GEM

A finite element mesh generator and data preparation program for radiation transport and fluids codes

User Notes

by

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1. Introduction

These notes give basic information on the use of the program **GEM**. The program is an interactive pre-processor for the radiation transport code **EVENT**. Its main task is to prepare the finite element mesh for the problem while at the same time incorporating the physical properties. The input specifies the problem by regions to filled with specified element type and specified material and source. The output is a list of elements, nodal coordinates and other items in the format required by **EVENT**. Though primarily designed for generating two-dimensional meshes, **GEM** is also capable of preparing input for one-dimensional problems, and has a limited capability for generating three-dimensional meshes.

2. Using GEM

2.1 Input commands

Input to **GEM** is given using simple free-format commands which are executed one at a time. The first character string on an input instruction is assumed to be a keyword. Subsequent strings may comprise of reserved words, names or numerical values.

The commands may be grouped into the following categories :

GEOMETRY
MESHING
MATERIAL SPECIFICATION
I/O
GRAPHICAL OUTPUT
GENERAL
EVENT RUN

Examples of commands are :

```
POINT P1 0.0 0.0        ; defines a point with name P1 and x- and y-coordinates (0.0,0.0)
MATERIAL MA11 1.0 0.0 0.0 0.0 1.0  ; defines cross-sectional data for material MA1
READ fred       ; read command sequence from file fred
```

The full list of commands available and their syntax is presented in section 2.4.

2.2 Command sequence

A sequence of input commands should be constructed for each problem. This sequence should essentially :

(i) describe the geometry of the problem in terms of simple natural geometrical objects such as points, lines and regions;
(ii) define physical parameters such as material x/s, sources and boundary conditions, and associate them to the geometrical model;
(iii) define main control parameters for the **EVENT** run;
(iv) define mesh control parameters and generate mesh;
(v) generate output data.

Steps (i) and (ii) are obligatory and represent the bulk of the command sequence preparation work. Step (iii) may be omitted but default values are used then. Step (iv) usually involves some experimentation with mesh

parameters in order to achieve the best compromise between effort and accuracy. This is best done interactively. Step (v) is only required if the objective of the **GEM** run is to produce an **EVENT** data file.

2.3 Command rules

(i) Keywords

The first word on cards other than comment or blank cards is the instruction keyword. The keyword is terminated by a blank, and only the first three characters are significant.

(ii) Reserved words

Further words are used in instruction parameters. These are up to six characters significant.

(iii) Keywords and reserved words may be input in lower or uppercase. The rest of the input is case sensitive.

(iv) Names

Identifiers for points, lines, regions, materials, and sources may be made up of any characters except *. All characters are significant in identifiers. Use of reserved words and keywords for identifiers should be avoided.

(v) The instructions occupy one line or more line or "cards" of input.

(vi) The character ^ indicates that the next card is a continuation card.

(vii) Blank cards, or lines beginning with @ are ignored.

2.4 GEM commands

In what follows words in bold and upper case are keywords or reserved words.

{ } denotes synonym
[ ] denotes optional parameters.
..... denotes a list of parameters of any length.

2.4.1 Geometry

DELETE	item list (not operational) deletes items in the list Example : **DELETE** R1
LINE	*lnam* p_1 p_2 [p_3] ..... [p_n] declares a line joining point p_1 to point p_2, with name *lnam* . If p_3 is included, the line is an arc centered on p_3 . If more than four points are named then a spline is fitted through the points. Examples : **LINE** L1 P1 P2 **LINE** L10 P15 P16 P3 N.B. Convention is anti-clockwise, i.e. when moving from p_1 to p_2 .
MOVE	*pntnam* x y z moves point *pntnam* to new co-ordinates (x,y,z) Example : **MOVE** P1 10.0 20.0
POLYGON	*polynam* *l1* *l2* *l3* .... *ln* defines a *n*-sided polygonal region
CIRCLE	*circnam* *p1* *r* *n* defines a circular region centered at point *p1* and radius r. The 4 quadrant circular arcs are subdivided into *n* intervals

RECTANGLE *rectnam* *p1* *l* *h* *n*

defines a rectangular region with lower bottom left-corner at point *p1* and length *l* and height *h*. The 4 sides are subdivided into *n* intervals

HEXAGON *hexnam p1p* *n*

defines an hexagonal region centered at point *p1* and pitch p The 6 sides are subdivided into *n* intervals

POINT {**PNT**} *pntnam* *x-coord* *y-coord* *z-coord*

declares a point with name *pntnam* and co-ordinates (x,y,z)

Example : **POINT** P1 0.0 0.0 0.0

REGION *regnam* l_1 l_2 l_3 $[l_4]$
regnam r_1 r_2 .....
regnam p_1 p_2 .....

defines a three-, four-sided or many-sided region with name *regnam* .

Examples : **REGION** R1 L1 L2 L3
REGION R6 L10 L5 L20 L21
REGION R4 R1 R6

2.4.2 Meshing

DEFAULT keyword value

default value for lines, material, average and source

Example : **DEFAULT** ITV 10
DEFAULT MATERIAL MA1
DEFAULT AVERAGE 1
DEFAULT SOURCE S1

DIVIDE n linelist .....

lines in linelist are to be divided into *n* intervals

Example : **DIVIDE** 10 L1 L2 L3 L4

FILL

fills up lines and regions with nodes and elements. Effect is cancelled by RESET command

---

INTERVALS {**ITV**} *lnam* *n* [ratio]

line *lnam* is to be divided into *n* intervals (with an optional common ratio which defaults to 1).

Example : **INTERVALS** L1 10

Default *n* for lines not appearing on interval cards is *n* = 1.

Overrides previous INTERVAL cards for same line.

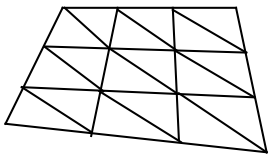
MESH *regnam* f_1 [f_2]

region regnam is to be filled according to parameters f_1 and f_2 .
Overrides previous mesh cards for same region. Permitted values for f_1 are (see Fig. 1) :

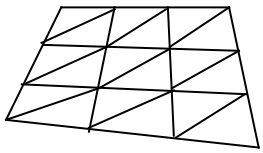
NONE	no mesh for region
SKEW1	
SKEW2	for 4 -sided regions
SKEW?	
QUAD	
TRIANGLE	for 3-sided regions
FRONT	for n-sided regions
DELAUNAY	

Permitted values for f_2 are : **BLEND** (default)
UNIFORM

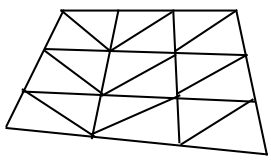
Example : **MESH** R1 **SKEW1 BLEND**
MESH R2 **TRIANGLE BLEND**



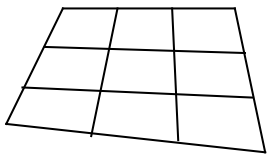
(a) skew1



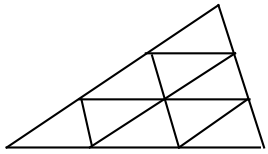
(b) skew2



(c) skew?



(d) quad



(e) triangle

Fig. 1 Region Element Fill Types

PITCH	value defines average pitch (mesh interval)
STRETCH	 smoothes the mesh
DEGREE	*order* order of finite element polynomial basis functions. Options are :- 1, 2 or 3
ZONE	[zone no. [height [no. of-intervals]]] define 3-dimensional axial zone parameters Example : **ZONE** 1 10.0 20

2.4.3 Material Specification and Boundary Conditions

AVERAGE *n* *reglist.....*

assign regions in *reglist* to **EVENT** integrating region *n* ,

Example : **AVERAGE** 1 R1 R2 R3

BOUNDARY type *linlist.....*
{BC} *{t }*
the lines in *linlist* are associated either with boundary conditions of the specified type, or with surface conditions with surface source *t* .

Permitted types are :

REFLECTOR
BARE
ZERO
PERIODIC

Bare and surface source lines are filled with 'surface' elements.

Examples : **BOUNDARY** **BARE** L1
BOUNDARY **REFLECTOR** L3

LIBRARY *libnam* [format]

defines name and format of library from where **GEM** will read material parameters.

Permitted values for format are : **EVENT**
FIDO
LASL

Examples : **LIBRARY** cask

MATERIAL *matnam* [x/s....]

defines a material with name *matnam* and given cross-section list. The expected order is σ_{tg}, σ_{ag}, $\nu\sigma_{tg}$, and $\sigma_{sgg'}$, g'= g, NGRPS for energy group g.

Example : **MATERIAL** MA1 1.0 0.5 0.2 0.0 0.5

PROPERTY *regnam* *matnam*[*S*]

region *regnam* is given material *matnam* (and source *S* if present)

regnam, *matnam* and *S* must have been previously declared.
Example : **PROPERTY** R1 MA1 S1

SOURCE **{VOLUME}** *S* [strength]

defines a volume source with name *S* and given strength.

Example : **SOURCE** S1 1.0

SURFACE *T* [strength]

defines a surface source with name *T* and given strength.

Example : **SURFACE** S2 0.3

VELOCITY **{SPEED}** v .....

particle speeds.

Example : **VELOCITY** 8.0E+9 4.0E+9

SPECTRUM x .....

fission spectrum

Example : **SPECTRUM** 0.7 0.2 0.15 0.05

XSTAB	*iht* *ihs* *ihm* material x/s table positions and length

2.4.4 Input/Output

DATA	[*file*] outputs present mesh data to given file (default is last opened file or file GEMOUT), as required by program **EVENT**. If file has been opened the output is appended. If file does not exist it is created.
PATH	[**IN**] *pathnam* [**OUT**] assigns input or output to path *pathnam* . Examples : **PATH IN** C:\FEMPN\FRED**GEM**DATA **PATH OUT** C:\FEMPN\FRED**EVENT**DAT
READ	*filenam* instructions are to be read from *filenam* until exhausted, when input is next attempted from the terminal. A blank file name redirects input to terminal. Example : **READ** fred
CLOSE	[*file*] closes current input channel Example : **CLOSE**

REWIND	channel no. rewinds file or channel no. Example : **REWIND** 10
WRITE	[channel no.] output is directed to the new channel no. until the next WRITE card. A blank channel no. redirects output to terminal. Example : **REWIND** 21

2.4.5 Graphical output

DEVICE	device initiates, or re-initiates, graphical output device. The following are allowed : **X11** **PS4** **PS4C** **PS3** **TEK**
SHOW	items ..... selected items are plotted on the device last specified by the **DEVICE** card. Possible items are :- **ALL** **LINES** **NODES** **ELEMENTS** **DOMAINS** **COLOURS** **FLUXES** A new picture is started for each item.

2.4.6 General

HELP [keyword]

invokes help facility.

Example : **HELP LIST**

LIST items .....
selected items are listed on the current output channel.

Possible items are : - **ALL**
ELEMENTS
EVENT
LINES
MATERIALS
NODES
POINTS
REGIONS
SOURCES or **VOLUME**
SURFACE

Examples : **LIST ELEMENTS**
LIST ALL

NEWS

RENUMBER **[** DUG **]**

renumber nodes to reduce matrix half-bandwidth to minimum.

RESET [**ALL**]

A **RESET** card causes all mesh filling to be forgotten, to allow modifications to **ITV** and **MESH** cards, and possibly extension of the mesh by new **PNT**, **LINE** and **REGION** cards.

STOP **{FINISH}** **{END}**	finishes the session

2.4.7 EVENT Control Parameters

TITLE	*title* specifies a title of up to 76 characters for lineprinter and graphical output
PRINT	*item* **EVENT** print option. Options are :- **NONE** **FLUXES** **MOMENTS** **ALL**
PLOT	*option* **EVENT** plot option. Options are :- **NONE** **FLUXES** **MOMENTS** **ALL**

GRAPH *option*

graphical output device in **EVENT** run

Options are :- **NOGRAPH**
PS4
PS4C
X11

CASE case

EVENT run case.

Options are :- **TEST**
EIGENVALUE
FIXED
TIME

GEOMETRY geom

problem geometry.
Possible geometries are :- **SLAB**
SPHERICAL
CYLINDRICAL
XY
RZ
XYZ

MODE mode

problem solution mode

Options are :- **FORWARD {DIRECT}**
ADJOINT
BOTH

SOLUTION	scheme Solution scheme
	Options are :- **PCG2** **PCG4**

ITERATIONS list .....

eigenvalue calculation parameters.

Parameters in list are :

MAXITS	max. no. of outer iterations
MAXCG	max. no. of pcg iterations
EIGTOL	eigenvalue error tolerance
VECTOL	eigenvector error tolerance

TIME list .....

time zone card containing list of control parameters

Parameters in list are :-

NSTEPS	no. of time steps
DELTAT	time-step size
TIMSCH	time integration scheme
NEWSCT	angular card flag
NEWGRP	energy card flag
NEWMSH	mesh cards flag
NEWMIX	mixing cards flag
NEWDAT	material cards flag
NEWSRC	source cards flag

ANGLE n
{MSCTR}
{PN} order of angular approximation

SCATTER n
{NSCTR}

order of scattering anisotropy

GROUPS ngrps

no. of energy groups.

COLLAPSE n list .....

collapse energy group structure to n broad groups with structure given by list ....

LUMP option

lumping approximation of source

Options are :- **NONE**
ODD
ALL

UPSCATTER flag

upscatter flag

Flag options are :- **NO**
YES

FORMAT format

material data format.

Options are :- **EVENT**
LASL
FIDO

MIXTURE [mixnum mixcom mixden]

mixing instructions for **EVENT**.

COMMENTS option

Insert **GEM** run output as comments in **EVENT** data file

Options are :- **NO**
YES

3. A worked example

The basic concepts concerning the use of **GEM** are best illustrated through a worked example. Consider the problem described in Fig.1 which we wish to solve with **EVENT**. The **GEM** file is constructed as follows :

(i) define geometry (see Fig. 2) :

```
@
@ - points
@
PNT P1 0.0 0.0
PNT P2 5.0025714 0.0     @ nb. radius corrected to preserve volume
PNT P3 10.0 0.0
PNT P4 0.0 5.0025714
PNT P5 3.5373522 3.5373522
PNT P6 10.0 5.0
PNT P7 0.0 10.0
PNT P8 5.0 10.0
PNT P9 10.0 10.0
@
@ - lines
@
LINE L1 P1 P2
LINE L2 P2 P3
LINE L3 P1 P4
LINE L4 P1 P5
LINE L5 P2 P5 P1          @ arc of circle
LINE L6 P3 P6
LINE L7 P5 P4 P1          @ arc of circle
LINE L8 P5 P6
LINE L9 P4 P7
LINE L10 P5 P8
LINE L11 P6 P9
LINE L12 P7 P8
LINE L13 P8 P9
@
@ - regions
@
REGION R1 L1 L5 L4
REGION R2 L4 L7 L3
REGION R3 L2 L6 L8 L5
REGION R4 L7 L10 L12 L9
REGION R5 L8 L11 L13 L10
@
@ - regional averages
@
AVERAGE 1 R1 R2
AVERAGE 2 R3 R4 R5
@
```

(ii) - define physical properties of problem :

```
@
MAT MA1 0.5 0.1 0.0 0.4
MAT MA2 1.0 0.9990  0.0 0.0 0.0010   @ highly absorbing medium
@
@ - sources
@
SOURCE S1 1.0
SOURCE S2 0.0
@
@ - boundary conditions
@
BOUNDARY BARE L6 L11 L12 L13
BOUNDARY REFLECTOR L1 L2 L3 L9
@
```

(iii) - assign material properties and sources to regions :

```
@
PROPERTIES R1 MA1 S1
PROPERTIES R2 MA1 S1
PROPERTIES R3 MA2 S2
PROPERTIES R4 MA2 S2
PROPERTIES R5 MA2 S2
@
```

(iv) - define **EVENT** run control parameters :

```
@
TITLE Case 1 : 5.0 cm sphere embedded in 10cm x 10cm cyl. (5x5 mesh)
CASE  FIXED          @ fixed-source calculation
GEOMETRY RZ          @ r-z geometry
ANGLE 7              @ P7 expansion of the angular flux
GROUPS 1             @ one energy group
COMMENTS  NO         @ don't include comment file ( this file )
@
```

(v) - define mesh control parameters and generate mesh :

```
@
@ - define type of fill for regions
@
MESH R1 TRIANG BLEND
MESH R2 TRIANG BLEND
MESH R3 QUAD BLEND
MESH R4 QUAD BLEND
MESH R5 QUAD BLEND
@
@ - line subdivisons
@
DIVIDE  4  L1 L3 L4 L5 L6 L7 L12     @ these lines must have same no. of intervals
@
DIVIDE  4  L2 L8 L9 L10 L11 L13      @ ditto
@
```

@ - fill regions
@
FILL
@

(vi) - generate data :

@
DATA
@

(vii) - end run :

@
STOP
@

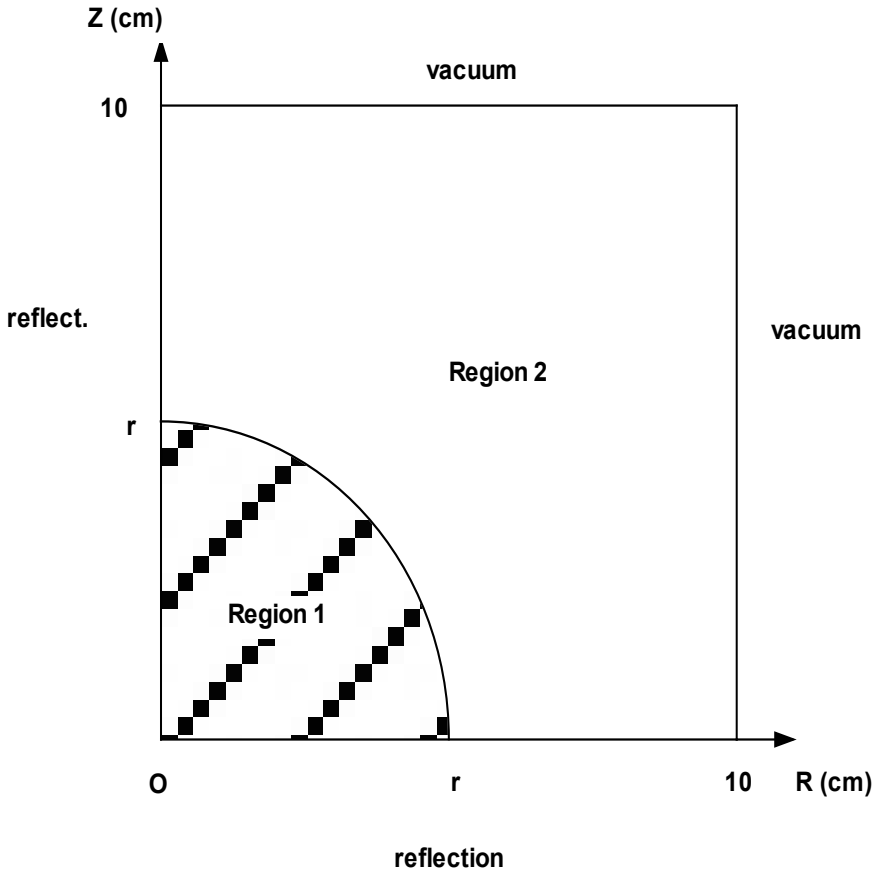
The resulting **EVENT** data file is :

```
Case 1 : 5.0 cm sphere embedded in 10cm x 10cm cyl. ( 4x4 mesh )
I/O           0    0    2    0    0    0    0
CASE          3    5    0    4    0    0    0
ITER         25   25  9.9999997E-06  9.9999997E-05    2
ANGLE         7    0    0
ENERGY        1    0    0    0
MESHFILE  /home/users/staff/cassiano/EVENT/data/exmpl2
SIZES        13    4    2   96   81   17    0    0    0
MATFILE   /home/users/staff/cassiano/EVENT/data/exmpl2     EVENT
MATXS         2    0    4    3    4    4    0
NCOM          0
ELEM     1    2    6    1    0    3   25
ELEM     2    2    6    1    0   25   26
ELEM     3    2    6    1    0   26   27
ELEM     4    2    6    1    0   27    6
ELEM     5    2   11    1    0    6   40
ELEM     6    2   11    1    0   40   41
ELEM     7    2   11    1    0   41   42
ELEM     8    2   11    1    0   42    9
ELEM     9    2   12    1    0    7   43
ELEM    10    2   12    1    0   43   44
ELEM    11    2   12    1    0   44   45
ELEM    12    2   12    1    0   45    8
ELEM    13    2   13    1    0    8   46
ELEM    14    2   13    1    0   46   47
ELEM    15    2   13    1    0   47   48
ELEM    16    2   13    1    0   48    9
ELEM    17    1    1    1    1    1   10   19
ELEM    18    1    1    1    1   10   49   19
ELEM    19    1    1    1    1   10   11   49
ELEM    20    1    1    1    1   11   50   49
ELEM    21    1    1    1    1   11   12   50
ELEM    22    1    1    1    1   12   22   50
ELEM    23    1    1    1    1   12    2   22
ELEM    24    1    1    1    1   19   49   20
ELEM    25    1    1    1    1   49   51   20
ELEM    26    1    1    1    1   49   50   51
ELEM    27    1    1    1    1   50   23   51
ELEM    28    1    1    1    1   50   22   23
```

```
ELEM    29    1    1    1    1   20   51   21
ELEM    30    1    1    1    1   51   24   21
ELEM    31    1    1    1    1   51   23   24
ELEM    32    1    1    1    1   21   24    5
ELEM    33    1    1    1    1    1   19   16
ELEM    34    1    1    1    1   19   52   16
ELEM    35    1    1    1    1   19   20   52
ELEM    36    1    1    1    1   20   53   52
ELEM    37    1    1    1    1   20   21   53
ELEM    38    1    1    1    1   21   28   53
ELEM    39    1    1    1    1   21    5   28
ELEM    40    1    1    1    1   16   52   17
ELEM    41    1    1    1    1   52   54   17
ELEM    42    1    1    1    1   52   53   54
ELEM    43    1    1    1    1   53   29   54
ELEM    44    1    1    1    1   53   28   29
ELEM    45    1    1    1    1   17   54   18
ELEM    46    1    1    1    1   54   30   18
ELEM    47    1    1    1    1   54   29   30
ELEM    48    1    1    1    1   18   30    4
ELEM    49   11    2    2    2    2   13   22   55
ELEM    50   11    2    2    2   13   14   55   56
ELEM    51   11    2    2    2   14   15   56   57
ELEM    52   11    2    2    2   15    3   57   25
ELEM    53   11    2    2    2   22   55   23   58
ELEM    54   11    2    2    2   55   56   58   59
ELEM    55   11    2    2    2   56   57   59   60
ELEM    56   11    2    2    2   57   25   60   26
ELEM    57   11    2    2    2   23   58   24   61
ELEM    58   11    2    2    2   58   59   61   62
ELEM    59   11    2    2    2   59   60   62   63
ELEM    60   11    2    2    2   60   26   63   27
ELEM    61   11    2    2    2   24   61    5   31
ELEM    62   11    2    2    2   61   62   31   32
ELEM    63   11    2    2    2   62   63   32   33
ELEM    64   11    2    2    2   63   27   33    6
ELEM    65   11    2    2    2    4   30   34   64
ELEM    66   11    2    2    2   30   29   64   65
ELEM    67   11    2    2    2   29   28   65   66
ELEM    68   11    2    2    2   28    5   66   37
ELEM    69   11    2    2    2   34   64   35   67
ELEM    70   11    2    2    2   64   65   67   68
ELEM    71   11    2    2    2   65   66   68   69
ELEM    72   11    2    2    2   66   37   69   38
ELEM    73   11    2    2    2   35   67   36   70
ELEM    74   11    2    2    2   67   68   70   71
ELEM    75   11    2    2    2   68   69   71   72
ELEM    76   11    2    2    2   69   38   72   39
ELEM    77   11    2    2    2   36   70    7   43
ELEM    78   11    2    2    2   70   71   43   44
ELEM    79   11    2    2    2   71   72   44   45
ELEM    80   11    2    2    2   72   39   45    8
ELEM    81   11    2    2    2    5   31   37   73
ELEM    82   11    2    2    2   31   32   73   74
ELEM    83   11    2    2    2   32   33   74   75
ELEM    84   11    2    2    2   33    6   75   40
ELEM    85   11    2    2    2   37   73   38   76
ELEM    86   11    2    2    2   73   74   76   77
ELEM    87   11    2    2    2   74   75   77   78
ELEM    88   11    2    2    2   75   40   78   41
```

```
ELEM    89   11    2    2    2   38   76   39   79
ELEM    90   11    2    2    2   76   77   79   80
ELEM    91   11    2    2    2   77   78   80   81
ELEM    92   11    2    2    2   78   41   81   42
ELEM    93   11    2    2    2   39   79    8   46
ELEM    94   11    2    2    2   79   80   46   47
ELEM    95   11    2    2    2   80   81   47   48
ELEM    96   11    2    2    2   81   42   48    9
NODE     1  0.0000000E+00  0.0000000E+00  0.0000000E+00   35
NODE     2  5.0025716E+00  0.0000000E+00  0.0000000E+00    1
NODE     3  1.0000000E+01  0.0000000E+00  0.0000000E+00   31
NODE     4  0.0000000E+00  5.0025716E+00  0.0000000E+00   81
NODE     5  3.5373521E+00  3.5373521E+00  0.0000000E+00   29
NODE     6  1.0000000E+01  5.0000000E+00  0.0000000E+00   23
NODE     7  0.0000000E+00  1.0000000E+01  0.0000000E+00   77
NODE     8  5.0000000E+00  1.0000000E+01  0.0000000E+00   73
NODE     9  1.0000000E+01  1.0000000E+01  0.0000000E+00   69
NODE    10  1.2506429E+00  0.0000000E+00  0.0000000E+00   22
NODE    11  2.5012858E+00  0.0000000E+00  0.0000000E+00   12
NODE    12  3.7519288E+00  0.0000000E+00  0.0000000E+00    5
NODE    13  6.2519288E+00  0.0000000E+00  0.0000000E+00    3
NODE    14  7.5012856E+00  0.0000000E+00  0.0000000E+00   10
NODE    15  8.7506428E+00  0.0000000E+00  0.0000000E+00   20
NODE    16  0.0000000E+00  1.2506429E+00  0.0000000E+00   45
NODE    17  0.0000000E+00  2.5012858E+00  0.0000000E+00   56
NODE    18  0.0000000E+00  3.7519288E+00  0.0000000E+00   68
NODE    19  8.8433802E-01  8.8433802E-01  0.0000000E+00   34
NODE    20  1.7686760E+00  1.7686760E+00  0.0000000E+00   33
NODE    21  2.6530142E+00  2.6530142E+00  0.0000000E+00   32
NODE    22  4.9064484E+00  9.7595328E-01  0.0000000E+00    4
NODE    23  4.6217732E+00  1.9144014E+00  0.0000000E+00    8
NODE    24  4.1594863E+00  2.7792799E+00  0.0000000E+00   18
NODE    25  1.0000000E+01  1.2500000E+00  0.0000000E+00   30
NODE    26  1.0000000E+01  2.5000000E+00  0.0000000E+00   27
NODE    27  1.0000000E+01  3.7500000E+00  0.0000000E+00   26
NODE    28  2.7792795E+00  4.1594863E+00  0.0000000E+00   42
NODE    29  1.9144011E+00  4.6217728E+00  0.0000000E+00   54
NODE    30  9.7595274E-01  4.9064484E+00  0.0000000E+00   67
NODE    31  5.1530142E+00  3.9030142E+00  0.0000000E+00   28
NODE    32  6.7686758E+00  4.2686758E+00  0.0000000E+00   25
NODE    33  8.3843384E+00  4.6343379E+00  0.0000000E+00   24
NODE    34  0.0000000E+00  6.2519288E+00  0.0000000E+00   80
NODE    35  0.0000000E+00  7.5012856E+00  0.0000000E+00   79
NODE    36  0.0000000E+00  8.7506428E+00  0.0000000E+00   78
NODE    37  3.9030142E+00  5.1530142E+00  0.0000000E+00   40
NODE    38  4.2686758E+00  6.7686758E+00  0.0000000E+00   50
NODE    39  4.6343379E+00  8.3843384E+00  0.0000000E+00   61
NODE    40  1.0000000E+01  6.2500000E+00  0.0000000E+00   37
NODE    41  1.0000000E+01  7.5000000E+00  0.0000000E+00   46
NODE    42  1.0000000E+01  8.7500000E+00  0.0000000E+00   58
NODE    43  1.2500000E+00  1.0000000E+01  0.0000000E+00   76
NODE    44  2.5000000E+00  1.0000000E+01  0.0000000E+00   75
NODE    45  3.7500000E+00  1.0000000E+01  0.0000000E+00   74
NODE    46  6.2500000E+00  1.0000000E+01  0.0000000E+00   72
NODE    47  7.5000000E+00  1.0000000E+01  0.0000000E+00   71
NODE    48  8.7500000E+00  1.0000000E+01  0.0000000E+00   70
NODE    49  2.3108866E+00  9.5720041E-01  0.0000000E+00   21
NODE    50  3.6240845E+00  9.7107112E-01  0.0000000E+00   11
NODE    51  3.2492657E+00  1.8759646E+00  0.0000000E+00   19
NODE    52  9.5720017E-01  2.3108866E+00  0.0000000E+00   44
```

```
NODE    53  1.8759630E+00  3.2492661E+00  0.0000000E+00   43
NODE    54  9.7106898E-01  3.6240849E+00  0.0000000E+00   55
NODE    55  6.1798358E+00  1.0444648E+00  0.0000000E+00    2
NODE    56  7.4532242E+00  1.1129766E+00  0.0000000E+00    9
NODE    57  8.7266121E+00  1.1814882E+00  0.0000000E+00   17
NODE    58  5.9663296E+00  2.0608010E+00  0.0000000E+00    7
NODE    59  7.3108869E+00  2.2072005E+00  0.0000000E+00    6
NODE    60  8.6554441E+00  2.3536003E+00  0.0000000E+00   16
NODE    61  5.6196151E+00  3.0219603E+00  0.0000000E+00   15
NODE    62  7.0797420E+00  3.2646394E+00  0.0000000E+00   14
NODE    63  8.5398703E+00  3.5073197E+00  0.0000000E+00   13
NODE    64  1.0444651E+00  6.1798368E+00  0.0000000E+00   66
NODE    65  2.0608010E+00  5.9663305E+00  0.0000000E+00   53
NODE    66  3.0219603E+00  5.6196151E+00  0.0000000E+00   41
NODE    67  1.1129768E+00  7.4532242E+00  0.0000000E+00   65
NODE    68  2.2072005E+00  7.3108869E+00  0.0000000E+00   52
NODE    69  3.2646394E+00  7.0797429E+00  0.0000000E+00   51
NODE    70  1.1814884E+00  8.7266121E+00  0.0000000E+00   64
NODE    71  2.3536003E+00  8.6554441E+00  0.0000000E+00   63
NODE    72  3.5073197E+00  8.5398703E+00  0.0000000E+00   62
NODE    73  5.4272604E+00  5.4272604E+00  0.0000000E+00   39
NODE    74  6.9515061E+00  5.7015061E+00  0.0000000E+00   38
NODE    75  8.4757538E+00  5.9757538E+00  0.0000000E+00   36
NODE    76  5.7015061E+00  6.9515061E+00  0.0000000E+00   49
NODE    77  7.1343379E+00  7.1343379E+00  0.0000000E+00   48
NODE    78  8.5671692E+00  7.3171692E+00  0.0000000E+00   47
NODE    79  5.9757538E+00  8.4757538E+00  0.0000000E+00   60
NODE    80  7.3171692E+00  8.5671692E+00  0.0000000E+00   59
NODE    81  8.6585846E+00  8.6585846E+00  0.0000000E+00   57
CONS     1    1   11
CONS     2    2    6
CONS     3    3    6
CONS     4    4   11
CONS     5    7   11
CONS     6   10    6
CONS     7   11    6
CONS     8   12    6
CONS     9   13    6
CONS    10   14    6
CONS    11   15    6
CONS    12   16   11
CONS    13   17   11
CONS    14   18   11
CONS    15   34   11
CONS    16   35   11
CONS    17   36   11
MA1         5.0000001E-01 1.0000000E-01  0.0000000E+00  0.0000000E+00
MA1         4.0000002E-01
MA2         1.0000000E+00  9.9900001E-01  0.0000000E+00  0.0000000E+00
MA2         1.0000000E-03
S1          1.0000000E+00
S2          0.0000000E+00
```



Problem Definition :

- single energy group
- the equation solved is :

$$\Omega.\nabla\psi + \sigma_t\psi = S + \frac{\sigma_s}{4\pi}\int_{4\pi} d\Omega'\ \psi(\Omega')$$

- source S = 1 in in sphere and zero elsewhere
- radius r = 5.0 cm
- in the spherical region : $\sigma_t = 0.5$; $\sigma_s = 0.4$ $\sigma_t = 0.1$
- in the external region : $\sigma_t = 1.0$; $\sigma_s = 0.999$

Fig 1 Sphere embedded in cylinder problem

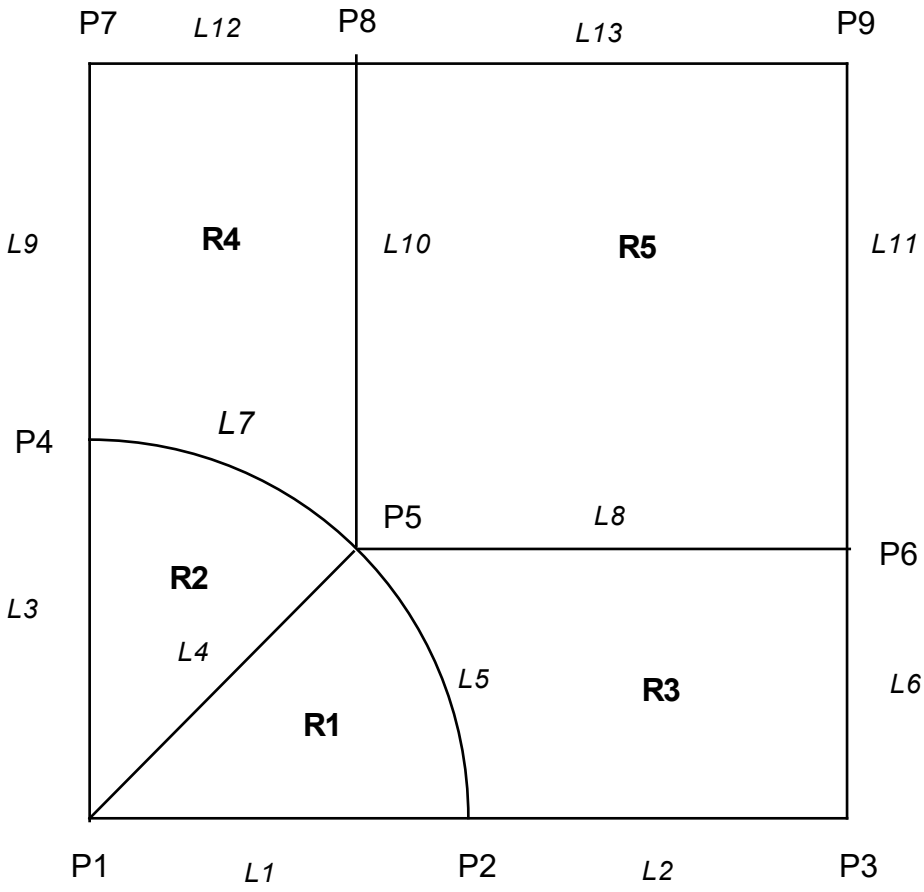


Fig. 2 Geometrical description of sphere embedded in cylinder problem as required by **GEM**