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THE EXCELL GEOMETRIES NUMBERING SCHEME IN DRAGON

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1 THE EXCELL 2-D NUMBERING SCHEME

In this section we will study the geometry numbering scheme used in the `EXCELT:` and `EXCELL:` modules of DRAGON for various types of 2-D Cartesian cells and assemblies.[1] As a result we will not discuss the cells or assemblies in an hexagonal geometry. Moreover, the cartesian cells which contain cluster sub-regions will not be discussed here. There are three reasons for this discussion. First, we will like to illustrate how the information generated in the DRAGON output file can be used to locate each region in the cell. The second reason is that a given geometry can often be described in DRAGON in many different ways but it numbering may differ depending on how it is initially defined. Finally, because of the possibility to use diagonal and cell center reflection conditions in the description of an assembly, it is not always evident where each region will end up after the cell unfolding has taken place.

1.1 Pure Cartesian cells and assemblies

We first considered the six different cells described in Figure 1 for which the DRAGON input is given below.

```
*----
*  GEOC1    :  1 REGION  2-D CELL
*  GEOA1    :  1 REGION  2-D 1 CELL ASSEMBLY
*----
GEOC1    := GEO: :: CAR2D 1 1
  X- REFL  MESHX 0.0 2.0 X+ REFL Y- REFL  MESHY 0.0 2.0 Y+ REFL
  MIX 1  ;
GEOA1    := GEO: :: CAR2D 1 1
  CELL GEOC1
  X- REFL  X+ REFL  Y- REFL  Y+ REFL
  ::: GEOC1   := GEO: CAR2D 1 1
    MESHX 0.0 2.0 MESHY 0.0 2.0 MIX 1 ;
  ;
*----
*  GEOC2    :  4 REGIONS 2-D CELL
*  GEOA2    :  4 REGIONS 2-D 1 CELL ASSEMBLY
*----
GEOC2    := GEO: :: CAR2D 2 2
  X- REFL MESHX 0.0 1.0 2.0 X+ REFL  Y- REFL MESHY 0.0 1.0 2.0 Y+ REFL
  MIX 1 1 1 1  ;
GEOA2    := GEO: :: CAR2D 1 1
  X- REFL  X+ REFL  Y- REFL  Y+ REFL
  CELL GEOC2
  ::: GEOC2   := GEO: CAR2D 2 2
    MESHX 0.0 1.0 2.0 MESHY 0.0 1.0 2.0 MIX 1 1 1 1 ;
  ;
*----
*  GEOC3    :  4 REGIONS 2-D CELL FROM SPLIT 2 OF GEOC1
*  GEOA3    :  4 REGIONS 2-D 1 CELL ASSEMBLY FROM SPLIT 2 OF GEOC1
*----
GEOC3    := GEO: GEOC1 ::
  SPLITX 2  SPLITY 2   ;
GEOA3    := GEO: GEOA1 ::
  ::: GEOC1 := GEO: GEOC1 SPLITX 2 SPLITY 2 ;
  ;
```

The first two geometries should be identical, namely they represent a one region cell. However, `GEOC1` has been defined using the pure cell geometry while `GEOA1` was defined using the assembly option of DRAGON. As one can see in Figure 1, they are indeed represented in DRAGON in exactly the same way. The next four geometries, namely `GEOC2`, `GEOA2`, `GEOC3`, `GEOA3`, are also identical since they correspond to a finer discretization of the cells `GEOC1` and `GEOA1`. For `GEOC2` and `GEOA2` the finer mesh was defined explicitly while for `GEOC3` and `GEOA3`, the automatic split options of DRAGON (`SPLITX` and `SPLITY`) were used to obtain this finer discretization. Again, as can be seen from Figure 1 these four geometries have the same final representation in DRAGON. In fact this is not surprising since in DRAGON the split options are processed for each cell individually before any other cell combination option is considered. Finally a typical DRAGON output for the cell `GEOC1` and `GEOA3` will look like:

```
 ECHO = >>> GEOMETRY NAME: GEOC1
  ====> GLOBAL MESHING
        X-COORDINATES:
            .0000  2.0000
        Y-COORDINATES:
            .0000  2.0000
 X-Y MESH
  ----------------------------
                -4
  ----------------------------
        -2        1       -3
  ----------------------------
                -1
  ----------------------------
 ECHO = >>> NB. OF REGIONS:     1


 ECHO = >>> GEOMETRY NAME: GEOA3
  ====> GLOBAL MESHING
        X-COORDINATES:
            .0000  1.0000  2.0000
        Y-COORDINATES:
            .0000  1.0000  2.0000
 X-Y MESH
  --------------------------------------
                -7        -8
  --------------------------------------
        -5        3         4        -6
  --------------------------------------
        -3        1         2        -4
  --------------------------------------
                -1        -2
  --------------------------------------
 ECHO = >>> NB. OF REGIONS:     4
```

where the notation is very similar to that described in Figure 1, namely the numbering runs from the left to the right and from the bottom to the top for regions and surfaces. Note that for these geometries the symmetry options (SYME and DIAG) are not supported since only one cell is considered in all cases.

We next considered the six different cells described in Figure 2 for which the DRAGON input is given below.

```
*----
*  GEOC4    :  9 REGIONS 2-D CELL
*  GEOA4    :  9 REGIONS 2-D 9 CELL ASSEMBLY
*  GEOA4X   :  6 REGIONS GEOA4 WITH X- SYME
*  GEOA4Y   :  6 REGIONS GEOA4 WITH X- SYME
*  GEOA4XY  :  4 REGIONS GEOA4 WITH X- SYME Y- SYME
*  GEOA4D   :  3 REGIONS GEOA4 WITH X- DIAG Y+ DIAG Y- SYME
*----
GEOC4    := GEO: :: CAR2D 3 3
  X- REFL  MESHX 0.0 1.0 2.0 3.0 X+ REFL
  Y- REFL  MESHY 0.0 1.0 2.0 3.0 Y+ REFL
  MIX 1 1 1 1 1 1 1 1 1  ;
GEOA4    := GEO: :: CAR2D 3 3
  CELL GEOC1 GEOC1 GEOC1 GEOC1 GEOC1 GEOC1 GEOC1 GEOC1 GEOC1
  X- REFL  X+ REFL Y- REFL  Y+ REFL
  ::: GEOC1   := GEO: CAR2D 1 1 MESHX 0.0 1.0 MESHY 0.0 1.0 MIX 1 ;
  ;
GEOA4X   := GEO: :: CAR2D 2 3
  CELL GEOC1 GEOC1 GEOC1 GEOC1 GEOC1 GEOC1
  X- SYME  X+ REFL Y- REFL  Y+ REFL
  ::: GEOC1   := GEO: CAR2D 1 1 MESHX 0.0 1.0 MESHY 0.0 1.0 MIX 1 ;
  ;
GEOA4Y   := GEO: :: CAR2D 3 2
  CELL GEOC1 GEOC1 GEOC1 GEOC1 GEOC1 GEOC1
  X- REFL  X+ REFL Y- SYME  Y+ REFL
  ::: GEOC1   := GEO: CAR2D 1 1 MESHX 0.0 1.0 MESHY 0.0 1.0 MIX 1 ;
  ;
GEOA4XY   := GEO: :: CAR2D 2 2
  CELL GEOC1 GEOC1 GEOC1 GEOC1
  X- SYME  X+ REFL Y- SYME  Y+ REFL
  ::: GEOC1   := GEO: CAR2D 1 1 MESHX 0.0 1.0 MESHY 0.0 1.0 MIX 1 ;
  ;
GEOA4D   := GEO: :: CAR2D 2 2
  CELL GEOC1 GEOC1 GEOC1
```

```
 X- DIAG  X+ REFL Y- SYME  Y+ DIAG
 ::: GEOC1   := GEO: CAR2D 1 1 MESHX 0.0 1.0 MESHY 0.0 1.0 MIX 1 ;
 ;
```

Again the first two geometries should be identical, namely they represent a 9 regions region cell. However, GEOC4 has been defined using the pure cell geometry while GEOA4 was defined using the assembly option of DRAGON. As one can see in Figure 2, they are indeed represented in DRAGON in exactly the same way. The next four geometries, namely GEOA4X, GEOA4Y, GEOA4XY and GEOA4D, show the effect of SYME and DIAG boundary conditions. The number of regions is dependent for these cases on the total assembly symmetry. The region numbering also starts at a different location depending on the specific symmetries used. In fact, the numbering follows the original cell order in the assembly before it is unfolded by the code. For example, for the GEOA4D geometry, the assembly was described in terms of only three cells which are located at position $(2,2)$, $(3,2)$ and $(3,3)$ along the $x-$ and $y-$ axis. The DRAGON output file will contain the following information for the GEOA4 and GEOA4D geometries.

```
ECHO = >>> GEOMETRY NAME: GEOA4
 ====> GLOBAL MESHING
       X-COORDINATES:
           .0000  1.0000  2.0000  3.0000
       Y-COORDINATES:
           .0000  1.0000  2.0000  3.0000
X-Y MESH
 ------------------------------------------------
                -9       -10       -12
 ------------------------------------------------
      -8         7         8         9       -11
 ------------------------------------------------
      -6         4         5         6        -7
 ------------------------------------------------
      -2         1         2         3        -5
 ------------------------------------------------
                -1        -3        -4
 ------------------------------------------------
ECHO = >>> NB. OF REGIONS:     9

ECHO = >>> GEOMETRY NAME: GEOA4D
 ====> GLOBAL MESHING
       X-COORDINATES:
           .0000  1.0000  2.0000  3.0000
       Y-COORDINATES:
           .0000  1.0000  2.0000  3.0000
X-Y MESH
 ------------------------------------------------
                -1        -2        -1
 ------------------------------------------------
      -1         3         2         3        -1
 ------------------------------------------------
      -2         2         1         2        -2
 ------------------------------------------------
      -1         3         2         3        -1
 ------------------------------------------------
                -1        -2        -1
 ------------------------------------------------
ECHO = >>> NB. OF REGIONS:     3
```

where the $x-y$ mesh description looks again very similar that described in Figure 2. Accordingly, for an assembly defined by cells which contain a single region the explicit numbering is also quite simple. However, in the case where the cells used in building the assembly are also subdivided the problem is more complex as will be illustrated by the six geometries described in Figure 3 will the cell limits indicated by thick lines. The DRAGON input for these geometries is given below.

```
*----
*  GEOC5    : 36 REGIONS 2-D CELL FROM SPLIT 2 OF GEOC4
*  GEOA5    : 36 REGIONS 2-D 9 CELL ASSEMBLY FROM SPLIT 2 OF GEOA4
*  GEOA5X   : 18 REGIONS GEOA5 WITH X- SYME
*  GEOA5Y   : 18 REGIONS GEOA5 WITH X- SYME
*  GEOA5XY  :  9 REGIONS GEOA5 WITH X- SYME Y- SYME
*  GEOA5D   :  6 REGIONS GEOA5 WITH X- DIAG Y+ DIAG Y- SYME
*----
```

```
GEOC5    := GEO: :: CAR2D 3 3
  X- REFL  MESHX 0.0 1.0 2.0 3.0 SPLITX 2 2 2 X+ REFL
  Y- REFL  MESHY 0.0 1.0 2.0 3.0 SPLITY 2 2 2 Y+ REFL
  MIX 1 1 1 1 1 1 1 1 1  ;
GEOA5    := GEO: :: CAR2D 3 3
  CELL GEOC1 GEOC1 GEOC1 GEOC1 GEOC1 GEOC1 GEOC1 GEOC1 GEOC1
  X- REFL  X+ REFL Y- REFL  Y+ REFL
  ::: GEOC1   := GEO: CAR2D 1 1
    MESHX 0.0 1.0 SPLITX 2 MESHY 0.0 1.0 SPLITY 2 MIX 1 ;
  ;
GEOA5X   := GEO: :: CAR2D 2 3
  CELL GEOC1 GEOC1 GEOC1 GEOC1 GEOC1 GEOC1
  X- SYME  X+ REFL Y- REFL  Y+ REFL
  ::: GEOC1   := GEO: CAR2D 1 1
    MESHX 0.0 1.0 SPLITX 2 MESHY 0.0 1.0 SPLITY 2 MIX 1 ;
  ;
GEOA5Y   := GEO: :: CAR2D 3 2
  CELL GEOC1 GEOC1 GEOC1 GEOC1 GEOC1 GEOC1
  X- REFL  X+ REFL Y- SYME  Y+ REFL
  ::: GEOC1   := GEO: CAR2D 1 1
    MESHX 0.0 1.0 SPLITX 2 MESHY 0.0 1.0 SPLITY 2 MIX 1 ;
  ;
GEOA5XY   := GEO: :: CAR2D 2 2
  CELL GEOC1 GEOC1 GEOC1 GEOC1
  X- SYME  X+ REFL Y- SYME  Y+ REFL
  ::: GEOC1   := GEO: CAR2D 1 1
    MESHX 0.0 1.0 SPLITX 2 MESHY 0.0 1.0 SPLITY 2 MIX 1 ;
  ;
GEOA5D   := GEO: :: CAR2D 2 2
  CELL GEOC1 GEOC1 GEOC1
  X- DIAG  X+ REFL Y- SYME  Y+ DIAG
  ::: GEOC1   := GEO: CAR2D 1 1
    MESHX 0.0 1.0 SPLITX 2 MESHY 0.0 1.0 SPLITY 2 MIX 1 ;
  ;
```

As one can see in Figure 3 even if the first two geometries (`GEOC5` and `GEOA5`) are identical, the numbering used in both cases are quite different. The reason is that each cells included in an assembly is first numbered independently using the same technique as that described above (region 1 to 4 for sub-geometry `GEOC1`). Then the global geometry is numbered by using an offset to displace all the region number associated with a specific cell to its adequate location in space. For the cell located at the position (I, J) in the assembly this offset $O_{I,J}$ is given by:

$$O_{I,J} = \sum_{i=1}^{I-1} \sum_{j=1}^{N_y} N_{i,j} + \sum_{j=1}^{J-1} N_{I,j}$$

where N_x and N_y represent respectively the number of cells in the x and y direction respectively and $N_{i,j}$ the number of region in the cell located at position (i, j) in the assembly. Similarly, for the surface of the full assembly the same technique is used provided the coupling surfaces between are eliminated properly. When the symmetries are taken into account, the region numbering also remains simple and is based on the initial location of each cell in the simplified input assembly description. However for the surfaces, the problem gets more complex since the surface number refers neither to the unfolded assembly surface numbering nor to a simplified input assembly numbering (see Figure 4 for the difference between the simplified input assembly numbering `GEO2DA5DNS` and the unfolded assembly numbering `GEO2DA5DNF`). The DRAGON output file will contain the following information for the `GEOA5` and `GEOA5D` geometries.

```
 ECHO = >>> GEOMETRY NAME: GEOA5
  ====> GLOBAL MESHING
        X-COORDINATES:
             .0000   .5000  1.0000  1.5000  2.0000  2.5000  3.0000
        Y-COORDINATES:
             .0000   .5000  1.0000  1.5000  2.0000  2.5000  3.0000
 X-Y MESH
  ---------------------------------------------------------------------------
                -17       -18       -19       -20       -23       -24
  ---------------------------------------------------------------------------
      -16        27        28        31        32        35        36       -22
  ---------------------------------------------------------------------------
```

```
      -15        25        26        29        30        33        34       -21
  ------------------------------------------------------------------------------
      -12        15        16        19        20        23        24       -14
  ------------------------------------------------------------------------------
      -11        13        14        17        18        21        22       -13
  ------------------------------------------------------------------------------
       -4         3         4         7         8        11        12       -10
  ------------------------------------------------------------------------------
       -3         1         2         5         6         9        10        -9
  ------------------------------------------------------------------------------
                 -1        -2        -5        -6        -7        -8
  ------------------------------------------------------------------------------
 ECHO = >>> NB. OF REGIONS:    36


 ECHO = >>> GEOMETRY NAME: GEOA5D
  ====> GLOBAL MESHING
       X-COORDINATES:
           .0000   .5000  1.0000  1.5000  2.0000  2.5000  3.0000
       Y-COORDINATES:
           .0000   .5000  1.0000  1.5000  2.0000  2.5000  3.0000
 X-Y MESH
  ------------------------------------------------------------------------------
                 -2        -1        -3        -3        -1        -2
  ------------------------------------------------------------------------------
       -2         6         5         3         3         5         6        -2
  ------------------------------------------------------------------------------
       -1         5         4         2         2         4         5        -1
  ------------------------------------------------------------------------------
       -3         3         2         1         1         2         3        -3
  ------------------------------------------------------------------------------
       -3         3         2         1         1         2         3        -3
  ------------------------------------------------------------------------------
       -1         5         4         2         2         4         5        -1
  ------------------------------------------------------------------------------
       -2         6         5         3         3         5         6        -2
  ------------------------------------------------------------------------------
                 -2        -1        -3        -3        -1        -2
  ------------------------------------------------------------------------------
ECHO = >>> NB. OF REGIONS:     6
```

1.2 Cartesian cells and assemblies with embedded annular region

Here we will first consider the case of a single cell which contains a central annular region. We also analyzed the effect of splitting both the cartesian and the annular part of this cell into two sub-regions. The DRAGON geometry input definition for these cases is:

```
*----
*  GEOAC1    :  2 REGION  2-D CELL
*  GEOAA1    :  2 REGION  2-D 1 CELL ASSEMBLY
*----
GEOAC1    := GEO: :: CARCEL 1
  X- REFL  MESHX 0.0 2.0 X+ REFL Y- REFL  MESHY 0.0 2.0 Y+ REFL
  RADIUS 0.0 0.75   MIX 1 1 ;
GEOAA1    := GEO: :: CAR2D 1 1
  CELL GEOAC1
  X- REFL  X+ REFL  Y- REFL  Y+ REFL
  ::: GEOAC1   := GEO: CARCEL 1
    MESHX 0.0 2.0 MESHY 0.0 2.0
    RADIUS 0.0 0.75 MIX 1 1 ;
  ;
*----
*  GEOAC2    : 12 REGIONS 2-D CELL FROM SPLIT 2 OF GEOAC1
*  GEOAA2    : 12 REGIONS 2-D 1 CELL ASSEMBLY FROM SPLIT 2 OF GEOAC1
*----
GEOAC2    := GEO: GEOAC1 ::
  SPLITX 2 SPLITY 2 SPLITR 2      ;
GEOAA2    := GEO: GEOAA1 ::
  ::: GEOAC1 := GEO: GEOAC1
    SPLITX 2 SPLITY 2 SPLITR 2    ;
  ;
```

where the cases GEOAC1 and GEOAC2 the models are defined in terms of pure geometries while for GEOAA1 and GEOAA2, the DRAGON assembly construction was used. As in the previous section, the two different methods gives exactly the same result. One can see in Figure 5 that for the each location (i, j) of the mesh in the cartesian plane, the most internal annular regions are numbered first, then one moves radially outward until the cartesian part of the mesh is reached. Again, one starts in the lower left corner of the Cartesian mesh, moves in the positive x direction, and then in the positive y direction to finish at the upper right corner of the mesh. One can easily locate the number associated with the annular sub-region k in mesh (i, j) using:

$$N_{i,j,k} = (i-1)N_j(N_k+1) + (j-1)(N_k+1) + k$$

for a mesh with N_i x intervals, N_j y intervals and N_k annular regions in each Cartesian mesh. Also note that the region number associated with the Cartesian part of the mesh can be obtained using $k = N_k + 1$ in the relation above. The surface numbering in this case is identical to that considered in the previous section since no annular region will ever encounter an external surface. The DRAGON output file for these geometry will contain the following information for `GEOAC1` and `GEOAA2`

```
ECHO = >>> GEOMETRY NAME: GEOAC1
 ====> GLOBAL MESHING
       X-COORDINATES:
           .0000  2.0000
       Y-COORDINATES:
           .0000  2.0000
       CELL(   1,   1,   1)  (X,Y)- CENTRE: (  1.0000  1.0000)
                         RADII:
                            .7500
X-Y MESH
 ----------------------------
               -4
           ABSENT
 ----------------------------
       -2         2        -3
   ABSENT         1    ABSENT
 ----------------------------
               -1
           ABSENT
 ----------------------------
ECHO = >>> NB. OF REGIONS:     2


ECHO = >>> GEOMETRY NAME: GEOAA2
 ====> GLOBAL MESHING
       X-COORDINATES:
           .0000  1.0000  2.0000
       Y-COORDINATES:
           .0000  1.0000  2.0000
       CELL(   1,   1,   1)  (X,Y)- CENTRE: (  1.0000  1.0000)
                         RADII:
                            .3750   .7500
X-Y MESH
 --------------------------------------
               -7        -8
           ABSENT    ABSENT
           ABSENT    ABSENT
 --------------------------------------
       -5         9        12        -6
   ABSENT         8        11    ABSENT
   ABSENT         7        10    ABSENT
 --------------------------------------
       -3         3         6        -4
   ABSENT         2         5    ABSENT
   ABSENT         1         4    ABSENT
 --------------------------------------
               -1        -2
           ABSENT    ABSENT
           ABSENT    ABSENT
 --------------------------------------
ECHO = >>> NB. OF REGIONS:    12
```

Note that the region are classified in the following way. The first line represent the Cartesian mesh point while the second and third line represents respectively the outer and inner annular regions. The word `ABSENT` means that the corresponding region is not numbered since such a region does not exists. This is the case for the surfaces associated with the annular part of the mesh in the case above.

The second set of geometries we will considered is illustrated in Figure 6. It consists in two similar assemblies which differs only by the use of boundary conditions. For the first geometry `GEOAC3`, a complete cell is considered while for `GEOAA3`, the `SYME` and `DIAG` symmetries conditions have been used. The DRGON geometry input data for these geometries is given as

```
*----
*  GEOAA3    : 14 REGIONS 2-D 9 CELL ASSEMBLY
*  GEOAA3D   :  5 REGIONS GEOAA3 WITH X- DIAG Y+ DIAG Y- SYME
*----
GEOAA3    := GEO: :: CAR2D 3 3
  CELL GEOAC1 GEOAC2 GEOAC1 GEOAC2 GEOAC1 GEOAC2 GEOAC1 GEOAC2 GEOAC1
  X- REFL  X+ REFL  Y- REFL  Y+ REFL
  ::: GEOAC1   := GEO: CARCEL 1
    MESHX 0.0 1.0    MESHY 0.0 1.0
    RADIUS 0.0 0.3   MIX 1 1  ;
  ::: GEOAC2   := GEO: CAR2D 1 1
    MESHX 0.0 1.0    MESHY 0.0 1.0 MIX 1  ;
  ;
GEOAA3D   := GEO: :: CAR2D 2 2
  CELL GEOAC1 GEOAC2 GEOAC1
  X- DIAG  X+ REFL  Y- SYME  Y+ DIAG
  ::: GEOAC1   := GEO: CARCEL 1
    MESHX 0.0 1.0    MESHY 0.0 1.0
    RADIUS 0.0 0.3   MIX 1 1  ;
  ::: GEOAC2   := GEO: CAR2D 1 1
    MESHX 0.0 1.0    MESHY 0.0 1.0 MIX 1  ;
  ;
```

while the DRAGON output file will contain the following information:

```
 ECHO = >>> GEOMETRY NAME: GEOAA3
  ====> GLOBAL MESHING
        X-COORDINATES:
            .0000  1.0000  2.0000  3.0000
        Y-COORDINATES:
            .0000  1.0000  2.0000  3.0000
        CELL(   1,   1,   1)  (X,Y)- CENTRE: (   .5000   .5000)
                          RADII:
                             .3000
        CELL(   3,   1,   1)  (X,Y)- CENTRE: (  2.5000   .5000)
                          RADII:
                             .3000
        CELL(   2,   2,   1)  (X,Y)- CENTRE: (  1.5000  1.5000)
                          RADII:
                             .3000
        CELL(   1,   3,   1)  (X,Y)- CENTRE: (   .5000  2.5000)
                          RADII:
                             .3000
        CELL(   3,   3,   1)  (X,Y)- CENTRE: (  2.5000  2.5000)
                          RADII:
                             .3000
 X-Y MESH
  ------------------------------------------------
                -9       -10       -12
            ABSENT    ABSENT    ABSENT
  ------------------------------------------------
        -8        11        12        14       -11
    ABSENT        10    ABSENT        13    ABSENT
  ------------------------------------------------
        -6         6         8         9        -7
    ABSENT    ABSENT         7    ABSENT    ABSENT
  ------------------------------------------------
        -2         2         3         5        -5
    ABSENT         1    ABSENT         4    ABSENT
  ------------------------------------------------
                -1        -3        -4
            ABSENT    ABSENT    ABSENT
  ------------------------------------------------
 ECHO = >>> NB. OF REGIONS:    14


 ECHO = >>> GEOMETRY NAME: GEOAA3D
  ====> GLOBAL MESHING
        X-COORDINATES:
            .0000  1.0000  2.0000  3.0000
```

```
       Y-COORDINATES:
           .0000  1.0000  2.0000  3.0000
       CELL(   1,   1,   1)  (X,Y)- CENTRE: (   .5000   .5000)
                         RADII:
                            .3000
       CELL(   3,   1,   1)  (X,Y)- CENTRE: (  2.5000   .5000)
                         RADII:
                            .3000
       CELL(   2,   2,   1)  (X,Y)- CENTRE: (  1.5000  1.5000)
                         RADII:
                            .3000
       CELL(   1,   3,   1)  (X,Y)- CENTRE: (   .5000  2.5000)
                         RADII:
                            .3000
       CELL(   3,   3,   1)  (X,Y)- CENTRE: (  2.5000  2.5000)
                         RADII:
                            .3000
 X-Y MESH
  ------------------------------------------------
                -1         -2         -1
            ABSENT     ABSENT     ABSENT
  ------------------------------------------------
        -1          5          3          5         -1
    ABSENT          4     ABSENT          4     ABSENT
  ------------------------------------------------
        -2          3          2          3         -2
    ABSENT     ABSENT          1     ABSENT     ABSENT
  ------------------------------------------------
        -1          5          3          5         -1
    ABSENT          4     ABSENT          4     ABSENT
  ------------------------------------------------
                -1         -2         -1
            ABSENT     ABSENT     ABSENT
  ------------------------------------------------
 ECHO = >>> NB. OF REGIONS:     5
```

Here the region and surface numbering is similar to that used for `GEOC4` and `GEOA4` in Figure 2 apart from the additional presence on the annular regions which are always numbered first inside any cell of an assembly. Also note that the DRAGON output file shows quite clearly the location of the various annular regions and also indicate with the `ABSENT` the cells where such annular regions are absent.

The final two geometries we will consider are related to the geometries `GEOAC3` and `GEOAA3` described above. They are illustrated in Figure 7 and 8. The main difference between these two geometries is the use of a fine mesh discretization in the second cell and the use of symmetries conditions. The input files for these geometries are of the form:

```
*----
*  GEOAA4    : 18 REGIONS 2-D CELL ASSEMBLY
*  GEOAA4D   : 38 REGIONS GEOAA4 WITH SPLIT AND SYMMETRIES
*----
GEOAA4    := GEO: :: CAR2D 3 3
  X- REFL  X+ REFL Y- REFL  Y+ REFL  CELL  F F F F P F F F F
  ::: F := GEO: CARCEL 1 RADIUS 0.000 0.52 MIX 2  1
    MESHX -0.625 0.625 MESHY -0.625  0.625           ;
  ::: P := GEO: CARCEL 1 RADIUS 0.000 0.52 MIX 3  1
    MESHX -0.625 0.625 MESHY -0.625 0.625            ;
  ;
GEOAA4D   := GEO: :: CAR2D 2 2
  X- DIAG  X+ REFL Y- SYME  Y+ DIAG  CELL  P F F
  ::: F := GEO: CARCEL 1 RADIUS 0.000 0.52 MIX 2  1
    MESHX -0.625 0.625 SPLITX 4 MESHY -0.625 0.625 SPLITY 4 ;
  ::: P := GEO: CARCEL 3 RADIUS 0.000 0.15 0.30 0.52 MIX 3 3 3 1
    MESHX -0.625 0.625 SPLITX 4 MESHY -0.625 0.625 SPLITY 4 ;
  ;
```

As one can see in Figure 7 the numbering of `GEOAC4` is very simple as illustrated in the output file:

```
 ECHO = >>> GEOMETRY NAME: GEOAA4
  ====> GLOBAL MESHING
       X-COORDINATES:
           .0000  1.2500  2.5000  3.7500
       Y-COORDINATES:
           .0000  1.2500  2.5000  3.7500
       CELL(   1,   1,   1)  (X,Y)- CENTRE: (   .6250   .6250)
```

```
                       RADII:
                          .5200
       CELL(   2,   1,   1)  (X,Y)- CENTRE: (  1.8750   .6250)
                       RADII:
                          .5200
       CELL(   3,   1,   1)  (X,Y)- CENTRE: (  3.1250   .6250)
                       RADII:
                          .5200
       CELL(   1,   2,   1)  (X,Y)- CENTRE: (   .6250  1.8750)
                       RADII:
                          .5200
       CELL(   2,   2,   1)  (X,Y)- CENTRE: (  1.8750  1.8750)
                       RADII:
                          .5200
       CELL(   3,   2,   1)  (X,Y)- CENTRE: (  3.1250  1.8750)
                       RADII:
                          .5200
       CELL(   1,   3,   1)  (X,Y)- CENTRE: (   .6250  3.1250)
                       RADII:
                          .5200
       CELL(   2,   3,   1)  (X,Y)- CENTRE: (  1.8750  3.1250)
                       RADII:
                          .5200
       CELL(   3,   3,   1)  (X,Y)- CENTRE: (  3.1250  3.1250)
                       RADII:
                          .5200
X-Y MESH
 ------------------------------------------------
                -9       -10       -12
            ABSENT    ABSENT    ABSENT
 ------------------------------------------------
       -8       14        16        18       -11
   ABSENT       13        15        17    ABSENT
 ------------------------------------------------
       -6        8        10        12        -7
   ABSENT        7         9        11    ABSENT
 ------------------------------------------------
       -2        2         4         6        -5
   ABSENT        1         3         5    ABSENT
 ------------------------------------------------
                -1        -3        -4
            ABSENT    ABSENT    ABSENT
 ------------------------------------------------
ECHO = >>> NB. OF REGIONS:    18
```

However, for GEOAA4 the notation is much more complex as can be seen in Figure 8 even if the numbering method remains identical. The output file will also look more complex will look like

```
X-Y MESH
----------------------------------------------------------------------
       -6        -5        -1        -2        -3        -4
   ABSENT    ABSENT    ABSENT    ABSENT    ABSENT    ABSENT
   ABSENT    ABSENT    ABSENT    ABSENT    ABSENT    ABSENT
   ABSENT    ABSENT    ABSENT    ABSENT    ABSENT    ABSENT
----------------------------------------------------------------------
       13        21        29        33        36        38        -4
   ABSENT    ABSENT    ABSENT    ABSENT    ABSENT    ABSENT    ABSENT
   ABSENT    ABSENT    ABSENT    ABSENT    ABSENT    ABSENT    ABSENT
       12        20        28        32        35        37    ABSENT
----------------------------------------------------------------------
   ABSENT        19        27    ABSENT    ABSENT        36        -3
   ABSENT    ABSENT    ABSENT    ABSENT    ABSENT    ABSENT    ABSENT
   ABSENT    ABSENT    ABSENT    ABSENT    ABSENT    ABSENT    ABSENT
       11        18        26        31        34        35    ABSENT
----------------------------------------------------------------------
   ABSENT        17        25    ABSENT    ABSENT        33        -2
   ABSENT    ABSENT    ABSENT    ABSENT    ABSENT    ABSENT    ABSENT
   ABSENT    ABSENT    ABSENT    ABSENT    ABSENT    ABSENT    ABSENT
       10        16        24        30        31        32    ABSENT
----------------------------------------------------------------------
        9        15        23        25        27        29        -1
   ABSENT    ABSENT    ABSENT    ABSENT    ABSENT    ABSENT    ABSENT
   ABSENT    ABSENT    ABSENT    ABSENT    ABSENT    ABSENT    ABSENT
        8        14        22        24        26        28    ABSENT
----------------------------------------------------------------------
        5         7        15        17        19        21        -5
        4         6    ABSENT    ABSENT    ABSENT    ABSENT    ABSENT
```

```
    ABSENT    ABSENT    ABSENT    ABSENT    ABSENT    ABSENT    ABSENT
    ABSENT    ABSENT        14        16        18        20    ABSENT
----------------------------------------------------------------------
    ABSENT         5         9    ABSENT    ABSENT        13        -6
         3         4    ABSENT    ABSENT    ABSENT    ABSENT    ABSENT
         2    ABSENT    ABSENT    ABSENT    ABSENT    ABSENT    ABSENT
         1    ABSENT         8        10        11        12    ABSENT
----------------------------------------------------------------------

 ECHO = >>> NB. OF REGIONS:    38
```

when only the upper right quarter of the assembly is considered. A few comments are required to understand correctly this output. First, the number of possible annular regions in each cell is equal to the maximum number of annular regions in a single cell. This is why there are always 3 possible annular regions in every cell even if only the central cell contains such a number of annular regions. A second comment is that for the regions with a single annular region this region is associated with the most internal annular region of the central cell even if this region has the same outer radius as the most external annular region of the first cell. The reason for this is that the annular regions are classified by order of decreasing radius and the third annular region of the first cell correspond just like the first annular region of the other cell to the most internal annular region. As a result, for all the cells except the central one, the second and third line will always indicate that such annular regions in the cell are `ABSENT`.

A second comment concerns the fact that for some cells (like the central cell) there is no region number associated with the cartesian mesh. This means that the final region in this cell, even if it has an external cartesian boundary (see Figure 8), is totally enclosed in an annular region. As a result, the material associated with this region will be that associated with the most outer annular region reached and not that associated with the Cartesian part of the cell. Again, as for all the two dimensional test cases presented, there is no external surface associated with annular regions. The numbering of these regions, always follows the pattern described in Section 1.2.

2 THE EXCELL 3-D NUMBERING SCHEME

In this section we will study the numbering scheme used for 3-D Cartesian cells and assemblies in the EXCELT: and EXCELL: modules of DRAGON.[1] The main difference between these cells and those presented in the previous section will be the possible presence of external surfaces which include annular sub-regions. There will also be the added difficulty of illustrating correctly these 3-D geometries using a 2-D graphical interface when Cartesian cells contains embedded cylindrical sub-regions.

2.1 Pure Cartesian cells and assemblies

In this section we will first consider simple 3-D extensions of the 2-D cells described in Figure 1. The first four geometries we will consider are defined in DRAGON using the following data:

```
*----
*  GEOC1    :  1 REGION  3-D CELL
*  GEOA1    :  1 REGION  3-D 1 CELL ASSEMBLY
*----
GEOC1    := GEO: :: CAR3D 1 1 1
  X- REFL  X+ REFL Y- REFL  Y+ REFL Z- REFL  Z+ REFL
  MESHX 0.0 2.0    MESHY 0.0 2.0    MESHZ 0.0 2.0
  MIX 1  ;
GEOA1    := GEO: :: CAR3D 1 1 1
  CELL GEOC1
  X- REFL  X+ REFL Y- REFL  Y+ REFL Z- REFL  Z+ REFL
  ::: GEOC1   := GEO: CAR3D 1 1 1
    MESHX 0.0 2.0  MESHY 0.0 2.0  MESHZ 0.0 2.0
    MIX 1    ;
  ;
*----
*  GEOC3    :  8 REGIONS 3-D CELL FROM SPLIT 2 OF GEOC1
*  GEOA3    :  8 REGIONS 3-D 1 CELL ASSEMBLY FROM SPLIT 2 OF GEOA1
*----
GEOC3    := GEO: GEOC1 ::
  SPLITX 2  SPLITY 2   SPLITZ 2   ;
GEOA3    := GEO: GEOA1 ::
  ::: GEOC1 := GEO: GEOC1
    SPLITX 2  SPLITY 2   SPLITZ 2     ;
  ;
```

which are similar to the geometries with the same name defined in Section 1.1, apart from their extension in the z direction. The region numbering schemes for GEOC1 and GEOA1 are also identical to those obtained for the 2-D case (a single region in each cell). However, the surface numbering scheme is somewhat different since one starts on the bottom z surface, then moves in the z plane to finish on the top z surface as can be seen in Figure 9. The equivalent DRAGON output file will present the following information:

```
 ECHO = >>> GEOMETRY NAME: GEOA1
  ====> GLOBAL MESHING
        X-COORDINATES:
            .0000  2.0000
        Y-COORDINATES:
            .0000  2.0000
        Z-COORDINATES:
            .0000  2.0000
 X-Y MESH ON TOP Z-SURFACE
  ----------------------------

  ----------------------------
                -6
  ----------------------------

  ----------------------------
 X-Y MESH IN Z-PLANE =          1
  ----------------------------
                -5
  ----------------------------
        -3         1        -4
  ----------------------------
```

```
                -2
 ----------------------------
X-Y MESH ON BOTTOM Z-SURFACE
 ----------------------------

 ----------------------------
                -1
 ----------------------------

 ----------------------------
ECHO = >>> NB. OF REGIONS:     1
```

Similarly, the DRAGON region and surface numbers associated with the geometries GEOC3 and GEOA3 are presented in Figure 10 for the various 2-D planes and the top and bottom surfaces for the geometry described in Figure 11. Typically, the DRAGON output associated with this geometry will look like:

```
ECHO = >>> GEOMETRY NAME: GEOA3
 ====> GLOBAL MESHING
       X-COORDINATES:
           .0000  1.0000  2.0000
       Y-COORDINATES:
           .0000  1.0000  2.0000
       Z-COORDINATES:
           .0000  1.0000  2.0000
X-Y MESH ON TOP Z-SURFACE
 --------------------------------------

 --------------------------------------
               -23       -24
 --------------------------------------
               -21       -22
 --------------------------------------

 --------------------------------------
X-Y MESH IN Z-PLANE =          2
 --------------------------------------
               -19       -20
 --------------------------------------
     -17         7         8       -18
 --------------------------------------
     -15         5         6       -16
 --------------------------------------
               -13       -14
 --------------------------------------
X-Y MESH IN Z-PLANE =          1
 --------------------------------------
               -11       -12
 --------------------------------------
      -9         3         4       -10
 --------------------------------------
      -7         1         2        -8
 --------------------------------------
                -5        -6
 --------------------------------------
X-Y MESH ON BOTTOM Z-SURFACE
 --------------------------------------

 --------------------------------------
                -3        -4
 --------------------------------------
                -1        -2
 --------------------------------------

 --------------------------------------
ECHO = >>> NB. OF REGIONS:     8
```

where the notation is similar to that described in Figure 10.

The last case we will consider is the assembly GEOA5 composed of 27 cells (each subdivided into 8 independent regions) presented in Figure 12. As shown in the next DRAGON geometry descriptions:

```
*----
*  GEOA5    : 216 REGIONS 3-D 27 CELL ASSEMBLY FROM SPLIT 2
*  GEOA5SB  : 27 REGIONS 3-D CELL WITH X- SYME Y- SYME Z- SYME
*  GEOA5ST  : 27 REGIONS 3-D CELL WITH X+ SYME Y+ SYME Z+ SYME
```

```
*----
GEOA5    := GEO: :: CAR3D 3 3 3
  X- REFL  X+ REFL Y- REFL  Y+ REFL Z- REFL  Z+ REFL
  CELL GEOC1 GEOC1 GEOC1 GEOC1 GEOC1 GEOC1 GEOC1 GEOC1 GEOC1
       GEOC1 GEOC1 GEOC1 GEOC1 GEOC1 GEOC1 GEOC1 GEOC1 GEOC1
       GEOC1 GEOC1 GEOC1 GEOC1 GEOC1 GEOC1 GEOC1 GEOC1 GEOC1
  ::: GEOC1   := GEO: CAR3D 1 1 1
    MESHX 0.0 1.0 MESHY 0.0 1.0 MESHZ 0.0 1.0
    SPLITX 2 SPLITY 2 SPLITZ 2
    MIX 1    ;
  ;
GEOA5SB   := GEO: :: CAR3D 2 2 2
  X- SYME  X+ REFL Y- SYME  Y+ REFL Z- SYME  Z+ REFL
  CELL GEOC1 GEOC1 GEOC1 GEOC1
       GEOC1 GEOC1 GEOC1 GEOC1
  ::: GEOC1   := GEO: CAR3D 1 1 1
    MESHX 0.0 1.0 MESHY 0.0 1.0 MESHZ 0.0 1.0
    SPLITX 2 SPLITY 2 SPLITZ 2
    MIX 1    ;
  ;
GEOA5ST   := GEO: :: CAR3D 2 2 2
  X- REFL X+ SYME Y- REFL Y+ SYME REFL Z- REFL Z+ SYME
  CELL GEOC1 GEOC1 GEOC1 GEOC1
       GEOC1 GEOC1 GEOC1 GEOC1
  ::: GEOC1   := GEO: CAR3D 1 1 1
    MESHX 0.0 1.0 MESHY 0.0 1.0 MESHZ 0.0 1.0
    SPLITX 2 SPLITY 2 SPLITZ 2
    MIX 1    ;
  ;
```

three different configuration are of this basic geometry are studied. First we will consider `GEOA5` which is an exact DRAGON representation of Figure 12. The two additional configuration studied are `GEOA5SB` where symmetry conditions are applied on the negative x, y and z faces and `GEOA5ST` where they are applied to the positive faces. Both geometries are in fact identical. However as can be seen in Figure 13 and Figure 14 the exact order for the volumes and surfaces definition differs between both geometries (the same octant of the cell is shown here). The reason for this is that the numbering in the case of `GEOA5SB` starts with the cell at the center of the assembly while for `GEOA5ST` it starts with the lower left corner cell. Also note that the region numbers inside each cell are consecutive, namely the numbering scheme remembers that the assemblies were defined in terms of cells. Typically the DRAGON output associated with these two geometries will contain the following information:

```
 ECHO = >>> GEOMETRY NAME: GEOA5SB
  ====> GLOBAL MESHING
        X-COORDINATES:
            .0000   .5000  1.0000  1.5000  2.0000  2.5000  3.0000
        Y-COORDINATES:
            .0000   .5000  1.0000  1.5000  2.0000  2.5000  3.0000
        Z-COORDINATES:
            .0000   .5000  1.0000  1.5000  2.0000  2.5000  3.0000
 X-Y MESH ON TOP Z-SURFACE
----------------------------------------

----------------------------------------
       -16       -11       -12
----------------------------------------
       -15        -9       -10
----------------------------------------
       -21       -19       -20
----------------------------------------
 X-Y MESH IN Z-PLANE =          6
----------------------------------------
       -14        -7        -8
----------------------------------------
        19        26        27        -6
----------------------------------------
        18        24        25        -5
----------------------------------------
        11        14        15       -18
----------------------------------------
 X-Y MESH IN Z-PLANE =          5
----------------------------------------
       -13        -3        -4
----------------------------------------
```

```
       17        22        23        -2
----------------------------------------
       16        20        21        -1
----------------------------------------
       10        12        13       -17
----------------------------------------
 X-Y MESH IN Z-PLANE =          4
----------------------------------------
      -26       -24       -25
----------------------------------------
        5         8         9       -23
----------------------------------------
        4         6         7       -22
----------------------------------------
        1         2         3       -27
----------------------------------------
 ECHO = >>> NB. OF REGIONS:    27


 ECHO = >>> GEOMETRY NAME: GEOA5ST
  ====> GLOBAL MESHING
        X-COORDINATES:
            .0000   .5000  1.0000  1.5000  2.0000  2.5000  3.0000
        Y-COORDINATES:
            .0000   .5000  1.0000  1.5000  2.0000  2.5000  3.0000
        Z-COORDINATES:
            .0000   .5000  1.0000  1.5000  2.0000  2.5000  3.0000
 X-Y MESH ON TOP Z-SURFACE
----------------------------------------

----------------------------------------
      -12       -17       -16
----------------------------------------
      -13       -19       -18
----------------------------------------
       -7        -9        -8
----------------------------------------
 X-Y MESH IN Z-PLANE =          6
----------------------------------------
      -14       -21       -20
----------------------------------------
        9         2         1       -22
----------------------------------------
       10         4         3       -23
----------------------------------------
       17        14        13       -10
----------------------------------------
 X-Y MESH IN Z-PLANE =          5
----------------------------------------
      -15       -25       -24
----------------------------------------
       11         6         5       -26
----------------------------------------
       12         8         7       -27
----------------------------------------
       18        16        15       -11
----------------------------------------
 X-Y MESH IN Z-PLANE =          4
----------------------------------------
       -2        -4        -3
----------------------------------------
       23        20        19        -5
----------------------------------------
       24        22        21        -6
----------------------------------------
       27        26        25        -1
----------------------------------------
 ECHO = >>> NB. OF REGIONS:    27
```

where again only one octant of the full cell is shown.

2.2 Cartesian cells and assemblies with embedded annular region

The first two geometries we will consider here represent a simple 3-D extension of the `GEOAC1` and `GEOAA1` geometries presented in Section 1.2. The DRAGON input used to define these geometries is:

```
*----
*  GEOAC1    :  2 REGION  3-D CELL
*  GEOAA1    :  2 REGION  3-D 1 CELL ASSEMBLY
*----
GEOAC1    := GEO: :: CARCELZ 1 1
  X- REFL X+ REFL Y- REFL Y+ REFL Z- REFL Z+ REFL
  MESHX 0.0 2.0 MESHY 0.0 2.0 MESHZ 0.0 2.0
  RADIUS 0.0 0.85   MIX 1 1 ;
GEOAA1    := GEO: :: CAR3D 1 1 1
  X- REFL X+ REFL Y- REFL Y+ REFL Z- REFL Z+ REFL
  CELL GEOAC1
  ::: GEOAC1   := GEO: CARCELZ 1 1
    MESHX 0.0 2.0 MESHY 0.0 2.0 MESHZ 0.0 2.0
    RADIUS 0.0 0.85 MIX 1 1 ;
  ;
```

Here the region numbering is identical to that defined for the 2-D equivalent of these geometries while the surface numbering changes. Recalling the fact that in 3-D geometries, one start with the surface at the bottom of the cell and finishes with the top surfaces, the numbering described in Figure 15 becomes evident. The DRAGON output file will contain information which reflects this numbering:

```
 ECHO = >>> GEOMETRY NAME: GEOAA1
  ====> GLOBAL MESHING
        X-COORDINATES:
            .0000  2.0000
        Y-COORDINATES:
            .0000  2.0000
        Z-COORDINATES:
            .0000  2.0000
        CELL(   1,   1,   1)  (X,Y)- CENTRE: (  1.0000  1.0000)
                        Z-RADII:
                            .8500
 X-Y MESH ON TOP Z-SURFACE
  ----------------------------


  ----------------------------
                -8
                -7
  ----------------------------


  ----------------------------
 X-Y MESH IN Z-PLANE =          1
  ----------------------------
                -6
            ABSENT
  ----------------------------
      -4         2       -5
    ABSENT        1    ABSENT
  ----------------------------
                -3
            ABSENT
  ----------------------------
 X-Y MESH ON BOTTOM Z-SURFACE
  ----------------------------


  ----------------------------
                -2
                -1
  ----------------------------


  ----------------------------
 ECHO = >>> NB. OF REGIONS:     2
```

In order to illustrate in more details the typical DRAGON output generated with such geometries we also repeated the analysis for the same cell but with the splitting option applied, namely we used

```
*----
*  GEOAC3    : 32 REGIONS 3-D CELL FROM SPLIT OF GEOAC1
*  GEOAA3    : 32 REGIONS 3-D 1 CELL ASSEMBLY FROM SPLIT OF GEOAC1
*----
```

```
GEOAC3    := GEO: GEOAC1 ::
  SPLITX 4 SPLITY 4 SPLITZ 1 SPLITR 2      ;
GEOAA3    := GEO: GEOAA1 ::
  ::: GEOAC1 := GEO: GEOAC1
    SPLITX 4 SPLITY 4 SPLITZ 1 SPLITR 2    ;
  ;
```

The specific 3-D geometry we used in this case is illustrated in Figure 16 while the numbering scheme is described in Figure 17 and illustrated by the following output from DRAGON:

```
 GEO3DA  : GEOAA3
  ====> GLOBAL MESHING
        X-COORDINATES:
            .0000   .5000  1.0000  1.5000  2.0000
        Y-COORDINATES:
            .0000   .5000  1.0000  1.5000  2.0000
        Z-COORDINATES:
            .0000  2.0000
        CELL(   1,   1,   1)  (X,Y)- CENTRE: (  1.0000  1.0000)
                        Z-RADII:
                            .4250   .8500
 X-Y MESH ON TOP Z-SURFACE
  ----------------------------------------------------------



  ----------------------------------------------------------
               -74       -76       -78       -80
               -73       -75       -77       -79
            ABSENT    ABSENT    ABSENT    ABSENT
  ----------------------------------------------------------
               -66    ABSENT    ABSENT       -72
               -65       -68       -70       -71
            ABSENT       -67       -69    ABSENT
  ----------------------------------------------------------
               -58    ABSENT    ABSENT       -64
               -57       -60       -62       -63
            ABSENT       -59       -61    ABSENT
  ----------------------------------------------------------
               -50       -52       -54       -56
               -49       -51       -53       -55
            ABSENT    ABSENT    ABSENT    ABSENT
  ----------------------------------------------------------



  ----------------------------------------------------------
 X-Y MESH IN Z-PLANE =          1
  ----------------------------------------------------------
               -45       -46       -47       -48
            ABSENT    ABSENT    ABSENT    ABSENT
            ABSENT    ABSENT    ABSENT    ABSENT
  ----------------------------------------------------------
       -43        26        28        30        32       -44
    ABSENT        25        27        29        31    ABSENT
    ABSENT    ABSENT    ABSENT    ABSENT    ABSENT    ABSENT
  ----------------------------------------------------------
       -41        18    ABSENT    ABSENT        24       -42
    ABSENT        17        20        22        23    ABSENT
    ABSENT    ABSENT        19        21    ABSENT    ABSENT
  ----------------------------------------------------------
       -39        10    ABSENT    ABSENT        16       -40
    ABSENT         9        12        14        15    ABSENT
    ABSENT    ABSENT        11        13    ABSENT    ABSENT
  ----------------------------------------------------------
       -37         2         4         6         8       -38
    ABSENT         1         3         5         7    ABSENT
    ABSENT    ABSENT    ABSENT    ABSENT    ABSENT    ABSENT
  ----------------------------------------------------------
               -33       -34       -35       -36
            ABSENT    ABSENT    ABSENT    ABSENT
            ABSENT    ABSENT    ABSENT    ABSENT
  ----------------------------------------------------------
 X-Y MESH ON BOTTOM Z-SURFACE
  ----------------------------------------------------------
```

```
 ---------------------------------------------------------
               -26       -28       -30       -32
               -25       -27       -29       -31
            ABSENT    ABSENT    ABSENT    ABSENT
 ---------------------------------------------------------
               -18    ABSENT    ABSENT       -24
               -17       -20       -22       -23
            ABSENT       -19       -21    ABSENT
 ---------------------------------------------------------
               -10    ABSENT    ABSENT       -16
                -9       -12       -14       -15
            ABSENT       -11       -13    ABSENT
 ---------------------------------------------------------
                -2        -4        -6        -8
                -1        -3        -5        -7
            ABSENT    ABSENT    ABSENT    ABSENT
 ---------------------------------------------------------


 ---------------------------------------------------------
ECHO = >>> NB. OF REGIONS:    32
```

where again ABSENT means that the Cartesian (first line) or annular (remaining lines) region is not present in the cell.

Finally we considered the more complex 3-D assembly shown in Figure 18 which involves cylinder in both the z and y directions. Again two cases were analyzed. First we used a full description of this geometry (GEOAA5) followed by a symmetric description of the same geometry with cell splitting in the x, y and z directions (GEOAA5S). The DRAGON instructions required to create these two geometries are

```
*----
*  GEOAA5    : 36 REGIONS 3-D CELL ASSEMBLY
*  GEOAA5S   : 36 REGIONS GEOAA5 WITH SPLIT AND SYMMETRIES
*----
GEOAA5    := GEO: :: CAR3D 3 3 3
  X- REFL X+ REFL Y- REFL Y+ REFL Z- REFL Z+ REFL
  CELL V V V   X V X   V V V
       V Y V   X Y X   V Y V
       V V V   X V X   V V V
  ::: X := GEO: CARCELZ 1 1   MIX 3  1
    RADIUS 0.0 0.85 MESHX 0.0 2.0 MESHY 0.0 2.0 MESHZ 0.0 2.0 ;
  ::: Y := GEO: CARCELY 1 1   MIX 3  1
    RADIUS 0.0 0.85 MESHX 0.0 2.0 MESHY 0.0 2.0 MESHZ 0.0 2.0 ;
  ::: V := GEO: CAR3D   1 1 1 MIX 1
    MESHX 0.0 2.0 MESHY 0.0 2.0 MESHZ 0.0 2.0 ;
  ;
GEOAA5S   := GEO: :: CAR3D 2 2 2
  X- SYME X+ REFL Y- SYME Y+ REFL Z- SYME Z+ REFL
  CELL Y X  Y V
       V X  V V
  ::: X := GEO: CARCELZ 1 1 MIX 3  1
    RADIUS 0.0 0.85 MESHX 0.0 2.0 MESHY 0.0 2.0 MESHZ 0.0 2.0
                    SPLITX 2      SPLITY 2      SPLITZ 2       ;
  ::: Y := GEO: CARCELY 1 1 MIX 3  1
    RADIUS 0.0 0.85 MESHX 0.0 2.0 MESHY 0.0 2.0 MESHZ 0.0 2.0
                    SPLITX 2      SPLITY 2      SPLITZ 2       ;
  ::: V := GEO: CAR3D   1 1 1 MIX 1
                    MESHX 0.0 2.0 MESHY 0.0 2.0 MESHZ 0.0 2.0
                    SPLITX 2      SPLITY 2      SPLITZ 2       ;
  ;
```

For GEOAA5, the numbering process is similar to that described for GEOAA1 except that one must now take into account, in addition to the radial regions on the top and bottom z surfaces, radial regions on the bottom and top y surfaces (see second plane in Figure 19). The output file resulting from an analysis on the above geometry will contain

```
ECHO = >>> GEOMETRY NAME: GEOAA5
 ====> GLOBAL MESHING
       X-COORDINATES:
           .0000  2.0000  4.0000  6.0000
       Y-COORDINATES:
```

```
         .0000  2.0000  4.0000  6.0000
      Z-COORDINATES:
         .0000  2.0000  4.0000  6.0000
      CELL(   2,   1,   2)  (Z,X)- CENTRE: (  3.0000  3.0000)
                      Y-RADII:
                          .8500
      CELL(   1,   2,   1)  (X,Y)- CENTRE: (  1.0000  3.0000)
                      Z-RADII:
                          .8500
      CELL(   3,   2,   1)  (X,Y)- CENTRE: (  5.0000  3.0000)
                      Z-RADII:
                          .8500
X-Y MESH ON TOP Z-SURFACE
 ------------------------------------------------


 ------------------------------------------------
              -55       -57       -60
           ABSENT    ABSENT    ABSENT
 ------------------------------------------------
              -48       -49       -52
              -47    ABSENT       -51
 ------------------------------------------------
              -40       -42       -45
           ABSENT    ABSENT    ABSENT
 ------------------------------------------------


 ------------------------------------------------
X-Y MESH IN Z-PLANE =          3
 ------------------------------------------------
              -54       -56       -59
           ABSENT    ABSENT    ABSENT
 ------------------------------------------------
    -53        34        35        36       -58
 ABSENT    ABSENT    ABSENT    ABSENT    ABSENT
 ------------------------------------------------
    -46        30        31        33       -50
 ABSENT        29    ABSENT        32    ABSENT
 ------------------------------------------------
    -39        26        27        28       -44
 ABSENT    ABSENT    ABSENT    ABSENT    ABSENT
 ------------------------------------------------
              -38       -41       -43
           ABSENT    ABSENT    ABSENT
 ------------------------------------------------
X-Y MESH IN Z-PLANE =          2
 ------------------------------------------------
              -33       -35       -37
           ABSENT       -34    ABSENT
 ------------------------------------------------
    -32        22        24        25       -36
 ABSENT    ABSENT        23    ABSENT    ABSENT
 ------------------------------------------------
    -30        17        19        21       -31
 ABSENT        16        18        20    ABSENT
 ------------------------------------------------
    -25        12        14        15       -29
 ABSENT    ABSENT        13    ABSENT    ABSENT
 ------------------------------------------------
              -24       -27       -28
           ABSENT       -26    ABSENT
 ------------------------------------------------
X-Y MESH IN Z-PLANE =          1
 ------------------------------------------------
              -18       -20       -23
           ABSENT    ABSENT    ABSENT
 ------------------------------------------------
    -17         9        10        11       -22
 ABSENT    ABSENT    ABSENT    ABSENT    ABSENT
 ------------------------------------------------
    -11         5         6         8       -15
 ABSENT         4    ABSENT         7    ABSENT
 ------------------------------------------------
     -3         1         2         3        -8
 ABSENT    ABSENT    ABSENT    ABSENT    ABSENT
 ------------------------------------------------
```

```
             -2        -5        -7
         ABSENT    ABSENT    ABSENT
 ------------------------------------------------
X-Y MESH ON BOTTOM Z-SURFACE
 ------------------------------------------------


 ------------------------------------------------
            -16       -19       -21
         ABSENT    ABSENT    ABSENT
 ------------------------------------------------
            -10       -12       -14
             -9    ABSENT       -13
 ------------------------------------------------
             -1        -4        -6
         ABSENT    ABSENT    ABSENT
 ------------------------------------------------


 ------------------------------------------------
ECHO = >>> NB. OF REGIONS:    36
```

where the presence of the radial regions on the y directed surfaces can be easily identified in the second plane (see Figure 19 for a graphical illustration of the DRAGON numbering scheme used for this geometry).

Finally the DRAGON output for `GEOAA5S` will contain:

```
ECHO = >>> GEOMETRY NAME: GEOAA5S
 ====> GLOBAL MESHING
       X-COORDINATES:
           .0000  1.0000  2.0000  3.0000  4.0000  5.0000  6.0000
       Y-COORDINATES:
           .0000  1.0000  2.0000  3.0000  4.0000  5.0000  6.0000
       Z-COORDINATES:
           .0000  1.0000  2.0000  3.0000  4.0000  5.0000  6.0000
       CELL(   2,   1,   2)  (Z,X)- CENTRE: (  3.0000  3.0000)
                       Y-RADII:
                           .8500
       CELL(   1,   2,   1)  (X,Y)- CENTRE: (  1.0000  3.0000)
                       Z-RADII:
                           .8500
       CELL(   3,   2,   1)  (X,Y)- CENTRE: (  5.0000  3.0000)
                       Z-RADII:
                           .8500
X-Y MESH ON TOP Z-SURFACE
 ----------------------------------------


 ----------------------------------------
        -16       -11       -12
     ABSENT    ABSENT    ABSENT
 ----------------------------------------
        -15        -9       -10
     ABSENT    ABSENT    ABSENT
 ----------------------------------------
        -23       -20       -22
     ABSENT       -19       -21
 ----------------------------------------
X-Y MESH IN Z-PLANE =          6
 ----------------------------------------
        -14        -7        -8
     ABSENT    ABSENT    ABSENT
 ----------------------------------------
         28        35        36        -6
     ABSENT    ABSENT    ABSENT    ABSENT
 ----------------------------------------
         27        33        34        -5
     ABSENT    ABSENT    ABSENT    ABSENT
 ----------------------------------------
         16        22        24       -18
     ABSENT        21        23    ABSENT
 ----------------------------------------
X-Y MESH IN Z-PLANE =          5
 ----------------------------------------
        -13        -3        -4
     ABSENT    ABSENT    ABSENT
```

```
 ----------------------------------------
        26        31        32        -2
    ABSENT    ABSENT    ABSENT    ABSENT
 ----------------------------------------
        25        29        30        -1
    ABSENT    ABSENT    ABSENT    ABSENT
 ----------------------------------------
        15        18        20       -17
    ABSENT        17        19    ABSENT
 ----------------------------------------
X-Y MESH IN Z-PLANE =          4
 ----------------------------------------
       -29       -26       -27
       -28    ABSENT    ABSENT
 ----------------------------------------
        10        13        14       -25
         9    ABSENT    ABSENT    ABSENT
 ----------------------------------------
         8        11        12       -24
         7    ABSENT    ABSENT    ABSENT
 ----------------------------------------
         2         4         6       -30
         1         3         5    ABSENT
 ----------------------------------------
ECHO = >>> NB. OF REGIONS:    36
```

where one octant of the cell has been illustrated. This information can also be easily correlated with that found in Figure 20. Note that, even if the DRAGON output only gives a compressed 2-D picture of the assembly, it is possible to locate the position and direction of the cylinders in the cell without too much problem.

References

[1] G. Marleau, A. Hébert and R. Roy, "A User's Guide for DRAGON", Report IGE-174 Rev. 2, École Polytechnique de Montréal, Institut de Génie Nucléaire (1997).

FIGURES

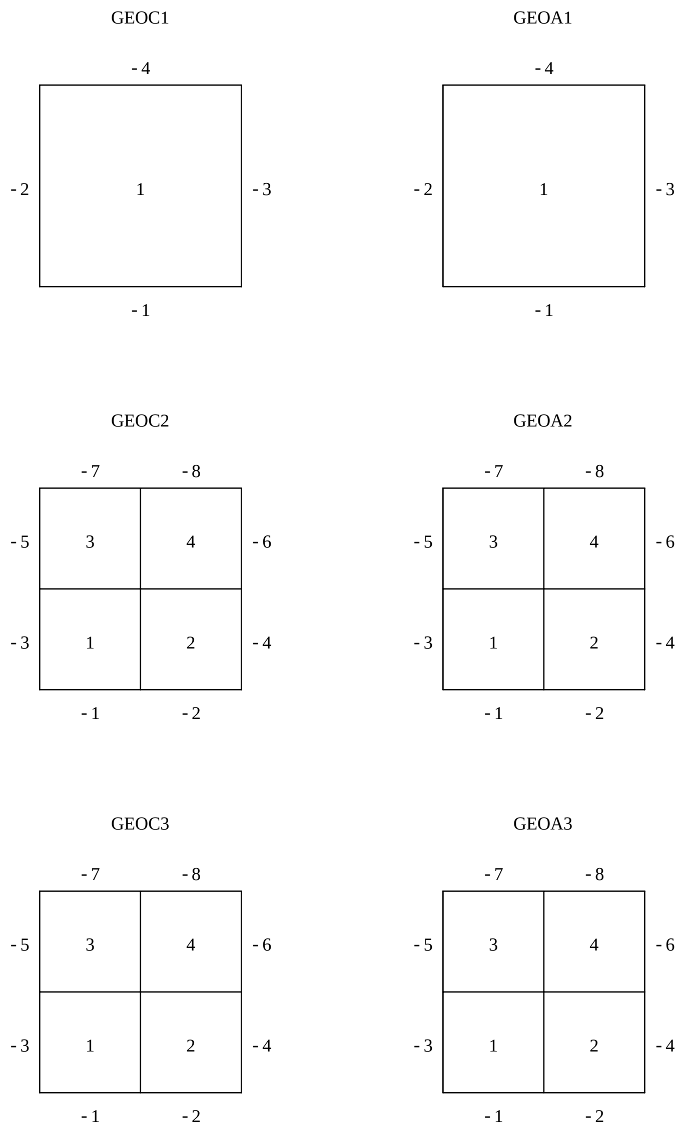

Figure 1: DRAGON numbering for the `GEOC1`, `GEOA1`, `GEOC2`, `GEOA2`, `GEOC3` and `GEOA3` 2-D geometries

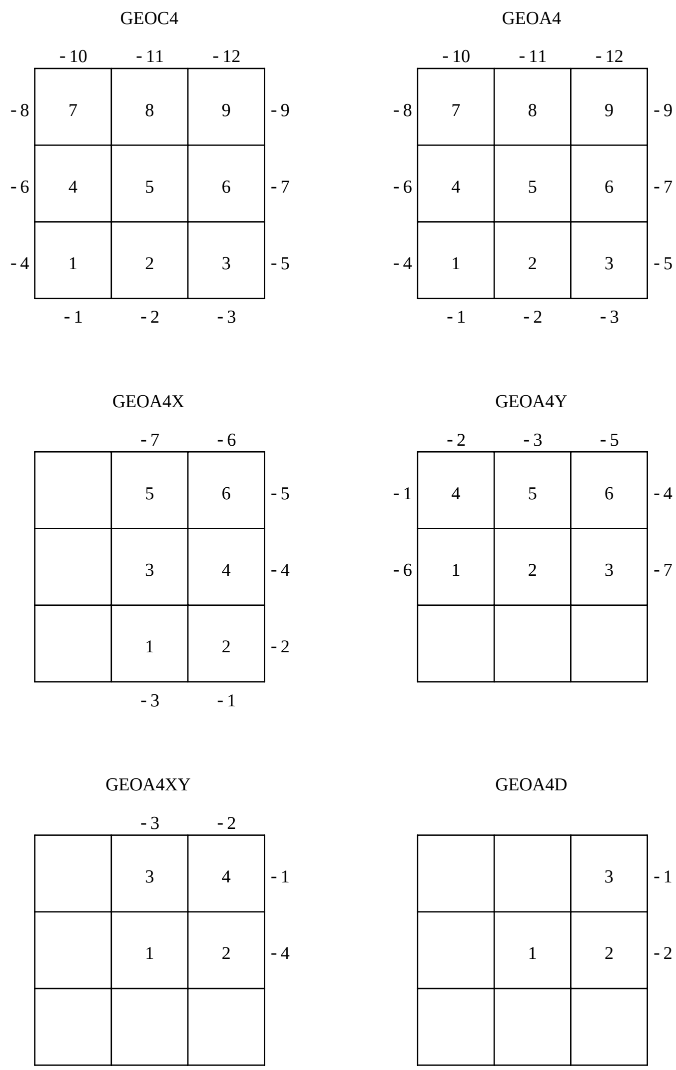

Figure 2: DRAGON numbering for the `GEOC4`, `GEOA4`, `GEOA4X`, `GEOA4Y`, `GEOA4XY` and `GEOA4D` 2-D geometries

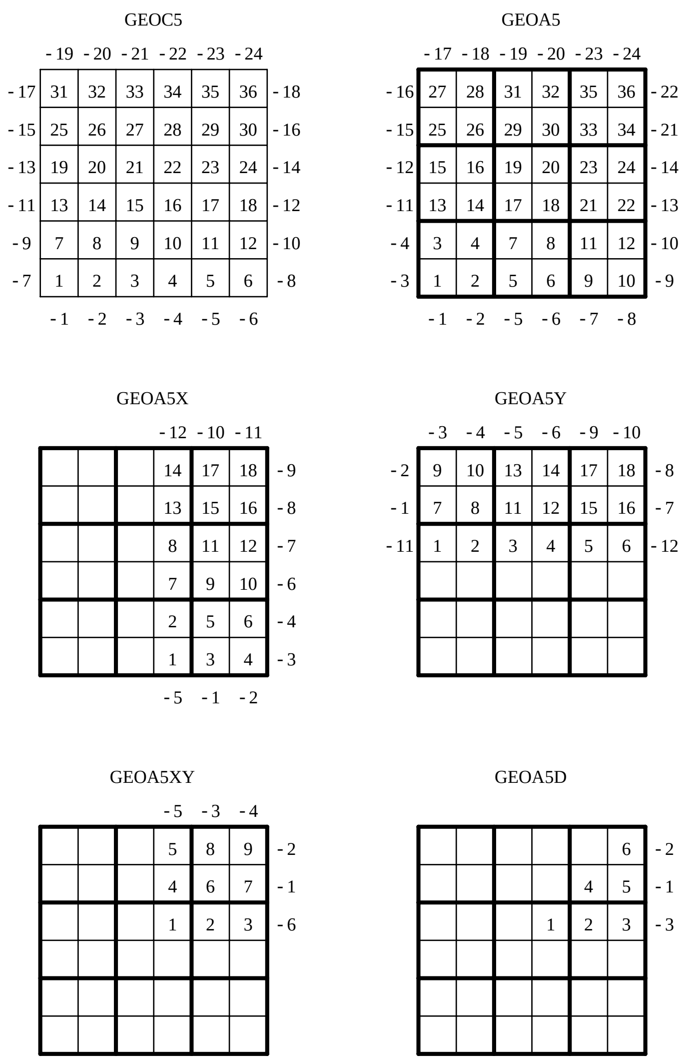

Figure 3: DRAGON numbering for the `GEOC5`, `GEOA5`, `GEOA5X`, `GEOA5Y`, `GEOA5XY` and `GEOA5D` 2-D geometries

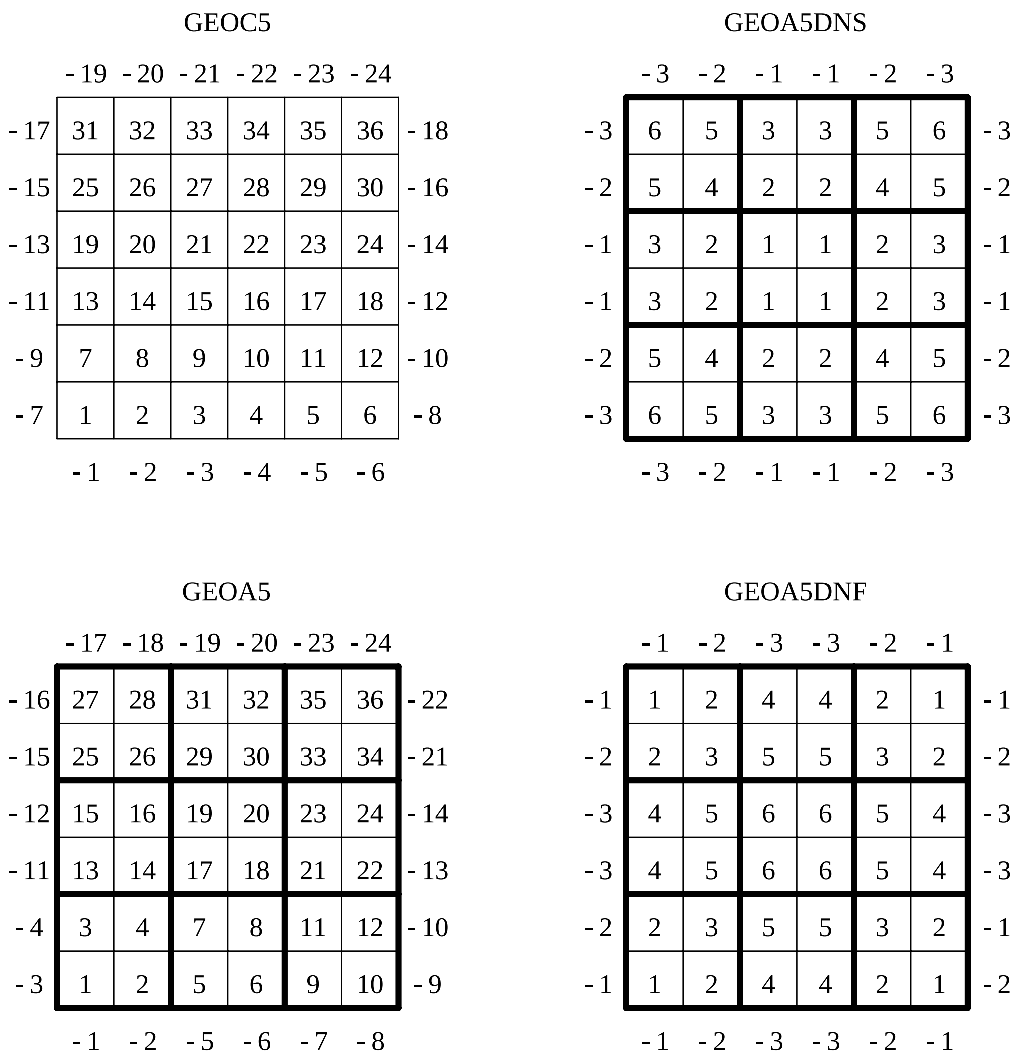

Figure 4: DRAGON numbering for the `GEOC5`, `GEOA5`, `GEOA5DNS` (simplified), and `GEOA5DNF` (full) 2-D geometries

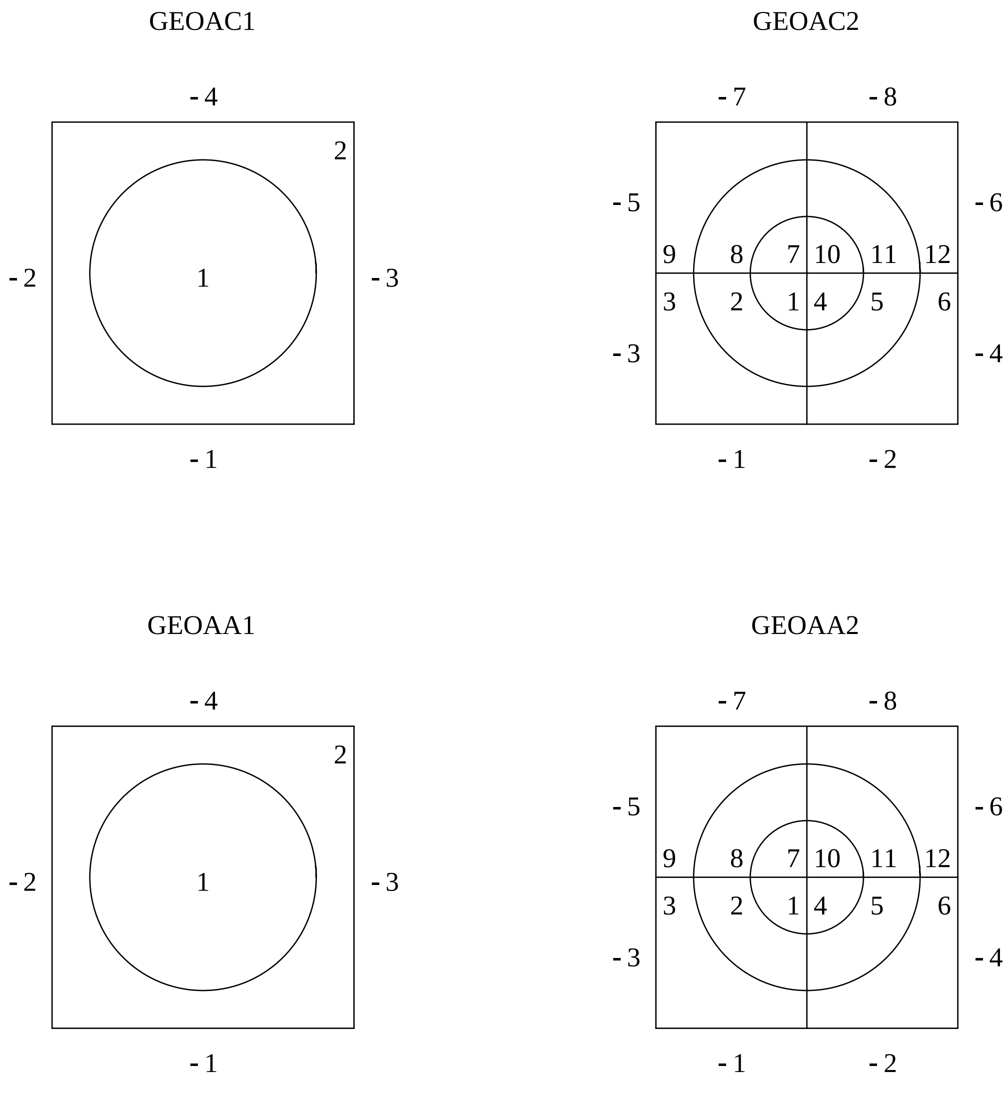

Figure 5: DRAGON numbering for the `GEOAC1`, `GEOAA1`, `GEOAC2` and `GEOAA2` 2-D geometries with embedded annular regions

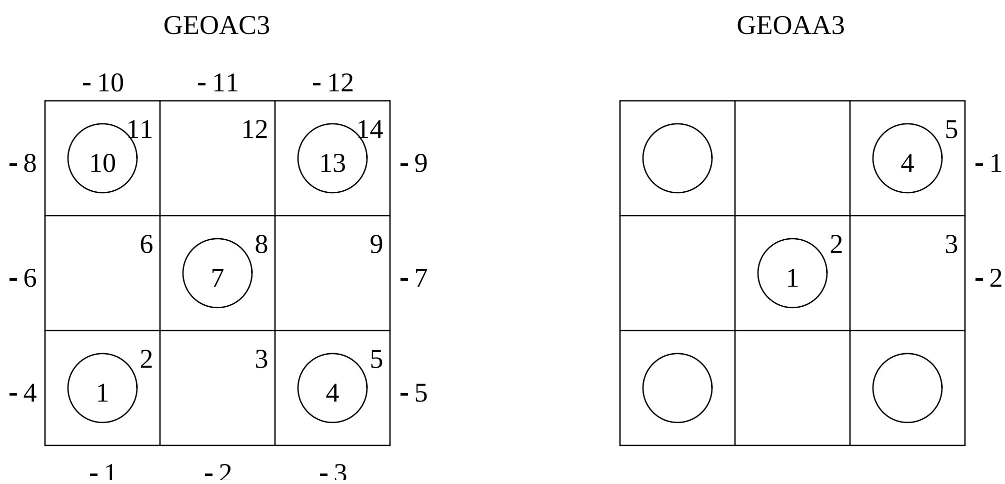

Figure 6: DRAGON numbering for the `GEOAC3` and `GEOAA3` 2-D geometries with embedded annular regions

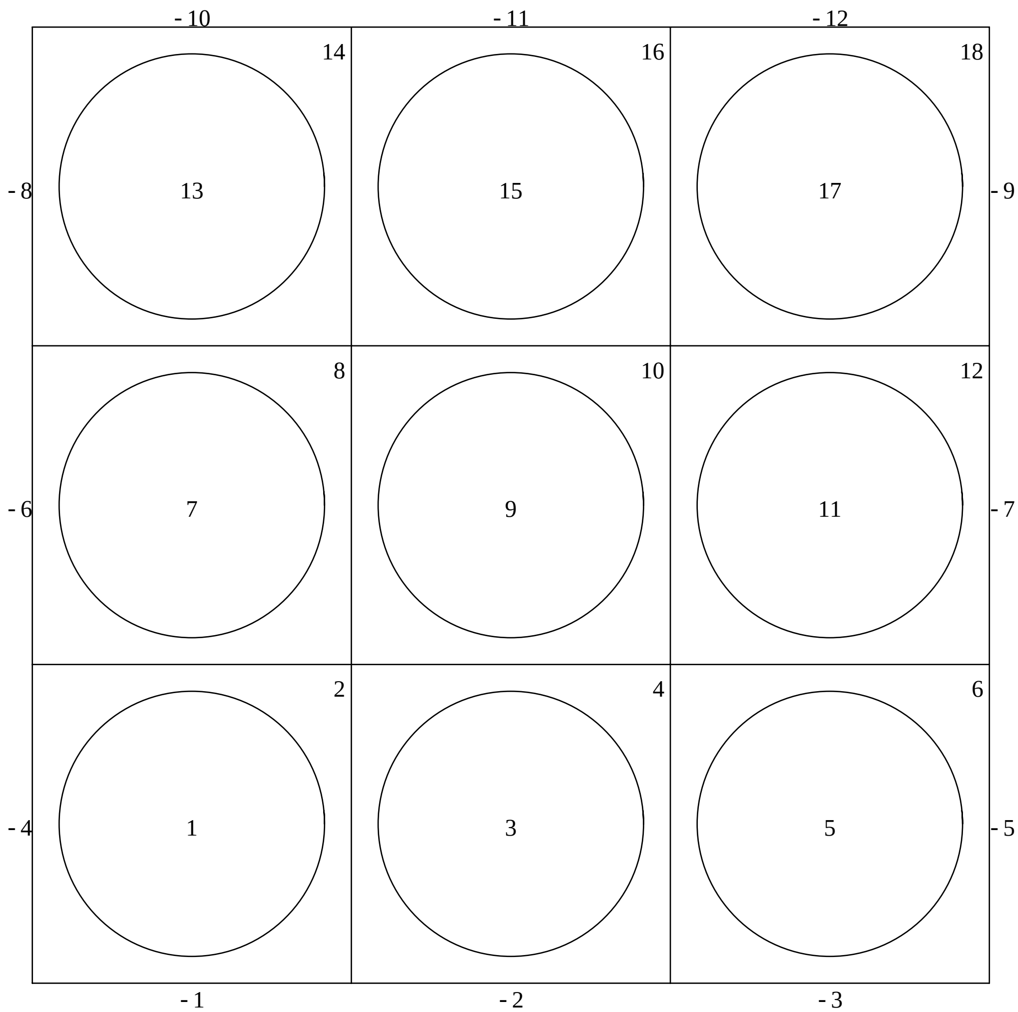

Figure 7: DRAGON numbering for the GEOAC4 2-D geometry with embedded annular regions

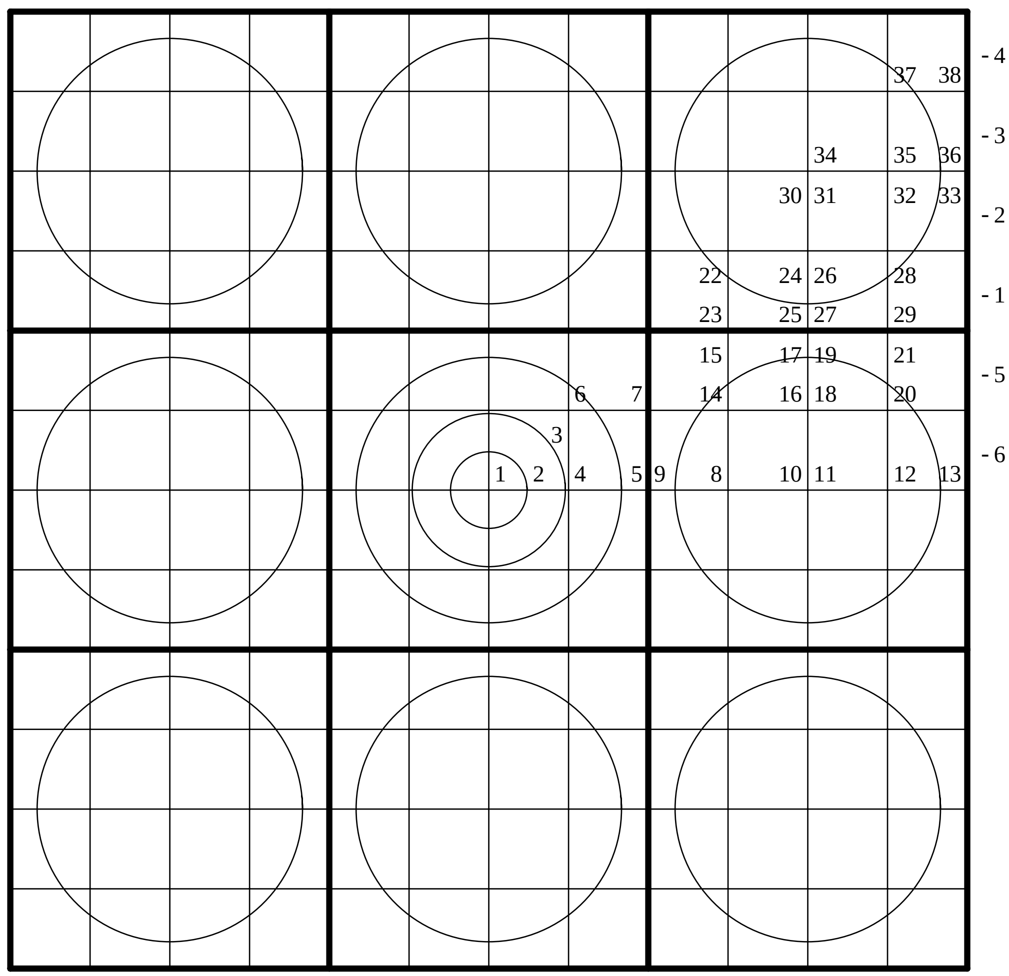

Figure 8: DRAGON numbering for the GEOAA4 2-D geometry with embedded annular regions

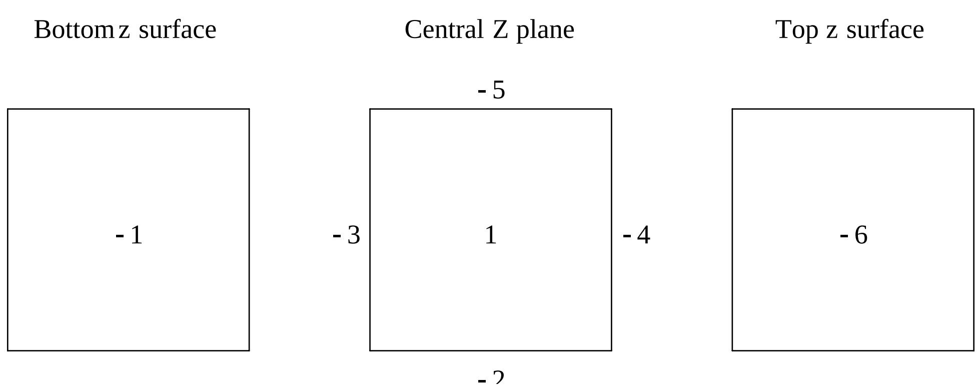

Figure 9: DRAGON numbering for the GEOC1, GEOA1, 3-D geometries

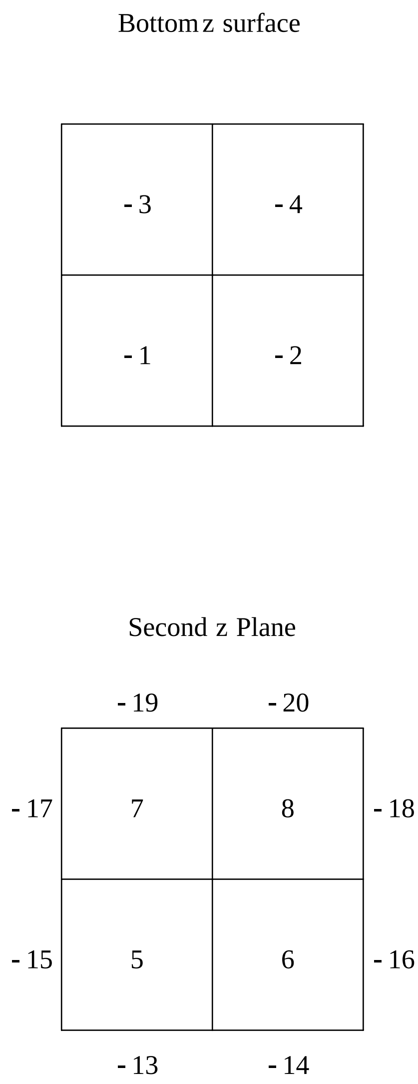

Figure 10: DRAGON numbering for the `GEOC3`, `GEOA3`, 3-D geometries

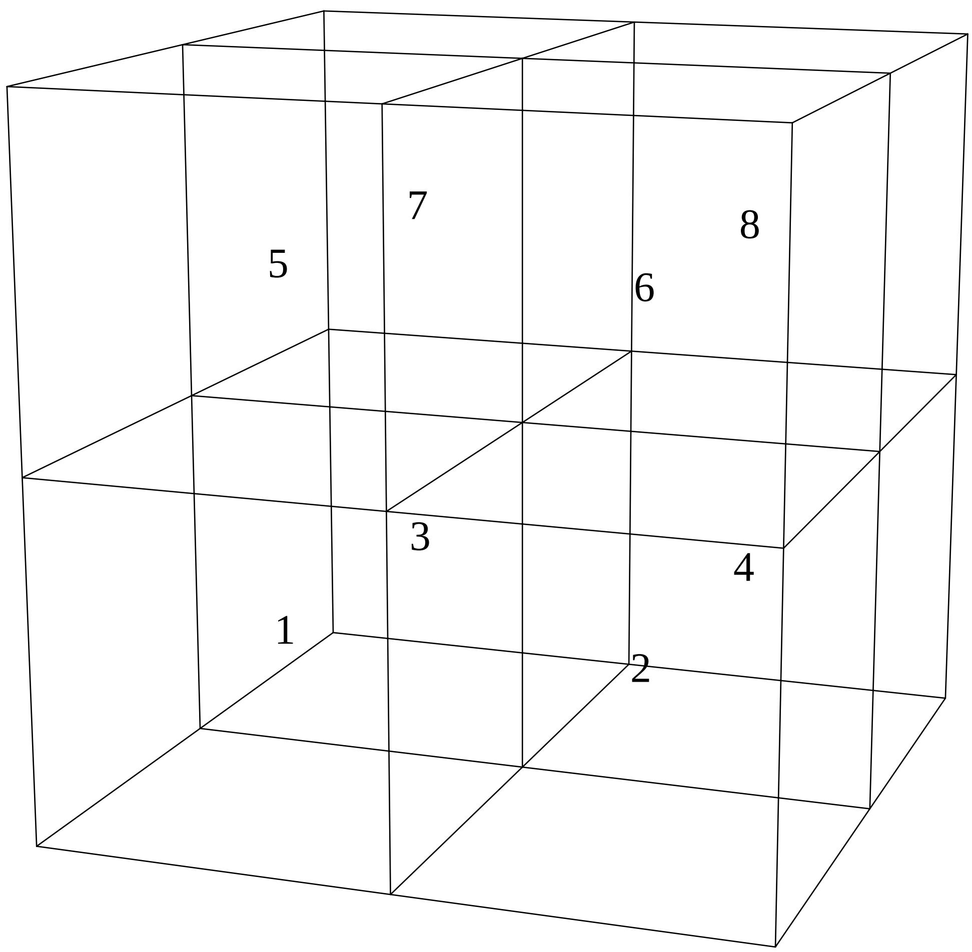

Figure 11: A 3-D view of the geometries GEOC3, GEOA3, with region numbering

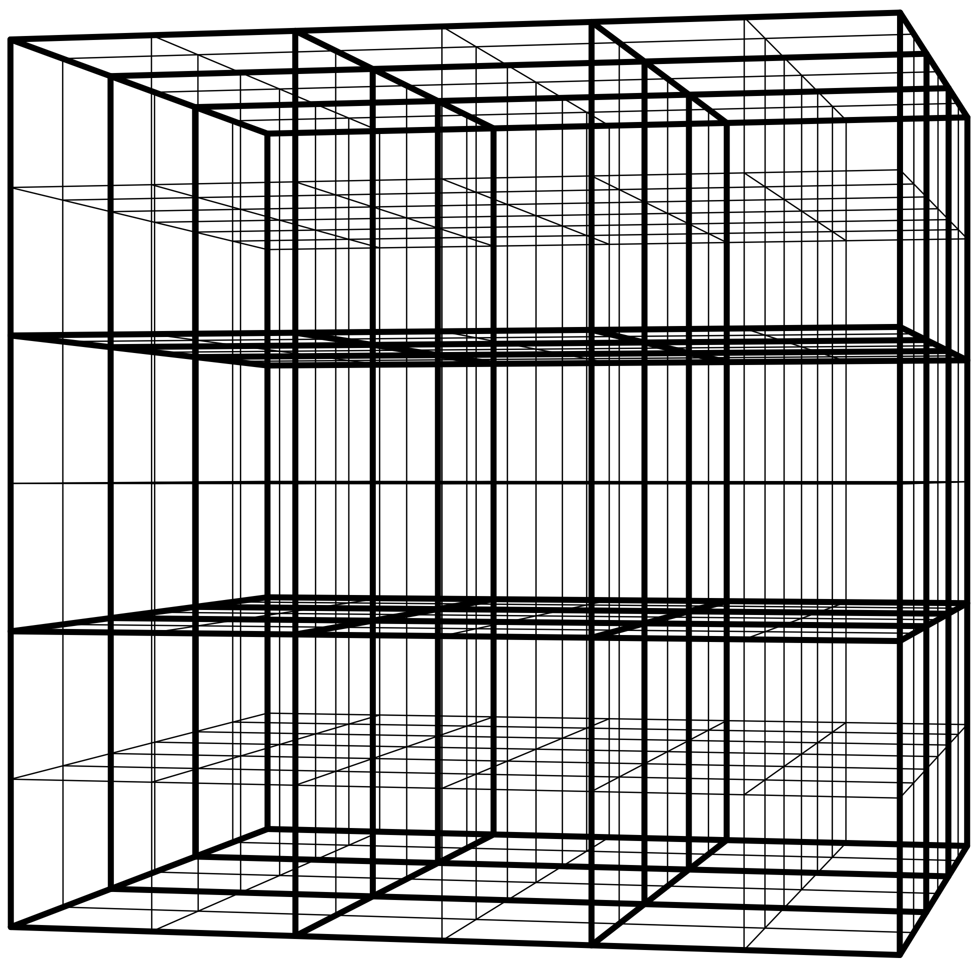

Figure 12: A 3-D view of the geometry GEOA5

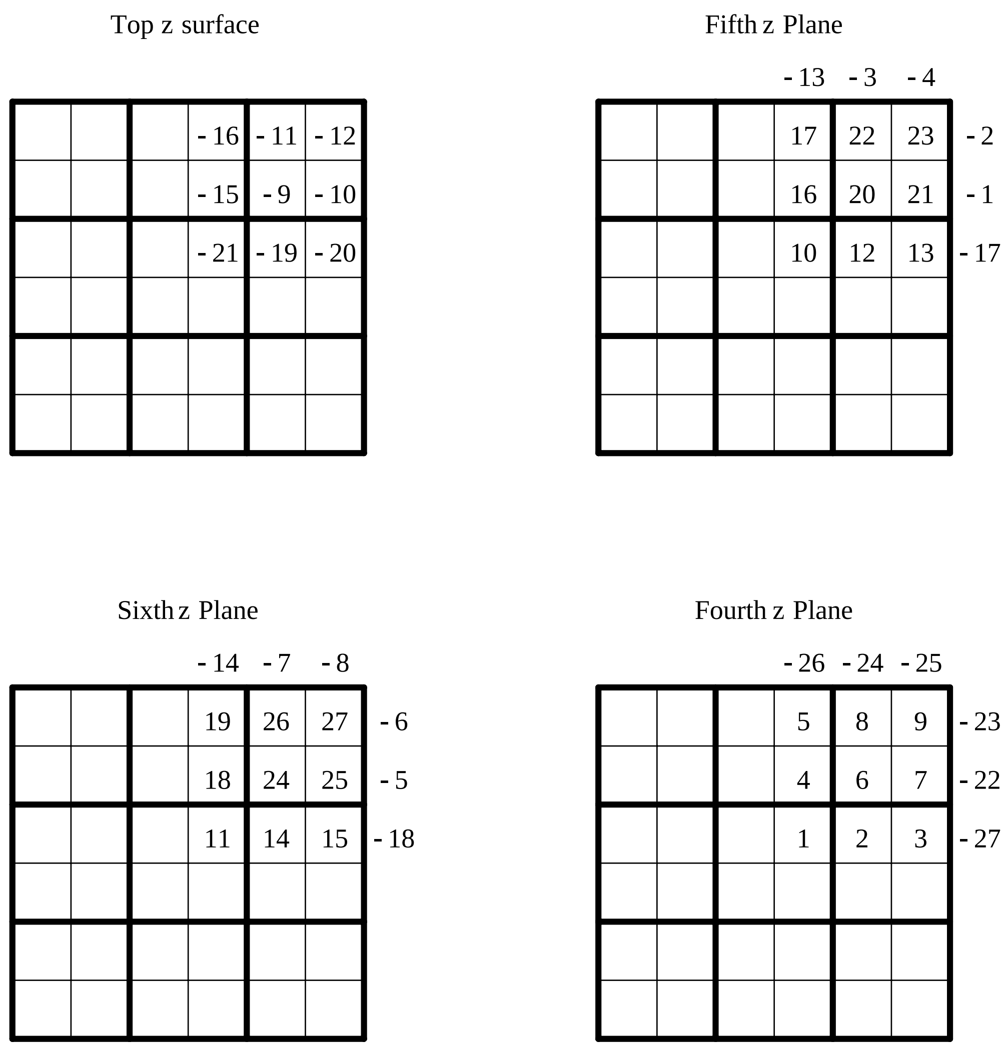

Figure 13: Regions and surfaces numbering for `GEOA5SB` 3-D geometry

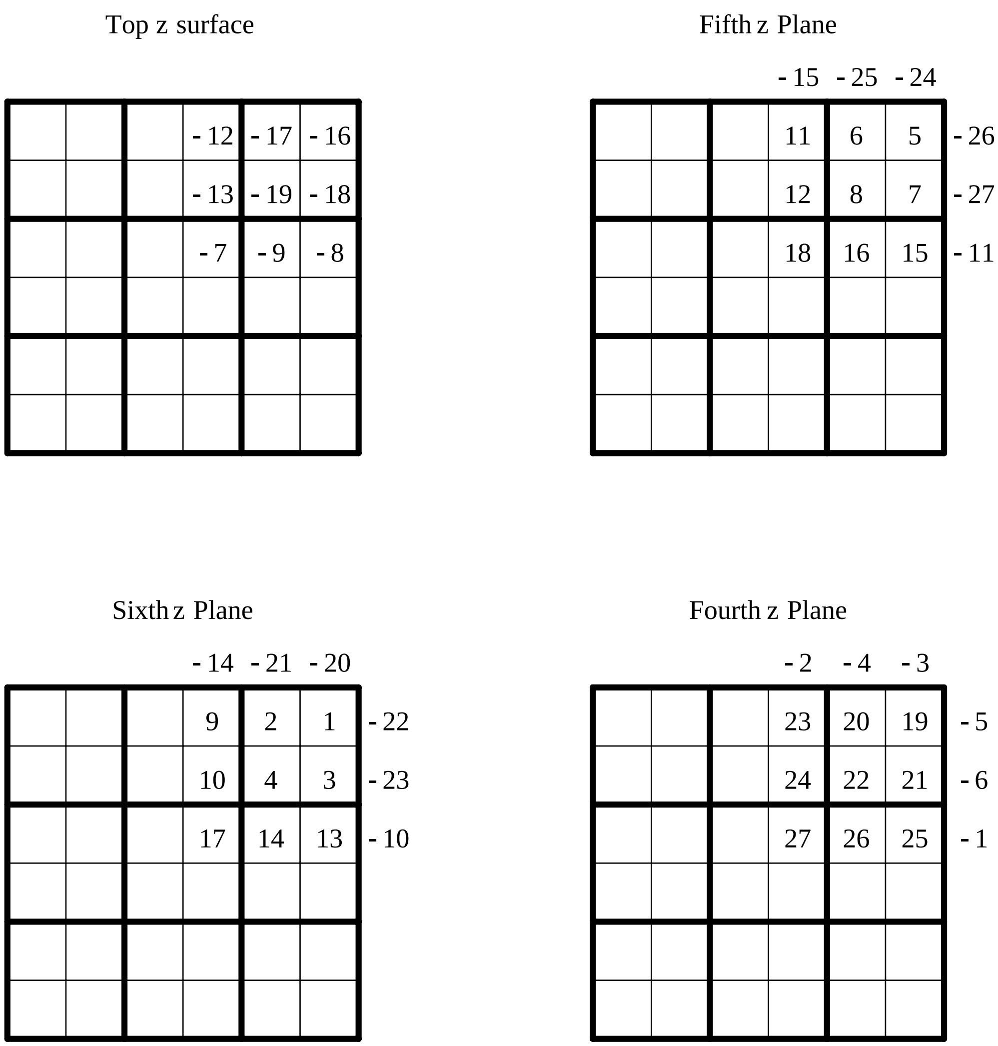

Figure 14: Regions and surfaces numbering for `GEOA5ST` 3-D geometry

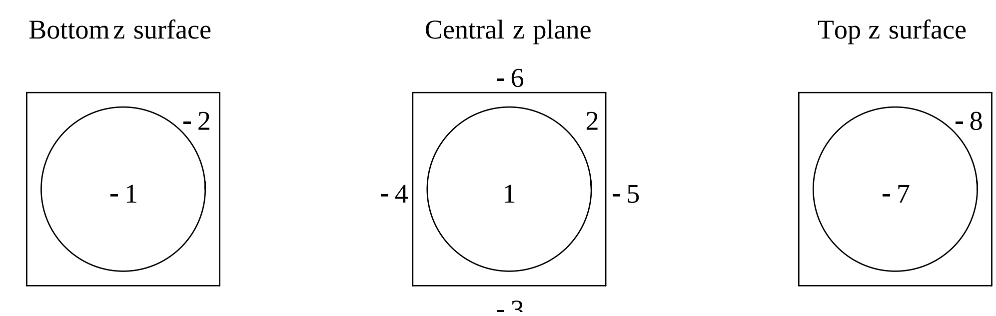

Figure 15: DRAGON numbering for the `GEOCA1` and `GEOAA1` 3-D geometries

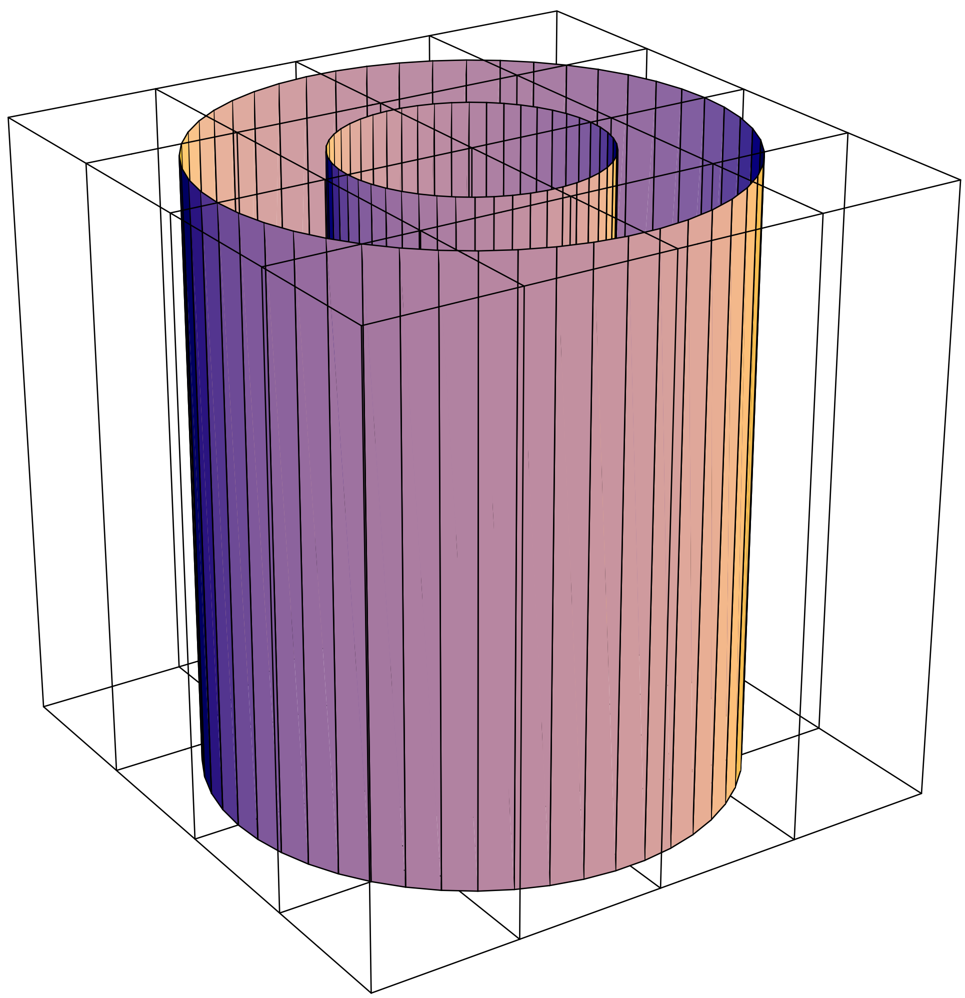

Figure 16: A 3-D view of the geometries GEOAA3

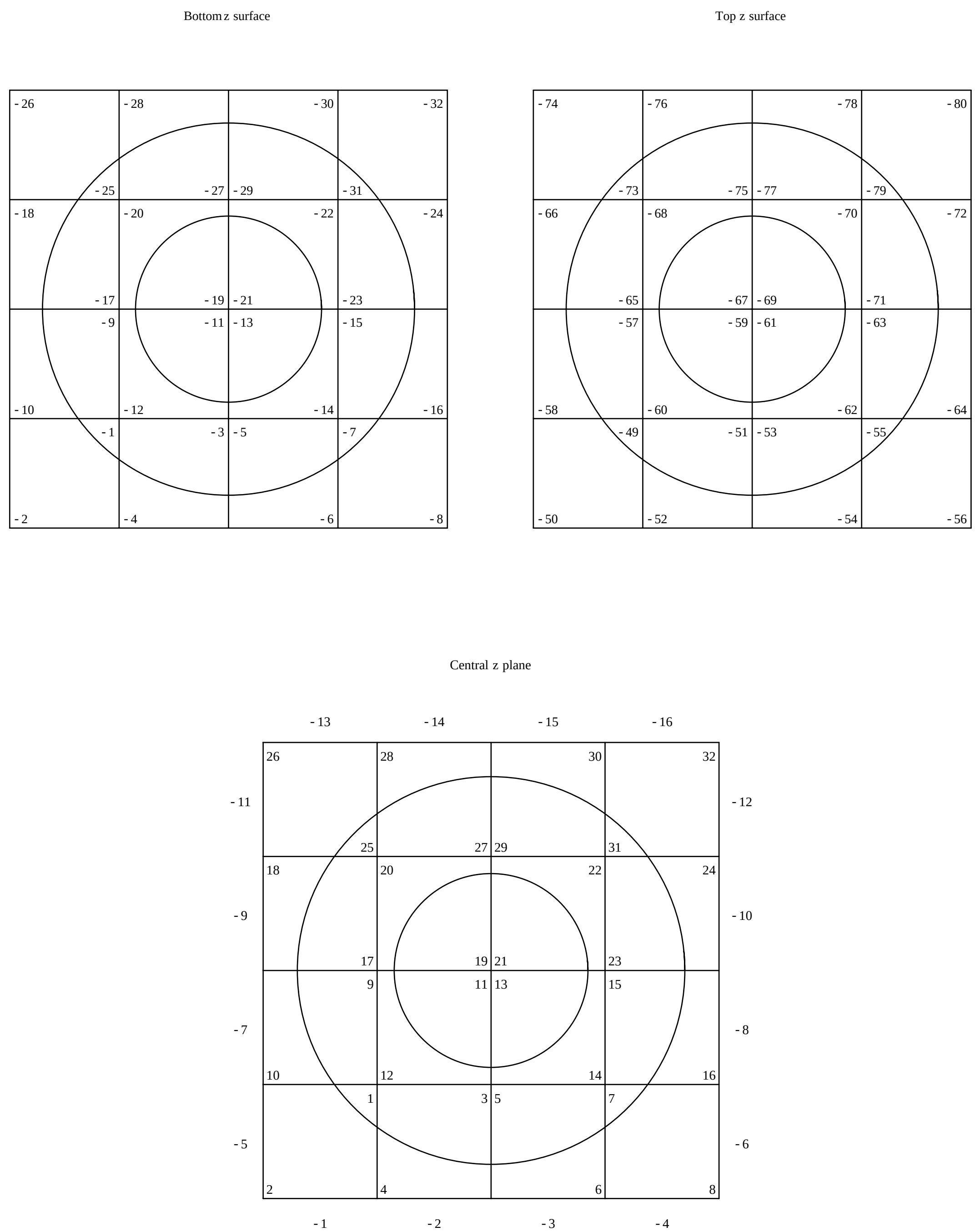

Figure 17: DRAGON numbering for the GEOCA3, GEOAA3, 3-D geometries

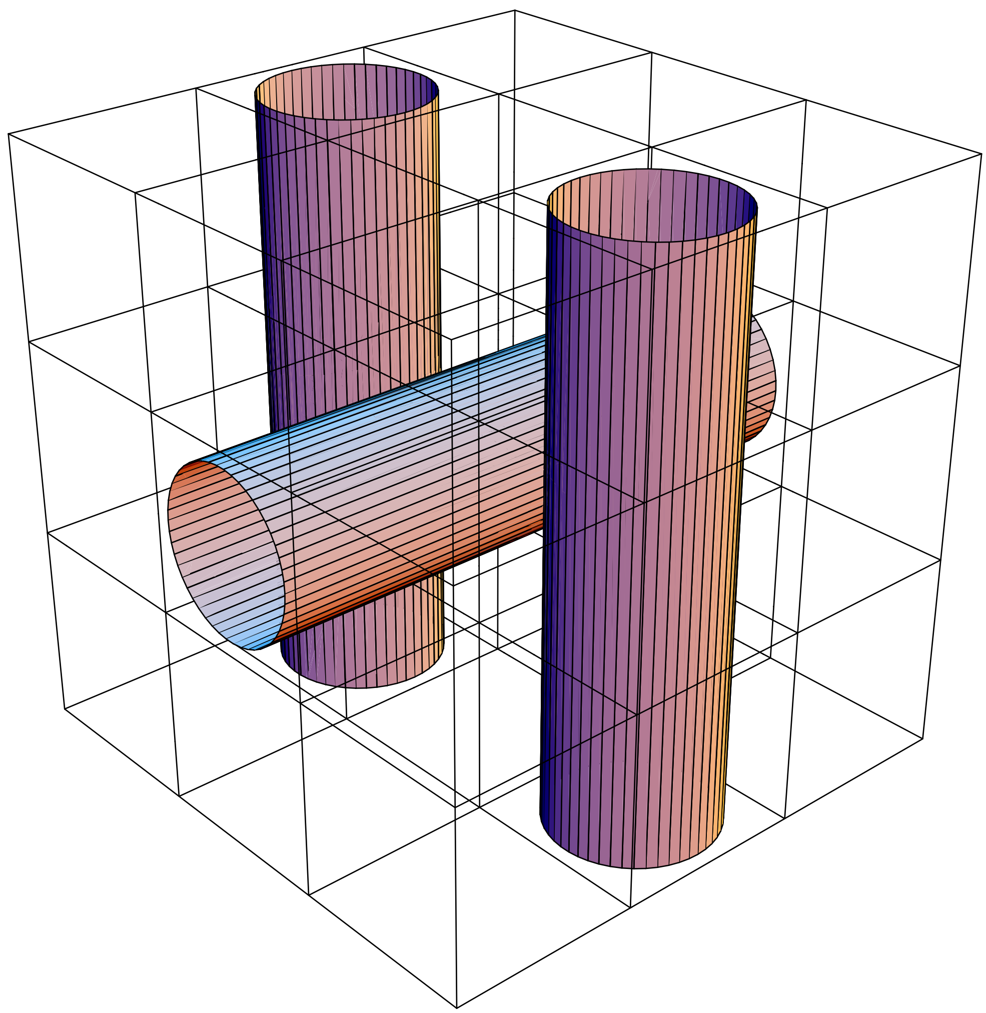

Figure 18: A 3-D view of the geometry GEOAA5

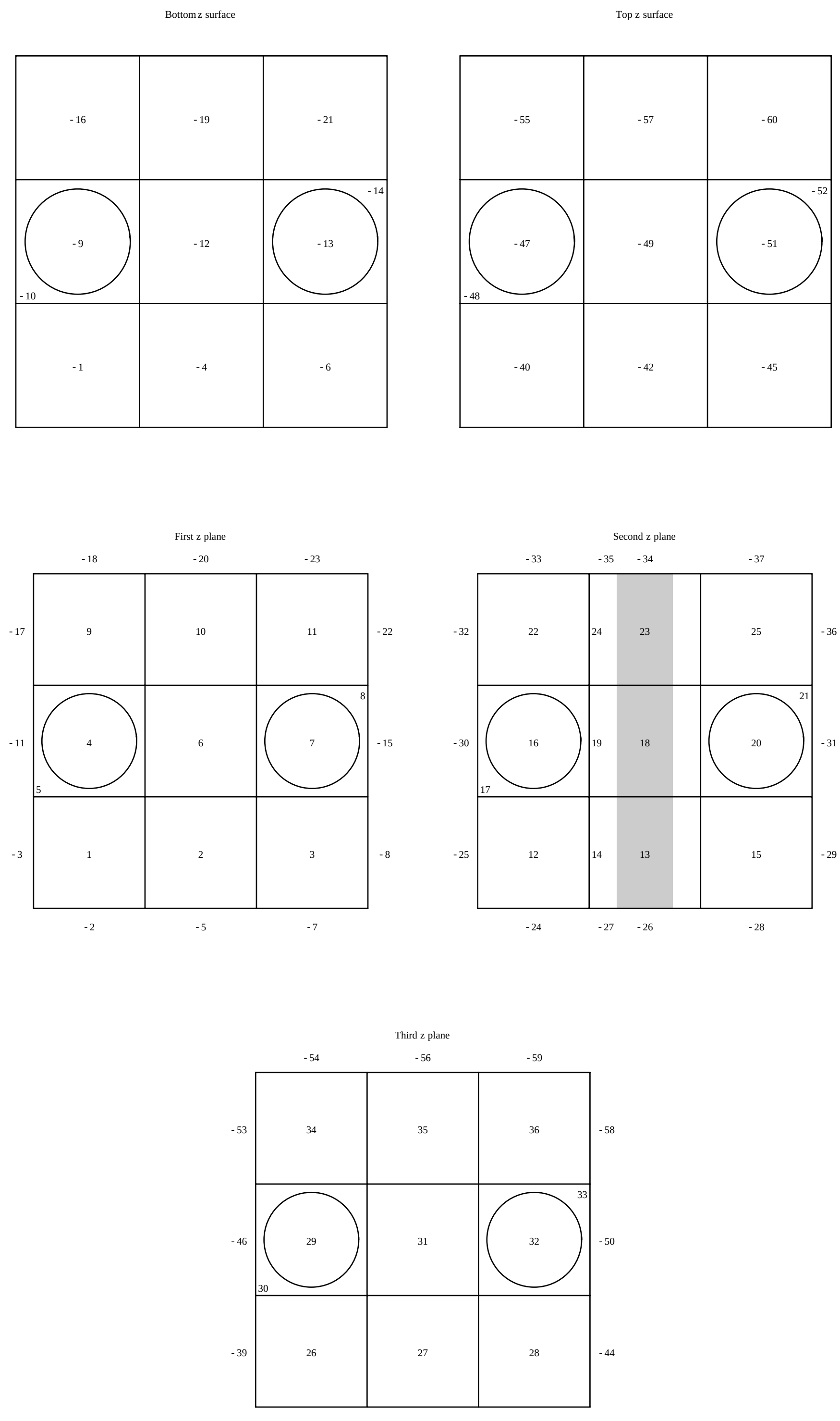

Figure 19: DRAGON numbering for the `GEOAA5` 3-D geometries

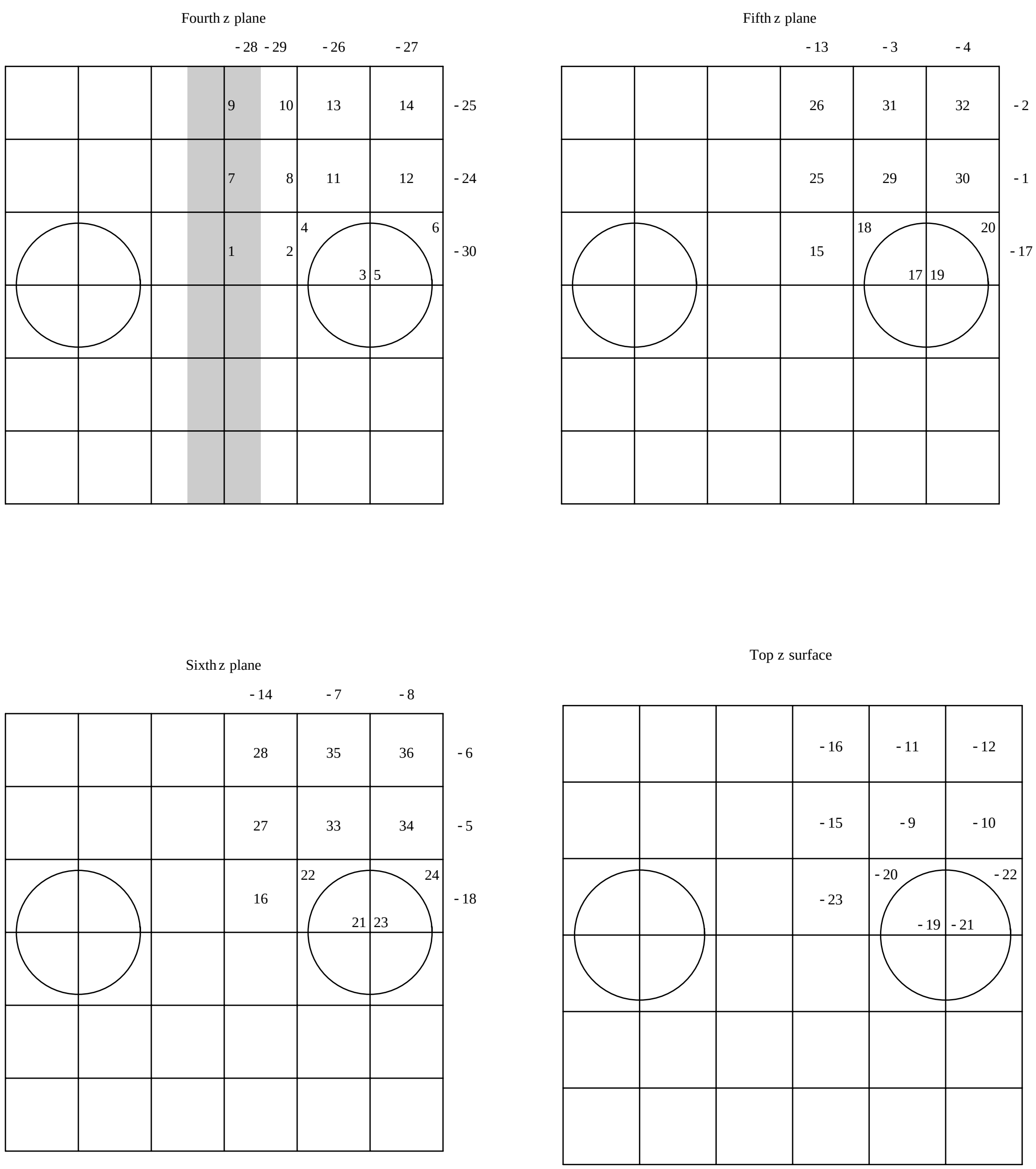

Figure 20: DRAGON numbering for the `GEOAA5S` 3-D geometries