: The enthalpy specified at the exit is not used by COBRA-TF if flow is in the positive direction (i.e. out of the model). In the case of positive flow, the user may enter any number for exit enthalpy.	btu/lbm °F	kJ/kg °C
BCVALUE3 (N)	Third boundary value: pressure - if ISPEC(N) = 1, 4, or 5 0.0 - if ISPEC(N) = 2 or 3 (See also description table at the end of CARD GROUP 13.)	psia	bar
INITGAS	Flag for the inlet boundary conditions of non-condensable gases (only relevant in case ISPEC (N) \neq 3): 0 - Inlet conditions will be entered in CARD 13.6 and CARD 13.7. 1 - Inlet conditions will be set equal to the initial conditions entered in CARD 1.3 and CARD 1.4 with the following assumptions: HMGA = HGIN GVALUE = VFRAC NHMFN = 0 NGFN = 0	-	-

CARD 13.5 is only read, if ISPEC (N) = 4 (mass injection boundary condition).

CARD 13.5 DROPS (N), NDFN (N), FDROPS (N), NDFFN (N)

<u>Variable</u>	<u>Description</u>	<u>US units</u>	<u>SI units</u>
DROPS (N)	Droplet diameter	in	m

NDFN (N)	Index number of the forcing function table by which the DROPS (N) parameter is varied	-	-
FDROPS (N)	Droplet mass flow rate at injection boundary	lbm/s	kg/s
NDFFN (N)	Index number of the forcing function table by which the FDROPS (N) parameter is varied	-	-

Cards CARD 13.6 and CARD 13.7 are read only if ISPEC (N) \neq 3 and INITGAS = 0. The structure of variables in CARD 13.6 is similar to that in CARD 1.3 and CARD 1.4, where enthalpy and void fractions are specified as *initial* conditions. (These initial values can be taken over by setting INITGAS = 1, see CARD 13.4).

CARD 13.6			
Variable	Description	US units	SI units
HMGA (N)	Enthalpy of non-condensable gas mixture	btu/lbm	kJ/kg
GVALUE (NGA, N)	Volume fractions (inlet boundary condition):		
	NGA = 1 - of liquid in the liquid-vapor-gas mixture		
	NGA = 2 - of vapor in the vapor-gas mixture		
	NGA \geq 3 - of gas (NGA-2) in the vapor-gas mixture		

CARD 13.7 NHMFN (N), (NGFN (NGA, N), NGA=1, NGAS+2)

Variable	Description	US units	SI units
NHMFN (N)	Index number of forcing function applied to the enthalpy of non-condensable gas mixture HMGA (see CARD 13.6)	-	-
NGFN (NGA, N)	Index number of forcing function applied to the volume fractions GVALUE (see CARD 13.6)	-	-

Cards CARD 13.8 and CARD 13.9 are read in pairs NIBND times.

CARD 13.8 is read only in case ISPEC (N) = 4 (mass injection boundary condition).

CARD 13.8 AINJT (K)

K = 1, 2, ..., total number of vertical boundary condition cells at which boundary condition type 4 is specified.

Variable	Description	US units	SI units
AINJT (K)	Flow area of the mass injection	in ²	m ²

CARD 13.9 is read only in case ISPEC (N) = 5 (pressure sink boundary condition).

CARD 13.9 ASINK (K), SINKK (K), DXSINK (K)

K = 1, 2, ..., total number of vertical boundary condition cells at which boundary condition type 5 is specified.

Variable	Description	US units	SI units
ASINK (K)	Flow area of the pressure sink	in ²	m ²
SINKK (K)	Pressure loss coefficient (velocity head) of the pressure	-	-

	sink		
DXSINK (K)	Length of the momentum control volume for the sink	in	m

CARD 13.10 is read NGBND times (only if NGBND > 0). That means, CARD 13.10 may be repeated as many times as necessary for a given gap K, in order to identify all axial levels that have zero cross flow. The total number of transverse momentum cells with zero cross flow boundary conditions specified by CARD 13.10 must sum to NKBND.

CARD 13.10 K, JSTART, JEND

<u>Variable</u>	<u>Description</u>	<u>US units</u>	<u>SI units</u>
K	Gap number to which a zero cross flow is to be applied	-	-
JSTART	Continuity cell number at which to start applying the zero cross flow	-	-
JEND	Continuity cell number at which to stop applying the zero cross flow	-	-

Note: The cross flow will be set to zero for gap K between nodes JSTART and JEND. The node numbers are given relative to the beginning of the section containing gap K.

CARD 13.11 is read NIBNDB times (Boron inlet boundary conditions)

CARD 13.11 ((IBOUNDB (L, N), L = 1, 2), N4FNB (N), BCVALUE4B (N), N = 1, NIBNDB)

<u>Variable</u>	<u>Description</u>	<u>US units</u>	<u>SI units</u>
IBOUNDB (1, N)	Index number of the channel at which boundary condition N is applied	-	-
IBOUNDB (2, N)	Vertical node number at which boundary condition N is applied Note: The node number counts relatively to the first node of the section that the channel identified in IBOUNDB (1, N) resides in. The auxiliary (boundary) cells are counts, too. Example: 1 section with NONODE = 80 continuity mesh cells → Inlet: IBOUNDB(2,N) = 1 → Outlet: IBOUNDB(2,N) = 82	-	-
N4FNB (N)	Index number of the forcing function table by which the forth parameter of the boundary condition (BCVALUE4) will be varied 0 - if the boundary condition is constant Note: The forcing function tables are numbered sequentially in the order they are read in CARD 13.3. For example: If N4FN (N) = 5, the specified boron concentration will be adjusted according to the 5th forcing function table entered in CARD 13.3. 0 - if the boundary condition is constant	-	-
BCVALUE4B (N)	Forth boundary value: boron concentration	ppm	ppm

Note 1: Variable NIBNDB, in CARD 13.1 and CARD 13.11 are only read if the boron tracking/precipitation model is activated (IBTM = 1)

Note 2: Variable NIBNDB, as number of boron inlet b.c., does not need to match with the number of inlet b.c. entered in CARD 13.4

Note 3: Must be a match between where the inlet b.c. and the boron inlet b.c. are applied; (IBOUND(L,N), L=1,2) and (IBOUNDB(L,N), L=1,2).

Note 4: Boron tracking/precipitation model is applied when ISPEC(N) = 1, 2 or 3. Variables related with boron inlet b.c. (N4FNB(N) and BCVALUE4B(N) are reassigned as extra inlet b.c. as N4FN(N) and BCVALUE4(N), N =1, NIBND.

1.16 CARD GROUP 14: Output Options (read by subroutine READ_CARD_14)

You have two options for specifying the code output options. The first option is the legacy Card Group 14. The second option is a new, more intuitive Card Group 14. The legacy Card Group 14 affords you some options that the new one does not (like specifying specific channels/rods to print out), but it is also more confusing to use and will not be supported any further going forward (e.g. you cannot turn the HDF5 file on/off from the legacy Card Group 14). These two options are described below. Only enter one of these two Card Groups 14s in the input deck.

LEGACY CARD GROUP 14

<u>Variable</u>	<u>Description</u>	<u>US units</u>	<u>SI units</u>
NGROUP	14	-	-

CARD 14.1 N1, NOUT1, NOUT2, NOUT3, NOUT4, IPROPP, IOPT, NDUM8, NDUM9, NDUM10, NDUM11, NDUM12, NDUM13, NDUM14

<u>Variable</u>	<u>Description</u>	<u>US units</u>	<u>SI units</u>
N1	General output option: 1 - print channels only 2 - print channels and gaps only 3 - print rods and unheated conductors only 4 - print rods, unheated conductors, and channels only 5 - print channels, gaps, rods, and unheated conductors 6 - Print nothing. The deck.out file will still be generated, but no channels, rods, or gaps information will be printed to the file. The results_channels.out and results_gaps.out files will not be generated. The DNB.out file will not be generated either. If you specified IMESH=1, the VTK file will still be printed. 7 - Same as N1=1, but the rods VTK file will be produced as well. Note that IMESH must equal 1, or else no VTK files will be produced.	-	-
NOUT 1	Number of <i>channels</i> to be printed (used if N1 ≠ 3). 0 - All channels will be printed. > 0 - An array of NOUT1 channel numbers must be entered on CARD 14.2.	-	-
NOUT 2	Number of <i>rods</i> to be printed (used if N1 > 2) 0 - All rods will be printed. > 0 - An array of NOUT2 rod numbers must be entered on CARD 14.4.	-	-
NOUT 3	Number of <i>gaps</i> to be printed (used if N1 = 2 or 5). 0 - All gaps will be printed. > 0 - An array of NOUT3 gap numbers must be entered on CARD 14.3.	-	-
NOUT 4	Number of <i>unheated conductors</i> to be printed (used if N1 > 2): 0 - All unheated conductors will be printed. > 0 - An array of NOUT4 unheated conductor numbers must be entered on CARD 14.5.	-	-

IPROPP	Property table print option:	-	-
	0 - do not print the property table		
	1 - print the property table		
<i>Note: In the current code version this option is available only for US units (ICOBRA = 2 or ICOBRA = 3); the property table will be printed in the output file deck.out.</i>			
IOPT	Debug print option:	-	-
	0 - normal printout only		
	2 - debug printout (print extra data for subchannels in file 'results_channels.out', print extra files 'time.out' and krysolv.out)		
	3 - optional printout (print averaged coolant temperature in file 'mixture_temp.out') (<i>may not be working</i>)		
	4 - optional printout (print subchannel void fraction in file 'void.out')		
ITTY	Flag to print out deck.run file	-	-
	0 - Print		
	1 - Do not print		
DNB	Flag to print the dnb.out file	-	-
	0 - Print		
	1 - Do not print		
IMASS	Flag to print the mass_balance.out file	-	-
	0 - Print		
	1 - Do not print		
IHEAT	Flag to print the heat_balance.out file	-	-
	0 - Print		
	1 - Do not print		
ICHAN	Flag to print the results_channels.out file	-	-
	0 - Print		
	1 - Do not print		
IGAP	Flag to print the results_gap.out file:	-	-
	0 - Print		
	1 - Do not print		
KRY	Flag to print the krylosolv.out file:	-	-
	0 - Print		
	1 - Do not print		

CARD 14.2 is read only if $N1 \neq 3$ and $NOUT1 > 0$.

CARD14.2 (PRINTC (I), I=1, NOUT1)

<u>Variable</u>	<u>Description</u>	<u>US units</u>	<u>SI units</u>
PRINTC (I)	Index numbers of <i>channels</i> to be printed	-	-

Sixteen values are entered per card. Repeat this card until NOUT1 values have been entered.

CARD 14.3 is read only if $N1 = 2$ or $N1 = 5$ and $NOUT3 > 0$.

CARD 14.3 (PRINTG (I), I=1, NOUT3)

<u>Variable</u>	<u>Description</u>	<u>US units</u>	<u>SI units</u>
PRINTG (I)	Index numbers of <i>gaps</i> to be printed	-	-

Sixteen values are entered per card. Repeat this card until NOUT3 values have been entered.

CARD 14.4 is read only if $N1 > 2$ and $NOUT2 > 0$.

CARD 14.4 (PRINTR(I), I=1, NOUT2)

<u>Variable</u>	<u>Description</u>	<u>US units</u>	<u>SI units</u>
PRINTR (I)	Index numbers of <i>rods</i> to be printed	-	-

Sixteen values are entered per card. Repeat this card until NOUT2 values have been entered.

CARD 14.5 is read only if $N1 > 2$ and $NOUT4 > 0$.

CARD 14.5 (PRINTHS (I), I=1, NOUT4)

<u>Variable</u>	<u>Description</u>	<u>US units</u>	<u>SI units</u>
PRINTHS (I)	Index numbers of <i>unheated conductors</i> to be printed	-	-

Sixteen values are entered per card. Repeat this card until NOUT4 values have been entered.

NEW CARD GROUP 14 (read by subroutine **READ_CARD_14_ALT**)

Use the new input format by entering a negative 14 instead of a positive one to start Card Group 14. Each option is simply entered as a key-value pair entered on separate lines (1 pair per line). You may enter the key-value pairs in any order. Not entering a key-value pair will result in the default behavior being used. You must terminate this card with the phrase “end 14” as the final line of this card group input.

Variable Description
NGROUP -14

<u>Key</u>	<u>Value</u>	<u>Meaning</u>	<u>Default</u>
hdf5	1	Write to the HDF5 file (only valid if IMESH=1)	1
	0	No HDF5 output	
rods_vtk	1	Write to the rods VTK file (only valid if IMESH=1)	0
	0	No Rod VTK output	
chan_edits	1	Write the channels.out file	0
	0	No channel output	
rod_edits	1	Write the conductor data to the deck.out file	0
	0	No rod/conductor output	
gap_edits	1	Write the gaps.out file	0
	0	No gap output	
fluid_vtk	1	Write the fluid VTK file (only valid if IMESH=1)	1
	0	No fluid VTK file output	
dnb_edits	1	Write the dnb.out file	0
	0	No dnb.out file	
krylo_out	1	Print krylov solver information	0
	0	No krylov solver information printed	
convergence	1	Write the convergence.out file	1
	0	No convergence parameter information written	
mass_out	1	Write the mass.out file (mass balance/storage)	1
	0	No mass balance/storage info written	
heat_out	1	Write the heat.out file (heat balance/storage)	1
	0	No heat balance/storage info written	
run_out	1	Write the run.out file (timestep/iteration information)	1
	0	No timestep/iteration information written	

end 14 ** If using the new Card Group 14 format, you must terminate the card with “end 14”

Example use of the new Card Group 14:

```
*NGR
  -14
*KEYS
  hdf5          0
  chan_edits   1
  rod_edits    1
  dnb_edits    1
  end 14
```

1.17 CARD GROUP 15: Time Domain Data (read by subroutine READ_CARD_15)

After all component data have been entered, the user must define the time domain for the simulation. The total time can be divided into several domains of specified duration. Each time domain can have different minimum and maximum time step sizes and different edit intervals.

If modeling a full transient (i.e. NOTRANS=0), then you may enter any number of groups of time data, with each group specified by its own line in Card 15.1. The last line of Card 15.1 should give DTMIN as a negative number. This will prompt CTF to stop reading. For example, if you are only specifying one time data group, you should have 2 lines; the first line gives the time data for the transient and the second line terminates the read of Card Group 15.

If modeling a pseudo-transient (i.e. NOTRANS=1), then you should only enter one line of time data. The minimum and maximum timestep sizes and the RTWFP values will be used by the code, but the TEND and EDINT values will be ignored. Do not enter more than one line on Card 15.1 if you set NOTRANS=1, as this will cause a read-error by CTF.

CARD GROUP 15

<u>Variable</u>	<u>Description</u>	<u>US units</u>	<u>SI units</u>
NGROUP	15	-	-

CARD 15.1 DTMIN, DTMAX, TEND, EDINT, DMPINT, RTWFP

<u>Variable</u>	<u>Description</u>	<u>US units</u>	<u>SI units</u>
DTMIN	Minimum time step allowed for this time domain Enter a <u>negative</u> value to <u>terminate</u> the calculation.	s	s
DTMAX	Maximum time step allowed for this domain	s	s
TEND	End of this time domain (related to the <i>total</i> time from the beginning at $t = 0$ s)	s	s
EDINT	Print interval for this time domain Output specified in CARD GROUP 14 will be printed every EDINT seconds (related to the beginning of the <i>current</i> time domain).	s	s
DMPINT	Restart dump interval Data for restart will be saved every DMPINT seconds (related to the beginning of the <i>current</i> time domain). The file will be overwritten each time. One can start only from the time step which was saved last. <i>Note: In case DUMPF = 0, the input value DMPINT is not used. In case DUMPF = 1 and DMPINT = 0, only one restart file is written at the end of the calculation.</i>	s	s
RTWFP	Ratio of time step sizes for heat conduction solution and fluid solution. To obtain <i>steady-state</i> conditions, the conduction solution can generally use time steps greater than the fluid solution. For <i>transient calculations</i> , RTWFP should be one. <i>Note: Ratios of RTWFP < 1 are not allowed. In this case, the code automatically sets RTWFP = 1.</i>	-	-

MAXITS Enter only if NOTRANS=1 (modeling pseudo-transient). Gives the maximum number of iterations that should be run before ending the simulation and printing results. - -

1.18 CARD GROUP 16: Meshing Information

This card group is currently not functional. It was put here to read in meshing data. Currently, meshing data is entered on Card Groups 2 and 3. It is intended that eventually the meshing information will be migrated from those card groups to this one for better organization of the input deck. Furthermore, the mesh is setup in CTF in a somewhat inefficient way right now- the cells are all free-standing, not knowing how they connect to one another. This leads to larger-than-necessary VTK files being produced. Eventually, this will be remedied and the necessary information for generating the new meshes will be put in this Card Group. Backwards compatibility will be retained for decks created using the old meshing technique using the IMESH option on Card Group 1.

1.19 CARD GROUP 17: Rod and Channel Map Information (read by subroutine READ_CARD_17)

This group gives a top-view of the map of channels and rods in the model. It is necessary for writing HDF5 edits. If you specify the MAPS variable on Card 1.1 to 1, you must enter this Card Group. If MAPS was set to 0, do not enter this group. CTF only supports square rod lattice geometry. Special consideration must be given to what assemblies own what rods and channels. Special considerations are also required for symmetry cases. It is not intended that this card group should be generated by hand. Rather, the PWR preprocessor should be used to create the input deck when HDF5 output is desired.

CARD GROUP 17

<u>Variable</u>	<u>Description</u>	<u>US units</u>	<u>SI units</u>
NGROUP	17	-	-

CARD 17.1: HDF5 NAME, VTK NAME

<u>Variable</u>	<u>Description</u>
HDF5 NAME	Desired name of the HDF5 file to be printed
VTK NAME	Desired name of the VTK file to be printed

CARD 17.2: TOTRODSROW, TOTRODSCOL

<u>Variable</u>	<u>Description</u>
TOTRODSROW	The number of rods in a single row of rods in the entire core model. See Figure 3 for reference. This particular model would have 9 rods in a row.
TOTRODSCOL	The number of rods in a single column of rods in the core model. Figure 3 would have 9 rods in a column.

CARD 17.3: TOTCHANSROW, TOTCHANSCOL

<u>Variable</u>	<u>Description</u>
TOTCHANSROW	The number of channels in a single row of channels in the entire core model. The model in Illustration 1 would have 10 channels per row.
TOTCHANSCOL	The number of channels in a single column of channels in the core model.

CARD 17.4: Rod Map

The rod map is entered as zeros, positive integers, and negative integers. A positive integer represents the assembly index that owns a solved rod. A negative integer represents the assembly index that owns an unsolved rod, due to the rod existing on the unsolved side of a symmetry line. A "0" represents a blank region. The map must be square. When CTF reads these values in, it will assign each entity a unique ID. It will read from left-to-right, starting at the top row and working down. IDs are assigned in that order. The rod map for Figure 3 would be as follows:

```

0 0 0 1 1 1 0 0 0
0 0 0 1 1 1 0 0 0

```

```

0 0 0 1 1 1 0 0 0
2 2 2 3 3 3 4 4 4
2 2 2 3 3 3 4 4 4
2 2 2 3 3 3 4 4 4
2 2 2 3 3 3 4 4 4
0 0 0 5 5 5 0 0 0
0 0 0 5 5 5 0 0 0
0 0 0 5 5 5 0 0 0

```

If modeling this case using quarter symmetry, the assemblies that exist on the symmetry line must have both their solved and unsolved rods given in the map. The unsolved rods are shown using a negative number. A quarter symmetry map of this case would look as follows:

```

-1 -1 -1 -2 -2 -2
-1 -1 -1 -2 -2 -2
-1 1 1 2 2 2
-3 3 3 0 0 0
-3 3 3 0 0 0
-3 3 3 0 0 0

```

Note that rod surface data will also be printed to the HDF5 file. CTF doesn't consider orientation of the rod surfaces; only how they connect to adjacent channels. However, the PWR preprocessor has a specific way of setting up the connections that allows us to track the orientation of each rod surface. For square rod lattice geometry, there will be four quadrants of each rod (i.e. northeast, southeast, southwest, and northwest). To ensure the orientation is correctly printed to the HDF5 file, you must use the PWR preprocessor to generate the CTF input deck.

CARD 17.5: Channel Map

The channel map is similarly given as positive and negative integers for solved and unsolved channels. Zeros represent blank regions in the map. Its indices are assigned in the same way as the rod map.

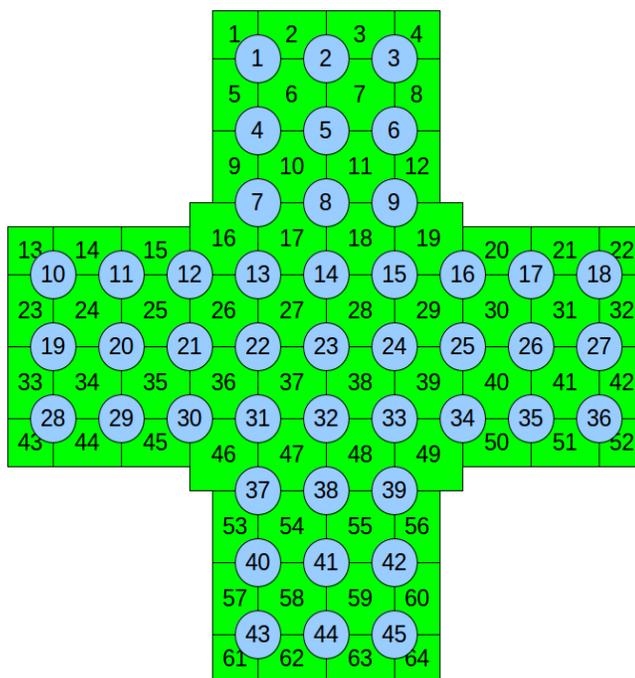


Figure 3: Core map of 3x3 assemblies

CARD 17.6 Assembly Map Information

Optional Card, but required when modeling core symmetry. Must enter the following tag prior to the card so CTF reads the input correctly:

{assem map}

<u>Variable</u>	<u>Description</u>	<u>US units</u>	<u>SI units</u>
SYM_OPT	Symmetry option being used: - 1 – full symmetry - 4 – quarter mirror symmetry - 5 – quarter rotational symmetry	--	--
NASSEM_ROW	Number of assemblies in each row of assemblies	--	--
NASSEM_COLS	Number of assemblies in each column of assemblies	--	--

CARD 17.7 Assembly Map

Must be entered if CARD 17.6 was entered. This is a top view map of the core with each index representing an assembly in the core. For Figure 3, the assembly map would look as follows:

```
0 1 0
2 3 4
0 5 0
```

When modeled using quarter symmetry, this map would look as follows:

```
1 2
3 0
```

2 Users' Guide

2.1 General

This section is intended to aid the user in learning to set up the input deck for CTF. There are three basic tasks the user must perform: 1) setting the geometry data to describe the system; 2) specifying the fluid conditions and forcing functions to define the state of the system; and 3) running the code and interpreting the output. The first two tasks are covered in this section.

Any vertical one-, two-, or three-dimensional component in the reactor vessel can be modeled with CTF. The exceptions are components such as pumps or pressurizers that have special boundary conditions not included in the code capabilities. In addition, the problem must be amenable to solution by the semi-implicit numerical algorithm used.

All geometries modeled are represented as a matrix of Eulerian mesh cells. The number of cells depends on the degree of detail required to resolve the flow field, the phenomena being modeled, and practical restrictions such as computing costs and storage limitations. In two-phase flow, the mesh cell should be large compared to the characteristic size of the two-phase flow pattern. For example, the mesh cell size should be large relative to the bubble size, so that averaged quantities (bubble size, drag, etc.) used in the calculation will be valid. In slug or film flow, the mesh cell size should be on the order of the hydraulic diameter or larger since the physical models for these flow regimes are based on physical dimensions of the flow path.

The equations for flow field in the reactor core are solved using a staggered difference scheme on the Eulerian mesh. The velocities are obtained at the mesh faces and the state variables (e.g., pressure, density, enthalpy, and phasic volume fractions) are obtained at the cell center. The mesh cell is characterized by cross-sectional area A , height Δx , and the width of the connections to the adjacent mesh cells, S . The basic mesh cell is shown in Figure 4. This cell defines the control volume for the scalar continuity and energy equations. The momentum equations are solved on a staggered mesh with the momentum cell centered on the scalar cell face. The momentum cell for axial velocities is shown in Figure 5 and that for transverse velocities in Figure 6.

The input has been constructed to allow the user a great deal of flexibility in defining the mesh for the irregular geometries typical of reactor vessel internals. The mesh cells are defined by input in terms of subchannels. A subchannel is a vertical stack of mesh cells, as illustrated in Figure 7. A subchannel may represent a fluid volume between four fuel rods, a lumped region of the core, a segment of the downcomer, or any other vertical flow path appropriate to the geometry being modeled.

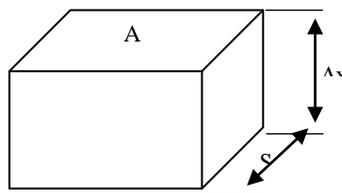


Figure 4: Basic Mesh Cell

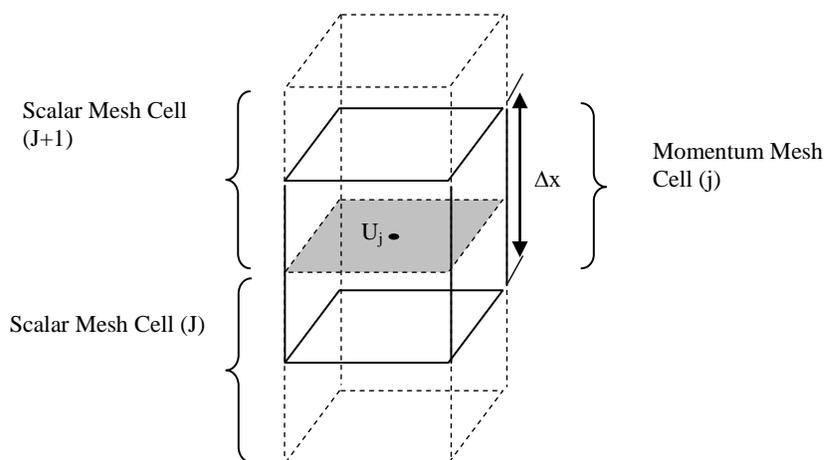


Figure 5: Mesh Cell for Axial Momentum

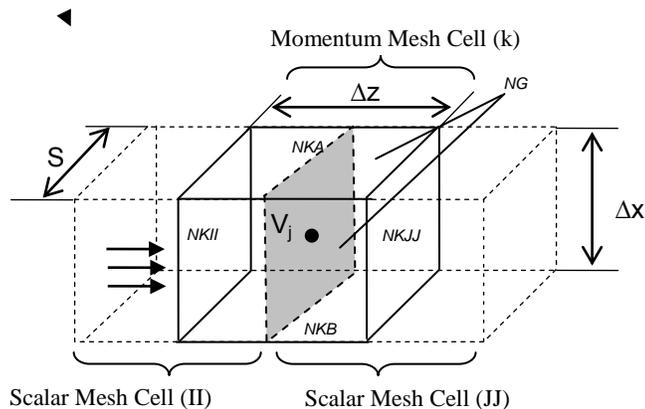


Figure 6: Mesh Cell for Transverse Momentum

Boundary data for each subchannel are stored in phantom nodes at its top and bottom. Between these two phantom nodes are NDX nodes that actually enter into calculation. Node $J = 1$ contains boundary conditions for the bottom of the subchannel and node $J = NDX + 2$ contains boundary conditions for the top of the subchannel. Boundaries between mesh cells are identified in Figure 7 with the lower case j and refer to

locations of the momentum mesh center, where velocities are obtained. The velocity corresponding to $J = 1$ is at the top of the continuity mesh cell corresponding to $J = 1$.

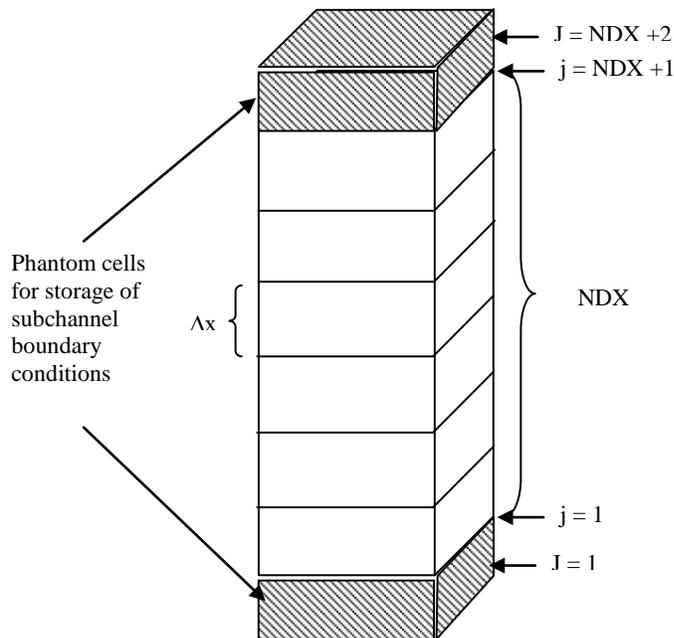


Figure 7: Basic Subchannel

Nominal flow area and wetted perimeter are specified for each subchannel by input. Each mesh cell within the subchannel is assumed to have nominal geometry unless variations for area or/and wetted perimeter are specified by the user. The mesh for a particular region of the vessel is developed by pacing a sufficient number of subchannels in the region to model the geometry and the important flow phenomena of the region. Transverse connections are specified between subchannels to complete the multidimensional mesh of the region. These connections are referred to as gaps. Gaps are defined by the width of the flow path between two subchannels and the distance between the subchannels centroids. The width of the gap between subchannels is assumed to be uniform along the total length of the subchannel unless an axial variation of the gap is specified. The centroid distance is always equal to the nominal value for the gap; no variation is allowed.

All regions composed of subchannels of same vertical length and beginning at the same level in the vessel are grouped together and referred to as a section. When all sections have been defined, the sections are joined together to form the complete mesh by specifying connections to the subchannels in adjacent sections at the top and bottom of each subchannel. The ability to connect one or more subchannels to the top or bottom of a subchannel is referred to as subchannel splitting. Each subchannel and gap in the problem is assigned a unique identification number by the input and these subchannel numbers are used to identify the connections at the top and bottom of each subchannel. Connections are not specified for subchannels without a physical flow

path at the inlet or outlet. Boundary conditions on the ends of subchannels that do not connect to subchannels in an adjacent section are specified by input.

Fuel rod simulators, nuclear fuel rods and the solid structures within the vessel can be modeled using the rod and unheated conductor model. Heat transfer through solid structures, thermal storage during transient, and quenching of hot dry surfaces can be calculated by the conduction model. The user has a great deal of flexibility in modeling geometries of solid structures in the system. They can be represented as cylindrical rods, hollow tubes, or flat walls composed of any number of different materials with specified thermal properties.

To summarize, the basic building block for the vessel mesh is the subchannel, which is a vertical stack of single mesh cells. Several subchannels can be connected together by gaps to model a region of the reactor vessel. Regions that occupy the same level form a section. Sections are connected axially to complete the vessel mesh by specifying subchannel connections between sections. Heat transfer surfaces and solid structures that interact significantly with the fluid can be modeled with rods and unheated conductors.

2.2 Specification of the Geometry Data

This section provides the user with guidance how to model the geometry of the problem being simulated. It covers the code input requirements for modeling of the subchannels and gaps, the splitting of axial sections, and the spacer grid data.

2.2.1 Instructions to CARD GROUP 2

The input for CARD GROUP 2 specifies the number of subchannels in the model and their geometrical characteristics. The total number of subchannels, NCHANL, is specified on CARD 2.1. Each subchannel is uniquely identified on CARD 2.2 by an index number I, flow area AN(I) and wetted perimeter PW(I). The subchannel identification numbers are completely arbitrary and the user is not required to number them sequentially. The only constrain on subchannel numbers is that they must be unique.

The variables ABOT and ATOP on CARD 2.2 are optional input to model the area at the top and the bottom of the subchannel for the momentum equation solution. By default both are equal to the subchannel nominal flow area AN(I). When at the section boundaries there are sudden changes in the geometry of the system (for example, orifice or flow distribution plates), ABOT and ATOP are used to supply the correct area at the bottom and the top of the subchannel for the momentum solution. Nonzero values for ABOT and ATOP will replace the nominal subchannel area at those locations.

If the axial velocities for a subchannel can convect transverse momentum between sections, the location of those velocities must be specified by the user. If this input is not provided, transverse momentum will accumulate in the affected cells of subchannel I at the section boundaries, causing errors in the pressure solution. The number of gaps for which subchannel I convects transverse momentum between sections is specified as the variable NAMGAP on CARD 2.2.

The connections for axial convection of transverse momentum across the section boundary by a given subchannel I are specified on CARD 2.3. The connections are defined by the node number INODE(I) of the axial velocity convecting momentum and the index numbers of the gaps, above and below the section boundary, whose momentum is convected. The node numbering convention is shown in Figure 8. The center of the scalar mesh are identified by $J = 1, 2, \dots (NONODE + 2)$ and the centers of the momentum cells are identified by $J = 1, 2, \dots (NONODE + 1)$. The node number INODE(I,N) will be 1 for the subchannel velocity at the bottom of the boundary of the section, or $NONODE + 1$ for the subchannel velocity at the top of the section. KGAPB(I,N) is the gap number on the lower side of the section boundary and KGAPA(I,N) is the gap number of the upper side of the section boundary. If the flow is positive, the axial velocity of

subchannel I convects transverse momentum from KGAPB to KGAPA. If the flow reverses, momentum is convected from KGAPA to KGAPB. This input is fairly obvious for cases where there is a gap both above and below the section boundary. But even if one or other is nonexistent this input must be provided to tell the code how to dissipate transverse momentum that is transported out of a gap across a section boundary. If there is a gap below, but no gap above the section boundary, KGAPA is entered zero and momentum convected out of KGAPB is considered dissipated. Similarly, if there is a gap above, but no gap below, KGAPB is entered zero. Reverse flow convects momentum out of KGAPA, which is considered dissipated. The area through which momentum is convected is calculated as the minimum of the $S_K L_K / 2$ for KGAPA and KGAPB and the flow area of subchannel I. A subchannel can convect transverse momentum to or from several gaps at the top and/or bottom of the section. For user convenience, when only one axial section is modeled, the input values of CARD 2.3 are ignored. They are created automatically by the code; that means, NAMGAP(I) can be set to zero and CARD 2.3 can be omitted.

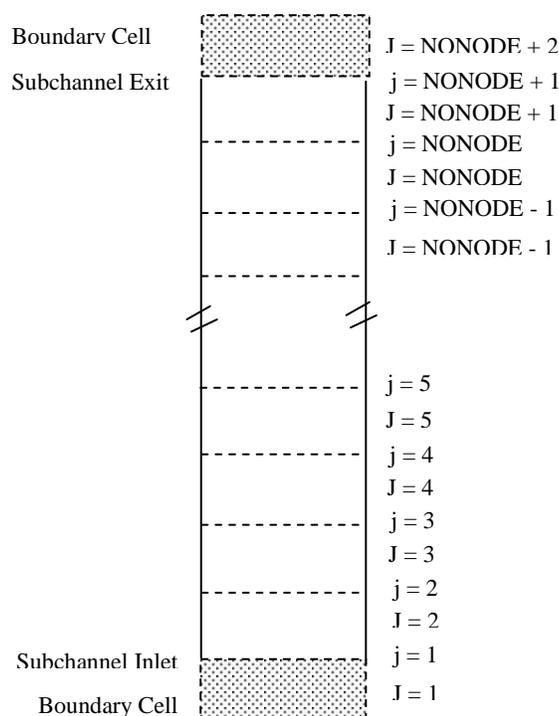


Figure 8: Subchannel Node Numbering Convention

In defining the input for CARD 2.3, the user must understand how the momentum equation is solved at the section boundaries, to determine if the axial velocities will be solved in subchannel I at the section boundary. It does not do any good to specify the NAMGAP connections for subchannels that are not solved at the section boundary, and conversely, they must be specified for those that are. Regardless of the geometry being modeled, there are three basic patterns for subchannel splitting connections. These are: 1) one

subchannel below connected to one subchannel above (see Figure 9 case (1)); 2) one subchannel below connected to many subchannels above (see Figure 9 case (2)); and 3) multiple subchannels below connected to one subchannel above (see Figure 9 case (3)).

Transverse momentum convection input data is required only for subchannels where the momentum equation will be solved at the section boundary, and velocities so obtained can convect transverse momentum from or to adjacent gaps. The momentum equation is solved at the top of subchannel 1 for case (1) and is not solved at the bottom of subchannel 2. The momentum equation is solved at the bottom of subchannels 2, 3, and 4 in case (2), and at the top of subchannels 1, 2, and 3 in case (3).

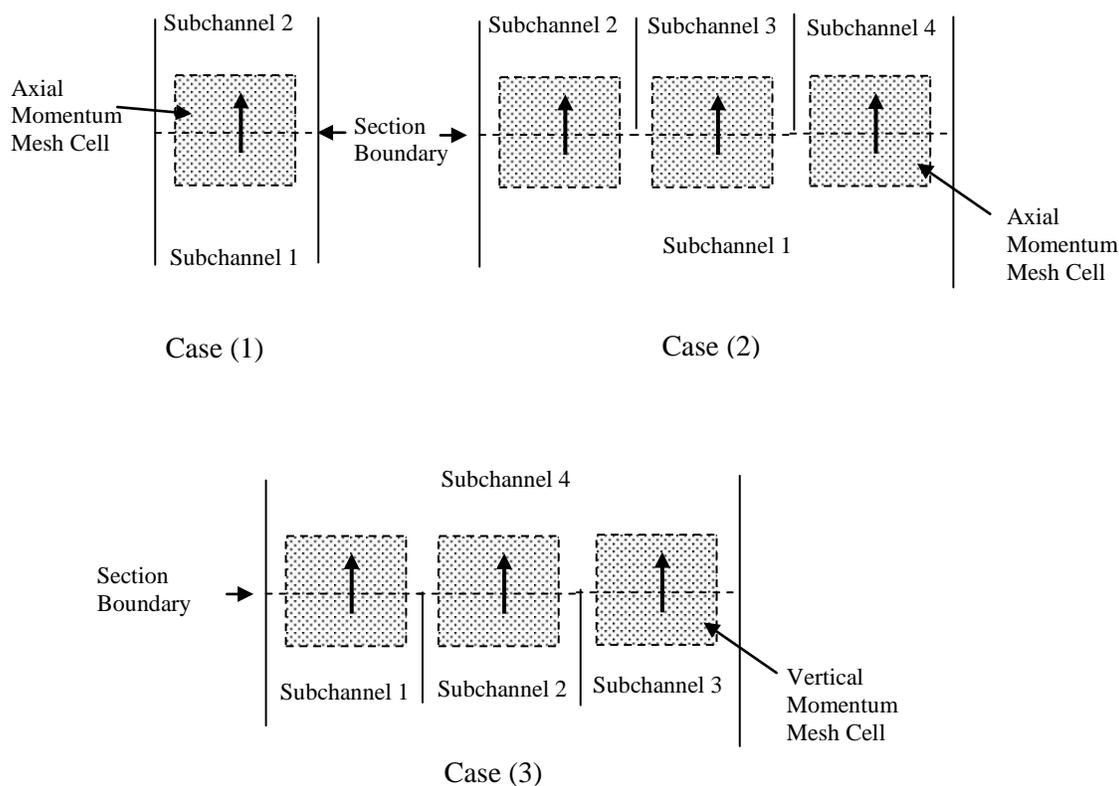


Figure 9: Subchannel Connections at Section Boundaries Allowed by the Subchannel Splitting Logic

The possible subchannel and gap configurations at section boundaries are outlined in Figure 10. The case where two subchannels below the section boundary connect to two subchannels above the section boundary with no change in the number of mesh cells between sections is illustrated in Figure 10 (a). The axial momentum equation is solved in the top nodes of subchannels **1** and **2** to obtain axial velocities at the section boundary. The velocity of subchannel **1** convects transverse momentum from the left side of the transverse momentum cell for gap **1** to the left side of the transverse momentum cell for gap **2**. Similarly, the velocity of subchannel **2** convects momentum from the right side of the momentum cell for gap **1** to the right side of the

momentum cell for gap **2**. For this example, the input for CARD 2.3 has to be supplied for both subchannels **1** and **2** as follows:

```
*****
* Axial section 1, subchannel 1
* Card 2.2
*   I      AN      PW ABOT ATOP NMGP
*   1     xxxx   xxxx  0.0  0.0   1
* Card 2.3
*   INODE KGAPB KGAPA
NONODE+1   1     2
* Axial section 1, subchannel 2
* Card 2.2
*   I      AN      PW ABOT ATOP NMGP
*   2     xxxx   xxxx  0.0  0.0   1
*   INODE KGAPB KGAPA
NONODE+1   1     2
* Axial section 2, subchannel 3
* Card 2.2
*   I      AN      PW ABOT ATOP NMGP
*   3     xxxx   xxxx  0.0  0.0   0
* Axial section 2, subchannel 4
* Card 2.2
*   I      AN      PW ABOT ATOP NMGP
*   4     xxxx   xxxx  0.0  0.0   0
*****
```

For the case shown in Figure 10 (b), there is no gap on the top side of the section boundary, so the axial velocities at the top of subchannels **1** and **2** convect momentum out of gap **1**, but the momentum is assumed to be dissipated since there is no transverse momentum cell to receive it. For this case, the input will be:

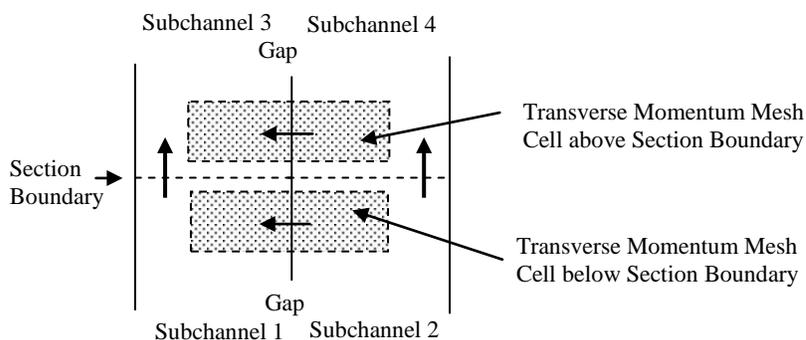
```
*****
* Axial section 1, subchannel 1
* Card 2.2
*   I      AN      PW ABOT ATOP NMGP
*   1     xxxx   xxxx  0.0  0.0   1
* Card 2.3
*   INODE KGAPB KGAPA
NONODE+1   1     0
* Axial section 1, subchannel 2
* Card 2.2
*   I      AN      PW ABOT ATOP NMGP
*   2     xxxx   xxxx  0.0  0.0   1
*   INODE KGAPB KGAPA
NONODE+1   1     0
* Axial section 2, subchannel 3
* Card 2.2
*   I      AN      PW ABOT ATOP NMGP
*   3     xxxx   xxxx  0.0  0.0   0
*****
```

If a gap exists both above and below the section boundary as in Figure 10 (a), but there is a flow straightener (such as a core support plate) at the section boundary, then the transverse momentum can be dissipated by specifying two connectors for each subchannel, one for positive flow and the other for negative

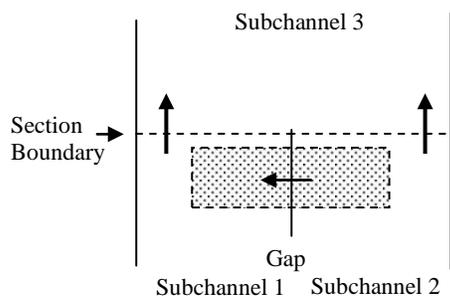
flow. Positive flow convects momentum from gap 1 and dissipates it; negative flow convects momentum from gap 2 and dissipates it:

```

*****
* Axial section 1, subchannel 1
* Card 2.2
*   I      AN      PW ABOT ATOP NMGP
*   1      xxxx   xxxx  0.0  0.0   2
* Card 2.3
*   INODE KGAPB KGAPA
NONODE+1   1     0
NONODE+1   0     2
* Axial section 1, subchannel 2
* Card 2.2
*   I      AN      PW ABOT ATOP NMGP
*   2      xxxx   xxxx  0.0  0.0   2
*   INODE KGAPB KGAPA
NONODE+1   1     0
NONODE+1   0     2
* Axial section 2, subchannel 3
* Card 2.2
*   I      AN      PW ABOT ATOP NMGP
*   3      xxxx   xxxx  0.0  0.0   0
* Axial section 2, subchannel 4
* Card 2.2
*   I      AN      PW ABOT ATOP NMGP
*   4      xxxx   xxxx  0.0  0.0   0
*****
    
```



(a)



(b)

Figure 10: Typical Configuration for Convection of Transverse Momentum between Sections

If momentum is convected by axial velocity from one gap on one side of the section boundary to several gaps on the other side (variable mesh) then transverse momentum convection connections must be specified for each gap. The momentum taken from the single gap is apportioned among the connecting gaps by the relative size of the areas through which the momentum is convected.

2.2.2 Instructions to CARD GROUP 3

The gap input defines the control volume for the transverse momentum equation, on either a subchannel analysis basis or for a three-dimensional analysis of transverse flow.

The total number of gaps, NK , is read on CARD 3.1. The geometry data for each gap is read on CARD 3.2. Each gap is identified by a unique number K . Gap K connects subchannel $IK(K)$ to subchannel $JK(K)$. By convention, $IK(K)$ is the lower-numbered subchannel of the pair, $JK(K)$ is the higher-numbered subchannel of the pair, and the crossflow through the gap K is positive when passing from $IK(K)$ to $JK(K)$. Flow the other way is negative. The nominal gap width is specified as $GAPN(K)$ and the distance between the centers of the connected subchannels is $LENGTH(K)$. $GAPN(K)$ and $LENGTH(K)$ define the width and length of the transverse momentum mesh cell. The flow area between the connecting subchannels is given by the product of the gap width and the axial length increment for the mesh, DXS (to be read on CARD 4.2). The gap width, $GAPN(K)$, is equal to the total width for transverse flow between the two adjacent regions modeled by the subchannels $IK(K)$ and $JK(K)$.

Form and wall drag in gap K is specified for the transverse momentum equations using the parameters $WKR(K)$ and $FWALL(K)$.

The form drag loss coefficient (velocity head), $WKR(K)$, is specified by the user. The value of $WKR(K)$ for a gap depends on the geometry of the flow path modeled. A value of 0.5 is typically used for flow across one row of rods or tubes. For lumped subchannels, this value is multiplied by the number of rod rows the gap momentum cell contains.

Wall friction in the gap is ordinarily included in the WKR parameter, but for gaps that are formed by vessel walls rather than rod arrays (as in the downcomer annulus, for example) the pressure loss in the gap is primarily a friction loss rather than a form loss and should be modeled accordingly. Wall friction factors in a gap are computed internally in the code according to the user-specified value of the $FWALL(K)$ parameter. If $FWALL(K)$ is zero, no wall friction is calculated (gap formed by a rods only). If $FWALL(K)$ is set equal to **0.5**, a wall with a surface of $DXS*LENGTH(K)$ is assumed (one side of the gap control volume is a solid wall). If $FWALL(K)$ is set equal to **1.0**, a wall with a surface of $2*DXS*LENGTH(K)$ is assumed (a solid wall on each side of the gap control volume). Both, a form loss and wall friction factor can be specified for a

gap, or one or the other can be set to zero, depending of the geometry of the problem. Both can be set to zero if the gap is in an open fluid region where the fluid-to-fluid shear within the continuous phase adequately models the transverse drag forces.

The input required to describe transverse convection of axial momentum between gaps across section boundaries employs the same sort of reasoning as does the input in CARD GROUP 2 to describe the axial convection of transverse momentum across section boundaries. The user must specify which transverse gap velocities can transport axial momentum into or out of the subchannels associated with gap K at the top and bottom of the section. The transverse velocity of gap IGAPB(K) (at node NONODE+1 in the section below) can convect axial momentum into or out of the bottom cell of the subchannels associated with gap K . The transverse velocity of gap IGAPA(K) (at node 2 in the section above) can convect axial momentum into or out of the top cell of the subchannels associated with gap K . Transverse convection of axial momentum at a section boundary is illustrated in Figure 11. In this example, axial momentum is convected between the two axial mesh cells by the transverse velocity of gap 1 below the section boundary and by the transverse velocity of gap 2 above the section boundary. The input for IGAPA(K) identifies the gap in the section above gap K that convects axial momentum between the axial momentum cells associated with the top of gap K . For the example shown in Figure 11, $IGAPA(K) = 2$ and the corresponding input will have the following format:

```
*****
* Card 3.2 - Gap 1
* K  IK  JK  GAPN  LNGT  WKR  FWAL  IGPB  IGPA  FACT  IGAP  JGAP  IGAP  JGAP  IGAP  JGAP
  1   1   2   X.X   X.X   X.X   X.X   0    2   X.X   X    X    X    X    X    X
*****
```

The input for IGAPB(K) identifies the gap in the section below gap K that convects axial momentum between the axial momentum cells associated with the top of gap K . For the example shown in Figure 11, $IGAPB(K) = 1$ and the input will have the following format:

```
*****
* Card 3.2 - Gap 2
* K  IK  JK  GAPN  LNGT  WKR  FWAL  IGPB  IGPA  FACT  IGAP  JGAP  IGAP  JGAP  IGAP  JGAP
  2   3   4   X.X   X.X   X.X   X.X   1    0   X.X   X    X    X    X    X    X
*****
```

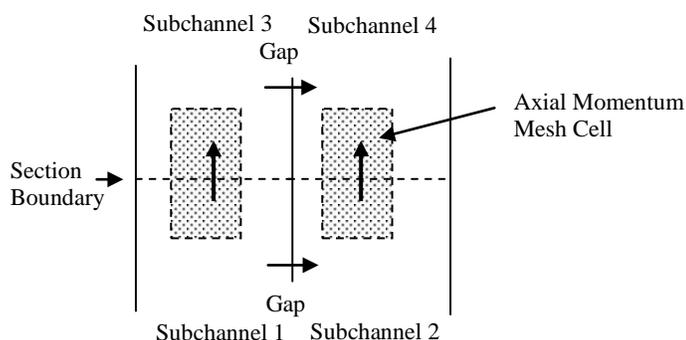


Figure 11: Axial Momentum Mesh Cell at Section Boundary

The remainder of the input for CARD 3.2 is required only for the three-dimensional form of the transverse momentum equation. If the subchannel formulation is desired for a specific problem, this input is omitted. It is used to define consistent transverse flow directions for the global coordinate system and to set up connections for orthogonal transport of momentum.

The normal crossflow sign convention is not always congruent with a global coordinate system. The user can convert the local transverse flow sign convention to an appropriate global system by specifying the variable FACTOR(K) to indicate the orientation of gap K in the global coordinate system. Figure 12 (a) gives two examples how FACTOR can be used. Example (a) shows an annular subchannel arrangement typically used in the downcomer. The annular flow subchannels are two-dimensional, so it is only necessary to define a transverse direction that is consistently positive. The normal convention for defining positive crossflow results in crossflow from subchannel 1 to subchannel 2 and from subchannel 3 to subchannel 4 is to have both being positive. Assuming that the clockwise direction is chosen as positive for the global coordinate system, if flow from IK(K) to JK(K) is clockwise, then FACTOR(K) is set to 1.0. If flow from IK(K) to JK(K) is counterclockwise, the sign convention must be reversed by setting FACTOR(K) to -1.0. In this example, FACTOR(2) is set to -1.0 and the input will have the following format:

```
*****
* Card 3.2 - Gap 1
* K  IK  JK  GAPN  LNGT  WKR  FWAL  IGPB  IGPA  FACT  IGAP  JGAP  IGAP  JGAP  IGAP  JGAP
  1   1   2   X.X   X.X   X.X   X.X   0    0   1.0   X    X    X    X    X    X
...
* Card 3.2 - Gap 2
* K  IK  JK  GAPN  LNGT  WKR  FWAL  IGPB  IGPA  FACT  IGAP  JGAP  IGAP  JGAP  IGAP  JGAP
  2   1   4   X.X   X.X   X.X   X.X   0    0  -1.0   X    X    X    X    X    X
...
* Card 3.2 - Gap 3
* K  IK  JK  GAPN  LNGT  WKR  FWAL  IGPB  IGPA  FACT  IGAP  JGAP  IGAP  JGAP  IGAP  JGAP
  3   2   3   X.X   X.X   X.X   X.X   0    0   1.0   X    X    X    X    X    X
...
* Card 3.2 - Gap 4
* K  IK  JK  GAPN  LNGT  WKR  FWAL  IGPB  IGPA  FACT  IGAP  JGAP  IGAP  JGAP  IGAP  JGAP
  4   3   4   X.X   X.X   X.X   X.X   0    0   1.0   X    X    X    X    X    X
*****
```

A three-dimensional subchannel array is shown in example (b) in Figure 12. For this case, the values of $FACTOR(K)$ must correspond to the actual orientation of the velocity vector in the gap on the global coordinate system. The arrows in the gaps indicate the positive crossflow direction defined by the normal convection. For gaps **1**, **3**, **6**, and **7**, this is the same as the global coordinates, so $FACTOR(1)$, $FACTOR(3)$, $FACTOR(6)$ and $FACTOR(7)$ are **1.0** for this case. But the positive flow direction in gaps **2**, **4**, and **5** is exactly opposite of the global convention, so $FACTOR(2)$, $FACTOR(4)$ and $FACTOR(5)$ must be specified as **-1.0** to reverse the sign on the crossflow velocity. The input will have the following format:

```

*****
* Card 3.2 - Gap 1
* K  IK  JK  GAPN  LNGT  WKR  FWAL  IGPB  IGPA  FACT  IGAP  JGAP  IGAP  JGAP  IGAP  JGAP
*   1   1   2   X.X   X.X   X.X   X.X   0    0   1.0   X    X    X    X    X    X
...
* Card 3.2 - Gap 2
* K  IK  JK  GAPN  LNGT  WKR  FWAL  IGPB  IGPA  FACT  IGAP  JGAP  IGAP  JGAP  IGAP  JGAP
*   2   1   4   X.X   X.X   X.X   X.X   0    0  -1.0   X    X    X    X    X    X
...
* Card 3.2 - Gap 3
* K  IK  JK  GAPN  LNGT  WKR  FWAL  IGPB  IGPA  FACT  IGAP  JGAP  IGAP  JGAP  IGAP  JGAP
*   3   2   3   X.X   X.X   X.X   X.X   0    0   1.0   X    X    X    X    X    X
...
* Card 3.2 - Gap 4
* K  IK  JK  GAPN  LNGT  WKR  FWAL  IGPB  IGPA  FACT  IGAP  JGAP  IGAP  JGAP  IGAP  JGAP
*   4   2   5   X.X   X.X   X.X   X.X   0    0  -1.0   X    X    X    X    X    X
...
* Card 3.2 - Gap 5
* K  IK  JK  GAPN  LNGT  WKR  FWAL  IGPB  IGPA  FACT  IGAP  JGAP  IGAP  JGAP  IGAP  JGAP
*   5   3   6   X.X   X.X   X.X   X.X   0    0  -1.0   X    X    X    X    X    X
...
* Card 3.2 - Gap 6
* K  IK  JK  GAPN  LNGT  WKR  FWAL  IGPB  IGPA  FACT  IGAP  JGAP  IGAP  JGAP  IGAP  JGAP
*   6   4   5   X.X   X.X   X.X   X.X   0    0   1.0   X    X    X    X    X    X
...
* Card 3.2 - Gap 7
* K  IK  JK  GAPN  LNGT  WKR  FWAL  IGPB  IGPA  FACT  IGAP  JGAP  IGAP  JGAP  IGAP  JGAP
*   7   5   6   X.X   X.X   X.X   X.X   0    0   1.0   X    X    X    X    X    X
*****

```

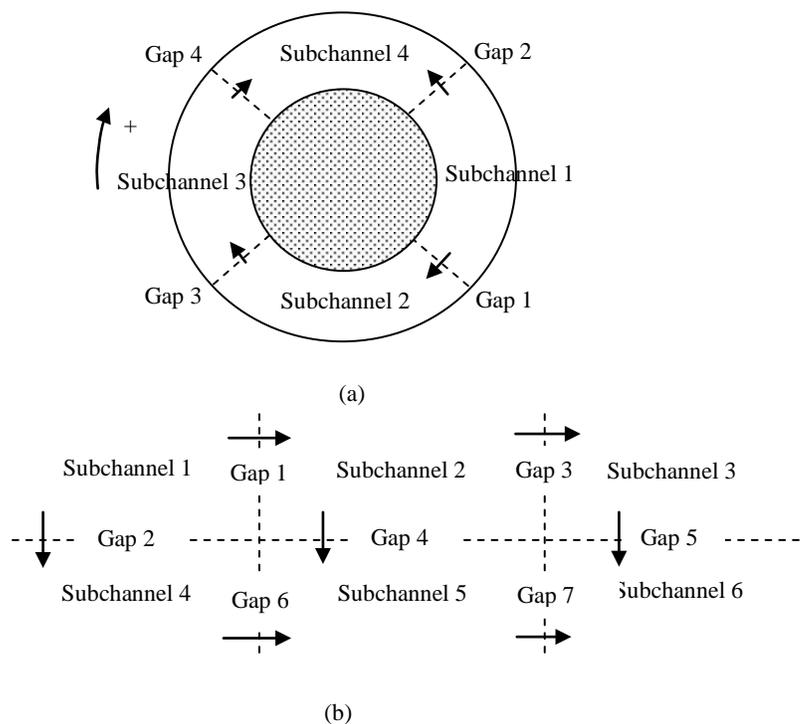


Figure 12: Global Coordinate Systems

For the three-dimensional form of the transverse momentum equation, the user must specify the gaps facing a given gap K . This information is required in the code to calculate the normal components ($\rho V^2 A$) of transverse momentum. The arrays IGAP(K,N) and JGAP(K,N) on CARD 3.2 are used to supply this data. The IGAP array holds the identification numbers of up to three gaps on the IK (or lower-numbered subchannel) side of gap K . The JGAP array holds the identification numbers of up to three gaps on the JK (or higher-numbered subchannel) side of gap K . This is illustrated in Figure 13. In this example, gap 4 connects subchannels 1 and 2, with the conventional positive flow direction shown by the arrow. Gaps 1 and 3 face the IK side of gap 4 and gaps 5 and 6 face the JK side. The input will have the following format:

```

*****
* Card 3.2 - Gap 1
* K  IK  JK  GAPN  LNLT  WKR  FWAL  IGPB  IGPA  FACT  IGAP  JGAP  IGAP  JGAP  IGAP  JGAP
  1   1   3   X.X   X.X   X.X   X.X   0    0  -1.0   4    -1    0    0    0    0
...
* Card 3.2 - Gap 2
* K  IK  JK  GAPN  LNLT  WKR  FWAL  IGPB  IGPA  FACT  IGAP  JGAP  IGAP  JGAP  IGAP  JGAP
  2   3   4   X.X   X.X   X.X   X.X   0    0  -1.0  -1   -1    0    0    0    0
...
* Card 3.2 - Gap 3
* K  IK  JK  GAPN  LNLT  WKR  FWAL  IGPB  IGPA  FACT  IGAP  JGAP  IGAP  JGAP  IGAP  JGAP
  3   1   4   X.X   X.X   X.X   X.X   0    0   1.0   4   -1    0    0    0    0
...
* Card 3.2 - Gap 4
* K  IK  JK  GAPN  LNLT  WKR  FWAL  IGPB  IGPA  FACT  IGAP  JGAP  IGAP  JGAP  IGAP  JGAP
  4   1   2   X.X   X.X   X.X   X.X   0    0   1.0   1    5    3    7    0    0
...
* Card 3.2 - Gap 5
* K  IK  JK  GAPN  LNLT  WKR  FWAL  IGPB  IGPA  FACT  IGAP  JGAP  IGAP  JGAP  IGAP  JGAP
  5   2   5   X.X   X.X   X.X   X.X   0    0   1.0   4   -1    0    0    0    0

```

```

...
* Card 3.2 - Gap 6
* K  IK  JK  GAPN  LNLT  WKR  FWAL  IGPB  IGPA  FACT  IGAP  JGAP  IGAP  JGAP  IGAP  JGAP
   6   5   6   X.X   X.X   X.X   X.X   0    0  -1.0  -1   -1    0    0    0    0
...
* Card 3.2 - Gap 7
* K  IK  JK  GAPN  LNLT  WKR  FWAL  IGPB  IGPA  FACT  IGAP  JGAP  IGAP  JGAP  IGAP  JGAP
   7   2   6   X.X   X.X   X.X   X.X   0    0   1.0   4   -1    0    0    0    0
*****

```

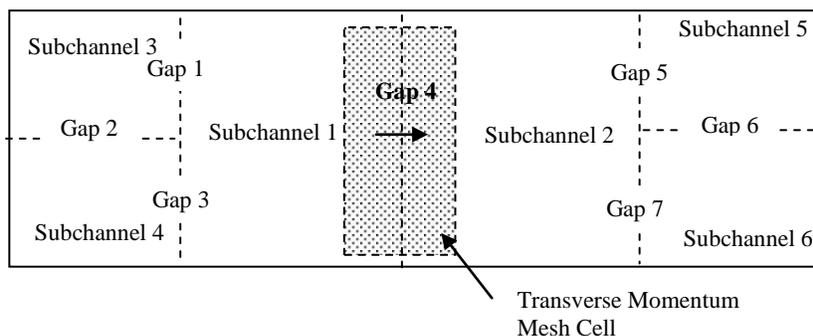


Figure 13: Normal Component of Transverse Momentum

CARD 3.3 must be read for each gap, following CARD 3.2. This input is designed to model gaps between subchannels that model large regions in the vessel. The nominal gap width, $GAPN(K)$ (supplied on CARD 3.2), is the total width for crossflow between subchannels. The characteristic width for two-phase flow through the gap, however, is the distance between the physical structures and not necessarily the total width of the connection between mesh cells. The parameter $GMULT(K)$, input on CARD 3.3, is the number of uniform spaces between structures in the region modeled by the gap. The characteristic dimension for two-phase flow is given by:

$$S' = \frac{GAPN(K)}{GMULT(K)} \quad (1)$$

The dimension S' determines the maximum bubble size that can pass between structures. If $GAPN(K)$ is the actual width available for flow, $GMULT(K)$ is set to 1.

$ETANR(K)$, which is also read on CARD 3.3, is the fraction of transverse droplet flow de-entrained on structures within the mesh cell. In a reactor vessel or test section the array of rods in the core and support columns and guide tubes in the upper plenum can contribute significantly to de-entrainment of droplets from the transverse component of the flow. The de-entrainment fraction, $ETANR(K)$, for a gap modelling an array of tubes is:

$$ETANR(K) = 1 - (1 - \eta_R)^N \quad (2)$$

where η_R is the de-entrainment fraction of a single row of tubes and N is the number of tubes. The de-entrainment fraction of a single row of tubes is:

$$\eta_R = \eta_I(1 + 4.5\beta^2) \quad (3)$$

where $\eta_I = 0.19$ for cylindrical tubes; $\eta_I = 0.27$ for square tubes; and β is the pitch-to-diameter ratio of the array.

ETANR(K) can be used to model the crossflow de-entrainment rate for geometries other than tube banks and rod bundles, but the user must determine the appropriate value for each particular application.

The CARDS 3.4 and 3.5 are required only for the three-dimensional form of the transverse momentum equation. The total number of gaps that convect orthogonal transverse momentum is specified as the NLMGAP parameter on CARD 3.4. The velocity of the gap identified in KGAP1(N) convects transverse momentum from KGAP3(N) to KGAP2(N) if the velocity is positive and from KGAP2(N) to KGAP3(N) if negative. This is illustrated in Figure 14. In this example, the velocity of gap 1 convects momentum from the left half of the momentum mesh cell for gap 4 to the left half for gap 2. The velocity of gap 3 convects momentum from the right half of the momentum mesh cell for gap 4 to the right half for gap 2. Gaps 2 and 4 also convect momentum from gap 1 to gap 3. Then, $KGAP1(1) = 1$; $KGAP2(1) = 2$; $KGAP1(2) = 3$; $KGAP3(2) = 4$; $KGAP1(3) = 2$; $KGAP2(3) = 3$; $KGAP3(3) = 1$; $KGAP1(4) = 4$; $KGAP2(4) = 3$; and $KGAP3(4) = 1$. The input will have the following format:

```
*****
* Card 3.4
* NLMGAP
  4
* Card 3.5
* KGAP1 KGAP2 KGAP3 KGAP1 KGAP2 KGAP3 KGAP1 KGAP2 KGAP3 KGAP1 KGAP2 KGAP3
  1     2     4     2     3     1     3     2     4     4     3     1
*****
```

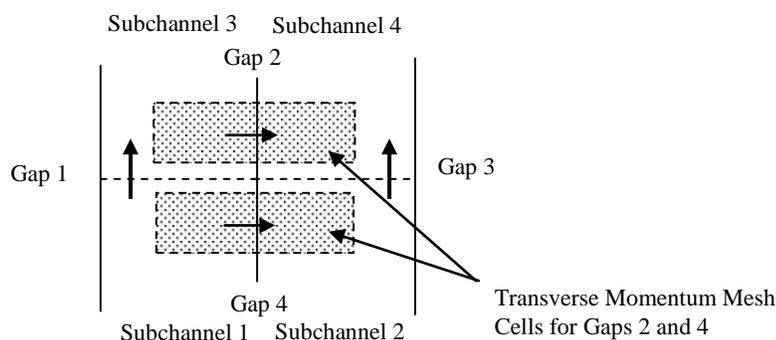


Figure 14: Convection of Transverse Momentum by an Orthogonal Transverse Velocity

In general, the convection of transverse momentum by transverse velocities in the gap between local and global (lumped) mesh cells is neglected. The transverse flow between local mesh and global mesh is assumed to be axisymmetric. The shape of the transverse momentum cell is idealized and requires the user's judgment in selecting values for the gap width and length. The gap width should be chosen such that the product of the gap width and the axial mesh length increment is equal to the physical area for the flow path between the local and global mesh cells. The shape of the momentum mesh cell is assumed rectangular and its length should be chosen to give a physically meaningful time constant for accelerating flow through the gap. A distance equal to the diameter of the local mesh is recommended for the centroid distance ((LENGTH(K)).

Setting up the gap geometry data is relatively simple even for peculiar geometries if the user bears in mind that GAPN(K) and LENGTH(K) define the transverse control volume for the gap. The size and shape of such control volume should bear some logical resemblance to the physical structure being modeled, within the constraints of the nodding philosophy used in the code. The control volume is important not only for defining the location and magnitude of the transverse flow, but also for determining axial transport of transverse momentum through the top and bottom surfaces of the control volume. Both aspects of the momentum solution must be considered in defining the gap width and centroid length.

2.2.3 Instructions to CARD GROUP 4

The input data for CARD GROUP 4 describes the axial subchannel connections between sections and defines the rebalancing and simultaneous solution group options.

CARD 4.1 provides the input for the total number of axial sections in the problem, NSEC; the total number of the simultaneous solution groups, NSIM, in the iterative pressure matrix solution; and the flag IREB for selection of the rebalancing option for enhancement of the convergence rate for the iterative solution (parameters NSIM and IREB will be discussed later in the text).

CARD 4.2 provides the input data describing each axial section in the problem. It contains the section number, ISEC; the number of subchannels, ICHN, in the section; the number of axial nodes, NONODE, in the section; the axial node length, DXS, in the section; and the flag IVARDX for variable node length in the section. The section boundaries are uniform at a given axial level, so all subchannels within the section have the same total length. The axial node length DXS defines the length of both the continuity and momentum control volumes. DXS is constant within the section and therefore the total axial length of the section is $DXS \cdot NONODE$. DXS can vary between sections and each section may have one or many axial nodes. The only constraint is that the change in DXS between adjacent sections should not be greater than factor of two.

CARD 4.3 specifies a variable axial node length within a section. The input data contains the last axial level JLEV(I) in a section to have a node length of VARDX(I), where I is the number of pairs to be read and it is equal to the parameter IVARDX read on CARD 4.2. For the example shown in Figure 15, the input will have the following format:

```
*****
* Card 4.1
* NSEC NSIM IREB NDM4 NDM5 NDM6 NDM7 NDM8 NDM9 NM10 NM11 NM12 NM13 NM14
   1   1   0   0   0   0   0   0   0   0   0   0   0   0
* Card 4.2
* ISEC NCHN NONO      DXS IVAR
   1   1   9  0.02556   3
* Card 4.3
* JLEV  VRDX JLEV  VRDX JLEV  VRDX
   5  0.04   8  0.01  10  0.02
*****
```

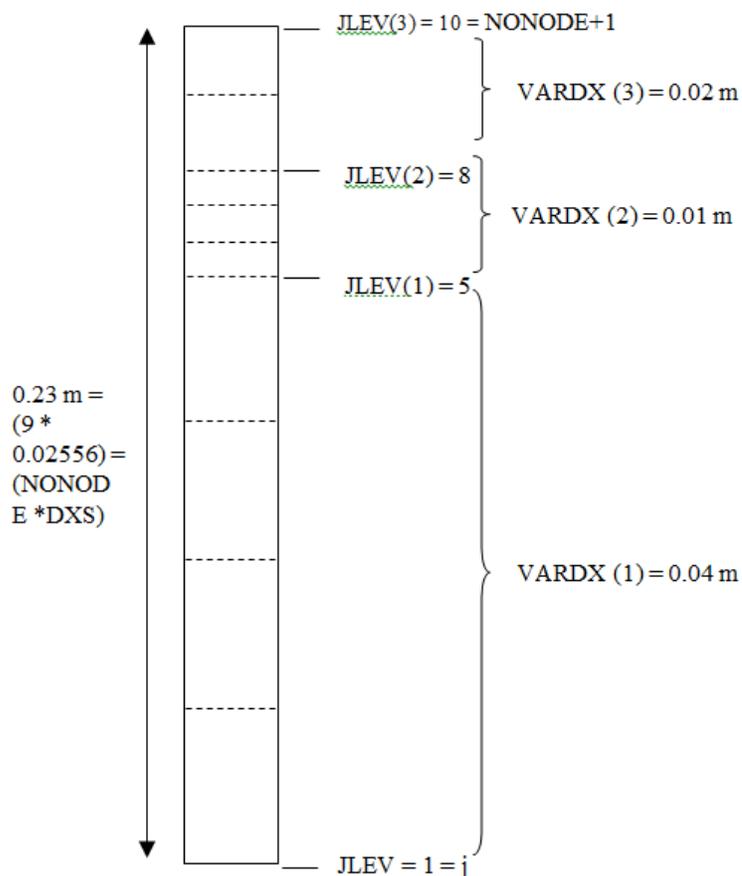


Figure 15: Diagram of the Variable Axial Node Length

CARD 4.4 specifies the axial connections for each subchannel in a section. A subchannel may connect up to six subchannels in the section above and six subchannels in the section below. The array KCHANA contains the index numbers of subchannels connected to the top of the subchannel and the array KCHANB contains the index numbers of the subchannels connected to the bottom. If a subchannel does not have a connection above or below, KCHANA or KCHANB is specified with the subchannel's own identification number. The code will not accept a subchannel with only zeros in KCHANA or KCHANB arrays.

There are three basic patterns possible for vertical connections between subchannels: a) one subchannel below connected to one subchannel above; b) one subchannel below connected to many subchannels above; and c) multiple subchannels below connected to a single subchannel above. As previously discussed, the momentum equation for the axial velocity at the section boundary is solved at the top node of the bottom subchannel for case (a); in the bottom node of each of the upper subchannels in case (b); and in the top node of each lower subchannel in case (c). The momentum mesh cells at the section boundary for these three cases are shown in Figure 16. Velocities are solved for in the momentum cells at the top of subchannel **1** for case (a); at the bottom of subchannels **2**, **3**, and **4** for case (b); and at the top of subchannels **1**, **2**, and **3** for case (c).

Velocities at the momentum cell faces, which are used to calculate the momentum flux terms, are obtained by averaging the velocities at the cell centers of adjacent momentum cells. At section boundaries where the connections are like those shown in cases (a) and (c) in Figure 16, the velocity at the top face of the momentum cell is obtained by averaging the velocities at the centers of the momentum mesh cells on the boundary with the velocity at the center of the first momentum mesh cell in the subchannel above. For case (a), the velocity of subchannel **2**, node **2**, is averaged with the velocity calculated in subchannel **1** at the boundary. For case (c), the velocity of subchannel **4**, node **2**, is averaged with the velocities calculated in subchannels **1**, **2**, and **3** at the boundary. For case (b), the velocity calculated at the last cell of subchannel **1** is averaged with velocities calculated in subchannels **2**, **3**, and **4** at the boundary. A subchannel with multiple connections to both the bottom and top must contain at least two mesh cells. If the subchannel had only one cell, the code would not be able to determine which velocities to use when obtaining average velocity at the cell face for momentum cells at the bottom of the subchannel or at the top of the subchannel.

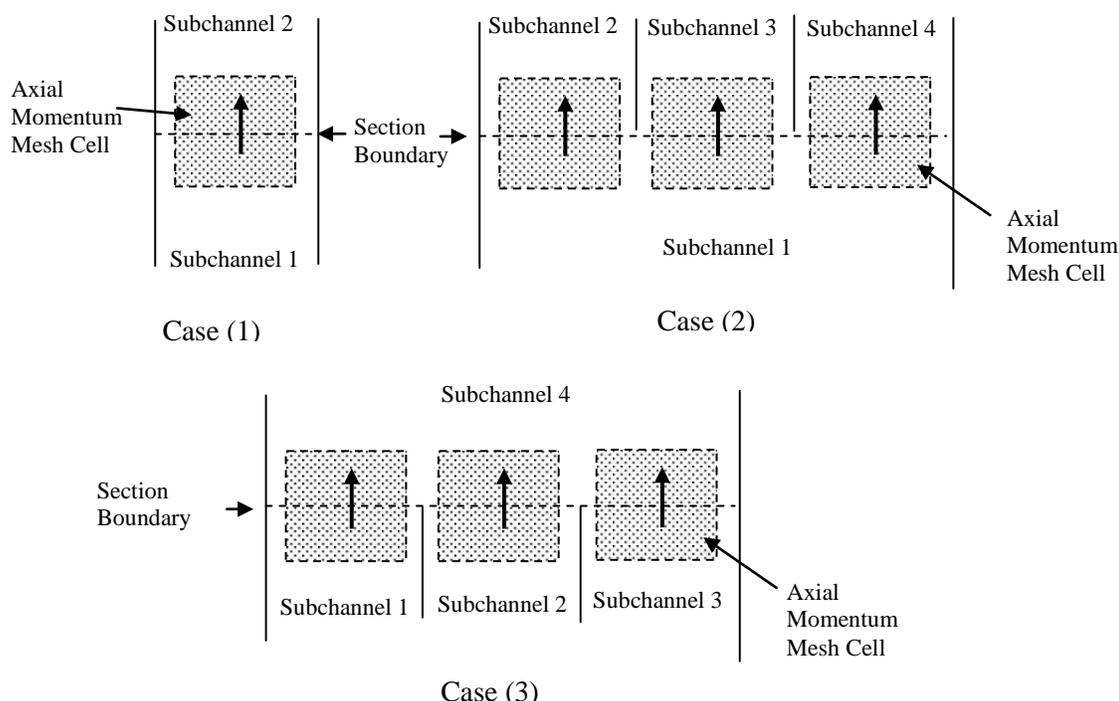


Figure 16: Allowable Vertical Connections between Subchannels at Section Boundaries

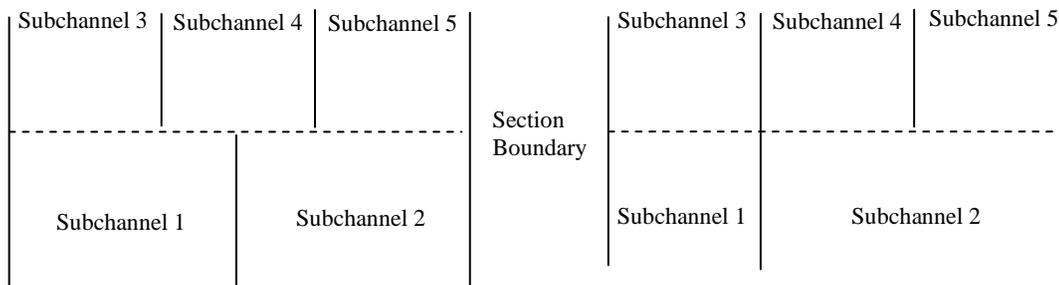
Figure 17 shows two examples of subchannel connections that are not permitted by the subchannel splitting logic of the code. In example (a), the subchannels below overlap in their connections to the subchannels above. In example (b), the subchannel **3** is only one cell long. The input for the correct subchannel splitting example shown in

Figure 17 (b) will have the following format:

```

*****
* Card 4.1
* NSEC NSIM IREB NDM4 NDM5 NDM6 NDM7 NDM8 NDM9 NM10 NM11 NM12 NM13 NM14
  3   1   0   0   0   0   0   0   0   0   0   0   0   0
* Axial Section 1
* Card 4.2
* ISEC NCHN NONO  DXS  IVAR
  1   2   x  x.x   0
* Card 4.4
*   I  KCHA KCHA KCHA KCHA KCHA KCHA KCHA KCHB KCHB KCHB KCHB KCHB KCHB
  1   3   0   0   0   0   0   1   0   0   0   0   0
  2   3   0   0   0   0   0   2   0   0   0   0   0
* Axial Section 2
* Card 4.2
* ISEC NCHN NONO  DXS  IVAR
  2   1   2  x.x   0
* Card 4.4
*   I  KCHA KCHA KCHA KCHA KCHA KCHA KCHB KCHB KCHB KCHB KCHB KCHB
  3   4   5   6   0   0   0   1   2   0   0   0   0
* Axial Section 3
* Card 4.2
* ISEC NCHN NONO  DXS  IVAR
  3   3   x  x.x   0
* Card 4.4
*   I  KCHA KCHA KCHA KCHA KCHA KCHA KCHB KCHB KCHB KCHB KCHB KCHB
  4   4   0   0   0   0   0   3   0   0   0   0
  5   5   0   0   0   0   0   3   0   0   0   0
  6   6   0   0   0   0   0   3   0   0   0   0
*****

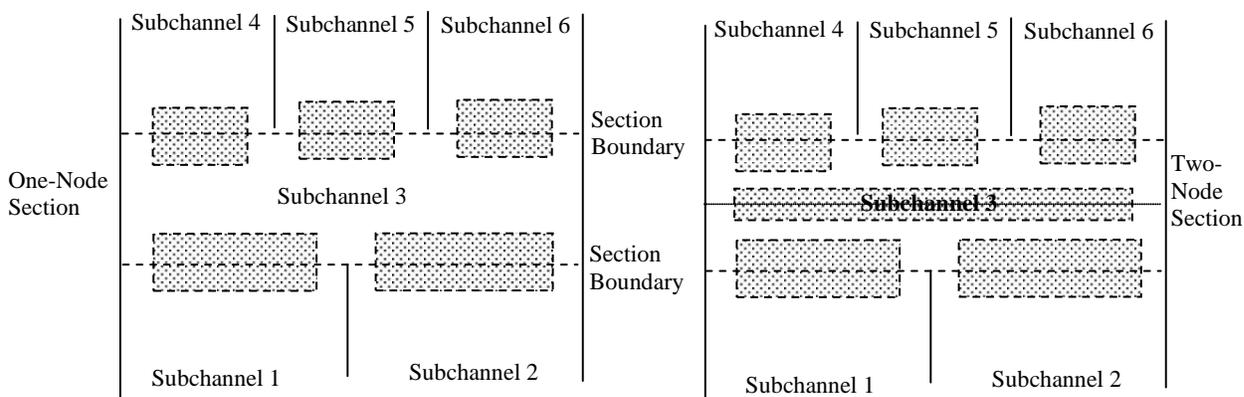
```



Wrong Splitting

Correct Splitting

(a)



Wrong Splitting

Correct Splitting

(b)

Figure 17: Common Subchannel Splitting Errors

The remainder of CARD GROUP 4 specifies the numerical solution procedure to be used for solving the linearized continuity and energy equations. The equations may be solved by a direct inversion of the system pressure matrix or a combination of direct inversion and Gauss-Seidel iterative method. (*The pressure matrix can be solved using different Krylov iterative solvers, but this option is controlled by the flag ISOL entered in CARD GROUP 1, ISOL > 0*). In the combination solution, the pressure matrix for groups of cells is solved by direct inversion while the pressure in cells surrounding each group is held constant. Gauss-Seidel iteration is then performed over the groups of cells to obtain a converged solution for the entire system pressure matrix.

The solution procedure used is determined by the parameter NSIM read on CARD 4.1. If the number of the simultaneous solution groups NSIM is set to one the solution is obtained by direct inversion. If NSIM is set to N (where N is an integer greater than one) the solution is obtained with a combination of direct inversion and iteration with N simultaneous solution groups. The convergence rate for the iterative solution can be enhanced by specifying the rebalancing option, **IREBAL = 1**. When rebalancing is done, a one-dimensional solution for the linear pressure variation at each axial level is obtained by direct inversion. This value is used as an initial estimate for the linear pressure variation in each cell in the group-by-group iteration.

A direct inversion is recommended for relatively small problems (up to 100 mesh cells). The Gauss-Seidel iterative technique is recommended for larger problems. However, an experience indicates that the significant speed-up with group-by-group iteration is observed only when stationary conditions or transients not involving mass flow rate variation are simulated. For flow transients Gauss-Seidel solver converges slowly, leading to tremendous increase of the CPU time (such lack of convergence cannot be overcome by using the rebalancing option). Therefore, for larger problems the Krylov solvers are highly recommended because of their competitive efficiency and better accuracy comparing to the Gauss-Seidel method.

The bandwidth of the pressure matrix is defined by the maximum difference between the index numbers of adjacent cells in a group that is being solved simultaneously. This maximum difference is specified by input as parameter IWIDE on CARD 4.5, and the maximum bandwidth of the pressure matrix is calculated as $(2 * IWIDE)$. The cell numbers used to define IWIDE are not subchannel numbers. Cell numbers are assigned in the following manner: beginning at the first subchannel in the first axial section, the first node in the subchannel (node $J = 2$) is assigned cell number one (1). The cells of all the subchannels in that section are numbered sequentially at the same level ($J = 2$). The cell numbering is continued on the next level, starting in the same first subchannel. This process continues until all cells for all axial sections have been assigned unique cell numbers. An example illustrating this numbering convention is shown in Figure 18. In the example, IWIDE is equal to 2 in simultaneous solution groups 1 and 5. In groups 3 and 4, **IWIDE = 1**. In

group 2 IWIDE is 3. The value of IWIDE entered in CARD 4.5 will be then 3 (the matrix must accommodate the largest bandwidth in all groups).

The MSIM array, the number of the last cell in each simultaneous solution group, is provided by CARD 4.6. The input for the example shown in Figure 18 will have the following format:

```
*****
* Card 4.5
* IWIDE
  3
* Card 4.6
* MSIM(1) MSIM(2) MSIM(3) MSIM(4) MSIM(5)
  6         28         29         31         35
*****
```

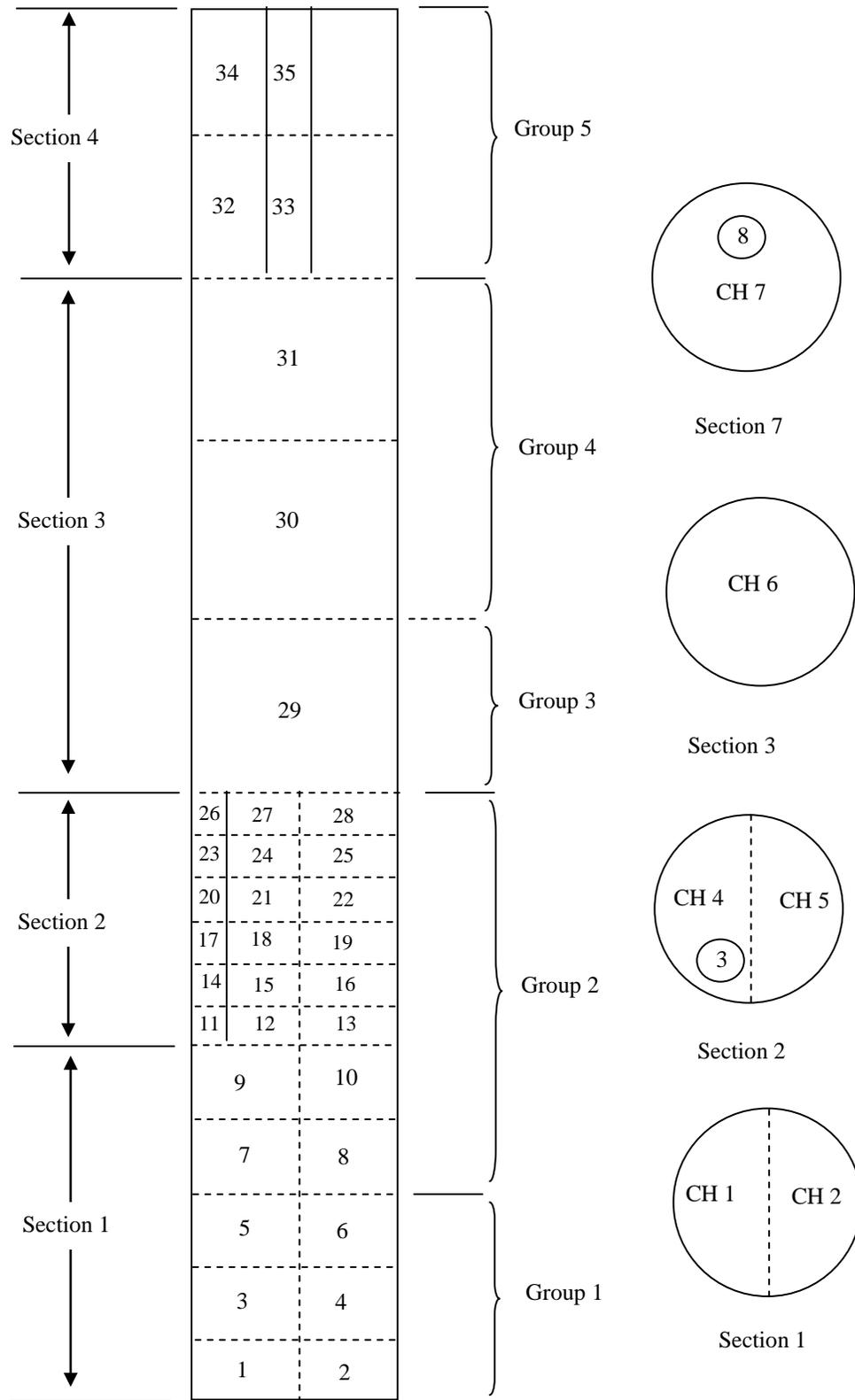


Figure 18: Example of Cell Numbering Scheme for Simultaneous Solution Groups

2.2.4 Instructions to CARD GROUS 5 and 6

The geometry of a subchannel or a gap is assumed to remain constant along the entire axial length at the nominal values specified by input. But CARD GROUPS 5 and 6 permits the user to specify axial variation in the geometry. This is an optional input and it is omitted if axial variation data is not needed. The input data is extremely general. The user provides tables of variation factors in CARD GROUP 5. Variation tables can be supplied for the continuity flow area, momentum flow area, and wetted perimeter of subchannels and the width of gaps. Variation tables are read on CARD 5.3 as tables of node number, JAXL(I,N), versus variation factor AFACT(I,N). The node number JAXL(I,N) refers to the continuity cell for continuity area and gap width and to the momentum cell for the momentum area and wetted perimeter. The variation factor is defined as:

$$AFACT(I,L) = \frac{\text{local value}}{\text{nominal value}} \quad (4)$$

The value AFACT(I,N) is applied in the code as a multiplier on the nominal value of the quantity being varied at the corresponding JAXL(I,N) node. Figure 19 shows two examples of subchannels with area variations that can be modeled with variation tables. For example (a), variations of the continuity area occur at nodes **7**, **8**, and **9**. Variations in the momentum area occur at nodes **7**, **8**, and **9** also, but because the geometry of the subchannel is tapered and the continuity and momentum nodes are staggered, the areas vary by different amounts. The tapered region in the subchannel is approximated by a stack of cells that have a uniform cross section along their individual lengths. The continuity areas of the cells should be defined so that the volumes of the cells are equal to the volumes of the regions they are intended to model. In the continuity solution, cells **7** and **8** model the tapered region. The momentum cells use the actual area at the location of the momentum cell center. In this example, the momentum area variation is modeled in cell **7**. The wetted perimeter is defined in the momentum cell, so variations in wetted perimeter must be located relative to the momentum cells. In example (a) in Figure 19, the gradually changing wetted perimeter must be approximated by step changes, as is the gradually changing flow area in the taper. For the circular cross section of this example, the simplest approach is to define the wetted perimeter as the perimeter of the momentum cells:

$$P_W = \pi D' \quad (5)$$

where $D' = \left(\frac{4A_{\text{momentum cell}}}{\pi} \right)^{1/2}$

The input for CARD GROUP 5 to model the variations in example (a) of Figure 19 consists of three variation tables ($NAFACT = 3$, read on CARD 5.1). The tables themselves are read on CARD 5.2

(specifying the number of entrees in a table) and on CARD 5.3 (filling the arrays for the node indices, JAXL, and variation factors, AFACT). The tables are numbered sequentially in the order they are read in.

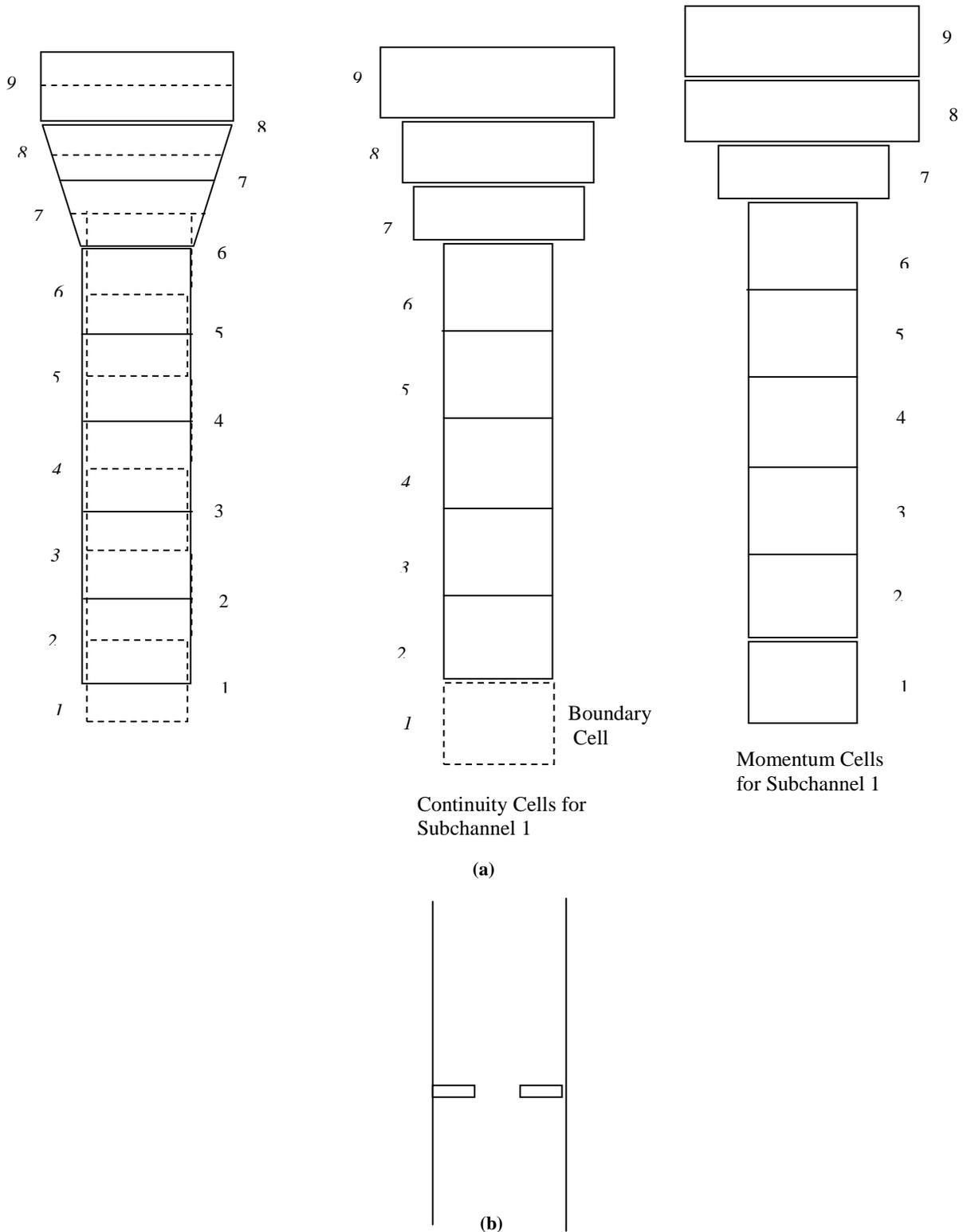


Figure 19: Examples of Axial Variation in Continuity and Momentum Area and Wetted Perimeter of a Subchannel

Example (b) in Figure 19 shows a different sort of area variation. The orifice plate in the straight pipe affects the momentum solution, but because it occurs over a relatively short distance compared to the node length, the continuity solution is largely unaffected. This could be modeled with a momentum area variation alone without any variation in the continuity cell area.

Gap width variations are specified in the same manner as axial variations in the wetted perimeter. The nodes that differ from nominal are identified in the JAXL array and the corresponding variation factors in the AFACT array.

The input for the example shown in Figure 19 (a) will have the following format:

```
*****
* GROUP 5.0 - Geometry Variation Data *
*****
* NGR
  5
* Card 5.1
* NFCT NAXL NDM3 NDM4 NDM5 NDM6 NDM7 NDM8 NDM9 NM10 NM11 NM12 NM13 NM14
  3   5   0   0   0   0   0   0   0   0   0   0   0
* Card 5.2
* JAXL AFACT JAXL AFACT JAXL AFACT JAXL AFACT JAXL AFACT
  1 1.000   6 1.000   7 x.xxx   8 y.yyy   9 z.zzz
  1 1.000   6 1.000   7 x.xxx   8 y.yyy   9 y.yyy
  1 1.000   6 1.000   7 v.vvv   8 w.www   9 w.www
*****
```

Variations encountered in most problems for CTF will not be as neat, generally, as the two examples shown in Figure 19. The user will have to make approximations appropriate for the particular geometry involved and nodding selected. Some general guidelines in setting up axial variations are:

1. In complex geometries, the user should preserve the same fluid volume as in the actual system.
2. The momentum area should approximate the actual flow area in the system at sudden changes.
3. The code interpolates linearly in the table to obtain variation factors for cells within the range of the table but not named explicitly. (Cells with identification numbers lower than the first element of a variation table or greater than the last element in the table remain at nominal values.)
4. The area in either the continuity cells or the momentum cells should not change by more than a factor of two between adjacent cells, even if the area in the system actually changes more abruptly. The code must be led gradually through a large change in a series of steps.

The input for CARD GROUP 6 specifies the subchannels or gaps to which the variation tables described in CARD GROUP 5 apply. Variation table assignments are read on CARD 6.2 for either subchannels or gaps. The variation tables are identified by sequence number; i.e., the first table read in CARD GROUP 5 is Table 1; the second table read in CARD GROUP 5 is Table 2; etc. The index number of the table to be used for continuity area variations is specified by IACT. The index number of the table to be used for momentum area

variations is specified by IAMT. The index number of the table to be used for wetted perimeter variations is specified by IPWT. The numbers of the subchannels using the variation tables named by IACT, IAMT, and IPWT are listed in array ICRG(M). Axial variation in gap width is specified by setting IACT to the negative of the variation table number, and naming the indices of the gaps using the table in array ICRG(M). When gap variations are specified, IAMT and IPWT are not used.

The input for CARD 6.2 is repeated until all subchannels and gaps having variations have been identified. It is not necessary to specify variations in continuity area, momentum area and wetted perimeter in a subchannel simultaneously. Any or all can be used, as appropriate for a given problem. It is possible to specify a continuity variation only; momentum area variation only, wetted perimeter only, or any combination of the three.

The input for the example shown in Figure 19 (a) will have the following format:

```
*****
* GROUP 6.0 - Channels and Gaps Affected by Variation Tables
*****
* NGR
  6
* Card 6.1
* N1 NDM2 NDM3 NDM4 NDM5 NDM6 NDM7 NDM8 NDM9 NM10 NM11 NM12 NM13 NM14
  1  0  0  0  0  0  0  0  0  0  0  0  0  0
* Card 6.2
* IACT IAMT IPWT ICRG ICRG
  1  2  3  1  0  0  0  0  0  0  0  0  0  0  0  0
*****
```

2.2.5 Instructions to CARD GROUP 7

The input for CARD GROUP 7 is designed to model local pressure losses in the axial flow due to spacer grids, orifice plates and other local obstructions in the flow field.

In the COBRA/TRAC code versions (*Thurgood, 1983*), the local pressure losses in vertical flow are modeled as velocity head loss:

$$\Delta P = \zeta \rho \frac{v^2}{2g_c} \quad (6)$$

where ζ denotes the pressure loss coefficient, ρ is the density, v is the flow velocity in vertical direction, and g_c is the gravitational conversion constant. The pressure loss coefficients are defined assuming positive upflow in a channel and specified for a momentum (not continuity) cell containing the obstruction.

Latter, grid heat transfer models for convective enhancement downstream of the spacers, grid rewet during bottom reflood, and droplet breakup on spacers were included in *Paik, et al., 1985*. In this code

version, rather than using input specified values for the spacer loss coefficients, they are calculated from grid dimensions:

$$\zeta_{grid} = \min\left(20196Re_{mix}^{-0.333}\right) f_{loss} \left(A_{blocked}^{spacer} + A_{blocked}^{springs}\right)^2 \quad (7)$$

where:

f_{loss} is the pressure loss coefficient multiplier (input value);

$A_{blocked}^{spacer}$ is the fraction of channel area blocked by the grid (input value);

$A_{blocked}^{springs}$ is the fraction of channel area blocked by the grid springs (input value);

Re_{mix} is the drops/bubbles mixture Reynolds number.

In the current code version, pressure losses must be specified either by ζ values or by geometrically modeled flow blockages. If pressure loss coefficients, CDL, are specified in CARD 7.2, then cards CARD 7.3 to CARD 7.9 must be omitted.

CARD 7.1 specifies the total number of loss coefficients, NDC; the number of grid types, NGT; the flag for grid quench front model IFGQF; the flag for small droplets model, IFSDRP; the flag for grid convective enhancement, IFESPV; the flag for two-phase enhancement of dispersed flow heat transfer, IFTPE; the flag for grid quench calculations, IGTEMP; the flag for flow blockages calculations NFBS; and IXFLOW, the flag for grid spacer influences on lateral exchange over gaps.

If the parameter NDC is equal to N, loss coefficient values CDL(N) are specified on CARD 7.2. CARD 7.2 contains also the identification number J of the axial node at which the pressure loss coefficient is applied and the ICDUM array of identification numbers of the subchannels for which the pressure loss coefficient is applied at axial node J . The pressure losses will be calculated according to Equation 6. The models for quench front and grid convective enhancement are not applicable when $NGT = 0$ ($NCD > 0$) and the flags IFGQF and IFESPV have to be set to zero in CARD 7.1. The input for the configuration shown in Figure 20 will have the following format:

```
*****
* GROUP 7.0 - Local Pressure Loss Coefficient and Grid Spacer Data
*****
* NGR
  7
* Card 7.1
* NCD  NGT  IFGQ  IFSD  IFES  IFTP  IGTP  NFBS  IFCD  IXFL  NM11  NM12  NM13  NM14
  3    0    0    0    0    0    0    0    0    0    0    0    0    0
* Card 7.2
*   CDL      J  ICD01  ICD02  ICD03  ICD04  ICD05  ICD06  ICD07  ICD08  ICD09  ICD10  ICD11  ICD12
  x.xxx     3    1    2    0    0    0    0    0    0    0    0    0    0
  x.xxx     5    1    2    0    0    0    0    0    0    0    0    0    0
  x.xxx     6    1    2    0    0    0    0    0    0    0    0    0    0
*****
```

There are two important points to remember:

1. The location of a loss coefficient is determined by node and subchannel number. The node refers to the momentum cell, not the continuity cell. This must be kept in mind when determining the node that corresponds to the location of the local loss in the system being modeled. Care must be used when placing a loss coefficient in a momentum cell at a section boundary. The loss coefficients must be defined in the subchannel where the momentum equation is solved.
2. The loss coefficients are defined assuming positive upflow in the subchannel. If the loss coefficient of a particular structure changes significantly when flow reverses through it, the code does not see the change. If reverse flow is the dominating pattern for such a situation, the user should specify the loss coefficient corresponding to reverse flow than the value for positive flow.

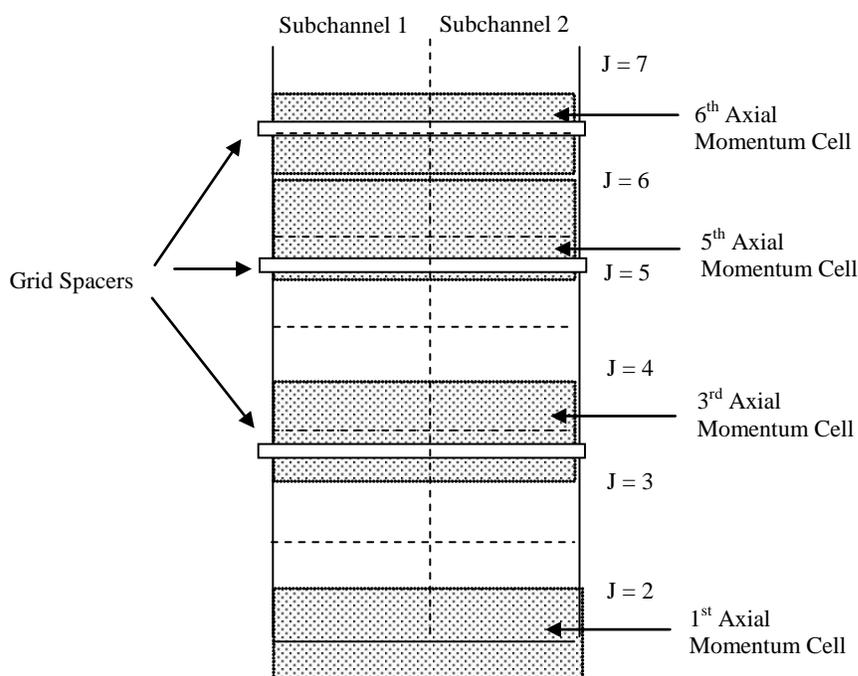


Figure 20: Example of Subchannels with Local Form Losses due to Spacer Grids

If the parameter NGT is greater than zero (0), the pressure loss coefficients will be calculated according to Equation 7. This option requires input for CARDS 7.3, 7.4, and 7.5. The physical meaning of the parameters that have to be specified is given in the Input Manual. An example of the input for the arrays NGROD and NGSURF is given below. It is a four subchannels problem with three spacer grids of same type ING along the axial length. The axial locations of the grids, NNGL, refer to the momentum cells containing the grids.

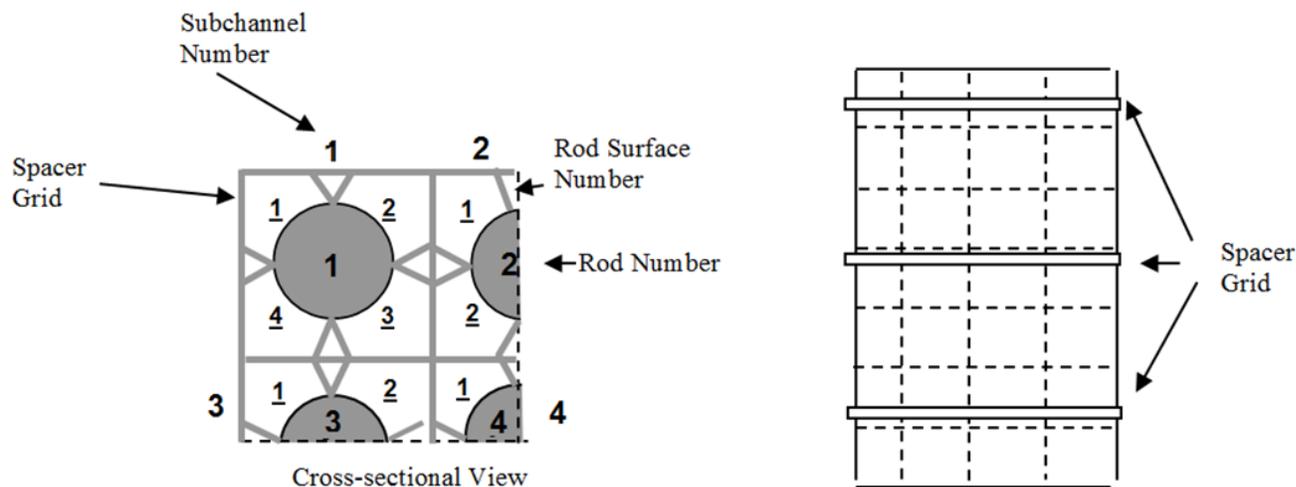


Figure 21: Example of Rod Surface Numbering in CARD 7.5

```

*****
* GROUP 7.0 - Local Pressure Loss Coefficient and Grid Spacer Data
*****
* NGR
  7
* Card 7.1
* NCD NGT IFGQ IFSD IFES IFTP IGTP NFBS IFCD IXFL NM11 NM12 NM13 NM14
  0  1  0  0  0  0  0  0  0  0  0  0  0  0  0
* Card 7.3
* ING NGAL NGCL IGMT GLOSS GABLOC GLONG GPERIM SPBLOC TPROBE
  1  3  4  1  1.0  x.xxx  x.xxx  x.xxx  x.xxx  x.xxx
* Card 7.4
* NNGL1 NNGL2 NNGL3
  2  5  7
* Card 7.5
* NCGL GMLT NGRD NGSF NGRD NGSF NGRD NGSF NGRD NGSF NGRD NGSF NGRD NGSF
  1 0.25  1  1  0  0  0  0  0  0  0  0  0  0  0
  2 0.50  1  2  2  1  0  0  0  0  0  0  0  0  0
  3 0.50  1  4  3  1  0  0  0  0  0  0  0  0  0
  4 1.00  1  3  2  2  3  2  4  1  0  0  0  0  0
*****

```

CARDS 7.6 and 7.7 are needed when flow blockages are modeled. CARD 7.8 provides input data for the grid quench calculations. For detailed description of the flow blockages modeling, the user should refer to *Paik, et al., 1985*.

CARD 7.8 is used if the updated spacer grid quench modeling is desired, which uses the grid re-wet model to calculate grid temperatures.

CARD 7.9 is used if the spacer grid crossflow effects are modeled. When $IXFLOW \neq 0$ then this card is required. The user must be able to supply data files on the spacer grids depending on the modeling option chosen. If $IXFLOW = 1$, then the directed crossflow modeling option is activated. If this model is invoked, then files 'xflow_data' and 'dirct_data.inp' must be provided in the working directory.

The first file, 'xflow_data', must contain a 2D table for the later flow rates corresponding to the spacer grid in use. This 2D table should contain vane angles [degrees] (in the x-direction) and axial distance [m] from the bottom of the rod (in the y-direction).

The first non-commented line for the file must contain 4 values: 1) the number of axial distances at which data are specified; 2) the number of angles for which lateral flow data are provided; 3) dummy variables (suggested value of 0); and 4) dummy variable (suggested value of 0).

The second non-commented line for the file must contain 1 value: the number of data sets (2D tables) to be read.

The third non-commented line for the file must contain N2 values (as specified by the number of mixing vane angles in the first line): the angles at which data are supplied.

The remaining lines in the document should contain N2+1 values each: 1) the axial position [m]; 2:N2+1) The spacer multiplier corresponding to the current axial location and angle.

A sample of this file is provided below. The '0.0000' values would be replaced by the values of the spacer multiplier at the given angle.

```
*****
* 2D table for the spacer multiplier *
*****
* N1  N2  N3  N4
   9   2   0   0
* NSET
   1
* N2_1 N2_2 (these are the angles)
   0.0 15.0
* V_N1  V_N2_1  V_N2_2
0.0000 0.0000 0.0000
0.2500 0.0000 0.0000
0.5000 0.0000 0.0000
0.7500 0.0000 0.0000
1.0000 0.0000 0.0000
1.2500 0.0000 0.0000
1.5000 0.0000 0.0000
1.7500 0.0000 0.0000
2.0000 0.0000 0.0000
*****
```

The data for these files are generally based on CFD calculations and are specific to each spacer grid design. The code linearly interpolates between the angles at which the data are specified to match that of VAL_ANG in the input deck, CARD 7.9.

2.3 Specification of the Conductors' Data

This section provides the user with guidance how to set up the input data required for the solution of the heat transfer and heat conduction. It covers the input for the heated and unheated conductors and specification of their material properties.

2.3.1 Instructions to CARD GROUP 8

The input for CARD GROUP 8 identifies the rods and unheated conductors modeling the solid structures that interact significantly with the fluid in a particular problem.

Rods and unheated conductors are both used to model solid structures in the vessel. There are two significant differences between them. First, rods can model either active or passive elements, but unheated conductors are always passive. Unheated conductors cannot have internal heat sources. Second, the quench front model with fine-mesh re-noding can be applied to rods if needed, but unheated conductors are assumed to never require it.

Examples of vessel structure that can be modeled with rods are: 1) an array of nuclear fuel pins; 2) an array of electrically-heated fuel pin simulators; 3) an electrically-heated annular test section with both cylinders heated; 4) a test section with an electrically heated flat plate as the heat source; etc. Examples of vessel structure that can be modeled with unheated conductors are: 1) a control rod guide tube; 2) a support column; 3) a section of downcomer annulus; 4) a canister of a BWR fuel assembly; etc.

CARD 8.1 identifies the number of rods in the problem, NROD; the number of unheated conductors, NSROD; the conduction solution flag, NC; the number of temperature initialization tables, NRRAB; the number of radiation channels, NRAD; the flag for steady-state calculation of rod temperature, NSTATE; the number of time steps between radiation calculations, NXF; the flag for Yamanouchi canister quench model, NCAN; the flag for the radiation heat transfer calculations, RADFLG; and the flag for critical heat flux calculation option.

The conduction solution flag, NC, must be set to select among no conduction (**NC = 0**); radial conduction only (**NC = 1**); radial and axial conduction (**NC = 2**); and radial, axial, and azimuthal conduction (**NC = 3**). The option for radial and axial conduction is recommended only for problems where a significant axial temperature gradient in the rods is expected. Similarly, if significant axial and azimuthal temperature gradients are expected, NC parameter is set to three (3). Problems involving reflooding and quenching of very hot surfaces should not use radial conduction option only. Problems involving relatively gradual heating or cooling of the system can be handled adequately with radial conduction only.

The simulation time can be speed-up by selecting the option for a steady state fuel rod temperature calculation (NSTATE is set greater than zero).

The rod identification parameters are read on CARDS 8.2, 8.3, and 8.4. If NROD is set to zero these cards are omitted. The rods are numbered sequentially from 1 to NROD. Each rod is uniquely identified by its index number, N , and geometry type number IFTYP(N). The geometry type number corresponds to a set of descriptive geometry data specified in CARD GROUP 9. An individual rod may have a unique geometry type, or several rods may be of the same geometry type.

Each rod has identified with it the number of an axial power profile table, IAXP(N). If IAXP(N) is left blank, an axially uniform table with a factor of unity is assumed. An axial profile table can serve any number of rods. The axial power profile tables (and the radial power factors) are specified in CARD GROUP 11. Together, the axial profile tables and the radial power factors define the local power generation in the individual rod.

In modeling large geometries it is sometimes convenient to represent regions of the vessel by average rods. A fuel pin array might be represented by a single average rod. The number of actual rods modeled by an average rod is specified in the variable RMULT(N). The values specified for RMULT can include fractional parts of rods.

The fine-mesh re-noding capability developed to resolve the quench front in reflooding requires some extra input for the rods. If fine-mesh re-noding is to be used for a particular rod, the flag NRENODE(N) is set to the number of calculational time steps to elapse between re-noding. How often the rod should be re-noded is primarily a function of the reflood rate and the size of time step expected during the reflood portion of the transient. In general, NRENODE(N) should be set that the quench front will not progress further than $\frac{1}{2}$ of the minimum node size, DAXMIN(N), between re-noding. For example, if the quench front velocity is **0.5** cm/sec, the maximum time step is **0.05** seconds, and the minimum node size is **0.1** cm, then:

$$NRENODE = \text{INT} \left(\frac{\frac{1}{2}(0.1)}{(0.5)(0.05)} \right) = 2 \quad (8)$$

If the rod is a tube quenching on the inside surface, then NRENODE(N) should be specified as a negative number and the absolute value of NRENODE(N) is used to determine the re-noding interval.

Variable HGAP(N), entered in CARD 8.2, specifies a constant value for the fuel rod gap conductance. (If a dynamic gap conductance modeling is desired, the required input will be provided by CARD GROUP 9.) If the rod N does not model a nuclear fuel rod HGAP(N) should be set to zero.

The code allows a rod to be included in more than one axial section. The total number of sections containing rod N is specified by the parameter ISECR(N).

The last two variables in CARD 8.2, HTAMB(N) and TAMB(N), provide input data for the heat transfer coefficient for heat loss to ambient from surface not connected to a subchannel and the sink temperature for ambient heat loss. This option is normally not related to the real fuel rod simulation. It is used in some simulations of experiments when the user wants to account for the heat loss from a non-water-cooled rod to the ambience or to the medium inside the tube.

CARD 8.3 describes the thermal connections between rods and subchannels for heat transfer between fluid and solid surfaces. All rods (and unheated conductors) must be connected to at least one subchannel. (However, not all subchannels have to be connected to a rod or unheated conductor.) Parameter NSCHC(IS,K) gives the subchannel number with thermal connection to rod **N** and parameter PIE(N,K) supplies the azimuthal fraction of rod **N** thermally connected to subchannel NSCHC(IS,K). Index **IS** varies from **1** to the total number of sections containing rod **N**, ISECR(N). Index **K** varies from **1** to **8** (Up to **8** sets of (NSCHC, PIE) may be entered. If the rod **N** is thermally connected to less than **8** channels, enter (0; 0.0) until **8** sets of (NSCHC, PIE) have been entered.)

If an inside surface of rod **N** exists, the number of the subchannel connected to the connected to the inside of azimuthal section **K** of rod **N**, NISCHC(N,IS,K) is provided by CARD 8.4.

The unheated conductors' identification parameters are read on CARD 8.5. If NSROD on CARD 8.1 is set to zero CARD 8.5 is omitted. The unheated conductors are numbered sequentially from **1** to **NSROD**. Each unheated conductor is uniquely identified by its index number, **N**, and geometry type number ISTYP(N). The geometry type number corresponds to a set of descriptive geometry data specified in CARD GROUP 9. An individual unheated conductor may have a unique geometry type, or several unheated conductors may be of the same geometry type.

The number of actual unheated conductors modeled by a single one unheated conductor is specified in the variable RMULS(N). The values specified for RMULS can include fractional parts of rods.

Unheated conductors do not generate heat but can transfer heat to and from the fluid and store thermal energy during a transient. For each unheated conductor **N** the user must specify the heated perimeter of the surface, HPERIM(N). If the conductor is a tube or wall that has contact with the fluid on its inner surface, then the heated perimeter of the inner surface, HPERIMI(N), must be specified as well. The parameter NOSLCH corresponds to the identification number of the subchannel adjacent to outside surface of the unheated conductor **N**. Respectively, the parameter NSLCHC corresponds to the identification number of the subchannel adjacent to inside surface of the unheated conductor **N**. If no subchannels are connected to the outside/inside surfaces, NOSLCH/ NSLCHC are set to zero.

In similarity to the rod modeling, the last two variables in CARD 8.6, HTAMBS(N) and TAMBS(N), provide input data for the heat transfer coefficient for heat loss to ambient from surface not connected to a subchannel and the sink temperature for ambient heat loss.

CARDS 8.6 through 8.9 set up the initial surface temperature of the rods and unheated conductors. On CARD 8.9, the temperatures are specified in tables of initial temperatures, TRINIT(I,L), versus axial distance, AXIALT(I,L), relative to the bottom of the vessel. The code interpolates linearly in the table along the axial length of the rod or unheated conductor it is applied to, so the first element of the AXIALT(I,L) array for a given table I must be at or below the bottom of the rod, and the last element must be at or below the top of the rod. A total NRTAB (as specified on CARD 8.1) tables must be supplied, but table I can be applied to more than one rod or unheated conductor. On CARD 8.6 the user must specify the number of rods NRT1(I) and the number of unheated conductors NST1(I) that use table I. The user must also identify how many pairs of TRINIT(I,L) and AXIAL(I,L) elements make up this particular table. The NRAX1(I) pairs of entries for table I are read on CARD 8.9.

If table I is used to initialize any rods, CARD 8.7 is read to fill array IRTAB(I,L) with the identification numbers of the rods. The steady-state conduction equation is solved for these rods using the temperatures from table I as a boundary condition on the rod surface. If any of the rods are tubes or walls and the table is to be used to initialize the temperatures on the inside surface, the rod identification number, N , is entered in IRTAB array as its negative.

If table I is used to initialize any unheated conductors, CARD 8.8 is read to fill array ISTAB(I,L) with the identification numbers of the unheated conductors. The code assumes an initially flat temperature profile in unheated conductors, so it is not necessary to specify whether the temperature applies to the inner or outer surface.

CARDS 8.10 and 8.11 are needed when radiation heat transfer has to be modeled. For detailed description, the user should refer to *Paik, et al., 1985*.

CARD 8.12 provides input data for the Yamanouchi canister quench model (*Yamanouchi, A., 1968*).

An example of CARD GROUP 8 for a 3×3 BWR bundle is following. The geometry of the bundle is given in Figure 22.

```

*****
* GROUP 8.0 - Rod and Unheated Conductor Data *
*****
* CARD GROUP 8
* NGR
  8
* Card 8.1
* NRRD NSRD  NC NRTB NRAD NLTY NSTA  NXF NCAN RADF  W3 NM12 NM13 NM14
  9    12    1  1  0  0  0  1  0  0  0  0  0  0  0
* Card 8.2
* N IFTY IAXP NRND  DAXMIN  RMULT  HGAP ISECR  HTAMB  TAMB
  1  1  1  0 0.00000  1.000 0.00000  1  0.000  0.000
* Card 8.3
* NSCH  PIE  NSCH  PIE
  1 0.250  2 0.250  6 0.250  5 0.250  0 0.000  0 0.000  0 0.000  0 0.000
*
* Cards 8.2 and 8.3 continued
  2  1  1  0 0.00000  1.000 0.00000  1  0.000  0.000
  2 0.250  3 0.250  7 0.250  6 0.250  0 0.000  0 0.000  0 0.000  0 0.000
*
  3  1  1  0 0.00000  1.000 0.00000  1  0.000  0.000
  3 0.250  4 0.250  8 0.250  7 0.250  0 0.000  0 0.000  0 0.000  0 0.000
*
  4  1  1  0 0.00000  1.000 0.00000  1  0.000  0.000
  5 0.250  6 0.250  10 0.250  9 0.250  0 0.000  0 0.000  0 0.000  0 0.000
*
  5  1  1  0 0.00000  1.000 0.00000  1  0.000  0.000
  6 0.250  7 0.250  11 0.250  10 0.250  0 0.000  0 0.000  0 0.000  0 0.000
*
  6  1  1  0 0.00000  1.000 0.00000  1  0.000  0.000
  7 0.250  8 0.250  12 0.250  11 0.250  0 0.000  0 0.000  0 0.000  0 0.000
*
  7  1  1  0 0.00000  1.000 0.00000  1  0.000  0.000
  9 0.250  10 0.250  14 0.250  13 0.250  0 0.000  0 0.000  0 0.000  0 0.000
*
  8  1  1  0 0.00000  1.000 0.00000  1  0.000  0.000
  10 0.250  11 0.250  15 0.250  14 0.250  0 0.000  0 0.000  0 0.000  0 0.000
*
  9  1  1  0 0.00000  1.000 0.00000  1  0.000  0.000
  11 0.250  12 0.250  16 0.250  15 0.250  0 0.000  0 0.000  0 0.000  0 0.000
*
* Card 8.5
* N ISTD  HPERIM  PERIMI  RMULT  NOSLCHC  NSLCHC  HTAMBS  TAMBS
  1  2 0.01698 0.00000  1.00  1  0  0.000  0.000
  2  3 0.01875 0.00000  1.00  2  0  0.000  0.000
  3  3 0.01875 0.00000  1.00  3  0  0.000  0.000
  4  2 0.01698 0.00000  1.00  4  0  0.000  0.000
  5  3 0.01875 0.00000  1.00  5  0  0.000  0.000
  6  3 0.01875 0.00000  1.00  8  0  0.000  0.000
  7  3 0.01875 0.00000  1.00  9  0  0.000  0.000
  8  3 0.01875 0.00000  1.00  12  0  0.000  0.000
  9  2 0.01698 0.00000  1.00  13  0  0.000  0.000
  10 3 0.01875 0.00000  1.00  14  0  0.000  0.000
  11 3 0.01875 0.00000  1.00  15  0  0.000  0.000
  12 2 0.01698 0.00000  1.00  16  0  0.000  0.000
*
* Card 8.6
* I NRT1  NST1  NRX1
  1  9  12  2
*
* Card 8.7
* IRTAB IRTAB
  1  2  3  4  5  6  7  8  9  0  0  0
*
* Card 8.8
* IRTAB IRTAB
  1  2  3  4  5  6  7  8  9  10  11  12
*
* Card 8.9
* AXIALT  TRINIT
0.0000000 300.00000
1.8300000 300.00000

```

*

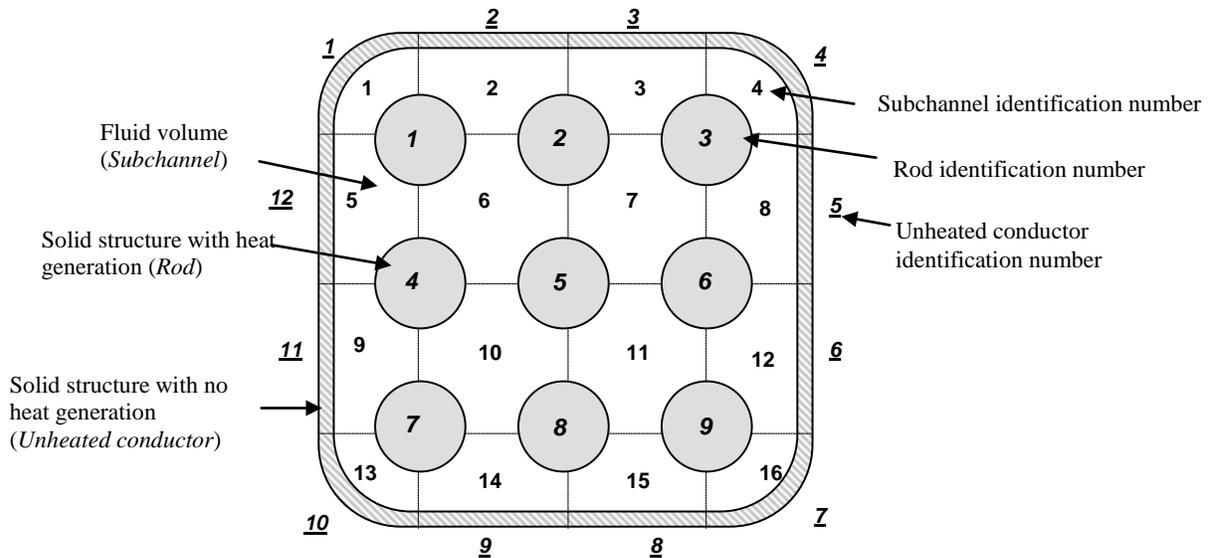


Figure 22: 3x3 BWR bundle

2.3.2 Instructions to CARD GROUP 9

The input for CARD GROUP 9 describes the characteristics of geometry types identified in the IFTYP(N) and ISTYP(N) arrays for rods and unheated conductors in CARD GROUP 8. Geometry types fall into two basic classes – nuclear fuel rods and all other conductors. The nonnuclear conductors can be characterized as solid cylinders, hollow tubes or flat plates.

On CARD 9.1, the user must specify total number of geometry types NFUEL. This must be equal to the number of unique entries in the IFTYP(N) and ISTYP(N) arrays. Two flags for fuel relocation, IRELF and ICONF, are also input on CARD 9.1. Relocation is an option in the dynamic gap conductance model. The last entree is the flag for metal-water reaction, IMWR. The option is applicable only for Zirconium dioxide.

CARDS 9.2 through 9.5 are related to the nuclear fuel rod geometry only and must be omitted if fuel rods are not modeled. More than one nuclear fuel geometry type can be specified. The input on CARD 9.2 sets the geometry type index, I, which corresponds to the IFTYP(N) value of the rods that are of this geometry type. The geometry flag FTYPE(I) for nuclear geometry types is NUCL. The geometry of the nuclear fuel rod type is defined by the outside diameter, DROD; the pellet diameter, DFUEL(I); the diameter of the central core, DCORE (zero if the fuel is solid); and the clad thickness, TCLAD. The code assumes that the rod is uniform in axial direction, so this data completely characterizes the physical dimensions of the rods being modeled by this geometry type.

On CARD 9.2, NFUEL defines the number of radial heat transfer nodes in the fuel pellet. NFUEL must be large enough for the code to resolve the temperature profile in the fuel pellet adequately, but more nodes specified with increase the time and space expenses when solving the heat conduction calculations. NFUEL between **5** and **10** is a good approximation for a fuel pellet diameter in the range of **1** cm, but the user must exercise a degree of judgment in the determining the number of radial nodes appropriate for the problem.

The remainder of the CARD 9.2 sets flags and options for the fuel material properties and the gap conductance model. The code contains properties for UO₂ fuel derived from MATPRO-11 (Revision 1). These can be flagged by setting IMATF to zero. The correlations from MATPRO-11 use the fuel theoretical density, FTDENS(I), as a parameter in calculation the UO₂ properties, which has to be supplied by the user even if IMATF is zero. FTDENS(I) is a fractional value, that depends on the properties of UO₂ pellets being modeled and is usually on the order of **0.95**. Alternatively, the user may select to specify a different material for the fuel, in which case IMATF must be set to the numerical index of a material property type specified in CARD GROUP 10. For cladding material properties, the code contains properties of Zircaloy and Zircaloy oxide from MATPRO-11 (Revision 1) and these can be flagged by setting IMATC(I) and IMATOX(I) to zero. If the cladding or cladding surface oxide is some other material for the nuclear rods being modeled by geometry I, IMATC(I) and IMATOX(I) must be assigned the numerical index of an appropriate material type specified in CARD GROUP 10.

For the example shown in Figure 23, the input data for a nuclear fuel rod with constant gap conductance will have the following format:

```
*****
* Card 9.1
* NFUEL IREL ICONF IMWR NDM5 NDM6 NDM7 NDM8 NDM9 NM10 NM11 NM12 NM13 NM14
  1      0      0      0      0      0      0      0      0      0      0      0      0
* Card 9.2: Nuclear Fuel Rod
* I FTYPE      DROD   DFUEL NFUEL IMATF IMATC IMTOX DCORE   TCLAD FTDENS IGPC IGFORC IRADP
  1 nucl      x.xx   y.yy   7      0      0      0   z.z   v.vv  0.95  0      0      0
*
*****
```

There are three options available for the gap conductance model for geometry type I: constant uniform gap conductance; axially non-uniform user-specified gap conductance; and a dynamic gap conductance model. The simplest of the three alternatives, and the easiest to implement is the constant uniform gap conductance. It is flagged by setting IGPC to zero. The gap conductance value specified on CARD 8.2 in HGAP(N) is used for rods with geometry type I and no further input is required.

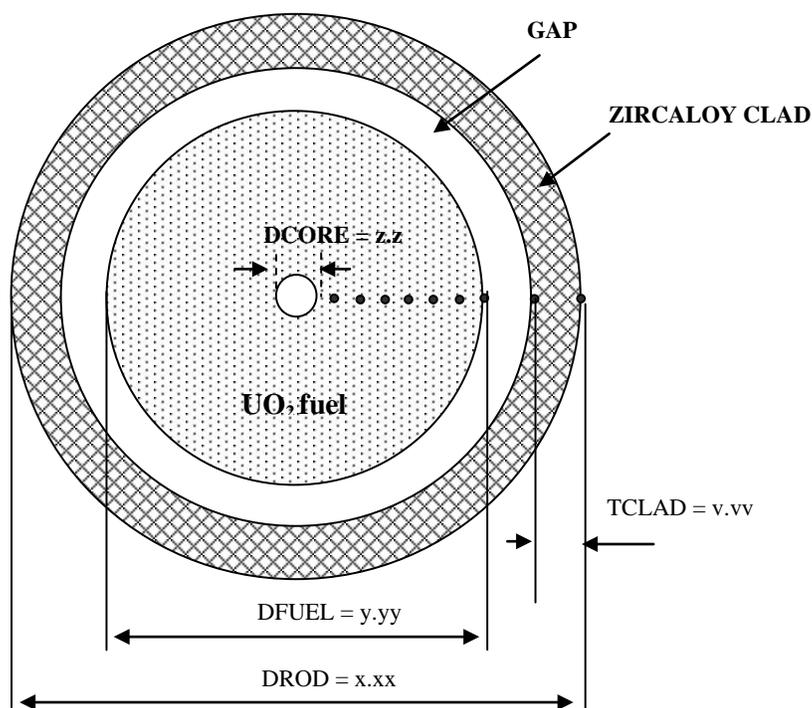


Figure 23: Nuclear Fuel Rod Geometry

The second option for a user-specified non-uniform gap conductance is a variation of the first option. The user specifies the value for gap conductance but can vary it axially and in time by means of input tables. The user specifies a table of pairs of values of axial location, $AXJ(L)$, and gap conductance, $AGFACT(L,I)$ on CARD 9.4. The number of pairs in the table is defined by the positive integer assigned to $IGAPC$ on CARD 9.2. The code determines the gap conductance in each axial node of the rods with geometry type I by linear interpolation in the table specified on CARD 9.4 and applies the gap conductance temporal forcing function, if one has been specified (the temporal forcing function is specified on CARD 11.6). An example is given below:

```
*****
* Card 9.1
* NFUELT IRELF ICONF IMWR NDM5 NDM6 NDM7 NDM8 NDM9 NM10 NM11 NM12 NM13 NM14
  1      0      0      0      0      0      0      0      0      0      0      0      0
* Card 9.2: Nuclear Fuel Rod
* I FTYPE      DROD   DFUEL NFUEL IMATF IMATC IMTOX DCORE   TCLAD FTDENS IGPC IGFORC IRADP
  1  nucl     x.xx   y.yy   7      0      0      0  z.z   v.vv  0.95  3      0      0
* Card 9.4: Gap conductance versus axial location
*   AXL  AGFACT  AXL  AGFACT  AXL  AGFACT
  w.w   u.uu   w.w   u.uu   w.w   u.uu
*****
```

In the dynamic gap conductance model, the code calculates the gap conductance based on the thermal and geometric properties in the gap. The model takes into account the thermal expansion of the fuel pellet and cladding and elastic deformation of the cladding in determining the size of the gap. The dimensions of the gap and the thermodynamic properties of the fill gas are used to calculate the gap conductance. The user must

specify the initial cold gap width in a table of axial location, $AXJ(L)$, versus cold gap width, $AGFACT(L,I)$, read on CARD 9.4. The cold gap width is the gap width before the fuel pin is brought to full power. But since the gap conductance model does not calculate the effects of the power history of the rod, the cold gap width specified by input must indicate any changes from as-built conditions due to burnup-dependent factors. The number of entries in the table read on CARD 9.4 is the absolute value of $IGPC$ ($IGPC$ is entered as a negative number to flag the dynamic gap conductance model).

In addition to the cold gap width, the user must supply data on composition of the fill gas and the internal characteristics of the gap for the dynamic gap conductance model. This data is read on CARD 9.3. The cold pin pressure, $PGAS(I)$, is the gas pressure at 295 K. The gas plenum volume, $VPLEN(I)$, is the volume of extra space between the top of the fuel pellet stack and the top of the rod. Both $PGAS(I)$ and $VPLEN(I)$ should be determined from the manufacturing specifications of the particular fuel rods being modeled by geometry I. The surface roughness of the fuel pellet and the cladding inner surface, $ROUFF(I)$ and $ROUFC(I)$, are used in the temperature jump discontinuity correlation in the gap conductance model. The correlation was optimized with values of 0.2×10^{-4} inches and 0.39×10^{-4} inches for $ROUFC$ and $ROUFF$, respectively, and even if the user knows the correct values, the optimized values will likely yield a more accurate answer.

The fuel relocation model (Yilmaz, 2014) can be included in the dynamic gap conductance calculations. Relocation allows fuel to move radially into the fuel-cladding gap. Cracks formed in the fuel by relocation reduce the effective conductivity of the fuel. When $IRELF$ on CARD 9.1 is set to one, both radial relocation and conductivity degradation are included in the calculation. Since the relocation model is an empirical correlation, the surface roughnesses should correspond to those used to derive the correlation. $ROUFC$ and $ROUFF$ are 0.45×10^{-4} inches and 0.85×10^{-4} inches, respectively in Thurgood (1983). (These values are different from the surface roughnesses used to optimize the temperature jump discontinuity correlation). Conductivity degradation can be calculated without relocation by setting $ICONF = 1$ and $IREFL = 0$. In this case the effect of radial relocation should be included in the specified cold gap width.

The code expects the fill gas to be composed of helium, xenon, argon, krypton, hydrogen and nitrogen. The composition of the gas for a given geometry type is specified by filling the $GSRAC(I)$ array on CARD 9.3 with values for the molar fractions ($GSRAC(I) \leq 1$) of the gases present. The $GSRAC(I)$ value for any one component can be any value between zero and one, inclusive, but the array must sum to unity:

$$\sum_{L=1}^6 GSRAC(L) = 1.00 \quad (9)$$

For example, if the fill gas were 100% helium, $GSRAC(1)$ would be 1.0 and $GSRAC(2)$ through $GSRAC(6)$ would all be 0.0.

An example for a nuclear fuel rod with dynamic gap conductance, a gap filled only with helium, and no fuel relocation is given below:

```
*****
* Card 9.1
* NFUEL  IRELF  ICONF  IMWR  NDM5  NDM6  NDM7  NDM8  NDM9  NM10  NM11  NM12  NM13  NM14
*      1      0      0      0      0      0      0      0      0      0      0      0      0      0
*
* Card 9.2: Nuclear Fuel Rod
* I  FTYPE      DROD      DFUEL  NFUEL  IMATF  IMATC  IMTOX  DCORE      TCLAD  FTDENS  IGPC  IGFORC  IRADP
* 1  nucl      x.x      y.y      7      0      0      0      z.z      v.v      0.95  -1      0      0
*
* Card 9.3: Fill gas composition
* PGAS  VPLEN      ROUFF      ROUFC  GSFR1  GSFR2  GSFR3  GSFR4  GSFR5  GSFR6  OXIDET
* a.a   b.b      c.c      d.d  1.000  0.000  0.000  0.000  0.000  0.000  1.00
*
* Card 9.4: Gap conductance versus axial location
* AXL  AGFACT
* w.w  u.u
*****
```

The code assumes that the radial power profile in a fuel pellet is uniform, but the user has the option of specifying a non-uniform radial profile in the pellet. If this option is selected, the pin radial power profile is read on CARD 9.5 as a table of relative radial location, $RODP(L)$, versus relative power factor, $POWER(L)$. The relative radial location is defined as:

$$RODP(L) = \frac{2(R(L) - \frac{DCORE}{2})}{(DFUEL - DCORE)} \quad (10)$$

where $DCORE$ is the diameter of center void (in inches); $DFUEL$ is the pellet diameter (in inches); and $R(L)$ is the radial location (in inches).

The relative power factor is defined as:

$$POWER(L) = \frac{\text{power at radial location } R(L)}{\text{average pin power}} \quad (11)$$

The profile constructed by the table of ($RODP(L)$, $POWER(L)$) is automatically normalized to unity.

CARDS 9.6 and 9.7 are related to the nonnuclear rod and unheated conductor geometry types. The geometry types are classified as solid cylinders, hollow tubes or flat plates. The physical elements of a reactor vessel or test section can be modeled with these geometries, even if they do not conform exactly to the ideal shape. A guide tube, for example, can be modeled as a flat wall, even though it is a tube. In modeling a solid element as a rod or unheated conductor, the important aspects to preserve are:

1. the surface area in contact with the fluid;
2. the mass available for thermal storage;
3. the thickness of any element (wall or tube) that has fluid contact on both surfaces.

The physical dimensions of the geometry types should be defined so that these three characteristics of the solid elements of the system are modeled with reasonable accuracy.

The nonnuclear geometry types are defined on CARD 9.6 by index number *I* and an alphanumeric value for *FTYPE(I)*: *HROD* for solid cylinder; *TUBE* for hollow tube, and *WALL* for a flat plate. The dimensions of the rods or unheated conductors modeled by a geometry type *I* are defined by *DROD* and *DIN*. For solid cylinder geometry, *DROD* is the outside diameter and *DIN* is zero. For a tube geometry, *DROD* is the outside diameter and *DIN* is the inside diameter. For flat plate geometry, *DROD* is the perimeter of the plate surface that is in contact with the fluid and *DIN* is the plate thickness.

In many problems, *DROD* and *DIN* will correspond exactly to the physical dimensions of the elements being modeled. However, let us consider that a square guide tube is being modeled. It could be represented by an equivalent conductor, such a flat plate. The guide tube, with width *W* and thickness *t*, has an outer diameter equal to $4W$. A flat plate with equivalent outer perimeter would have $DROD = 4W$ and $DIN = t$. (In this case the user has to remember that an unheated conductor can be connected to only one fluid subchannel. If the guide tube from the above example is connected to more than one subchannel, it has to be split to several walls with corresponding dimensions. See Figure 21)

The number of different material regions modeled in the rods or unheated conductors of geometry *I* is specified by the value of *NFUEL* on CARD 9.6. The number of heat transfer nodes in a region is specified by input on the subsequent CARD 9.7. A region defines a radial ring (or layer, for walls) of uniform material properties for the conduction solution. For example, a heater, composed of an electrical heater wire made from nichrome, a boron silicate filler material, and a stainless steel cladding, consists of three different materials: nichrome; boron silicate; and stainless steel. Four separate regions of materials are formed by the rod geometry: the central core of boron silicate; the nichrome heater wire; the outer layer of boron silicate; and the stainless steel cladding. Therefore, four material regions ($NFUEL = 4$) are required to describe this heater rod geometry type.

The remaining input for CARD 9.6 defines the material properties used to determine the minimum film boiling temperature for the heat transfer surfaces of the geometry type. Most physical systems in contact with water, particularly at high temperatures, develop an oxide layer that significantly affects the thermal properties of the surface. The user may specify the thermal properties of the oxide material on the outside and inside surface by setting *IMATOX(I)* and *IMATIX(I)* to the index number of a material properties table specified in CARD GROUP 10. (The variable *IMATIX(I)* applies only to *TUBE* or *WALL* geometries with fluid contact on the inside surface. For solid cylinders (*HROD*) and *TUBES* or *WALLS* with fluid contact only on the outside surface, it is ignored.) If a particular geometry type does not have oxide scale on its heat transfer surfaces, *IMATOX(I)* and *IMATIX(I)* should be assigned values that correspond to the material properties

table for the material the rods or unheated conductors are composed of at the surface. If IMATOX(I) and IMATIX(I) are set to zero, the oxide property index defaults to the built-in zirconium dioxide property table.

The material composition and radial nodding in the NFUEL regions identified for a geometry type I are read on CARD 9.7. The user must specify a material property table index for the region MATR(L), corresponding to a properties table supplied in CARD GROUP 10. The physical thickness of each region must be specified in the variable TREG(L), with the number of radial models in that region, NODER(L). The code automatically calculates the size of each node within the region by dividing the region into NODER(L) nodes of equal thickness.

The material temperature is calculated at the center of mass of each node. The only exception to this placement occurs for a region where one edge forms a heat transfer surface in contact with the fluid. In this case, the node closest to the surface is given only one-half the nominal thickness. The node temperature is calculated at the surface rather than the center of the half-width node.

For the above described heater rod with four material regions ($NFUEL = 4$), Figure 24 shows a typical temperature profile in the heater rod and the radial nodding in the various region required to resolve it. Region 1, the boron silicate in the center of the rod, must of necessity be at a uniform temperature in steady state, and, since it is a relatively small region, it can be modeled adequately with a single node. The nichrome wire fills a thin enough region in the heater rod to be considered almost a line source and cannot have a significant temperature gradient (because of the thermal properties of nichrome), so this region too can be modeled with a single node. The region between the heater wire and the cladding has a very gradual slope because of the thermal properties of boron silicate, so two nodes are enough to resolve it adequately. The region defined by the steel cladding is relatively thin, but because of the thermal properties of steel, the temperature profile may have a relatively steep slope here, so two nodes are required in this region. **However, because of special data handling inside the code, the following restrictions hold: $2 \leq NODER(L) \leq NFUEL$.**

The number of radial nodes to use within a region of geometry is governed by two factors: 1) the temperature gradient expected in the structure; and 2) the calculational cost for large number of heat transfer conditions being modeled. Beyond a certain limit, however, doubling the number of nodes does not double the accuracy of the solution, but it nearly quadruples the computational time required for elements with that geometry type. The user must exercise some judgment as to what constitutes an adequate but not excessive number of radial nodes for the heat transfer solution in a particular problem.

The radial power factor QREG(L), specified for each region, defines which regions of a nonnuclear rod generate heat internally. In heated rods, the QREG(L) values for all the regions of the rod are automatically normalized to unity, relative to the total power generated in a rod. Nonzero values of QREG are ignored in the unheated conductors.

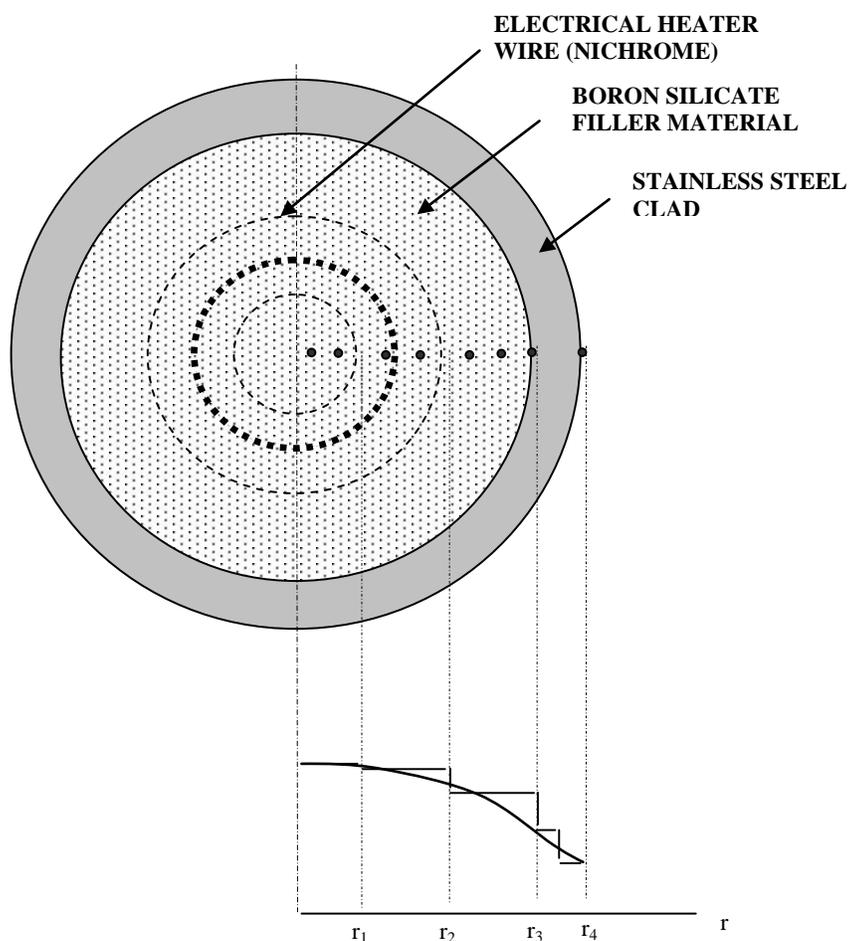


Figure 24: Heater Rod Geometry

The input for the heater rod shown in Figure 24 will be:

```

*****
* Card 9.1
* NFUEL IREL ICONF IMWR NDM5 NDM6 NDM7 NDM8 NDM9 NM10 NM11 NM12 NM13 NM14
  1      0      0      0      0      0      0      0      0      0      0      0      0
*
* Card 9.6: Heater Rod
* I FTYPE DROD DIN NFUEL IMATOX IMATIX NDUM8 NDUM9 NDUM10 NDUM11 NDUM12 NDUM13 NDUM14
  1 hrod  x.x  0.0    4      0      0      0      0      0      0      0      0      0
*
* Card 9.7: Regions' description ; L = 1, NFUEL
*NODER(L) MATR(L) TREG(L) QREG(L)
  2         1      r1      0.0
  2         2    (r2-r1)  1.0
  2         1    (r3-r2)  0.0
  2         3    (r4-r3)  0.0
*****

```

2.3.3 Instructions to CARD GROUP 10

The input for CARD GROUP 10 supplies the material properties selected by numerical indices in the geometry type input on CARD GROUP 9. If all the geometry types specified in CARD GROUP 9 use the build-in nuclear fuel rod properties for UO₂, Zircaloy, and ZiO₂, the input for CARD GROUP 10 is omitted. Otherwise, properties tables must be supplied for NMAT material, where NMAT is the number of unique indices specified in CARD GROUP 9 input for the variables IMATF, IMATC, MATR(L), IMATOX(I), and IMATIX(I).

The material properties tables are entered on CARDS 10.2 and 10.3. Both cards are read for each table. CARD 10.2 identifies the table by its numerical index and specifies the number of entrees, NNTDP in the table. The cold-state density of the material, RCOLD(N), is also entered on this card. RCOLD(N) is the density at normal (as-built) conditions and is used to calculate the mass of the nodes. This approach eliminates the tedious process of calculating the relocation of the radial nodes due to thermal expansion during the transient.

The properties table itself is read on CARD 10.3. The material properties included in the table are specific heat, CPF(I,N), and thermal conductivity, THCF(I,N), as functions of the temperature, TPROP(I,N). The temperature range of the table must be great enough to encompass the temperature extremes expected in the calculation; otherwise the run will abort due to property lookup failure. The user does may specify constant properties for a material type. This is done by entering only one element in the table; i.e., setting NNTDP to 1, and reading CARD 10.3 for only one set of CPF(I,N), THCF(I,N), and TPROP(I,N). The values specified in TPROP(I,1) is in this case is superfluous. The values specified in CPFF(I,1) and THCF(I,1) will be used for material type I regardless of the material temperature.

An example of the material properties input for a heated tube made from Inconel 600 is given below.

```
*****
* GROUP 10 - Material Properties Tables *
*****
*NGRP
  10
*NMAT NDM2 NDM3 NDM4 NDM5 NDM6 NDM7 NDM8 NDM9 NM10 NM11 NM12 NM13 NM14
  1    0    0    0    0    0    0    0    0    0    0    0    0    0
*   N NNTDP   RCOLD                    IMATAN
  1    6   8470.57                    Inconel 600
*   TPROP    CPF1      THCF
    -73    0.377    13.40
     93    0.464    15.71
    204    0.485    17.44
    427    0.527    20.90
    649    0.586    24.79
    871    0.623    28.83
*
*****
```

2.4 Specification of the Initial and Boundary Conditions

The next sections provide instructions to the specification of the initial and boundary conditions as well as the axial and radial power distribution. The initial operating conditions are read on CARD GROUP 1. The power distribution is prescribed on CARD GROUP 11. The boundary conditions are read on CARD GROUP 13.

2.4.1 Instructions to CARD GROUP 1

The rod friction correlation, the entrainment and deposition model, the turbulent mixing and void drift models, and the pressure matrix solver to be utilized are selected via input on CARD 1.1. The number of non-condensable gases to be considered is specified by the parameter NGAS (eight in maximum). The rod friction correlation is chosen by the input flag IRFC. The modeling of entrainment and deposition at annular flow regime is activated by setting the input flag EDMOD equal to one. The turbulent mixing and void drift models are chosen by the input flag IMIX. The input flag ISOL selects the numerical solver for the system of pressure equations.

The initial operating conditions are specified in CARDS 1.2 and 1.3. The bundle (total) inlet flow rate, GTOT; the average linear heat rate, AFLUX; and the fraction of the heat rate generated directly in the coolant, DHFRAC, are read on CARD 1.2. The system pressure, PREF; the inlet fluid enthalpy, HIN (or the inlet temperature, TIN); the mass flux into the system, GIN; and the initial volume fraction of liquid in the liquid-vapor-gas mixture, VFRAC(1); and the initial volume fraction of vapor in the vapor-gas mixture, VFRAC(2) are read on CARD 1.3.

The system pressure, PREF, and enthalpy, HIN (or the enthalpy derived from the temperature: TIN), are used to determine the initial properties of the fluid. During the calculation the enthalpy and pressure change depending on the state of fluid and the local heat generation rate. The initial mass flux GIN is not, in general, compatible with the initial pressures, which are calculated based on gravity head losses only. The code must iterate to a correct solution. It is usually most expedient to specify the initial mass flux as zero; i.e., a “standing start”.

If GTOT is set to non-zero value and the inlet boundary condition type (see CARD 13.4) is inlet mass flow rate and inlet enthalpy (BC type 2), the code will calculate subchannel mass flow rates according to the subchannels flow areas as specified on CARD 2.1 and will ignore the subchannel mass flow rates in CARD 13.4. If GTOT is set to zero and the inlet boundary condition type is inlet mass flow rate and inlet enthalpy (BC type 2), the user must specify subchannel mass flow rates in CARD 13.4.

If non-condensable gases are considered, their types (names) and volumetric fractions are specified on CARD 1.4 with the parameters GTYPE(I) and VFRAC(I+2), respectively. Valid non-condensable gas names include 'air', 'argo', 'heli', 'hydr', 'kryp', 'nitr', 'oxyg', and 'xeno'. Even without modeling non-condensable gases, at least one type (usually air) should be specified with negligibly small volumetric fraction. An example of CARD GROUP 1 is given below.

```
*****
* GROUP 1 - Calculation Variables and Initial Conditions *
*****
* NGR
  1
* Card 1.1
* NGAS IRFC EDMD IMIX ISOL NDM6 NDM7 NDM8 NDM9 NM10 NM11 NM12 NM13 NM14
  1    1    1    2    0    0    0    0    0    0    0    0    0
* Card 1.2
*   GTOT      AFLUX      DHFRAC
  0.          10.         .0
* Card 1.3
*   PREF      HIN        HGIN      VFRAC1    VFRAC2
 1000.      485.5      124.0      1.0      .9999
* Card 1.3
*   GTYPE      VFRAC
air          .0001
*****
```

2.4.2 Instructions to CARD GROUP 11

The input for CARD GROUP 11 defines the steady state and transient two-dimensional power distribution. In addition, the user may specify temporal forcing functions on the total power generation rate and the nuclear fuel rods gap conductance. If no rods are specified in CARD GROUP 8 input, the input for CARD GROUP 11 is unnecessary and may be omitted entirely.

The CARD 11.1 specifies the number of transient changes of the axial profile, NQA (NQA must be equal to 1 for steady state calculations); the number of axial profile tables to be read for each transient point, NAXP (the identification numbers must correspond to the values specified in the IAXP array on CARD 8.2 and at least one table must be supplied); the maximum number of pairs of elements in any axial power profile table, MNXN (minimum two values, for the top and bottom of the rod, must be provided for the simplest case of an uniform power profile); the number of pairs of elements in the total power forcing function table, NQ (NQ is set to zero if total power is constant); the number of pairs of elements in the gap conductance forcing function table, NGPFF (NGPFF is set to zero if gap conductance is constant); and the number of radial profile tables, NQR (NQR corresponds to the transient points of time, for which different radial profiles will be read).

CARDS 11.2 through 11.4 are read NQA times. CARD 11.2 specifies the transient time, YQA, for which the axial power profile table will be read on the CARD 11.4. CARD 11.3 gives the identification number, I,

and the number of pairs of elements, $NAXN(I)$, in the axial power profile table I to be read in the following CARD 11.3. The table itself is read as $NAXN(I)$ pairs of $Y(I,N)$ and $AXIALZ(M,I,N)$, where $Y(I,N)$ is the axial location relative to the bottom and $AXIALZ(M,I,N)$ is the power factor at that location. (Index M varies from 1 to NQR .) $AXIALZ(M,I,N)$ is defined as the ratio of the local power to average power in the rod (rods) the table is applied to. Figure 25 shows a nuclear fuel rod with a 3.66 m active (heated) length and a chopped cosine power profile.

The axial power table is used to interpolate linearly for axial power factors at the boundaries of the axial heat transfer cells, and the profile is re-integrated over each cell to obtain an average linear heat rate for the cell. When re-noding occurs, the axial power profile is re-integrated to obtain the average linear heat rate in the new cells. In the example shown in Figure 26, an electrical heater rod with step approximation to a cosine power profile is modeled in a subchannel with **0.305** m continuity nodes. The linear heat rate in the cell is modeled as a uniform Q_{in} along entire length of the cell.

With subchannel splitting it is possible to extend a rod through several sections of channel geometry. A rod can be used to model an average heater rod in a test section, as illustrated in Figure 27. Channel **3** in Section **1** models a portion of the region penetrated by the cold ends of the rods modeled by the average heater rod 1. Channel 3 connects to Channel **10** above. Channel **10** in Section **2** models a portion of the core containing the rods modeled by Heater Rod **1**. Channel 10 connects to Channels **15**, **16**, and **17** above, in Section **3**, but the heater rod ends at the boundaries between Sections **2** and **3**.

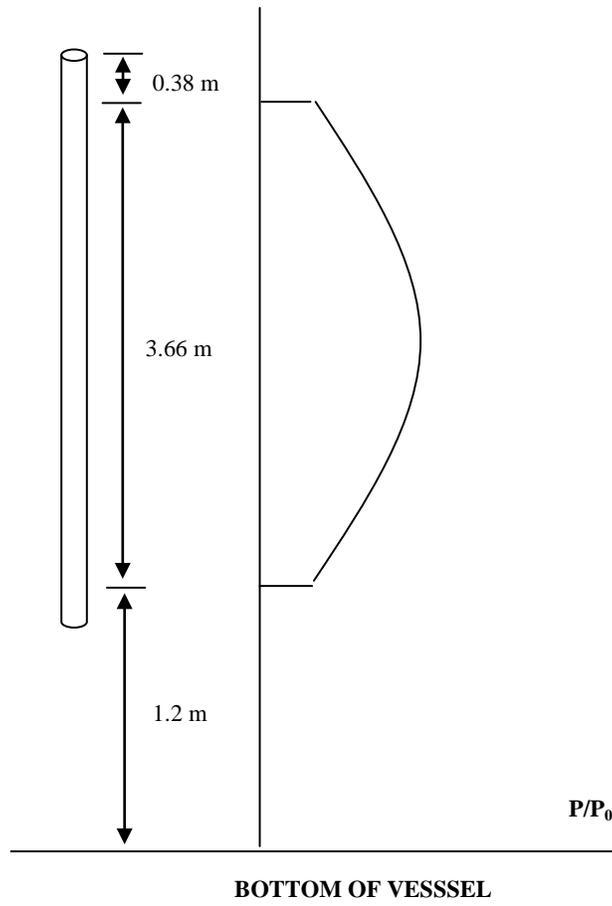


Figure 25: Nuclear Fuel Rod Power Profile

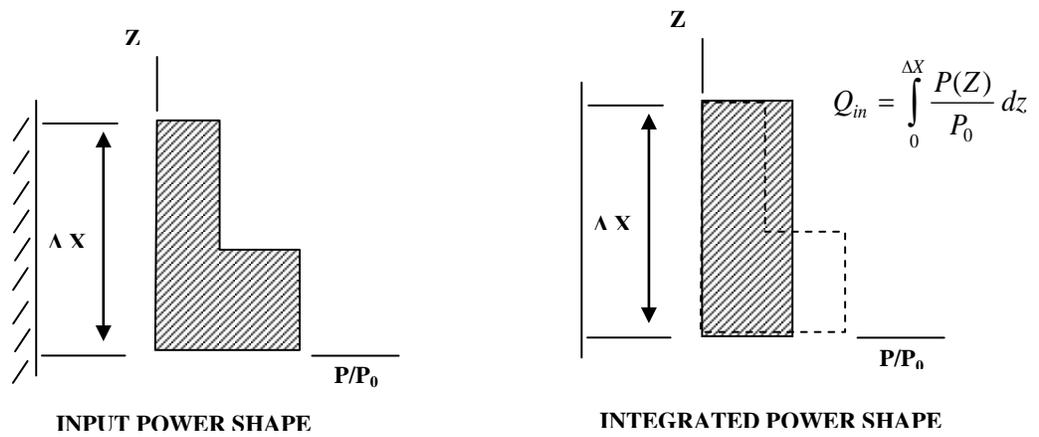


Figure 26: Heat Input over One Fluid Node

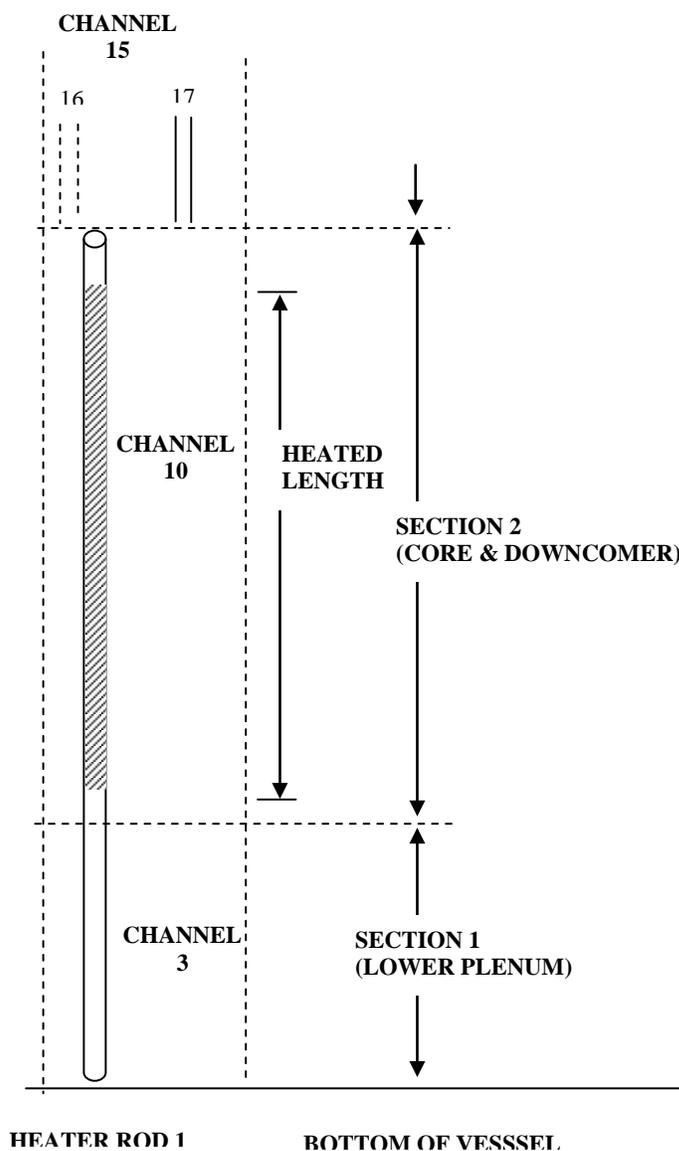


Figure 27: Heater Rod Crossing Section Boundaries

In general, a rod can pass through any number of contiguous vertical sections with fluid connections in different subchannels in each section, but the rod must begin and end at a section boundary. The vertical locations of the beginning and end of each rod must be considered when defining section boundaries in CARD GROUP 4. Unheated conductors do not require axial power profiles and may not cross section boundaries, but they must also be considered in the section boundary locations. Unheated conductors are assumed by the code to have the same axial length as the sections that contain them.

The total power forcing functions are read on CARD 11.5 in NQ pairs of transient time YQ(N) and power factor FQ(N). The power factor FQ(N) is the ratio of power at time YQ(N) and the initial power. The code interpolates linearly in the power forcing function table to determine the current value of total power at each step.

The gap conductance forcing functions are specified on CARD 11.6 as NGPFF pairs of transient time YGPFF(N) and gap conductance factor FGPFF(N). The input convention for this table follows the logic as the other tables in CARD GROUP 11. The gap conductance factor FGPFF(N) is defined as the ratio of the gap conductance value at the time YGPFF(N) and the initial value. The forcing function is applied uniformly along the axial length for nuclear fuel rods with a gap conductance forcing function specified on CARD 9.2 (*IGPC* > 0).

The last two cards, CARDS 11.7 and 11.8, provide the radial power profile and its transient behavior. CARD 11.7 specifies the transient time, YQR, for which an array FQR(N), containing the radial power factors of rods (the local power generation in each individual rod), will be read in the CARD 11.8.

The code calculates the local linear heat rate (which is transferred through the rod surface to heat up the coolant) as follows:

$$\dot{q}(rod, x, t) = (1 - d)\dot{\bar{q}}_{time}(t)f_{axial}(x, t)f_{radial}(rod, t) \quad (12)$$

where $\dot{\bar{q}}$ is the AFLUX read on CARD 1.2; d is the DHFRAC read on CARD 1.2; $f_{time}(t)$ is the FQ read on CARD 11.5; $f_{axial}(x, t)$ is the AXIALZ read on CARD 11.4; and $f_{radial}(rod, t)$ is the FQR read on CARD 11.8.

An example of input for CARD GROUP 11 for the configuration shown in Figure 22 with a constant uniform axial and radial power distributions and transient total power is given below.

```
*****
* GROUP 11.0 - Axial Power Tables and Forcing Functions *
*****
* CARD GROUP 11
* NGR
  11
* Card 11.1
* NQA NAXP MNXN   NQ NGPF  NQR NDM7  NDM8  NDM9  NM10  NM11  NM12  NM13  NM14
   1   1   2   0   0   1   0   0   0   0   0   0   0   0
*
* Axial Power Forcing Functions
* Card 11.2
*   YQA
   0.0
* Card 11.3
*   I NAXN
   1   2
* Card 11.4
*   Y       AXIAL
  0.000000  1.000000
  1.830000  1.000000
*
* Total Power Forcing Functions
* Card 11.5
*   YQ       FQ
*   0.0000   0.0000
*   1.0000   1.0000
*  100.0000  1.0000
*
* Radial Power Forcing Functions
* Card 11.7
```

```

*      YQR
      0.0
* Card 11.8
*      FQR(1)   FQR(2)   FQR(3)   FQR(4)   FQR(5)   FQR(6)   FQR(7)   FQR(8)
      1.0000   1.0000   1.0000   1.0000   1.0000   1.0000   1.0000   1.0000
*      FQR(9)
      1.0000
*
*****

```

2.4.3 Instructions to CARD GROUP 13

Two main types of boundary conditions can be specified by the input in CARD GROUP 13. These are 1) inlet or outlet boundary conditions on subchannels and 2) specific boundary conditions on particular cells within the mesh for both the vertical and transverse control volumes. Inlet or outlet boundary conditions must be specified for subchannels that do not have vertical connections to other subchannels in the system at their inlet or outlet. This, obviously, must include the inlet of subchannels in the first axial section and the outlet of subchannels in the last axial section. But other subchannels within the stack of sections can be unconnected at the top or bottom to other subchannels. Mesh boundary conditions may be applied wherever needed, on any face of any cell within the vessel mesh. But only one boundary condition can be applied to any one node.

The number of subchannel mesh cell boundary conditions, including inlet, outlet, and internal mesh cells, in a given problem is specified by the value of NIBND on CARD 13.1. The NIBND boundary conditions are set by reading CARD 13.4 for each boundary, specifying the subchannel number, IBOUND(1,M); axial node number, IBOUND(2,M); boundary type number, ISPEC(M); the first boundary value, BCVALUE1; the second boundary value, BCVALUE2; and the third boundary value, BCVALUE3. The forcing functions for a given boundary condition type are identified by table number in parameters N1FN, N2FN, and N3FN for the first, second and third boundary values, respectively. The boundary conditions that can be specified for subchannel mesh cells are listed in Table 1.

The general application of the boundary conditions is summarized in Table 2.

If boundary condition type 1 is selected, the pressure in subchannel $I = \text{IBOUND}(1,M)$ at node $J = \text{IBOUND}(2,M)$ is set to BCVALUE3 and the enthalpy is set to BCVALUE2; BCVALUE1 is not used. For a boundary condition type 2, the flow at the top face of node IBOUND(2,M) in the subchannel IBOUND(1,M) is set to BCVALUE1 and the enthalpy is set to BCVALUE2; BCVALUE3 is not used. The flow may be positive or negative. For a boundary condition type 3, the flow is set to BCVALUE1; BCVALUE2 and BCVALUE3 are not used. This boundary condition is used to shut off vertical flows within the mesh or to specify flow into or out of the top of a subchannel, where it is not desirable to specify the node enthalpy, as it is done for a boundary condition type 2. A boundary condition type 4 is used to specify a mass source in any cell. BCVALUE1 is set to mass flow rate, BCVALUE2 is set to enthalpy, and BCVALUE3 is

set to pressure. Boundary condition type **5** is used to specify a pressure sink connected to any mesh cell. BCVALUE3 is the pressure sink, BCVALUE2 is the enthalpy of the fluid in the sink; BCVALUE1 is not used.

Table 1: Boundary Conditions Types

Boundary condition type		Internal mesh cells	Boundary cells	Input in CARDS
1	Pressure and enthalpy ³	-	X	13.4, 13.6, 13.7
2	Mass flow rate and enthalpy	-	X	13.4, 13.6, 13.7
3	Mass flow rate	X	X	13.4
4	Mass source	X	-	13.4, 13.5, 13.6, 13.7, 13.8
5	Pressure sink	X	-	13.4, 13.6, 13.7, 13.9
-	Crossflow set to zero	X	-	13.10

In addition to the axial boundary conditions, the transverse flow between subchannels connected by a gap can be shut off at any elevation within the vessel by specifying input for CARD 13.7. This input is read if parameter NKBND on CARD 13.1 is greater than **0**. The input for CARD 13.7 consists simply of the gap identification number **K** and the contiguous axial levels JSTART to JEND where the crossflow will be set to zero. This format makes it very easy to zero out a sequence of crossflows, from **J = 2** to **J = 15**, for example.

If flow is to be shut off in more than one segment of a gap, CARD 13.7 input can be specified for gap **K** more than once, until all of the axial levels to be zeros have been specified.

Unless otherwise indicated, the special boundary conditions applied to cells as specified in CARD GROUP 13 are constant in time. The user may, however, specify forcing functions on BCVALUE1, BCVALUE2, and BCVALUE3 for any or all of the special boundary conditions. The number of forcing functions is specified by the value of NFUNCT on CARD 13.1.

The forcing functions on the special boundary conditions are specified in the same way as any other forcing function in the vessel input – as tables of forcing function factors versus time. The number of elements in a given table is read in CARD 11.2 as NPTS; then NPTS pairs of ABSCIS(K,I) and ORDINT(K,I) are read on CARD 13.3. The ABSCIS array contains the transient time, in seconds, when the corresponding forcing function factor ORDINT is to be applied. ORDINT is defined as the ratio of the value at time ABSCIS(K,I) of the parameter being forced and its initial value. The factor is determined at any given time step by linear

³ The enthalpy must be specified in case there is flow *into* the system across the corresponding boundary. (The pressure boundary condition does not determine whether the flow goes into or out of the system).

interpolation in the forcing function table. The forcing function tables are numbered sequentially from 1 to NFUNCT in the order they are read in.

In the code, the initial mass flow rate is specified as zero in the whole flow domain by default. That means a “standing start” is performed. (Otherwise there could be severe problems with convergence.) For this reason the inlet mass flow rate is also highly recommended to start as zero and to be run up by means of a ramp which can be specified by a forcing function (see variable N1FN). This concerns boundary condition types **2**, **3**, and **4**.

If a mass source boundary condition (type 4) has been specified for a cell on CARD 13.4, additional information must be supplied on CARD 13.5 specifying the droplet diameter DROPS(N) and droplet mass flow rate FDROPRS(N) at the injection boundary. The index number of the forcing function table, NDFN(N), by which the droplet diameter will vary and the index number of the forcing function table, NDFFN(N), by which the droplet mass flow rate will vary have to be provided as well.

For all types of boundary conditions except for type 3 the enthalpy of the non-condensable gases mixture, HMGA(N), and their volumetric fractions, GVALUE(NGA,N), have to be specified on CARD 13.6. The corresponding forcing functions NHMFN(N) and NGFN(NGA,N) are read on CARD 13.7. CARDS 13.6 and 13.7 are not needed and can be omitted by setting INITGAS on CARD 13.4 to **1**, when the inlet conditions for the non-condensable gases are considered equal to the initial conditions entered on CARDS 1.3 and 1.4 (**HMGA = HGIN; GVALUE = VFRAC; NHMFN = 0; and NGFN = 0**).

If a pressure sink boundary condition (type 5) has been specified for a cell on CARD 13.4, additional information describing the sink geometry must be supplied on CARD 13.9. Flow in or out of the sink is defined for a special control volume, as shown in Figure 28. The flow area of the control volume is ASINK and the length of the cell is DXSINK. The sink boundary condition usually models a real hole in the system and in this case ASINK is the area of the hole. The control volume length should be on the order of the centroid length of the channel in which the sink lies. The flow in and out of the sink generally encounters some unrecoverable pressure loss due to expansion at the orifice and the loss coefficient associated with the sink flow is defined by SINKK on CARD 13.9. The type 5 boundary conditions are numbered sequentially within the code in the order they are read in on CARD 13.4. CARD 13.9 should be read for the sink in the same sequential order. CARD 13.8 is read for the flow area of mass sources in the same manner.

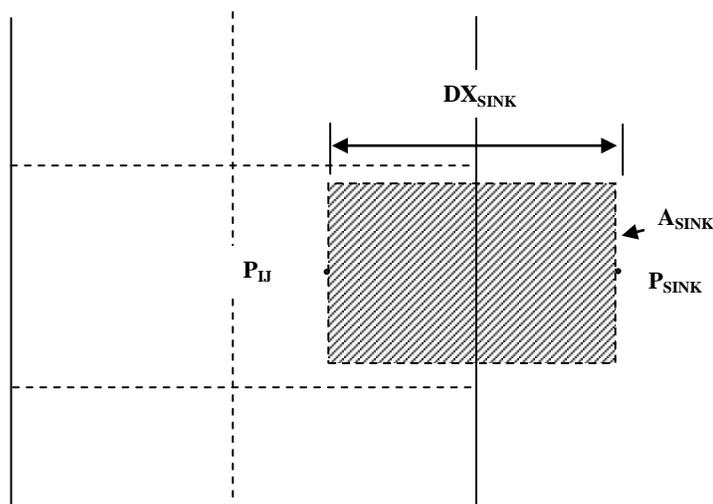


Figure 28: Control Volume for Pressure Sink Boundary Condition

An example of input for CARD GROUP 13 for the configuration shown in Figure 22 at steady state conditions is given below.

```

*****
* GROUP 13.0 - Boundary Condition Data
*****
* CARD GROUP 13
* NGR
  13
* Card 13.1
* NBND NKBD NFUN NGBD NDM5 NDM6 NDM7 NDM8 NDM9 NM10 NM11 NM12 NM13 NM14
  32   0   1   0   0   0   0   0   0   0   0   0   0   0
* Card 13.2
* NPT
  4
* Card 13.3
* ABSC ORDINT   ABSC ORDINT   ABSC ORDINT
  0.0 0.000   0.1 0.000   0.2 1.000 1500.0 1.000
* Card 13.4
* Inlet b.c. -----
* IBD1 IBD2 ISPC N1FN N2FN N3FN   BCVALUE1   BCVALUE2   BCVALUE3 INITGAS
   1   1   2   1   0   0       0.0     918.77     0.0000     1
   2   1   2   1   0   0       0.0     918.77     0.0000     1
...
   16   1   2   1   0   0       0.0     918.77     0.0000     1
* Outlet b.c. -----
* IBD1 IBD2 ISPC N1FN N2FN N3FN   BCVALUE1   BCVALUE2   BCVALUE3 INITGAS
   1  38   1   0   0   0       0.0000     918.77     70.00     1
   2  38   1   0   0   0       0.0000     918.77     70.00     1
...
   16  38   1   0   0   0       0.0000     918.77     70.00     1
*****

```

Table 2: General Application of the Boundary Conditions – Summary

BC type	BCVALUE1	BCVALUE2 ⁴	BCVALUE3	DROPS	FDROPS	HMGA	GVALUE (1,...,NGA)	AINJT	ASINK /SINKK / DXSINK
<i>1</i>	0.0	enthalpy (of flow into the system) across this boundary)	pressure	-	-	enthalpy (of non-condensable gas mixture)	volume fractions	-	-
<i>2</i>	mass flow rate ⁵	enthalpy	0.0	-	-	enthalpy (of non-condensable gas mixture)	volume fractions	-	-
<i>3</i>	mass flow rate	0.0	0.0	-	-	-	-	-	-
<i>4</i>	mass flow rate (of the mass source)	enthalpy (of the mass source)	pressure (of the mass source)	diameter (of droplets)	mass flow rate (of droplets)	enthalpy (of non-condensable gas mixture)	volume fractions	flow area (of the mass injection)	-
<i>5</i>	0.0	enthalpy (of the fluid in the sink)	pressure (in the sink)	-	-	enthalpy (of non-condensable gas mixture)	volume fractions	-	flow area, pressure loss coeff., length of control volume (of the pressure sink)
<i>crossflow set to zero</i> ⁶	-	-	-	-	-	-	-	-	-
Forcing function identifier	N1FN	N2FN	N3FN	NDFN	NDFFN	NHMFN	NGFN (1,...,NGA)	-	-

⁴ The second and third input variables (BCVALUE2, BCVALUE3) must *not* be omitted. The input of “0.0” (see in table) is *obligatory*. This involves also, that in case of BCVALUE2 = 0.0 or BCVALUE3 = 0.0 the forcing function identifiers N2FN and N3FN have to be set explicitly to “0”.

⁵ The flow rate may be either positive or negative.

⁶ There is a special input procedure for suppressed cross flows in CARD 13.10. CARDS 13.4, 13.5, 13.6, and 13.7 do *not* have to be taken into account.

2.4.4 Boron Tracking and Precipitation Modeling

A. Application of the Boron Tracking/Precipitation Model

The boron tracking model is controlled in the CTF input deck along with the rest of the CTF user-defined parameters. All of the parameters related with the boron tracking and precipitation model are conditioned to the variable IBTM (defined in CARD 1.1), the flag of the model. The user can choose between the First Order Accurate Upwind Scheme and the Second Order Accurate Modified Godunov Scheme (explained in Section A).

Initial conditions of the boron are defined in CARD 1.3 where the initial boron concentration (BRIN) of the system is uniformly defined, and the boron physical diffusion coefficient (RDIF). The boron physical diffusion coefficient is only used when is applied the Second Order Accurate Modified Godunov Scheme (IBTM=2). The suggested values are: 0.0 (IBTM=1) and 1.0 (IBTM=2), due to RDIF is the result of experimental data.

The boron tracking model boundary conditions are defined in CARD 13.11. As with other CTF boundary conditions, forcing functions may be defined for the inlet boron concentration (CARDS 13.2 and 13.3) and the total number of vertical mesh cell boundary conditions, number of boron inlet boundary conditions (NIBNDB, in CARD 13.1); this value may be not the same as the number of inlet boundary conditions entered in CARD 13.4. This allows the user to control the inlet boron with respect to time as the CTF-modeled transient progresses.

CARD 13.11 follows the same scheme as CARD 13.4: IBOUNDB(1,N), index number of channel at which boundary condition N is applied ; IBOUNDB(2,N), vertical node number at which boundary condition N is applied; N4FNB(N), index number of the forcing function table by which the forth parameter of the boundary condition (BCVALUE4B) will be varied; and BCVALUE4B(N), forth boundary condition represents the boron concentration [ppm]; where $N=1, NIBNDB$.

Must be a match between where the inlet boundary conditions and the boron inlet boundary conditions are applied, (IBOUND(L,N), $L=1,2$) and (IBOUND(L,N), $L=1,2$).

The boron tracking/precipitation model is applied when ISPEC(N) = 1, 2 or 3, what that means, except when a source (ISPEC=4) or a sink (ISPEC=5) is the boundary condition. The boron inlet boundary condition, BCVALUE4B, and its associated forcing function, N4FNB; are reassigned to the variables BCVALUE4(N) and N4FN(N), $N=1, NIBND$, as an extra boundary condition, based on the subchannel and axial level where the boron inlet boundary conditions are applied.

B. Example of Card Group 1 and Card Group 13 (Boron Tracking/Precipitation Model)

```

*****
* GROUP 1 - Calculation Variables and Initial Conditions *
*****
* NGR
  1
* Card 1.1
* NGAS IRFC EDMD IMIX ISOL GINT NTRN MESH MAPS IPRO MFLX IBTM NM13 NM14
  1 1 1 2 0 0 0 0 0 0 0 2 0 0
* Card 1.2
* GTOT AFLUX DHFRAC
  0. 10. .0
* Card 1.3
* PREF HIN HGIN VFRAC1 VFRAC2 BRIN RDIF
  1000. 485.5 124.0 1.0 .9999 0.0 1.0
* Card 1.3
* GTYPE VFRAC
  air .0001
*****

*****
* GROUP 13.0 - Boundary Condition Data *
*****
* CARD GROUP 13
* NGR
  13
* Card 13.1
* NBND NKBD NFUN NGBD NBNDB NDM6 NDM7 NDM8 NDM9 NM10 NM11 NM12 NM13 NM14
  32 0 1 0 16 0 0 0 0 0 0 0 0 0
* Card 13.2
* NPT
  4
* Card 13.3
* ABSC ORDINT ABSC ORDINT ABSC ORDINT
  0.0 0.000 0.1 0.000 0.2 1.000 1500.0 1.000
* Card 13.4
* Inlet b.c. -----
* IBD1 IBD2 ISPC N1FN N2FN N3FN BCVALUE1 BCVALUE2 BCVALUE3 INITGAS
  1 1 2 1 0 0 0.0 918.77 0.0000 1
  2 1 2 1 0 0 0.0 918.77 0.0000 1
...
  16 1 2 1 0 0 0.0 918.77 0.0000 1
* Outlet b.c. -----
* IBD1 IBD2 ISPC N1FN N2FN N3FN BCVALUE1 BCVALUE2 BCVALUE3 INITGAS
  1 38 1 0 0 0 0.0000 918.77 70.00 1
  2 38 1 0 0 0 0.0000 918.77 70.00 1
...
  16 38 1 0 0 0 0.0000 918.77 70.00 1
* Card 13.11
* Boron (Inlet) b.c. -----
* IBD1 IBD2 N4FN BCVALUE4
  1 1 1 2000.0
  2 1 1 2000.0
...
  16 1 1 2000.0

```

2.5 Turbulent Mixing and Void Drift Modeling

CARD GROUP 12 provides input for the turbulent mixing and void drift model as specified by IMIX on CARD 1.1. This input is optional and should be used only for problems where is a significant effect of these phenomena on the behavior of the system.

In the subchannel codes, the exchange of momentum, energy, and mass due to turbulence, or the so-called turbulent diffusion or turbulent mixing, is commonly modeled in analogy to the molecular diffusion under the assumption of a linear dependence between the exchange rate of the given quantity and its gradient in the medium. The proportionality coefficients are called turbulent diffusion coefficients. Unlike molecular diffusion coefficients, which are material dependent, the turbulent diffusion coefficients depend only on the location in the flow domain. The turbulent kinematical viscosity and turbulent temperature diffusivity are in the same order of magnitude (turbulent Prandtl number approaches unity). Latter allows applying the same turbulent diffusion coefficient to all momentum, mass, and energy exchanges: $C_t := D_t = \nu_t = a_t$. In case of a gradient in y direction, the aforementioned assumption takes the form of:

Turbulent mixing of mass:

$$\dot{m}_k = -\rho D_t \frac{dc}{dy} A = -C_t \frac{d(\alpha_k \rho_k)}{dy} A \quad (35)$$

Turbulent mixing of momentum:

$$\dot{I}_k = -\rho \nu_t \frac{dU}{dy} A = -C_t \frac{d(\alpha_k \rho_k U_k)}{dy} A = -C_t \frac{dG_k}{dy} A \quad (36)$$

Turbulent mixing of energy:

$$\dot{Q}_k = -\rho c_p a_t \frac{dT}{dy} A = -C_t \frac{d(\alpha_k \rho_k c_{p,k} T_k)}{dy} A = -C_t \frac{d(\alpha_k \rho_k h_k)}{dy} A \quad (37)$$

Here, the index k stands for the given field (liquid, vapor, and droplets); D_t is the turbulent diffusion coefficient for mass transfer; ν_t is the turbulent kinematical viscosity; a_t is the turbulent temperature conductivity; c is the concentration; c_p is the specific heat capacity; A is the area relevant for lateral exchange; α , ρ , U , and h are, respectively, the volume fraction of given field, density, vertical velocity, and enthalpy.

In the subchannel analyses, very often the ratio C_t/dy is substituted with the ratio of the turbulent kinematic viscosity ε and the mixing length l , ε/l , and the mixing length is commonly approximated as the centroid distance between the adjacent subchannels. Regarding turbulent diffusion coefficients, a dimensionless parameter can be defined:

$$\beta = \frac{c_t}{\Delta y \bar{U}}, \quad (38)$$

where $\bar{U} = \frac{A_i U_i + A_j U_j}{A_i + A_j}$ is the area averaged vertical velocity of the adjacent subchannels⁷.

Using the definition of the turbulent mixing coefficient, the exchange rate of mass, momentum and energy (Equations 35 through 37) can be written as:

Turbulent mixing of mass:

$$\dot{m}_k = -\beta \frac{\bar{G}}{\rho} \Delta(\alpha_k \rho_k) A \quad (39)$$

Turbulent mixing of momentum:

$$\dot{i}_k = -\beta \frac{\bar{G}}{\rho} \Delta G_k A \quad (40)$$

Turbulent mixing of energy:

$$\dot{Q}_k = -\beta \frac{\bar{G}}{\rho} \Delta(\alpha_k \rho_k h_k) A \quad (41)$$

$$\text{where } \bar{G} = \frac{A_i G_{tot,i} + A_j G_{tot,j}}{A_i + A_j}.$$

As concluded from Equation 39, the turbulent mixing coefficient is a function of the particular geometry and the flow conditions. Under single-phase flow conditions, it is usually correlated to the flow Reynolds number, subchannel hydraulic diameter, heated rod diameter, gap width, and the centroid between the adjacent subchannels: $\beta_{SP} = f(Re, d_{hyd}, d_{rod}, \Delta y)$.

It is experimentally observed that in a two-phase flow the turbulent mixing is much higher than in a single-phase flow. Most often, the dependence of the mixing rate on the flow regime is modeled by the Beus correlation (Beus, S.G., 1970). The two-phase turbulent velocity is assumed to be a function of the single-phase turbulent velocity: $\left(\frac{\varepsilon}{l}\right)_{TP} = \theta_{TP} \left(\frac{\varepsilon}{l}\right)_{SP}$, where the “two-phase multiplier”, θ_{TP} , depends on the quality. The approach by Faya (Faya, A.J.G., 1979) has been adopted in the subchannel analysis codes. Faya has slightly modified the Beus approach by applying the two-phase multiplier θ_{TP} to the single-phase mixing coefficient:

$$\beta_{TP} = \theta_{TP} \beta_{SP} \quad (42)$$

where $\theta_{TP} = f(x)$

⁷ If simple averaging is taken, β is reduced to the mixing Stanton number.

The mixing rate, and hence the turbulent velocity, reaches its maximum at the slug-annular regime transition point. According to the model of Wallis (*Wallis, G.B., 1969*), this point can be obtained by an expression for the corresponding quality:

$$x_{max} = \frac{0.4 \sqrt{g \rho_{liq} (\rho_{liq} - \rho_{vap}) d_{hyd}} + 0.6}{G_{tot} \sqrt{\frac{\rho_{liq}}{\rho_{vap}} + 0.6}} \quad (43)$$

The function for θ_{TP} is assumed to increase linearly for $x \leq x_{max}$ and to decrease hyperbolically for $x > x_{max}$.

$$\theta_{TP} = 1 + (\theta_{max} - 1) \frac{x}{x_{max}} \quad \text{if } x \leq x_{max} \quad (44)$$

$$\theta_{TP} = 1 + (\theta_{max} - 1) \frac{x_{max} - x_0}{x - x_0}, \quad \text{with } \frac{x_0}{x_{max}} \quad \text{if } x > x_{max} \quad (45)$$

where $Re = \frac{G_{tot} d_{hyd}}{\mu_{mix}}$ and $\mu_{mix} = (1 - \alpha_{vap}) \mu_{liq} + \alpha_{vap} \mu_{vap}$.

The parameter θ_{max} , which is the maximum of the ratio $\frac{\theta_{TP}}{\beta_{SP}}$, is treated as a constant and can be estimated experimentally.

In the COBRA/TRAC code version, only a single-phase mixing (single-phase liquid for void fractions below a value of **0.6**, single-phase vapor for void fractions above a value of **0.8**, and a ramp between the two) has been modeled by means of the traditional mixing coefficient approach. Later, in the FLECHT SEASET code version, a void drift model based on the work of Lahey and Kelly has been employed. Void drift was only assumed to occur when the liquid is continuous phase and its modeling has been not applied to the hot wall flow regimes.

The current turbulent mixing and void drift models assume that the net two-phase mixing (including void drift) is proportional to the non-equilibrium void fraction gradient. At an annular film flow regime a void drift offset is assumed and only the turbulent mixing of vapor and entrained droplets is modeled. In other words, the void drift is only modeled in bubbly, slug, and churn flow, where liquid is the continuous phase and vapor is the dispersed phase.

The lateral exchange due to turbulent mixing is modelled as follows:

Turbulent mixing of mass in phase k :

$$\dot{m}_k^{TM} = -\beta \frac{\bar{G}}{\bar{\rho}} \Delta(\alpha_k \rho_k) A = \beta \frac{\bar{G}}{\bar{\rho}} (\alpha_{k,j} \rho_{k,j} - \alpha_{k,i} \rho_{k,i}) \quad (46)$$

Turbulent mixing of momentum in phase k :

$$\dot{I}_k^{TM} = -\beta \frac{\bar{G}}{\bar{\rho}} \Delta G_k A = \quad (47)$$

Turbulent mixing of energy in phase k :

$$\dot{Q}_k^{TM} = -\beta \frac{\bar{G}}{\bar{\rho}} \Delta(\alpha_k \rho_k h_k) A \quad (48)$$

In Equations 46 through 48, $\beta = \theta_{TP} \beta_{SP}$ is the two-phase turbulent mixing coefficient.

Currently the single phase mixing coefficient β_{SP} may be either specified as a single input value or internally calculated with an empirical correlation by Rogers and Rosehart (*Rogers, J. T. and Rosehart, R. G., 1972*):

$$\beta_{SP} = \frac{1}{2} 0.0058 \left(\frac{d_{gap}}{d_{rod}} \right)^{-1.46} Re^{-0.1} \left[1 + \left(\frac{d_{hyd,j}}{d_{hyd,i}} \right)^{1.5} \right] \frac{d_{hyd,i}}{d_{rod}} \quad (49)$$

The two-phase multiplier θ_{TP} is calculated using the Beus' approach for two-phase turbulent mixing.

The lateral exchange due to void drift is modeled as follows:

Mass exchange in phase k by void drift:

$$\dot{m}_k^{VD} = \beta \frac{\bar{G}}{\bar{\rho}} (\alpha_{k,j,EQ} \rho_{k,j,EQ} - \alpha_{k,i,EQ} \rho_{k,i,EQ}) A \quad (50)$$

Momentum exchange in phase k by void drift:

$$\dot{I}_k^{VD} = \beta \frac{\bar{G}}{\bar{\rho}} (G_{k,j,EQ} - G_{k,i,EQ}) A \quad (51)$$

Energy exchange in phase k by void drift:

$$\dot{Q}_k^{VD} = \beta \frac{\bar{G}}{\bar{\rho}} (\alpha_{k,j,EQ} \rho_{k,j,EQ} h_{k,j,EQ} - \alpha_{k,i,EQ} \rho_{k,i,EQ} h_{k,i,EQ}) A \quad (52)$$

According to Levy (Levy, S., 1963) the equilibrium density distribution is related to the mass flux distribution by the expression:

$$\rho_{mix,EQ} = \alpha_{liq} \rho_{liq} + \alpha_{vap} \rho_{vap} = \alpha G_{tot,EQ} + b \quad (53)$$

For phase k that yields:

$$(\alpha_{k,j,EQ} \rho_{k,j,EQ} - \alpha_{k,i,EQ} \rho_{k,i,EQ}) = f_{sign} \frac{\alpha_{vap} \rho_k}{\bar{\rho}_{tot}} (G_{tot,j,EQ} - G_{tot,i,EQ}) \quad (54)$$

where $f_{sign} = 1$ for vapor and $f_{sign} = -1$ for liquid.

Other parameters are:

$$\bar{G}_{tot} = \frac{A_i G_{tot,i} + A_j G_{tot,j}}{A_i + A_j},$$

$$\frac{\alpha_{vap} \rho_{vap}}{\alpha_{vap} \rho_{liq}} = \frac{A_i \alpha_{vap,i} \rho_{vap,i} + A_j \alpha_{vap,j} \rho_{vap,j}}{A_i + A_j},$$

$$\frac{\alpha_{vap} \rho_{liq}}{\alpha_{vap} \rho_{liq}} = \frac{A_i \alpha_{vap,i} \rho_{liq,i} + A_j \alpha_{vap,j} \rho_{liq,j}}{A_i + A_j},$$

The equilibrium vapor phase distribution is given by

$$(\alpha_{vap,j,EQ} \rho_{vap,j,EQ} - \alpha_{vap,i,EQ} \rho_{vap,i,EQ}) = K_M \frac{G_{tot,j} - G_{tot,i}}{G_{tot,i} + G_{tot,j}} (\alpha_{vap,i} \rho_{vap,i} + \alpha_{vap,j} \rho_{vap,j}) \quad (54)$$

and the equilibrium liquid phase distribution is given by

$$(\alpha_{liq,j,EQ} \rho_{liq,j,EQ} - \alpha_{liq,i,EQ} \rho_{liq,i,EQ}) = K_M \frac{G_{tot,j} - G_{tot,i}}{G_{tot,i} + G_{tot,j}} (\alpha_{vap,i} \rho_{liq,i} + \alpha_{vap,j} \rho_{liq,j}) \quad (55)$$

The corresponding equilibrium momentum flux distribution becomes for the vapor phase

$$\begin{aligned} (G_{vap,j,EQ} - G_{vap,i,EQ}) &= K_M \frac{G_{tot,j} - G_{tot,i}}{G_{tot,i} + G_{tot,j}} (\alpha_{vap,i} \rho_{vap,i} U_{vap,i} + \alpha_{vap,j} \rho_{vap,j} U_{vap,j}) = \\ &= K_M \frac{G_{tot,j} - G_{tot,i}}{G_{tot,i} + G_{tot,j}} (G_{vap,i} + G_{vap,j}) \end{aligned} \quad (56)$$

and for the liquid phase

$$\begin{aligned} (G_{liq,j,EQ} - G_{liq,i,EQ}) &= K_M \frac{G_{tot,j} - G_{tot,i}}{G_{tot,i} + G_{tot,j}} (\alpha_{vap,i} \rho_{liq,i} U_{liq,i} + \alpha_{vap,j} \rho_{liq,j} U_{liq,j}) = \\ &= K_M \frac{G_{tot,j} - G_{tot,i}}{G_{tot,i} + G_{tot,j}} (G_{liq,i} + G_{liq,j}) \end{aligned} \quad (57)$$

The corresponding equilibrium energy distribution becomes for the vapor phase

$$\begin{aligned} (\alpha_{vap,j,EQ} \rho_{vap,j,EQ} h_{vap,j,EQ} - \alpha_{vap,i,EQ} \rho_{vap,i,EQ} h_{vap,i,EQ}) &= \\ &= K_M \frac{G_{tot,j} - G_{tot,i}}{G_{tot,i} + G_{tot,j}} (\alpha_{vap,i} \rho_{vap,i} h_{vap,i} + \alpha_{vap,j} \rho_{vap,j} h_{vap,j}) \end{aligned} \quad (58)$$

and for the liquid phase

$$\begin{aligned} (\alpha_{liq,j,EQ} \rho_{liq,j,EQ} h_{liq,j,EQ} - \alpha_{liq,i,EQ} \rho_{liq,i,EQ} h_{liq,i,EQ}) &= \\ &= K_M \frac{G_{tot,j} - G_{tot,i}}{G_{tot,i} + G_{tot,j}} (\alpha_{vap,i} \rho_{liq,i} h_{liq,i} + \alpha_{vap,j} \rho_{liq,j} h_{liq,j}) \end{aligned} \quad (59)$$

2.5.1 Instructions to CARD GROUP 12

The choice of the turbulent mixing and void drift modeling is controlled by the parameter IMIX specified on CARD 1.1. If IMIX is set to zero, neither turbulent mixing nor void drift are modeled and CARD GROUP 12 is omitted.

If IMIX is set to one (1), a constant mixing coefficient BETA (used at both single- and two-phase conditions) and the equilibrium distribution weighting factor AAAK (K_M in the above equations) are specified on CARD 12.1. A suggested value of AAAK is 1.4 according to *Kelly, et al. (1981)*. An example is given below.

```
*****
* GROUP 12 - Turbulent mixing data *
*****
* CARD GROUP 12
* NGR
  12
* Card 12.1
* AAAK      BETA
  1.4      0.04
*
*****
```

If IMIX is set to two (2), the single-phase mixing coefficient will be calculated with the correlation by Rogers and Rosehart and the two-phase multiplier will be calculated using the Beus approach. The input on CARD 12.2 includes the equilibrium distribution weighting factor AAAK; the outside rod diameter DFROD (d_{rod} in Equation 36); and the ratio between the maximum two-phase turbulent mixing and the single-phase liquid mixing THETM (θ_{max} in Equations 33 and 34). The value of the outside rod diameter, DFROD, should be consistent with DROD read on CARD 9.2 or CARD 9.6). A suggested value of THETM is 5.0 according to Sato (1992). An example is given below.

```
*****
* GROUP 12 - Turbulent mixing data *
*****
* CARD GROUP 12
* NGR
  12
* Card 12.2
* AAAK      DFROD  THEM
  1.4      x.xxx   5.0
*
*****
```

2.6 Results Reporting

The output information to be printed out is selected by input on the legacy CARD GROUP 14. In total, ten output files can be generated. A short description of the CTF output files (produced by the legacy card group 14) is provided in Table 3. Guidance to CARD GROUP 14 is given in the following section.

Table 3: List of Generated Output Files

File name	Description	SI units	US units
deck.cdm	A dump file for restarting the calculation; generated if DUMPF=1 in CARD INPUT.2; empty if DUMPF=0.	X	X
deck.crs	An empty restart file; it must be overwritten by deck.cdm before a restart calculation is executed.	X	X
deck.out	Input repetition, geometry information Subchannel, gap, rod, and unheated conductor results.	-	X
deck.run	Convergence history.	-	X
dnb.out	DNB information.	-	X
heat.time	Global transient heat balance.	X	X
krysolv.out	Debug output for Krylov solver convergence. Generated if the flag IOPT read on CARD 14.1 is set to 2.	-	-
massflow.time	Global transient mass balance.	X	X
mixture_temp.out	Average coolant temperature in node (i,j) (simplified output needed for validation purposes). Generated if the flag IOPT read on CARD 14.1 is set to 3.	X	-
results_channel.out	Subchannel results.	X	-
results_gap.out	Gap results.	X	-
time.out	Debug output for inner/outer iterations information. Generated if the flag IOPT read on CARD 14.1 is set to 2.	-	-
void.out	Subchannel void fraction (simplified output needed for uncertainty analyses). Generated if the flag IOPT read on CARD 14.1 is set to 4.	-	-

2.6.1 Instructions to CARD GROUP 14 (Legacy)

The user can require a complete printout of the calculated results by setting the parameter N1 on CARD 14.1 equal to **5** and the parameters NOUT1, NOUT2, NOUT3 and NOUT4 equal to zero. In this case results for all subchannels, gaps, heated and unheated conductors will be printed out in the corresponding output files. If the user needs output information for selected subchannels, gaps, or conductors only, that can be specified by different combinations of values for N1, NOUT1, NOUT2, NOUT3 and NOUT4 and additional input on CARDS 4.2 through 4.5.

The property table will be printed out in deck.out file if the parameter IPROPP on CARD 4.1 is set to **1**. The parameter IOPT controls the printout of additional debug information.

For the example given below, the output will contain results for subchannels **5, 13, 17, and 20**; for gaps **9, 25, and 36**; for heated conductors **4, 10, and 12**; and for unheated conductors **5 and 8**. In addition, the subchannel void fractions (for all subchannels) will be provided in the output file void.out.

```
*****
* Group 14 - Output Options
*****
*NGRP
  14
* Card 4.1
*  N1 NOUT1 NOUT2 NOUT3 NOUT4 IPROPP IOPT NDM8 NDM9 NM10 NM11 NM12 NM13 NM14
   5   4   3   3   2   0   4   0   0   0   0   0   0   0
* Card 4.2: Subchannels to be printed
*PRCH
   5  13  17  20
* Card 4.3: Gaps to be printed
*PRTG
   9  25  36
* Card 4.4: Heated conductors to be printed
*PRTR
   4  10  12
* Card 4.5: Unheated conductors to be printed
*PRTS
   5   8
*
*****
```

2.7 Main Problem Control and Time Domain Data

A brief description of the required input for the main problem control data and time domain data is provided in the following sub-sections.

2.7.1 Instructions to Input of Main Problem Control Data

The main problem control data is read on CARDS INPUT 1 through 3 and CARD COBRA 1. CARD INPUT 1 selects the units in input and output files (SI or US). CARD INPUT 2 specifies initial or restart calculation will be performed and whether a restart file deck.cdm will be generated. The inner and outer iterations limits are read on CARD INPUT 4. CARD COBRA 1 gives alphanumeric information to identify the simulation.

In the example of input for main problem control data given below the input deck will be written in US units, but the output decks will be in SI units (*ICOBRA = 0*); it will be an initial run (*INITIAL = 1*) and a restart file will not be generated (*DUMPF = 0*); the outer iteration convergence criterion (EPSO) is set to *10⁻³*; the maximum number of outer iterations (OITMAX) is equal to *5*; and the maximum number of inner iterations (IITMAX) is equal to *40*.

```
*****
* MAIN PROBLEM CONTROL DATA *
*****
* CARD INPUT 1
*   ICOBRA
*       0
* CARD INPUT 2
*   INITIAL          DUMPF
*       1              0
* CARD INPUT 3
*   EPSO            OITMAX          IITMAX
*   0.001           5              40
* CARD COBRA 1
*<-----TEXT----->
*   **2sub-channels**
*****
```

2.7.2 Instructions to Input of Time Domain Data

After all component data have been entered, the user must define the time domain for the simulation. The total time can be divided into several domains of specified duration. Each time domain can have different minimum and maximum time step sizes and different edit intervals as entered in Card 15.1. The card must be repeated for each time domain desired. A final time domain with a negative value for DTMIN must be entered to terminate the calculation.

In the example below, the whole calculation of **12** seconds is divided into two time domains. The first time domain has a duration of **2** seconds ($TEND = 2.0$), a minimum time step size of 10^{-6} seconds ($DTMIN = 10^{-6}$) and a maximum time step size of 10^{-3} seconds, $DTMAX = 10^{-3}$. The results will be printed out every half second ($EDINT = 0.5$) and the dump file deck.cdm will be written every second. The second time domain has a duration of **10** seconds ($TEND = 10.0$), a minimum time step size of 10^{-6} seconds, ($DTMIN = 10^{-6}$), and an increased maximum time step of 10^{-2} seconds, ($DTMAX = 10^{-2}$). The results will be printed out only once at the end ($EDINT = 10.0$) and the dump file deck.cdm will be written every **5** seconds.

The parameter RTWFP is a ratio of time step sizes for heat conduction solution and fluid solution. To obtain steady-state conditions, the conduction solution can generally use time steps greater than the fluid solution. For transient calculations RTWFP should be 1.0.

```
*****
* Group 15 - TIME DOMAIN DATA *
*****
* CARD GROUP 15
* NGR
  15
* Card 15.1
*      DTMIN      DTMAX      TEND      EDINT      DMPINT      RTWFP
*      0.000001    0.001      2.0      0.5      1.0      1.0
*      DTMIN      DTMAX      TEND      EDINT      DMPINT      RTWFP
*      0.000001    0.01      10.0     10.0     5.0      1.0
* Card 15.2
*      DTMIN (if negative stop)
*      -.001      0.0      0.0      0.0      0.0      0.0
*
*****
```

2.7.3 Instructions to Preparation of Input Files for Restart Calculations

When the parameter DUMPF read on CARD INPUT 2 is not set to zero, a dump file 'deck.cdm' is generated. In order to restart the calculation, a restart file 'deck.crs' has to be read. Because the initial calculation will generate an empty 'deck.crs' file, the dump file 'deck.cdm' has to be renamed to 'deck.crs' before restarting the calculation.

Two dump/restart options are possible, "simple" and "full" restart. During the so-called "simple" restart run the user is allowed to change only the time domain data, but not the power distribution and the flow conditions. The input file for the "simple" restart must contain CARDS INPUT.1, INPUT.2, INPUT.3, COBRA.1, and CARD GROUP 15; and must not contain CARD GROUP 1, ..., CARD GROUP 14.

During a "full" restart run, the user can specify changes in the operating conditions, power distribution, boundary conditions, printout options, and the time domain data. The input file for the "full" restart must

contain CARDS INPUT.1, INPUT.2, INPUT.3, COBRA.1, and CARD GROUP 15; can contain CARD GROUP 1, CARD GROUP 11, CARD GROUP 12, CARD GROUP 13, and CARD GROUP 14; and must not contain CARD GROUP 2, CARD GROUP 3, CARD GROUP 4, CARD GROUP 5, CARD GROUP 6, CARD GROUP 7, CARD GROUP 8, CARD GROUP 9, or CARD GROUP 10.

Examples for “simple” and “full” restart input files are fowling.

“SIMPLE” RESTART

```

*****
* 9 Channel PWR Core Model; Embedded Mesh Structure *
* Loss of Coolant Transient *
* Ref.: Avramova, M., et al., "Comparative Analysis of PWR Core Wide and Hot *
* Channel Calculations",ANS Winter Meeting, 2002 *
*****
* CARD INPUT 1
* ICOBRA
* 1
* CARD INPUT 2
* INITIAL DUMPF
* 3 1
* CARD INPUT 3
* EPSO OITMAX IITMAX
* 0.001 1 40
* CARD COBRA 1
*<-----TEXT----->
* ****9_chan_PWR_core****
*
*****
* Group 15 - TIME DOMAIN DATA *
*****
*NGRP
* 15
* DTMIN DTMAX TEND EDINT DMPINT RTWFP
* 0.000001 0.01 4.0 1.0 1.0 1.0
* DTMIN DTMAX TEND EDINT DMPINT RTWFP
* 0.000001 0.01 14.8 0.2 14.8 1.0
* DTMIN (if negative stop)
* -1.0 0.0 0.0 0.0 0.0 0.0
*
*****
* END GROUP 15 *
*****

```

“FULL” RESTART

```

*****
* 9 Channel PWR Core Model; Embedded Mesh Structure *
* Loss of Coolant Transient *
* Ref.: Avramova, M., et al., "Comparative Analysis of PWR Core Wide and Hot *
* Channel Calculations",ANS Winter Meeting, 2002 *
*****
* CARD INPUT 1
*   ICOBRA
*     1
* CARD INPUT 2
*   INITIAL          DUMPF
*     2              1
* CARD INPUT 3
*   EPSO            OITMAX          IITMAX
*   0.001          1              40
* CARD COBRA 1
* <-----TEXT----->
*   ****9_chan_PWR_core****
*
*****
*GROUP 1 - Calculation Variables and Initial Conditions *
*****
*NGRP
*  1
*  NGAS  IRFC  EDMD  IMIX  ISOL  NDM6  NDM7  NDM8  NDM9  NM10  NM11  NM12  NM13  NM14
*    1    2    1    1    0    0    0    0    0    0    0    0    0    0
*   GTOT  AFLUX  DHFRAC
*    0.    0.0    .0
*   PREF  HIN    HGIN    VFRAC1  VFRAC2
*  160.00 1251.255 288.233    1.0    .9999
*GTYPE          VFRAC
*  air          .0001
*****
* END GROUP 1 *
*****
* Group 11 - Axial Power Tables and Forcing Functions *
*****
*NGRP
*  11
*  NQA  NAXP  MNXN    NQ  NGPF    NQR  NDM7  NDM8  NDM9  NM10  NM11  NM12  NM13  NM14
*    1    1   30   30    0    2    0    0    0    0    0    0    0    0
*
* Axial Power Distribution/Forcing Functions
*   YQ
*   10.0
*   I  NAXN
*   1   30
*   Y    AXIAL
*  1.0000  1.0000
*  0.0820  1.0000
*  0.1665  1.0000
*  0.2485  1.0000
*  0.3330  1.0000
*  0.4150  1.0000
*  0.4995  1.0000
*  0.5815  1.0000
*  0.6660  1.0000
*  0.7480  1.0000
*  0.8325  1.0000

```

```

0.9145    1.0000
0.9990    1.0000
1.0810    1.0000
1.1655    1.0000
1.2475    1.0000
1.3320    1.0000
1.4140    1.0000
1.4985    1.0000
1.5805    1.0000
1.6650    1.0000
1.7470    1.0000
1.8315    1.0000
1.9135    1.0000
1.9980    1.0000
2.0800    1.0000
2.1645    1.0000
2.2465    1.0000
2.3310    1.0000
2.4130    1.0000
*
* Total Power Forcing Functions
*      YQ      FQ      YQ      FQ      YQ      FQ      YQ      FQ
*      0.0    0.0000    1.0    0.1000    2.0    1.0000    10.0   1.0000
      10.0   1.0000    11.8   1.0000    11.9   0.9815    12.0   0.9629
      12.1   0.9444    12.2   0.9259    12.3   0.9073    12.4   0.8888
      12.5   0.8702    12.6   0.8517    12.7   0.8303    12.8   0.8096
      12.9   0.7908    13.0   0.7734    13.1   0.7571    13.2   0.7418
      13.3   0.7273    13.4   0.7135    13.5   0.7003    13.6   0.6877
      13.7   0.6756    13.8   0.6639    14.8   0.5638    15.8   0.4835
      16.8   0.4146    17.8   0.3546    18.8   0.3029    19.8   0.2589
      20.8   0.2226    21.8   0.2162
* Radial Power Distribution/Forcing Functions
*      YQR
      0.0
*      FQR      FQR      FQR      FRQ      FQR      FRQ      FQR      FRQ
      1.55769   1.55769   1.55769   1.55769   1.52627   1.50229   1.51086   1.51087
      0.95895
*      YQR
      10.0
*      FQR      FQR      FQR      FRQ      FQR      FRQ      FQR      FRQ
      1.55769   1.55769   1.55769   1.55769   1.52627   1.50229   1.51086   1.51087
      0.95895
*****
* END GROUP 11
*****
*
*
*****
*GROUP 12 - Turbulent mixing data
*****
*NGRP
  12
* Card 12.1
* AAAK  BETA
  1.0  0.051
*****
* END GROUP 12
*****
*
*
*****
* Group 13 - Boundary Conditions Data
*****

```

```

*NGRP
  13
*NBNND NKBD NFUN NGBD NDM5 NDM6 NDM7 NDM8 NDM9 NM10 NM11 NM12 NM13 NM14
  18   0   1   0   0   0   0   0   0   0   0   0   0   0
*NPTS
  32
*
*ABSC   ORDINT ABSC   ORDINT ABSC   ORDINT
  0.0   0.0000  0.1   1.0000 10.0   1.0000 10.1   0.9976 10.2   0.9929
 10.3   0.9867 10.4   0.9795 10.5   0.9716 10.6   0.9632 10.7   0.9547
 10.8   0.9459 10.9   0.9371 11.0   0.9283 11.1   0.9196 11.2   0.9109
 11.3   0.9023 11.4   0.8938 11.5   0.8855 11.6   0.8773 11.7   0.8693
 11.8   0.8615 11.9   0.8537 12.0   0.8462 13.0   0.7817 14.0   0.7363
 15.0   0.6960 16.0   0.6593 17.0   0.6259 18.0   0.5953 19.0   0.5672
 20.0   0.5413 21.8   0.5413
*
* Inlet b.c. -----
*IBD1 IBD2 ISPC N1FN N2FN N3FN BCVALUE1 BCVALUE2 BCVALUE3 INITGAS
  1   1   2   1   0   0   .24961 1251.255   0.0   1
  2   1   2   1   0   0   .24961 1251.255   0.0   1
  3   1   2   1   0   0   .28699 1251.255   0.0   1
  4   1   2   1   0   0   .24961 1251.255   0.0   1
  5   1   2   1   0   0   3.1446 1251.255   0.0   1
  6   1   2   1   0   0   9.5544 1251.255   0.0   1
  7   1   2   1   0   0   32.872 1251.255   0.0   1
  8   1   2   1   0   0   75.777 1251.255   0.0   1
  9   1   2   1   0   0  1522.97 1251.255   0.0   1
*
* Outlet b.c. -----
*IBD1 IBD2 ISPC N1FN N2FN N3FN BCVALUE1 BCVALUE2 BCVALUE3 INITGAS
  1  42   1   0   0   0   0.0 1251.255 156.3042   1
  2  42   1   0   0   0   0.0 1251.255 156.3042   1
  3  42   1   0   0   0   0.0 1251.255 156.3042   1
  4  42   1   0   0   0   0.0 1251.255 156.3042   1
  5  42   1   0   0   0   0.0 1251.255 156.3042   1
  6  42   1   0   0   0   0.0 1251.255 156.3042   1
  7  42   1   0   0   0   0.0 1251.255 156.3042   1
  8  42   1   0   0   0   0.0 1251.255 156.3042   1
  9  42   1   0   0   0   0.0 1251.255 156.3042   1
*****
* END GROUP 13
*****
*
*
*****
* Group 14 - Output Options
*****
*NGRP
  14
* N1 NOU1 NOU2 NOU3 NOU4 IPRP IOPT IRWR NDM9 NM10 NM11 NM12 NM13 NM14
  5   0   0   0   0   0   2   1   0   0   0   0   0   0
*PRCH
*
*PRTG
*
*PRTR
*
*****
* END GROUP 14
*****
*
*
*****

```

```
* Group 15 - TIME DOMAIN DATA *
*****
*NGRP
  15
*   DTMIN  DTMAX  TEND  EDINT  DMPINT  RTWFP
* 0.000001  0.01  3.0   3.0   3.0   1.0
*   DTMIN  DTMAX  TEND  EDINT  DMPINT  RTWFP
* 0.000001  0.01 14.8   0.2   14.8   1.0
*   DTMIN (if negative stop)
*   -1.0   0.0   0.0   0.0   0.0   0.0
*
*****
* END GROUP 15 *
```

3 Appendix: Calc Notes and Listing of the Input Deck for 3x3 GE Experiments

3.1 GE 3x3 Experimental Parameters

Table 4: Geometrical characteristics of the GE 3x3 Test Section

Parameter	Value
Number of Rods	9
Rod Diameter	14.7066 mm
Rod-Rod Clearance	4.2672 mm
Rod-Wall Clearance	3.429 mm
Radius of Channel Corner	10.16 mm
Heated Length	1828.8 mm
Hydraulic Diameter	12.0396 mm

Table 5: Experimental Parameters of GE 3x3

Name of the test	GE 3x3
Reference in literature	<p>Janssen, E., (1971): <i>Two-Phase Flow and Heat Transfer in Multi-Rod Geometries – Final Report</i>, GEAP-10347 AEC Research and Development Report</p> <p>Lahey, R. T., et al., (1970): <i>Two-phase flow and heat transfer in multi-rod geometries: Sub-channel and Pressure Drop Measurements in Nine-Rod Bundle for Diabatic and Adiabatic Conditions</i>, GEAP-13049 AEC Research and Development Report</p>
Measured quantities	<p>Mixing tests, yielding</p> <ul style="list-style-type: none"> • mass flow rate, • equilibrium quality at the bundle outlet • for the total bundle, • for 3 subchannels each representing a characteristic class of subchannels (corner, side, central) → non-simultaneous sampling, only one subchannel sampled at a certain measurement
Measuring uncertainties	<p>Total bundle mass flow rate: $\pm 8\%$</p> <p>Subchannel flow rate and subchannel enthalpy: $\pm 3\%$</p>
Geometrical configuration	<p>Bundle consisting of:</p> <ul style="list-style-type: none"> • 9 rods (3 x 3) • 16 subchannels • small pins instead of spacer grids (to achieve a minimum flow disturbance)

Time-dependence	Stationary
No. of state points in the experiment	21 (4 single-phase tests with unheated rods, 13 two-phase tests with uniformly heated rods, 4 two-phase tests with non-uniformly heated rods)
Pressure	70 bar
Radial power distribution	<i>Single-phase tests:</i> unheated <i>Two-phase tests:</i> uniform and non-uniform
Axial power distribution	<i>Single-phase tests:</i> unheated <i>Two-phase tests:</i> uniform
Total power	0 ... 1600 kW
Heat flux density	0 ... 213 W/cm ²
Total inlet mass flow rate	1.2 kg/s ... 5.1 kg/s
Inlet mass flux	651 ... 2672 kg/(m ² s)
Inlet equilibrium quality	-77.9 % ... -4.5 %
Resulting flow conditions	<i>Single-phase tests:</i> <ul style="list-style-type: none"> • single-phase flow <i>Two-phase tests:</i> <ul style="list-style-type: none"> • two-phase flow • no dryout
Resulting average outlet equilibrium quality	2.9 % ... 31.8 % (Two-Phase Tests)

Table 6: GE 3x3 Test Points

No. of test point	Total inlet mass flow rate [kg/s]	Inlet enthalpy [kJ/kg]	Total rod power [kW]	Exit pressure [bar]
1B	1.231	93.7	0	70
1C	2.538	93.7	0	70
1D	3.871	93.7	0	70
1E	5.050	93.7	0	70
2B2	1.359	918.7	532	70
2B3	1.372	1014.6	532	70
2B4	1.372	1144.6	532	70
2C1	2.717	1134.4	532	70
2C2	2.738	1185.8	532	70
2D1	1.384	664.5	1064	70
2D3	1.384	978.1	1064	70
2E1	2.769	936.2	1064	70
2E2	2.769	1042.5	1064	70
2E3	2.717	1199.7	1064	70
2G1	2.743	742.0	1596	70
2G2	2.769	825.9	1596	70
2G3	2.743	926.2	1596	70
3B2	1.372	1237.4	532	70
3D1	1.397	2474.9	1064	70
3E1	2.769	2474.9	1064	70
3E2	2.717	2312.0	994	70

3.2 CTF Model of the GE 3x3 Test Section

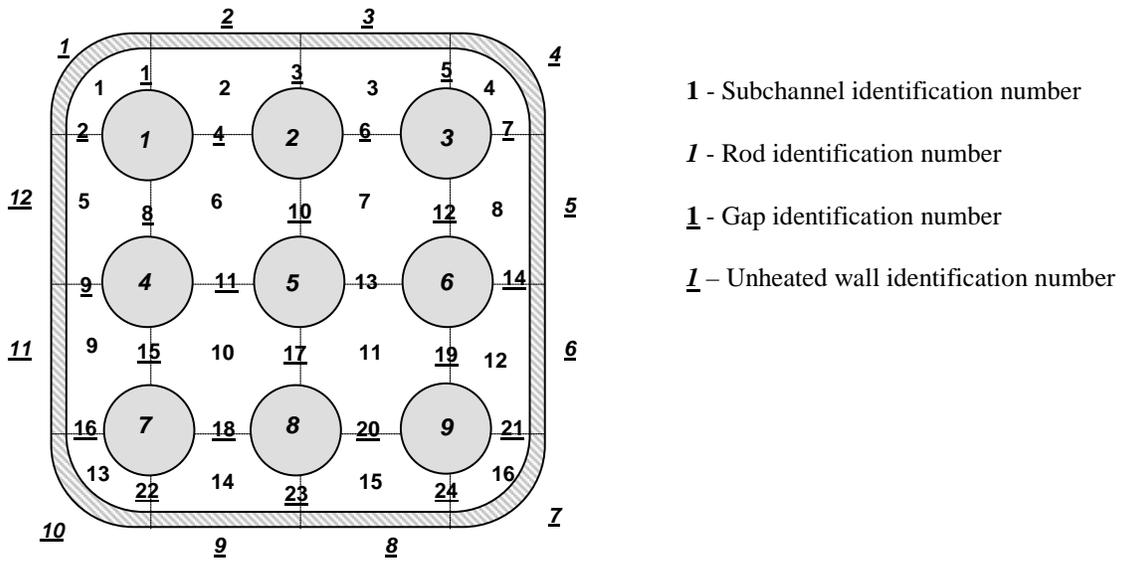


Figure 29: Cross Section of the CTF model of GE 3x3 Rod Bundle

Table 7: Geometrical Characteristics of the CTF Model of the GE 3x3 Test Section

Subchannel Parameters (16 subchannels)					
Subchannel type	No. of sampled sub-ch. in experiment	No. of sampled sub-ch. in CTF	Nominal area [m²]	Wetted perimeter [m]	
Corner subchannel	1	1	5.052×10^{-5}	0.0283	
Side subchannel	2	2	1.177×10^{-4}	0.0415	
Internal subchannel	6	6	1.868×10^{-4}	0.0455	
Transverse Connections Parameters (24 transverse connections)					
Gap type		Gap width [m]		Gap length [m]	
Corner-Side		3.429×10^{-3}		0.0147	
Side-Side		3.429×10^{-3}		0.0187	
Side-Internal		4.267×10^{-3}		0.0147	
Internal-Internal		4.267×10^{-3}		0.0187	
Heater Rod Parameters (9 heater rods)					
Conductor type	Material	Outside diameter [m]	Inside diameter [m]	Wetted perimeter [m]	Thickness [m]
Heated tube	Inconel	0.0145	0.0124	0.0455	1.016×10^{-3}
Unheated Conductors Parameters (12 unheated conductors)					
Conductor type	Material	Outside Perimeter [m]	Inside Perimeter [m]	Wetted perimeter [m]	Thickness [m]
Corner Wall	Inconel	0.0170	0.0170	0.0170	1.016×10^{-3}
Side Wall	Inconel	0.0187	0.0187	0.0187	1.016×10^{-3}

Table 8: CTF Modeling Parameters for the GE 3x3 Tests

Units in input file	US units
Entrainment / deposition model	Original CTF model (Paleev and Filippovich correlation for entrainment, Cousins model for deposition)
Direct heating of the coolant (by neutron moderation)	none
Initial pressure of the fluid	equal to the outlet pressure
Initial enthalpy of the fluid	equal to the inlet enthalpy
Heat loss to ambient	none
Initial rod temperature	149 °C (137 K below the saturation temperature at 70 bars)
Radiation	none
Fuel pellet model (inside the rods)	none
Forcing functions for rod power	<i>Test points 1B-1E: none</i> <i>Test points 2B2-2G3: none</i> <i>Test points 3B2-3E2: non-uniform radial peaking pattern (but not time-dependent)</i>
Mixing model	Standard mixing and void drift model according to user specified mixing coefficient BETA. BETA=0.02, $K_M=1.4$
Boundary condition type	Inlet: mass flow rate and enthalpy Outlet: pressure and enthalpy
Simulation time	10 s to reach stationary conditions
No. of test points in the calculation	21

3.3 CTF Input Deck for the GE 3x3 Test Point 2B2

```

*****
* GE 3x3 void experiments: Janssen, E., "Two-phase flow and heat transfer in
* multi-rod geometries - Final Report", GEAP-10347, March 1971
* CTF input deck for test case 2B2
*****
* MAIN PROBLEM CONTROL DATA
*****
* CARD INPUT 1
*   ICOBRA
*     1
* CARD INPUT 2
*   INITIAL          DUMPF
*     1              1
* CARD INPUT 3
*   EPSO            OITMAX          IITMAX
*   0.001           10              40
* CARD COBRA 1
*----- TEXT ----->
  *** GE 3x3 mixing test 2B2 ***
*****
* GROUP 1 - Calculation Variables and Initial Conditions
*****
* CARD GROUP 1
* NGR
*   1
* Card 1.1
* NGAS IRFC EDMD IMIX ISOL NDM6 NDM7 NDM8 NDM9 NM10 NM11 NM12 NM13 NM14
*   1     1     1     2     0     0     0     0     0     0     0     0     0     0
* Card 1.2
*   GTOT      AFLUX      DHFRAC
*   1.359     32.322      0.0
* Card 1.3
*   PREF      HIN        HGIN      VFRAC1    VFRAC2
*   70.00     918.77     288.4     1.0      0.9999
* Card 1.4
* GTP(1)    VFRAC(3)  GTP(2)    VFRAC(4)  GTP(3)    VFRAC(5)  GTP(4)    VFRAC(6)
air         .0001
*****
* GROUP 2.0 - Channel Description
*****
* CARD GROUP 2
* NGR
*   2
* Card 2.1
* NCHA NDM2 NDM3 NDM4 NDM5 NDM6 NDM7 NDM8 NDM9 NM10 NM11 NM12 NM13 NM14
*   16   0   0   0   0   0   0   0   0   0   0   0   0   0
* Card 2.2
*   I      AN      PW ABOT ATOP NMGP
*   1 0.00005050 0.02834629 0.0 0.0 0.0
*   2 0.00011766 0.04148719 0.0 0.0 0.0
*   3 0.00011766 0.04148719 0.0 0.0 0.0
*   4 0.00005050 0.02834629 0.0 0.0 0.0
*   5 0.00011766 0.04148719 0.0 0.0 0.0
*   6 0.00018675 0.04548398 0.0 0.0 0.0
*   7 0.00018675 0.04548398 0.0 0.0 0.0
*   8 0.00011766 0.04148719 0.0 0.0 0.0
*   9 0.00011766 0.04148719 0.0 0.0 0.0
*  10 0.00018675 0.04548398 0.0 0.0 0.0
*  11 0.00018675 0.04548398 0.0 0.0 0.0
*  12 0.00011766 0.04148719 0.0 0.0 0.0
*  13 0.00005050 0.02834629 0.0 0.0 0.0
*  14 0.00011766 0.04148719 0.0 0.0 0.0
*  15 0.00011766 0.04148719 0.0 0.0 0.0
*  16 0.00005050 0.02834629 0.0 0.0 0.0
*

```

```

*****
* GROUP 3.0 - Transverse Channel Connection (Gap) Data *
*****
* CARD GROUP 3
* NGR
  3
* Card 3.1
* NK NDM2 NDM3 NDM4 NDM5 NDM6 NDM7 NDM8 NDM9 NM10 NM11 NM12 NM13 NM14
  24   0   0   0   0   0   0   0   0   0   0   0   0   0
* Card 3.2
*   K   IK   JK   GAPN  LNPTH  WKR  FWL  IGPB  IGPA  FACT  IGAP  JGAP  IGAP  JGAP  IGAP  JGAP
  1   1   1   2 0.00343 0.01471 0.50 0.5   0   0  1.0  -1   3   0   0   0   0
* Card 3.3
* GMLT  ETNR
  1.000 0.000
* Cards 3.2 and 3.3 continued
  2   1   5 0.00343 0.01471 0.50 0.5   0   0  1.0  -1   9   0   0   0   0
1.000 0.000
  3   2   3 0.00343 0.01875 0.50 0.5   0   0  1.0   1   5   0   0   0   0
1.000 0.000
  4   2   6 0.00427 0.01471 0.50 0.0   0   0  1.0  -1  11   0   0   0   0
1.000 0.000
  5   3   4 0.00343 0.01471 0.50 0.5   0   0  1.0   3  -1   0   0   0   0
1.000 0.000
  6   3   7 0.00427 0.01471 0.50 0.0   0   0  1.0  -1  13   0   0   0   0
1.000 0.000
  7   4   8 0.00343 0.01471 0.50 0.5   0   0  1.0  -1  14   0   0   0   0
1.000 0.000
  8   5   6 0.00427 0.01471 0.50 0.0   0   0  1.0  -1  10   0   0   0   0
1.000 0.000
  9   5   9 0.00343 0.01875 0.50 0.5   0   0  1.0   2  16   0   0   0   0
1.000 0.000
 10   6   7 0.00427 0.01875 0.50 0.0   0   0  1.0   8  12   0   0   0   0
1.000 0.000
 11   6  10 0.00427 0.01875 0.50 0.0   0   0  1.0   4  18   0   0   0   0
1.000 0.000
 12   7   8 0.00427 0.01471 0.50 0.0   0   0  1.0  10  -1   0   0   0   0
1.000 0.000
 13   7  11 0.00427 0.01875 0.50 0.0   0   0  1.0   6  20   0   0   0   0
1.000 0.000
 14   8  12 0.00343 0.01875 0.50 0.5   0   0  1.0   7  21   0   0   0   0
1.000 0.000
 15   9  10 0.00427 0.01471 0.50 0.0   0   0  1.0  -1  17   0   0   0   0
1.000 0.000
 16   9  13 0.00343 0.01471 0.50 0.5   0   0  1.0   9  -1   0   0   0   0
1.000 0.000
 17  10  11 0.00427 0.01875 0.50 0.0   0   0  1.0  15  19   0   0   0   0
1.000 0.000
 18  10  14 0.00427 0.01471 0.50 0.0   0   0  1.0  11  -1   0   0   0   0
1.000 0.000
 19  11  12 0.00427 0.01471 0.50 0.0   0   0  1.0  17  -1   0   0   0   0
1.000 0.000
 20  11  15 0.00427 0.01471 0.50 0.0   0   0  1.0  13  -1   0   0   0   0
1.000 0.000
 21  12  16 0.00343 0.01471 0.50 0.5   0   0  1.0  14  -1   0   0   0   0
1.000 0.000
 22  13  14 0.00343 0.01471 0.50 0.5   0   0  1.0  -1  23   0   0   0   0
1.000 0.000
 23  14  15 0.00343 0.01875 0.50 0.5   0   0  1.0  22  24   0   0   0   0
1.000 0.000
 24  15  16 0.00343 0.01471 0.50 0.5   0   0  1.0  23  -1   0   0   0   0
1.000 0.000
*
* Card 3.4
* NLGP
  0
*
*****
* GROUP 4.0 - Vertical Channel Connection Data *
*****
* CARD GROUP 4

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* NGR
  4
* Card 4.1
* NSEC NSIM IREB NDM4 NDM5 NDM6 NDM7 NDM8 NDM9 NM10 NM11 NM12 NM13 NM14
  1      1      0      0      0      0      0      0      0      0      0      0      0
* Card 4.2
* ISEC NCHN NONO      DXS  IVAR
  1     16     36 0.05080      0
* Card 4.3
*      I  KCHA  KCHA  KCHA  KCHA  KCHA  KCHA  KCHA  KCHB  KCHB  KCHB  KCHB  KCHB  KCHB
  1      1      0      0      0      0      0      0      1      0      0      0      0      0
  2      2      0      0      0      0      0      0      2      0      0      0      0      0
  3      3      0      0      0      0      0      0      3      0      0      0      0      0
  4      4      0      0      0      0      0      0      4      0      0      0      0      0
  5      5      0      0      0      0      0      0      5      0      0      0      0      0
  6      6      0      0      0      0      0      0      6      0      0      0      0      0
  7      7      0      0      0      0      0      0      7      0      0      0      0      0
  8      8      0      0      0      0      0      0      8      0      0      0      0      0
  9      9      0      0      0      0      0      0      9      0      0      0      0      0
 10     10      0      0      0      0      0      0     10      0      0      0      0      0
 11     11      0      0      0      0      0      0     11      0      0      0      0      0
 12     12      0      0      0      0      0      0     12      0      0      0      0      0
 13     13      0      0      0      0      0      0     13      0      0      0      0      0
 14     14      0      0      0      0      0      0     14      0      0      0      0      0
 15     15      0      0      0      0      0      0     15      0      0      0      0      0
 16     16      0      0      0      0      0      0     16      0      0      0      0      0
* Card 4.5
* IWDE
  16
* Card 4.6
* MSIM
  576
*
*****
* GROUP 7 - Local Loss Coefficient and Grid Spacer Data
*****
* CARD GROUP 7
* NGR
  7
* Card 7.1
* NCD  NGT  IFGQ  IFSD  IFES  IFTP  IGTM  NFBS  NDM9  NM10  NM11  NM12  NM13  NM14
  18    0    1    1    1    1    0    0    0    0    0    0    0    0
* Card 7.2
* CDL   J  ICDM
0.111  2  1  4  13  16  0  0  0  0  0  0  0  0
0.120  2  2  3  5  8  9  12  14  15  0  0  0  0
0.177  2  6  7  10 11  0  0  0  0  0  0  0  0
*
0.111  8  1  4  13  16  0  0  0  0  0  0  0  0
0.120  8  2  3  5  8  9  12  14  15  0  0  0  0
0.177  8  6  7  10 11  0  0  0  0  0  0  0  0
*
0.111 14  1  4  13  16  0  0  0  0  0  0  0  0
0.120 14  2  3  5  8  9  12  14  15  0  0  0  0
0.177 14  6  7  10 11  0  0  0  0  0  0  0  0
*
0.111 20  1  4  13  16  0  0  0  0  0  0  0  0
0.120 20  2  3  5  8  9  12  14  15  0  0  0  0
0.177 20  6  7  10 11  0  0  0  0  0  0  0  0
*
0.111 26  1  4  13  16  0  0  0  0  0  0  0  0
0.120 26  2  3  5  8  9  12  14  15  0  0  0  0
0.177 26  6  7  10 11  0  0  0  0  0  0  0  0
*
0.111 32  1  4  13  16  0  0  0  0  0  0  0  0
0.120 32  2  3  5  8  9  12  14  15  0  0  0  0
0.177 32  6  7  10 11  0  0  0  0  0  0  0  0
*
*****
* GROUP 8.0 - Rod and Unheated Conductor Data
*****

```

```

* CARD GROUP 8
* NGR
  8
* Card 8.1
* NRRD NSRD  NC NRTB NRAD NLTY NSTA  NXF NCAN RADF  W3 NM12 NM13 NM14
  9  12  1  1  0  0  0  1  0  0  -1  0  0  0
* Card 8.2
* N IFTY IAXP NRND  DAXMIN  RMULT  HGAP ISECR  HTAMB  TAMB
  1  1  1  1  0 0.00000  1.000 0.00000  1  0.000  0.000
* Card 8.3
* NSCH  PIE  NSCH  PIE
  1 0.250  2 0.250  6 0.250  5 0.250  0 0.000  0 0.000  0 0.000  0 0.000
*
* Cards 8.2 and 8.3 continued
  2  1  1  0 0.00000  1.000 0.00000  1  0.000  0.000
  2 0.250  3 0.250  7 0.250  6 0.250  0 0.000  0 0.000  0 0.000  0 0.000
*
  3  1  1  0 0.00000  1.000 0.00000  1  0.000  0.000
  3 0.250  4 0.250  8 0.250  7 0.250  0 0.000  0 0.000  0 0.000  0 0.000
*
  4  1  1  0 0.00000  1.000 0.00000  1  0.000  0.000
  5 0.250  6 0.250  10 0.250  9 0.250  0 0.000  0 0.000  0 0.000  0 0.000
*
  5  1  1  0 0.00000  1.000 0.00000  1  0.000  0.000
  6 0.250  7 0.250  11 0.250  10 0.250  0 0.000  0 0.000  0 0.000  0 0.000
*
  6  1  1  0 0.00000  1.000 0.00000  1  0.000  0.000
  7 0.250  8 0.250  12 0.250  11 0.250  0 0.000  0 0.000  0 0.000  0 0.000
*
  7  1  1  0 0.00000  1.000 0.00000  1  0.000  0.000
  9 0.250  10 0.250  14 0.250  13 0.250  0 0.000  0 0.000  0 0.000  0 0.000
*
  8  1  1  0 0.00000  1.000 0.00000  1  0.000  0.000
  10 0.250  11 0.250  15 0.250  14 0.250  0 0.000  0 0.000  0 0.000  0 0.000
*
  9  1  1  0 0.00000  1.000 0.00000  1  0.000  0.000
  11 0.250  12 0.250  16 0.250  15 0.250  0 0.000  0 0.000  0 0.000  0 0.000
*
* Card 8.5
* N ISTDY  HPERIM  PERIMI  RMULT  NOSLCHC  NSLCHC  HTAMBS  TAMBS
  1  2 0.01698 0.00000  1.00  1  0  0.000  0.000
  2  3 0.01875 0.00000  1.00  2  0  0.000  0.000
  3  3 0.01875 0.00000  1.00  3  0  0.000  0.000
  4  2 0.01698 0.00000  1.00  4  0  0.000  0.000
  5  3 0.01875 0.00000  1.00  5  0  0.000  0.000
  6  3 0.01875 0.00000  1.00  8  0  0.000  0.000
  7  3 0.01875 0.00000  1.00  9  0  0.000  0.000
  8  3 0.01875 0.00000  1.00  12  0  0.000  0.000
  9  2 0.01698 0.00000  1.00  13  0  0.000  0.000
  10  3 0.01875 0.00000  1.00  14  0  0.000  0.000
  11  3 0.01875 0.00000  1.00  15  0  0.000  0.000
  12  2 0.01698 0.00000  1.00  16  0  0.000  0.000
*
* Card 8.6
* I NRT1  NST1  NRX1
  1  9  12  2
*
* Card 8.7
* IRTAB IRTAB
  1  2  3  4  5  6  7  8  9  0  0  0
*
* Card 8.8
* IRTAB IRTAB
  1  2  3  4  5  6  7  8  9  10  11  12
*
* Card 8.9
* AXIALT  TRINIT
  0.0000000  300.00000
  1.8300000  300.00000
*
*****

```

```

* GROUP 9.0 - Conductor Geometry Description *
*****
* CARD GROUP 9
* NGR
  9
* Card 9.1
* NFLT IRLF ICNF IMWR NDM5 NDM6 NDM7 NDM8 NDM9 NM10 NM11 NM12 NM13 NM14
  3  0  0  0  0  0  0  0  0  0  0  0  0  0  0
*
* Card 9.6
* I FTYP DROD DIN NFUL ITOX ITIX NDM8 NDM9 NM10 NM11 NM12 NM13 NM14
  1 tube 0.01448 0.01248 1 1 1 0 0 0 0 0 0 0 0
* Card 9.7
* NODR MATR TREG QREG
  2  1 0.00100 1.00000
*
* Card 9.6
* I FTYP DROD DIN NFUL ITOX ITIX NDM8 NDM9 NM10 NM11 NM12 NM13 NM14
  2 wall 0.01698 0.00100 1 1 1 0 0 0 0 0 0 0 0
* Card 9.7
* NODR MATR TREG QREG
  2  1 0.00100 0.00000
*
* Card 9.6
* I FTYP DROD DIN NFUL ITOX ITIX NDM8 NDM9 NM10 NM11 NM12 NM13 NM14
  3 wall 0.01875 0.00100 1 1 1 0 0 0 0 0 0 0 0
* Card 9.7
* NODR MATR TREG QREG
  2  1 0.00100 0.00000
*
*****
* GROUP 10 - Material Properties Tables
*****
* CARD GROUP 10
* NGR
  10
* Card 10.1
* NMAT NDM2 NDM3 NDM4 NDM5 NDM6 NDM7 NDM8 NDM9 NM10 NM11 NM12 NM13 NM14
  1  0  0  0  0  0  0  0  0  0  0  0  0  0
* Card 10.2
* N NTDP RCOLD IMATAN
  1  6 8470.57 Inconel 600
* Card 10.3
* TPROP CPF1 THCF
  -73 0.377 13.40
  93 0.464 15.71
  204 0.485 17.44
  427 0.527 20.90
  649 0.586 24.79
  871 0.623 28.83
*
*****
* GROUP 11.0 - Axial Power Tables and Forcing Functions *
*****
* CARD GROUP 11
* NGR
  11
* Card 11.1
* NQA NAXP MNXN NQ NGPF NQR NDM7 NDM8 NDM9 NM10 NM11 NM12 NM13 NM14
  1  1  2  0  0  1  0  0  0  0  0  0  0  0
*
* Axial Power Forcing Functions
* Card 11.2
* YQA
  0.0
* Card 11.3
* I NAXN
  1  2
* Card 11.4
* Y AXIAL
  0.000000 1.000000

```

```

1.830000  1.000000
*
* Total Power Forcing Functions
* Card 11.5
*   YQ      FQ
*   0.0000  0.0000
*   1.0000  1.0000
*   100.0000  1.0000
*
* Radial Power Forcing Functions
* Card 11.7
*   YQR
*   0.0
* Card 11.8
*   FQR      FQR      FQR      FQR      FQR      FQR      FQR      FQR
*   1.0000  1.0000  1.0000  1.0000  1.0000  1.0000  1.0000  1.0000
*   1.0000
*
*****
* GROUP 12 - Turbulent mixing data *
*****
* CARD GROUP 12
* NGR
* 12
* Card 12.2
* AAAK      DFRD  THEM
* 1.4      0.01448  5.0
*
*****
* GROUP 13.0 - Boundary Condition Data *
*****
* CARD GROUP 13
* NGR
* 13
* Card 13.1
* NBND NKBD NFUN NGBD NDM5 NDM6 NDM7 NDM8 NDM9 NM10 NM11 NM12 NM13 NM14
* 32  0  1  0  0  0  0  0  0  0  0  0  0  0  0
* Card 13.2
* NPT
* 4
* Card 13.3
* ABSC ORDINT  ABSC ORDINT  ABSC ORDINT
* 0.0 0.000  0.1 0.000  0.2 1.000 1500.0 1.000
* Card 13.4
* Inlet b.c. -----
* IBD1 IBD2 ISPC N1FN N2FN N3FN BCVALUE1 BCVALUE2 BCVALUE3 INITGAS
* 1 1 2 1 0 0 0.0 918.77 0.0000 1
* 2 1 2 1 0 0 0.0 918.77 0.0000 1
* 3 1 2 1 0 0 0.0 918.77 0.0000 1
* 4 1 2 1 0 0 0.0 918.77 0.0000 1
* 5 1 2 1 0 0 0.0 918.77 0.0000 1
* 6 1 2 1 0 0 0.0 918.77 0.0000 1
* 7 1 2 1 0 0 0.0 918.77 0.0000 1
* 8 1 2 1 0 0 0.0 918.77 0.0000 1
* 9 1 2 1 0 0 0.0 918.77 0.0000 1
* 10 1 2 1 0 0 0.0 918.77 0.0000 1
* 11 1 2 1 0 0 0.0 918.77 0.0000 1
* 12 1 2 1 0 0 0.0 918.77 0.0000 1
* 13 1 2 1 0 0 0.0 918.77 0.0000 1
* 14 1 2 1 0 0 0.0 918.77 0.0000 1
* 15 1 2 1 0 0 0.0 918.77 0.0000 1
* 16 1 2 1 0 0 0.0 918.77 0.0000 1
* Outlet b.c. -----
* IBD1 IBD2 ISPC N1FN N2FN N3FN BCVALUE1 BCVALUE2 BCVALUE3 INITGAS
* 1 38 1 0 0 0 0.0000 918.77 70.00 1
* 2 38 1 0 0 0 0.0000 918.77 70.00 1
* 3 38 1 0 0 0 0.0000 918.77 70.00 1
* 4 38 1 0 0 0 0.0000 918.77 70.00 1
* 5 38 1 0 0 0 0.0000 918.77 70.00 1
* 6 38 1 0 0 0 0.0000 918.77 70.00 1
* 7 38 1 0 0 0 0.0000 918.77 70.00 1

```

```

      8  38  1  0  0  0  0.0000  918.77  70.00  1
      9  38  1  0  0  0  0.0000  918.77  70.00  1
     10  38  1  0  0  0  0.0000  918.77  70.00  1
     11  38  1  0  0  0  0.0000  918.77  70.00  1
     12  38  1  0  0  0  0.0000  918.77  70.00  1
     13  38  1  0  0  0  0.0000  918.77  70.00  1
     14  38  1  0  0  0  0.0000  918.77  70.00  1
     15  38  1  0  0  0  0.0000  918.77  70.00  1
     16  38  1  0  0  0  0.0000  918.77  70.00  1
*
*****
* Group 14 - Output Options *
*****
*NGRP
  14
* N1 NOU1 NOU2 NOU3 NOU4 IPRP IOPT IRWR NDM9 NM10 NM11 NM12 NM13 NM14
  5  0  0  0  0  0  4  1  0  0  0  0  0  0
*PRCH
*  5  13  17  20
*PRTG
*  9  25  36
*PRTR
*  4  10  12
*PRTS
*  5  8
*
*****
* Group 15 - TIME DOMAIN DATA *
*****
* CARD GROUP 15
* NGR
  15
* Card 15.1
*      DTMIN      DTMAX      TEND      EDINT      DMPINT      RTWFP
      .0000001      .01      10.      10.      20.0      1.0
* Card 15.2
*      DTMIN (if negative stop)
      -.001      0.0      0.0      0.0      0.0      0.0
*
*****
* END GROUP TIME DOMAIN DATA *
*****
*

```

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