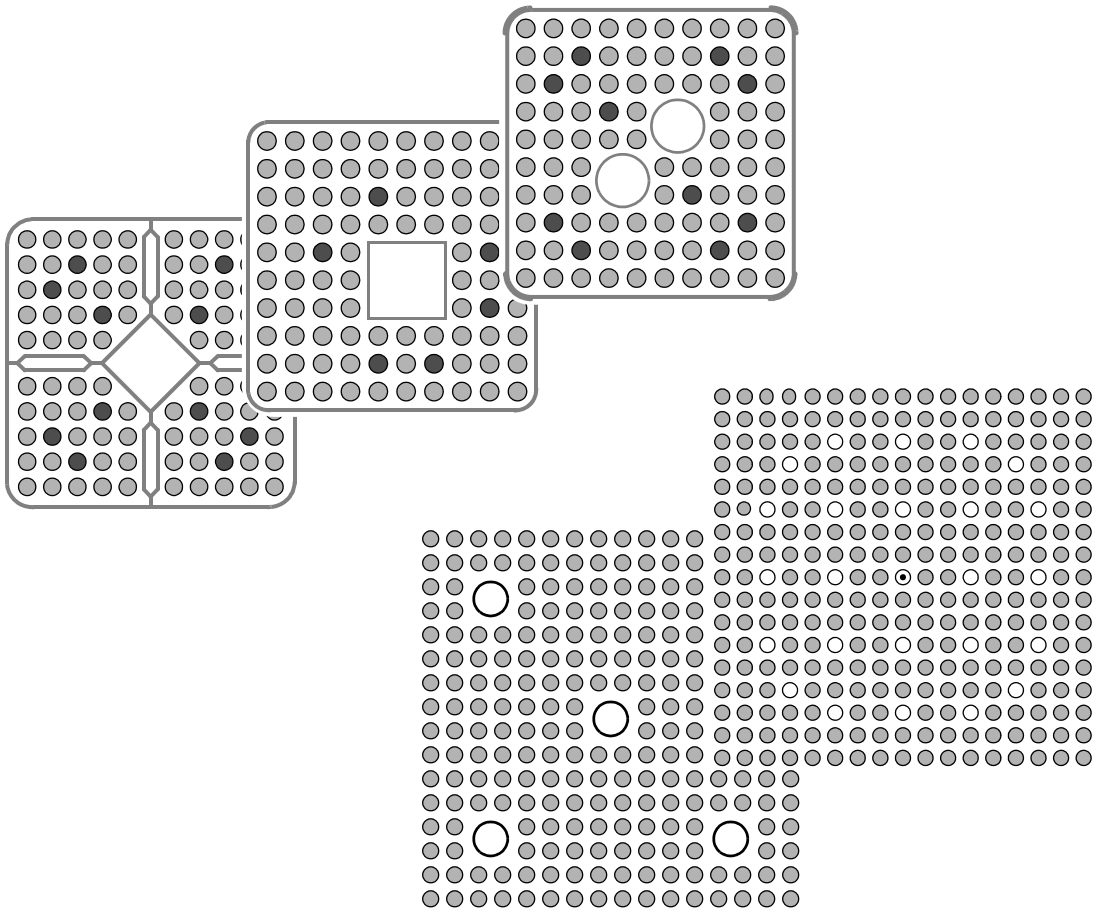
CASMO-4E

Extended Capability CASMO-4

User's Manual



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1.1 CASMO-4E Overview

CASMO-4E is an extended version of the lattice physics code CASMO-4 which has additional, optional capabilities beyond the base version. Some of these capabilities offer extensive functionality well beyond the standard CASMO-4, e.g., the MxN model which can perform full core, 2D transport theory calculations.

The optional CASMO-4E modules include:

1) MxN calculation (arbitrary arrangements of multiple fuel assemblies)

2) Generalized fuel storage rack calculation

3) Hexagonal geometry calculations (VVER-440 and VVER-1000)

4) Calculations with ENDF/B- VI library

5) Cluster/Magnox/AGR calculations

6) Azimuthal depletion (AZI and LAZ)

7) Pn-scattering model

This document covers the additional cards needed for the above models. For the description of input cards not documented here, the user is referred to the base CASMO-4 User's Manual.

2 CASMO-4E Input

CASMO-4E follows the same input convention as CASMO-4. The CASMO-4E input is divided into data blocks (in the following for brevity called "cards"), which are identified by an alphanumeric string of three characters. The input of one card may be given on one or several lines and several cards are allowed on the same line. Each line may contain up to 80 characters. Data beyond column 80 will generate a fatal error. A card name or any other input parameter must not be divided on two lines.

Input parameters are given in a way similar to (but not identical to) standard format free FORTRAN. Parameters are separated by a separator: **blank ( ), comma (,), equal sign (=), semicolon (;)**, or **the end of a line**. A **slash (/)** is used as a separator between arrays of variable length. A separator may be surrounded by any number of blanks.

The three character card identifier must be surrounded by separators. A **slash is not allowed in the first position after the card identifier**, i.e., the card name must be followed by one of the other separators, e.g., by a blank. All **alphanumeric character strings other than card identifiers must be contained within single quotes (')**, e.g., 'MOD'.

A repetition factor can be used to specify the same parameter value to several consecutive positions. **The repetition factor is an integer immediately followed by an asterisk and the parameter value**, e.g., 4*1 is identical to 1,1,1,1.

A position for a parameter value can be skipped in input by inputting two consecutive commas. The default value or the value from the previous card of the same type then remains unaltered. If a card of the same type is given more than once in the input, then **the parameters of the last card overwrites earlier data**. This is also the case for stacked cases and restart cases (where CASMO-4E reads the original input from the restart file).

A slash is not needed at the end of a card.

Comments can be written on any input card after an asterisk, which must be preceded by a separator. This feature also allows extra comment cards starting with an asterisk.

Tabs and other hidden characters should be avoided in the input.

The input description in Section 2 divides the cards into five categories, viz.

Default values are provided whenever it is possible. **SSP recommends that the default values be used as much as possible**. This reduces the risk of input errors and makes the input shorter and easier to check. The user should not change defaults for options in the program unless there is a clear understanding of how that specific option affects the calculation.

The user should not stack cases of different type, e.g., a single bundle and a 2x2 segment calculation. Multiple depletion and coefficient calculations can be stacked. Coefficient calculations are allowed in the same run as the depletion(s), i.e., CASMO-4E can generate and read a restart file in the same run. Colorset cases may not be stacked.

Most input cards can be combined. There are of course, some obvious exceptions where the cards would be contradictory. There are also certain limitations in the code. It has been attempted to mark in the input description when particular combinations of cards are not allowed.

CASMO-4E uses **metric units** if nothing else is clearly marked in the description of the input card. Units not generally marked in the manual are:

Material densities	gram/cm^3
Temperatures	K (Kelvin)
Dimensions	cm
Burnup (Exposure)	MWd/kg (= GWd/metric ton)

CASMO-4E performs an automatic **thermal expansion** of dimensions and densities. This automatic thermal expansion can be bypassed by using the THE card.

Table 2.1 lists all input cards by module and shows where to find the detailed input description.

Table 2.1 List of Input Cards by Module

2.1 MxN Input

This section describes the CASMO-4E MxN function which allows for a more general specification of problem geometry than can be given on the BWR/PWR or BAS (2x2 segment input) cards. This module allows CASMO-4E to model large configurations, e.g., 1/4 or full core using full 2D characteristics transport theory.

The cards MXN, LSE, LRO, LCR, LVD, LTF, LTM, LEX, LSD, BPS, BAF, BRL, PAD, SUM, S3I, AUT, and SMR are MxN specific cards. The cards: BAS, SEG may be used in other calculations, e.g., standard 2x2 colorsets.

No cards other than LSE, LRO, LCR, LVD, LTF, LTM, LSD, LEX, BAF, BRL, PAD, BPS, and SUM are allowed between the MXN and BAS cards. **The MXN card must immediately follow the TTL card.**

The LSE card must be the first card of the "MxN Map cards" since it provides the master layout of the calculation. Any BAF, BRL or PAD cards must precede the LSE map.

For MxN applications the user will most likely need to use the MEM card and the FIL card as described in the base CASMO-4 manual.

Card image files are not generated for MxN calculations and automated coefficient calculations (including S3C) are not available. Furthermore, stacked cases are not supported for MxN calculations.

MXN Multi-segment input

MXN	ISYM, IAXIS, PRIMXN, IBUNEXP

ISYM Problem symmetry indicator:

1 Full rectangular problem geometry.

2 Diagonal problem symmetry. Only diagonally symmetric assemblies are allowed on the diagonal. All input must truly be diagonally symmetric. This option applies diagonal symmetry only in the 2D characteristics solution (which can save considerable memory). If diagonal symmetry is requested, the various MxN related maps, e.g., LSE, LRO etc. must still be input in full geometry.

IAXIS Axis spanning assemblies

0 Axis spanning assemblies not present (BWR and even lattice PWRs)

1 Axis spanning assemblies present on north and west sides (typically odd lattice PWR) (not available for rotational B.C.)

PRIMXN MxN edit control

1 Minimal assembly oriented output --This is an edit control flag

2 Maximum assembly oriented output (includes pin by pin output)

3 Not currently used

4 Mega-option. Adds additional data for auto-generated assemblies which would normally be suppressed.

IBUNEXP Restart file exposure interpretation

0 Interpret restart files as marked (when read) with cycle exposure

1 Interpret restart files as marked (when read) with assembly average exposure

Default:

ISYM 1

IAXIS 0

PRIMXN 1

IBUNEXP 0

Example:

```
MXN 1 * Default full problem geometry
MXN 2 1 * Diagonal symmetry with axis spanning assembly
```

Comment:

1.The MxN card signals to CASMO that it is to perform an MxN calculation. This card may not appear in a single assembly or standard 2x2 calculation. The MXN card must follow immediately after the TTL card.

2.The axis spanning assembly option is limited to 1/4 core, i.e., both major axes contain axis spanning assemblies --half core modeling is not available. The spanning axes are the north and west sides. One caveat when using the axis spanning assembly option is that if an axis spanning assembly has an odd number of pin, then **all axis spanning assemblies must have the same number of pins.**

3. Requesting PRIMXN=2 or 4 can generate large output files.

4.The IBUNEXP parameter is relevant only if performing a calculation which reads pre-existing CASMO restart files.
The MxN input follows a strict hierarchy of order dependent input cards. An MxN input deck should be structured as follows:

```
MEM (if needed)  * dynamic memory
TTL (required)   * Title cards
MXN (required)   * MxN sentinel
BAF (optional)   * PWR baffle
BRL (optional)   * PWR barrel
PAD (optional)   * PWR pad
LSE (required)   * Layout of MxN segments
LRO (optional)   * Input rotation map
LCR (optional)   * Control rod maps
LTF (optional)   * Fuel temperature maps
LTM (optional)   * Moderator temperature maps
LVD (optional)   * Void maps
LSD (optional)   * Shutdown cooling map
LEX (optional)   * Exp map (present only if using restart files)
BAS
    Data common to all segments
SEG 1
    Segment 1 data
SEG 2
    Segment 2 data
 .      .     .
 .     .      .
 .     .      .
SEG N
    Segment N data
STA
```

LSE Layout of segments for MxN

LSE	N_1 N_2 N_3
	- - -
	- - -
	- - N_n /NLSEX NLSEY

N_i Segment number (matching a segment number given on SEG card later in the input). The same segment can be placed in more than one position. A zero in a position indicates that an autogenerated reflector occupies that position.

NLSEX Number of segments in the x direction.

NLSEY Number of segments in the y direction.

Default: None

Example:

```
LSE
1 2 0
2 3 2
0 2 1 / 3 3   * A 3x3 assembly layout with 2 water holes
```

Comment:

1. This card is required for all MxN calculations.
2. Placing a 0 in the LSE map indicates that the assembly location is vacant and CASMO will create an appropriate composition in that location (unvoided water) for an auto-generated reflector segment (unvoided water) or an appropriate PWR baffle, barrel, and pads if requested. The moderator temperature for these auto-generated segments is taken from the TMO card located in the BAS section of the input.
3. The LSE map is the "MASTER MAP" for the MxN input and as such must proceed any of the other MxN map cards such as LEX, LTF, LTM, LVD, LSD, LCR, LRO etc.
4. If running in diagonal symmetry, the entire LSE map (NLSEX by NLSEY) must still be input.

BAS Base problem data

BAS	

Default: None

Comment:

Data that is common to all segments is to follow the BAS card. After an MXN card, no parameters should be given on the BAS card (unlike a BAS card in a standard 2x2 calculation). An MxN input deck should roughly be structured:

```
MEM (if needed)  * dynamic memory
TTL (required)   * Title card
MXN (required)   * MXN sentinel
BAF (optional)   * PWR baffle
BRL (optional)   * PWR barrel
PAD (optional)   * PWR pad
LSE (required)   * Layout of MxN segments
LRO (optional)   * Input rotation map
LCR (optional)   * Input control rod maps
LTF (optional)   * Fuel temperature maps
LTM (optional)   * Moderator temperature maps
LVD (optional)   * Void maps
LSD (optional)   * Shutdown cooling map
LEX (optional)   * Exp map (present only if using restart files)

BAS
           Data common to all segments
SEG 1
           Segment 1 data
SEG 2
           Segment 2 data

 .    .    .
 .    .    .
 .    .    .
SEG N
           Segment N data
STA
END
```

SEG Segment specific data

SEG	N

N Segment number which corresponds to a segment number in the LSE map.

Default: None

Comment:

The SEG card functions like the SEG card in a standard 2x2 calculation, that is, after the SEG card follows segment specific data. An MxN input deck should roughly be structured:

```
MEM (if needed)  * dynamic memory
TTL (required)   * Title card
MXN (required)   * MXN sentinel
BAF (optional)   * PWR baffle
BRL (optional)   * PWR barrel
PAD (optional)   * PWR pad
LSE (required)   * Layout of MxN segments
LRO (optional)   * Input rotation map
LCR (optional)   * Input control rod maps
LTF (optional)   * Fuel temperature maps
LTM (optional)   * Moderator temperature maps
LVD (optional)   * Void maps
LEX (optional)   * Exp map (present only if using restart files)

BAS
           Data common to all segments
SEG 1
           Segment 1 data
SEG 2
           Segment 2 data
 .    .    .
 .    .    .
 .    .    .
SEG N
           Segment N data
STA
END
```

LCR Control rod disposition map

LCR	N_1 N_2 N_3 - - - - - - - - N_n /'cr_1','cr_i'/ EXP_1 EXP_2

N_i Disposition of control rod. 0 for withdrawn, and > 0 for inserted. Enter a value for each assembly location (corresponding to the LSE and LRO maps). The integer value corresponds to the listing of the control rod pnames, e.g., 'cr_1'.

'cr_i' Name of the control rod associated with rod type i. These names must correspond with those names (PNAMES) used on the PIN/CRD/PRM cards (maximum of 10).

EXP_1 Starting cycle exposure for exposure range for which the LCR map is valid (MWd/kg).

EXP_2 Ending cycle exposure for exposure range for which the LCR map is valid (MWd/kg).

Default: All rods withdrawn.

Example:

```
LCR
1   0   0
0   0   0
0   0   2/ 'CR0' 'CR1' * 3x3 PWR with 2 rod types inserted

LCR
0   0   0   0
0   1   1   0
0   1   1   0
0   0   0   0/'CRD' 4x4 BWR with central assemblies rodded
```

Comment:

1.The shape of this map should match the LSE map.

2. Multiple LCR maps may be placed after the MxN card (and before the BAS card) if exposure dependent maps are required. The exposure range over which that particular map is valid is specified via EXP_1 and EXP_2 .

3. EXP_1 and EXP_2 are required only if exposure dependent maps are required. If EXP_1 and EXP_2 are not input, then the map values are assumed to be constant for the depletion.

4. If exposure dependent maps are specified, then the exposure range from EXP_1 of the first map to EXP_2 of the last map must be complete and continuous. Up to 50 exposure dependent LCR maps may be entered in any single MxN run.

LEX Exposure map

LEX	E_1	E_2	E_3
	-	-	-
	-	-	-
	-	-	E_n

E_i Exposure in MWd/kg for segment i.

Default: None

Example:

```
LEX
00.0 20.0 00.0
20.0 00.0 20.0
00.0 20.0 00.0
```

Comment:

1. This card can be used to insert depleted assemblies into the MxN calculation.
2. This card will only work when using CASMO restart files generated by the same version of CASMO. When used in combination with the FIL card, the LEX map makes it unnecessary to put RES cards into the SEG inputs.
3. The exposure values on the LEX card must exist on the CASMO restart files being read.

LRO Segment rotation map

LRO	N_1 N_2 N_3
	- - -
	- - -
	- - N_n

N_i Rotation index of segment n in the multi-segment layout.
The rotation index can have only the following values (the rotation is clockwise).

Index	Rotation (degrees)
0	0
1	90
2	180
3	270

Default: PWR: All zero.

BWR: 0 1
3 2

Example:

```
LRO
0 1 0 1
3 2 3 2
0 1 0 1 * Default BWR rotations for 4x4
```

Comment:

1.The shape of this map should match the LSE map.

2. If no LRO card is input, and a BWR is being run, then the code autogenerates the following rotation sequences:

   0 1

   3 2

3. The rotations indicated in the LRO map are absolute rotations and not incremental. This is an important point when bringing data back via restart files through multiple cycles.

LSD Shutdown cooling map (SDC)

LSD	T_1 T_2 T_3
	- - -
	- - -
	- - T_n / 'dt'

T_i Shutdown cooling time for segment i.

'dt' 'DD' Shutdown cooling time in days

'DH' Shutdown cooling time in hours

Default:

T_i None

'dt' 'DH'

Example:

```
LSD
500.0 500.0 500.0
500.0 500.0 500.0
500.0 500.0 500.0 / 'DD'   * Cool all assemblies 500 days
```

Comment:

1. This card can be used to specify shutdown cooling times for reinserted assemblies.
2. When an LSD map is detected, the code will perform a calculation at cycle exposure =0.0 (an initialization statepoint of 1 iteration), perform the shutdown cooling statepoint, and then proceed with any full power depletion.
3. The SDC calculation is performed at a PDE of 1.0E-6.
4. The shape of this map should match the LSE map.
5. Only one LSD map may appear in any MxN calculation.

LTF Fuel temperature map

LTF	T_1 T_2 T_3 - - - - - - - - T_n / EXP_1 EXP_2

T_i Fuel temperature in Kelvin for segment i.

EXP_1 Starting cycle exposure for exposure range for which the LTF map is valid (MWd/kg).

EXP_2 Ending cycle exposure for exposure range for which the LTF map is valid (MWd/kg).

Default: None

Example:

```
LTF
900.0 900.0 900.0
900.0 880.0 900.0
900.0 900.0 900.0
```

Comment:

1. The shape of this map should match the LSE map.
2. Multiple LTF maps may be placed after the MxN card (and before the BAS card) if exposure dependent maps are required. The exposure range over which that particular map is valid is specified via EXP_1 and EXP_2.
3. If exposure dependent maps are specified, then the exposure range from EXP_1 of the first map to EXP_2 of the last map must be complete and continuous.
4. EXP_1 and EXP_2 are required only if exposure dependent maps are required. If EXP_1 and EXP_2 are not input, then the map values are assumed to be constant for the depletion.
5. Up to 50 LTF maps may be entered in any one run.
6. No interpolation is performed.
7. If auto-generated reflector segments are present then a TFU card must still appear in the BAS part of the input.

LTM Moderator temperature map

LTM	T_1 T_2 T_3
	- - -
	- - -
	- - T_n / EXP_1 EXP_2

T_i Moderator temperature in Kelvin for segment i.

EXP_1 Starting cycle exposure for exposure range for which the LTM map is valid (MWd/kg).

EXP_2 Ending cycle exposure for exposure range for which the LTM map is valid (MWd/kg).

Default: None

Example:

```
LTM
550.0 550.0 550.0
550.0 560.0 550.0
550.0 550.0 550.0
```

Comment:

1. The shape of this map should match the LSE map.
2. Multiple LTM maps may be placed after the MxN card (and before the BAS card) if exposure dependent maps are required. The exposure range over which that particular map is valid is specified via EXP_1 and EXP_2 .
3. If exposure dependent maps are specified, then the exposure range from EXP_1 of the first map to EXP_2 of the last map must be complete and continuous.
4. EXP_1 and EXP_2 are required only if exposure dependent maps are required. If EXP_1 and EXP_2 are not input, then the map values are assumed to be constant for the depletion.
5. Up to 50 LTM maps may be entered in any one run.
6. No interpolation is performed.
7. If auto-generated reflector segments are present then a TMO card must still appear in the BAS part of the input.

LVD Void map

LVD	V_1 V_2 V_3 - - - - - - - - V_n / EXP_1 EXP_2

V_i Percent void for segment i.

EXP_1 Starting cycle exposure for exposure range for which the LVD map is valid (MWd/kg).

EXP_2 Ending cycle exposure for exposure range for which the LVD map is valid (MWd/kg).

Default: None

Example:

```
LVD
40.0 40.0 40.0
40.0 70.0 40.0
40.0 40.0 40.0

LVD
40.0 40.0 40.0
40.0 70.0 40.0
40.0 40.0 40.0 / 0.0 2.5 * map valid over range 0.0 to 2.5 MWd/kg
```

Comment:

1. The shape of this map should match the LSE map.
2. Multiple LVD maps may be placed after the MxN card (and before the BAS card) if exposure dependent maps are required. The exposure range over which that particular map is valid is specified via EXP_1 and EXP_2.
3. If exposure dependent maps are specified, then the exposure range from EXP_1 of the first map to EXP_2 of the last map must be complete and continuous.
4. EXP_1 and EXP_2 are required only if exposure dependent maps are required. If EXP_1 and EXP_2 are not input, then the map values are assumed to be constant for the depletion.
5. Up to 50 LVD maps may be entered in any one run.
6. No interpolation is performed.

BAF Ex-core PWR baffle auto-generation

```
BAF     'MAT', NPINS, SSA_OPT
```

'MAT'		Material of baffle
NPINS		Baffle constructed will be this many pins pitches thick
SSA_OPT	'ON'	Apply SSA correction to sigma transport in baffle SS and iron in auto-generated baffle segments
	'OFF'	Do not apply SSA correction to sigma transport in baffle SS and iron in auto-generated baffle segments

Default:

'MAT'	= 'MAT'
NPINS	= 3
SSA_OPT	= 'ON'

Example:

```
BAF
BAF 'MI1' * Use MI1 for baffle material
```

Comment:

1. This card is valid only for an MxN calculation.
2. This card will auto-generate PWR baffle segments around the periphery of the fueled core regions.
3. **The BAF card must appear before the LSE card.**
4. With the BAF card present, the user does not need to input manually built baffle segments, however, the LSE map still needs to provide space for the auto-generated segments (zero's around the real fuel).
5. The SSA (correction to the transport cross section for stainless steel in baffle/reflector) ON/OFF option controls this option for all baffle/barrel/reflector segments and normally should be ON for these segments when using the L-library. SSP recommends use of the defaults.
6. This data is not written to the CASMO restart file.

BRL Ex-core PWR barrel or BWR shroud auto-generation

```
BRL     RADIUS_IN, RADIUS_OUT, 'MAT1', 'MAT2', 'MAT3',
        'MAT4'
```

RADIUS_IN	Inner radius of core barrel in cm
RADIUS_OUT	Outer radius of core barrel in cm
'MAT1'	PWR: Material of barrel BWR: Material of shroud
'MAT2'	PWR: Material between baffle and barrel (interior to barrel) BWR: Material between core and shroud (interior to shroud)
'MAT3'	PWR: Material between barrel and pads BWR: Material between shroud and vessel (downcomer material)
'MAT4'	PWR: Material outside of pad regions BWR: Material outside of pressure vessel

Default:

RADIUS_IN	= None
RADIUS_OUT	= None
'MAT1'	= 'CRS'
'MAT2'	= 'MOD'
'MAT3'	= 'MOD'
'MAT4'	= 'MOD'

Example:

```
BRL 187.95, 194.0
BRL 187.95, 194.0 'MI1'  * Use material MI1 for barrel
```

Comment:

1. This card can be used to model the PWR core barrel or a BWR shroud.

2. This card is valid only for an MxN calculation.

3. The BRL card must appear before the LSE card.

4. This card will auto-generate barrel material in segments located around the periphery of the problem.

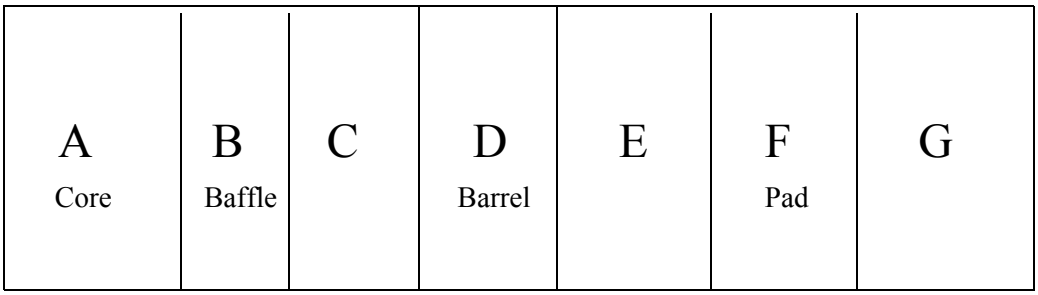
5. With the BRL card present, the LSE map still needs to provide space for the auto-generated segments (zero's around the real fuel).

6. If the user is inputting data for 'MAT2', 'MAT3' and 'MAT4', then the user is responsible for ensuring that the materials are at the proper density and temperature.

7. This data is not written to the CASMO restart file.

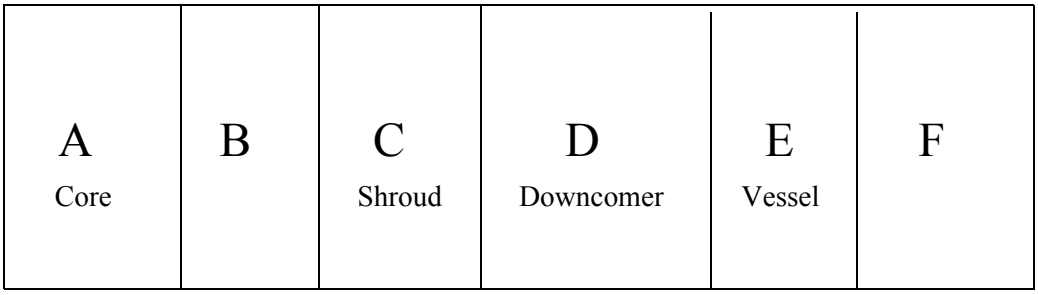
8. See Figures 2.1 and 2.2 on the next page for the relationships of the various ex-core regions.

Fig. 2.1 PWR Ex-core Regions




```
A: Core region
B: PWR baffle region (see BAF card)
C: Region between baffle and barrel (MAT2)
D: Barrel region (MAT1)
E: Region between barrel and pad (MAT3)
F: Pad region (See PAD card)
G: Region outside of pads (MAT4)
```

Fig. 2.2 BWR Ex-core Regions




```
A : Core region
B : Region between core and shroud (MAT2)
C : Shroud (MAT1)
D : Downcomer region (MAT3)
E : BWR pressure vessel (see PAD card)
F : Region outside of pressure vessel (MAT4)
```

PAD Ex-core PWR pad or BWR vessel auto-generation

PAD	RADIUS_IN, RADIUS_OUT, ANGLE_START, ANGLE_END, 'MAT'

RADIUS_IN	Inner radius of pad or vessel in cm
RADIUS_OUT	Outer radius of pad or vessel core barrel in cm
ANGLE_START	Starting angle in degrees (0-360)
ANGLE_END	Ending angle in degrees (0-360)
'MAT'	Material of pad or vessel

Default:

RADIUS_IN	= None
RADIUS_OUT	= None
ANGLE_START	= None
ANGLE_END	= None
'MAT'	= 'CRS'

Example:

```
PAD 194.8 201.8  32.5  65.0     *  Pad 1
PAD 194.8 201.8 112.5 147.5     *  Pad 2
PAD 194.8 201.8 212.5 245.0     *  Pad 3
PAD 194.8 201.8 292.5 327.5     *  Pad 4
```

Comment:

1. This card can be used to model pads around PWR core barrel or the vessel around a BWR.

2. This card is valid only for an MxN calculation.

3. The PAD card must appear before the LSE card.

4. This card will auto-generate barrel material in segments located around the periphery of the problem.

5. The PAD card is multiple input card, i.e. it is permitted to have multiple PAD cards in the input.

6. The code is currently limited to 5 pads.

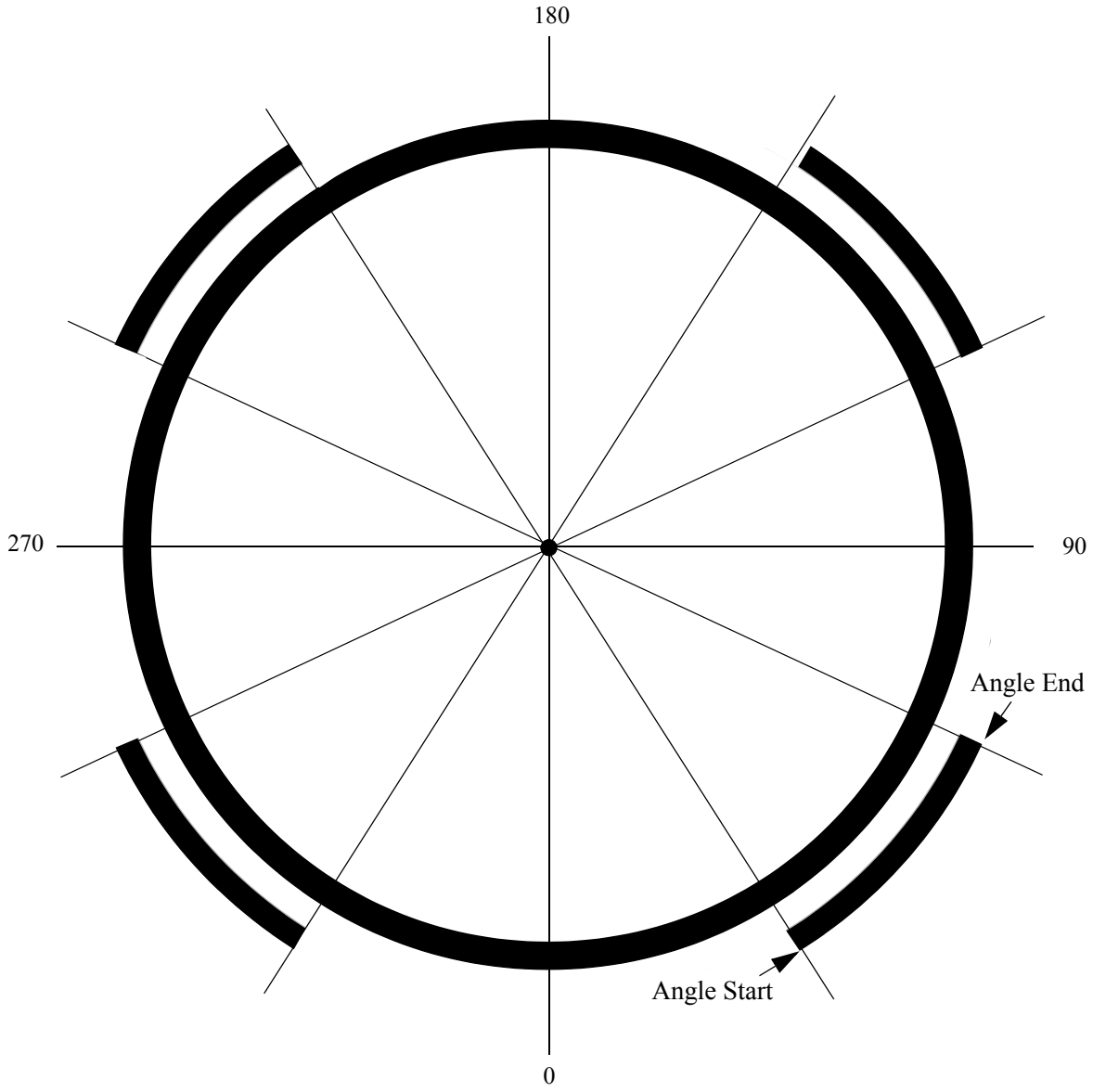
7. The co-ordinate system for the orientation of the starting and ending angles is 0 degrees straight down, and proceeds counterclockwise such that 90 degrees is to the right, 180 degrees straight up, and 270 degrees to the left. This is shown in the following figure:

13. For BWR applications the PAD cards can be used to model the outer reactor pressure vessel by having each pad encompass the entirety of their respective quadrants, i.e.,

```
PAD 194.8 201.8   0.0  90.0
PAD 194.8 201.8  90.0 180.0
PAD 194.8 201.8 180.0 270.0
PAD 194.8 201.8 270.0 360.0
```

7. This data is not written to the CASMO restart file.

Fig. 2.3 Angular co-ordinate system for placement of pads outside of the barrel



General Comments on the MxN Barrel/Baffle/Pad Model

1. The thickness of the baffle is limited to an integer number of pins (typically 2 or 3 pins thick).

2. The automated barrel and pad cannot be used with manual (user built) baffle segments.

3. The code is currently limited to modeling 5 pads around the exterior of the barrel.

4. The BAF/BRL and PAD cards must appear in the MXN section of the input and must appear **before** the MxN LSE map.

5. The LSE map must be "padded" with 0's around the periphery of the fuel to provide a space in which the code may place the auto-generated segments. If the LSE map is too small, then part of the barrel and pads may fall outside the calculated geometry. A warning is issued, but it is allowed.

6. If the user is overriding a default material with a user constructed material, e.g., an MIx specification, then that specification must appear in the BAS segment of the input.

7. Due to the limitation of a curved barrel and curved pads being modeled with square pin cells, the spatial resolution of the barrel and pads is approximately one pin pitch.

8. The same restrictions that apply to auto-generated reflector segments also apply to the BAF/BRL and PAD segments. These types of segments do not deplete and do not appear in any normalizations in the MxN summary. The macro-group calculation is active for these segments. Restart files are not generated for these segments.

9. The SSA (correction to the transport cross section for stainless steel in baffle/reflector) ON/OFF option on the BAF card controls this option for all baffle/barrel/reflector segments and normally should be ON for these segments if running with the L-library.

10. In the case where the pads are not symmetric about the diagonal axis, a 1/4 core calculation can not be run with diagonal symmetry, e.g., MXN 2, 1 cannot be used.

11. This model makes sense only in the context of CASMO-4E MxN and has no application in single assembly calculations. Also, the user should be aware that any input modeling all the way out to the pads is a spatially large problem and that significant computer memory (and other computer resources) will be required.

12. The pin pitch for auto-generated segments is taken from the **last segment** encountered in the input stream. This allows the user to include a dummy segment at the end of the input with a customized PWR card to control the number of pins and their pitch in these segments.

13. A pad spanning across the 360 degree point must be split into two pads.

AUT Autogenerated reflector pitch

AUT	PITCH

PITCH Assembly pitch in cm that the code will use to build auto-generated reflectors

Default:

If no AUT card is present, the code will attempt to determine the pitch from the last BWR/PWR card it encountered in the input stream.

Example:

```
AUT 21.8
```

Comments:

1. This card is only for MxN cases which use auto-generated reflectors (0 in the LSE map).
2. The code will "suggest" an appropriate value if an AUT card is required.
3. This card will usually be encountered when using MxN and FSS/FSC in combination, but otherwise should rarely be needed.

BPS BP shuffle

BPS	'File_in1',EXP1,'File_in2',EXP2,'File_out'

'File_in1' CASMO-4E restart file name from which to retrieve B.P. data.

EXP1 Exposure (MWd/kg) for file_in1 at which to retrieve B.P. data.

'File_in2' CASMO-4E restart file name from which fuel and assembly data is to be taken.

EXP2 Exposure (MWd/kg) for file_in2 at which to retrieve fuel and assembly data.

'File_out' File name of restart file to be created from the merge of B.P. data from File_in1 at EXP1 into restart file File_in2 at EXP2.

Default: None

Example:

```
BPS 'single.res' 10.0  'host.res' 12.0  'merge.seg1.res'
```

Comment:

1. This card is used to shuffle B.P. data (number densities) from one CASMO-4E restart file into another. The process leaves the original restarts unmodified and produces a third (merged) restart file.
2. B.P. shuffles may be performed only in the context of an MxN calculation and must appear in the MxN section of the input (before the BAS card).
3. Multiple BPS cards are allowed.
4. Interpretation of exposure marking on the restart files (cycle exposure or assembly average) is controlled by the IBUNEXP parameter on the MXN card.
5. The only mechanism to shuffle B.P. data is via CASMO-4E restart files. To insert depleted B.P.'s into a fresh assembly, a restart file at 0.0 exposure must be created for that fresh assembly before the shuffle process.
6. The BPS card may span multiple lines since the filenames may be longer than the 80 column limit for input lines.
7. There is no provision to perform "password" searching on the incoming restart files. It is assumed that the restart files have generated from single assembly straight depletions (no branches) or previous MxN calculations.
8. The merged restart file created is marked with exposure EXP2 (the exposure of the "host" assembly).

S3I Generate equivalent SIMULATE input

S3I	COPT, TRIM_OPT, LIB_OPT

OPT	'OFF'	: No generation of SIMULATE-3 input
	'FULL'	: Generation of SIMULATE-3 input in full core geometry
	'1/4'	: Generation of SIMULATE-3 input in 1/4 core geometry
TRIM_OPT	'TRIM'	: Trim baffle/barrel/pad segments to equivalent SIMULATE input
LIB_OPT	'LIB'	: Generate extra cards (commented out) to facilitate use with a real SIMULATE-3 library (FUE.LAB and FUE.MOD)
	'SUP'	: Do not generate extra cards (suppress)

Default:

COPT='OFF'
TRIM_OPT= 'NO'
LIB_OPT='LIB'

Example:

```
S3I '1/4'
```

Comment:

1. This card will generate a SIMULATE input equivalent to the MxN case which has just been run.
2. This card is valid only for an MxN calculation.
3. Only full and 1/4 core geometry generation is supported.
4. The user has no control of the filename of the generated SIMULATE input which is: s3."input_filename" where input_filename is the name of the CASMO input file.
5. A file is generated only for the first statepoint.
6. This option is provided as only an aid for building an equivalent SIMULATE-3 input deck and some user modifications of the generated deck may be required. This is particularly true for PWR baffle segments which are treated as real assemblies in C4 but are part of the reflector in SIMULATE.
7. If making direct comparisons between an MxN CASMO and a SIMULATE using a library generated from single assembly inputs, the user must be careful to run the single assembly CASMOs with comparable options, e.g., FUM,,3.
8. This option has no effect in a single assembly calculation.
9. This edit is suppressed if a simultaneous gamma calculation is requested.

SMR Gamma smearing factor for MxN

SMR	VAL

VAL Fraction of gamma smearing on pin power distribution.

Default:

VAL=0.07 (single assembly and standard 2x2)
VAL=0.00 (MxN)

Example:

```
VAL=0.07
```

Comment:

1. This data is written to the restart file.
2. This data is not written to the card image file.
3. The default value of 0.0 for MxN calculations allows for easy power distribution comparisons to SIMULATE-3. If comparing an MxN power distribution to a single assembly power distribution then the value of 0.07 should be input into the MxN calculation.

SSA Sigma-transport correction for steel in baffle/reflector

SSA	'COPT'

'COPT' 'ON' : Apply sigma transport correction to iron and steel in baffle/reflector.
'OFF' : Do not apply sigma transport correction to iron and steel in baffle/reflector.

Default:

'COPT' = 'ON' for single assembly (REF cases only)
'OFF' for MxN cases

Example:

```
SSA 'OFF'  * Turn OFF steel correction in baffle/reflector
```

Comment:

1. This card controls the application of a correction factor to the transport cross section for iron and steel (isotope IDs= 347 and 26000) in reflector regions of reflector calculations. In single assembly non-reflector cases, this flag has no impact.
2. When running an MxN calculation with user built baffle/reflector segments present, since the code cannot automatically identify these segments as reflector/baffle regions, those particular segments should turn on the SSA correction (the user should include an SSA 'ON' in those particular segments) to be consistent with single assembly results. If the user is using the BAF card instead of manually building the baffle segments, the SSA correction is turned on by default for those segments.

SUM Generate MxN summary file

SUM	COPT

OPT ’OFF’ : No generation of MxN summary file

’ON’ : Generation of MxN summary file

Default:

COPT=’OFF’

Example:

```
SUM ’ON’
```

Comment:

1. This card is valid only for an MxN calculation.
2. This card will generate an ASCII data file which summarizes the MxN calculation. Although the file is ASCII it is not a lot of data (about 1.2 megabytes per statepoint for a full core PWR MxN calculation).
3. The output summary file will be named: **input_basename.sum**, where input_basename is the root part of the input filename (without the .inp).
4. This file is designed to be read by other programs (post-processors) and is not designed to be particularly person readable.
5. The file is divided in blocks delimited by STA and END to facilitate searching by user written post-processing programs.
6. The SUM card should appear in the BAS part of the input.
7. A SUM card with no COPT indicates SUM ’ON’.

2.2 Fuel Storage Rack Input

These cards describe the geometry and compositions of rack regions around a segment.

FSS Fuel Storage Rack Side

(See Figure 2.4 at end of FSS description).

FSS	T_1 /$dx_{1,1}$, $dx_{1,2}$,...$dx_{1,m}$/'$c_{1,1}$', '$c_{1,2}$',... '$c_{1,m}$'/ T_2 /$dx_{2,1}$, $dx_{2,2}$,...$dx_{2,m}$/'$c_{2,1}$', '$c_{2,2}$',... '$c_{2,m}$'/ . . . . T_n /$dx_{n,1}$, $dx_{n,2}$,...$dx_{n,m}$/'$c_{n,1}$', '$c_{n,2}$',...'$c_{n,m}$'// 'l_1',...'l_k' / XSP1, XSP2, TWID $1 \le k \le 4$, $1 \le m \le 40$, $1 \le n \le 10$

T_j	Thickness of $slab_j$ (cm) $1 \le j \le 10$
$dx_{j,i}$	Length of sub-$slab_{j,i}$ (cm) $1 \le j \le 40$ The sum of sub-slab length must be equal to the segment width.
'$c_{j,i}$'	Composition for sub-slab $_{j,i}$
'l_i'	Side position indicator, 'N', 'E' ,'S' or 'W' $1 \le i \le 4$ Note the double slash before 'l_i'
XSP1	Mesh spacing (1 mesh per XSP1 cm) for slabs < TWID cm
XSP2	Mesh spacing (1 mesh per XSP2 cm) for slabs >TWID cm
TWID	Threshold slab thickness in cm to change from mesh spacing XSP1 to XSP2

Default:

T_n:	**None**
'$dx_{j,i}$':	**None**
'$c_{j,i}$':	**None**
'l_i' :	**'N', 'E', 'S', 'W'**
XSP1:	**0.2 (mesh/cm)**
XSP2:	**0.4 (mesh/cm)**
TWID:	**5.0 (cm)**

Comment:

1. This card is to be used in conjunction with the FSC card.

2. For each side, FSS is specified 'as you see it' when the rack is rotated so that the FSS side is located above (north of) the segment. The ordering of slabs, T_j, within FSS is from the outside to the inside (closest to the segment). The sub-slabs, $dx_{j,i}$, are specified from left to right. If the side position indicator is omitted, then the same side description is used for all sides, clock wise rotated around. Up to four FSS cards are allowed, one for each side. The number of slabs (and the thickness) may be different for each side. The number of sub-slabs (and the lengths) may be different for each slab. For each slab, the sum of the sub-slab lengths must be equal to the width of fuel segment (including outer water gaps).

3. Default mesh spacing is recommended. By default, for slabs < 5.0 cm thick, the mesh spacing is one mesh every 0.3 cm, and for slabs > 5.0 cm thick the mesh spacing is one mesh every 0.5 cm. This two level implementation is a provision to reduce the number of mesh in regions where a fine mesh spacing is not important.

4. The following options are set automatically with the FSS/FSC model:
   Fundamental mode: OFF
   Thermal expansion: OFF
   Number of 2D energy groups: 40
   (The default number of 2D groups may be overridden by input of the GRP or CON card as long as 2D and macro groups are the same, e.g. GRP 25 25)

Code Limitations:

1. There is currently a maximum of 10 slabs allowed per side (out from the fuel segment) each of which may be composed of up to a maximum 40 sub-slab lengths. There is a limitation of a maximum of three sub-slab lengths across any one pincell width.

2. The FSS/FSC calculation is mutually exclusive with the following calculations: BUF, CRD, FST, REF, AGR, CLU, HEX, MOVEROD and S3C. Cruciform control rods (CRD) are not permitted in an FSS/FSC model. Library generation with S3C is not supported.

3. **The FSC/FSS model is only supported in full geometry (ISYM=1).**
   However, if the segment data is coming via a restart file (e.g., from a standard depletion), the segment data can be generated in half assembly and the code will expand it out to full geometry (if an appropriate BWR/PWR card with ISYM=1 is present) for the FSS/FSC rack calculation.

4. The macrogroup calculation is not active (and may not be turned on) for any FSS/FSC calculation.

5. FSS/FSC data is not written to the restart file.

6. MOD should be used instead of COO for FSS regions (COO may contain smeared SPA).

Example:

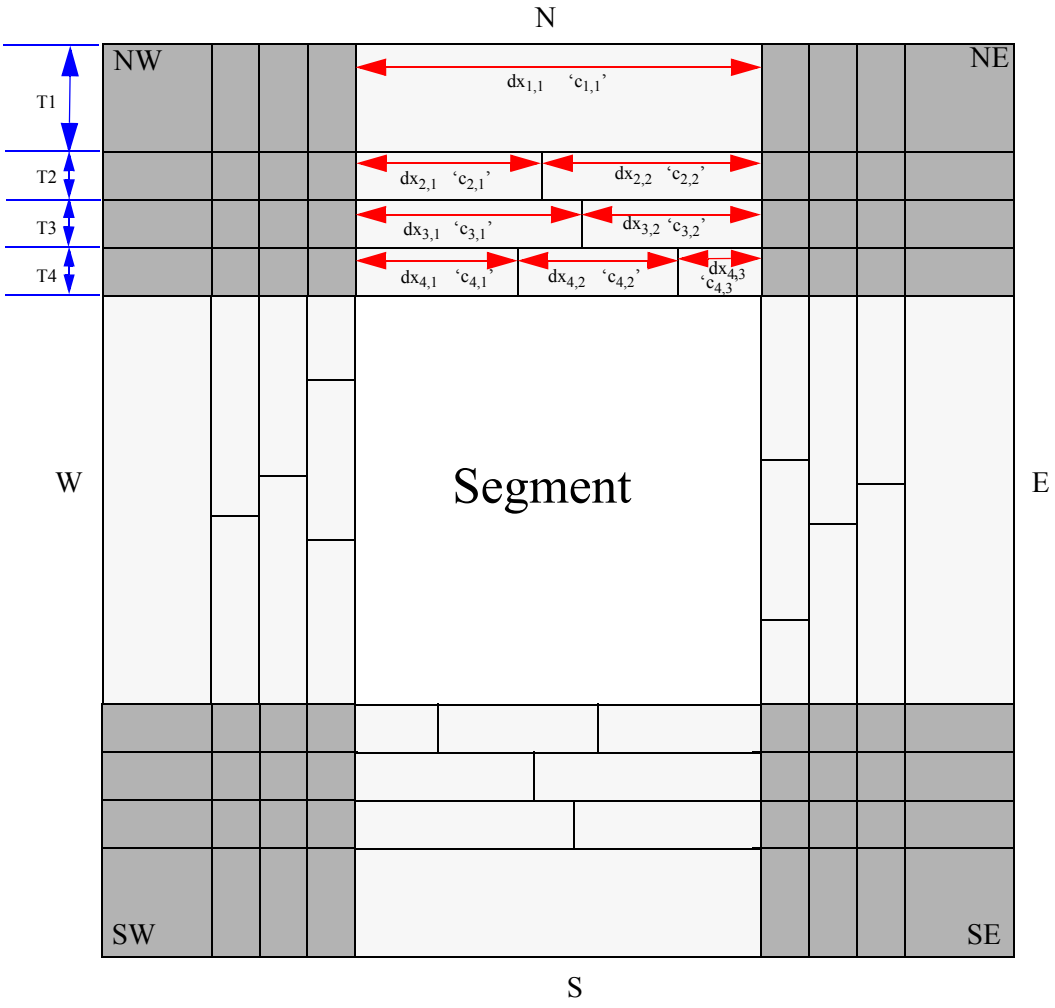
```
* Thickness (cm)/ Sub-slab lengths (cm)        / Sub-slab compositions/
*
FSS  1.5        / 15.25                        / 'MOD' /              * Outermost slab
     0.25       / 2.0 1.5 3.0 2.25 3.0 1.5 2.0 / 'CRC' 'MI2' 'CRC' 'MI2' 'CRC' 'MI2' 'CRC'/
     0.5        / 15.25                        / 'CRS' /
     0.5        / 2.5 10.25 2.5                / 'CRC' 'MI2' 'CRC' /
     0.2        / 15.25                        / 'CRS' /
     0.3        / 2.0 11.25 2.0                / 'CRC' 'MI2' 'CRC' /  * Innermost slab
```

or the equivalent input:

```
* Thickness (cm)/ Sub-slabs
*
FSS  1.5        / 15.25              * Outermost slab
                / 'MOD'
    /0.25       /  2.0   1.5   3.0  2.25   3.0   1.5   2.0
                / 'CRC' 'MI2' 'CRC' 'MI2' 'CRC' 'MI2' 'CRC'
    /0.5        / 15.25
                / 'CRS'
    /0.5        /  2.5  10.25  2.5
                / 'CRC' 'MI2' 'CRC
    /0.2        / 15.25
                / 'CRS'
    /0.3        /  2.0  11.25  2.0   * Innermost slab
                / 'CRC' 'MI2' 'CRC'
```

Fig. 2.4 Specification of FSS/FSC Fuel Storage Rack Geometry

FSS side regions are in light shade, and FSC corners in darker shade. Dimensions and compositions are shown for the 'reference' north FSS region. The other sides are clockwise rotated (default if FSS is not specified for individual sides).



FSC Fuel Storage Rack Corner

(See Figure 2.4 at end of FSS description).

FSC	$'c_{1,1}'$, $'c_{1,2}'$,... $'c_{1,m}'$ $'c_{2,1}'$, $'c_{2,2}'$,... $'c_{2,m}'$ . . . . $'c_{n,1}'$, $'c_{n,2}'$,...$'c_{n,m}'$/ $'P_1'$,...$'P_k'$ / $IROT_1$....$IROT_k$ $1 \le k \le 4$, $1 \le m \le 10$, $1 \le n \le 40$

$'c_{j,i}'$ Composition for corner region j,i

$'P_i'$ Corner position indicator, 'NW', 'NE', 'SE' or 'SW'. $1 \le i \le 4$

$IROT_i$ Clockwise rotation factor(s) to be applied to the input orientation(s):

0 = 0 degrees (as is)
1 = 90 degrees
2 = 180 degrees
3 = 270 degrees

$IROT_i$ refers to the corner defined by position indicator P_i.
Specify $IROT_i$ for each position P_i.

Default:

$'c_{j,i}'$: None

$'P_i'$: **If the corner position indicator is omitted, then data are applied to all corners and rotated appropriately, i.e. the program will automatically add position indicators / rotation factors:**
'NW', 'NE', 'SE', 'SW'/ 0, 1, 2, 3
to the input. See comment 3.

$IROT_i$: **0**

Comment:

1. This card is to be used in conjunction with the FSS card (see additional comments there).

2. FSC only specifies compositions in the corners. The number of corner regions, and the size of the corner regions, are determined by the intersections of the FSS slabs. For example, if the north FSS face has 5 slabs, and the west FSS face has 4 slabs, then the NW corner will have 4*5 = 20 regions. If the number of slabs is different where two sides intersect, then the corner region and the FSC input will be rectangular.

3. If the FSC card is encountered without any corner position indicator, then the input array of compositions is presumed to be in the NW corner, and this array is subsequently rotated as it is positioned in the other corners. If the FSC card is encountered with corner position indicator(s) then it is applied directly as it appears in the input unless the user has specifically requested a rotation via the IROT parameter. This allows the user to specify the corners as they appear in-situ in the problem.

4. MOD should be used instead of COO for FSC regions (COO may contain smeared SPA).

5. This data is not written to the restart file.

Example:

```
* Compositions of fuel storage rack corner as it sits in the NW corner
* and use it for all corners (NW, NE, SE, SW). Code will auto-rotate.
* Matrix is 6x6 since each side has 6 slabs
*
FSC  'MOD' 'MOD' 'MOD'  'MOD'  'MOD' 'MOD'
     'MOD' 'CRC' 'CRC'  'CRC'  'CRC' 'CRC'
     'MOD' 'CRC' 'CRS'  'CRS'  'CRS' 'CRS'
     'MOD' 'CRC' 'CRS'  'CRC'  'CRC' 'CRC'
     'MOD' 'CRC' 'CRS'  'CRC'  'CRS' 'CRS'
     'MOD' 'CRC' 'CRS'  'CRC'  'CRS' 'CRC'
```

CCT Concrete composition

CCT	D, C, T/ID_1= W_1, ..., ID_n= W_n

D	Density of the composition
C	Thermal expansion coefficient
T	Temperature (K)
ID_i	Nuclide identification
W_i	Weight percent of nuclide ID_i

Default:

The program provides the following default as an example of a composition for concrete. The composition is intended to provide scattering and absorption similar to a real concrete mixture.

CCT 2.4 / 1001=0.5 8000=50. 13000=8 14000=39.5 26000=2

See comment below.

Example:

See default above.

Comment:

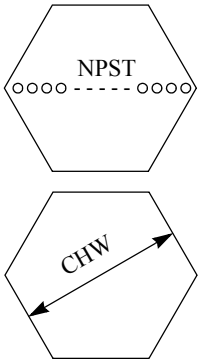
1. **Concrete compositions can vary considerably.** The amount of moisture (hydrogen) and iron in the default is arbitrary, but within a typical range.
2. The default is provided as a matter of convenience to the user. The default should be used only in applications where the concrete composition has very little influence on results, e.g. in a reflector region outside of racks. **The user should define his own composition if more appropriate information about the concrete present in his application is available.**

2.3 Hexagonal Geometry Input

These cards describe the layout and geometry of the hexagonal geometry reactors that can be modeled with CASMO. This model was specifically designed for reactor of VVER-440 and VVER-1000 designs.

HEX Hexagonal geometry option

HEX	NPST, S, CHW, BXW, GAO, ISYM



NPST Number of pins along a diagonal of the bundle

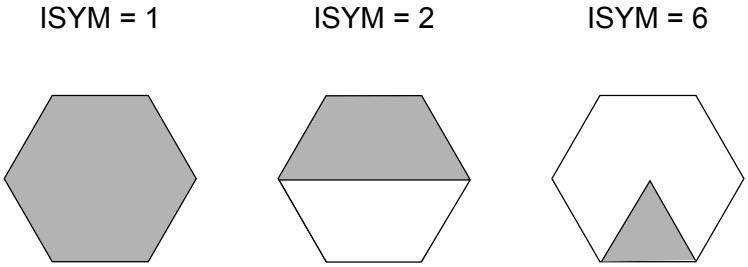
S Pin pitch (triangular pitch)

CHW Inner distance between parallel box walls (VVER 440)
Interassembly pitch (VVER 1000)

BXW The thickness of the box wall (VVER 440)
BXW = 0 for VVER 1000

GAO The thickness of half the outer water gap (VVER 440)
GAO = 0 for VVER 1000

ISYM Symmetry indicator:
1 full bundle
2 half bundle
6 one sixth bundle



Default:

CHW Calculated from number of pins and pin pitch

BXW 0

GAO 0

ISYM 6

Example:

```
* * * Full bundle VVER 440 input
 HEX 13, 1.22  14.0  0.2 0.2  1
*
 LPI                          * Layout of pins
          1 1 1 1 1 1 1
         1 1 1 1 1 1 1 1
        1 1 1 1 1 1 1 1 1
       1 1 1 1 1 1 1 1 1 1
      1 1 1 1 1 1 1 1 1 1 1
     1 1 1 1 1 1 1 1 1 1 1 1
    1 1 1 1 1 1 2 1 1 1 1 1 1
     1 1 1 1 1 1 1 1 1 1 1 1
      1 1 1 1 1 1 1 1 1 1 1
       1 1 1 1 1 1 1 1 1 1
        1 1 1 1 1 1 1 1 1
         1 1 1 1 1 1 1 1
          1 1 1 1 1 1 1
 LFU                          * Layout of FUE
          1 1 1 1 1 1 1
         1 1 1 1 1 1 1 1
        1 1 1 1 1 1 1 1 1
       1 1 1 1 1 1 1 1 1 1
      1 1 1 1 1 1 1 1 1 1 1
     1 1 1 1 1 1 1 1 1 1 1 1
    1 1 1 1 1 1 0 1 1 1 1 1 1
     1 1 1 1 1 1 1 1 1 1 1 1
      1 1 1 1 1 1 1 1 1 1 1
       1 1 1 1 1 1 1 1 1 1
        1 1 1 1 1 1 1 1 1
         1 1 1 1 1 1 1 1
          1 1 1 1 1 1 1
* * *
* * * 1/6 bundle VVER 440 input
 HEX 13, 1.22  14.0  0.2 0.2  6
*
 LPI                          * Layout of pins
             2
            1 1
           1 1 1
          1 1 1 1
         1 1 1 1 1
        1 1 1 1 1 1
       1 1 1 1 1 1 1
```

```
 LFU
              0
             1 1
            1 1 1
           1 1 1 1
          1 1 1 1 1
         1 1 1 1 1 1
        1 1 1 1 1 1 1
* * *
* * * 1/6 bundle VVER 440 Control Cell input
 TTL TFU=300 TMO=300 BOR=600 * VVER-440 CONTROL CELL
 FUE 1  10.28/4.35
 BOX 7.9/347=100
 CRA 7.9/347=98 5000=2
 CAN 5.85
 HEX 13 1.22 14.0 0.2 0.15
*Define the Absorber Cell. Negative values represent hexagonal zones.
*Absorber "rod" occupies all 127 pin cell locations.
 PIN 1 2.0 5.15 5.7 -6.15 -6.85/'CRS' 'COO' 'CRS' 'COO' 'CRA'//127
 PIN 2 0.378 0.455/'1' 'CAN'     * Pin of neighbouring bundle
 LPI 2 27*1           * At least 1 (dummy) fuelled pin needed
*                     * for formal (program) reasons
 BUF 2 8                         * Buffer zone, representing part of
*                                * neighbouring bundle
 STA
* * *
* * * 1/6 bundle VVER 1000 input
 TTL TFU=850 TMO=580 BOR=1000 * VVER-1000 Fuel Assembly
 FUE 1  10.282/2.4
 HEX 21 1.275 23.4 ,,, 6
 PIN 1  0.07 0.378 0.387 0.455/'AIR' '1' 'AIR' 'CAN'
 PIN 2  0.56 0.63/'MOD' 'CRS'
 PIN 3  0.56 0.63/'MOD' 'CRS'
 PIN 3  0.35 0.41 0.56 0.63/'B4C' 'CRS' 'MOD' 'CRS'//1 'RCC' 'ROD'
 LPI       2          * Pin layout (also specifies fuel)
          1 1
         1 1 1
        1 1 3 1
       1 1 1 1 1
      3 1 1 1 1 3
     1 1 1 3 1 1 1
    1 1 1 1 1 1 1 1
   1 1 1 1 1 1 1 1 1
  1 1 1 1 1 1 1 1 1 1
 1 1 1 1 1 1 1 1 1 1 1
```

1. The HEX input card must precede all layout cards (LPI, LFU etc). If not, the execution is aborted with an error message.

PIN Pin geometry

PIN	N, R_1, ..., R_n/'c_1', ..., 'c_n'/m_1, ..., m_n/ C,'pname' 'ROD' $1 \leq n \leq 20$

N — Pin type number $1 \leq N \leq 28$.

R_i — Radii of pin. The thickness of a ring must be ≥ 0.002.
See Example 6 below for a large circular tube and Example 7 for a large square box.
For a square box R_i is half the distance between the flat surfaces of the box.
The zone outside R_n will contain COO.
Enter a negative value for hexagonal zones of a VVER-440 control cell or dummy assembly. For a hexagonal zone R_i is half the distance between the flat surfaces of the hexagon.

'c_i' — Compositions for the pin regions. For fuel compositions use the FUE number.

m_i — Micro meshes between radii R_i and R_{i-1}

C — The pin occupies C pin cells ($C \leq 16$, except for VVER-440 control bundle). C = 1 for normal pins, C = 4 for large C-E rods, C = 3.5 for GE-11 water rods, C = 9 for a circular water rod and C = -9 for a square rod occupying 9 pin cells. For the control bundle or dummy bundle of a VVER-440 reactor, enter the total number of pin cell locations in the bundle (e.g., C=127).

'pname' — Three character identification. The identification is written to the CI file, block TIT, if the pin type is given in the LPI card.
'pname' should normally be blank. It is recommended that control rods are marked by e.g. 'RCC' so that linking codes reading the card image file can separate rodded cases from unrodded. See Example 3 below.
'pname' = 'CRD' or 'CRx' (x is an integer $0 \leq x \leq 9$) activates the program to calculate the control history, ECH, written to block TIT in the CI file. This is of importance only when rodded depletions are made.

'ROD' — A PIN card used to define a control rod must have a 'pname' and be marked 'ROD' if the ROD card is to be used for insertion and withdrawal of rods.
A PIN card marked 'ROD' will only be activated by the ROD card, and it will then replace a previous PIN card with the same pin type number.
Up to four different PIN cards can be marked 'ROD' if they have different 'pname'.

Default:

'c_i' — 'c_1' = 'fuel', 'c_2' = 'CAN ' if n = 2
'c_1' = 'fuel', 'c_2' = 'AIR', 'c_3' = 'CAN' if n = 3
The fuel composition number is determined by the LFU cards.

	All compositions must be given if any of the default values cannot be used.	
$m_1...m_k$	= 10	for fuel with Gd_2O_3
	= 1	for all other regions
C	= 1	
'pname'	blank	

Example:

1. Fuel pin:

```
PIN 1 .50 .55
```

2. Annular fuel pin:

```
PIN 2 .237 .530 .540 .61/'AIR' '1' 'AIR' 'CAN'
```

Defaults can not be used for annular fuel pins.

3. Burnable poison rod in PWR:

```
PIN 4 .20   .23   .24   .43   .44   .48   .56   .60/
   'AIR' 'CRS'  'AIR' 'MI1' 'AIR' 'CRS' 'COO' 'BOX'//1 'BPR'
```

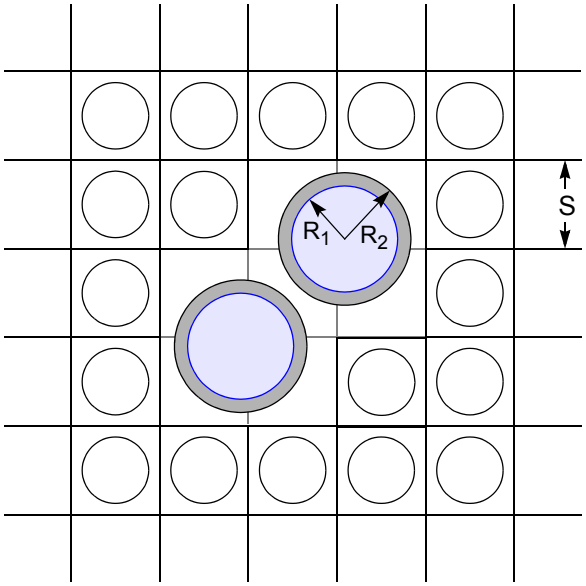
4. Guide tube of ABB/C-E type:

```
PIN 2 1.27 1.37/'MOD' 'BOX'//4
```

5. GE-11 type water rod:

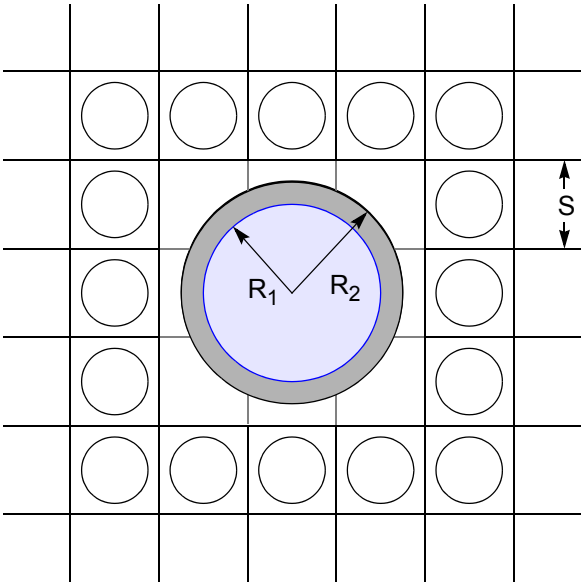
```
PIN 2 1.1 1.2/'MOD' 'BOX'//3.5
```

This design has two large water rods, together occupying 7 pin cells, i.e. 3.5 pin cells each.



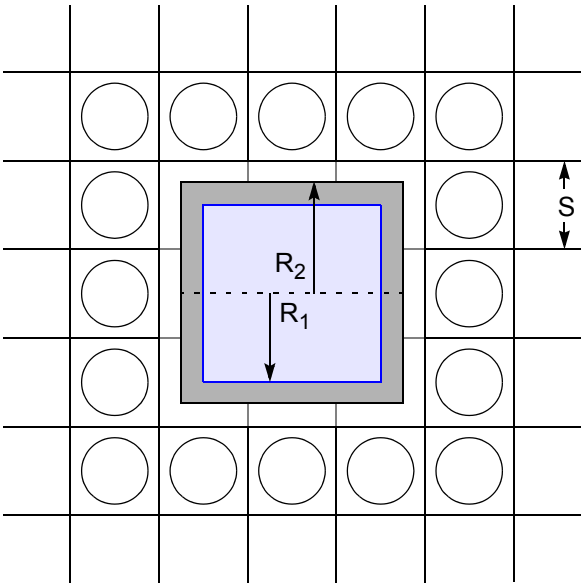
6. Circular tube occupying 9 pin cells.

```
PIN 2 2.0 2.1/'MOD' 'BOX'//9
```



7. Square rod occupying 9 pin cells.

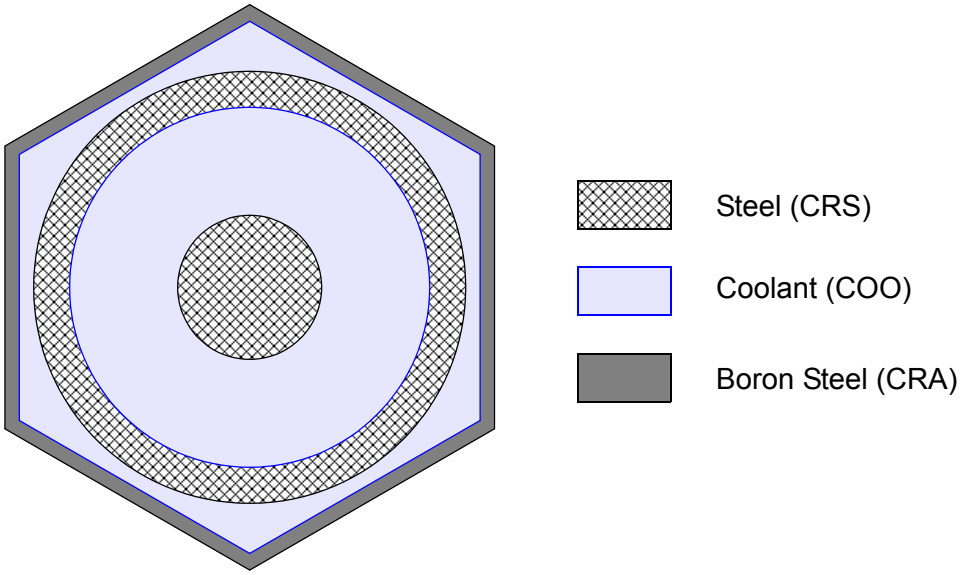
```
PIN 2 2.0 2.1/'MOD' 'BOX'//-9
```



8. Absorber Cell of a VVER-440 Reactor.

```
PIN 1 2.0 5.0 6.0 -6.2 -6.8/'CRS' 'COO' 'CRS' 'COO' 'CRA'//127
```

This design contains 3 inner circular regions and 2 outer hexagonal regions and occupies all pin cell locations in the assembly.



2.4 Cluster/Magnox/AGR Input

These cards describe the layout and geometry of various cluster type reactors that can be modeled with CASMO. Specifically, this includes reactors of the RBMK, CANDU, Magnox, and AGR designs. Modeling these types of reactors also requires the CASMO ENDF/B-VI library.

CLU Cluster specification (RBMK and CANDU)

CLU	R_1, N_1, $NPIN_i$, ..., R_n, N_n, $NPIN_n/R_{n+1}$, ..., R_{n+k}/ 'c_{n+1}', ..., 'c_{n+k}'/ $1 \le i \le n$; $1 \le j \le k$

R_i Radius on which centers of pins in ring i are placed.

N_i Pin type number for pins in ring i (unique for each ring).

$NPIN_i$ Number of pins of type N_i in ring i.

R_{n+j} Outer radius of each region j outside of the final pin ring n.

'c_{n+j}' Composition of each region j outside of the final pin ring n.

Default: Novε

Example:

```
TTL *RBMK EXAMPLE
TFU=800 TMO=400 VOI=40
FUE 1 10.2/2.0
PIN 1 .575 .675/'MOD' 'CAN'
PIN 2 .575 .675/'1' 'CAN'
PIN 3 .575 .675/'1' 'CAN' * keep unique for each ring
CLU 0.0  1  1
    1.6  2  6
    3.2  3 12/
    3.95 4.4 5.7 14.1/'COO' 'BOX' 'MI1' 'MI2'
MI1 1.1,, 623/6001=100 * graphite rings surrounding pressure tube
MI2 2.2,,1023/6001=100 * graphite moderator
PDE 20
THE 0
STA
END
```

For the input example above CASMO will internally create the following additional input cards in order to allow the program to go through its normal calculational sequence.

```
PWR 11  1.60000 ,,,,,,1,2
PIN 51  0.90070  0.90170 /  'BOX' 'CAN'
PIN 52  0.90070  0.90170 /  'MI1' 'CAN'
PIN 53  0.90070  0.90170 /  'MI2' 'CAN'
LPI
 53 53 53 53 53 53 53 53 53 53 53
 53 52 52 52 52 52 52 52 52 52 53
 53 52 51 51 51 51 51 51 51 52 53
 53 52 51  3  3  3  3  3 51 52 53
 53 52 51  3  1  1  1  3 51 52 53
```

```
 53 52 51  3  1  2  1  3 51 52 53
 53 52 51  3  1  1  1  3 51 52 53
 53 52 51  3  3  3  3  3 51 52 53
 53 52 51 51 51 51 51 51 51 52 53
 53 52 52 52 52 52 52 52 52 52 53
 53 53 53 53 53 53 53 53 53 53 53
```

Comments:

1. When CLU is used for an RBMK, the neutron data library must be ENDF-B/VI which contains necessary data for graphite (6001). Below is shown the cluster specified in the input example (approximately to scale, except the outermost circle).

2. CLU cards cannot be stacked.

3. The same PIN number cannot appear in more than one ring (must be unique).

4. A white boundary condition is applied at the edge of the problem.

Fig. 2.5 RBMK Example

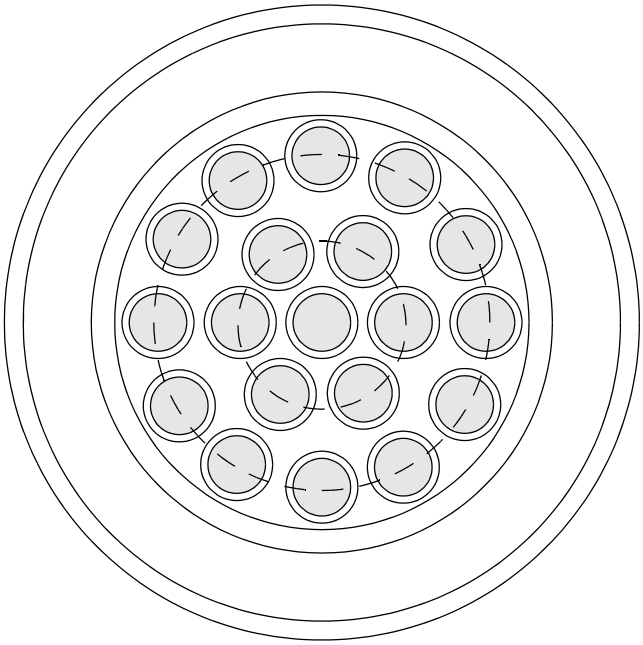
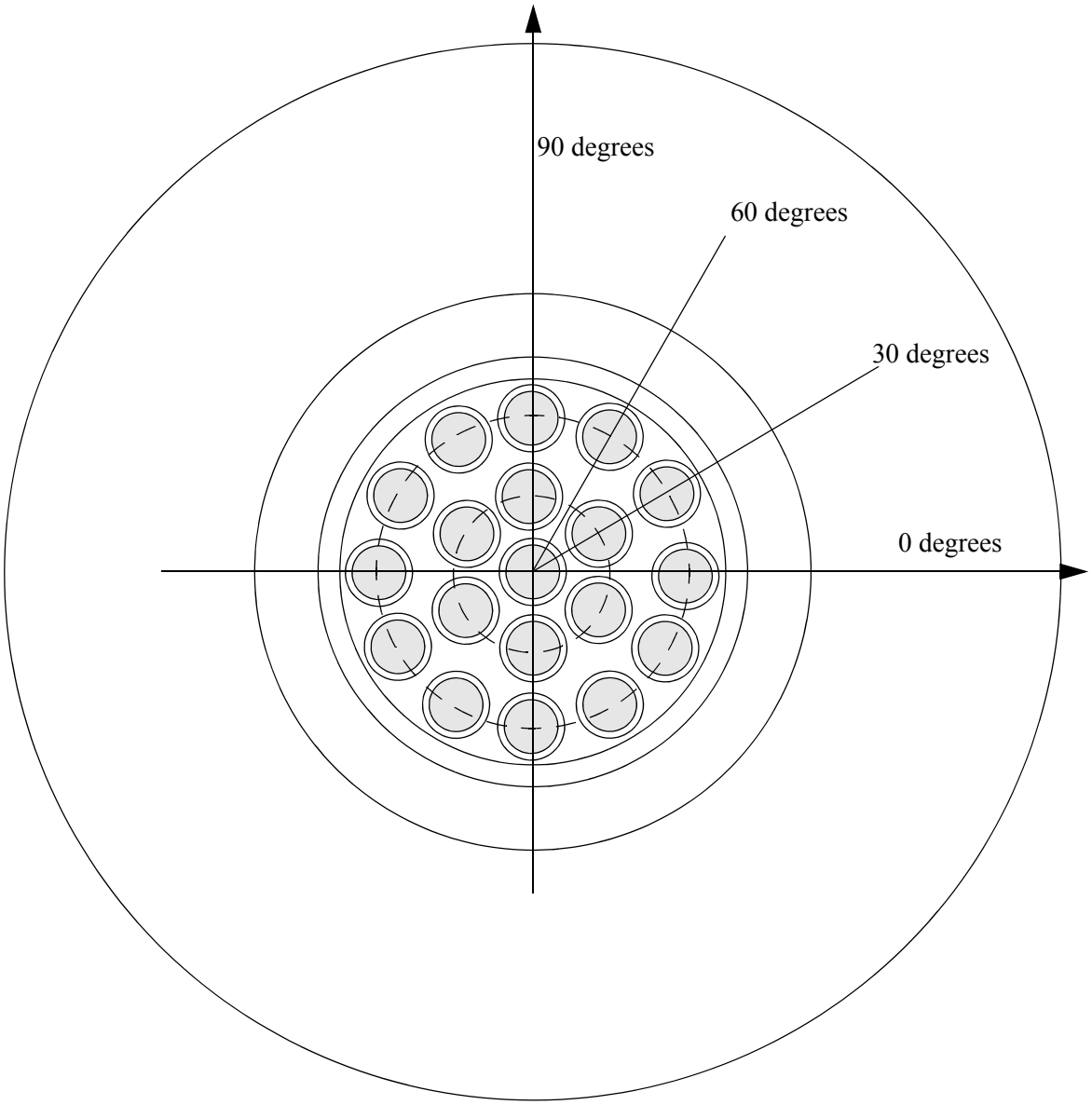


Fig. 2.6 Cluster Geometry



MAG Pin cell for British Magnox fuel rod

MAG	R_1, ..., R_n/'c_1', ..., 'c_n'/m_1, ..., m_n
	$1 \leq n \leq 30$

R_i Outer radius of ring i

'c_i' Compositions for the pin regions. For fuel compositions use the FUE number.

m_i Micro meshes between radii R_i and R_{i-1}.

Default:

'c_i' 'c_1' = 'fuel', 'c_2' = CAN, 'c_3' = COO if n = 3

The MAG card resets the materials AIR, COO, MOD and CAN to the following default values:

```
COO 1.65/6001=100 * Graphite
MOD 1.65/6001=100 * Graphite
CAN 1.74/12000=100 * Magnesium cladding
AIR 0.025/6000=27.2727 8000=72.7273 * CO2 coolant
```

And resets the coefficients used to distribute the U-238 resonance absorptions (card DRI):

```
DRI 1.0, 13.0, -17.0, 0.5
```

Example:

```
MAG 1.5 2.5 5.0 11.0/'1' 'CAN' 'AIR' 'COO'/20, 1, 1, 1
```

Comment:

1. The user should be sure that the cross section library contains both graphite and magnesium.
2. The MAG card functions in a similar way to that of the PIC card, with the exception of the above mentioned default settings.
3. If the MAG card is present, the code will check the fuel composition for the presence of oxygen and, if found, will abort execution. The user may override this fatal error via the ERR card.
4. The outer radius of the pin cell gets converted to a square region with reflective boundaries for the two-dimensional transport calculation. The user should ensure that the value used for the outer radius is chosen appropriately.

AGR Cluster specification for British AGR assembly designs

AGR	R_1, N_1, $NPIN_i$, ..., R_n, N_n, $NPIN_n/R_{n+1}$, ..., R_{n+k}/ 'c_{n+1}', ..., 'c_{n+k}' / $1 \le i \le n$; $1 \le j \le k$

R_i Radius on which centers of pins in ring i are placed.

N_i Pin type number for pins in ring i (unique for each ring).

$NPIN_i$ Number of pins of type N_i in ring i.

R_{n+j} Outer radius of each region j outside pin ring n.

'c_{n+j}' Composition of each region j outside pin ring n.

Default:

The AGR card resets the materials COO and MOD to the following default values:

```
COO 0.0308/6000=27.29 8000=72.71 * CO2
MOD 1.65/6001=100                * Graphite
```

Example:

```
TTL *AGR EXAMPLE
TFU=850 TMO=700
FUE 1 10.4/2.55
PIN 1 .7/'MOD' 'CAN'
PIN 2 .3 .7 .8/'AIR' '1' 'CAN'
PIN 3 .3 .7 .8/'AIR' '1' 'CAN'
PIN 4 .3 .7 .8/'AIR' '1' 'CAN'
AGR 0.0  1   1
    1.6  2   6
    3.2  3  12
    6.0  4  18/
    7.0 8.0 11.0 25.0/'COO' 'MOD' 'COO' 'MOD'
PDE 20
THE 0
. . .
STA
END
```

Comments:

1. The AGR card functions in a similar way to that of the CLU card.
2. AGR cards cannot be stacked.
3. The same PIN number cannot appear in more than one ring (must be unique).
4. A white boundary condition is applied at the edge of the problem.

2.5 Pn-Scattering Input

These cards control the Pn higher order scattering model in CASMO-4E. Use of the Pn-scattering model requires the CASMO ENDF/B-VI advanced data library.

PNO Pn scattering order for advanced data libraries

PNO	IORD

IORD Pn scattering order to use in the forward flux solution (0 through 7)

Default:

IORD=0

Example:

```
PNO 5 * Pn-scattering order set to 5
```

Comment:

1.This card can only be used with E6 data library which contains Pn scattering data.

2. The Pn-scattering calculation requires a unified quadrature for the 2D transport solution and automatically uses the UNQ card defaults. An UNQ card is not required unless the characteristics ray spacing or number of azimuthal angles needs to be refined.

3. The Pn-scattering calculation has not been implemented in diagonal symmetry (IGEOM=2 or 8). If the input is not in full geometry, the code automatically expand the problem to full geometry.

4.The E6 advanced data library contains anisotropic scattering data (matrices) for the following 20 idents: (H in H2O), O, Al, Si, Cr, Mn, Fe, Ni, Zr, Nb, U-235, U-238, Pu-239, Zirc-2, Zirc-4, ZIRLO, stainless steel, Inconel-718, Inconel-750 with Pn data available up to order 7 for most of the idents (the heavy isotopes have data only up to order 5). These idents cover most of the important contributors to higher order scattering.

5. The Pn-scattering model is fully compatible with the S3C option.

6. Use of the Pn-scattering model will be CPU and memory intensive. Some cases may require use of the MEM card to increase the amount of memory available to the job.

7. P3 is generally sufficient in most cases to capture any Pn-effect.

8. This data is not written to the restart file.

9. This card is not normally required.

UNQ Uniform quadrature for 2D transport calculation

UNQ	NAZIM, NPOLAR, XSPACE

NAZIM Number of azimuthal angles

NPOLAR Number of polar angles

XSPACE Ray-spacing (cm)

Default:

NAZIM=32

NPOLAR=3 (=5 for MOX)

XSPACE=0.1 cm

Example:

```
UNQ 128 5 0.05  * 128 azi, 5 polars and 0.05 cm spacing
```

Comment:

1. This card instructs the code to use a unified quadrature in the characteristics based, 2D neutron transport solution (based on the input parameters on the card) rather than the standard 3-level quadrature.
2. All three values must entered on the UNQ card.
3. This card has no effect on the quadrature used in the gamma transport calculation.
4. This card is useful when used in conjunction with the Pn-scattering model where some cases may require refinement of the ray-spacing or number of azimuthal angles.
5. SSP recommends use of the default values. Use of values less than the default values can seriously degrade the accuracy of the 2D transport solution.
6. This card is not normally required.

2.6 Miscellaneous Input

AZI Azimuthal subdivision of pins

AZI	N_1, 'opt$_{11}$', 'opt$_{12}$', .../N_2, 'opt$_{21}$', 'opt$_{22}$', ..

N_i 1, 4 or 8; azimuthal subdivision will be done in 1 (no subdivision), 4 or 8 equal parts of pins of type 'opt$_{ij}$'.

'opt$_{ij}$'
- 'GD' pins containing Gd
- 'B10' pins containing burnable boron (5010)
- 'ER' pins containing Er
- 'ALL' all pins **containing burnable nuclides**

Default:

```
AZI 1 'ALL'
```

Example:

```
AZI 4 'GD'
```

Comment:

The segments are numbered counterclockwise as shown below.

Edits for azimuthal regions can be obtained using the RAD input card.

LAZ Layout of azimuthal subdivision of pins

LAZ	N_1				**or**	N_1	N_2	N_3	-
	N_2	N_3				-	-	-	-
	-	-	-			-	-	-	-
	-	-	-	-		-	-	-	-

N_i 1, 4 or 8; azimuthal subdivision of pin i will be done in 1 (no subdivision), 4 or 8 equal parts.
Specify N_i for each pincell in that part of the bundle for which the calculation will be done according to parameter ISYM on card BWR/PWR.

Default:

N_i = 1

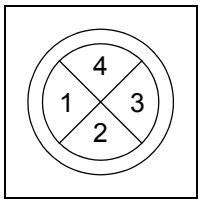
Example:

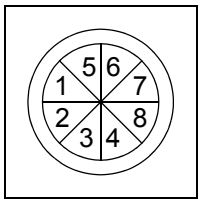
```
LAZ
1
1 1
1 4 1
1 1 1 1
1 8 1 8 1
1 1 1 1 1 1
```

Comment:

A number must be given in each position. Pins **not** containing burnable nuclides (e.g. water holes) will **not** be subdivided irrespective of the value of N_i on the LAZ card.

The segments are numbered counterclockwise as shown below.





Edits for azimuthal regions can be obtained using the RAD input card.

OFF Turn OFF models

OFF	'copt$_1$, 'copt$_2$' ... 'copt$_n$'

'copt$_n$' Any of the following parameters:

'GAD'	Turn off advanced quadratic Gd depletion model (reverts to previous "sub-step" skipping model)
'LEG'	Turn off Legendre polynomials for polar angles integration (reverts to previous cosine**2 weighting model)
'SSA'	Turn off iron and stainless steel correction to transport cross section in baffle/reflector
'RND'	Turn off rounding of input statepoint parameters

Comment:

1. This card is not normally required.

PSC Generate color graphic of geometry

PSC	I1, I2, I3, I4 // XSTRT,YSTRT,SCALE/IFPSC

I1 Drawing data type 0<I1<=2 (in increasing order of spatial resolution)

0: By LFU type (with major materials in separate colors)

1: By X-S set type

2: Flat source regions (smallest spatial sub-division in CASMO)

I2 Azimuthal angle number (0 indicates draw all angles which is generally what the user wants). If I2 is input as a negative number, then reflective counterpart angles are also drawn. (Needed only for special cases).

I3 1: Generate graphic for neutron thermal quadrature

2: Generate graphic for neutron epithermal quadrature

3: Generate graphic for neutron fast quadrature

I4 0: Fullest possible resolution (best picture, largest file size)

1: 600 DPI

2: 300 DPI (smallest file size)

I5 0: COO and MOD different colors of blue in graphic (default)

1: COO and MOD both light blue in graphic

2: COO and MOD both dark blue in graphic

XSTRT X position offset of lower left hand corner of drawing

YSTRT Y position offset of lower left hand corner of drawing

SCALE Multiplicative scale factor for sizing of drawing

IFPSC 0: Generate Tiff format, 1: Generate PostScript Format

Default:

I1=0, I2=0, I3=1, I4=2, I5=0, XSTRT=0.0, YSTRT=0.0, SCALE=1.0, IFPSC=0

Example:

```
PSC
```

Comment:

1. This card is intended primarily for debugging the physical layout of MxN or FSS/FSC geometries. Since the resulting picture is built up from the individual tracks in the characteristics ray-tracing (very low level), this diagram provides an accurate picture of the geometry as actually seen by the 2D transport solution and is very different from picture generation schemes which interpret the input and attempt to draw cylinders and squares etc.
2. The output file is generated in the file: baseinput.name.yy, where yy is ps or tif. (see the PSF card for renaming the file).
3. The generated graphics file may be quite large and the generation of this file does increase run time.
4. The default file format for the generated files is Tiff which will generate a smaller file than the equivalent PostScript file. Both file formats may be viewed by a variety of graphics viewers. SSP does not support or recommend any specific Tiff or PostScript viewers.
5. The picture may be centered on the page through use of XSTRT and YSTRT parameters. (Note, it is possible for the XSTRT and YSTRT to move the generated picture off the page!).
6. Only one graphic will be generated within any one particular run and then only for the first statepoint.
7. It is possible for two adjacent regions to have the same color, i.e., there is no guarantee of spatial color distinctiveness.
8. **The resultant graphics are not intended to be "publication quality" and the capability is provided only to help the user verify the input geometry.**

PSF Filename for PostScript/Tiff graphic

PSF	'FILE_NAME'

FILE_NAME Filename for ray tracing graphic

Default:

The graphic file is generated in the file: baseinput.name.xxx, where xxx may be ps or tif.

Example:

```
PSF 'ge-12.tif' * Name the file ge-12.tif
```

Comment:

1. This card works in concert with the PSC card.

2. The file produced is named exactly as input (no .ps or .tif suffix is automatically applied).

3. This data is not written to restart file or the Card Image File.

QCK Quick execution

QCK	

Example:

QCK

Default: None

Comment:

1. This card runs the input in a greatly reduced spatial and energy detail in order to check the complete mechanics of the run. Specifically, the number of 2D energy groups is set to 4 and the quadrature to: 32 azimuthal angles, 1 polar angle, and a mesh spacing of 0.2 cm. The macrogroup calculation is skipped.
2. **This option is not to be used for analysis as the accuracy of the solution will be severely degraded.**
3. This option can be helpful when setting up large MxN problems.
4. Card image files are not generated during a QCK execution.
5. The following warning is issued when a QCK card is detected:

[WARNING] IN ROUTINE <INP_QCK>. QCK card detected --Do not use results for analysis!!

and at termination:

```
 ******************************
  *  CASMO-4E NORMAL TERMINATION  *
  *      -WARNINGS ENCOUNTERED-    *
 ******************************
 ====>Quick option used ---Results not appropriate for analy-
sis.....
STOP: C-4E Complete....
```

2.7 Input Examples

This section contains complete inputs for typical CASMO-4E applications.

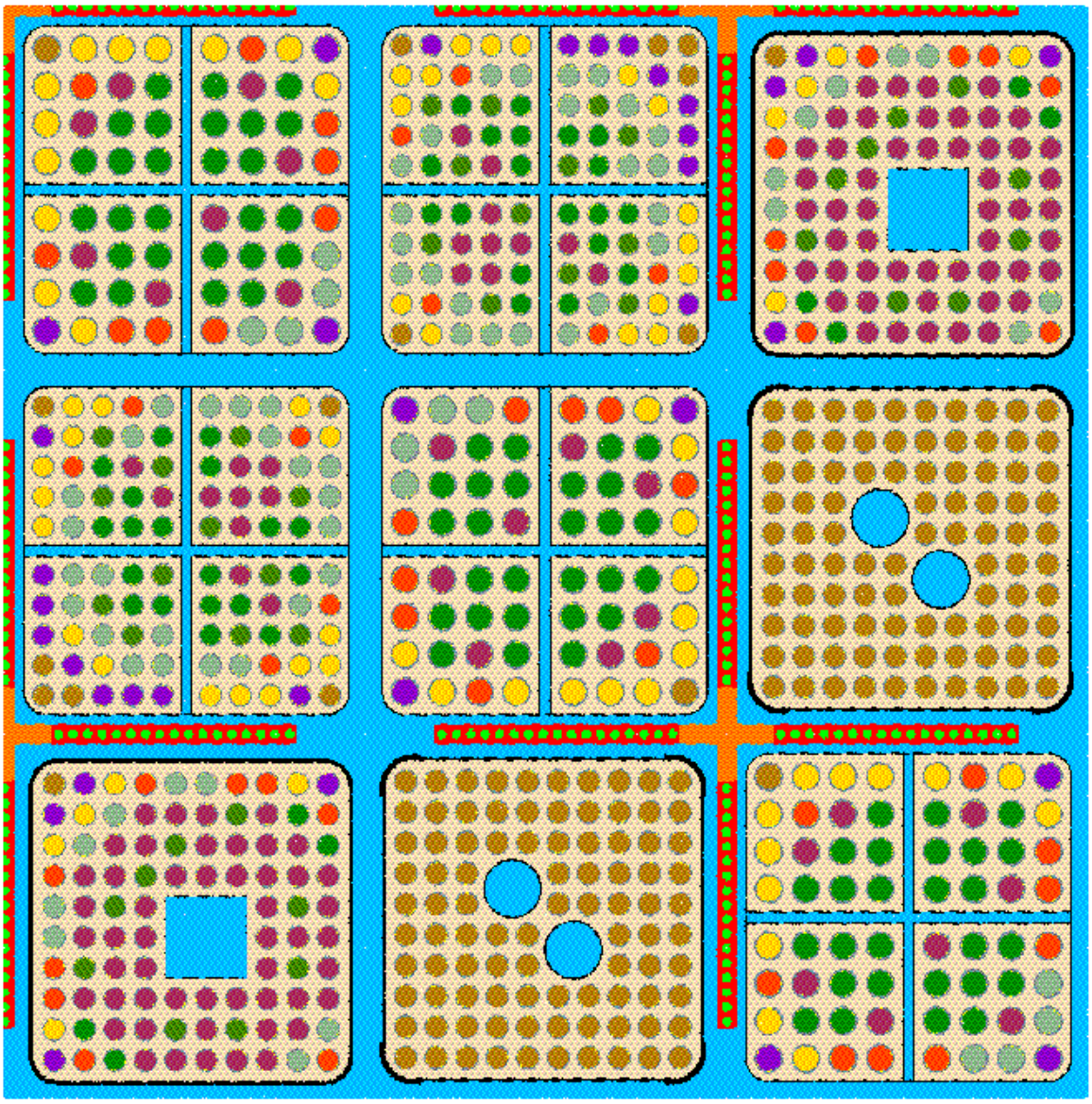
2.8.1 MxN Input Example 1: Mixed 3x3 BWR

Example 1 is a 3x3 lattice of mixed BWR assemblies (see Figure 2.7) depleted to 1.0 GWd/MT and with the gamma calculation active. All dimensions and enrichments are approximate and are merely intended to be representative of normal values.

```
MEM 50 30 30
TTL *Mixed BWR 3x3
MXN 2 * Diagonal Sym.

LSE 3 4 1
    4 3 2
    1 2 3/3 3

LCR 1 1 1
    1 1 1
    1 1 1/'CRD'

BAS
TFU 750 TMO 560
PDE 50.00 'KWL'
CRD 0.415 0 1.98 10.3608 0.2110 0.5756/'CRA' 'CRS'//'CRD','ROD'
DEP -1.0
GAM
* Note: all design numbers are approximate
SEG 1 *Atrium like
BWR 10 1.295 13.40 0.2 1.000 0.5 1.25
PIN 1 0.43 0.44 0.50
PIN 2 1.70 1.75/'MOD','BOX'//-9
PIN 3 0.50     /'COO'
LPI
1 1 1 1 1 1 1 1 1 1
1 1 1 1 1 1 1 1 1 1
1 1 1 1 1 1 1 1 1 1
1 1 1 1 1 1 1 1 1 1
1 1 1 1 2 2 2 1 1 1
1 1 1 1 2 2 2 1 1 1
1 1 1 1 2 2 2 1 1 1
1 1 1 1 1 1 1 1 1 1
1 1 1 1 1 1 1 1 1 1
1 1 1 1 1 1 1 1 1 1
FUE 1 10.314/1.60
FUE 2 10.314/2.10
FUE 3 10.314/2.60
FUE 4 10.314/2.90
FUE 5 10.314/3.20
FUE 6 10.314/3.60
FUE 7 10.314/3.80
FUE 8 10.189/3.30,64016=2.00
LFU
1 2 3 4 5 5 4 4 3 2
2 3 5 7 7 7 8 7 6 4
3 5 7 7 8 7 7 7 7 6
4 7 7 8 7 7 7 7 7 7
5 7 8 7 0 0 0 7 8 7
5 7 7 7 0 0 0 7 7 7
4 8 7 7 0 0 0 7 8 7
4 7 7 7 7 7 7 7 7 7
3 6 7 7 8 7 8 7 7 5
2 4 6 7 7 7 7 7 5 4
SEG 2 *GE-12 like
BWR 10 1.295 13.406 0.135 0.952 0.672 1.308 1 /0.25,3.59
PIN 1 0.44 0.45 0.51
PIN 2 1.17 1.25/'MOD','BOX'//4
PIN 3 0.51     /'COO'
LPI
1 1 1 1 1 1 1 1 1 1
1 1 1 1 1 1 1 1 1 1
1 1 1 1 1 1 1 1 1 1
1 1 1 1 1 2 2 1 1 1
1 1 1 1 1 2 2 1 1 1
1 1 1 2 2 1 1 1 1 1
1 1 1 2 2 1 1 1 1 1
1 1 1 1 1 1 1 1 1 1
1 1 1 1 1 1 1 1 1 1
1 1 1 1 1 1 1 1 1 1
FUE 1 10.450/0.71
LFU
1 1 1 1 1 1 1 1 1 1
1 1 1 1 1 1 1 1 1 1
1 1 1 1 1 1 1 1 1 1
1 1 1 1 1 0 0 1 1 1
1 1 1 1 1 0 0 1 1 1
1 1 1 0 0 1 1 1 1 1
1 1 1 0 0 1 1 1 1 1
1 1 1 1 1 1 1 1 1 1
```

```
1 1 1 1 1 1 1 1 1 1
1 1 1 1 1 1 1 1 1 1
SEG 3 * SVEA-64 Like
BWR 9 1.58 13.74 0.08 0.758 0.642 1.01
PIN 1 0.52 0.53 0.62
SLA 3 0.195 0.076 0.1435/'MOD','BOX'
LPI
1 1 1 1 3 1 1 1 1
1 1 1 1 3 1 1 1 1
1 1 1 1 3 1 1 1 1
1 1 1 1 3 1 1 1 1
3 3 3 3 3 3 3 3 3
1 1 1 1 3 1 1 1 1
1 1 1 1 3 1 1 1 1
1 1 1 1 3 1 1 1 1
1 1 1 1 3 1 1 1 1
FUE 2 10.395/1.4
FUE 3 10.395/1.8
FUE 4 10.395/2.5
FUE 5 10.395/2.8
FUE 6 10.395/3.2
FUE 7 10.395/3.7
FUE 9 10.252/3.0,64016=2.0
LFU
2 4 4 4 0 4 5 4 3
4 5 9 7 0 7 9 7 4
4 9 7 7 0 7 7 7 5
4 7 7 7 0 7 7 9 5
0 0 0 0 0 0 0 0 0
4 7 7 7 0 9 7 7 5
5 9 7 7 0 7 7 7 6
4 7 7 9 0 7 7 9 6
3 4 5 5 0 5 6 6 3
SEG 4  *SVEA-100 Like
BWR 11 1.27 13.74 0.08 0.758 0.642 1.01
SLA 3 0.195 0.076 0.109/'MOD' 'BOX'
PIN 1 0.41 0.42 0.49
LPI
1 1 1 1 1 3 1 1 1 1 1
1 1 1 1 1 3 1 1 1 1 1
1 1 1 1 1 3 1 1 1 1 1
1 1 1 1 1 3 1 1 1 1 1
1 1 1 1 1 3 1 1 1 1 1
3 3 3 3 3 3 3 3 3 3 3
1 1 1 1 1 3 1 1 1 1 1
1 1 1 1 1 3 1 1 1 1 1
1 1 1 1 1 3 1 1 1 1 1
1 1 1 1 1 3 1 1 1 1 1
1 1 1 1 1 3 1 1 1 1 1
FUE 1 10.395/1.6
FUE 2 10.395/2.5
FUE 3 10.395/2.8
FUE 4 10.395/3.3
FUE 5 10.395/3.5
FUE 6 10.395/4.2
FUE 7 10.395/4.7
FUE 8 10.228/4.0,64016=2.0
LFU
1 1 2 2 2 0 3 3 3 2 1
1 2 3 5 5 0 5 5 4 3 3
2 3 5 8 5 0 6 8 6 8 3
2 5 8 6 6 0 6 6 7 5 4
2 5 5 6 8 0 6 7 8 6 5
0 0 0 0 0 0 0 0 0 0 0
3 5 6 6 6 0 8 7 6 6 5
3 5 8 6 7 0 7 7 7 8 5
3 4 6 7 8 0 6 7 7 5 5
2 3 8 5 6 0 6 8 5 4 3
1 3 3 4 5 0 5 5 5 3 1
STA
END
```

Fig. 2.7 Diagram of MxN Input Example 1 (Mixed 3x3 BWR)



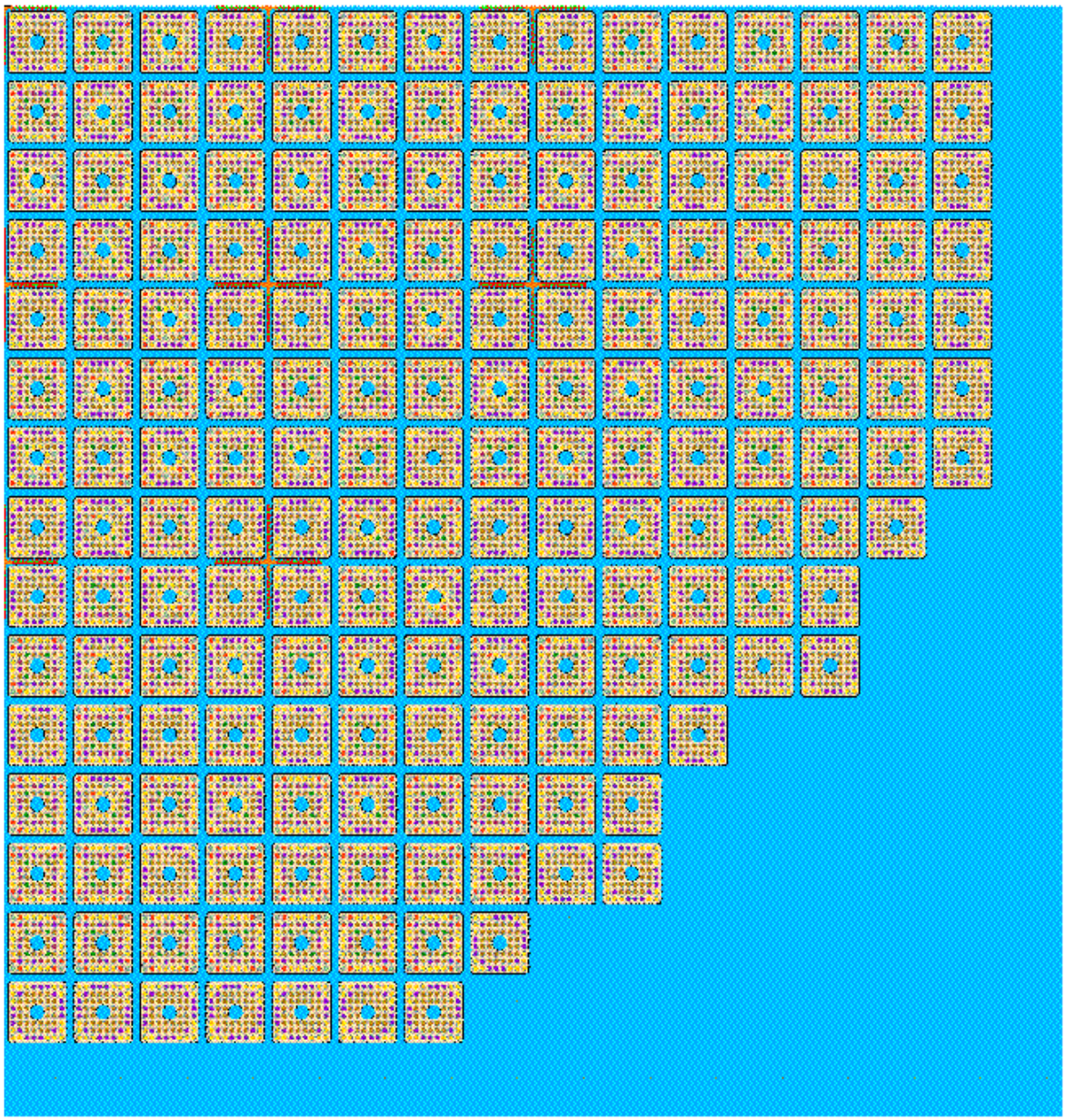
2.8.2 MxN Input Example 2: 1/8 Core BWR Depletion

Example 2 shows a typical input for a 1/8 core BWR calculation. All dimensions and enrichments are approximate and are merely intended to be representative of normal values.

```
MEM 190 80
TTL  * 1/8 BWR Core Calc
MXN  2 * Diagonal Symmetry
* Note: all design numbers are approximate
LSE
    1 3 2 1 1 3 2 1 1 3 1 3 3 3 1 0
    3 2 3 2 3 2 3 2 3 2 3 2 3 3 1 0
    2 3 2 3 2 3 2 3 2 3 1 3 1 3 1 0
    1 2 3 1 1 2 3 1 1 2 3 2 3 3 1 0
    1 3 2 1 1 3 2 1 1 3 1 3 3 3 1 0
    3 2 3 2 3 3 3 2 3 2 3 2 3 3 1 0
    2 3 2 3 2 3 1 3 2 3 1 3 3 3 1 0
    1 2 3 1 1 2 3 1 1 2 3 3 3 1 0 0
    1 3 2 1 1 3 2 1 1 3 3 3 1 0 0 0
    3 2 3 2 3 2 3 2 3 3 3 1 1 0 0 0
    1 3 1 3 1 3 1 3 3 3 1 0 0 0 0 0
    3 2 3 2 3 2 3 3 3 1 0 0 0 0 0 0
    3 3 1 3 3 3 3 3 1 1 0 0 0 0 0 0
    3 3 3 3 3 3 3 1 0 0 0 0 0 0 0 0
    1 1 1 1 1 1 1 0 0 0 0 0 0 0 0 0
    0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0/ 16 16

LRO
    0 1 0 1 0 1 0 1 0 1 0 1 0 1 0 1
    3 2 3 2 3 2 3 2 3 2 3 2 3 2 3 2
    0 1 0 1 0 1 0 1 0 1 0 1 0 1 0 1
    3 2 3 2 3 2 3 2 3 2 3 2 3 2 3 2
    0 1 0 1 0 1 0 1 0 1 0 1 0 1 0 1
    3 2 3 2 3 2 3 2 3 2 3 2 3 2 3 2
    0 1 0 1 0 1 0 1 0 1 0 1 0 1 0 1
    3 2 3 2 3 2 3 2 3 2 3 2 3 2 3 2
    0 1 0 1 0 1 0 1 0 1 0 1 0 1 0 1
    3 2 3 2 3 2 3 2 3 2 3 2 3 2 3 2
    0 1 0 1 0 1 0 1 0 1 0 1 0 1 0 1
    3 2 3 2 3 2 3 2 3 2 3 2 3 2 3 2
    0 1 0 1 0 1 0 1 0 1 0 1 0 1 0 1
    3 2 3 2 3 2 3 2 3 2 3 2 3 2 3 2
    0 1 0 1 0 1 0 1 0 1 0 1 0 1 0 1
    3 2 3 2 3 2 3 2 3 2 3 2 3 2 3 2

LCR
    1 0 0 1 1 0 0 1 1 0 0 0 0 0 0 0
    0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
    0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
    1 0 0 1 1 0 0 1 1 0 0 0 0 0 0 0
    1 0 0 1 1 0 0 1 1 0 0 0 0 0 0 0
    0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
    0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
    1 0 0 1 1 0 0 0 0 0 0 0 0 0 0 0
    1 0 0 1 1 0 0 0 0 0 0 0 0 0 0 0
    0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
    0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
    0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
    0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
    0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
    0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
    0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 /'CRD'

BAS
THE 0
DEP -15.0
PDE 50. 'KWL'
BWR 8 1.6 13.25 0.25 0.75 0.75 1.0
CRD 0.415 0 1.98 10.36 0.21 0.578/’CRA’ ’CRS’//’CRD’,’ROD’
TFU=800.
TMO=560.
VOI=00
PIN 1 0.51 0.61
PIN 2 1.6000 1.7000 / 'MOD' 'BOX' // 4.0
LPI
  1
  1  1
  1  1  1
  1  1  1  2
  1  1  1  2  2
  1  1  1  1  1  1
  1  1  1  1  1  1  1
  1  1  1  1  1  1  1  1

SEG 1
FUE  1 10.494/1.300
FUE  2 10.494/1.300
```

```
FUE  3 10.494/0.710
LFU
  3
  3  2
  3  1  1
  2  1  1  0
  2  1  1  0  0
  2  1  1  1  1  1
  3  2  1  1  1  1  2
  3  3  2  2  2  3  3  3

SEG 2
FUE  1 10.494/2.800
FUE  2 10.494/2.450
FUE  3 10.494/2.100
FUE  4 10.494/1.700
FUE  5 10.250/1.700 7301=4.0
FUE  6 10.250/1.700 7301=4.0
LFU
  4
  3  2
  2  1  6
  2  1  3  0
  2  1  3  0  0
  2  1  1  3  3  4
  3  2  1  5  1  1  2
  4  3  2  2  2  2  3  4

SEG 3
FUE  1 10.494/4.400
FUE  2 10.494/3.900
FUE  3 10.494/3.400
FUE  4 10.494/3.000
FUE  5 10.494/2.100
FUE  6 10.250/3.400 7301=4.0
FUE  7 10.250/3.400 7301=4.0
LFU
  5
  4  2
  3  1  6
  3  2  1  0
  3  7  1  0  0
  3  1  6  1  1  6
  4  2  1  7  2  1  2
  5  4  3  3  3  3  4  5

STA
END
```

Fig. 2.8 Diagram of MxN Input Example 2 (1/8 Core Model)



2.8.3 MxN Input Example 3: 1/4 Core PWR Base Depletion

This particular PWR 1/4 input contains 2 MOX assemblies and demonstrates several features: boron letdown via PVD, exposure dependent TMO values specified by assembly on the LTM card, and also demonstrates how to manually model the PWR baffle (instead of using the BAF card). **All dimensions and enrichments are approximate and are merely intended to be representative of normal values.**

```
MEM 210  60
TTL * MxN PWR depletion Test Case with 2 mox assemblies
MXN 2 1   * Diagonal sym. with axis spanning assemblies
* Note: all design numbers are approximate
LSE 2 1 2 1 2 1 1 4
    1 2 1 2 1 2 1 4
    2 1 2 3 2 1 1 4
    1 2 3 2 1 1 6 5
    2 1 2 1 1 6 5 0
    1 2 1 1 6 5 0 0
    1 1 1 6 5 0 0 0
    4 4 4 5 0 0 0 0 /8 8

LRO 0 0 0 0 0 0 0 3
    0 0 0 0 0 0 0 3
    0 0 0 0 0 0 0 3
    0 0 0 0 0 0 0 0
    0 0 0 0 0 0 0 0
    0 0 0 0 0 0 0 0
    0 0 0 0 0 0 0 0
    0 0 0 0 0 0 0 0

LTM  550 550 550 550 550 550 550 550
     550 550 550 550 550 550 550 550
     550 550 550 550 550 550 550 550
     550 550 550 550 550 550 550 550
     550 550 550 550 550 550 550 550
     550 550 550 550 550 550 550 550
     550 550 550 550 550 550 550 550
     550 550 550 550 550 550 550 550/ 0.0 1.0

LTM  560 560 560 560 560 560 560 560
     560 560 560 560 560 560 560 560
     560 560 560 560 560 560 560 560
     560 560 560 560 560 560 560 560
     560 560 560 560 560 560 560 560
     560 560 560 560 560 560 560 560
     560 560 560 560 560 560 560 560
     560 560 560 560 560 560 560 560/ 1.0 4.0

LTM  565 565 565 565 565 565 565 565
     565 565 565 565 565 565 565 565
     565 565 565 565 565 565 565 565
     565 565 565 565 565 565 565 565
     565 565 565 565 565 565 565 565
     565 565 565 565 565 565 565 565
     565 565 565 565 565 565 565 565
     565 565 565 565 565 565 565 565/ 4.0 30.0

BAS
* Boron Letdown:
PVD 'BOR' 0.000 1200.0
          0.151 1150.0
          0.501 1120.0
          1.001 1100.0
          3.001 1000.0
          6.001  800.0
         10.001  450.0
         14.001  300.0
         16.001  200.0
         20.001  100.0
         25.001   50.0
         35.001   10.0
WRI -100 /'RES'   * Write restart files for each segment as every statepoint
TFU 840
TMO 560
PDE 35.0
```

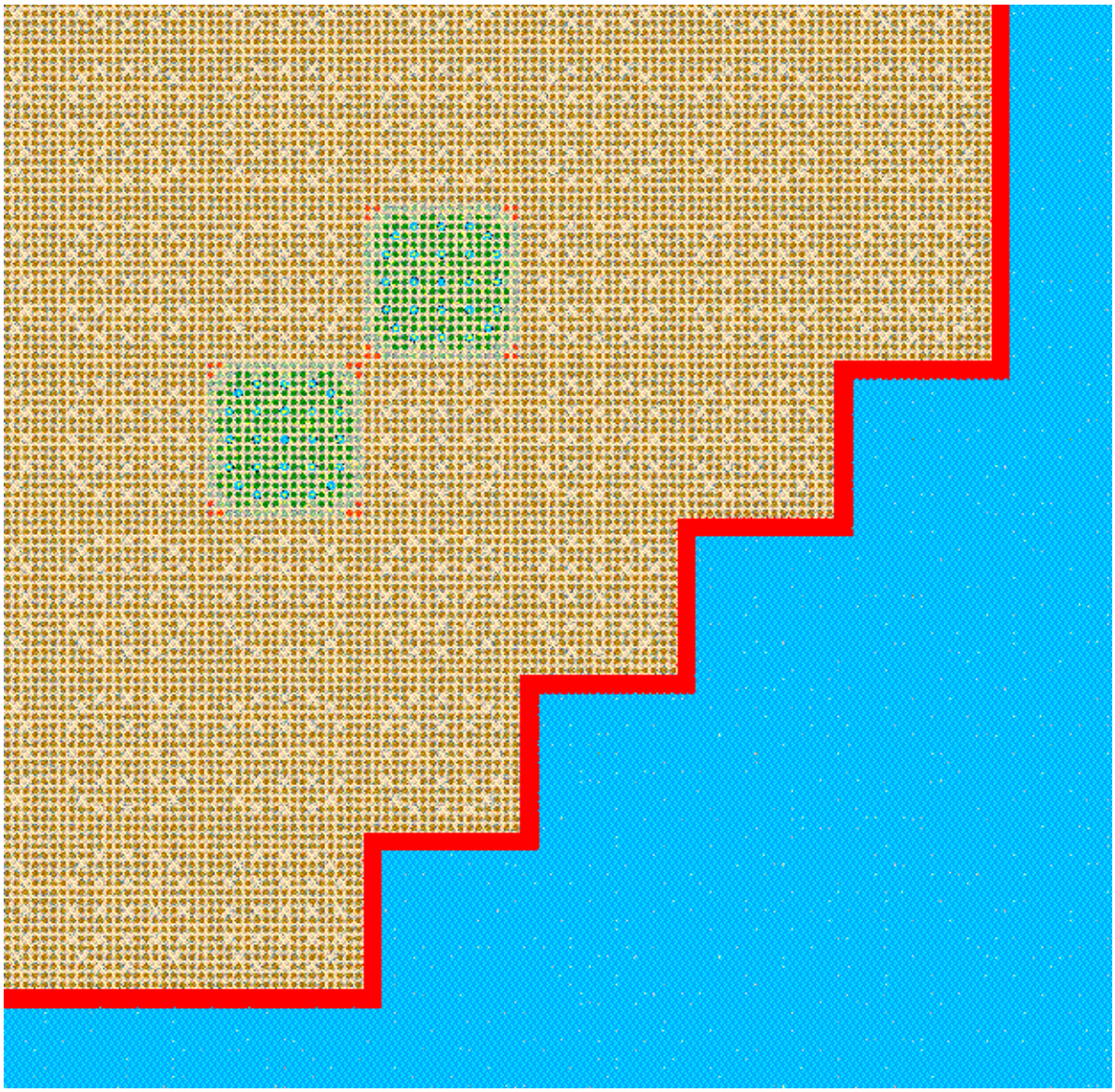
```
THE 0
XEN 2
DEP -20.0
S3I 'ON'

SEG 1    *
PWR 17,1.26,,,,,,1
FUE 1 10.41/3.50
PIN 1 .41 .475/'1' 'CAN'
PIN 2 .57 .615/'COO' 'CAN'
LPI
1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
1 1 1 1 1 2 1 1 2 1 1 2 1 1 1 1 1
1 1 1 2 1 1 1 1 1 1 1 1 1 2 1 1 1
1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
1 1 2 1 1 2 1 1 2 1 1 2 1 1 2 1 1
1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
1 1 2 1 1 2 1 1 2 1 1 2 1 1 2 1 1
1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
1 1 2 1 1 2 1 1 2 1 1 2 1 1 2 1 1
1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
1 1 1 2 1 1 1 1 1 1 1 1 1 2 1 1 1
1 1 1 1 1 2 1 1 2 1 1 2 1 1 1 1 1
1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1

SEG 2 *
PWR 17,1.26,,,,,,1
FUE 1 10.41/2.00
PIN 1 .41 .475/'1' 'CAN'
PIN 2 .57 .615 /'COO' 'CAN'
LPI
1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
1 1 1 1 1 2 1 1 2 1 1 2 1 1 1 1 1
1 1 1 2 1 1 1 1 1 1 1 1 1 2 1 1 1
1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
1 1 2 1 1 2 1 1 2 1 1 2 1 1 2 1 1
1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
1 1 2 1 1 2 1 1 2 1 1 2 1 1 2 1 1
1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
1 1 2 1 1 2 1 1 2 1 1 2 1 1 2 1 1
1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
1 1 1 2 1 1 1 1 1 1 1 1 1 2 1 1 1
1 1 1 1 1 2 1 1 2 1 1 2 1 1 1 1 1
1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1

SEG 3 * Representative Mox assembly with bp
PWR 17,1.26,,,,,,2
MI1,2.23/14000=40.9006,8000=55.2174,5010=0.7182,5011=3.1638
MI2,7.90,18.E-6/347=100
PIN,1,.41,.42,.475
PIN,2,.57,.61/'MOD','BOX'
PIN,3,.57,.61/'MOD','BOX'
PIN,4,.214,.231,.242,.427,.437,.500,.572,.610/
      'AIR','MI2','AIR','MI1','AIR','MI2','MOD','BOX'
FUE,1,10.2/4.0
FUE,2,10.2/0.72,94238=0.05,94239=2.5,94240=1.0,94241=0.3,
                94242=0.15
FUE,3,10.2/0.72,94238=0.075,94239=3.75,94240=1.5,94241=0.45,
                94242=0.225
FUE,4,10.2/0.72,94238=0.1,94239=5.,94240=2.0,94241=0.60,
                94242=0.300
LPI
1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
1 1 1 1 1 4 1 1 4 1 1 4 1 1 1 1 1
1 1 1 4 1 1 1 1 1 1 1 1 1 4 1 1 1
1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
1 1 4 1 1 4 1 1 4 1 1 4 1 1 4 1 1
1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
1 1 4 1 1 4 1 1 2 1 1 4 1 1 4 1 1
1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
```

```
1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
1 1 4 1 1 4 1 1 4 1 1 4 1 1 4 1 1
1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
1 1 1 4 1 1 1 1 1 1 1 1 1 4 1 1 1
1 1 1 1 1 4 1 1 4 1 1 4 1 1 1 1 1
1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1

LFU
2 2 3 3 3 3 3 3 3 3 3 3 3 3 3 2 2
2 3 3 4 4 3 4 4 3 4 4 3 4 4 3 3 2
3 3 4 4 4 0 4 4 0 4 4 0 4 4 4 3 3
3 4 4 0 4 4 4 4 4 4 4 4 4 0 4 4 3
3 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 3
3 3 0 4 4 0 4 4 0 4 4 0 4 4 0 3 3
3 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 3
3 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 3
3 3 0 4 4 0 4 4 0 4 4 0 4 4 0 3 3
3 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 3
3 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 3
3 3 0 4 4 0 4 4 0 4 4 0 4 4 0 3 3
3 4 4 4 4 4 4 4 4 4 4 4 4 4 4 4 3
3 4 4 0 4 4 4 4 4 4 4 4 4 0 4 4 3
3 3 4 4 4 0 4 4 0 4 4 0 4 4 4 3 3
2 3 3 4 4 3 4 4 3 4 4 3 4 4 3 3 2
2 2 3 3 3 3 3 3 3 3 3 3 3 3 3 2 2

SEG 4 * Flat bottom
PWR 17,1.26,,,,,,1
FUE 1 10.41/2.00
PIN 1 0.11 0.12 /'MOD' 'COO' 'MOD'
PIN 2 0.10 0.11 0.12 /'1' 'CAN' 'COO' 'MOD'
PIN 3 0.5 /'CRS' 'CRS'
LPI
3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3
3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3
1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
1 1 1 1 1 1 1 1 2 1 1 1 1 1 1 1 1
1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1

SEG 5 * Notch
PWR 17,1.26,,,,,,1
FUE 1 10.41/2.00
PIN 1 0.11 0.12 /'MOD' 'COO' 'MOD'
PIN 2 0.10 0.11 0.12 /'1' 'CAN' 'COO' 'MOD'
PIN 3 0.5 /'CRS' 'CRS'
LPI
3 3 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
3 3 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
1 1 1 1 1 1 1 1 2 1 1 1 1 1 1 1 1
1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1

SEG 6 * Inside corner
PWR 17,1.26,,,,,,1
FUE 1 10.41/2.00
```

```
PIN 1 0.11 0.12 /'MOD' 'COO' 'MOD'
PIN 2 0.10 0.11 0.12 /'1' 'CAN' 'COO' 'MOD'
PIN 3 0.5 /'CRS' 'CRS'
LPI
3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3
3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3
3 3 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
3 3 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
3 3 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
3 3 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
3 3 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
3 3 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
3 3 1 1 1 1 1 1 2 1 1 1 1 1 1 1 1
3 3 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
3 3 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
3 3 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
3 3 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
3 3 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
3 3 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
3 3 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1

STA
END
```

Comment: In preparation for a shuffle run, restart files were written at every statepoint resulting in approximately 250 megabytes worth of restart files.

Fig. 2.9 Diagram of MxN Input Example 3 (1/4 Core PWR Pre-Shuffle)



Comment: The two MOX assemblies are clearly visibly in this PWR 1/4 case. The Tiff file for this diagram was approximately 49 megabytes and the PostScript file 696 megabytes.

2.8.4 MxN Input Example 4: 1/4 Core PWR Shuffle

In this input, the two MOX assemblies have been shuffled, and two new fresh assemblies placed in the core. All data for the depleted assemblies comes from the CASMO-4E restart files generated by the input given in the previous example (Example 3). This input also demonstrates use of the FIL card to attach the CASMO restart files. Three fresh assemblies have also been inserted. A LEX map could also have been used in this example. **All dimensions and enrichments are approximate and are merely intended to be representative of normal values.**

```
MEM  210  60
TTL * MxN PSSP 10*1
MXN 1 1  * Full symmetry, axis spanning assemblies present
* Note: all design numbers are approximate

LSE 57 58 59 60 61 62 63 64
    49 99 51 52 44 99 55 56
    41 42 43 53 45 46 47 48
    33 34 26 36 37 38 39 40
    25 35 27 28 29 30 31  0
    17 99 19 20 21 22  0  0
    9  10 11 12 13  0  0  0
    1   2  3  4  0  0  0  0 /8 8

LRO 0 0 0 0 0 0 0 3
    0 0 0 0 0 0 0 3
    0 0 0 0 0 0 0 3
    0 0 0 0 0 0 0 0
    0 0 0 0 0 0 0 0
    0 0 0 0 0 0 0 0
    0 0 0 0 0 0 0 0
    0 0 0 0 0 0 0 0

BAS
THE 0
XEN 2
DEP 0.0
S3I 'ON'
PDE 35.0
PVD 'BOR' 0.000 1200.0
          0.151 1150.0
          0.501 1120.0
          1.001 1100.0
          3.001 1000.0
          6.001  800.0
         10.001  450.0
         14.001  300.0
         16.001  200.0
         20.001  100.0
         25.001   50.0
         35.001   10.0
TFU 840
TMO 550
DEP -0.1
S3I '1/4'
PWR 17,1.26,,,,,,1   *Needed for auto-generated reflectors

SEG 1    *
FIL 'pwr.qtr.seg1.res'
RES '*' 10.0

SEG 2    *
FIL 'pwr.qtr.seg2.res'
RES '*' 10.0

SEG 3    *
FIL 'pwr.qtr.seg3.res'
RES '*' 10.0

SEG 4    *
FIL 'pwr.qtr.seg4.res'
RES '*' 10.0
```

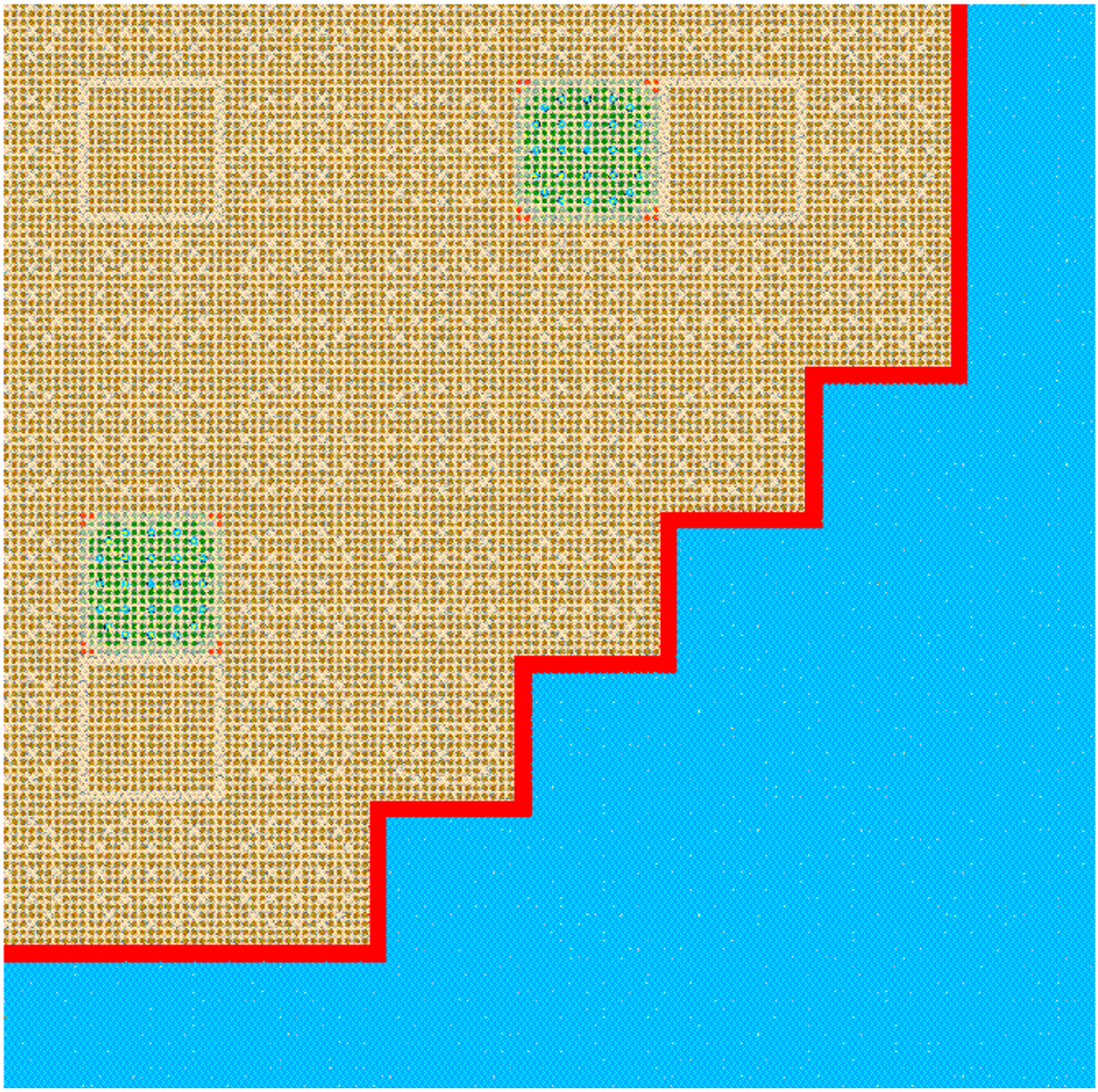
```
SEG 9    *
FIL 'pwr.qtr.seg9.res'
RES '*' 10.0

SEG 10    *
FIL 'pwr.qtr.seg10.res'
RES '*' 10.0

SEG 11    *
FIL 'pwr.qtr.seg11.res'
RES '*' 10.0

SEG 12    *
FIL 'pwr.qtr.seg12.res'
RES '*' 10.0

SEG 13   *
FIL 'pwr.qtr.seg13.res'
RES '*' 10.0

SEG 17   *
FIL 'pwr.qtr.seg17.res'
RES '*' 10.0

SEG 18   *
FIL 'pwr.qtr.seg18.res'
RES '*' 10.0

SEG 19    *
FIL 'pwr.qtr.seg19.res'
RES '*' 10.0

SEG 20   *
FIL 'pwr.qtr.seg20.res'
RES '*' 10.0

SEG 21    *
FIL 'pwr.qtr.seg21.res'
RES '*' 10.0

SEG 22  *
FIL 'pwr.qtr.seg22.res'
RES '*' 10.0

SEG 25    *
FIL 'pwr.qtr.seg25.res'
RES '*' 10.0

SEG 26   *
FIL 'pwr.qtr.seg26.res'
RES '*' 10.0

SEG 27   *
FIL 'pwr.qtr.seg27.res'
RES '*' 10.0

SEG 28   *
FIL 'pwr.qtr.seg28.res'
RES '*' 10.0

SEG 29   *
FIL 'pwr.qtr.seg29.res'
RES '*' 10.0

SEG 30   *
FIL 'pwr.qtr.seg30.res'
RES '*' 10.0

SEG 31   *
FIL 'pwr.qtr.seg31.res'
RES '*' 10.0

SEG 33   *
FIL 'pwr.qtr.seg33.res'
RES '*' 10.0

SEG 34   *
FIL 'pwr.qtr.seg34.res'
RES '*' 10.0
```

```
SEG 35   *
FIL 'pwr.qtr.seg35.res'
RES '*' 10.0

SEG 36   *
FIL 'pwr.qtr.seg36.res'
RES '*' 10.0

SEG 37   *
FIL 'pwr.qtr.seg37.res'
RES '*' 10.0

SEG 38   *
FIL 'pwr.qtr.seg38.res'
RES '*' 10.0

SEG 39   *
FIL 'pwr.qtr.seg39.res'
RES '*' 10.0

SEG 40   *
FIL 'pwr.qtr.seg40.res'
RES '*' 10.0

SEG 41    *
FIL 'pwr.qtr.seg41.res'
RES '*' 10.0

SEG 42   *
FIL 'pwr.qtr.seg42.res'
RES '*' 10.0

SEG 43   *
FIL 'pwr.qtr.seg43.res'
RES '*' 10.0

SEG 44   *
FIL 'pwr.qtr.seg44.res'
RES '*' 10.0

SEG 45   *
FIL 'pwr.qtr.seg45.res'
RES '*' 10.0

SEG 46   *
FIL 'pwr.qtr.seg46.res'
RES '*' 10.0

SEG 47   *
FIL 'pwr.qtr.seg47.res'
RES '*' 10.0

SEG 48   *
FIL 'pwr.qtr.seg48.res'
RES '*' 10.0

SEG 49   *
FIL 'pwr.qtr.seg49.res'
RES '*' 10.0

SEG 50   *
FIL 'pwr.qtr.seg50.res'
RES '*' 10.0

SEG 51   *
FIL 'pwr.qtr.seg51.res'
RES '*' 10.0

SEG 52   *
FIL 'pwr.qtr.seg52.res'
RES '*' 10.0

SEG 53   *
FIL 'pwr.qtr.seg53.res'
RES '*' 10.0

SEG 54   *
FIL 'pwr.qtr.seg54.res'
RES '*' 10.0
```

```
SEG 55   *
FIL 'pwr.qtr.seg55.res'
RES '*' 10.0

SEG 56   *
FIL 'pwr.qtr.seg56.res'
RES '*' 10.0

SEG 57   *
FIL 'pwr.qtr.seg57.res'
RES '*' 10.0

SEG 58   *
FIL 'pwr.qtr.seg58.res'
RES '*' 10.0

SEG 59   *
FIL 'pwr.qtr.seg59.res'
RES '*' 10.0

SEG 60   *
FIL 'pwr.qtr.seg60.res'
RES '*' 10.0

SEG 61   *
FIL 'pwr.qtr.seg61.res'
RES '*' 10.0

SEG 62   *
FIL 'pwr.qtr.seg62.res'
RES '*' 10.0

SEG 63   *
FIL 'pwr.qtr.seg63.res'
RES '*' 10.0

SEG 64   *
FIL 'pwr.qtr.seg64.res'
RES '*' 10.0

SEG 99   * Fresh Assembly
PWR 17,1.26,,,,,,1
FUE 1 10.41/4.00
PIN 1 .4096 .4750/'1' 'CAN'
PIN 2 .5690 .6147/'COO' 'CAN'
LPI
2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2
2 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 2
2 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 2
2 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 2
2 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 2
2 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 2
2 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 2
2 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 2
2 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 2
2 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 2
2 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 2
2 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 2
2 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 2
2 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 2
2 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 2
2 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1 2
2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2 2

STA
END
```

Fig. 2.10 Diagram of MxN Input Example 4 (1/4 Core PWR Post Shuffle)

Comment: The 2 MOX assemblies in this PWR 1/4 case have clearly been shuffled from their previous locations (Example 3) and 3 fresh assemblies have been added (visible as squares in the diagram).



2.8.5 AZI Sample Input

```
TTL TFU=850 TMO=560 VOI=00 * Ex: AZI Option
FUE 1 10.16/2.5
FUE 2 10.16/3.3
FUE 3 10.16/3.5
FUE 4 10.16/4.0
FUE 5 10.16/4.9
FUE 6 10.16/2.2
FUE 7  9.98/2.2   7300=7
LFU 1
    2 7
    3 4 4
    4 5 5 7
    4 7 5 0 0
    4 5 5 5 0 7
    3 4 4 5 5 5 4
    2 7 4 5 7 5 4 7
    1 2 3 4 4 4 3 2 1
AZI 8 'ALL'
BWR 9  1.4300 13.2461 0.3048 0.6921 0.6921 1.2700
PIN 1  0.47 0.48 0.56
PIN 2  0.45 0.46 0.53
PIN 3  0.66 0.69/'MOD' 'CAN'
PIN 4  0.46 0.53/'MOD' 'CAN'
LPI 1
    1 1
    1 1 1
    1 2 2 2
    1 2 2 3 4
    1 2 2 2 3 2
    1 1 1 2 2 2 1
    1 1 1 2 2 2 1 1
    1 1 1 1 1 1 1 1 1
PDE 50 'KWL'
DEP -10
* Edit azimuthal data for Gd
RAD 11 14 17 30 32 39 44/64152 -64160
STA
END
```

2.8.6 LAZ Sample Input

```
TTL TFU=850 TMO=560 VOI=00 * Ex: LAZ Option
BWR 9  1.4300 13.2461 0.3048 0.6921 0.6921 1.2700
FUE 1 10.16/2.5
FUE 2 10.16/3.3
FUE 3 10.16/3.5
FUE 4 10.16/4.0
FUE 5 10.16/4.9
FUE 6 10.16/2.2
FUE 7  9.98/2.2   7300=7
LFU 1
    2 7
    3 4 4
    4 5 5 7
    4 7 5 0 0
    4 5 5 5 0 7
    3 4 4 5 5 5 4
    2 7 4 5 7 5 4 7
    1 2 3 4 4 4 3 2 1
LAZ 1
    1 8
    1 1 1
    1 1 1 8
    1 8 1 1 1
    1 1 1 1 1 8
    1 1 1 1 1 1 1
    1 8 1 1 8 1 1 8
    1 1 1 1 1 1 1 1 1
PIN 1  0.47 0.48 0.56
PIN 2  0.45 0.46 0.53
PIN 3  0.66 0.69/'MOD' 'CAN'
PIN 4  0.46 0.53/'MOD' 'CAN'
LPI 1
    1 1
    1 1 1
    1 2 2 2
    1 2 2 3 4
    1 2 2 2 3 2
    1 1 1 2 2 2 1
    1 1 1 2 2 2 1 1
    1 1 1 1 1 1 1 1 1
PDE 50 'KWL'
DEP -40
STA
END
```

2.8.7 CLU/MAG/AGR Sample Inputs

```
TTL TFU=300 TMO=300 * TEST OF *CLU* APPLICATION
ERR 9
* ENDF-VI library needed
FUE 1  9.54/2.0
MOD 1.695/6001=100
CLU 0.0 1 1
    1.6 2 6/
    2.6 3.0 14.1/'COO' 'BOX' 'MOD'
PIN 1  0.75/'BOX'
PIN 2  0.5915 0.6815/'1' 'CAN'
PIN 3  0.6815/'COO'
STA
END
```

```
TTL TFU=760 TMO=571 * GENERIC MAGNOX PINCELL CALCULATION
*UO2 DENSITY = 18.66G/CC, INITIAL 235U=0.71 WT%
FUE 1 18.66/0.71 92238=99.29 8000=0
MAG 1.406 2.51 5.03 11.12/'1' 'CAN' 'AIR' 'MOD'/10
PDE 20
DEP -10
STA
END
```

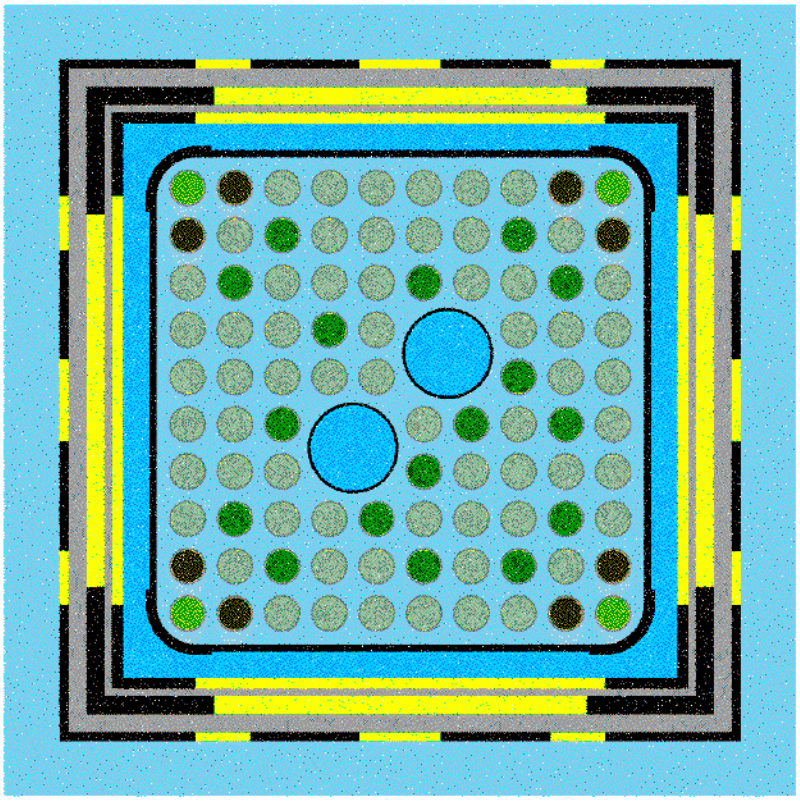
```
TTL *AGR EXAMPLE
TFU=850 TMO=700
FUE 1 10.4/2.55
PIN 1 .7/'MOD' 'CAN'
PIN 2 .3 .7 .8/'AIR' '1' 'CAN'
PIN 3 .3 .7 .8/'AIR' '1' 'CAN'
PIN 4 .3 .7 .8/'AIR' '1' 'CAN'
AGR 0.0  1   1
    1.6  2   6
    3.2  3  12
    6.0  4  18/
    7.0 8.0 11.0 25.0/'COO' 'MOD' 'COO' 'MOD'
PDE 20
THE 0
STA
END
```

2.8.8 FSS/FSC Sample Input

```
MEM 45 10
TTL  * EX: FSS/FSC FUEL STORAGE RACK EXAMPLE
*
* Calculation will be in 40 energy groups, (no macrogroup calc.)
* Thermal expansion will be OFF and fundamental mode calc. will be omitted
*
TFU=920
TMO=560.0
MI2 7.9 / 14000=1.5   24000=18.0  25000=1.0   26000=70.0  28000=9.5
PSC
*
* Describe fuel storage rack side with 6 slabs (and various sub-slabs)
* Description is for the north side and will be used for all sides (N,W,S,E)
*
* Thickness (cm) / sub-slab lengths (cm)         / sub-slab materials/
FSS  1.5         / 15.25                        / 'COO' /   * Outermost slab
     0.25        / 2.0 1.5 3.0 2.25 3.0 1.5 2.0  /
                          'CRC' 'MI2' 'CRC' 'MI2' 'CRC' 'MI2' 'CRC'/
     0.5         / 15.25                          / 'CRS' /
     0.5         / 2.5 10.25 2.5                  / 'CRC' 'MI2' 'CRC' /
     0.2         / 15.25                          / 'CRS' /
     0.3         / 2.0 11.25 2.0                  / 'CRC' 'MI2' 'CRC' /
*
* Describe fuel storage rack corner as it sits in the NW corner
* and use it for all corners (NW,SW,SE,NE) (code will auto-rotate)
* Matrix is 6x6 since each side has 6 slabs
*
FSC  'COO' 'COO' 'COO' 'COO' 'COO' 'COO'
     'COO' 'CRC' 'CRC' 'CRC' 'CRC' 'CRC'
     'COO' 'CRC' 'CRS' 'CRS' 'CRS' 'CRS'
     'COO' 'CRC' 'CRS' 'CRC' 'CRC' 'CRC'
     'COO' 'CRC' 'CRS' 'CRC' 'CRS' 'CRS'
     'COO' 'CRC' 'CRS' 'CRC' 'CRS' 'CRC'
*
* Generic BWR fuel segment
*
FUE 1 10.50/2.5
FUE 2 10.50/3.5
FUE 3 10.50/4.5
FUE 4 10.27/4.5 64016=4.0
LFU 1
    2  3
    3  4  3
    3  3  3  4
    3  3  3  3  3
    3  3  4  0  0  3
    3  3  3  0  0  4  3
    3  4  3  3  4  3  3  3
    2  3  4  3  3  4  3  4  3
    1  2  3  3  3  3  3  3  2  1
```

```
BWR 10 1.3 13.4 0.19 0.74 0.73 1.3 1/0.30 3.9
PIN 1 0.44 0.45 0.51
PIN 2 1.17 1.25/'MOD' 'BOX'//4
LPI 1
    1  1
    1  1  1
    1  1  1  1
    1  1  1  1  1
    1  1  1  2  2  1
    1  1  1  2  2  1  1
    1  1  1  1  1  1  1  1
    1  1  1  1  1  1  1  1  1
    1  1  1  1  1  1  1  1  1  1
PDE 54.0 'KWL'
STA
END
```

Fig. 2.11 FSS/FSC Example



2.8.9 Pn Scattering Sample Input

```
TTL * Ex21, 8x8 BWR WITH GD AND PN ORDER=3
* REQUIRES ADVANCED E6 DATA LIBRARY
TFU=790 TMO=559 VOI=40 IDE='EX21'
SIM 'SEGNAME' 2.74 5.0 4 4 * See note below
PNO 3                     * Set Pn scattering order=3
BWR 8 1.63 13.4 .23 1. .5 1.2
FUE 1 10.15/1.6
FUE 2 10.15/2.3
FUE 3 10.15/3.2
FUE 4 9.98/2.9 64016=5    * 2.9% enr, 5 % GD2O3
SPA 2.22
PIN 1 .53 .54 .61         * Fuel rod
PIN 2 .54 .61/'MOD' 'BOX'  * Water rod
LPI                       * Layout of pins
1
1 1
1 1 1
1 1 1 1
1 1 1 1 2
1 1 1 1 1 1
1 1 1 1 1 1 1
1 1 1 1 1 1 1 1
LFU                       * Layout of FUE
1
1 2
2 2 4
2 3 3 3
2 3 4 3 0
2 3 3 3 3 3
2 2 3 4 3 3 4
1 2 2 3 3 3 2 2
PDE 20                    * Power density
DEP -50
STA
END
```

3 MxN Description

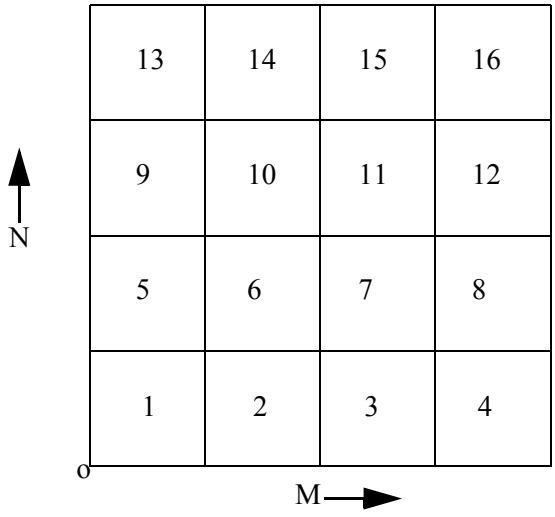
This section describes the MxN module of CASMO-4E for modeling arbitrary arrays of assemblies.

3.1 General Description of MxN Capability

The MxN multi-segment option of CASMO-4E is a general extension of the CASMO 2x2 color set calculation in which an arbitrary array of assemblies may be modeled. In the MxN calculation each assembly may have its own individual design and rotation. Control rods may be inserted in any location and each assembly may be modeled at separate conditions (e.g., fuel temperature, void fraction, etc.). Assemblies may be defined via card input or through the attachment of a restart file, allowing for the placement of depleted assemblies among fresh assemblies. In addition, the MxN calculation provides for the easy inclusion of empty locations, which are filled with material MOD (typically unvoided water). The method of characteristics (MOC) is used to solve for the 2D flux distribution for the entire problem. Furthermore, the full depletion capability of single assembly calculations is available as well as gamma calculations.

The MxN option is based on the assembly grid illustrated in Fig. 3.1. For purposes of clarity, "M" is the number of assembly mesh along the x-axis and "N" is the number of assembly mesh along the y-axis. CASMO-4 segment numbering starts in the lower left hand corner with segment 1 and proceeds left to right and then up. Understanding this numbering scheme is crucial in order to interpret the MxN output as edits and warning messages will frequently reference "Segment N" where N is the segment's location in the background mesh. In 1 below, the MxN layout is a 4x4 array of assemblies (also referred to as segments). The user specifies the segment type residing in each location via the LSE card (see description of input) and the corresponding rotation of each segment via the LRO card. The individual segments are then defined under the SEG cards in a way similar to that used for the standard 2x2 color set option.

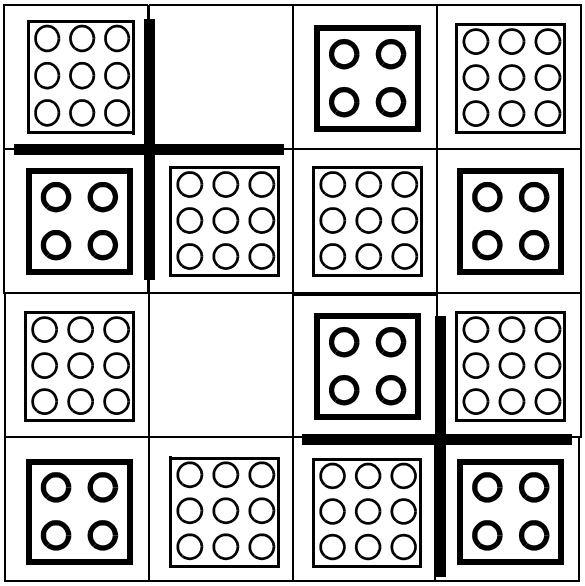
Fig. 3.1 MxN Segment Numbering



Note that the background mesh must align with their neighbors and that this restriction requires that the segments have a common assembly pitch. However, segments may be of completely different designs (e.g., BWR assemblies with differing number of pins may occupy adjacent

segment locations as illustrated in Fig. 3.2.). However, if using the axis spanning assembly option, if an axis spanning assembly has an odd number of pin, then **all axis spanning assemblies must have the same number of pins.**

Fig. 3.2 Placement of Segments into MxN Background Mesh



In this example, there are two different segment designs present in the problem, plus two empty locations. It is not necessary for the user to specifically define the empty segment - CASMO will do that automatically (referred to as "auto-generated reflector segments"). If the user wishes to skew a particular segment to one corner of the background mesh then this may be accomplished by redefining the original segment and using the GAP card to reposition the assembly within the cell. Note that the presence of the control blade does not require the user to re-define segments. Control blades (and control rods of PWRs) may be inserted and withdrawn via the LCR input map.

For square problems exhibiting diagonal symmetry, the user may choose to perform the calculation on only the lower left triangular half of the problem. This reduces the overall size and memory requirements of the calculation and roughly cuts the execution time in half. There are no other symmetry options available for the MxN calculation (e.g., the inner eighth and quarter symmetry options for 2x2 color set PWRs are unavailable for the MxN calculation).

3.2 MxN Methodology

The calculation sequence flows in a manner similar to that of the 2x2 color set calculation. Each segment is processed on an individual basis until the 2D MOC transport module is reached, at which time the complete problem is constructed. Following the 2D calculation, the segments are de-coupled and once again treated on an individual basis for edits and burnup.

More specifically, pin cell calculations (i.e., the micro-group calculation) and the two-dimensional macro group calculation are performed on an individual segment basis. Following the pin cell calculations and two-dimensional macro group calculation, cross sections are condensed to the 2D group structure and the 2D MOC transport calculation is performed on the entire multi-segment problem. It is at this point that the segments are rotated into their proper orientation and placed into the appropriate location. The 2D transport calculation is then performed with the same detail as is used in single segment applications. Also as with the standard 2x2 calculation, the fundamental mode calculation is skipped (FUM,,3). If a gamma calculation has been requested then it is performed at this point before taking any burnup steps.

3.3 MxN Depletion Calculations

The MxN option is capable of performing depletion calculations, however, **stacked depletions are not allowed** (this is also true of the 2x2 color set option). Unlike single segment or 2x2 color set depletion calculations, the MxN option will not generate card image files (cax files) for the segments and will generate restart files only if specifically requested. All MxN problems are depleted using the new SSP proprietary gadolinium-depletion model which has been found to be more accurate and efficient for spatially large problems when compared with fine time-step analysis.

3.4 MxN Boundary Conditions

Either mirror or periodic boundary conditions may be applied to the outer edge of the MxN problem. Rotational symmetry is not available for the MxN calculation (nor for the 2x2 calculation). The periodic boundary condition is applied only during the 2D transport calculation. When performing an MxN calculation, mirror boundary conditions are always used for the two-dimensional macro group calculation.

3.5 Empty Locations: Autogenerated Reflectors

The MxN option makes available the easy modeling of empty assembly locations. CASMO will automatically generate the necessary data for such empty locations and the user does not to define an additional segment type. In such applications, CASMO gathers the necessary information for the empty location from the global data, i.e., input data which exists between the BAS card and the first SEG card. This includes such information as material temperatures, boron content (if any), definition of control rods which might be present in the empty location cell, etc. Users should take care that they define all necessary parameters in the proper location, otherwise, the code may not have enough information to construct the empty location properly. A PWR/BWR card must be present in the BAS input in order for CASMO to properly build an autogenerated reflector segment. Also a TFU and a TMO card must appear in the BAS part of the input.

Data for an auto-generated reflector segment will look something like:

```
SEG   1  *SEGMENT TYPE: 0 POSITION (LSE)    (X,Y) :( 1  1)
FUE 1 0.01/0.1
PIN 1 .4            /'MOD'
PIN 2 .4 .41 .42 .43/'MOD' '1' 'CAN' 'COO' 'MOD'
PWR  17  1.25980  0.00000  0.00000  0.00000  0.00000  0.00000 1 0
LPI 288*2 1  LFU 288*0 1
   LST 1 1 0 SPA 0 VOI 0 PDE 0 MCO 1 1
```

3.6 Using Single Assembly CASMO Restart Files

Restart files generated from single segment depletion analyses may be attached for use in an MxN application, e.g., for interactions between depleted and fresh fuel. For 2x2 color set applications, restart files may be attached via the system JCL (typically the cas4 script) for each of the three or four segments being modeled. For MxN applications this method is impractical, since the number of restart files needed may much greater than 4 and may vary from case to case. To resolve this problem, the FIL card has been created which allows the user to declare the name of the restart file directly within the input deck. To function properly, the FIL card must follow the SEG card and precede the RES card, as illustrated e.g.,

```
TTL * Example of the FIL card
MXN 1
. . .
SEG 1
FIL '../single.assy.depl.res' * attach this file
RES , , 20.0 * at this exposure
. . .
```

Users must also be aware that CASMO can only expand data on a restart file from octant to quarter symmetry or from half to full symmetry. This is true of all CASMO applications, not just the MxN option. Since the MxN option can only accommodate half and full symmetry, all restart files must be generated using at least half symmetry during the single segment depletion analysis. This is irrelevant for BWR applications, but it is important to note for PWR applications, where single segment analyses are typically performed on only an octant of the problem. Therefore it is recommended to run single assembly cases in full geometry if the restart file is to be used in an MxN calculation.

Users should also exercise caution when defining global parameters immediately following the BAS card and prior to the first SEG card (this also applies to the 2x2 option). Any input cards present between the BAS and the first SEG card will overwrite the corresponding data from the restart file. To this end, it is sometimes safer to simply define each segment under its own SEG

card, even though this method may be somewhat more cumbersome to implement than defining global values for all segments under the BAS card.

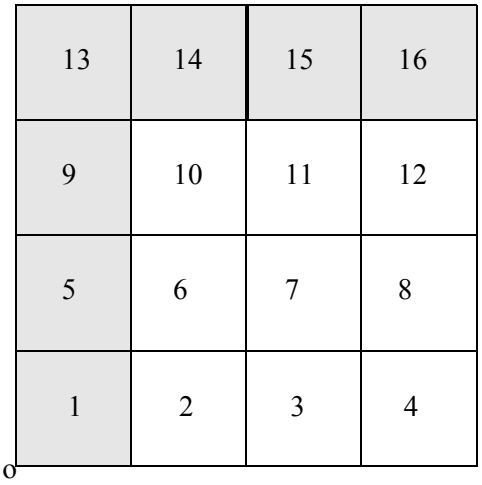
3.7 Boron Letdown During MxN Depletion

Boron letdown during an MxN depletion maybe accomplished through use of a PVD card inserted in the BAS part of the input. The other PVD parameters are available as well, e.g., TFU, TMO, etc. PVD parameters are interpreted in terms of cycle exposure for an MxN calculation.

3.8 Axis Spanning Assemblies

Specially developed for modeling PWR 1/4 cores is the capability to model half assemblies on the north and west major axes ("axis spanning assemblies"). This modeling is applied to both axes simultaneously and hence this capability is limited to 1/4 core (not available for 1/2 core). In the following diagram representing the lower right hand quadrant of a 7x7 core the axis spanning assemblies are shaded. One caveat when using the axis spanning assembly option is that if an axis spanning assembly has an odd number of pin, then **all axis spanning assemblies must have the same number of pins.**

Fig. 3.3 MxN Axis Spanning Assemblies



3.9 MxN Shuffle Capability

It is possible to save CASMO restart files from one MxN calculation for use in a subsequent MxN calculation. If a WRI card is included in the input, e.g., WRI -100/'RES' then restart files will be generated for each segment (except for auto-generated segments). The restart files will be named: inputfile.name.seg1.res, inputfile.name.seg2.res, up to inputfile.name.segN.res. The

segments are numbered according to **position** in the background mesh with segment #1 in the lower left hand corner and proceeding across the bottom row (see Figure 1). Numbers on the SEG card are not used here since they may not be unique in the LSE map. Care must be taken that a job that is going to use the restart files generated in a previous run not overwrite the restart files being read, i.e., the input file name should be different from the run that generated the restart files (or they should be manually re-named).

When restart files are being written from an MxN case they are "marked" with the current cycle exposure and the individual assembly exposures. When reading the restart files back, there is an option on the MXN card (IBUNEXP) which determines whether the restart files are interpreted as being marked with the cycle exposure or assembly average exposure.

Any restart files that are being read, must have been generated with the exact version of CASMO that is reading them (this is true for any CASMO and not specific to CASMO-4E). Also, because CASMO has the tendency to append to previously existing restart files (even if partially written), if an MxN case which writes restart files is prematurely terminated, then the user should make sure to remove any partially written restart files before starting the job again. Otherwise, the job will append to the partially written restart files and this will cause CASMO trouble later when it tries to read these restarts in another job, e.g. shuffle to next cycle.

No MxN data is written to CASMO restart files, so that the entire MxN input section must be present for any cases using restart files. Furthermore, if a fresh fuel segment is being introduced, then it must contain all the data needed for its description, this includes quantities that might typically appear under the BAS segment, in other words the fresh fuel segment is not going to pick up any of that data from the restart files --the segment must stand on its own.

When performing an MxN depletion, the DEP card is in terms of cycle exposure and not core average exposure.

Saving CASMO restart files from a 1/4 core or full core depletion represents a significant amount of information and adequate disk space must be available.

Examples provided later in this document demonstrate a 1/4 core PWR base depletion and a shuffle.

3.10 B.P. Shuffle Model

The CASMO-4E MxN model has the capability to shuffle B.P.'s via the use of CASMO-4E restart files. This includes the ability to shuffle depleted B.P.'s into depleted or fresh assemblies (in addition to the simple requirement of pulling the B.P.

3.11 Shutdown Cooling Calculation

To model long outages or intervals between cycles, the code has the capability to accept a map of shutdown cooling times (in delta days or hours) in the MxN section of the input. The code

will perform an initialization statepoint (limited to 1 iteration) and then performs the shutdown cooling statepoint using a PDE of 1.0E-6, and then proceeds with any normal full power depletion.

3.12 Baffle/Barrel/Pad Automation

The BAF card will relieve the user from having to manually generate baffle/reflector segments around the edge of the problem (and any rotations of said baffle segments). The SSA correction can also be turned ON/OFF for all baffle segments via this card.

If the code is to auto-generate the baffle segments the LSE map must still provide segments (zeroes) for the baffle segments. Zeroes next to fuel will be a baffle segment, zeroes out away from the core will be standard auto-generated reflector segments. A full core LSE map might look like:

```
LSE
0  0  0  0   0   0   0   0   0   0   0   0   0   0   0   0  0
0  0  0  0   0   6   7   6   7   6   7   6   0   0   0   0  0
0  0  0  6   6   9   2  10   1  10   2   9   6   6   0   0  0
0  0  6  8   5   2   4   2   5   2   4   2   5   8   6   0  0
0  0  6  5   1   4   2   3   1   3   2   4   1   5   6   0  0
0  6  9  2   4   4   4   2   4   2   4   4   4   2   9   6  0
0  7  2  4   2   4   1   4   2   4   1   4   2   4   2   7  0
0  6 10  2   3   2   4   2   4   2   4   2   3   2  10   6  0
0  7  1  5   1   4   2   4   1   4   2   4   1   5   1   7  0
0  6 10  2   3   2   4   2   4   2   4   2   3   2  10   6  0
0  7  2  4   2   4   1   4   2   4   1   4   2   4   2   7  0
0  6  9  2   4   4   4   2   4   2   4   4   4   2   9   6  0
0  0  6  5   1   4   2   3   1   3   2   4   1   5   6   0  0
0  0  6  8   5   2   4   2   5   2   4   2   5   8   6   0  0
0  0  0  6   6   9   2  10   1  10   2   9   6   6   0   0  0
0  0  0  0   0   6   7   6   7   6   7   6   0   0   0   0  0
0  0  0  0   0   0   0   0   0   0   0   0   0   0   0   0  0 / 17 17
```

A typical auto-generated baffle segment will look something like:

```
SEG  49  *SEGMENT TYPE: 0 POSITION (LSE)    (X,Y) :(15  3)
PWR  17  1.26000  0.00000  0.00000  0.00000  0.00000  0.00000 1 1
FUE 1 0.01/0.1
PIN 1 .4            /'MOD'
PIN 2 .4 .41 .42 .43/'MOD' '1' 'CAN' 'COO' 'MOD'
PIN 3 0.5 /'CRS' 'CRS'
LPI
 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3
 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3 3
 3 3 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
 3 3 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
 3 3 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
 3 3 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
 3 3 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
 3 3 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
 3 3 1 1 1 1 1 1 2 1 1 1 1 1 1 1 1
 3 3 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
 3 3 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
 3 3 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
 3 3 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
 3 3 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
 3 3 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
 3 3 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
 3 3 1 1 1 1 1 1 1 1 1 1 1 1 1 1 1
```

In this case there is baffle along the left side and the top of the segment. The code can generate up to 12 different appropriate baffle segments (top only, bottom only, left only, right only, left and top, left and bottom, right and top, right and bottom, notch NW corner, notch NE corner, notch SE corner, notch SW corner. The code will build the baffle segment with correct number of pins and pin pitch and uses a baffle three pins thick.

The barrel model simply takes the inner and outer radius of the core barrel and then sweeps through the position of all the pins outside the core. If the center of the pin is between the inner and outer radius of the barrel, that pin will converted to barrel material. This will make a "ragged" model of the barrel on the pin level, but it should be sufficiently accurate for the application. The pad model is constructed similarly. This model can also be used to model BWR ex-core regions.

3.13 MxN Output Edits

Any parameter which can be edited for single segment applications is also available for editing during an MxN calculation. However, users should be aware that most information is edited on a single segment basis. For instance, the magnitude of the flux distribution gets normalized on a per segment basis, rather than on a global basis. To this end, it is sometimes difficult to directly compare edits from one segment against similar edits from other segments because the normalization factor may be different for each segment. However, this does provide the advantage of making comparisons to single assembly calculations much easier. Specifically for MxN calculations, there are some wrap-up edits printed at the conclusion of the calculation which are designed for easy comparison to SIMULATE-3, e.g., 2EXP, 2RPF etc. In order to reduce the size of the output, by default only minimal assembly oriented data is edited during an MxN calculation, however there is a flag on the MXN card to produce more detailed data for each assembly if that level of detail is desired.

3.14 MxN SUMMARY File

A machine readable summary file summarizing the results is produced is a SUM card is present. The file is roughly structured into various blocks which start with STA, and terminate with END. This structure makes it easy to written post-processing programs to extract data from this file.

A typical file MxN summary might look like:

```
CASMO-4E MxN Summary File
-------------------------
Executable file        : \rhodesii\C4QAF\c4.exe
Neutron data library   : /CMSNT/CasLib/library/e4lbl70
CASMO-4E version       : 2.10.00
CASMO-4E creation date : 01/06/12
Execution date (start) : 01/06/19
Execution time (start) : 19:48:18
CPU Time (seconds)     :    254.1
Case Title             : MxN PWR depletion Test Case with 2 mox assemblies
Statepoints            :   1
END=========================================================================================

STA MXN INPUT SUMMARY=======================================================================
   MxN Input maps
END INPUT=================================================================================================



STA STATEPOINT SUMMARY=====================================================================================

Various Scalar Statepoint results
     VOID    TFU    TMO    BOR    CORE AVE.   CYCLE      K-INF
      (%)    (K)    (K)   (PPM)   (MWD/KG)   (MWD/KG)
```

```
 ------------------------------------------------------------
   1  0.0  840.0  560.0      0.0    0.000      0.000    1.27157
END CORE STATEPOINT SUMMARY=============================================================================


STA CORE MAPS===========================================================================================
CORE MAPS STATEPOINT:   1---------------------------------------------------------------------------


STA STATEPOINT SUMMARY==================================================================================
     VOID    TFU    TMO     BOR    CORE AVE.   CYCLE      K-INF
      (%)    (K)    (K)    (PPM)   (MWD/KG)   (MWD/KG)
 ------------------------------------------------------------
   1  0.0  840.0  560.0      0.0    0.000      0.000    1.27157
END CORE STATEPOINT SUMMARY=============================================================================
STA CORE MAPS===========================================================================================

CORE MAPS STATEPOINT:   1---------------------------------------------------------------------------
STA                                                                                          SEGMENT
SUMMARY=================================================================================================
 SEG SP  VOID   TFU    TMO    TCO    BOR ROD   BURNUP   K-INF   K-INF     M2      PIN   U-235 FISS PU  TOT PU MAC KRM  CYC.
                                              MWD/KG             TWO-GROUP     PEAK    WT %    WT %    WT % ITS ITS  EXP.
  9   1  0.0  840.0  560.0  560.0    0.0        0.000 1.36634 1.36471  53.32   1.427   3.500   0.000   0.000   0   7  0.000
 10   1  0.0  840.0  560.0  560.0    0.0        0.000 1.37147 1.36481  53.30   1.576   3.500   0.000   0.000   0   7  0.000
 11   1  0.0  840.0  560.0  560.0    0.0        0.000 1.36808 1.36469  53.16   1.781   3.500   0.000   0.000   0   7  0.000
 17   1  0.0  840.0  560.0  560.0    0.0        0.000 1.37520 1.36489  53.40   1.226   3.500   0.000   0.000   0   7  0.000


END SEGMENT SUMMARY=====================================================================================
STA                             SEGMENT                                                              9
DETAIL==================================================================================================
Detailed pinxpin data by segment and statepoint
SEGMENT   9 XS BLOCK Pos:001,002 Statepoints:   1
      Cyc. Exp. Bun. Exp.     D1        D2       SIGR      SIGA1     SIGA2   SIGNUF1   SIGNUF2   KAPPA/NU
  1    0.000     0.000    1.356571  0.325580  0.017311  0.009918  0.088172  0.007600  0.150556 1.326070E-11/
-------------------------------------------------------------------------------------------------------------------
SEGMENT   9 ADF BLOCK POS:001,002 Statepoint:   1 Cyc. Exp:  0.000 Bun. Exp:  0.000
ADFS, 2 Group XS, Surface Fluxes,
Maps of PinxPin power distribution
Maps of PinxPin exposures

END                             SEGMENT                                                              9
DETAIL==================================================================================================
STA                                  SEGMENT                                                        10
DETAIL==================================================================================================
SEGMENT  10 XS BLOCK Pos:002,002 Statepoints:   1
      Cyc. Exp. Bun. Exp.     D1        D2       SIGR      SIGA1     SIGA2   SIGNUF1   SIGNUF2   KAPPA/NU
  1    0.000     0.000    1.356583  0.325698  0.017315  0.009924  0.088291  0.007606  0.150783 1.326312E-11/
-------------------------------------------------------------------------------------------------------------------
```

Although the file is ASCII, it does not represent a lot of data (about 1.2 megabytes per statepoint for a full core PWR MxN calculation) and file size should not be a problem.

3.15 Maximum MxN Problem Size and Resources

CASMO-4E as delivered is dimensioned to handle a maximum MxN problem size of 20x20 assemblies. To run problems larger than 20x20, the parameter NBUNM needs to be increased and the code recompiled. It should be noted that to run a 17x17 problem in diagonal symmetry requires roughly 1 gigabyte of RAM and approximately 1.5 gigabytes of free disk space. Memory use will of course increase if the number of angles (polar and azimuthal), mesh and/or number of energy groups is greater than default. The **MEM** card which controls the CASMO-4E dynamic memory is required for most MxN applications.

When running large MxN problems it is recommended that the Fortran scratch files (temporary files generated by the job) be placed in the working directory instead of in /tmp (since if /tmp is memory mapped, then the files will compete with the job for system memory). If the /tmp directory is memory mapped, and files are not directed to the working directory, then the machine must have enough memory (RAM) for both the scratch files and the memory required

to run job (typically a combined total of around 2 gigabytes for a 1/4 core calculation). See -T option of the cas4 script.

For very large MxN problems (> 2 gigabytes) executables must be compiled in 64-bit mode.

4 Fuel Storage Rack

This section describes the generalized fuel storage rack capability of CASMO-4E.

4.1 General Description of FSS/FSC Capability

Previous versions of CASMO-3, CASMO-4 and CASMO-4E have included a rudimentary fuel storage rack calculation via the FST card. However, the FST capability is limited in its ability to model modern more complicated rack geometries. The old FST calculation is limited to 16 regions (2 slabs per side and 2 regions in each corner). To extend the capability of CASMO-4E to more general rack geometries, the FSS/FSC fuel storage rack model has been implemented.

The new model allows up to 10 slabs of arbitrary thickness on each side of the segment, each of which may be sub-divided into up to 40 arbitrary lengths and unique compositions. The model is implemented through two new CASMO-4E input cards: FSS (Fuel Storage Side) and FSC (Fuel Storage Corner).

The **FSS card** describes a single "side" of the rack in terms of slabs of various thicknesses, lengths and compositions. These lengths must all sum to the width of the segment (out to, and including the outer gaps). By projecting the slab dimensions out into a corner, the discretization of the corner regions (intersection of two sides) is automatically defined by the intersection of the slabs. The user then simply uses the **FSC card** to specify the compositions of these corner regions. This provides quite a bit more flexibility in terms of geometry than the old FST calculation.

Racks are frequently symmetric. Therefore, the input allows the same FSS/FSC cards to be used for all four sides. However, by providing multiple FSS/FSC cards each side/corner is allowed to be unique.

4.2 Special Features of the FSS/FSC Calculation

The FSS/FSC fuel storage rack model is intended to produce a "high-fidelity" transport solution. The calculation is performed in 40 energy groups (which helps model high energy leakage). The macro-group calculation is not performed, thermal expansion is OFF and the fundamental mode calculation is omitted.

As FSS/FSC cases can be of many different sizes (some small, most large), most FSS/FSC calculations will require the **MEM** (Memory) card to be given as the first card of the input (for example, MEM 50 10). For further discussion of the MEM card see the base CASMO-4 manual.

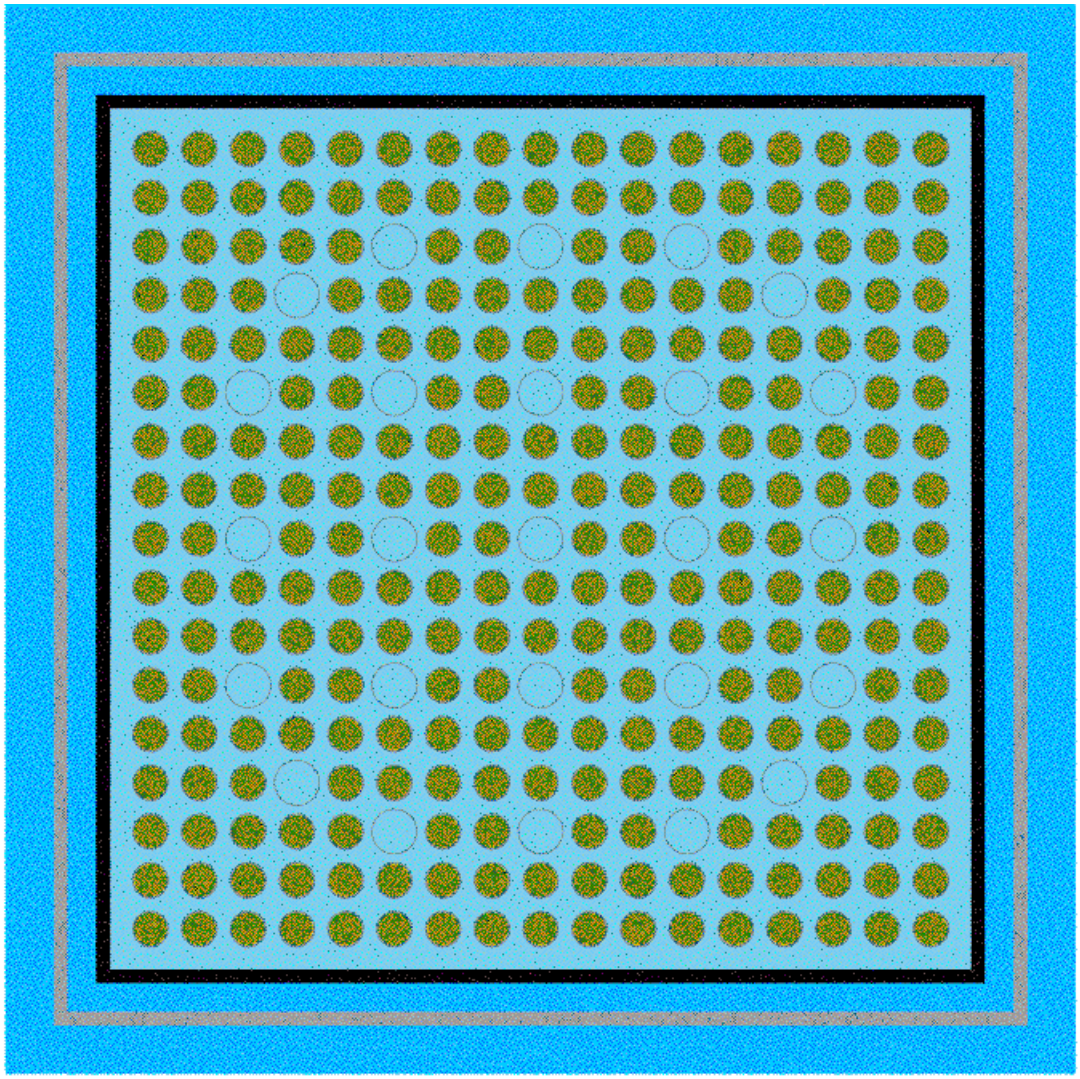
The FSS/FSC model is supported for MxN applications for clients who have the optional MxN (multi-segment) capability.

The user is also recommended to use the **PSC** (color graphic of geometry) card to 'verify' the geometry of the model.

The FSC/FSS model is only supported in full geometry (ISYM=1).

The figure below is an example of a fuel storage racked modeled with FSS/FSC. Note that what looks like a boxwall (the black regions) around the assembly is actually an FSS slab. This is notables since some old FST models actually used boxwall and slab CRD's to model "extra" FST regions. This type of "trick" is no longer necessary with the FSS/FSC fuel storage rack model.

Fig. 4.1 Example FSS/FSC fuel rack model



5 Hexagonal Model Description

This section describes the hexagonal capability of CASMO-4E for analyzing VVER-440 and VVER-1000 type reactors.

5.1 General Description of Hexagonal Capability

CASMO is a multigroup two-dimensional transport theory code for burnup calculations on BWR and PWR assemblies. The HEX option allows CASMO to extend its application to assembly designs of the Russian VVER-440 and VVER-1000 type.

Features of the CASMO hexagonal option are:

- The two-dimensional transport calculation is performed in the heterogeneous geometry using the Method of Characteristics (MOC).
- Gd depletion and other absorber depletions are done automatically within CASMO without the need for auxiliary codes.
- Multi-depletion and coefficient capability for easy generation of complete nuclear data for advanced nodal codes in one execution.

Some programming limitations to the CASMO hexagonal option exist and include:

- Inability to move pins around in the cell, i.e., pins must be centered.
- Colorset (2x2) and MxN is not available for hexagonal geometry.
- Size of the outer water gaps are limited by the pin pitch.
- Inability to model pins which occupy more than one pin cell location.
- Equivalent one-dimensional annular geometry for generating data associated with the absorber control cell of a VVER-440.

The flow of the hexagonal calculation is identical to the program flow for standard CASMO with the exception that no macrogroup calculation is performed.

6 Pn-Scattering Model Description

This section describes the Pn-scattering capability of CASMO-4E.

6.1 General Description of Pn-Scattering Capability

Anisotropic scattering of neutrons in CASMO-4E is normally handled by using a special transport corrected total scattering cross section. This works quite well for single assembly problems (such as those typically run for cross section generation for use in a 3D nodal code), where the flux is relatively isotropic, but for larger problems, e.g., multi-assembly MxN, critical experiments, reflector calculations, or any other problem where neutron leakage is high, the use of a transport corrected scattering cross section may not give sufficiently accurate results. By implementing a higher order scattering model in CASMO-4E one can achieve several goals:

1. It is possible to use a more accurate method directly to calculate neutronic parameters.
2. It is possible to extend the range of problems to which CASMO-4E may be applied, e.g., deep penetration problems.
3. It is possible to estimate the error that is introduced by using transport corrected cross sections.

A theoretically attractive calculational scheme to model anisotropic scattering is to expand the scattering cross sections into a more general sum of Legendre polynomials than that used for the calculation of normal transport corrected scattering cross sections (where only orders of 0 and 1 are used) and extend the method to higher orders, e.g., 2, 3, 4, etc., to form the basis of the "Pn-Scattering model":

$$\sigma_{s,\,tot}{}^{x,\,(E'\rightarrow E,\Omega'\rightarrow\Omega)} = \sum_{l=0}^{\infty} \frac{(2l+1)}{4\pi} \bullet \sigma_{s,\,tot,\,l}{}^{(x,\,E'\rightarrow E)} \bullet P_l(\mu_0)$$

where x is the spatial position, E', W' and E, W are the energy and angular direction of the neutron before and after the scattering process, μ_0 = cosine of the scattering angle, and the P_l's are the Legendre polynomials of order *l*.

The SSP E6 advanced data library contains anisotropic scattering data (matrices) for the following 20 idents: (H in H2O), O, Al, Si, Cr, Mn, Fe, Ni, Zr, Nb, U-235, U-238, Pu-239, Zirc-2, Zirc-4, ZIRLO, Stainless Steel, Inconel-718, Inconel-750 with Pn data available up to order 7 for most of the idents (the heavy isotopes have data only up to order 5). These idents cover most of the important contributors to higher order scattering.

The higher order anisotropic scattering (Pn-model) has been implemented in CASMO-4E uses the Method of Characteristics to solve the 2D Boltzmann transport equation.

This new transport solver uses a unified quadrature (same ray-spacing and number of azimuthal angles and polar angles for all energy groups). However, there are some limitations to the Pn-scattering model as implemented in CASMO-4E:

1. The Pn-scattering model is only implemented in **full geometry** in CASMO-4E.

2. The maximum Legendre order is available is order=7 (this is the current maximum on the neutron data library).

3. A Pn-scattering calculation is a computationally intensive calculation and CPU time and total memory use will be increased when using the Pn-scattering model.

4. Large Pn-scattering problems may require a 64-bit executable.

7 ENDF/B-VI Neutron Data Library

This section describes the ENDF/B-VI neutron data library for CASMO-4E. The following description is applicable for the E60200 data library.

7.1 ENDF-B/VI Overview

A data library based on the evaluated data file ENDF/B-VI has been processed for CASMO-4 and CASMO-4E. The E6LIB data library is based on data from ENDF/B-VI, the evaluated neutron data file developed at the Brookhaven National Nuclear Data Center. In the following, the notation "E6" denotes the ENDF/B-VI library.

The library contains cross sections, decay constants and fission yields for 337 materials, most of which are individual nuclides. Some materials are elements with natural isotopic composition, and cross sections for these were obtained by adding cross sections for the constituent nuclides according to their natural abundance. Other materials, such as construction materials, are mixtures of elements. Cross sections for these materials are obtained by adding the cross sections of the constituent elements, according to the composition of the material.

The program NJOY-94.105, originally from Los Alamos, but with Studsvik Scandpower modifications, was used to generate the library into the CASMO format. Other Studsvik Scandpower programs were then used to calculate cross sections for complex materials, and to extract and handle decay constants and fission yields.

Microscopic cross sections are tabulated in 70 energy groups. The energy group structure is shown in Table 7.1 and is the same as the standard 70 group, SSP L-library. This group structure fulfills the following requirements:

- The 14 fast groups give enough detail in the fast energy region to calculate the leakage and fast fission accurately.
- The 13 resonance groups (down to 4.0 eV) provide correct flux levels as a function of energy for the calculation of resonance absorption. Some nuclides have "extended" resonance data down to 0.625 eV (an additional 19 groups for 32 total resonance groups).
- The 43 thermal groups (below 4 eV, which is the cut off for up-scattering) make the thermal cross sections independent of the weighting spectrum used for their generation. Groups are concentrated around the 0.3 eV resonance in Pu-239 and the 1 eV resonance in Pu-240.

The E6 library contains absorption, fission, nu*fission, transport and scattering cross sections. Data are tabulated as functions of temperature when needed. Shielded resonance integrals versus effective potential background cross section and temperature are tabulated for resonance absorbers.

The E6 library further contains decay constants for fission products and heavy nuclides, and fission product yield values. The structure of the fission product representation determines whether independent or cumulative yield shall be used for each fission product. The selected structure and yield values give yield sums for each fission precursor very close to 2.0.

Nuclides are identified by a five digit (or less) **ID**, which in general is chosen such that the **first digit(s) are equal to the atomic number of the nuclide and the last three digits show the isotope number**. Three zeros (000) are used in the place of the isotope number for elements of natural composition. Nuclides, elements, compositions and artificial nuclides are identified by the ID numbers as shown in Table 7.2. In some instances the reader is referred to special comments following the table. The temperatures at which each ID is evaluated are given in Table 7.7.

Table 7.1 Group Boundaries for the ENDF/B-VI Library

Group	Upper energy boundary	Energy Width	Lethargy Width
1	10.0 **MeV**	3.9345 **MeV**	0.49997
2	6.0655	2.3865	0.49998
3	3.679	1.448	0.50019
4	2.231	0.878	0.50013
5	1.353	0.532	0.49956
6	0.821	0.321	0.49592
7	0.500	0.1975	0.50253
8	0.3025	0.1195	0.50260
9	0.183	0.072	0.49996
10	0.1110	0.04366	0.49978
11	0.06734	0.02649	0.49985
12	0.04085	0.01607	0.49987
13	0.02478	0.00975	0.49999
14	0.01503	0.005912	0.49980
15	9118.0 **eV**	3588.0 **eV**	0.50006
16	5530.0	2010.9	0.45198
17	3519.1	1279.65	0.45198
18	2239.45	814.35	0.45199
19	1425.1	518.202	0.45197
20	906.898	539.636	0.90395
21	367.262	218.534	0.90396
22	148.728	73.2266	0.67797
23	75.5014	27.4494	0.45187
24	48.052	20.352	0.55085
25	27.700	11.732	0.55085
26	15.968	6.091	0.48038
27	9.877	5.877	0.90391
28	4.00	0.700	0.19237
29	3.30	0.700	0.23841
30	2.60	0.500	0.21357
31	2.10	0.245	0.12405
32	1.855	0.355	0.21242
33	1.50	0.200	0.14310
34	1.30	0.150	0.12260
35	1.150	0.027	0.02376
36	1.123	0.026	0.02342
37	1.097	0.026	0.02399

Table 7.1 Group Boundaries for the ENDF/B-VI Library

Group	Upper energy boundary	Energy Width	Lethargy Width
38	1.071	0.026	0.02458
39	1.045	0.025	0.02421
40	1.020	0.024	0.02381
41	0.996	0.024	0.02439
42	0.972	0.022	0.02289
43	0.950	0.040	0.04302
44	0.910	0.060	0.06821
45	0.850	0.070	0.08594
46	0.780	0.155	0.22154
47	0.625	0.125	0.22314
48	0.500	0.100	0.22314
49	0.400	0.050	0.13353
50	0.350	0.030	0.08961
51	0.320	0.020	0.06454
52	0.300	0.020	0.06899
53	0.280	0.030	0.11333
54	0.250	0.030	0.12783
55	0.220	0.040	0.20067
56	0.180	0.040	0.25131
57	0.140	0.040	0.33647
58	0.100	0.020	0.22314
59	0.080	0.013	0.17733
60	0.067	0.009	0.14425
61	0.058	0.008	0.14842
62	0.050	0.008	0.17435
63	0.042	0.007	0.18232
64	0.035	0.005	0.15415
65	0.030	0.005	0.18232
66	0.025	0.005	0.22314
67	0.020	0.005	0.28768
68	0.015	0.005	0.40547
69	0.010	0.005	0.69315
70	0.005	0.005	

Shading indicates the resonance groups (lighter shading indicates the extended resonance groups).

Table 7.2 Nuclides for the ENDF/B-VI Library

ID	Description	Reson. Data	XS Model	# Temps	Pn Data	File 5 Data	Com-ment
1	1/v absorber	No	Absorption only	1	No	No	4
2	Unit absorber	No	Absorption only	1	No	No	4
3	Unit scatterer	No	Full set	1	No	No	4
302	Zircaloy-2	No	Full set	4	Yes	No	3
304	Zircaloy-4	No	Full set	4	Yes	No	3
306	Nb-added Zy-4	No	Full set	4	Yes	No	3
347	Stainless steel	No	Full set	2	Yes	No	2
718	Inconel-718	No	Full set	2	Yes	No	2
750	Inconel-750	No	Full set	2	Yes	No	2
1001	H	No	Full set	6	Yes	No	
1002	D	No	Full set	5	No	No	
1107	H in ZrH	No	Full set	6	No	No	10
2003	He-3	No	Full set	1	No	No	
3000	Li	No	Full set	1	No	No	
4000	Be-9	No	Full set	2	No	No	
5000	B	No	Full set	2	No	Yes	1
5010	B-10	No	Full set	2	No	Yes	1
5011	B-11	No	Full set	2	No	No	1
6000	C	No	Full set	4	No	No	
6001	Graphite	No	Full set	6	No	No	
7000	N	No	Full set	1	No	No	
8000	O	No	Full set	8	Yes	No	
9000	F	No	Full set	1	No	No	
11000	Na	No	Full set	1	No	No	
12000	Mg	No	Full set	2	No	No	
13000	Al	No	Full set	2	Yes	No	
14000	Si	No	Full set	2	Yes	No	
15000	P	No	Full set	1	No	No	
16000	S	No	Full set	1	No	No	
17000	Cl	No	Full set	1	No	No	10
19000	K	No	Full set	1	No	No	
20000	Ca	No	Full set	1	No	No	
23000	V	No	Absorption only	2	No	No	
24000	Cr	No	Full set	2	Yes	No	
25000	Mn	No	Full set	2	Yes	No	
26000	Fe	No	Full set	2	Yes	No	
26054	Fe-54	No	Full set	4	No	Yes	

Table 7.2 Nuclides for the ENDF/B-VI Library

ID	Description	Reson. Data	XS Model	# Temps	Pn Data	File 5 Data	Com-ment
26055	Fe-55	No	Yield/Decay only	1	No	Yes	7
27059	Co-59	No	Full set	1	No	No	
28000	Ni	No	Full set	2	Yes	No	
28058	Ni-58	No	Full set	2	No	No	
28062	Ni-62	No	Full set	2	No	No	
29000	Cu	No	Full set	1	No	No	
29063	Cu-63	No	Absorption only	1	No	No	
30064	Zn-64	No	Absorption only	1	No	No	
31000	Ga	No	Full set	2	No	No	
32000	Ge	No	Absorption only	1	No	No	
32076	Ge-76	No	Absorption only	1	No	Yes	
32077	Ge-77	No	Yield/Decay only	1	No	Yes	7
33000	As	No	Absorption only	1	No	No	
33077	As-77	No	Yield/Decay only	1	No	Yes	7
34000	Se	No	Absorption only	1	No	No	
34077	Se-77	No	Absorption only	1	No	Yes	
34078	Se-78	No	Absorption only	1	No	Yes	
34079	Se-79	No	Yield/Decay only	1	No	Yes	7
34080	Se-80	No	Absorption only	1	No	Yes	
34081	Se-81	No	Yield/Decay only	1	No	Yes	7
34082	Se-82	No	Absorption only	1	No	Yes	
34083	Se-83	No	Yield/Decay only	1	No	Yes	7
35081	Br-81	No	Absorption only	1	No	Yes	
35082	Br-82	No	Yield/Decay only	1	No	Yes	7
35083	Br-83	No	Yield/Decay only	1	No	Yes	7
36082	Kr-82	No	Absorption only	1	No	Yes	
36083	Kr-83	No	Absorption only	4	No	Yes	
36084	Kr-84	No	Absorption only	1	No	Yes	
36085	Kr-85	No	Absorption only	1	No	Yes	
36086	Kr-86	No	Absorption only	1	No	Yes	
36087	Kr-87	No	Yield/Decay only	1	No	Yes	7
36985	Kr-85m	No	Yield/Decay only	1	No	Yes	7
37085	Rb-85	No	Absorption only	1	No	Yes	
37087	Rb-87	No	Absorption only	1	No	Yes	
38088	Sr-88	No	Absorption only	1	No	Yes	
38089	Sr-89	No	Absorption only	1	No	Yes	
38090	Sr-90	No	Absorption only	1	No	Yes	
38091	Sr-91	No	Yield/Decay only	1	No	Yes	7
39089	Y-89	No	Absorption only	1	No	Yes	

Table 7.2 Nuclides for the ENDF/B-VI Library

ID	Description	Reson. Data	XS Model	# Temps	Pn Data	File 5 Data	Com-ment
39090	Y-90	No	Absorption only	1	No	Yes	
39091	Y-91	No	Absorption only	1	No	Yes	
40000	Zr	No	Full set	4	Yes	No	
40090	Zr-90	No	Absorption only	1	No	Yes	
40091	Zr-91	No	Absorption only	1	No	Yes	
40092	Zr-92	No	Absorption only	1	No	Yes	
40093	Zr-93	No	Absorption only	1	No	Yes	
40094	Zr-94	No	Absorption only	1	No	Yes	
40095	Zr-95	No	Absorption only	1	No	Yes	
40096	Zr-96	No	Absorption only	1	No	Yes	
40097	Zr-97	No	Yield/Decay only	1	No	Yes	7
40158	Zr in ZrH	No	Full set	4	No	No	10
41000	Nb	No	Full set	2	Yes	No	
41095	Nb-95	No	Absorption only	1	No	Yes	
41096	Nb-96	No	Yield/Decay only	1	No	Yes	7
41097	Nb-97	No	Yield/Decay only	1	No	Yes	7
42000	Mo	No	Absorption only	1	No	No	
42095	Mo-95	No	Absorption only	1	No	Yes	
42096	Mo-96	No	Absorption only	1	No	Yes	
42097	Mo-97	No	Absorption only	1	No	Yes	
42098	Mo-98	No	Absorption only	1	No	Yes	
42099	Mo-99	No	Absorption only	1	No	Yes	
42100	Mo-100	No	Absorption only	1	No	Yes	
42101	Mo-101	No	Yield/Decay only	1	No	Yes	7
43099	Tc-99	No	Absorption only	1	No	Yes	
43100	Tc-100	No	Yield/Decay only	1	No	Yes	7
43101	Tc-101	No	Yield/Decay only	1	No	Yes	7
44100	Ru-100	No	Absorption only	1	No	Yes	
44101	Ru-101	No	Absorption only	1	No	Yes	
44102	Ru-102	No	Absorption only	1	No	Yes	
44103	Ru-103	No	Absorption only	1	No	Yes	
44104	Ru-104	No	Absorption only	1	No	Yes	
44105	Ru-105	No	Absorption only	1	No	Yes	
44106	Ru-106	No	Absorption only	1	No	Yes	
45103	Rh-103	No	Full set	4	No	Yes	
45104	Rh-104	No	Yield/Decay only	1	No	Yes	7
45105	Rh-105	No	Absorption only	1	No	Yes	
45106	Rh-106	No	Yield/Decay only	1	No	Yes	7
46104	Pd-104	No	Absorption only	1	No	Yes	

Table 7.2 Nuclides for the ENDF/B-VI Library

ID	Description	Reson. Data	XS Model	# Temps	Pn Data	File 5 Data	Com-ment
46105	Pd-105	No	Absorption only	1	No	Yes	
46106	Pd-106	No	Absorption only	1	No	Yes	
46107	Pd-107	No	Absorption only	1	No	Yes	
46108	Pd-108	No	Absorption only	1	No	Yes	
46109	Pd-109	No	Yield/Decay only	1	No	Yes	7
46110	Pd-110	No	Absorption only	1	No	Yes	
46111	Pd-111	No	Yield/Decay only	1	No	Yes	7
47000	Ag (natural)						6
47107	Ag-107	Yes	Full Set	4	No	No	5, 13
47109	Ag-109	Yes	Full Set	4	No	Yes	5, 13
47110	Ag-110	No	Yield/Decay only	1	No	Yes	7
47111	Ag-111	No	Absorption only	1	No	Yes	
47910	Ag-110m	No	Yield/Decay only	1	No	Yes	7
48000	Cd (natural)						6
48106	Cd-106	No	Absorption only	1	No	No	
48108	Cd-108	No	Absorption only	1	No	No	10
48110	Cd-110	No	Absorption only	1	No	Yes	
48111	Cd-111	No	Absorption only	1	No	Yes	
48112	Cd-112	No	Absorption only	1	No	Yes	
48113	Cd-113	No	Full set	2	No	Yes	10
48114	Cd-114	No	Absorption only	1	No	Yes	
48115	Cd-115	No	Yield/Decay only	1	No	Yes	7
48116	Cd-116	No	Absorption only	1	No	Yes	
48117	Cd-117	No	Yield/Decay only	1	No	Yes	7
49113	In-113	No	Absorption only	2	No	No	
49115	In-115	Yes	Full Set	2	No	Yes	5, 13
49116	In-116	No	Yield/Decay only	1	No	Yes	7
49117	In-117	No	Yield/Decay only	1	No	Yes	7
50000	Sn	No	Full set	2	Yes	No	
50116	Sn-116	No	Absorption only	1	No	Yes	
50117	Sn-117	No	Absorption only	1	No	Yes	
50118	Sn-118	No	Absorption only	1	No	Yes	
50119	Sn-119	No	Absorption only	1	No	Yes	
50120	Sn-120	No	Absorption only	1	No	Yes	
50121	Sn-121	No	Yield/Decay only	1	No	Yes	7
50122	Sn-122	No	Absorption only	1	No	Yes	
50123	Sn-123	No	Absorption only	1	No	Yes	
50124	Sn-124	No	Absorption only	1	No	Yes	
50125	Sn-125	No	Absorption only	1	No	Yes	

Table 7.2 Nuclides for the ENDF/B-VI Library

ID	Description	Reson. Data	XS Model	# Temps	Pn Data	File 5 Data	Com-ment
50126	Sn-126	No	Absorption only	1	No	Yes	
51121	Sb-121	No	Absorption only	1	No	Yes	
51122	Sb-122	No	Yield/Decay only	1	No	Yes	7
51123	Sb-123	No	Absorption only	1	No	Yes	
51124	Sb-124	No	Absorption only	1	No	Yes	
51125	Sb-125	No	Absorption only	1	No	Yes	
51126	Sb-126	No	Absorption only	1	No	Yes	
51127	Sb-127	No	Yield/Decay only	1	No	Yes	7
52122	Te-122	No	Absorption only	1	No	Yes	
52123	Te-123	No	Absorption only	1	No	Yes	
52124	Te-124	No	Absorption only	1	No	Yes	
52125	Te-125	No	Absorption only	1	No	Yes	
52126	Te-126	No	Absorption only	1	No	Yes	
52127	Te-127	No	Yield/Decay only	1	No	Yes	7
52927	Te-127m	No	Absorption only	1	No	Yes	
52128	Te-128	No	Absorption only	1	No	Yes	
52129	Te-129	No	Yield/Decay only	1	No	Yes	7
52929	Te-129m	No	Absorption only	1	No	Yes	
52130	Te-130	No	Absorption only	1	No	Yes	
52131	Te-131	No	Yield/Decay only	1	No	Yes	7
52132	Te-132	No	Absorption only	1	No	Yes	
53127	I-127	No	Absorption only	1	No	Yes	
53128	I-128	No	Yield/Decay only	1	No	Yes	7
53129	I-129	No	Absorption only	1	No	Yes	
53130	I-130	No	Absorption only	1	No	Yes	
53131	I-131	No	Absorption only	1	No	Yes	
53135	I-135	No	Absorption only	1	No	Yes	
54128	Xe-128	No	Absorption only	1	No	Yes	
54129	Xe-129	No	Absorption only	1	No	Yes	
54130	Xe-130	No	Absorption only	1	No	Yes	
54131	Xe-131	No	Absorption only	1	No	Yes	
54132	Xe-132	No	Absorption only	1	No	Yes	
54133	Xe-133	No	Absorption only	1	No	Yes	
54134	Xe-134	No	Absorption only	1	No	Yes	
54135	Xe-135	No	Absorption only	1	No	Yes	
54136	Xe-136	No	Absorption only	1	No	Yes	
54137	Xe-137	No	Yield/Decay only	1	No	Yes	7
55133	Cs-133	No	Absorption only	1	No	Yes	
55134	Cs-134	No	Absorption only	1	No	Yes	

Table 7.2 Nuclides for the ENDF/B-VI Library

ID	Description	Reson. Data	XS Model	# Temps	Pn Data	File 5 Data	Com-ment
55135	Cs-135	No	Absorption only	1	No	Yes	
55136	Cs-136	No	Absorption only	1	No	Yes	
55137	Cs-137	No	Absorption only	1	No	Yes	
55138	Cs-138	No	Yield/Decay only	1	No	Yes	7
56134	Ba-134	No	Absorption only	1	No	Yes	
56135	Ba-135	No	Absorption only	1	No	Yes	
56136	Ba-136	No	Absorption only	1	No	Yes	
56137	Ba-137	No	Absorption only	1	No	Yes	
56138	Ba-138	No	Absorption only	1	No	Yes	
56139	Ba-139	No	Yield/Decay only	1	No	Yes	7
56140	Ba-140	No	Absorption only	1	No	Yes	
57139	La-139	No	Absorption only	1	No	Yes	
57140	La-140	No	Absorption only	1	No	Yes	
58140	Ce-140	No	Absorption only	1	No	Yes	
58141	Ce-141	No	Absorption only	1	No	Yes	
58142	Ce-142	No	Absorption only	1	No	Yes	
58143	Ce-143	No	Absorption only	1	No	Yes	
58144	Ce-144	No	Absorption only	1	No	Yes	
59141	Pr-141	No	Absorption only	1	No	Yes	
59142	Pr-142	No	Absorption only	1	No	Yes	
59143	Pr-143	No	Absorption only	1	No	Yes	
59144	Pr-144	No	Yield/Decay only	1	No	Yes	7
60142	Nd-142	No	Absorption only	1	No	Yes	
60143	Nd-143	No	Absorption only	1	No	Yes	
60144	Nd-144	No	Absorption only	1	No	Yes	
60145	Nd-145	No	Absorption only	1	No	Yes	
60146	Nd-146	No	Absorption only	1	No	Yes	
60147	Nd-147	No	Absorption only	1	No	Yes	
60148	Nd-148	No	Absorption only	1	No	Yes	
60149	Nd-149	No	Yield/Decay only	1	No	Yes	7
60150	Nd-150	No	Absorption only	1	No	Yes	
60151	Nd-151	No	Yield/Decay only	1	No	Yes	7
61147	Pm-147	No	Absorption only	1	No	Yes	
61148	Pm-148	No	Absorption only	1	No	Yes	
61948	Pm-148m	No	Absorption only	1	No	Yes	
61149	Pm-149	No	Absorption only	1	No	Yes	
61150	Pm-150	No	Yield/Decay only	1	No	Yes	7
61151	Pm-151	No	Absorption only	1	No	Yes	
62147	Sm-147	No	Absorption only	4	No	Yes	

Table 7.2 Nuclides for the ENDF/B-VI Library

ID	Description	Reson. Data	XS Model	# Temps	Pn Data	File 5 Data	Com-ment
62148	Sm-148	No	Absorption only	1	No	Yes	
62149	Sm-149	No	Absorption only	4	No	Yes	
62150	Sm-150	No	Absorption only	4	No	Yes	
62151	Sm-151	No	Absorption only	4	No	Yes	
62152	Sm-152	No	Absorption only	4	No	Yes	
62153	Sm-153	No	Absorption only	1	No	Yes	
62154	Sm-154	No	Absorption only	1	No	Yes	
62155	Sm-155	No	Yield/Decay only	1	No	Yes	7
63151	Eu-151	Yes	Absorption only	4	No	No	5, 13
63152	Eu-152	No	Absorption only	4	No	No	10
63153	Eu-153	Yes	Absorption only	4	No	Yes	13
63154	Eu-154	No	Absorption only	4	No	Yes	10
63155	Eu-155	No	Absorption only	4	No	Yes	10
63156	Eu-156	No	Absorption only	1	No	Yes	
63157	Eu-157	No	Absorption only	1	No	Yes	
63158	Eu-158	No	Yield/Decay only	1	No	Yes	7
64000	Gd (natural)						6,9
64152	Gd-152	No	Absorption only	1	No	No	
64154	Gd-154	No	Absorption only	1	No	No	
64155	Gd-155	Yes	Full set	1	No	No	5, 13
64156	Gd-156	Yes	Absorption only	1	No	No	5
64157	Gd-157	Yes	Full set	1	No	No	5, 13
64158	Gd-158	Yes	Absorption only	1	No	No	5
64160	Gd-160	No	Absorption only	1	No	No	
64254	Gd-154 F.P.	No	Absorption only	1	No	Yes	5,8
64255	Gd-155 F.P.	Yes	Full set	1	No	Yes	5,8
64256	Gd-156 F.P.	Yes	Absorption only	1	No	Yes	5,8
64257	Gd-157 F.P.	Yes	Full set	1	No	Yes	5,8,13
64258	Gd-158 F.P.	Yes	Absorption only	1	No	Yes	5,8
64259	Gd-159 F.P.	No	Yield/Decay only	1	No	Yes	7,8
65159	Tb-159	No	Absorption only	1	No	Yes	
65160	Tb-160	No	Absorption only	1	No	Yes	
66164	Dy-164	No	Absorption only	1	No	No	
68000	Er (natural)						6
68162	Er-162	No	Absorption only	1	No	No	
68163	Er-163	No	Yield/Decay only	1	No	Yes	7
68164	Er-164	No	Absorption only	1	No	No	
68165	Er-165	No	Yield/Decay only	1	No	Yes	7
68166	Er-166	No	Absorption only	1	No	No	

Table 7.2 Nuclides for the ENDF/B-VI Library

ID	Description	Reson. Data	XS Model	# Temps	Pn Data	File 5 Data	Com-ment
68167	Er-167	Yes	Absorption only	4	No	No	5
68168	Er-168	No	Absorption only	1	No	No	
68169	Er-169	No	Yield/Decay only	1	No	Yes	7
68170	Er-170	No	Absorption only	1	No	No	
68171	Er-171	No	Absorption only	1	No	Yes	
69169	Tm-169	No	Absorption only	1	No	No	
69170	Tm-170	No	Absorption only	1	No	Yes	
69171	Tm-171	No	Absorption only	1	No	Yes	
71176	Lu-176	No	Absorption only	1	No	No	
72000	Hf (natural)						6
72174	Hf-174	No	Absorption only	2	No	No	
72176	Hf-176	Yes	Absorption only	2	No	No	5, 13
72177	Hf-177	Yes	Absorption only	2	No	No	5, 13
72178	Hf-178	Yes	Absorption only	2	No	No	5, 13
72179	Hf-179	Yes	Absorption only	2	No	No	5, 179
72180	Hf-180	Yes	Absorption only	2	No	No	5, 180
74000	W	No	Absorption only	2	No	No	
78195	Pt-195	No	Absorption only	1	No	No	
79000	Au	No	Absorption only	1	No	No	
82000	Pb	No	Full set	1	No	No	10
83000	Bi	No	Absorption only	1	No	No	
90230	Th-230	Yes	Full set	4	No	Yes	5
90231	Th-231	No	Yield/Decay only	1	No	Yes	7
90232	Th-232	Yes	Full set	4	No	Yes	5,12
90233	Th-233	No	Yield/Decay only	1	No	Yes	7
91231	Pa-231	No	Full set	1	No	Yes	
91232	Pa-232	No	Absorption only	1	No	Yes	
91233	Pa-233	No	Full set	1	No	Yes	
91234	Pa-234	No	Yield/Decay only	1	No	Yes	7
92232	U-232	No	Full set	1	No	Yes	
92233	U-233	Yes	Full set	4	No	Yes	5,12
92234	U-234	Yes	Full set	4	No	Yes	5,12
92235	U-235	Yes	Full set	6	Yes	Yes	5,11,12
92236	U-236	Yes	Full set	1	No	Yes	5,12
92237	U-237	No	Full set	1	No	Yes	
92238	U-238	Yes	Full set	6	Yes	Yes	5,11,12
92239	U-239	No	Yield/Decay only	1	No	Yes	7
93236	Np-236	No	Yield/Decay only	1	No	Yes	7
93237	Np-237	No	Full set	1	No	Yes	12

Table 7.2 Nuclides for the ENDF/B-VI Library

ID	Description	Reson. Data	XS Model	# Temps	Pn Data	File 5 Data	Com-ment
93238	Np-238	No	Full set	1	No	Yes	12
93239	Np-239	No	Full set	1	No	Yes	
94236	Pu-236	No	Full set	4	No	Yes	
94238	Pu-238	No	Full set	1	No	Yes	12
94239	Pu-239	Yes	Full set	6	Yes	Yes	5,11,12
94240	Pu-240	Yes	Full set	6	No	Yes	5,12
94241	Pu-241	Yes	Full set	6	No	Yes	5,12
94242	Pu-242	Yes	Full set	6	No	Yes	5,12,13
94243	Pu-243	No	Full set	1	No	Yes	
95241	Am-241	Yes	Full set	4	No	Yes	5,12
95242	Am-242	No	Full set	1	No	Yes	
95942	Am-242m	Yes	Full set	4	No	Yes	5,12
95243	Am-243	No	Full set	4	No	Yes	12
95244	Am-244	No	Yield/Decay only	1	No	Yes	7
96242	Cm-242	No	Full set	1	No	Yes	
96243	Cm-243	No	Full set	1	No	Yes	
96244	Cm-244	No	Full set	1	No	Yes	12
96245	Cm-245	No	Full set	1	No	Yes	12
96246	Cm-246	No	Full set	1	No	Yes	
96247	Cm-247	No	Full set	1	No	Yes	
96248	Cm-248	No	Full set	1	No	Yes	
96249	Cm-249	No	Yield/Decay only	1	No	Yes	7
97249	Bk-249	No	Full set	1	No	Yes	
97250	Bk-250	No	Yield/Decay only	1	No	Yes	7
98249	Cf-249	No	Full set	1	No	Yes	
98250	Cf-250	No	Full set	1	No	Yes	
98251	Cf-251	No	Full set	1	No	Yes	
98252	Cf-252	No	Full set	1	No	Yes	

Comments to the list of nuclides (Table 7.2)

For many nuclides, such as fission products, cross sections are given for absorption only and at 600 K only. Cross sections have been included in the library for two or more temperatures only if the temperature dependence is of importance for LWR analysis, and CASMO then interpolates in the data for different temperatures. Table 7.7 provides the temperatures at which each nuclide is tabulated on the library.

1. ID = 5000 represents natural boron and must be used when boron should not be depleted, e.g. as soluble boron in water. It can also be used in control rods.
   ID = 5010 represents **B-10 and must be used when boron is to be depleted,** e.g. in burnable poison rods. CASMO also accepts ID = -5000 for depletable boron. The input processor will split the natural boron up into its components: 18.3 w% B-10 and 81.7 w% B-11.

2 The compositions of stainless steel (ID = 347), Inconel-718 (ID = 718) and Inconel-750 (ID = 750) are in weight percent:

Nuclide	347	718	750
Al (13000)	0	0	0.98
Si (14000)	0.51	0.35	0
Cr (24000)	17.40	18.96	20.14
Mn (25000)	1.99	0.87	0.99
Fe (26000)	68.35	27.93	8.88
Ni (28000)	11.70	51.19	69.02

3 The compositions of Zircaloy-2 (ID = 302), Zircaloy-4 (ID = 304) and Zirlo (ID = 306) are in weight percent:

Nuclide	302	304	306
O (8000)	0.125	0.125	0.125
Cr (24000)	0.10	0.10	0.10
Fe (26000)	0.135	0.21	0.21
Ni (28000)	0.055	-	-
Zr (40000)	98.135	98.115	97.115
Nb (41000)	-	-	1.00
Sn (50000)	1.45	1.45	1.45

4. The dummy nuclide ID = 0 can be added to any composition in order to make the total weight percentage add up to 100%. ID = 0 has no influence on the results and cannot be used in FUE materials.
   The 1/v-absorber (ID = 1) is normalized to 1 barn at 2200 m/sec.
   The unit absorber (ID = 2) has a constant 1 barn absorption cross section.

The unit scatterer (ID = 3) has a constant 1 barn in-group scattering cross section and zero absorption. The atomic weight for nuclides 1, 2, and 3 is also unity.

5. Shielded resonance data are tabulated versus background cross section and temperature. The temperatures are normally 293 K, 600 K, 900 K and 1500 K. For U-235, U-238, Pu-239, Pu-240, Pu-241 and Pu-242 two additional temperatures 2100 K and 2700 K are tabulated.

6. Cross sections for the following natural elements are not tabulated in the library, but CASMO accepts their ID numbers. The CASMO input processor will split up an element into its individual components and calculate the cross section for the element from the composition and the cross sections of the components:

	ID	Component weight percents		
Ag	47000	47107 = 51.36	47109 = 48.64	
Cd	48000	48106 = 1.178	48108 = 0.854	48110 = 12.21
		48111 = 12.63	48112 = 24.02	48113 = 12.30
		48114 = 29.11	48115 = 7.723	
In	49000	49113 = 4.21	49115 = 95.79	
Gd	64000	64152 = 0.20	64154 = 2.10	64155 = 14.51
		64156 = 20.30	64157 = 15.64	64158 = 24.98
		64160 = 22.27		
Er	68000	68162 = 0.136	68164 = 1.529	68166 = 33.13
		68167 = 22.85	68168 = 27.21	68170 = 15.14
Hf	72000	72174 = 0.166	72176 = 5.13	72177 = 18.35
		72178 = 27.13	72179 = 13.84	72180 = 35.40

For Gd_2O_3 use 64016. For Er_2O_3 use 68016.

7. Identifiers with only fission yields and decay constants (zero cross sections) are included in the depletion chains and are tracked by number density, but are not involved neutronically in the calculation. These nuclides can be specified in input, however, they are not available for reaction rate edits, e.g., RRI, FRR, or RRX, edits.

8. Gd-15n (n = 4, 5, 6, 7, 8) as fission product (ID = 6425n) is treated separately from Gd-15n as a burnable absorber (ID = 6415n).

9. Idents 64016 and 68016 represent Gd_2O_3 and Er_2O_3 respectively. CASMO will calculate the concentrations of the individual isotopes according to the description in the comment to the FUE Card.

10. Pn data only to order 5 for this nuclide.

11. Fission data present for this nuclide.

12. Extended resonance data (32 groups) present for this nuclide.

13. Gamma data for the gamma data library have not yet been processed from the ENDF/B-VI data files.

14. **L**umped **F**ission **P**roduct edits **(ID=401, 402, and 403)**:
    For E6 data library, (unlike previous CASMO libraries, e.g., the L-library), lumped fission products, **ID=401** (LFP1, non-saturating), and **ID=402** (LFP2, slowly saturating), are not present on the data libraries, but rather **are edited as a summation of the number densities of the constituent nuclides.** Also edited is an extended LFP, **ID=403 (**EXTFP) which is the sum of the number densities of all additional fission product nuclides which **do not** appear in the explicit number density edit, or in ID's 401 or 402. **Note, although not all nuclides are explicitly edited, CASMO tracks all the constituent nuclides individually.** Also note that LFP ID's: 401, 402 and 403, **may not be** used to define materials. Tables 7.3 though 7.6 show the disposition by nuclide of the edited fission products, and LFP ID's, 401, 402 and 403.

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Table 7.3 Edited Fission Products

(29 Nuclides + 3 LFPs)							
36083	Kr-83	55134	Cs-134	61148	Pm-148	63153	Eu-153
45103	Rh-103	55135	Cs-135	61149	Pm-149	63154	Eu-154
45105	Rh-105	55137	Cs-137	61948	Pm148m	63155	Eu-155
47109	Ag-109	56140	Ba-140	62147	Sm-147	63156	Eu-156
53135	I-135	57140	La-140	62149	Sm-149	64255	Gd155F
54131	Xe-131	60143	Nd-143	62150	Sm-150	401	LFP1
54135	Xe-135	60145	Nd-145	62151	Sm-151	402	LFP2
55133	Cs-133	61147	Pm-147	62152	Sm-152	403	EXTFP

Table 7.4 Lumped Fission Product Nuclides ID=401

ID=401 (45 Nuclides)							
32076	Ge-76	40092	Zr-92	48111	Cd-111	54136	Xe-136
34078	Se-78	40093	Zr-93	48112	Cd-112	56138	Ba-138
34080	Se-80	40094	Zr-94	48114	Cd-114	58140	Ce-140
35081	Br-81	40096	Zr-96	48116	Cd-116	60144	Nd-144
36084	Kr-84	42097	Mo-97	50117	Sn-117	60148	Nd-148
36085	Kr-85	42098	Mo-98	50119	Sn-119	60150	Nd-150
36086	Kr-86	42100	Mo-100	50120	Sn-120	62154	Sm-154
37085	Rb-85	44101	Ru-101	50122	Sn-122	64256	Gd-156F
37087	Rb-87	44102	Ru-102	52128	Te-128	64258	Gd-158F
38090	Sr-90	44104	Ru-104	52130	Te-130		
39089	Y-89	44106	Ru-106	54132	Xe-132		
40091	Zr-91	46110	Pd-110	54134	Xe-134		

Table 7.5 Lumped Fission Product Nuclides ID=402

ID=402 (15 Nuclides)							
34077	Se-77	46107	Pd-107	51123	Sb-123	59141	Pr-141
34079	Se-79	46108	Pd-108	53127	I-127	60146	Nd-146
42095	Mo-95	49115	In-115	53129	I-129	65159	Tb-159
43099	Tc-99	51121	Sb-121	57139	La-139		

Table 7.6 Lumped Fission Product Nuclides ID=403

ID=403 (105 Nuclides)							
32077	Ge-77	44103	Ru-103	51126	Sb-126	56137	Ba-137
33077	As-77	44105	Ru-105	51127	Sb-127	56139	Ba-139
34081	Se-81	45104	Rh-104	52122	Te-122	58141	Ce-141
34082	Se-82	45106	Rh-106	52123	Te-123	58142	Ce-142
34083	Se-83	46104	Pd-104	52124	Te-124	58143	Ce-143
35082	Br-82	46105	Pd-105	52125	Te-125	58144	Ce-144
35083	Br-83	46106	Pd-106	52126	Te-126	59142	Pr-142
36082	Kr-82	46109	Pd-109	52127	Te-127	59143	Pr-143
36985	Kr-85m	47110	Ag-110	52927	Te127m	59144	Pr-144
36087	Kr-87	47111	Ag-111	52129	Te-129	60142	Nd-142
38088	Sr-88	47910	Ag110m	52929	Te129m	60147	Nd-147
38089	Sr-89	48110	Cd-110	52131	Te-131	60149	Nd-149
38091	Sr-91	48113	Cd-113	52132	Te-132	60151	Nd-151
39090	Y-90	48115	Cd-115	53128	I-128	61150	Pm-150
39091	Y-91	48117	Cd-117	53130	I-130	61151	Pm-151
40090	Zr-90	49116	In-116	53131	I-131	62148	Sm-148
40095	Zr-95	49117	In-117	54128	Xe-128	62153	Sm-153
40097	Zr-97	50116	Sn-116	54128	Xe-128	62155	Sm-155
41095	Nb-95	50118	Sn-118	54129	Xe-129	63157	Eu-157
41096	Nb-96	50121	Sn-121	54130	Xe-130	63158	Eu-158
41097	Nb-97	50123	Sn-123	54133	Xe-133	64254	Gd154F
42096	Mo-96	50124	Sn-124	54137	Xe-137	64257	Gd157F
42099	Mo-99	50125	Sn-125	55136	Cs-136	64259	Gd159F
43100	Tc-100	50126	Sn-126	55138	Cs-138	65160	Tb-160
44100	Ru-100	51122	Sb-122	56134	Ba-134		
42101	Mo-101	51124	Sb-124	56135	Ba-135		
43101	Tc-101	51125	Sb-125	56136	Ba-136		

Table 7.7 Temperatures for the ENDF/B-VI Library

ID	Description	Temperature(s) K							
1	1/V AB	293.6							
2	UNAB	293.6							
3	UNSC	293.6							
302	Zr-2	293.0	600.0	900.0	1500.0				
304	Zr-4	293.0	600.0	900.0	1500.0				
306	ZIRLO	293.0	600.0	900.0	1500.0				
347	SS	293.0	600.0						
718	INC718	293.0	600.0						
750	INC750	293.0	600.0						
1001	H	293.6	373.6	473.6	523.6	573.6	623.6		
1002	D	293.6	373.6	473.6	573.6	673.6			
1107	H-ZRH	296.0	400.0	500.0	600.0	800.0	1200.0		
2003	He-3	293.0							
3000	Li	293.0							
4000	Be	293.6	400.0						
5000	B	293.0	600.0						
5010	B-10	293.0	600.0						
5011	B-11	293.0	600.0						
6000	C	293.0	400.0	500.0	600.0				
6001	C-gr	293.6	500.0	800.0	1200.0	1600.0	2000.0		
8000	O	293.6	373.6	473.6	523.6	573.6	623.6	900.0	1500.0
7000	N	293.0							
9000	F	293.0							
11000	Na	293.0							
12000	Mg	293.0	600.0						
13000	Al	293.0	600.0						
14000	Si	293.0	600.0						
15000	P	293.0							
16000	S	293.0							
17000	Cl	293.0							
19000	K	293.0							
20000	Ca	293.0							
23000	V	293.0	600.0						
24000	Cr	293.0	600.0						
25000	Mn	293.0	600.0						
26000	Fe	293.0	600.0						
26054	Fe-54	293.0	600.0	900.0	1500.0				
26055	Fe-55	293.0							

Table 7.7 Temperatures for the ENDF/B-VI Library

ID	Description	Temperature(s) K							
27059	Co-59	293.0	600.0						
28000	Ni	293.0	600.0						
28058	Ni-58	293.0	600.0						
28062	Ni-62	293.0	600.0						
29000	Cu	293.0							
29063	Cu-63	300.0							
30064	Zn-64	293.0							
31000	Ga	293.0	600.0						
32000	Ge	293.0							
32076	Ge-76	600.0							
32077	Ge-77	600.0							
33000	As	293.0							
33077	As-77	600.0							
34000	Se	293.0							
34077	Se-77	600.0							
34078	Se-78	600.0							
34079	Se-79	600.0							
34080	Se-80	600.0							
34081	Se-81	600.0							
34082	Se-82	600.0							
34083	Se-83	600.0							
35081	Br-81	600.0							
35082	Br-82	600.0							
35083	Br-83	600.0							
36083	Kr-83	293.0	600.0	900.0	1500.0				
36084	Kr-84	600.0							
36085	Kr-85	600.0							
36086	Kr-86	600.0							
37085	Rb-85	600.0							
37087	Rb-87	600.0							
38088	Sr-88	600.0							
38089	Sr-89	600.0							
38090	Sr-90	600.0							
39089	Y-89	600.0							
36082	Kr-82	600.0							
36985	Kr-85m	600.0							
36087	Kr-87	600.0							
38091	Sr-91	600.0							
39090	Y-90	600.0							
39091	Y-91	600.0							

Table 7.7 Temperatures for the ENDF/B-VI Library

ID	Description	Temperature(s) K							
40000	Zr	293.0	600.0	900.0	1500.0				
40090	Zr-90	600.0							
40095	Zr-95	600.0							
40097	Zr-97	600.0							
40158	Zr-ZRH	296.0	500.0	800.0	1200.0				
41000	Nb	293.0	600.0						
41097	Nb-97	600.0							
42096	Mo-96	600.0							
42099	Mo-99	600.0							
42101	Mo-101	600.0							
43100	Tc-100	600.0							
43101	Tc-101	600.0							
45103	Rh-103	293.0	600.0	900.0	1500.0				
45105	Rh-105	600.0							
47107	Ag-107	293.0	600.0	900.0	1500.0				
47109	Ag-109	293.0	600.0	900.0	1500.0				
40091	Zr-91	600.0							
40092	Zr-92	600.0							
40093	Zr-93	600.0							
40094	Zr-94	600.0							
40096	Zr-96	600.0							
41095	Nb-95	600.0							
41096	Nb-96	600.0							
42000	Mo	293.0							
42095	Mo-95	600.0							
42097	Mo-97	600.0							
42098	Mo-98	600.0							
42100	Mo-100	600.0							
43099	Tc-99	600.0							
44100	Ru-100	600.0							
44101	Ru-101	600.0							
44102	Ru-102	600.0							
44103	Ru-103	600.0							
44104	Ru-104	600.0							
44105	Ru-105	600.0							
44106	Ru-106	600.0							
45104	Rh-104	600.0							
45106	Rh-106	600.0							
46104	Pd-104	600.0							
46105	Pd-105	600.0							

Table 7.7 Temperatures for the ENDF/B-VI Library

ID	Description	Temperature(s) K							
46106	Pd-106	600.0							
46107	Pd-107	600.0							
46108	Pd-108	600.0							
46109	Pd-109	600.0							
46110	Pd-110	600.0							
46111	Pd-111	600.0							
47110	Ag-110	600.0							
47910	Ag110m	600.0							
47111	Ag-111	600.0							
48106	Cd-106	600.0							
48108	Cd-108	600.0							
48110	Cd-110	600.0							
48111	Cd-111	600.0							
48112	Cd-112	600.0							
48113	Cd-113	293.0	600.0						
48114	Cd-114	600.0							
48115	Cd-115	600.0							
48116	Cd-116	600.0							
48117	Cd-117	600.0							
49113	In-113	293.0	600.0						
49115	In-115	293.0	600.0						
49116	In-116	600.0							
49117	In-117	600.0							
50000	Sn	293.0	600.0						
50116	Sn-116	600.0							
50117	Sn-117	600.0							
50118	Sn-118	600.0							
50119	Sn-119	600.0							
50120	Sn-120	600.0							
50121	Sn-121	600.0							
50122	Sn-122	600.0							
50123	Sn-123	600.0							
50124	Sn-124	600.0							
50125	Sn-125	600.0							
50126	Sn-126	600.0							
51121	Sb-121	600.0							
51122	Sb-122	600.0							
51123	Sb-123	600.0							
51124	Sb-124	600.0							
51125	Sb-125	600.0							

Table 7.7 Temperatures for the ENDF/B-VI Library

ID	Description	Temperature(s) K							
51126	Sb-126	600.0							
51127	Sb-127	293.0							
52122	Te-122	600.0							
52123	Te-123	600.0							
52124	Te-124	600.0							
52125	Te-125	600.0							
52126	Te-126	600.0							
52127	Te-127	600.0							
52927	Te127m	600.0							
52128	Te-128	600.0							
52129	Te-129	600.0							
52929	Te129m	600.0							
52130	Te-130	600.0							
52131	Te-131	600.0							
52132	Te-132	600.0							
53127	I-127	600.0							
53128	I-128	600.0							
53129	I-129	600.0							
53130	I-130	600.0							
53131	I-131	600.0							
53135	I-135	600.0							
54128	Xe-128	600.0							
54129	Xe-129	600.0							
54130	Xe-130	600.0							
54131	Xe-131	600.0							
54132	Xe-132	600.0							
54133	Xe-133	600.0							
54134	Xe-134	600.0							
54135	Xe-135	600.0							
54136	Xe-136	600.0							
54137	Xe-137	600.0							
55133	Cs-133	600.0							
55134	Cs-134	600.0							
55135	Cs-135	600.0							
55136	Cs-136	600.0							
55137	Cs-137	600.0							
55138	Cs-138	600.0							
56134	Ba-134	600.0							
56135	Ba-135	600.0							
56136	Ba-136	600.0							

Table 7.7 Temperatures for the ENDF/B-VI Library

ID	Description	Temperature(s) K							
56137	Ba-137	600.0							
56138	Ba-138	600.0							
56139	Ba-139	600.0							
56140	Ba-140	600.0							
57139	La-139	600.0							
57140	La-140	600.0							
58140	Ce-140	600.0							
58141	Ce-141	600.0							
58142	Ce-142	600.0							
58143	Ce-143	600.0							
58144	Ce-144	600.0							
59141	Pr-141	600.0							
59142	Pr-142	600.0							
59143	Pr-143	600.0							
59144	Pr-144	600.0							
60142	Nd-142	600.0							
60143	Nd-143	600.0							
60144	Nd-144	600.0							
60145	Nd-145	600.0							
60146	Nd-146	600.0							
60147	Nd-147	600.0							
60148	Nd-148	600.0							
60149	Nd-149	600.0							
60150	Nd-150	600.0							
60151	Nd-151	600.0							
61147	Pm-147	600.0							
61148	Pm-148	600.0							
61948	Pm148m	600.0							
61149	Pm-149	600.0							
61150	Pm-150	600.0							
61151	Pm-151	600.0							
62147	Sm-147	293.0	600.0	900.0	1500.0				
62148	Sm-148	600.0							
62149	Sm-149	293.0	600.0	900.0	1500.0				
62150	Sm-150	293.0	600.0	900.0	1500.0				
62151	Sm-151	293.0	600.0	900.0	1500.0				
62152	Sm-152	293.0	600.0	900.0	1500.0				
62153	Sm-153	600.0							
62154	Sm-154	600.0							
62155	Sm-155	600.0							

Table 7.7 Temperatures for the ENDF/B-VI Library

ID	Description	Temperature(s) K							
63151	Eu-151	293.0	600.0	900.0	1500.0				
63152	Eu-152	293.0	600.0	900.0	1500.0				
63153	Eu-153	293.0	600.0	900.0	1500.0				
63154	Eu-154	293.0	600.0	900.0	1500.0				
63155	Eu-155	293.0	600.0	900.0	1500.0				
63156	Eu-156	600.0							
63157	Eu-157	600.0							
63158	Eu-158	600.0							
64152	Gd-152	600.0							
64154	Gd-154	600.0							
64254	Gd154F	600.0							
64155	Gd-155	600.0							
64255	Gd155F	600.0							
64156	Gd-156	600.0							
64256	Gd156F	600.0							
64157	Gd-157	600.0							
64257	Gd157F	600.0							
64158	Gd-158	600.0							
64258	Gd158F	600.0							
64259	Gd159F	600.0							
64160	Gd-160	600.0							
65159	Tb-159	600.0							
65160	Tb-160	600.0							
66164	Dy-164	293.0							
68162	Er-162	600.0							
68163	Er-163	600.0							
68164	Er-164	600.0							
68165	Er-165	600.0							
68166	Er-166	600.0							
68167	Er-167	293.0	600.0	900.0	1500.0				
68168	Er-168	600.0							
68169	Er-169	600.0							
68170	Er-170	600.0							
68171	Er-171	600.0							
69169	Tm-169	600.0							
69170	Tm-170	600.0							
69171	Tm-171	600.0							
71176	Lu-176	293.0							
72174	Hf-174	293.0	600.0						
72176	Hf-176	293.0	600.0						

Table 7.7 Temperatures for the ENDF/B-VI Library

ID	Description	Temperature(s) K							
72177	Hf-177	293.0	600.0						
72178	Hf-178	293.0	600.0						
72179	Hf-179	293.0	600.0						
72180	Hf-180	293.0	600.0						
74000	W	293.0	600.0						
78195	Pt-195	300.0							
79000	Au	293.0							
82000	Pb	293.0							
83000	Bi	293.0							
90230	Th-230	293.0	600.0	900.0	1500.0				
90231	Th-231	600.0							
90232	Th-232	293.0	600.0	900.0	1500.0				
90233	Th-233	600.0							
91231	Pa-231	600.0							
91232	Pa-232	600.0							
91233	Pa-233	600.0							
91234	Pa-234	600.0							
92232	U-232	600.0							
92233	U-233	293.0	600.0	900.0	1500.0				
92234	U-234	293.0	600.0	900.0	1500.0				
92235	U-235	293.0	600.0	900.0	1500.0	2100.0	2700.0		
92236	U-236	600.0							
92237	U-237	600.0							
92238	U-238	293.0	600.0	900.0	1500.0	2100.0	2700.0		
92239	U-239	600.0							
93236	Np-236	600.0							
93237	Np-237	600.0							
93238	Np-238	600.0							
93239	Np-239	600.0							
94236	Pu-236	293.0	600.0	900.0	1500.0				
94238	Pu-238	600.0							
94239	Pu-239	293.0	600.0	900.0	1500.0	2100.0	2700.0		
94240	Pu-240	293.0	600.0	900.0	1500.0	2100.0	2700.0		
94241	Pu-241	293.0	600.0	900.0	1500.0	2100.0	2700.0		
94242	Pu-242	293.0	600.0	900.0	1500.0	2100.0	2700.0		
94243	Pu-243	600.0							
95242	Am-242	600.0							
95244	Am-244	600.0							
95241	Am-241	293.0	600.0	900.0	1500.0				
95942	Am242m	293.0	600.0	900.0	1500.0				

Table 7.7 Temperatures for the ENDF/B-VI Library

ID	Description	Temperature(s) K							
95243	Am-243	293.0	600.0	900.0	1500.0				
96242	Cm-242	600.0							
96243	Cm-243	600.0							
96244	Cm-244	600.0							
96245	Cm-245	600.0							
96246	Cm-246	600.0							
96247	Cm-247	600.0							
96248	Cm-248	600.0							
96249	Cm-249	600.0							
97249	Bk-249	600.0							
97250	Bk-250	600.0							
98249	Cf-249	600.0							
98250	Cf-250	600.0							
98251	Cf-251	600.0							
98252	Cf-252	600.0							

7.2 Heavy Nuclide Chains in E6

The heavy nuclides are represented in a matrix form as shown in Figures 7.1 and 7.2. Specific sections of the periodic table have been selected to include all relevant uranium isotopes, and all significant transuranium nuclides being formed by the processes in a nuclear reactor up to, and including, Cf-252.

In the figure, transfers between nuclides have been indicated by arrows in a self-explanatory way. For many nuclides there is a "removal mode" by both an (n,γ) reaction and a radioactive decay (usually beta decay). To indicate to the user which reaction is dominant, only one removal mode has been shown where it is estimated to be at least 100 times as large as the other. Arrows which lead out of the system have been omitted.

The metastable state of Am-242 has also been explicitly represented (which is important for the production of higher nuclides).

Certain information on decay modes, half lives, cross sections, branching ratios etc., is also given in Figures 7.1 and 7.2. These data are approximate and do not necessarily agree with the data in the library.

The production rate of nuclide *m* due to capture in the predecessor *m'* is determined by

$$\gamma_{m'} = I_{a,m'} - I_{f,m'} \tag{7.1}$$

$$= \sum_g (\sigma^{lib}_{a,m',g} - \sigma^{lib}_{f,m',g})\Phi_g f_p$$

σ^{lib}_a and σ^{lib}_f are the cross sections tabulated in the library. (n,2n) cross sections are not listed in the library but (n,2n) reactions are taken into account by reducing the absorption cross section such that

$$\sigma^{lib}_{a,g} = \sigma_{c,g} + \sigma_{f,g} - \sigma_{(n,2n),g} \tag{7.2}$$

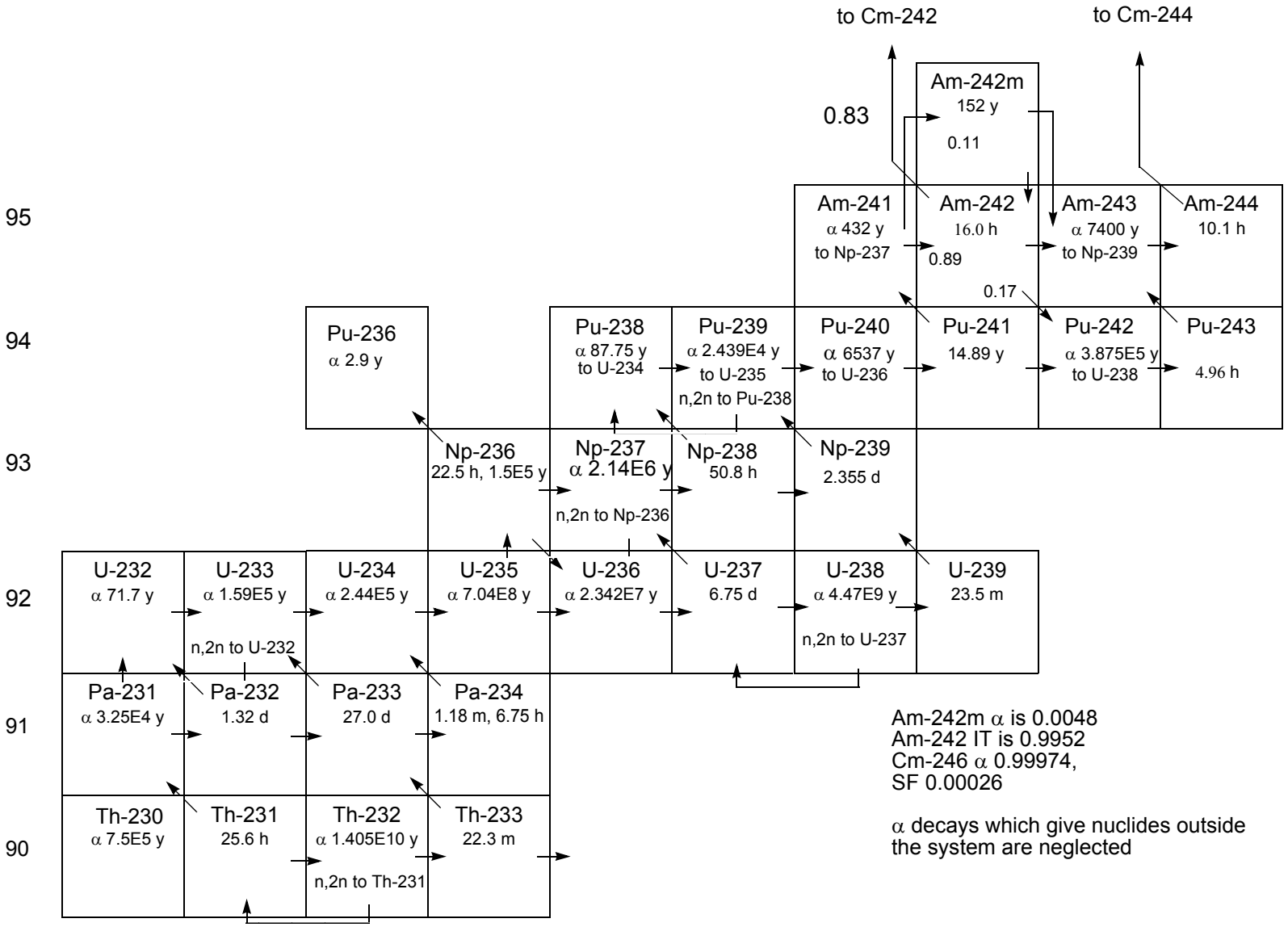
In order to find the (*n*,2*n*) reaction rates, the code uses the fact that $\sigma_{n,2n}$ is different from zero only in micro group 1 and that $\sigma_{n,\gamma}$ is negligible in this group. Therefore, $\sigma_{n,2n}$ can be determined by

$$\sigma_{(n,2n),1} = \sigma^{lib}_{f,1} - \sigma^{lib}_{a,1} \tag{7.3}$$

For nuclides with (n,2n) reactions Eq. (7.1) is replaced by

$$\gamma_{m'} = I_{a,m'} - I_{f,m'} + \sigma_{(n,2n),1}\,\Phi_1 f_p$$

Fig. 7.1 E6 Heavy Nuclides: Lower Part (to Am-244)



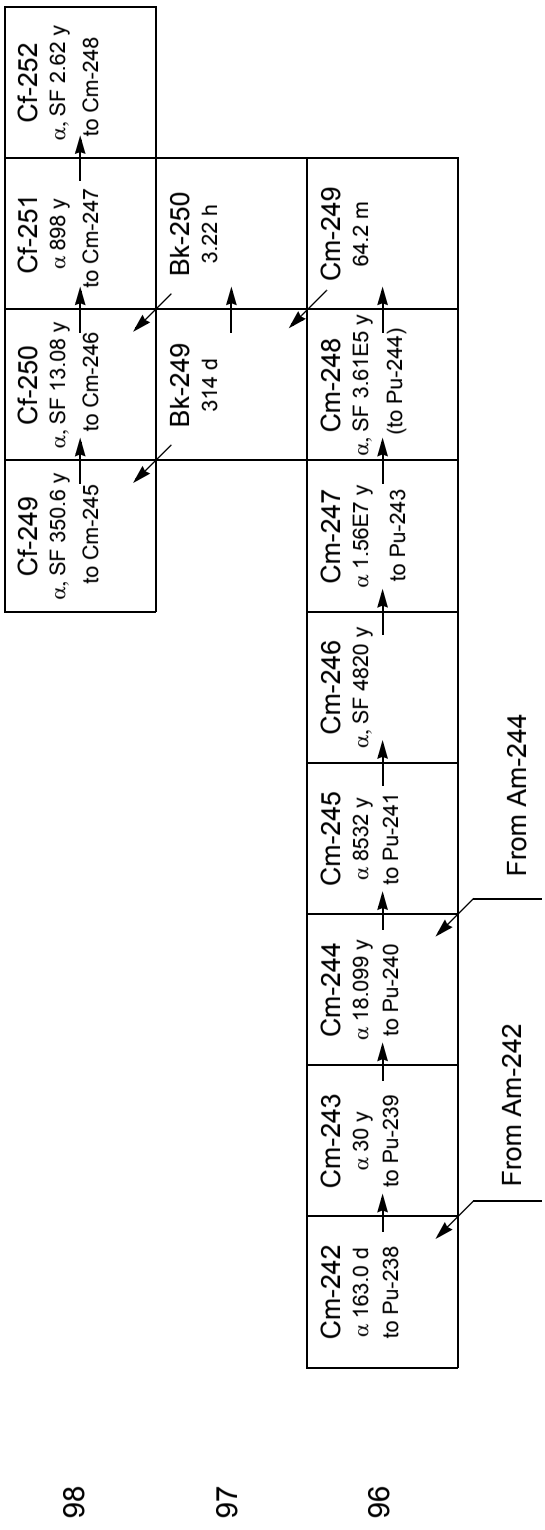


Fig. 7.2 E6 Heavy Nuclides: Upper Part (to Cf-252)

7.3 Fission Product Chains in E6

For fission products, a representation similar to the one for heavy nuclides has been chosen. The selected nuclides and their relations are shown in Figures 7.3 through 7.10. All significant fission products have been included. The position of a nuclide in the matrix determines whether cumulative or independent fission yield shall be used. For nuclides on the "southeast" edge of the matrix cumulative yield values are used. For all other nuclides (which lie "in the shadow" of those on the southeast edge) independent yield values are used. The selected structure and yield values give yield sums for each fission precursor very close to the theoretical value 2.0.

Certain information on decay modes, half lives, cross sections, branching ratios etc. is also given in Figures 7.3 through 7.10. When two half lives are given, they refer to metastable state and ground state respectively. Cross sections are (n,γ) 2200 m/s cross sections. Two cross sections with a comma between them refer to metastable state and ground state of the nuclide itself for production of the next higher nuclide. Two (or three) cross sections with plus sign(s) between them refer to production of metastable state(s) and ground state of the next higher nuclide.

The data given are approximate and do not necessarily agree with the data in the library.

Fig. 7.3 E6 Fission Products Mass Numbers 76-87

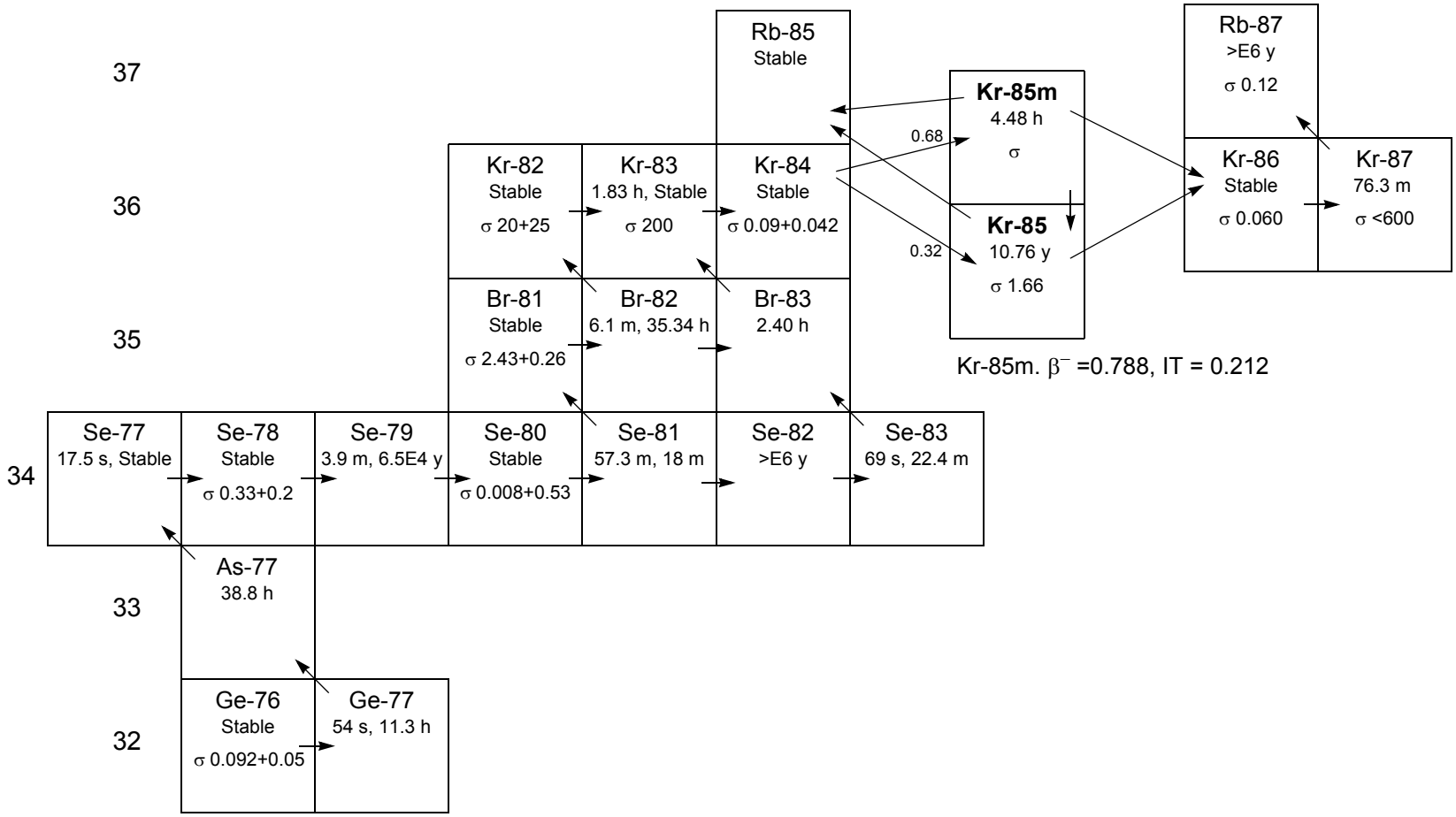


Fig. 7.4 E6 Fission Products Mass Numbers 88-100

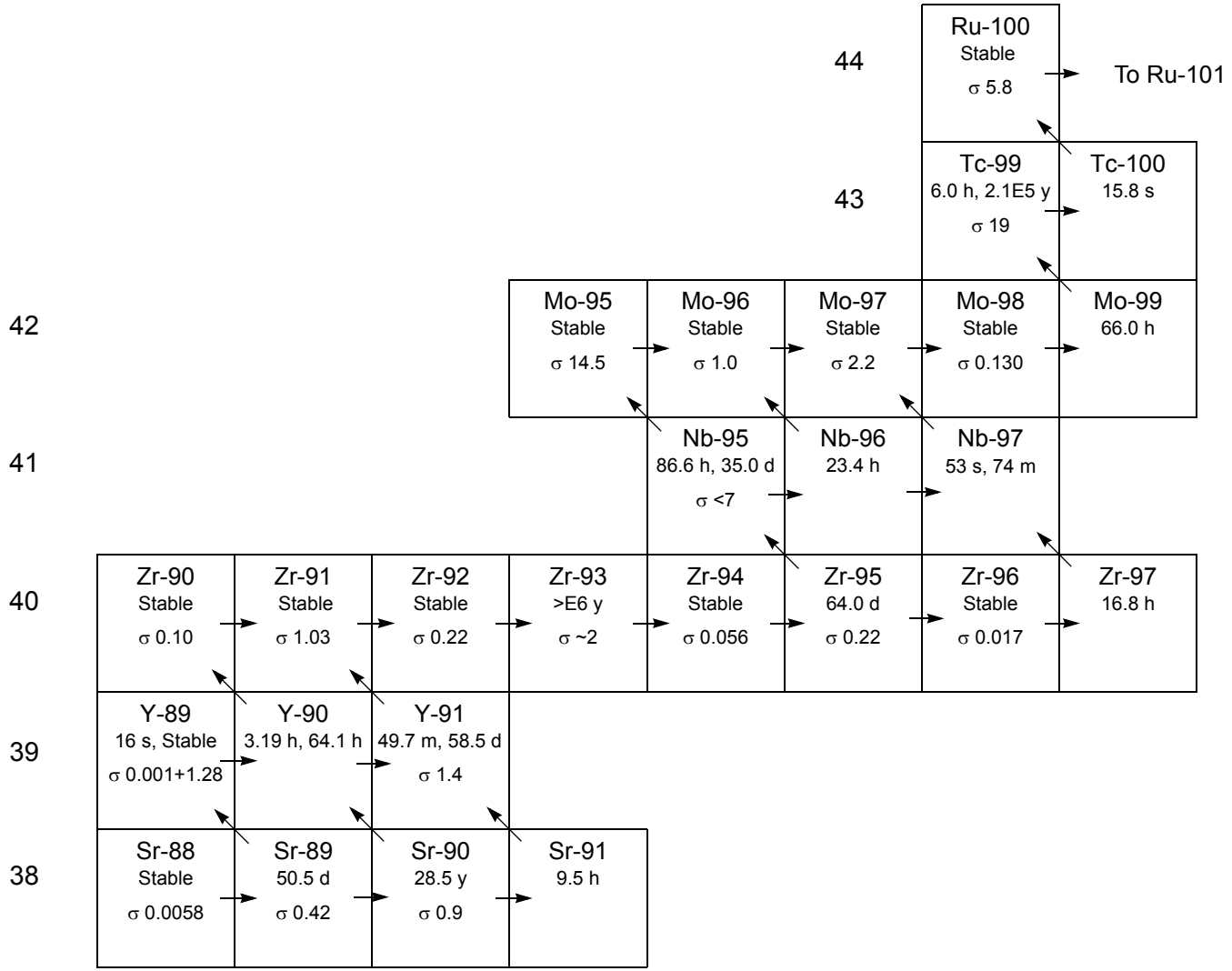


Fig. 7.5 E6 Fission Products Mass Numbers 100-110

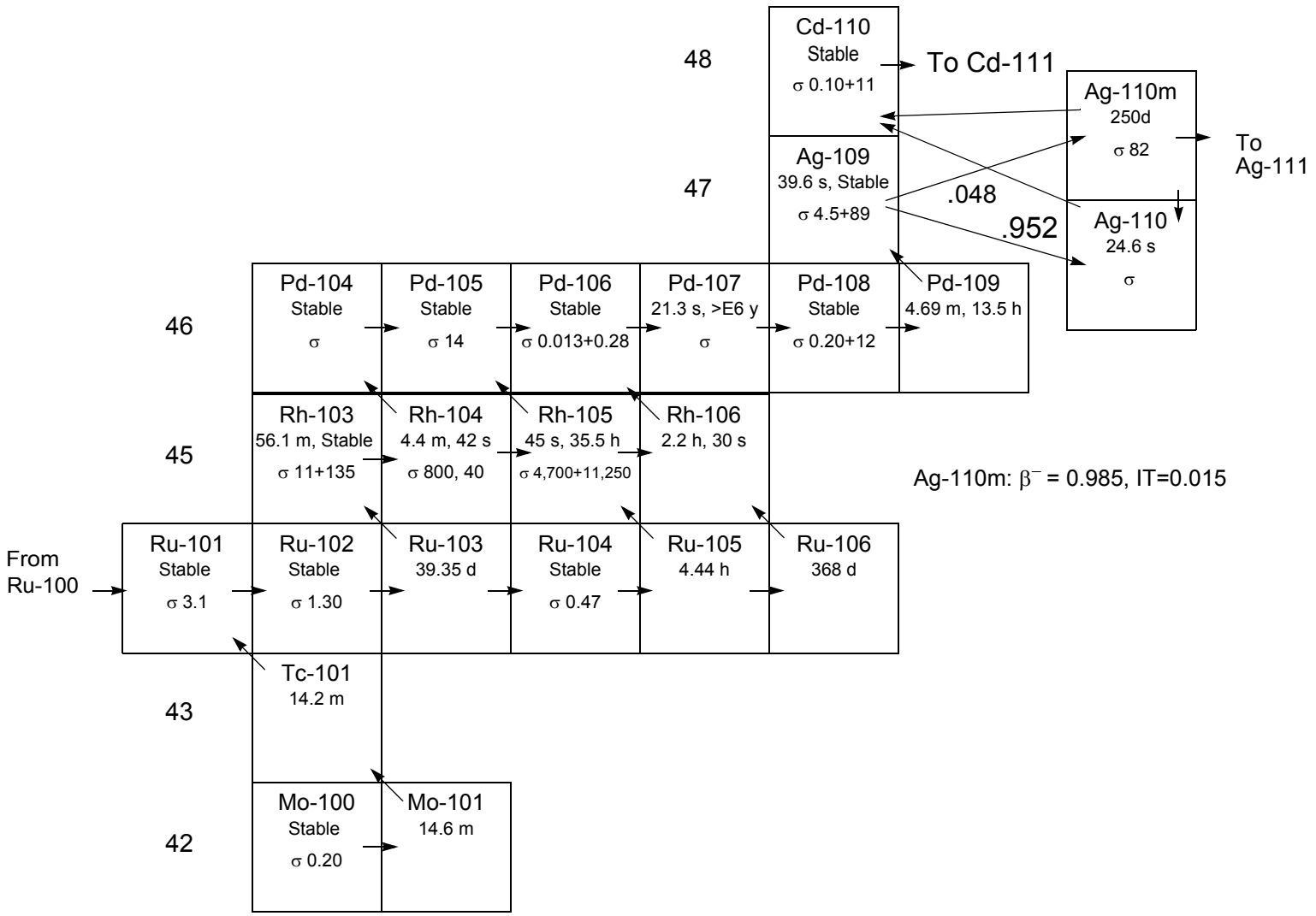


Fig. 7.6 E6 Fission Products Mass Numbers 110-121

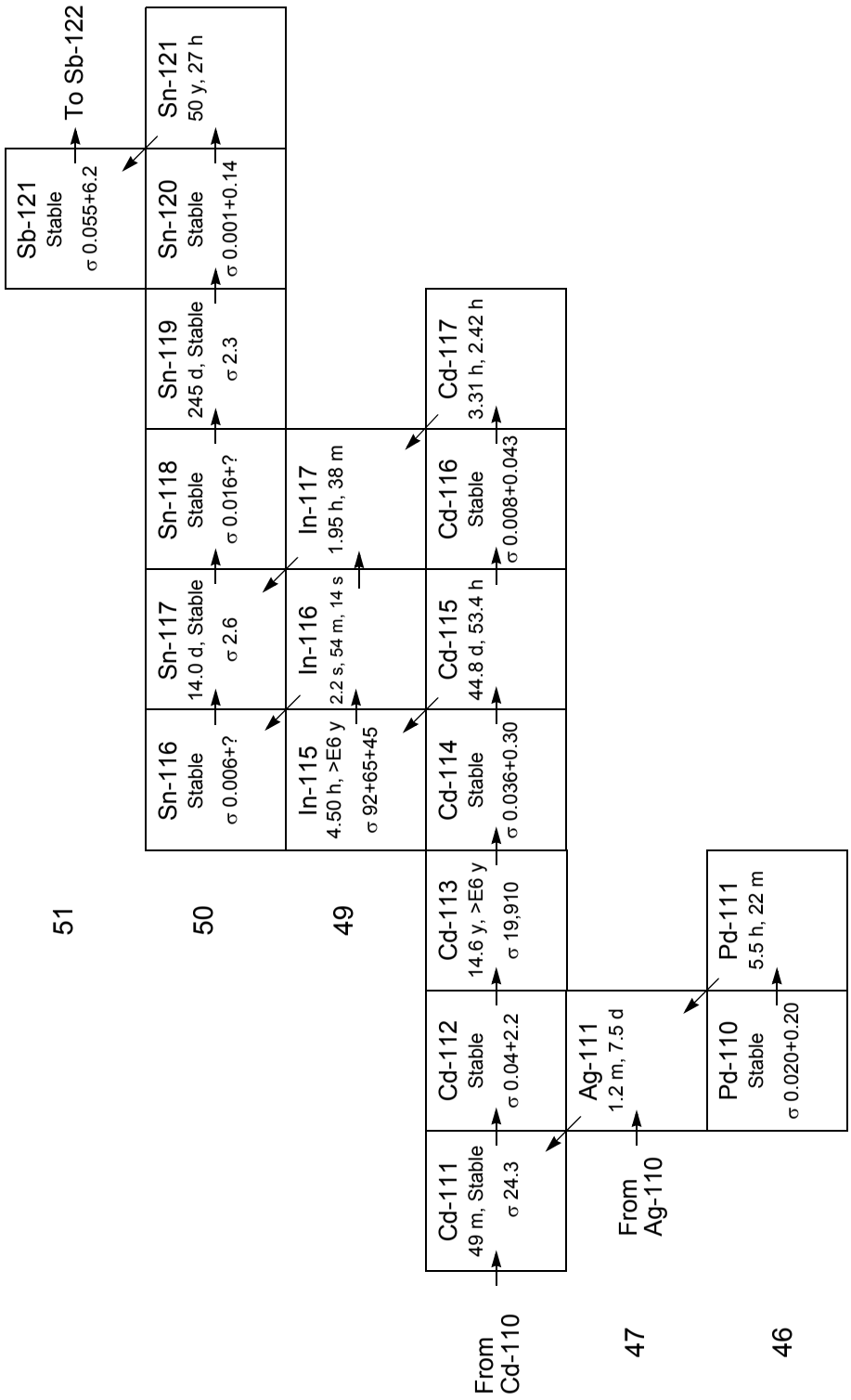
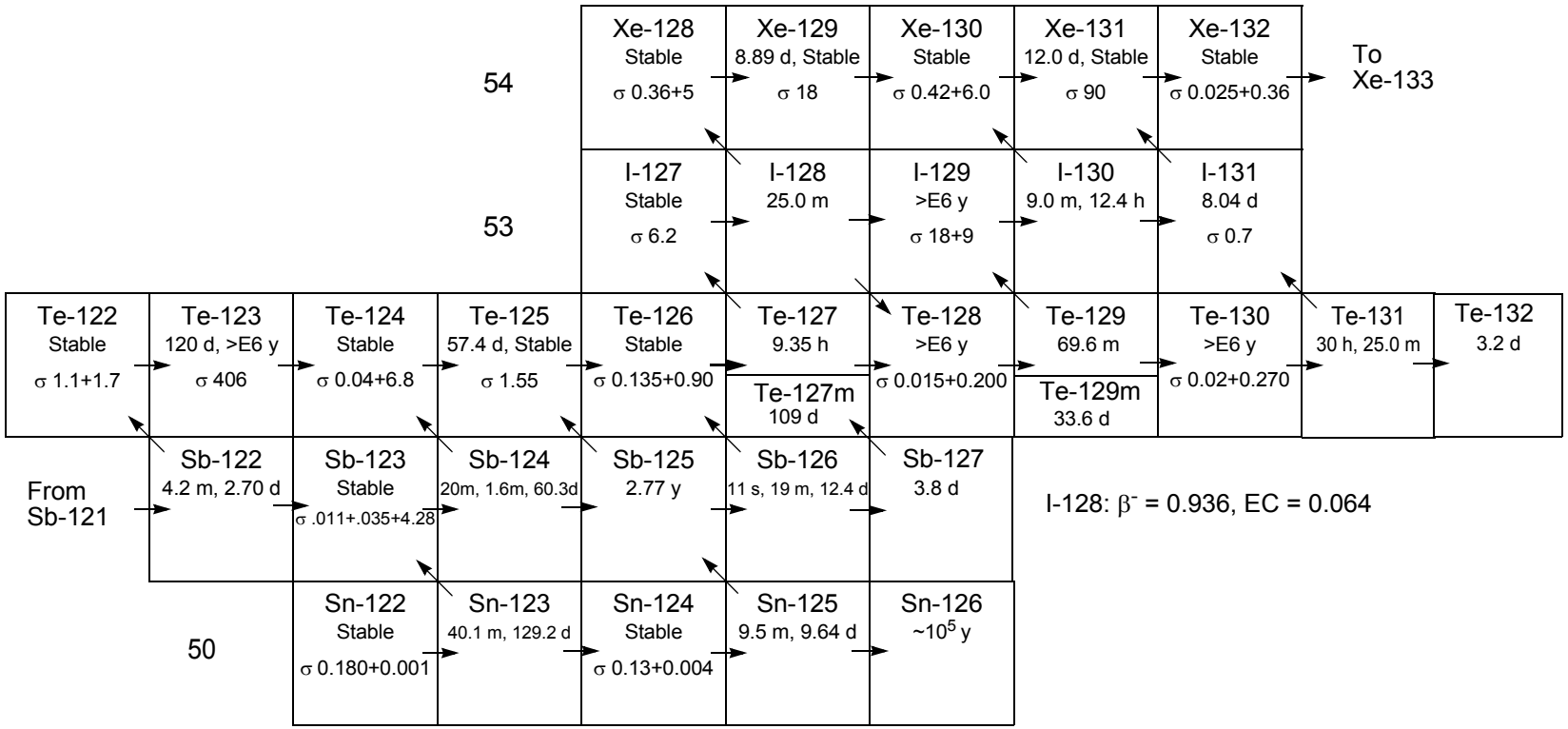


Fig. 7.7 E6 Fission Products Mass Numbers 122-132



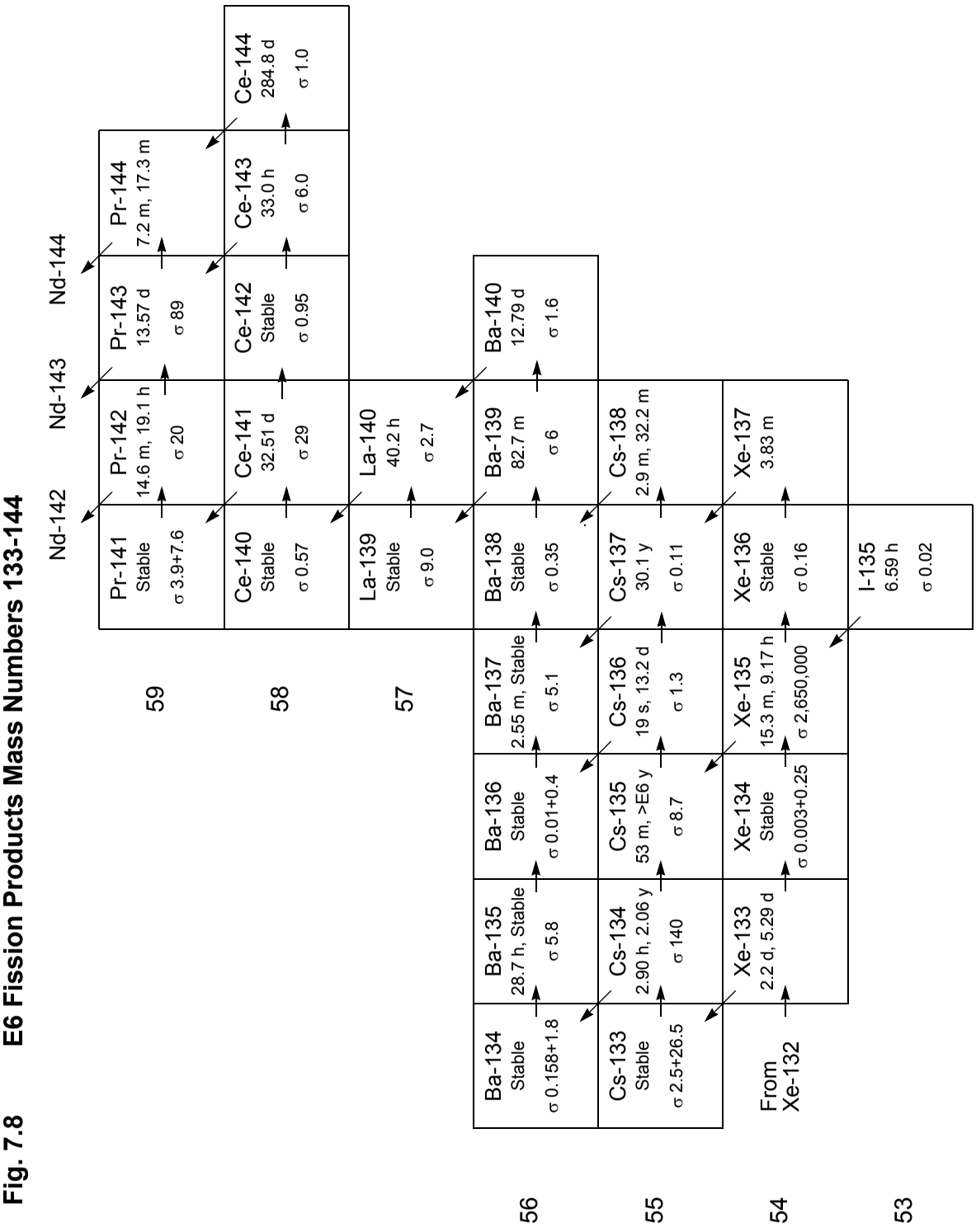


Fig. 7.8 E6 Fission Products Mass Numbers 133-144

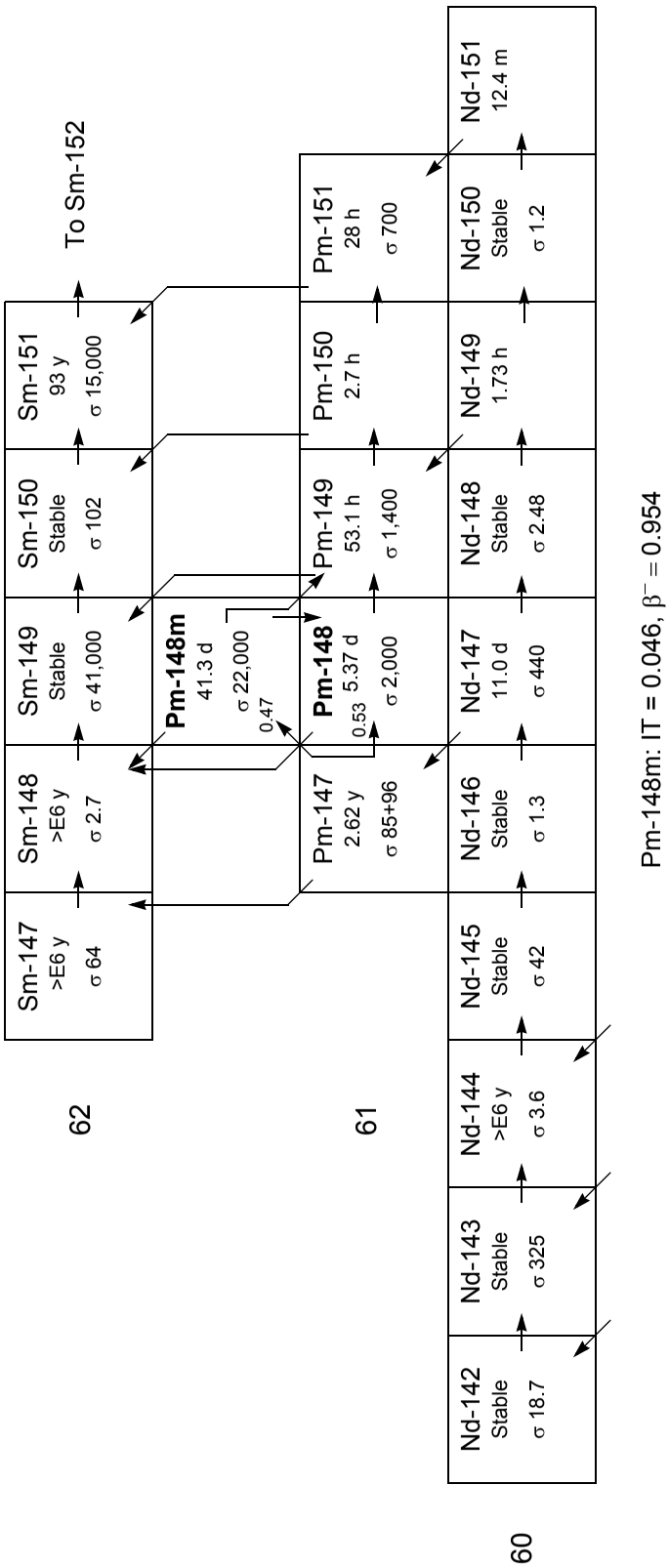
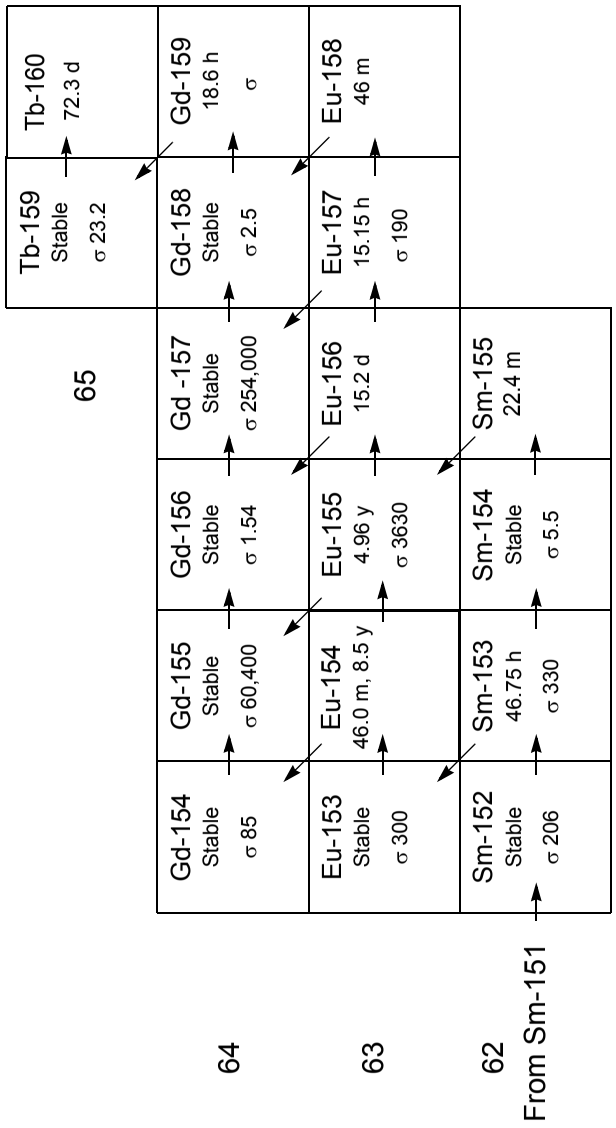


Fig. 7.9 E6 Fission Products Mass Numbers 142-151

Fig. 7.10 E6 Fission Products Mass Numbers 152-160



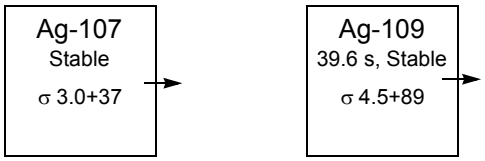
7.4 Burnable Absorber Chains in E6

The burnable absorber depletion chains are shown in Fig. 7.11 and 7.12 below. In this figure arrows leading out of each system have been shown to indicate removal by (n,γ) reaction or radioactive decay.

Fig. 7.11 E6 Burnable Absorbers: Ag, Cd, In

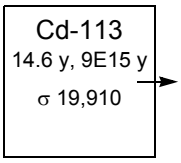
Ag

47



Cd-113

48



In-115

49

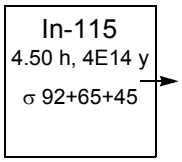
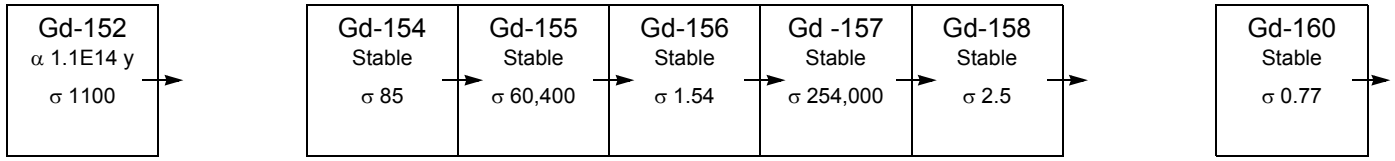
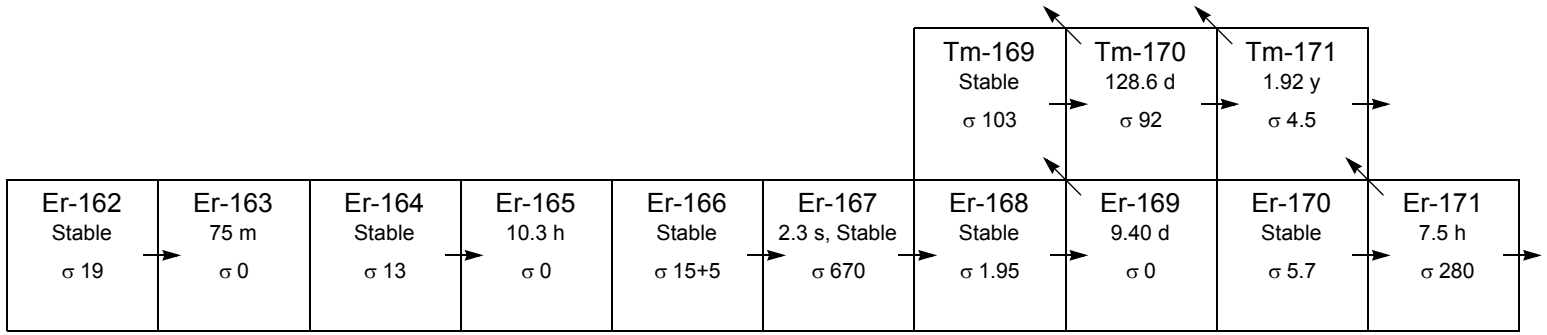


Fig. 7.12 E6 Burnable Absorbers: Gd, Er, Hf

Gd



Er



Hf