The Abdus Salam
International Centre for Theoretical Physics

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School on Physics, Technology and Applications of Accelerator Driven Systems (ADS)

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Background Information for P. SATYAMURTHY's talk on Thermal Hydraulics of Heavy Liquid Metal Target for ADS.

"FLUKA EXERCISE" by Harphool KUMAWAT

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FLUKA Exercise

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Heat deposition calculation using FLUKA

- Brief introduction of the heat deposition calculation method

$$S=\frac{4\pi e^4 Z_2}{m_e v^2} Z_1^2 \left[\ln \frac{2mv^2}{<I>} - \ln(1-\beta^2) - \beta^2 - \frac{C}{Z_2} - \frac{\delta}{2} \right]$$

+ Nuclear contribution

C= shell correction

δ= Density correction

- How to Install and run ?
- How to make input file ?

Beam parameters, Geometry, material, format of the output, number of particles.

How to run FLUKA ?

INSTALLATION and RUNNING

- mkdir fluka
- Cd fluka
- Tar zxvf …./flukalinux.tar.gz unzipping
- Export FLUPRO=$pwd for bash
- Cd $FLUPRO
- $FLUPRO/flutil/lfluka –m fluka linking
- $FLUPRO/flutil/rfluka –M5 sample executation

INPUT file

BEAM

Energy/Momentum, Distribution, Particle Type, Position

GEOMETRY

Actual geometry types, defining regions

MATERIAL & COMPOSITION

Material properties (Z, A, Density, volume fraction)

OUTPUT

Type of output (energy, neutron, ..), binning structure

Number of events/particles

END

INPUT file cards

TITLE

comments regarding the calculation (1 line only)

BEAM **(06 values has to be defined) + type of particle**

```
*...+....1....+...      .2....+....  3....+....      4....+... .5... .+....   6....+....7....+....8
BEAM       -1.0E+00                                    11.50        0.0       -1.0PROTON
                  WHAT(1)  WHAT(2)  WHAT(3)  WHAT(4) WHAT(5)  WHAT(6)
```

WHAT(1) = **<0 energy, >0 momentum**

WHAT(2)= **momentum spread**

<0 Gaussian FWHM

>0 rectangular

WHAT(3) = angular divergence

<0 Gaussian FWHM

>0 Rectangular >2000π isotropic

Energy = 1.0GeV
Spread in energy =0.0GeV
Angular spread= 0.0rad
R_{max} of uniform beam= 11.5 cm
R_{min} of uniform beam= 0.0 cm
Particle =proton

BEAM card continued…..

WHAT (4) **Beam spatial width**

>0 rectangular width in X direction if WHAT(6) >0

> 0 R_{max} annular distribution if WHAT(6) < 0

<0 Gaussian FWHM in X direction

WHAT (5) **Beam spatial width**

>0 rectangular width in Y direction if WHAT(6) >0

> 0 R_{min} annular distribution if WHAT(6) < 0

<0 Gaussian FWHM in Y direction

WHAT (6) **Particle weight** **SDUM= Particle name**

BEAM POSITION

```
*...+....1....+....2....+....3....+....4....+....5....+....6....+....7....+....8
BEAMPOS          0.0       0.0      -50.0
```

WHAT(1) WHAT(2) WHAT(3) WHAT(4) WHAT(5) WHAT(6)

WHAT(1) **X position of beam spot**

WHAT(2) **Y position of beam spot**

WHAT(3) **Z position of beam spot**

WHAT(4) **Direction cosine along X**

WHAT(5) **Direction cosine along Y**

WHAT(6) **Not used**

DSUM **default is +Z direction otherwise write NEGATIVE for -Z**

GEOMETRY

GEOBEGIN COMBNAME

Defining different bodies with dimension

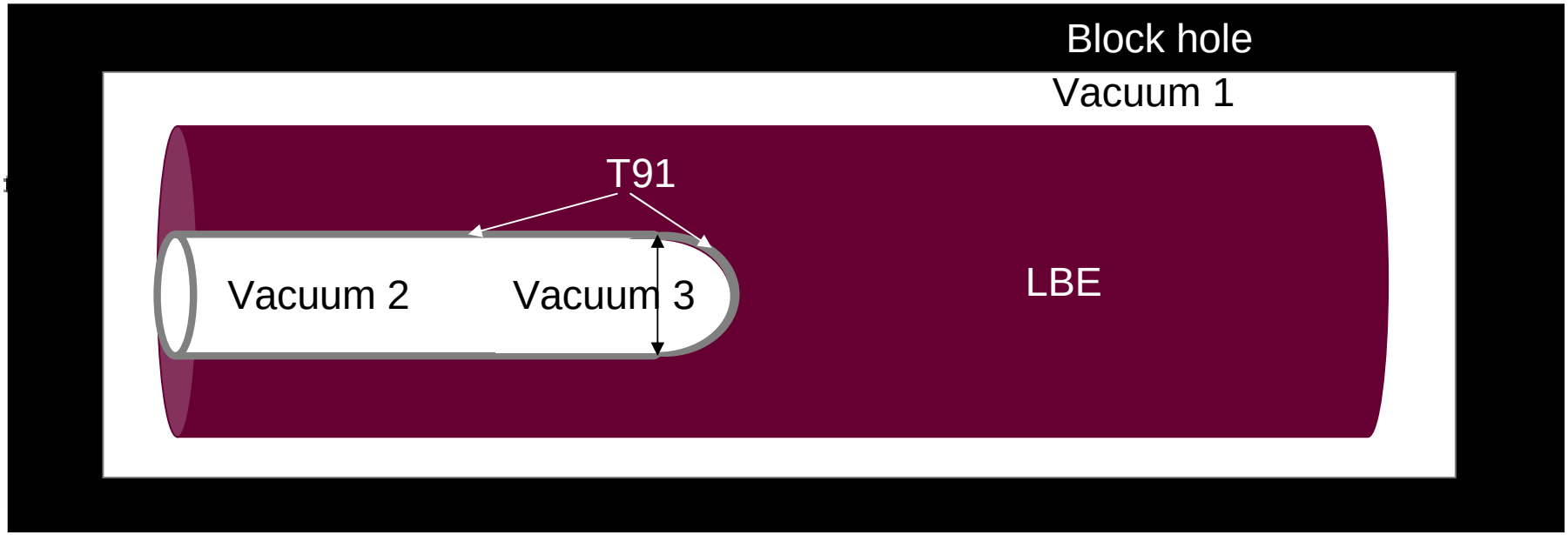
END

Defining regions with bodies

END

GEOEND

Sample geometry



Total length of the target loop	**110 cm**
Distance above the center of window	**20 cm**
Distance below the center of window 150-63	**100 cm**
Beam pipe outer radius	**13 cm**
Beam pipe inner radius	**12.8 cm**
Window (Hemi-Spherical) with uniform thickness	**02 mm**
Target material	**LBE (44.5%Pb+55.5%Bi weight percent)**
Window material	**T91**

Geometry card

```
GEOBEGIN                                                        COMBNAME
    0  0          (2I5,10X,A60)
RPP  ppbh   -500.0   +500.0   -500.0   +500.0   -500.0   +500.0      BOX
RPP  ppvac  -200.0   +200.0   -200.0   +200.0   -200.0   +200.0      BOX
RCC  cylbe    0.0   0.0    0.0    0.0    0.0   +110.0   +19.50       CYLINDER
RCC  cylbpo  0.0   0.0    0.0    0.0    0.0   +10.0   +13.0         CYLINDER
RCC  cylbpi  0.0   0.0    0.0    0.0    0.0   +10.0   +12.8         CYLINDER
SPH  wsph1   0.0   0.0  +10.0  +13.0                                SPHERE
SPH  wsph2   0.0   0.0  +10.0  +12.8                                SPHERE
XYP  wpln1  +10.0                                                 PLANE
END
•black hole
rbhole   6     +ppbh –ppvac
•vacuum around
rvac     6     | +ppvac -cylbe | +cylbpi |  wsph2 -wpln1
*LBE
rlbe     6     +cylfg -cylbpo -wsph1
*Beam Pipe Wall
rbpw     6     +cylbpo -cylbpi
*Target Window
rwndw    6     +wsph1 -wsph2 -wpln1
END
GEOEND
```

MATERIAL card

```
*...+....    1....+....  2....+....   3....+....  4....+...  .5....+...6...+..7....+....8
*                    Z        A        DENSITY MATERIAL NO.  NAME
*
MATERIAL       82.0    207.2    11.35     17.0                LEAD
MATERIAL       83.0    209.0    9.747     26.0                BISMUTH
MATERIAL        6.0  12.0107    2.000      6.0                CARBON
MATERIAL       25.0  54.9380    7.210     27.0                MANGANES
MATERIAL       15.0  30.9740    1.820     28.0                PHOSPHO
MATERIAL       16.0  32.0650    2.070     29.0                SULFUR
MATERIAL       14.0  28.0855    2.329     14.0                SILICON
MATERIAL       24.0  51.9960    7.180     30.0                CHROMIUM
MATERIAL       42.0  95.9400    10.22     31.0                MOLYBDEN
MATERIAL       27.0  58.6930    8.900     32.0                COBALT
MATERIAL       23.0  50.9415    6.110     33.0                VANADIUM
MATERIAL        7.0  14.0067  0.00117      7.0                NITROGEN
MATERIAL       41.0     92.9    8.570     34.0                NIOBIUM
MATERIAL       13.0 26.981538    2.699     10.0                ALUMINUM
MATERIAL       26.0   55.845    7.874     11.0                IRON
MATERIAL        8.0  15.9994  0.00133      8.0                OXYGEN
MATERIAL                      10.359     35.0                 LBE
MATERIAL                       8.23     36.0                 STEEL
```

Compound card

```
*...+....  1....+....2....+.3....+...4...+...5....+...  6....+...  .7....+....8
COMPOUND     -0.445     17.0   -0.555     26.0     0.0     0.0          LBE
COMPOUND    -0.0008      6.0   -0.003     27.0  -0.0002     28.0        STEEL
COMPOUND    -0.0001     29.0   -0.002     14.0   -0.08      30.0        STEEL
COMPOUND    -0.0085     31.0   -0.004     32.0  -0.0018     33.0        STEEL
COMPOUND    -0.0003      7.0  -0.0006     34.0  -0.0004     10.0        STEEL
COMPOUND    -0.8983     11.0
```

ASSIGNMAT card

```
ASSIGNMAT  LBE      rlbe
ASSIGNMAT  STEEL    rbpw       rwndw
ASSIGNMAT  VACUUM   rvac
ASSIGNMAT  BLCKHOLE rbhole
```

USERBIN card

Scoring of heat deposition in R-Z binning

```
*...+....      1....+....2....+....3....+....4....+....5....+...     .6....+..  ..7....+....8
*Cartesian binning of the deposited energy inside the target

USRBIN         11.0     208.0      49.0      19.5       0.0     110. Edeposit
USRBIN          0.0       0.0       0.0      50.0       1.0     400.0   &
```

END of input

```
*...+....1....+...          .2....+....3....+....4....+....5....+....6....+....7....+....8
RANDOMIZE        1.0
*...+....1....+....          2....+....3....+....4....+....5....+....6....+....7....+....8
START      1000000.0
STOP
```

Heat Deposition Data from FLUKA

```
 *****    Sample problem for ictp                                                  *****

          DATE: 11/ 6/ 7,  TIME: 12:31: 5

         Total number of particles followed       1000, for a total weight of  1.0000E+03

1
   R - Z     binning n.   1  "wndheat   " , generalized particle n.  208
      R coordinate: from  0.0000E+00 to  1.3000E+01 cm,   400 bins ( 3.2500E-02 cm wide)
      Z coordinate: from  1.0000E+01 to  2.3000E+01 cm,   400 bins ( 3.2500E-02 cm wide)
      axis coordinates: X = 0.0000E+00, Y =  0.0000E+00 cm
      Data follow in a matrix A(ir,iz), format (1(5x,1p,10(1x,e11.4)))

      accurate deposition along the tracks requested
```

0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00
0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00

4.3124E-05	4.1943E-05	1.7500E-04	5.9315E-05	1.1034E-05	3.4028E-05	3.0433E-05	9.0781E-05	2.0965E-04	6.4648E-05
6.0821E-05	8.5781E-05	1.0771E-04	9.4115E-05	8.1027E-05	2.3352E-05	6.4469E-05	1.6286E-05	1.2889E-05	7.3044E-05
8.7458E-05	8.1810E-05	6.4090E-05	6.4758E-05	7.9055E-05	8.9944E-05	6.1860E-05	6.9519E-05	4.0733E-05	8.7049E-05
1.5654E-05	6.0990E-05	4.6512E-05	5.7037E-05	3.9447E-05	6.5139E-05	2.6619E-05	3.8518E-05	4.6089E-05	6.4684E-05
2.3484E-05	4.7856E-05	1.9353E-04	9.5061E-05	2.2095E-05	6.0408E-05	6.7627E-05	3.6409E-05	2.5694E-05	3.1143E-05
4.0047E-05	4.9240E-05	1.0979E-05	2.5938E-05	4.7175E-05	2.7720E-05	0.0000E+00	2.8654E-05	2.7012E-05	1.8144E-05
3.4628E-05	1.5131E-05	4.5066E-05	3.2459E-05	1.2780E-05	2.5943E-05	3.4707E-05	5.4359E-05	3.0120E-05	2.7325E-05
4.9206E-05	1.5630E-05	2.9753E-05	2.0893E-05	2.1897E-05	4.0512E-05	1.9034E-05	4.4154E-05	5.9634E-05	3.8828E-05
7.1954E-05	3.9784E-05	4.4350E-05	4.4295E-05	2.4405E-05	4.4528E-05	7.9386E-05	1.0796E-04	8.0515E-05	1.8130E-05
4.7109E-05	4.1312E-05	9.2846E-05	1.1382E-04	5.3635E-05	3.9620E-05	5.7864E-05	2.8659E-05	3.1786E-05	3.5142E-05
1.0783E-04	4.9688E-05	5.4442E-05	5.8466E-05	3.5264E-05	3.1127E-05	5.9573E-05	3.1346E-05	2.1156E-05	3.4545E-05
2.9998E-05	0.0000E+00	5.6908E-05	4.2226E-05	4.5451E-05	3.2502E-05	2.8402E-05	2.4997E-05	4.2396E-05	6.9706E-05
2.7470E-05	5.2683E-05	2.0240E-05	1.1284E-04	4.1551E-05	3.4723E-05	1.3074E-04	1.4650E-05	3.0844E-05	1.5875E-04
2.4605E-05	3.9376E-05	3.3638E-05	9.7710E-05	5.0456E-05	4.2784E-05	7.1042E-05	2.0124E-05	3.2508E-05	4.0544E-05
2.4145E-05	2.0629E-05	3.7049E-05	3.3939E-05	4.5475E-05	3.0675E-05	1.4079E-05	1.1297E-05	1.6920E-05	1.0630E-05
2.8275E-05	1.5132E-05	1.7964E-05	2.5299E-05	1.2706E-05	8.8021E-07	1.5264E-05	0.0000E+00	1.7718E-05	1.3758E-05
1.2286E-05	2.4868E-05	1.2895E-05	9.6323E-06	7.3003E-06	5.4665E-06	1.6340E-05	1.0736E-05	2.9535E-05	2.9363E-05
1.1617E-05	1.6214E-05	7.1590E-06	7.1181E-06	7.0779E-06	5.9531E-06	2.0738E-05	6.2759E-06	1.2550E-05	0.0000E+00
5.7875E-07	1.0583E-07	0.0000E+00	0.0000E+00	0.0000E+00	1.1462E-05	8.4999E-08	0.0000E+00	0.0000E+00	1.4635E-06
3.0665E-06	9.0771E-06	2.8885E-06	0.0000E+00	0.0000E+00	0.0000E+00	9.9265E-06	1.6355E-07	1.1364E-05	1.8298E-05

Code to Rearrange Data for TECPLOT

```
subroutine post( IDATA, IOUT, NRBIN, NZBIN, NEPL, dr, dz )
implicit double precision ( a-h, o-z )
dimension A(1:NRBIN,1:NZBIN)
dimension B(1:NEPL)
pi = 4.d0*atan(1.d0)
do i = 1, NRBIN
   do j = 1, NZBIN
      A(i,j) = 0.d0
   enddo
enddo
 do j = 1, NEPL
   B(j) = 0.d0
enddo
NTOT  = NRBIN*NZBIN
NLEFT = mod(NTOT-1,NEPL) + 1
NLINE = (NTOT - NLEFT)/NEPL + 1
do i = 1, 15
   read(IDATA,*)
enddo
do i = 1, NLINE - 1
     read(IDATA,*) ( B(j), j = 1, NEPL )
      do k  = 1, NEPL
         n        = (i-1)*NEPL + k
         n2       = mod(n-1,NRBIN) + 1
         n1       = (n - n2)/NRBIN + 1
         A(n2,n1) = B(k)
     enddo
enddo
read(IDATA,*) ( B(j), j = 1, NLEFT )
  do k  = 1, NLEFT
     n        = (NLINE-1)*NEPL + k
     n2       = mod(n-1,NRBIN) + 1
     n1       = (n - n2)/NRBIN + 1
     A(n2,n1) = B(k)
enddo
```

```
fluka data is in GeV/cm3/proton, output shall be in W/m3/mA
cfac = 1.0e12
write(IOUT,*) 'TITLE="HGEN"'
write(IOUT,*) 'VARIABLES="r" "z" "q"'
write(IOUT,*) 'ZONE I=',NRBIN, ' J=', NZBIN, ' F=POINT'
sum1 = 0.d0
sum2 = 0.d0
do j = 1, NZBIN
    z = (j-0.5)*dz*1e-2
   do i = 1, NRBIN
       r = (i-0.5)*dr*1e-2
      write(IOUT,*) r, z, cfac*A(i,j)
      sum1 = sum1 + r*cfac*A(i,j)
      if(z.gt.(0.1).and.r.lt.(0.13)) sum2 = sum2 + r*cfac*A(i,j)
      if(z.gt.(0.0)) then
          rad=dsqrt(r**2+(z-0.0)**2)
        if(rad.lt.(0.13)) sum2 = sum2 + r*cfac*A(i,j)
      endif
   enddo
enddo
ht_tot =  2.d0*pi*sum1*dr*dz*1.0e-4/1.0e6
ht_win =  2.d0*pi*sum2*dr*dz*1.0e-4/1.0e3
write(*,*) sum2, sum1
 write(*,100) "Total Heat Deposited (in MW/mA) = ", ht_tot
 write(*,100) "Heat Deposited in Window (in kW/mA) = ", ht_win
format(1x,a40,f10.2)
return
end
```

```
TITLE="HGEN"
VARIABLES="r" "z" "q"
ZONE I= 50 J= 400 F=POINT
 0.00194999996  0.00137499997  0.
 0.00584999987  0.00137499997  0.
 0.00974999978  0.00137499997  0.
 0.0136499997  0.00137499997  0.
 0.0175499996  0.00137499997  0.
 0.0214499995  0.00137499997  0.
 0.0253499994  0.00137499997  0.
 0.0292499993  0.00137499997  0.
 0.0331499993  0.00137499997  0.
 0.0370499992  0.00137499997  0.
 0.0409499991  0.00137499997  0.
 0.044849999  0.00137499997  0.
 0.0487499989  0.00137499997  0.
 0.0526499988  0.00137499997  0.
 0.0565499987  0.00137499997  0.
 0.0604499986  0.00137499997  0.
 0.0643499986  0.00137499997  0.
 0.0682499985  0.00137499997  0.
 0.0721499984  0.00137499997  0.
 0.0760499983  0.00137499997  0.
 0.0799499982  0.00137499997  0.
 0.0838499981  0.00137499997  0.
 0.087749998  0.00137499997  0.
 0.091649998  0.00137499997  0.
 0.0955499979  0.00137499997  0.
 0.0994499978  0.00137499997  0.
 0.103349998  0.00137499997  0.
 0.107249998  0.00137499997  0.
 0.111149998  0.00137499997  0.
 0.115049997  0.00137499997  0.
 0.118949997  0.00137499997  0.
 0.122849997  0.00137499997  0.
 0.126749997  0.00137499997  124259.999
 0.130649997  0.00137499997  451629.998
 0.134549997  0.00137499997  316489.999
 0.138449997  0.00137499997  223339.999
 0.142349997  0.00137499997  216029.999
 0.146249997  0.00137499997  145159.999
 0.150149997  0.00137499997  123389.999
 0.154049997  0.00137499997  104100.
 0.157949996  0.00137499997  84176.9997
```

Data arranged for TECPLOT

Thank you

Rectangular parallepiped (RPP)

RPP $X_{min}, X_{max}, Y_{min}, Y_{max}, Z_{min}, Z_{max}$

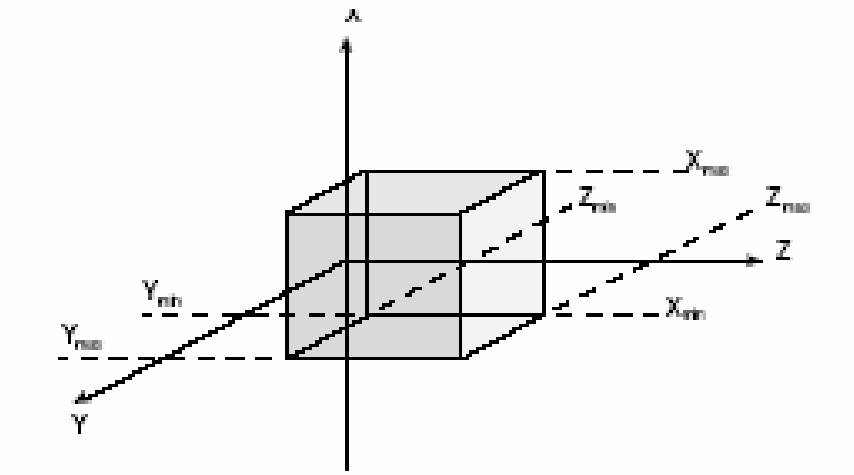


Fig. 1.1: Rectangular Parallelepiped (RPP)

Right Circular Cylinder (RCC)

RCC Vx, Vy, Vz, Hx, Hy, Hz, R

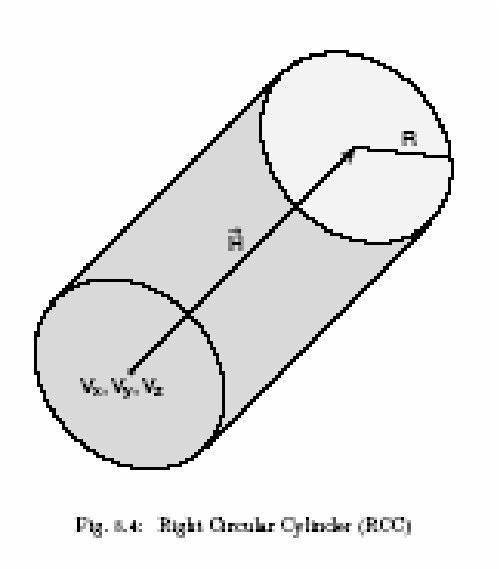


Fig. 8.4: Right Circular Cylinder (RCC)

Sphere (SPH)

SPH Vx, VY, Vz, R

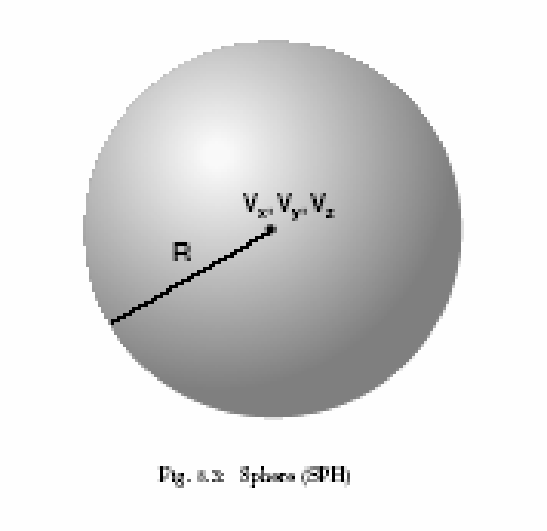


Fig. 8.2: Sphere (SPH)

Plane perpendicular to Z axis (XYP)

XYP Z

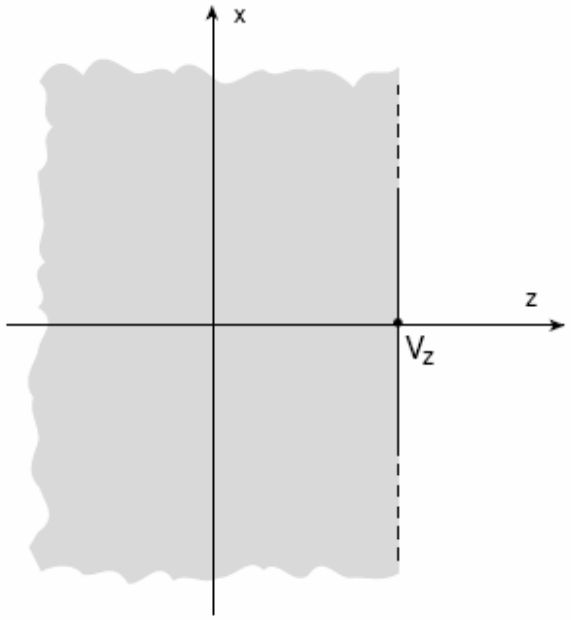


Fig. 8.10: Infinite half-space delimited by a plane perpendicular to the z axis (XYP)

Compound

If **WHAT(1)** > 0.0 and **WHAT(2)** > 0.0:

WHAT(1) = atom relative content of first material in the compound
WHAT(2) = index of first material

If **WHAT(1)** < 0.0 and **WHAT(2)** > 0.0:

|**WHAT(1)**| = mass fraction of first material in the compound
WHAT(2) = index of first material

If **WHAT(1)** < 0.0 and **WHAT(2)** < 0.0:

|**WHAT(1)**| = volume fraction of first material in the compound
|**WHAT(2)**| = index of first material

No default

In a similar way, WHAT(3) and WHAT(4) refer to the second material in the compound, WHAT(5) and WHAT(6) to the third one.

SDUM : name of the compound

Default (option COMPOUND not requested): no compound is defined

For more than three materials in the same compound, add as many COMPOUND cards with the same SDUM name as needed (but the maximum number of components per compound is 80, and the maximum total number of components is 1000).

Continuation card: (not needed if the defaults are acceptable)

WHAT(1) = For R–Z and R—Z binning: Rmin

WHAT(2) =For R–Z binning: X coordinate of the binning axis.

WHAT(3) =For Cartesian, R–Z and R—Z binnings: Zmin

WHAT(5) =For R—Z: number of bins. (Default is R—Z = R–Z, i.e., 1 bin)

.

WHAT(4) =For R–Z and R—Z binning: number of R bins

WHAT(6) =For Cartesian, R–Z and R—Z binnings: number of Z bins

SDUM = “&” in any position in column 71 to 78

RANDOMIZE:

WHAT(1) : logical file unit from which to read the seeds.

Default = 1.0 (reads the random number seeds from unit 1)

WHAT(2) =any number < 2 · 109 (see Note 5)

.

Default = 1234598765

WHAT(3) – WHAT(6), SDUM: not used

START: Defines termination conditions, gets a primary from a beam or from asource and starts the transport.

WHAT(1) =maximum number of primary histories

WHAT(2) : not used

WHAT(3) =time left for termination and printout (in seconds)

WHAT(4) : not used

WHAT(5) = 0.0: a line reporting the number of calls to the random number generator (in hexadecimalform) is printed at the beginning of each history only for the first ones, and then with
decreasing frequency
> 0.0: the number of calls is printed at the beginning of each history.

WHAT(6) =time reserved for an interactive run

SDUM : not used

WHAT(1) : code indicating the type of binning selected. Each type is characterised by a number of properties:

- structure of the mesh (spatial: R–Z, R–Φ–Z, Cartesian, or special — by region, or user-defined)
- quantity scored (energy, star, fission, neutron balance, specific activity or track-length density)
- method used for scoring (old algorithm where the energy lost in a step by a charged particle is deposited in the middle of the step, or new algorithm where the energy lost is apportioned among different bins according to the relevant step fraction — see more in Note 7)
- mesh symmetry (no symmetry, or specular symmetry around one of the coordinate planes, or around the origin point)

= `0.0`: Mesh: Cartesian, no symmetry
Quantity scored:

- if WHAT(2) = `208.0, 211.0, 229.0` or `230.0`: energy density (deposited with the old algorithm at midstep, see Note 7)
- if WHAT(2) = `219.0, 220.0` or `221.0`: fission density
- if WHAT(2) = `222.0`: neutron balance density
- if WHAT(2) = `234.0` or `235.0`: specific activity
- otherwise, density of stars produced by particles (or families of particles) with particle code = WHAT(2)

= `1.0`: Mesh: R–Z or R–Φ–Z, no symmetry. Φ is the azimuthal angle around the Z axis, measured from $-\pi$ to $+\pi$ relative to the X axis.
Quantity scored: same as for WHAT(1) = `0.0`

= `2.0`: Mesh: by region (1 bin corresponds to n regions, with $n = 1$ to 3)
Quantity scored: same as for WHAT(1) = `0.0`

= `3.0`: Mesh: Cartesian, with symmetry ± X (i.e., `|x|` is used for scoring)
Quantity scored: same as for WHAT(1) = `0.0`

= `4.0`: Mesh: Cartesian, with symmetry ± Y (i.e., `|y|` is used for scoring)
Quantity scored: same as for WHAT(1) = `0.0`

= `5.0`: Mesh: Cartesian, with symmetry ± Z (i.e., `|z|` is used for scoring)
Quantity scored: same as for WHAT(1) = `0.0`

= `6.0`: Mesh: Cartesian, with symmetry around the origin (i.e., `|x|, |y|` and `|z|` are used for scoring)
Quantity scored: same as for WHAT(1) = `0.0`

= 7.0: Mesh: R–Z or R–Φ–Z, with symmetry ± Z (i.e., |z| is used for scoring)
Quantity scored: same as for WHAT(1) = 0.0

= 8.0: Special user-defined 3-D binning. Two variables are discrete (e.g., region number), the third one is continuous, but not necessarily a space coordinate. See 13.2.9 for instructions on how to write, compile and link the user routines.

Variable	Type	Default	Override routine
1^{st}	integer	region number	MUSRBR
2^{nd}	integer	lattice cell number	LUSRBL
3^{rd}	continuous	pseudorapidity	FUSRBV

= 10.0: Mesh: Cartesian, no symmetry
Quantity scored: if WHAT(2) = 208.0, 211.0, 229.0 or 230.0: energy density (apportioned with the new algorithm along the step as explained in Note 7).
If WHAT(2) = 219.0, 220.0 or 221.0: fission density.
Otherwise: fluence (track-length density) of particles (or families of particles) with particle code = WHAT(2)

= 11.0: Mesh: R–Z or R–Φ–Z, no symmetry
Quantity scored: same as for WHAT(1) = 10.0

= 13.0: Mesh: Cartesian, with symmetry ± X (|x| used for scoring)
Quantity scored: same as for WHAT(1) = 10.0

= 14.0: Mesh: Cartesian, with symmetry ± Y (|y| used for scoring)
Quantity scored: same as for WHAT(1) = 10.0

= 15.0: Mesh: Cartesian, with symmetry ± Z (|z| used for scoring)
Quantity scored: same as for WHAT(1) = 10.0

= 16.0: Mesh: Cartesian, with symmetry around the origin (|x|, |y|, |z| used for scoring)
Quantity scored: same as for WHAT(1) = 10.0

= 17.0: Mesh: R–Z or R–Φ–Z, with symmetry ± Z (|z| used for scoring)
Quantity scored: same as for WHAT(1) = 10.0

Default = 0.0 (Cartesian scoring without symmetry, star density or energy density deposited at midstep with the old algorithm)

WHAT(2) : particle (or particle family) type to be scored
If WHAT(2) = 208.0, 211.0, 229.0 or 230.0: if WHAT(1) < 10.0, the binning will score energy deposition with the old algorithm.
If WHAT(1) ≥ 10.0, the new deposition algorithm will be used (more accurate, see Note 7).
Any other particle (or family of particles) requested will score:

- if WHAT(1) < 10.0, density of stars produced by particles (or family of particles) with particle code = WHAT(2). Of course, this choice is meaningful only for particles which can produce stars (hadrons, photons and muons).
- if WHAT(1) ≥ 10.0, fluence of particles (or family of particles) with particle code = WHAT(2).

Note that it is not possible to score energy fluence with this option alone (it is possible, however, by writing a special version of the user routine FLUSCW — see 13.2.6)

Default = 208.0 (total energy density)

WHAT(3) = logical output unit:
> 0.0: formatted data are written on WHAT(3) unit
< 0.0: unformatted data are written on |WHAT(3)| unit
Values of |WHAT(3)| < 21.0 should be avoided (with the exception of +11).

Default = 11.0 (standard output unit)

WHAT(4) = For Cartesian binning: X_{max}
For R–Z and R–Φ–Z binning: R_{max}
For region binning: last region of the first region set
For special binnings, upper limit of the first user-defined variable (last region if the default version of the `MUSRBR` routine is not overridden)

Default: No default

WHAT(5) = For Cartesian binning: Y_{max}
For R–Z binning: Y coordinate of the binning axis.
For region binning: last region of the second region set
For special binnings, upper limit of the second user-defined variable (last lattice cell if the default version of the `LUSRBL` routine is not overridden)

Default: No default

WHAT(6) = For R–Z, R–Φ–Z and Cartesian binnings: Z_{max}
For region binnings, last region of the third region set
For special binnings, upper limit of the third user-defined variable (η_{max} if the default version of the `FUSRBV` routine is not overridden)

Default: No default

SDUM = any character string (not containing "&") identifying the binning (max. 10 characters)

Continuation card: (not needed if the defaults are acceptable)

WHAT(1) = For Cartesian binning: X_{min} (if X symmetry is requested, X_{min} cannot be negative)
For R–Z and R–Φ–Z binning: R_{min}
For region binnings, first region of the first region set. Default: equal to last region (= WHAT(4) in the first USRBIN card)
For special binnings, lower limit of the first user-defined variable (first region if the default version of the `MUSRBR` routine is not overridden)
Default = `0.0`

WHAT(2) = For Cartesian binning: Y_{min} (if Y symmetry is requested, Y_{min} cannot be negative)
For R–Z binning: X coordinate of the binning axis.
For region binnings, first region of the second region set. Default: equal to last region (= WHAT(5) in the first USRBIN card)
For special binnings, lower limit of the second user-defined variable (first lattice cell if the default version of the `LUSRBL` routine is not overridden)
Default = `0.0`

WHAT(3) = For Cartesian, R–Z and R–Φ–Z binnings: Z_{min} (if Z symmetry is requested, Z_{min} cannot be negative)
For region binnings, first region of the third region set. Default: equal to last region (= WHAT(6) in the first USRBIN card)
For special binnings, lower limit of the third user-defined variable (η_{min} if the default version of the `FUSRBV` routine is not overridden)
Default = `0.0`

WHAT(4) = For Cartesian binning: number of X bins. (Default: `30.0`)
For R–Z and R–Φ–Z binning: number of R bins (default: `50.0`)
For region binnings, step increment for going from the first to the last region of the first region set. (Default: `1.0`)
For special binnings, step increment for going from the first to the last "region" (or similar). (Default: `1.0`)

WHAT(5) = For Cartesian binning: number of Y bins. (Default: `30.0`).
For R–Φ–Z: number of Φ bins. (Default is R–Φ–Z = R–Z, i.e., `1` Φ bin).
For region binnings, step increment for going from the first to the last region of the second region set. (Default: `1.0`).
For special binnings, step increment for going from the first to the last "lattice cell" (or similar). (Default: `1.0`).

WHAT(6) = For Cartesian, R–Z and R–Φ–Z binnings: number of Z bins (default: `10.0` for Cartesian, `50.0` for R–Z and R–Φ–Z)
For region binnings, step increment for going from the first to the last region of the third region set. (Default: `1.0`).
For special binnings, number of intervals for the third variable ("η", or similar). (Default: `1.0`).

SDUM = "&" in any position in column 71 to 78 (or in the last field if free format is used)

Default (option USRBIN not given): no binning