How to Download and Use Phantoms

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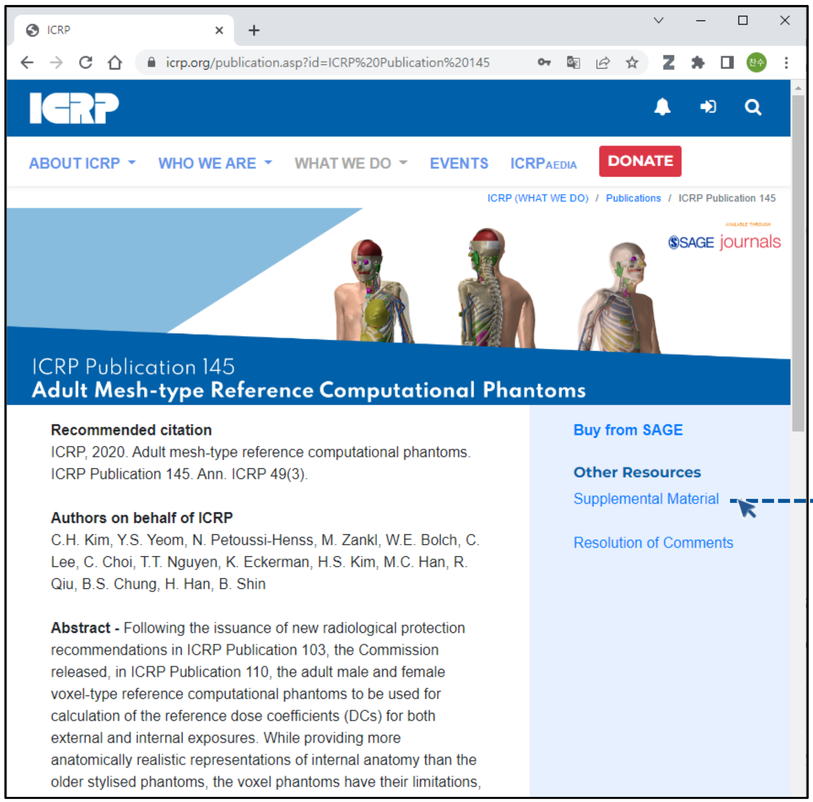
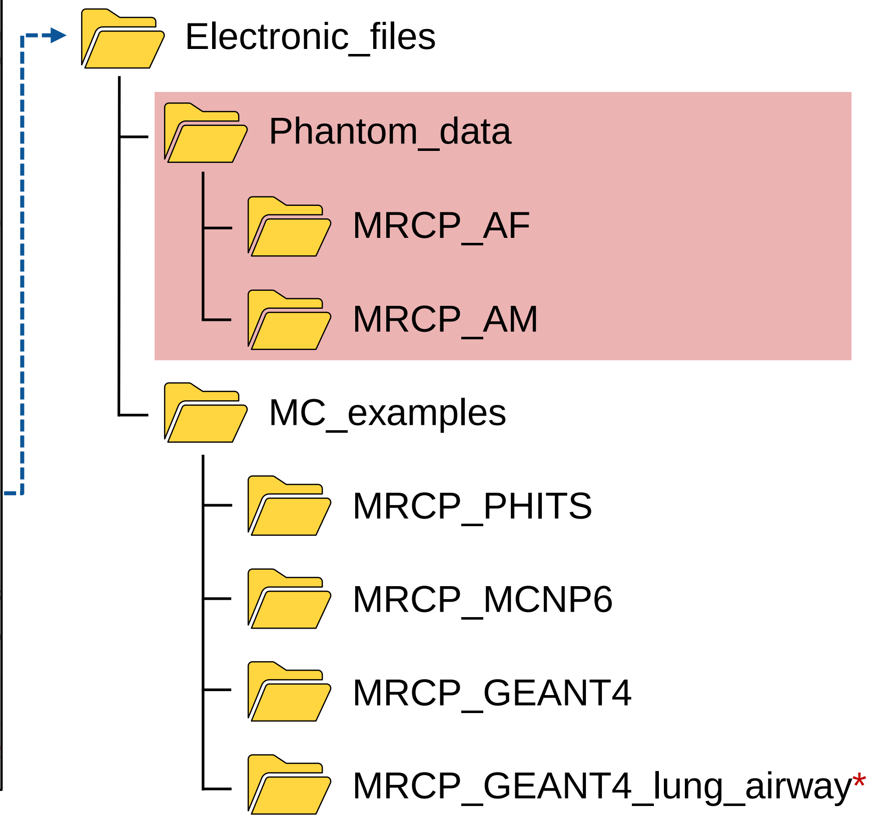
Objectives

- The Commission provides supplemental electronic files with Publication 145 to provide users with the phantoms and to help users use the phantoms.
- The presentation will cover **a detailed description on these electronic files** and **useful information for their applications**.



WHAT WE DO → PUBLICATIONS → ICRP Publication 145



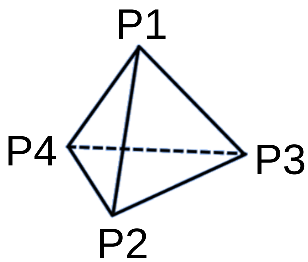
** this folder will be updated soon*

Phantom Data

- Phantom_data
  - MRCP_AF
    - MRCP_AF.ele
    - MRCP_AF.node
    - MRCP_AF.obj
    - MRCP_AF.mtl
    - MRCP_AF_media.dat
    - MRCP_AF_bone.dat
    - MRCP_AF_blood.dat
    - MRCP_AF.pdf
  - MRCP_AM*
    - MRCP_AM.ele
    - ⋮
    - MRCP_AM.pdf

** same as MRCP_AF*

MRCP_AF.node and MRCP_AF.ele



Tetrahedron is defined by …

4 vertices	4 facets
(X_{P1}, Y_{P1}, Z_{P1}) (X_{P3}, Y_{P3}, Z_{P3})	(P1, P2, P3) (P1, P3, P4)
(X_{P2}, Y_{P2}, Z_{P2}) (X_{P4}, Y_{P4}, Z_{P4})	(P1, P4, P2) (P2, P4, P3)
MRCP_AF.node	**MRCP_AF.ele**

- MRCP_AF.node
  - First line

1279642	3	0	0
<# of nodes>	**<dimension>**	**<n/a>**	**<n/a>**

  - Remaining line list # of points

0	1.728173	0.27409899999999998	33.475464000000002
1	1.550969	0.48175099999999998	33.402968999999999
<node ID>	**<x>**	**<y>**	**<z>**

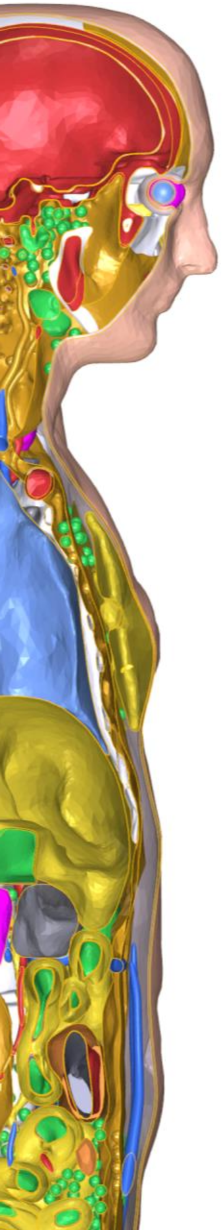
- MRCP_AF.ele
  - First line

8582677	4	1
<# of tet>	**<nodes per tet>**	**<# of attributes (for organ ID)>**

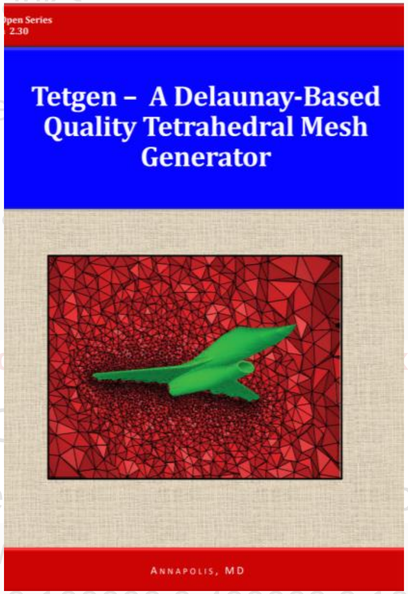
  - Remaining line list # of points

0	1226007	1148977	1225948	1149037	12501
1	901017	459351	901018	459350	11700
<tet ID>	**<node 1>**	**<node 2>**	**<node 3>**	**<node 4>**	**<organ ID>**

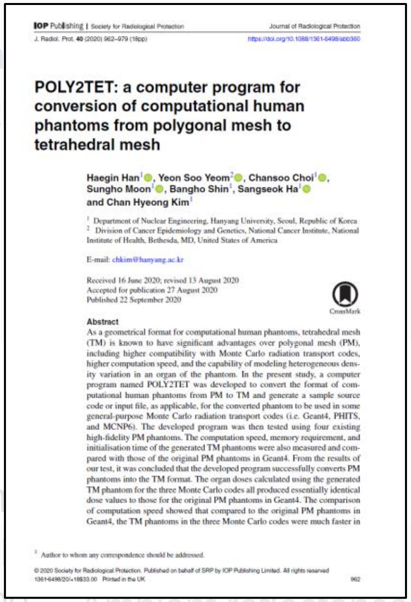
MRCP_AF.obj and MRCP_AF.mtl



Tetrahedralization



TETGEN



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POLY2TET: a computer program for conversion of computational human phantoms from polygonal mesh to tetrahedral mesh

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Abstract
As a geometrical format for computational human phantoms, tetrahedral mesh (TM) is known to have significant advantages over polygonal mesh (PM), including higher compatibility with Monte Carlo radiation transport codes, higher computation speed, and the capability of modeling heterogeneous density variation in an organ of the phantom. In the present study, a computer program named POLY2TET was developed to convert the format of computational human phantoms from PM to TM and generate a sample source code or input file, as applicable, for the converted phantom to be used in some general-purpose Monte Carlo radiation transport codes (i.e. Geant4, PHITS, and MCNP6). The developed program was then tested using four existing high-fidelity PM phantoms. The computation speed, memory requirement, and initialisation time of the generated TM phantoms were also measured and compared with those of the original PM phantoms in Geant4. From the results of our test, it was concluded that the developed program successfully converts PM phantoms into the TM format. The organ doses calculated using the generated TM phantom for the three Monte Carlo codes all produced essentially identical dose values to those for the original PM phantoms in Geant4. The comparison of computation speed showed that compared to the original PM phantoms in Geant4, the TM phantoms in the three Monte Carlo codes were much faster in

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POLY2TET

MRCP_AF_media.dat (Copy of Table B.2 in Annex B)

- MRCP_AF_media.dat contains the **physical property information** (elemental compositions and densities) **on each tissue**.

No.	Tissues to be used in the Monte Carlo simulation:	1 H	6 C	7 N	8 O	11 Na	12 Mg	15 P	16 S	17 Cl	19 K	20 Ca	26 Fe	53 I	density (g/cm3)
							(% by mass)								
1	Adrenal	10.4	23.3	2.8	62.5	0.1	0.0	0.2	0.3	0.2	0.2	0.0	0.0	0.0	1.035
2	ET, Trachea, BB, bb, Gall bladder wall, Pituitary gland, ..	10.5	25.2	2.7	60.6	0.1	0.0	0.2	0.3	0.2	0.2	0.0	0.0	0.0	1.031
3	Oral mucosa, Tongue	10.2	14.2	3.4	71.1	0.1	0.0	0.2	0.3	0.1	0.4	0.0	0.0	0.0	1.050
4	Blood	10.2	11.0	3.3	74.5	0.1	0.0	0.1	0.2	0.3	0.2	0.0	0.1	0.0	1.060
5	Cortical bone	3.6	15.9	4.2	44.8	0.3	0.2	9.4	0.3	0.0	0.0	21.3	0.0	0.0	1.904
6	Medullary cavity	11.5	63.7	0.7	23.8	0.1	0.0	0.0	0.1	0.1	0.0	0.0	0.0	0.0	0.981
7	Humeri, upper, spongiosa	8.6	39.2	2.6	39.0	0.1	0.1	3.1	0.2	0.1	0.1	6.9	0.0	0.0	1.185
8	Humeri, lower, Ulnae and radii, Wrists and hand bones, Femora, ...	9.5	49.8	1.7	31.1	0.1	0.0	2.3	0.2	0.1	0.0	5.2	0.0	0.0	1.117
			⋮												
52	Water	11.2	0.0	0.0	88.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

100%

Table A.2. List of organ identification (ID) number, medium, density, and mass of each organ/tissue in polygon mesh (PM) phantoms.

Organ ID	Organ/tissue	Medium	Density ($g\,cm^{-3}$) Male	Density ($g\,cm^{-3}$) Female	Mass (g) Male	Mass (g) Female
100	Adrenal, left	1	1.036	1.035	8.683	6.817
200	Adrenal, right	1	1.036	1.035	8.683	8.649
300	ET_1, 8 μm	2	1.031	1.031	0.022	0.009
301	ET_1, 40 μm	2	1.031	1.031	0.090	0.035
302	ET_1, 50 μm	2	1.031	1.031	0.028	0.011
303	ET_1, surface	2	1.031	1.031	11.291	4.375
400	ET_2, 0 μm	52	1.000	1.000	0.141	0.104

MRCP_AF_blood.dat

- MRCP_AF_blood.dat contains the **information on the fraction of blood content in the media**.

Med	Ratio	
1	0.159	**15.9% of blood content** in *Adrenal*
2	0.024	**2.4% of blood content** in *ET, Trachea, BB, bb, Gall bladder wall, Pituitary gland, …*
3	0.024	**2.4% of blood content** in *Oral mucosa, Tongue*
4	1.000	**100.0% of blood content** in *Blood*
5	0.010	**1.0% of blood content** in *Cortical bone*
6	0.014	**1.4% of blood content** in *Medullary cavity*
7	0.061	**6.1% of blood content** in *Humeri, upper, spongiosa*
8	0.025	**2.5% of blood content** in *Humeri, lower, Ulnae and radii, Wrists and hand bones, Femora, …*
⋮		⋮
52	0.000	**0.0% of blood content** in *Water*

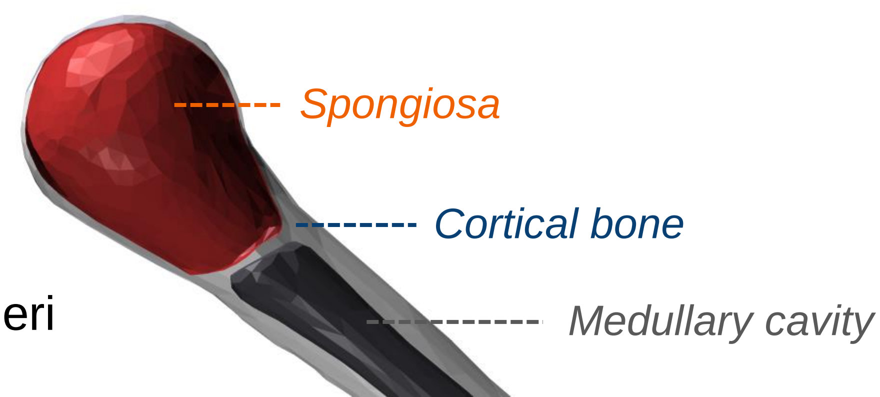
MRCP_AF_bone.dat

- MRCP_AF_bone.dat contains the **information on the fraction of bone constituents in the bone sites**.

Reb bone marrow (RBM), yellow bone marrow (YBM), trabecular bone (TB), Cortical bone (CB), and miscellaneous skeletal tissue (MST)

Organ ID	Organ/tissue	Organ/tissue mass exclusive of blood content (ratio)					Organ/tissue mass inclusive of blood content (ratio)				
		RBM	YBM	TB	CB	MST	RBM	YBM	TB	CB	MST
1300	Humeri, upper, cortical	0.000	0.000	0.000	1.000	0.000	0.000	0.000	0.000	1.000	0.000
1400	Humeri, upper, spongiosa	0.205	0.387	0.340	0.000	0.068	0.227	0.369	0.339	0.000	0.065
1500	Humeri, upper, medullary cavity	0.000	1.000	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000
1600	Humeri, lower, cortical	0.000	0.000	0.000	1.000	0.000	0.000	0.000	0.000	1.000	0.000
1700	Humeri, lower, spongiosa	0.000	0.702	0.248	0.000	0.050	0.000	0.694	0.257	0.000	0.049
1800	Humeri, lower, medullary cavity	0.000	1.000	0.000	0.000	0.000	0.000	1.000	0.000	0.000	0.000
1900	Ulnae and radii, cortical	0.000	0.000	0.000	1.000	0.000	0.000	0.000	0.000	1.000	0.000
2000	Ulnae and radii, spongiosa	0.000	0.702	0.248	0.000	0.050	0.000	0.694	0.257	0.000	0.049
	⋮										
5600	Sternum, spongiosa	0.610	0.249	0.118	0.000	0.023	0.643	0.225	0.111	0.000	0.021

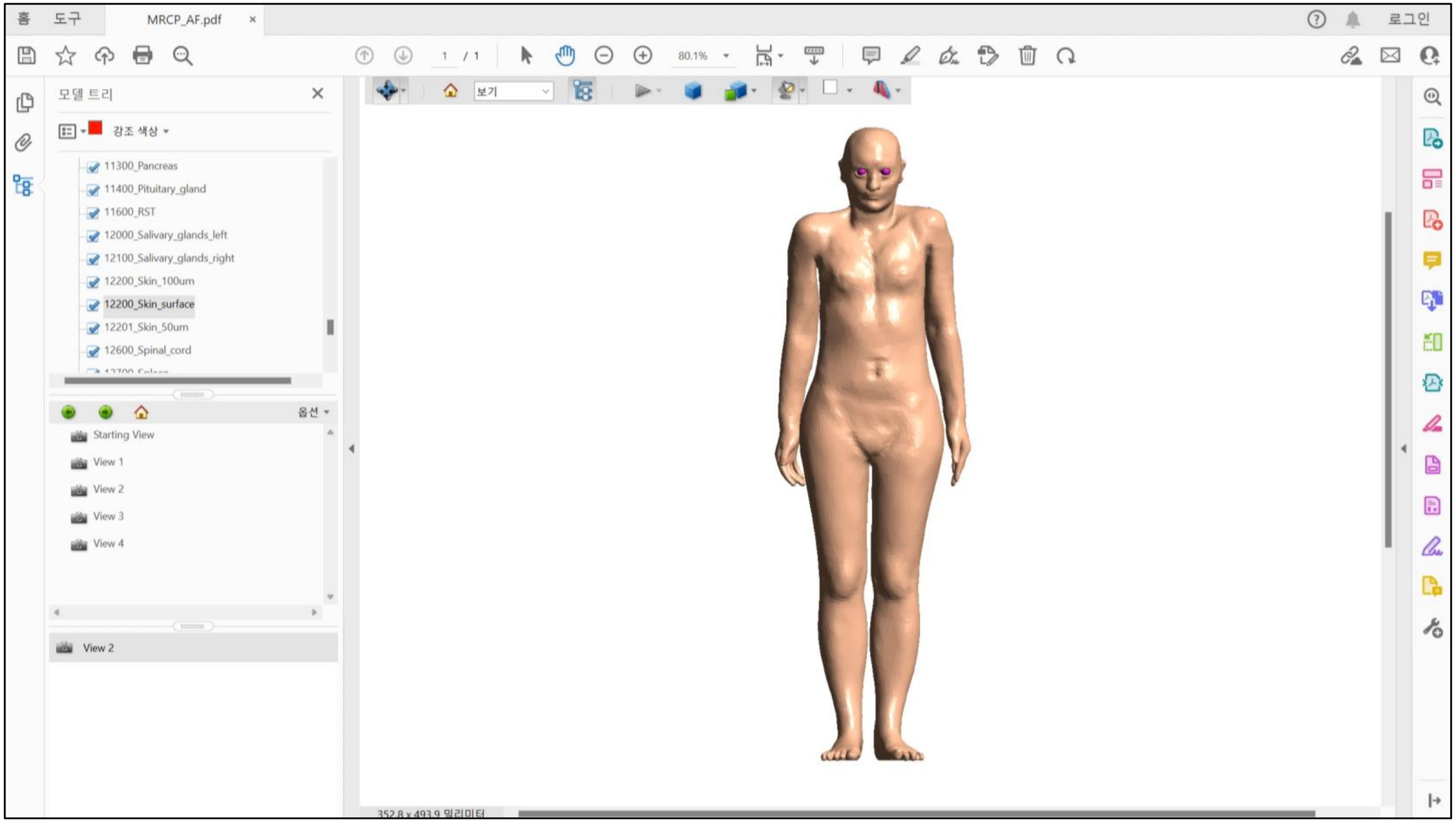
1.000 **1.000**



Upper humeri

MRCP_AF.pdf

- MRCP_AF.pdf visualize the phantoms in a 3D view and **can be opened in Acrobat** (Adobe Systems, San Jose, CA, USA).
- Detailed instruction on these 3D PDF files can be found on the following website: https://helpx.adobe.com/acrobat/using/displaying-3d-models-pdfs.html.



Monte Carlo Code Input Examples

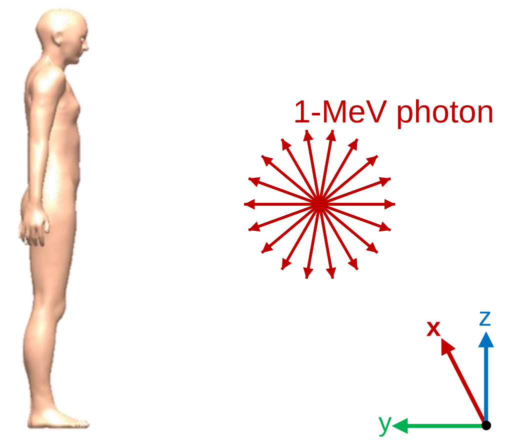
- MC_examples
  - MRCP_PHITS
    - External
    - Internal
    - phantoms
    - Visualisation
  - MRCP_MCNP6
    - External
    - Internal
    - phantoms
  - MRCP_GEANT4
    - External
    - Internal
    - phantoms
  - MRCP_GEANT4_lung_airway*
    - External
    - Internal
    - phantoms

** this folder will be updated soon*

Example Exposure Scenarios

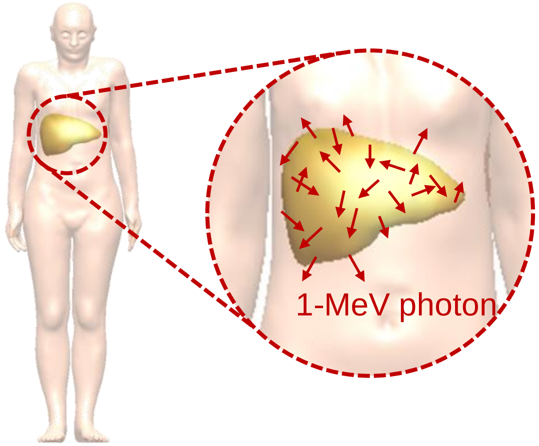
Common **external** exposure scenario

- Particle: photon
- Energy: 1 MeV
- Type and position: point source located 1 m in front of the phantom
- Direction: isotropic
- Result: average absorbed dose for each ID



Common **internal** exposure scenario

- Particle: photon
- Energy: 1 MeV
- Type and position: homogeneous liver source
- Direction: isotropic
- Result: average absorbed dose for each ID



Monte Carlo Code Input Examples

PHITS Code

- MRCP_PHITS
  - External
    - result
    - MRCP-AF_external_input.pin
    - MRCP-AM_external_input.pin
  - Internal*
  - phantoms
    - MRCP_AM.cell
    - MRCP_AM.ele
    - MRCP_AM.material
    - MRCP_AM.node
    - ⋮
    - MRCP_AF.node
  - Visualisation*

** same as External*

PHITS Code Input File

```
file = MRCP-AF_external_input.pin
# ----------------------------------------------------------------------------
#     name                : MRCP PHANTOM
#     sex                 : FEMALE
#     author              : HUREL
# ----------------------------------------------------------------------------

[ Parameters ]
 icntl     =           0      # (D=0) 3:ECH 5:NOR 6:SRC 7,8:GSH 11:DSH 12:DUMP
 maxcas    =     1000000      # (D=10) number of particles per one batch
 maxbch    =          10      # (D=10) number of batches
 itetvol   =           0      # (D=0) =1 Volume calculation for tetrahedrons
 ntetelem =         2000      # Number of tetra element allowed in sub-block
 maxbnk    =     1000000      # (D=10000) maximum bank memory length
 itetra    =           0      # (D=0) tetra data is read(=1)/write(=2) on binary
 file(6)   = MRCP-AF_external.out # (D=phits.out) general output file name
 file(7)   = (path to 'xsdir.jnd' file) # nuclear data input file name
 file(20) = (path to egs folder)       # Directory library data for EGS5
 negs      =           1      # (D=-1) 1:EGS
 ipegs     =           0      # [EGS](D=0) 0:Full

[ Source ]
  totfact =     1.00          # (D=1.0) global factor
   s-type =     1             # cylindrical source
     proj =    photon         # kind of incident particle
       e0 =     1.00          # energy of beam [MeV/u]
       r0 =     0.00          # radius [cm]
       x0 =     0.00          # (D=0.0) center position of x-axis [cm]
       y0 =  -100.00          # (D=0.0) center position of y-axis [cm]
       z0 =     0.00          # minimum position of z-axis [cm]
       z1 =     0.00          # maximum position of z-axis [cm]
      dir =    all            # z-direction of beam [isotropic]

```

PHITS Code Input File (Cont’d)

```
[ Material ]
$ ----------------------------------------------------------------------------
$ MATERIAL DATA FOR EACH ORGAN/TISSUE
$ ----------------------------------------------------------------------------
infl:{../phantoms/MRCP-AF.material}

[ Surface ]
  10  rpp -35.2695 35.2695 -23.60994 23.60994 -91.50872 91.50872  $ Phantom box
  20  rpp -35.4695 35.4695 -23.80994 23.80994 -91.70872 91.70872
  90  box -1000 -1000 -1000 2000 0 0 0 2000 0 0 0 2000         $ World boundary

[ Cell ]
$ ----------------------------------------------------------------------------
$ CELLS FOR PHANTOM
$ ----------------------------------------------------------------------------
infl:{../phantoms/MRCP-AF.cell}

[ T-deposit ]
# Deposit energy in a certain region
 file   = Result_MRCP-AF_external.out        # file name of output for the axis
 mesh   = reg               # mesh type is region-wise
 reg    = all               # all regions become tallying region
 axis   = reg               # axis of output
 unit   = 0                 # unit is [Gy/source]

[ End ]

```

[Parameters] Section – Set PHITS Path

- **Before PHITS version 3.00** – set the file(7) and file(20).

```
[ Parameters ]
 icntl     =          0      # (D=0) 3:ECH 5:NOR 6:SRC 7,8:GSH 11:DSH 12:DUMP
 maxcas    =    1000000      # (D=10) number of particles per one batch
 maxbch    =         10      # (D=10) number of batches
 itetvol   =          0      # (D=0) =1 Volume calculation for tetrahedrons
 ntetelem  =       2000      # Number of tetra element allowed in sub-block
 maxbnk    =    1000000      # (D=10000) maximum bank memory length
 itetra    =          0      # (D=0) tetra data is read(=1)/write(=2) on binary
 file(6)   = MRCP-AF_external.out # (D=phits.out) general output file name
 file(7)   = (path to 'xsdir.jnd' file) # nuclear data input file name
 file(20)  = (path to egs folder)       # Directory library data for EGS5
 negs      =          1      # (D=-1) 1:EGS
 ipegs     =          0      # [EGS](D=0) 0:Full
```

```
           data]$ ls
RIsource.ack  RIsource.bet  RIsource.dat  RIsource.rad  aama.dat  material.inp  multiplier  trxcrd.dat  xsdir.jnd
[sh@server-205 data]$ pwd
/share/codes/PHITS310/phits/data
           data]$
```

Path to “xsdir.jnd” file

Nuclear data input file

ex) file(7) = /share/codes/PHITS310/phits/data/xsdir.jnd

```
           egs]$ pwd
/share/codes/PHITS310/phits/XS/egs
[sh@server-205 egs]$ ls
K1.dat       bcomp.dat  density_corrections  int_coherent_cs  pgs5form.dat  shellwise_Compton_profile
aprime.data  dcslib     incoh.dat            int_form_factor  pgs5phtx.dat
           egs]$
```

Path to egs folder

Files in egs folder

ex) file(20) = /share/codes/PHITS310/phits/XS/egs

[Parameters] Section – Set PHITS Path (Cont'd)

- **From PHITS version 3.00** – set the file(1).

```
[ Parameters ]
 icntl    =           0     # (D=0) 3:ECH 5:NOR 6:SRC 7,8:GSH 11:DSH 12:DUMP
 maxcas   =     1000000     # (D=10) number of particles per one batch
 maxbch   =          10     # (D=10) number of batches
 itetvol  =           0     # (D=0) =1 Volume calculation for tetrahedrons
 ntetelem =        2000     # Number of tetra element allowed in sub-block
 maxbnk   =     1000000     # (D=10000) maximum bank memory length
 itetra   =           0     # (D=0) tetra data is read(=1)/write(=2) on binary
 file(6)  = MRCP-AF_external.out # (D=phits.out) general output file name
 file (1) = (PHITS installation folder path)
 negs     =           1     # (D=-1) 1:EGS
 ipegs    =           0     # [EGS](D=0) 0:Full
```

```
XS   build310  dchain-sp  lecture  phits_LinIfort_OMP_310  recommendation  src
bin  data      document   manual   phits_LinIfort_OMP_317  sample          utility
[sh@server-205 phits]$ pwd
/share/codes/PHITS310/phits
```

PHITS installation folder path

ex) file(1) = /share/codes/PHITS310/phits

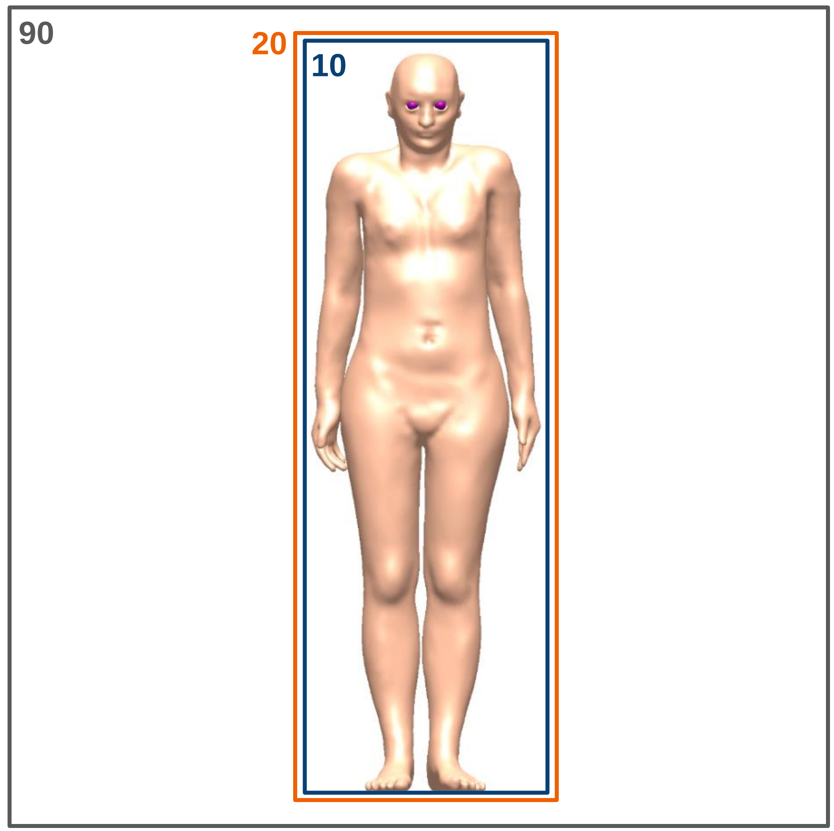
- If the file(1) is set, file(7) and file(20) are automatically determined.
  - ✓ file(7) : "file(1)/data/xsdir.jnd"
  - ✓ File(20) : "file(1)/XS/egs"

[Surface] Section

- Define **three surfaces** in the [Surface] section.

```
[ Surface ]
  10  rpp -35.2695 35.2695 -23.60994 23.60994 -91.50872 91.50872  $ Phantom box
  20  rpp -35.4695 35.4695 -23.80994 23.80994 -91.70872 91.70872
  90  box -1000 -1000 -1000 2000 0 0 0 2000 0 0 0 2000          $ World boundary
```

- Phantom box (10)
- Box for Universe and Fill (20)
  - ✓ A slightly larger box than the phantom box
- World (90)



[Cell] Section

- Define cell information from the **"*.cell" file in the "phantoms" folder.**

```
[ Cell ]
$ ------------------------------------------------------------------------------
$ CELLS FOR PHANTOM
$ ------------------------------------------------------------------------------
infl:{../phantoms/MRCP-AF.cell}
```

Cell no.1 is a universe (U=15000)
Cell no.2 is a component of the main space
Fill the component in main space by using the universe (FILL=15000)

```
$ CELLS FOR PHANTOM
 00001        0      -20             U=15000 LAT=3 tfile=../phantoms/MRCP-AF
 00002        0      -10             FILL=15000
 00003        0      -20     10
 00004        0      -90     20
 00005       -1       90
 00100      100   -1.035    -90      u=100       VOL=6.5860223745
 00200      200   -1.035    -90      u=200       VOL=8.3560907999
 00300      300   -1.031    -90      u=300       VOL=0.0083071216
 00301      301   -1.031    -90      u=301       VOL=0.0335120084
 00302      302   -1.031    -90      u=302       VOL=0.0105656479
 00303      303   -1.031    -90      u=303       VOL=4.2430444590
 00400      400   -1.000    -90      u=400       VOL=0.1041581236
 00401      401   -1.031    -90      u=401       VOL=0.2792021263
 00402      402   -1.031    -90      u=402       VOL=0.0701327051
 00403      403   -1.031    -90      u=403       VOL=0.0351422639
 00404      404   -1.031    -90      u=404       VOL=0.0703011119
 00405      405   -1.031    -90      u=405       VOL=13.7539583151
 00500      500   -1.050    -90      u=500       VOL=0.0629945782
 00501      501   -1.050    -90      u=501       VOL=0.0153500757
 00600      600   -1.050    -90      u=600       VOL=0.0179283414
 00700      700   -1.031    -90      u=700       VOL=7.9545323172
 00800      800   -1.000    -90      u=800       VOL=0.0102339567
 00801      801   -1.031    -90      u=801       VOL=0.0122541229
 00802      802   -1.031    -90      u=802       VOL=0.0204685170
 00803      803   -1.031    -90      u=803       VOL=0.0514337142
```

<cell no.> <mat. no.><density> <univ. no.>

'LAT=3' means that the geometry by the node and element files with names specified by TFILE is used.

[Material] Section

- Define material information from the **"*.material" file in the "phantoms" folder**.

```
[ Material ]
$ ----------------------------------------------------------------------------
$ MATERIAL DATA FOR EACH ORGAN/TISSUE
$ ----------------------------------------------------------------------------
infl:{../phantoms/MRCP-AF.material}
```

```
$ MATERIALS FOR EACH ORGAN/TISSUE
$ Adrenal_left 1.035 g/cm3
MAT[100] <mat. no.>
     1000        -0.104
     6000        -0.233
     7000        -0.028
     8000        -0.625
     11000       -0.001
     15000       -0.002
     16000       -0.003
     17000       -0.002
     19000       -0.002
mt100
$ Adrenal_right 1.035 g/cm3
MAT[200] <mat. no.>
     1000        -0.104
     6000        -0.233
     7000        -0.028
     8000        -0.625
     11000       -0.001
     15000       -0.002
     16000       -0.003
     17000       -0.002
     19000       -0.002
mt200
```

[T-deposit] Section

- Use the [T-deposit] section to calculate the **energy deposition (heat) of organs**.

```
[ T-deposit ]
# Deposit energy in a certain region
 file    = Result_MRCP-AF_external.out        # file name of output for the axis
 mesh    = reg                  # mesh type is region-wise
 reg     = all                  # all regions become tallying region
 axis    = reg                  # axis of output
 unit    = 0                    # unit is [Gy/source]
```

- Set the geometry option by the “mesh” parameters.
  - ✓ reg: region mesh (cell number)
- Set the specific region for calculating energy deposition by “reg” parameter.
  - ✓ all: all cell regions (calculation of the energy deposition for all the organs separately)
- If the user wants to calculate the energy deposition for the **specific organ**, **enter the cell number**.

  ex) reg = 100

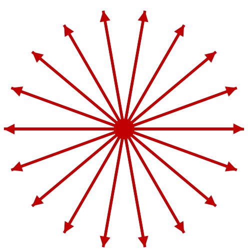
- If the user wants to calculate the energy deposition for the **several organs together**, **enter their cell number in parentheses.**

  ex) reg = (9700 9900)

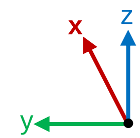
[Source] Section – External Exposure

- Set the external source.

```
[ Source ]
  totfact =     1.00        # (D=1.0) global factor
   s-type =     1           # cylindrical source
     proj =   photon        # kind of incident particle
       e0 =     1.00        # energy of beam [MeV/u]
       r0 =     0.00        # radius [cm]
       x0 =     0.00        # (D=0.0) center position of x-axis [cm]
       y0 =  -100.00        # (D=0.0) center position of y-axis [cm]
       z0 =     0.00        # minimum position of z-axis [cm]
       z1 =     0.00        # maximum position of z-axis [cm]
      dir =   all           # z-direction of beam [isotropic]
```



- **Type: point source**
- **Particle: photon**
- **Energy: 1 MeV**
- **Position: (0, -100, 0)**
- **Direction: isotropic**



[Source] Section – Internal Exposure

- **Before PHITS version 3.02** – use the **“s-type = 2” (rectangular solid)** to generate the source particles using the **rejection method**.

```
[ Source ]
  totfact =    1.00          # (D=1.0) global factor
   s-type =    2             # rectangular-solid source
     proj =   photon         # kind of incident particle
       e0 =    1.00          # energy of beam [MeV/u]
       x0 =  -14.00          # minimum position of x-axis [cm]
       x1 =    8.00          # maximum position of x-axis [cm]
       y0 =  -10.00          # minimum position of y-axis [cm]   <box size
       y1 =    9.00          # maximum position of y-axis [cm]  information>
       z0 =   26.00          # minimum position of z-axis [cm]
       z1 =   45.00          # maximum position of z-axis [cm]
      dir =   all            # z-direction of beam [isotropic]
 # region selection of source
      reg =    9500  <organ/cell number>
    ntmax =    1000          # (D=1000) maximum trial number of region selection
```

- **From PHITS version 3.02** – use the **“s-type = 24” (tetra-mesh source)** to generate the source particles **directly from the tetrahedrons**.

```
[ Source ]
  totfact =    1.00          # (D=1.0) global factor
   s-type =    24
   tetreg =    9500  <organ/cell number>
     proj =    photon
      dir =    all
       e0 =    0.01
```

Tip for Reducing Implementation Time

- Phantom implementation time can be reduced by **generating and reading the tetrahedron geometry data file in binary format (“Tetra.bin”) file**.

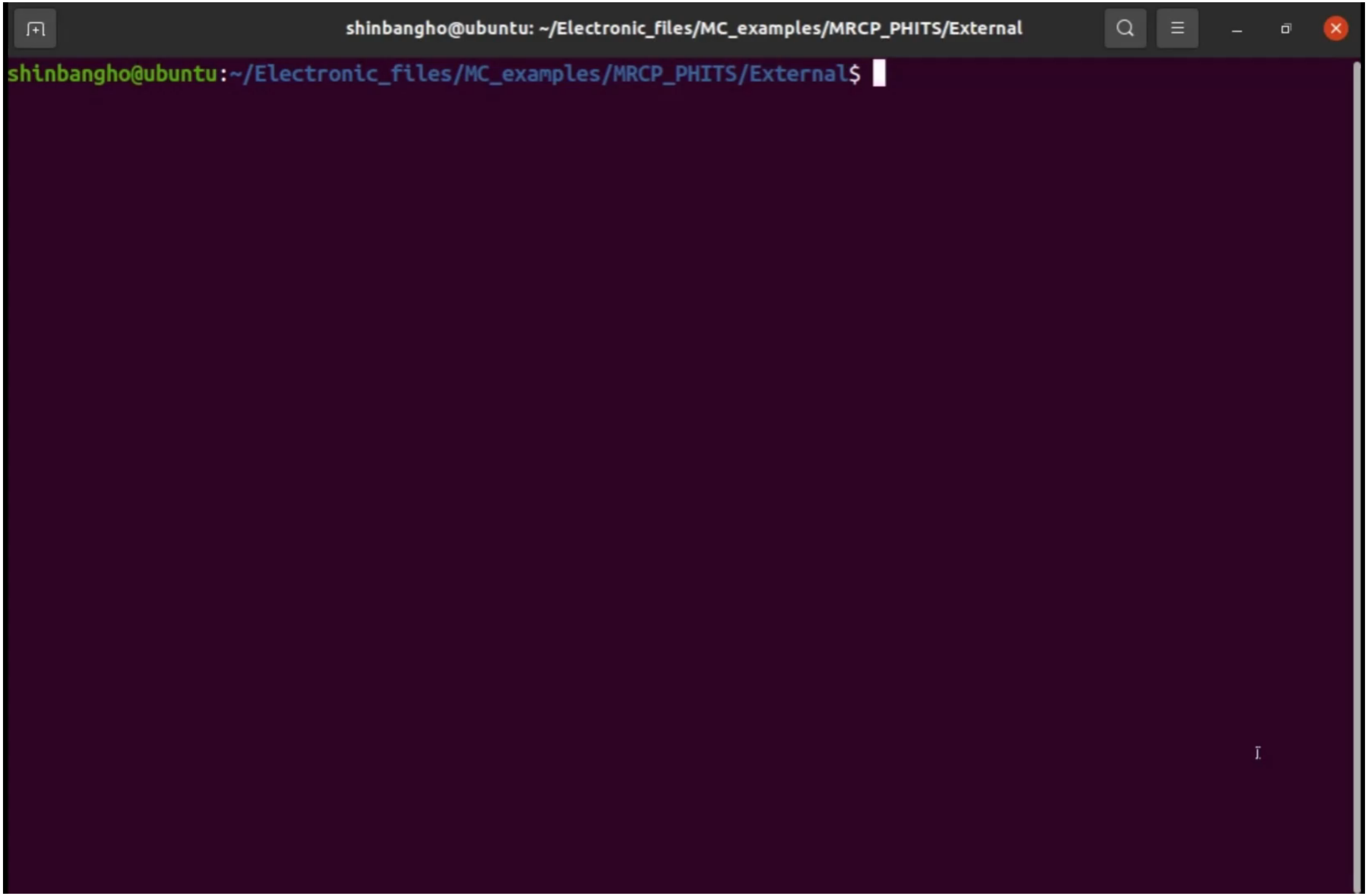
```
[ Parameters ]
 icntl    =         0      # (D=0) 3:ECH 5:NOR 6:SRC 7,8:GSH 11:DSH 12:DUMP
 maxcas   =   1000000      # (D=10) number of particles per one batch
 maxbch   =        10      # (D=10) number of batches
 itetvol  =         0      # (D=0) =1 Volume calculation for tetrahedrons
 ntetelem =      2000      # Number of tetra element allowed in sub-block
 maxbnk   =   1000000      # (D=10000) maximum bank memory length
 itetra   =         0      # (D=0) tetra data is read(=1)/write(=2) on binary
 file(6)  = MRCP-AF_external.out # (D=phits.out) general output file name
 file(7)  = (path to 'xsdir.jnd' file) # nuclear data input file name
 file(20) = (path to egs folder)       # Directory library data for EGS5
 negs     =         1      # (D=-1) 1:EGS
 ipegs    =         0      # [EGS](D=0) 0:Full
```

- Itetra = 0 : read the ELE/NODE files; **1: read the binary file; 2: write the binary file**
- The binary file name is fixed as “Tetra.bin”.

Phantom file	Implementation time
ELE/NODE file	~15 minutes
Binary file (“Tetra.bin”)	~1 minutes

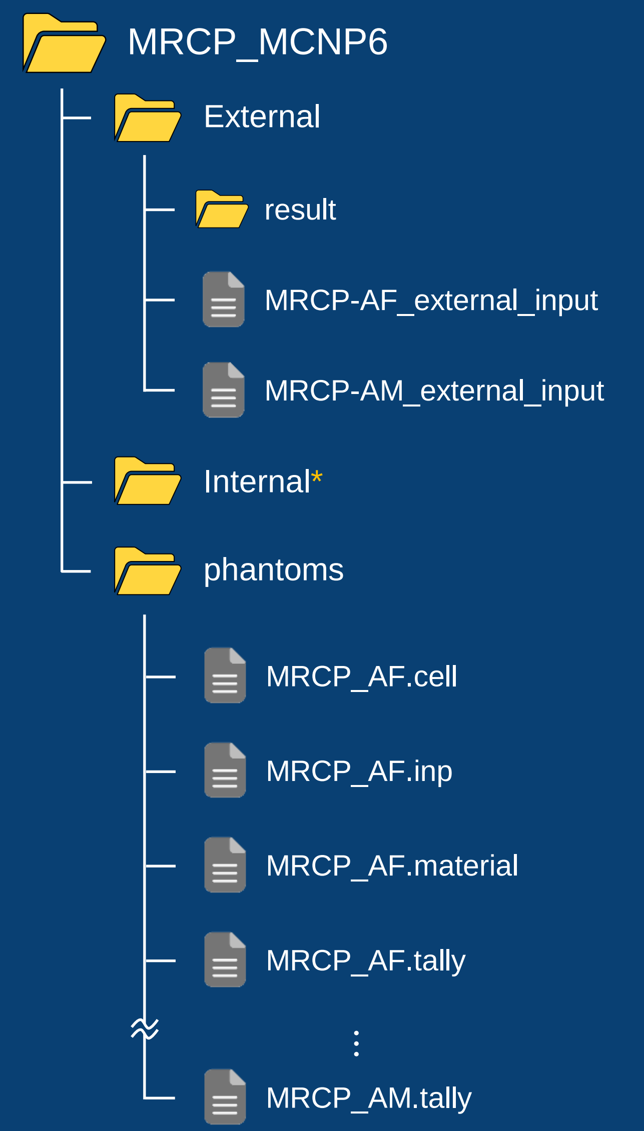
** Time was measured in “Intel® Core(TM) i7-8700K CPU @ 3.70GHz and PHITS ver.3.27 was used.*

Execution of PHITS – Demo Video



Monte Carlo Code Input Examples

MCNP6 Code



** same as External*

MCNP6 Code Input File

```
MRCP MALE PHANTOM - EXTERNAL
C ---------------------------------------------------------------------------
C    name                  : MRCP PHANTOM
C    sex                   : MALE
C    author                : HUREL
C ---------------------------------------------------------------------------
C ***************************************************************************
C                             CELL CARDS
C ***************************************************************************
C ---------------------------------------------------------------------------
C PSUEDO CELLS FOR ABAQUS
C ---------------------------------------------------------------------------
read file=../phantoms/mrcp-am.cell
C ---------------------------------------------------------------------------
C LEGACY CELLS
C ---------------------------------------------------------------------------
666  0   -10  fill=2           $ Phantom box
777  0   -99  10               $ Void in the world
999  0        99               $ World

C ***************************************************************************
C                          SURFACE CARDS
C ***************************************************************************
10  rpp -37.8854 37.8854 -24.56301 24.56301 -98.00236 98.00236   $ Phantom box
99  box -1000 -1000 -1000 2000 0 0 0 2000 0 0 0 2000         $ World boundary
```

MCNP6 Code Input File (Cont'd)

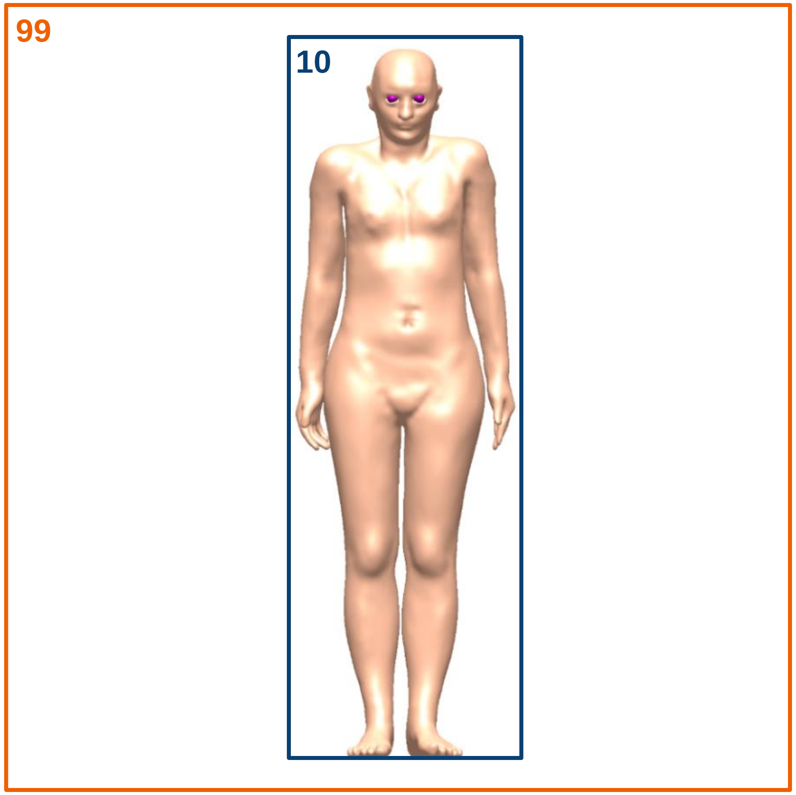
```
C ******************************************************************************
C                               DATA CARDS
C ******************************************************************************
dbcn 48j 1                    $ Debug information
mode p e                      $ Track photons and electrons
mphys on                      $ Turn on model physics
imp:p,e 1 189r 0              $ Importance
prdmp 10000000 10000000  -1   $ Print and dump cycle
rand  seed=RNSEED             $ Random seed
nps 10000000                  $ Number of particles
sdef par=p erg=1 pos=0 -100 0  $ General source definition
C ------------------------------------------------------------------------------
C TALLIES FOR EACH ORGAN/TISSUE
C ------------------------------------------------------------------------------
read file=../phantoms/mrcp-am.tally
C ------------------------------------------------------------------------------
C MATERIAL DATA FOR EACH ORGAN/TISSUE
C ------------------------------------------------------------------------------
read file=../phantoms/mrcp-am.material
C ------------------------------------------------------------------------------
C EMBED is required for embedding a mesh geometry into MCNP6 input
embed2 meshgeo=abaqus                        $ Format specification
       mgeoin=../phantoms/mrcp-am.inp        $ Name of the input file
       background=15000                      $ Cell number of the background
       matcell=    1   100     2   200     3   300     4   301     5   302
                   6   303     7   400     8   401     9   402    10   403
                  11   404    12   405    13   500    14   501    15   600
                  16   700    17   800    18   801    19   802    20   803
                  21   804    22   805    23   806    24   807    25   808
                  26   900    27   910    28  1000    29  1010    30  1100
                  31  1110    32  1200    33  1210    34  1300    35  1400
                  36  1500    37  1600    38  1700    39  1800    40  1900
                  41  2000    42  2100    43  2200    44  2300    45  2400
                  46  2500    47  2600    48  2700    49  2800    50  2900
```

Surface Card

- Define **two surfaces** in the surface card.

```
C ****************************************************************************
C                              SURFACE CARDS
C ****************************************************************************
10  rpp -37.8854 37.8854 -24.56301 24.56301 -98.00236 98.00236   $ Phantom box
99  box -1000 -1000 -1000 2000 0 0 0 2000 0 0 0 2000          $ World boundary
```

- Phantom box (10)
- World (99)



Cell Card

- Define cell information from the **".cell" file in the "phantoms" folder** and **fill the phantom box with the universe**.

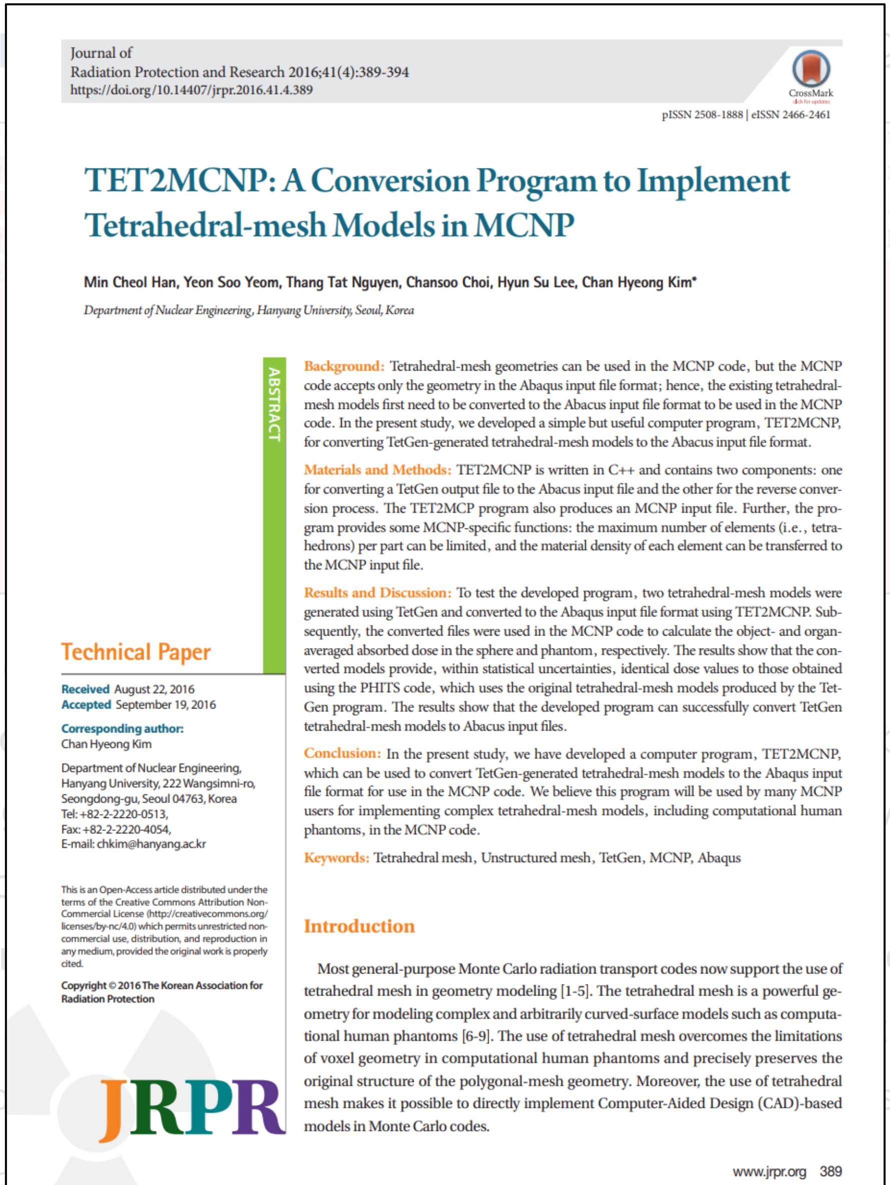
```
C **************************************************************************
C                              CELL CARDS
C **************************************************************************
C ---------------------------------------------------------------------------
C PSUEDO CELLS FOR ABAQUS
C ---------------------------------------------------------------------------
read file=../phantoms/mrcp-am.cell
C ---------------------------------------------------------------------------
C LEGACY CELLS
C ---------------------------------------------------------------------------
666   0    -10   fill=2           $ Phantom box
777   0    -99   10               $ Void in the world
999   0          99               $ World
```

```
C PSUEDO CELLS FOR ABAQUS
 00100    100   -1.0360   0   u=2 vol=8.3810227046
 00200    200   -1.0360   0   u=2 vol=8.3810261890
 00300    300   -1.0310   0   u=2 vol=0.0216382260
 00301    301   -1.0310   0   u=2 vol=0.0868396813
 00302    302   -1.0310   0   u=2 vol=0.0272322935
 00303    303   -1.0310   0   u=2 vol=10.9517030365
          ⋮
 14000 14000   -0.0010   0   u=2 vol=140.1650804136
 15000      0             0   u=2  <background>
```

<pseudo cell no.> <mat. no.> <density> <univ. no.>

<0 for pseudo cell>

Data Card – EMBED



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TET2MCNP: A Conversion Program to Implement Tetrahedral-mesh Models in MCNP

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ABSTRACT

Background: Tetrahedral-mesh geometries can be used in the MCNP code, but the MCNP code accepts only the geometry in the Abaqus input file format; hence, the existing tetrahedral-mesh models first need to be converted to the Abacus input file format to be used in the MCNP code. In the present study, we developed a simple but useful computer program, TET2MCNP, for converting TetGen-generated tetrahedral-mesh models to the Abacus input file format.

Materials and Methods: TET2MCNP is written in C++ and contains two components: one for converting a TetGen output file to the Abacus input file and the other for the reverse conversion process. The TET2MCP program also produces an MCNP input file. Further, the program provides some MCNP-specific functions: the maximum number of elements (i.e., tetrahedrons) per part can be limited, and the material density of each element can be transferred to the MCNP input file.

Results and Discussion: To test the developed program, two tetrahedral-mesh models were generated using TetGen and converted to the Abaqus input file format using TET2MCNP. Subsequently, the converted files were used in the MCNP code to calculate the object- and organ-averaged absorbed dose in the sphere and phantom, respectively. The results show that the converted models provide, within statistical uncertainties, identical dose values to those obtained using the PHITS code, which uses the original tetrahedral-mesh models produced by the TetGen program. The results show that the developed program can successfully convert TetGen tetrahedral-mesh models to Abacus input files.

Conclusion: In the present study, we have developed a computer program, TET2MCNP, which can be used to convert TetGen-generated tetrahedral-mesh models to the Abaqus input file format for use in the MCNP code. We believe this program will be used by many MCNP users for implementing complex tetrahedral-mesh models, including computational human phantoms, in the MCNP code.

Keywords: Tetrahedral mesh, Unstructured mesh, TetGen, MCNP, Abaqus

Technical Paper

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Introduction

Most general-purpose Monte Carlo radiation transport codes now support the use of tetrahedral mesh in geometry modeling [1-5]. The tetrahedral mesh is a powerful geometry for modeling complex and arbitrarily curved-surface models such as computational human phantoms [6-9]. The use of tetrahedral mesh overcomes the limitations of voxel geometry in computational human phantoms and precisely preserves the original structure of the polygonal-mesh geometry. Moreover, the use of tetrahedral mesh makes it possible to directly implement Computer-Aided Design (CAD)-based models in Monte Carlo codes.

Data Card – Material

- Define material information from the **“*.material” file in the “phantoms” folder**.

```
C ------------------------------------------------------------------------------
C MATERIAL DATA FOR EACH ORGAN/TISSUE
C ------------------------------------------------------------------------------
read file=../phantoms/mrcp-am.material
C ------------------------------------------------------------------------------
```

```
C MATERIALS FOR EACH ORGAN/TISSUE
C Adrenal_left 1.036 g/cm3
m100 <mat. no.>
       1000      -0.104
       6000      -0.228
       7000      -0.028
       8000      -0.63
       11000     -0.001
       15000     -0.002
       16000     -0.003
       17000     -0.002
       19000     -0.002
C
C Adrenal_right 1.036 g/cm3
m200 <mat. no.>
       1000      -0.104
       6000      -0.228
       7000      -0.028
       8000      -0.63
       11000     -0.001
       15000     -0.002
       16000     -0.003
       17000     -0.002
       19000     -0.002
C
```

Data Card – Tally

- Define tally information from the **"*.tally" file in the "phantoms" folder**.
- Use the **+F6 tally** to calculate the **energy deposition of organs**.

```
C -----------------------------------------------------------------------------
C TALLIES FOR EACH ORGAN/TISSUE
C -----------------------------------------------------------------------------
read file=../phantoms/mrcp-am.tally
C -----------------------------------------------------------------------------
```

```
C TALLIES FOR EACH ORGAN/TISSUE
+f1006    ( 100 ) $Adrenal_left
+f2006    ( 200 ) $Adrenal_right
+f3006    ( 300 ) $ET1(0-8)
+f3016    ( 301 ) $ET1(8-40)
+f3026    ( 302 ) $ET1(40-50)
+f3036    ( 303 ) $ET1(50-Surface)
+f4006    ( 400 ) $ET2(-15-0)
+f4016    ( 401 ) $ET2(0-40)
+f4026    ( 402 ) $ET2(40-50)
+f4036    ( 403 ) $ET2(50-55)
+f4046    ( 404 ) $ET2(55-65)
+f4056    ( 405 ) $ET2(65-Surface)
+f5006    ( 500 ) $Oral_mucosa_tongue
```

<+F6 tally> <pseudo-cell no.>

- If the user wants to calculate the **energy deposition for several organs together**, enter their pseudo-cell number **in parentheses**.

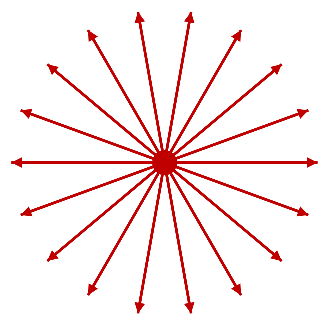
ex) +f16 (9700 9900)

+f26 (400 401 402 403 404 405)

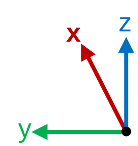
Data Card – Source for External Exposure

- Define the **external source** using the **SDEF.**

```
sdef par=p erg=1 pos=0 -100 0  $ General source definition
C ---------------------------------------------------------------------------
```



- **Type: point source**
- **Particle: photon**
- **Energy: 1 MeV**
- **Position: (0, -100, 0)**
- **Direction: isotropic**



Data Card – Source for Internal Exposure

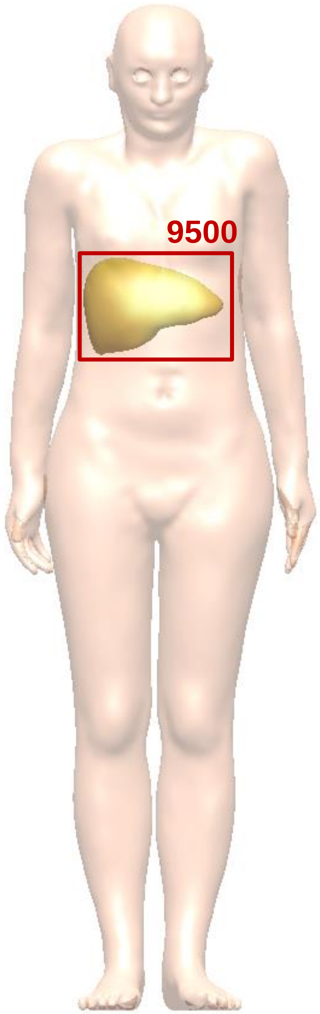
- Define the **internal source** using the **SDEF** and **"ABAQUS" file**.
  - Set **"pos=volumer"** in the **SDEF**.

```
sdef par=p erg=1 pos=volumer    $ General source definition
C -----------------------------------------------------------------
```

  - Add the **source line** in the **"ABAQUS" file**.

```
12563,   3664,   3890,   3979,   3260
12564,   3887,   3894,   3981,   3871
12565,   3890,   3981,   3871,   3979
12566,   3668,   3888,   3689,   3211
12567,   3977,   3976,   3968,   3953
12568,   3894,   3890,   3981,   3871
12569,   3982,   3877,   3976,   3239
12570,   3877,   3982,   3211,   3239
12571,   3982,   3698,   3211,   3239
12572,   3982,   3698,   3902,   3211
*Nset, nset=Set-material_9500, generate
1,    3982,    1
*Elset, elset=Set-material_9500, generate
1,    12572,    1
*Nset, nset=Set-statistic_9500, generate
1,    3982,    1
*Elset, elset=Set-statistic_9500, generate
1,    12572,    1
*Elset, elset=Set-source_9500, generate
1,    12572,    1
*End Part
**
```

<# of tetrahedrons for the source organ>



Tip for Reducing Implementation Time

- From MCNP 6.2, phantom implementation time can be reduced by **generating and reading the "MCNPUM" file**.
  - The user can **convert the "ABAQUS" file to the "MCNPUM" file by using the "um_convert" program**, which is automatically installed during the "MCNP 6.2" installation process.

ABAQUS file

```
[sbh95@server-205 phantoms]$ ls
mrcp-af.cell  mrcp-af.material  mrcp-am.cell  mrcp-am.material  um_convert.out
mrcp-af.inp   mrcp-af.tally     mrcp-am.inp   mrcp-am.tally
[sbh95@server-205 phantoms]$ um_convert -a mrcp-am.inp -um mrcp-am.um

 UM_CONVERT input processing begins.        1- 5-2023 @ 15:07:34
```

✓ -a: ABAQUS input file

✓ -um: MCNPUM output file

  - Some parts of the EMBED should also be modified to read the "MCNPUM" file.

```
embed2 meshgeo=abaqus
       mgeoin=../phantoms/mrcp-am.inp
```

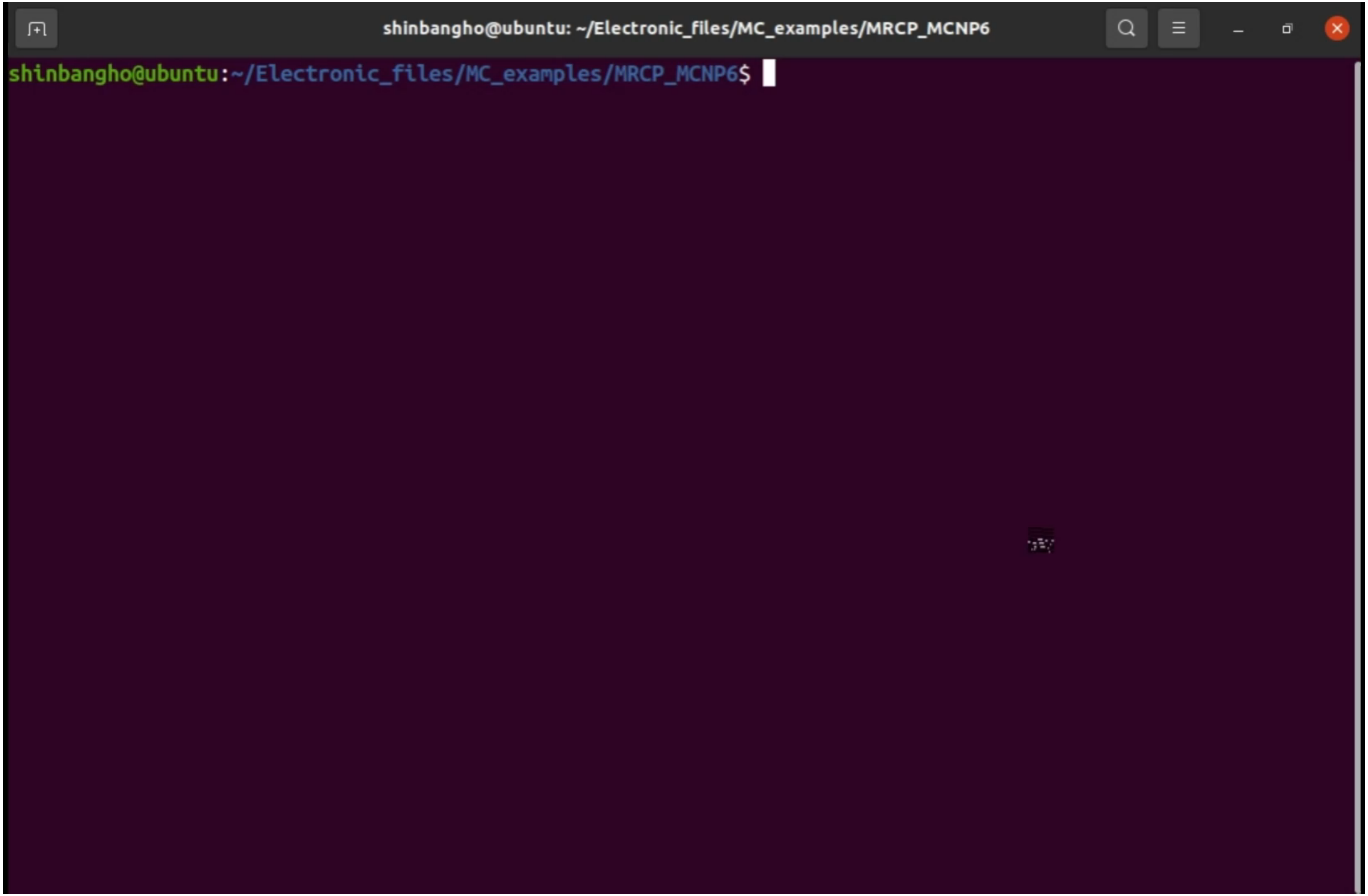
✓ In "meshgeo", abaqus → mcnpum

✓ In "mgeoin", mrcp-am.inp → mrcp-am.um

Phantom file	Implementation time
ABAQUS file	About half a day
MCNPUM file	~2 minutes

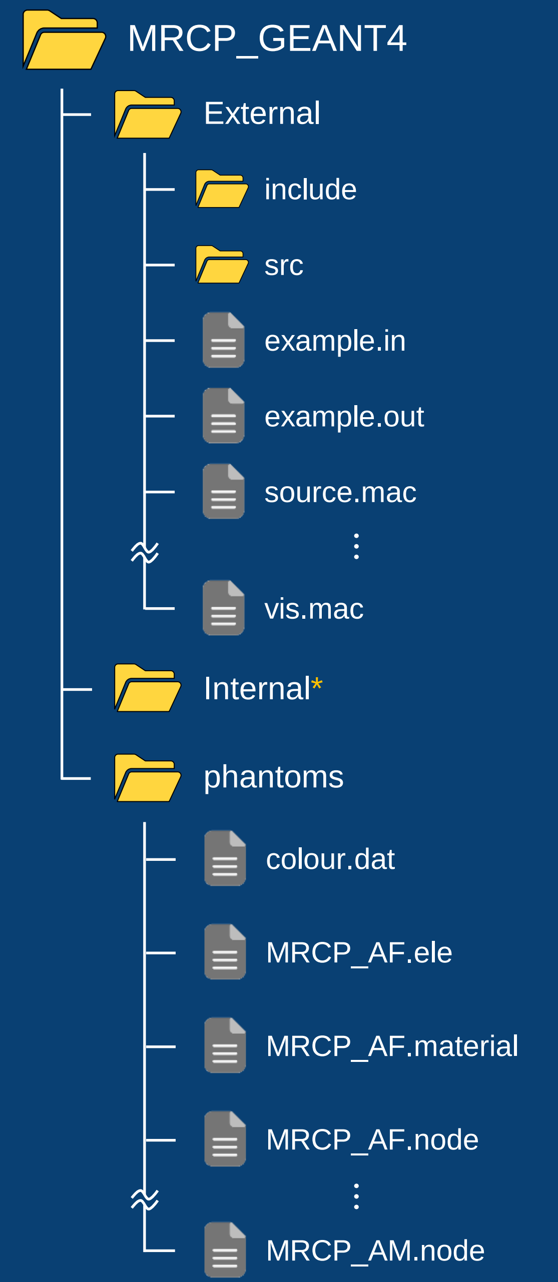
** Time was measured in "Intel® Core(TM) i7-8700K CPU @ 3.70GHz.*

Execution of MCNP6 – Demo Video



Monte Carlo Code Input Examples

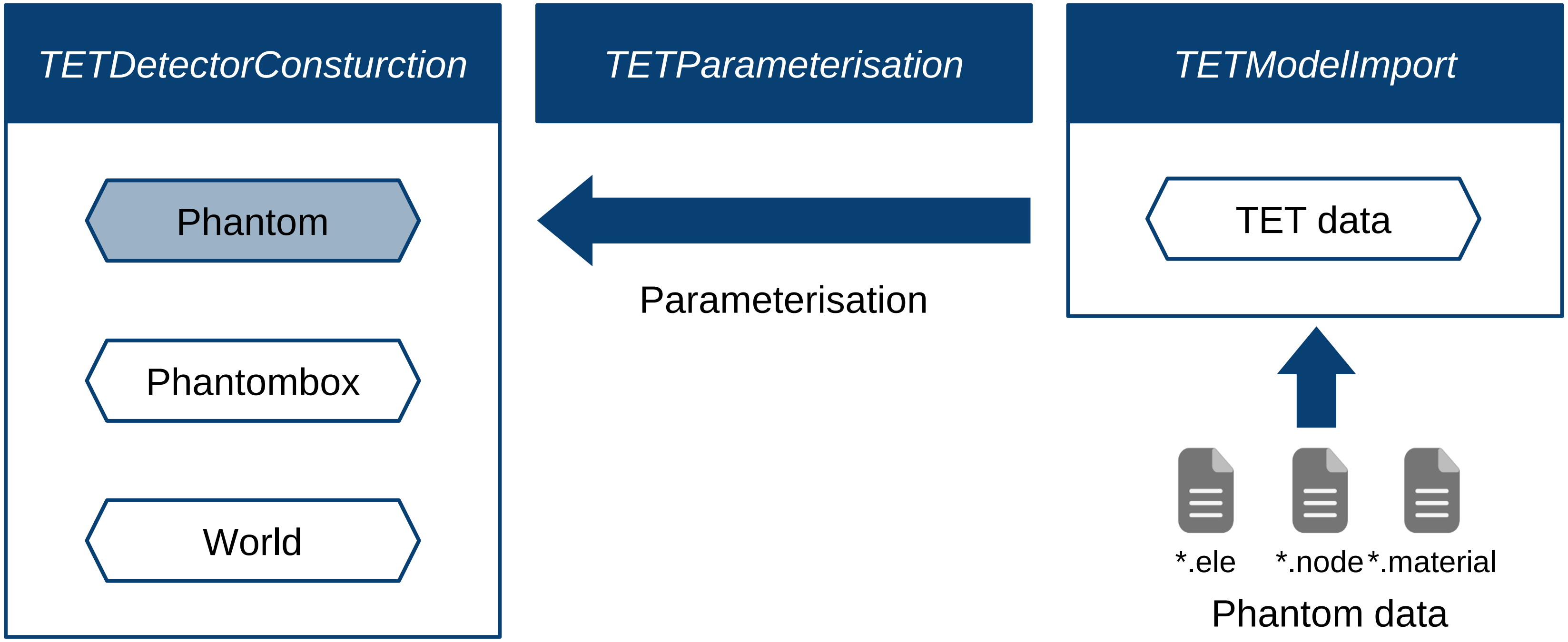
GEANT4 Code



** same as External*

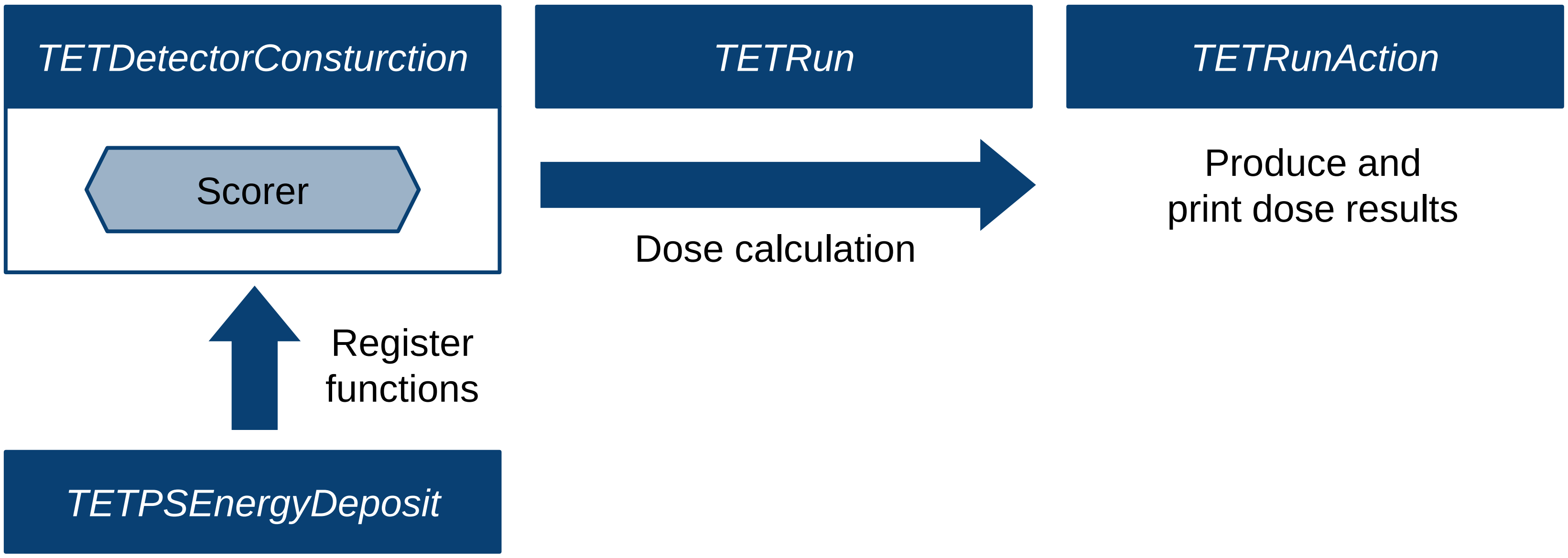
Geant4 Classes – Geometries

- *TETDetectorConsturction* is to **construct the phantom and other geometries** (phantombox, world, scorer).
- *TETModelImport* is to **import the phantom data** (“*.ele”, “*.node”, “*.material” files).
- *TETParameterisation* is to **define the tetrahedral mesh phantom** by parameterisation using the phantom data which is imported in *TETModelImport*.



Geant4 Classes – Organ Dose Calculation

- *TETDetectorConstruction* is to **construct scorer** in the phantom to get doses in organs.
- *TETPSEnergyDeposit* is to **specify scorer functions** for energy deposition.
- *TETRun* is to **calculate organ doses**.
- *TETRunAction* is to **produce and print dose results**.

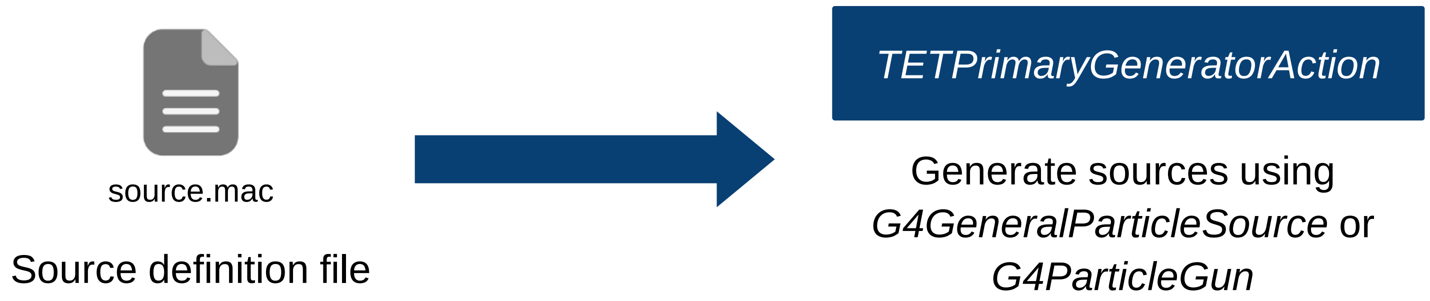


Geant4 Classes – etc.

- *TETActionInitialization* is to **initialize action classes** (e.g., *TETRunAction*).
- *TETSteppingAction* is to **resolve stuck particles** in each step.
- *TETPhysicsList* is to **define physics models**.

Geant4 Classes – Set Source

- *TETPrimaryGeneratorAction* is to **generate sources**.
  - External exposure
    - ✓ Sources are generated through *G4GeneralParticleSource.*
  - Internal exposure
    - ✓ Sources are generated through *G4ParticleGun*.
- **Source information** (e.g., particle type, energy, ...) is specified in **source definition file** (“*.mac”).



Source Definition File Example

- Source definition file ("Source.mac") for **external exposure**

```
# GeneralParticleSource :
# isotropic 1 MeV-gamma point source at (0, -1 m, 0)
/gps/ang/type iso
/gps/energy 1 MeV
/gps/particle gamma
/gps/pos/type Point
/gps/pos/centre 0 -1. 0 m
```

**** For more details about G4GeneralParicleSource ("/gps/"), see Geant4 GPS manual.***

- Source can be specified by using macro commands for *G4GeneralParticleSource*.
- **Particle direction, energy, type, geometry, position** is set in sequence in the "source.mac" file.

- Source definition file ("Source.mac") for **internal exposure**

```
# ParticleGun macro:
# 1 MeV-gamma source
/gun/particle gamma
/gun/energy 1. MeV
```

**** For more details about G4ParticleGun ("/gun/"), see Geant4 Users Guide.***

- Source can be specified by using macro commands for *G4ParticleGun*.
- **Particle type and energy** is set in sequence in the "source.mac" file.
- **Source position** (i.e., source organ) is defined in the **command line for execution.**

Input Macro File Example

- Input macro file ("sample.in")

```
# Example macro file to run in the batch mode

# Set the verbose
/run/verbose 2

# Set the number of threads for multi-threading mode
#/run/numberOfThreads 1

# Initialize
/run/initialize

# source setting
/control/execute source.mac

# Set the nps
/run/beamOn 10000000
```

- Set the **number of threads** for Geant4 simulation using "/run/numberOfThreads" (Geant4 should be compiled in multi-threaded mode).
- Set the **source definition file path** using "/control/execute".
- Set the **number of particles (NPS)** for each run using "/run/beamOn"

How to Compile Geant4

- Geant4 compile (with CMake)
  - Command
    1. cd PATH_to_example (either “External” or “Internal” folder)
    2. mkdir example_build
    3. cd example_build
    4. cmake ..
    5. make

Compile example

```
kimhl0924@연구실PC:~/MRCP_GEANT4$ cd ~/MRCP_GEANT4/External/
kimhl0924@연구실PC:~/MRCP_GEANT4/External$ mkdir example_build
kimhl0924@연구실PC:~/MRCP_GEANT4/External$ cd example_build
kimhl0924@연구실PC:~/MRCP_GEANT4/External/example_build$ cmake ..
```

⋮

```
-- Configuring done
-- Generating done
-- Build files have been written to: /home/kimhl0924/MRCP_GEANT4/External/example_build
kimhl0924@연구실PC:~/MRCP_GEANT4/External/example_build$ make
```

⋮

```
[100%] Linking CXX executable External
[100%] Built target External
```

init_vis.mac	1KB
External	4,528KB

Created!

init_vis.mac	1KB
Internal	3,449KB

Created!

How to Execute Geant4

- Geant4 execution
  - Option
    1. ./*: Executable “External” or “Internal” file
    2. –m: input macro file (not provided->interactive mode)
    3. –o: output file (default: [Input macro file name].out)
    4. –f: optional switch to change the phantom to MRCP-AF (default: MRCP-AM)
    5. –i: ID of source organ (mandatory)

Execution example for external exposure

```
~/MRCP_GEANT4/External/example_build$ ./External -m example.in -o example.out -f
```

PATH ① ② ③ ④

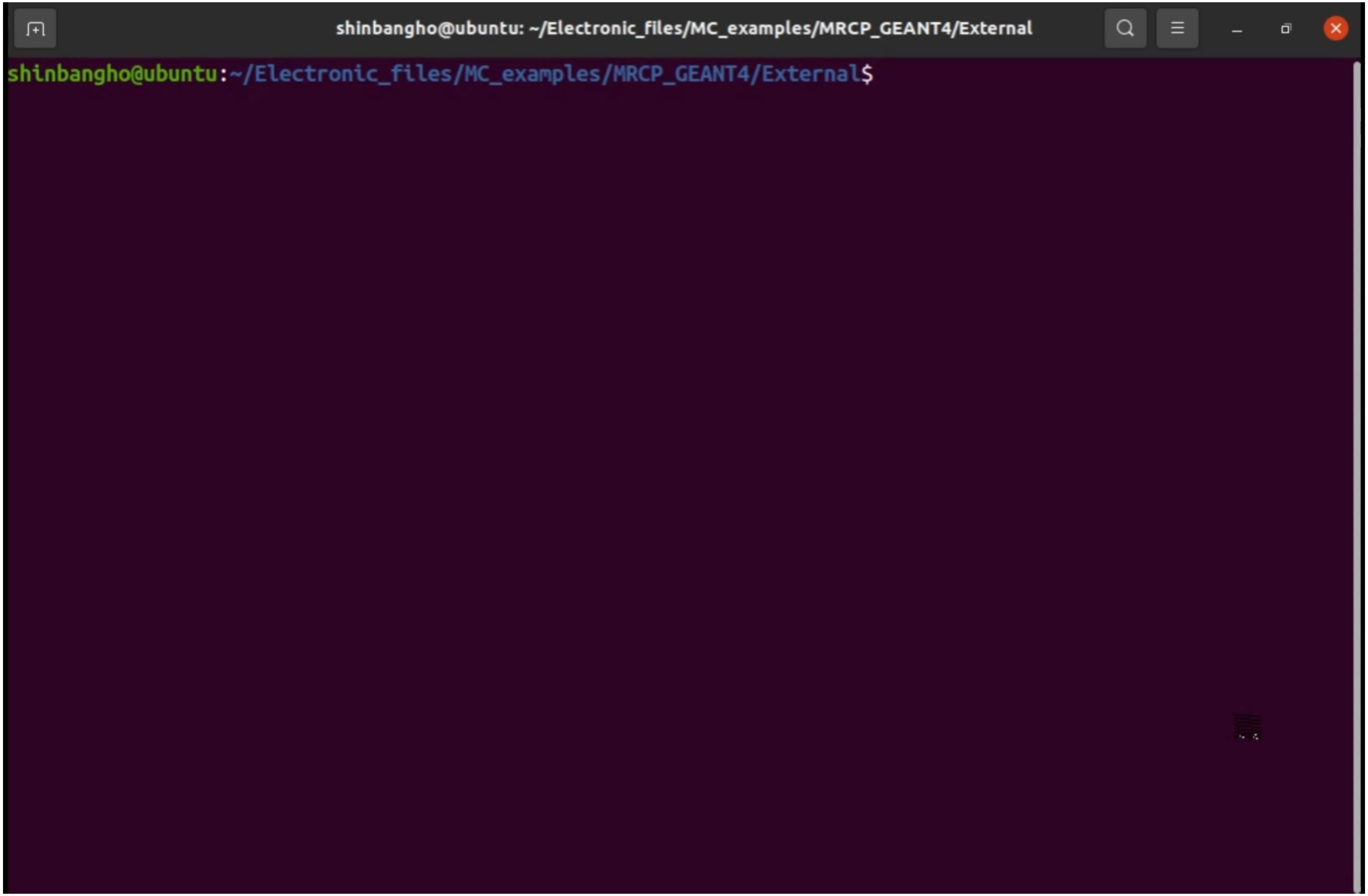
Execution example for internal exposure

```
~/MRCP_GEANT4/Internal/example_build$ ./Internal -i 9500 -m example.in -o example.out
```

PATH ① ⑤ ② ③

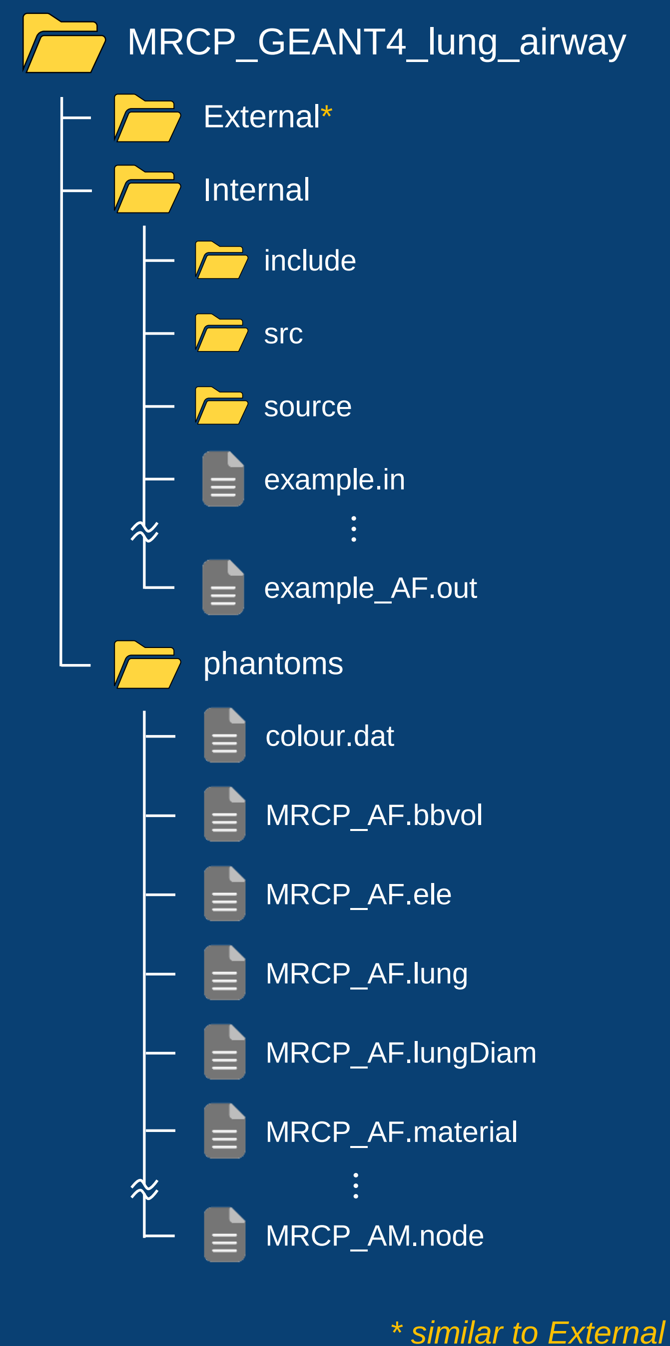
**** PATH: “example_build” folder which contains the executable “External” or “Internal” file***

Compile and Execution of Geant4 – Demo Video



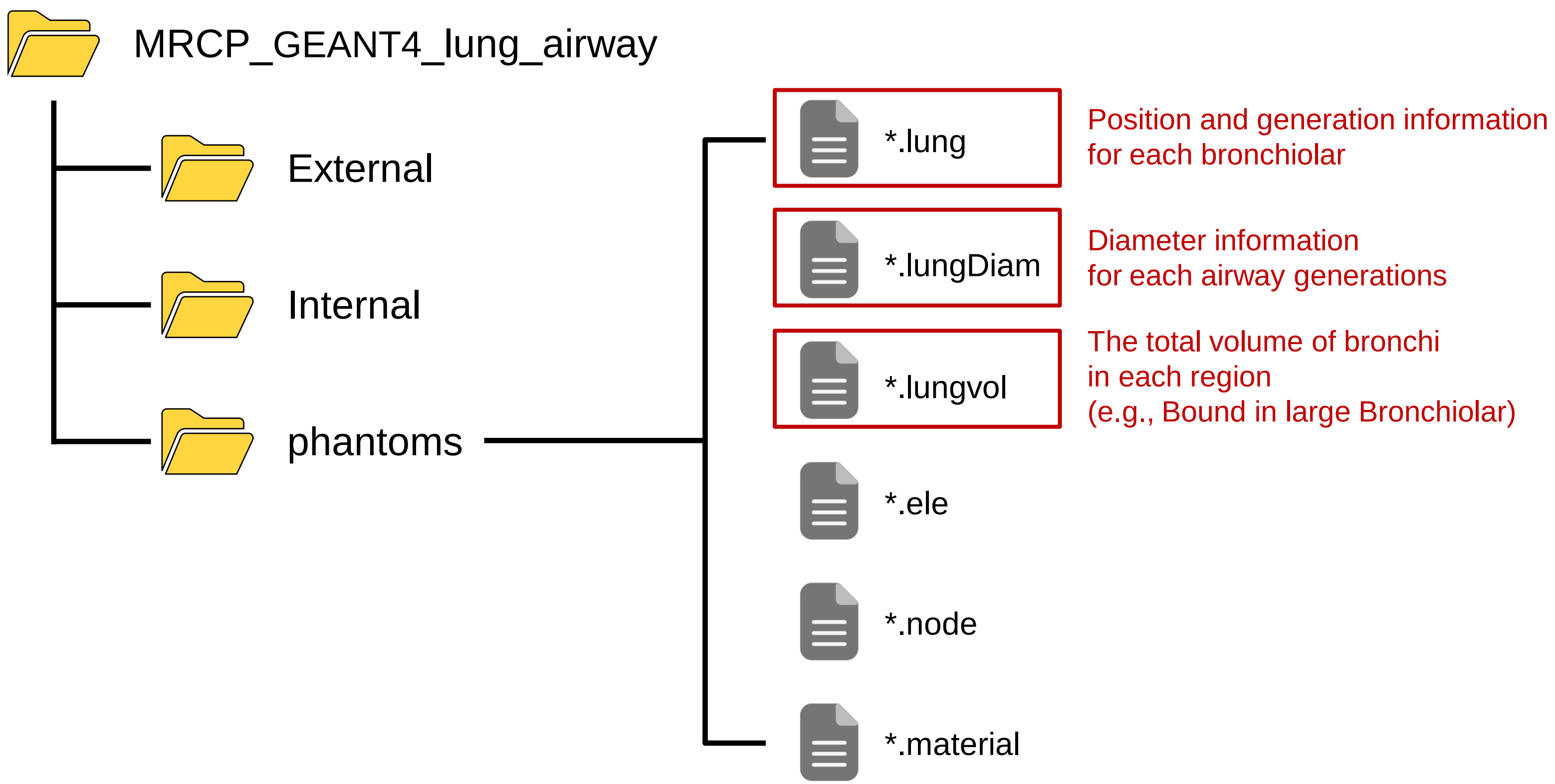
Monte Carlo Code Input Examples

Lung Airway



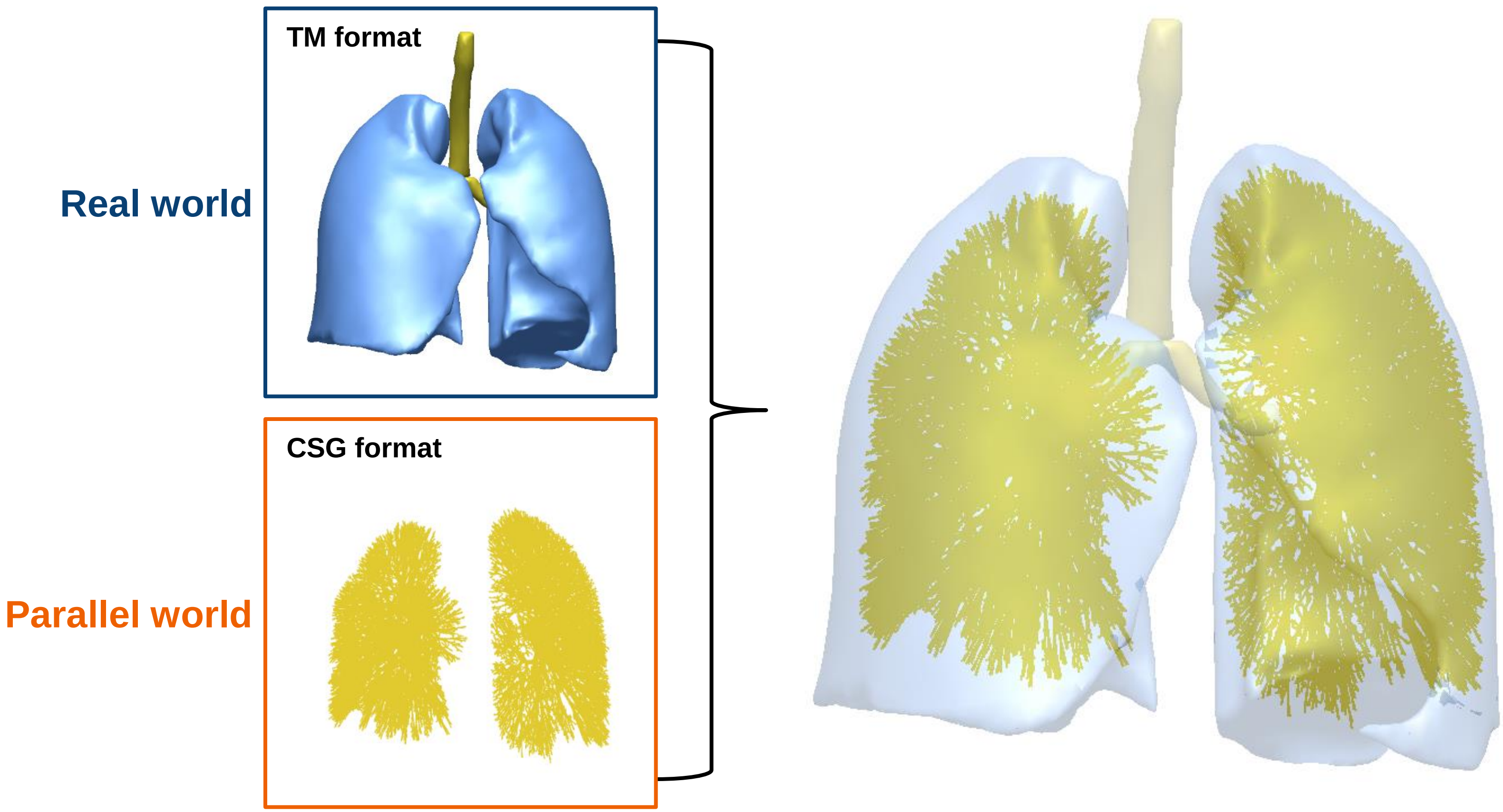
Lung Airway Files in "phantoms" Folder

- The "phantoms" folder contains additional information files for the lung airway with existing files.
- **Information list: position, generation, diameter, volume**



Installation of Lung Airway in MRCPs

- Lung airway is developed in **constructive solid geometry (CSG) format**, while the MRCPs are in tetrahedral-mesh (TM) format.
- To install the lung airways in the MRCPs, **"*G4VUserParallelWorld*" class** of the Geant4 code was used.



How to Execute Geant4 – External Exposure

- ./External -m [macro] -o [output] -f
  - -m: macro file name
    - ✓ example.in (for only execution) and init_vis.mac (for visualization).
  - -o: output file name
  - -f: option for female phantom

Output file example

```
=========================================================
 Run #0 / Number of event processed : 10000000
=============================================================================
        organ ID|      Organ Mass (g)   Dose (Gy/source)     Relative Error
        BB_basal|               0.272          3.361e-17              0.238
    BB_secretory|               0.530          2.193e-17              0.218
    bb_secretory|               1.385          2.243e-17              0.130
   Lung(AI)_left|             427.256          2.314e-17              0.029
  Lung(AI)_right|             522.518          2.593e-17              0.025
=============================================================================
```

700	2836	10.052	1.031	10.364	Trachea
800	7422	0.025	1.000	0.025	BB(-11--6)
801	7418	0.030	1.031	0.031	BB(-6-0)
802	7426	0.050	1.031	0.052	BB(0-10)
803	7423	0.126	1.031	0.130	BB(10-35)
804	7425	0.025	1.031	0.026	BB(35-40)
805	7419	0.051	1.031	0.052	BB(40-50)
806	7421	0.051	1.031	0.052	BB(50-60)
807	7425	0.051	1.031	0.053	BB(60-70)
808	7466	2.693	1.031	2.777	BB(70-surface)
900	8205	1.419	1.060	1.504	Blood_in_large_arteries_head
910	6686	6.551	1.060	6.944	Blood_in_large_veins_head
1000	199191	182.261	1.060	193.197	Blood_in_large_arteries_trunk
1010	194214	418.901	1.060	444.035	Blood_in_large_veins_trunk
1100	79908	30.626	1.060	32.463	Blood_in_large_arteries_arms
1110	64710	157.801	1.060	167.269	Blood_in_large_veins_arms
1200	143952	102.671	1.060	108.832	Blood_in_large_arteries_legs
1210	130064	367.680	1.060	389.741	Blood_in_large_veins_legs
1300	4516	83.612	1.904	159.196	Humeri_upper_cortical
1400	1590	118.158	1.233	145.689	Humeri_upper_spogiosa
1500	1038	34.907	0.981	34.244	Humeri_upper_medullary_cavity
1600	4205	56.050	1.904	106.720	Humeri_lower_cortical
1700	1605	45.888	1.109	50.890	Humeri_lower_spongiosa
1800	793	38.121	0.981	37.397	Humeri_lower_medullary_cavity

822	0.729	1.031	0.752	bb(air-12)_9to15gen
821	0.725	1.031	0.747	bb(air-20)_9to15gen
820	0.355	1.000	0.355	bb(air-25)_9to15gen
829	32.794	0.001	0.033	bb(air)_9to15gen

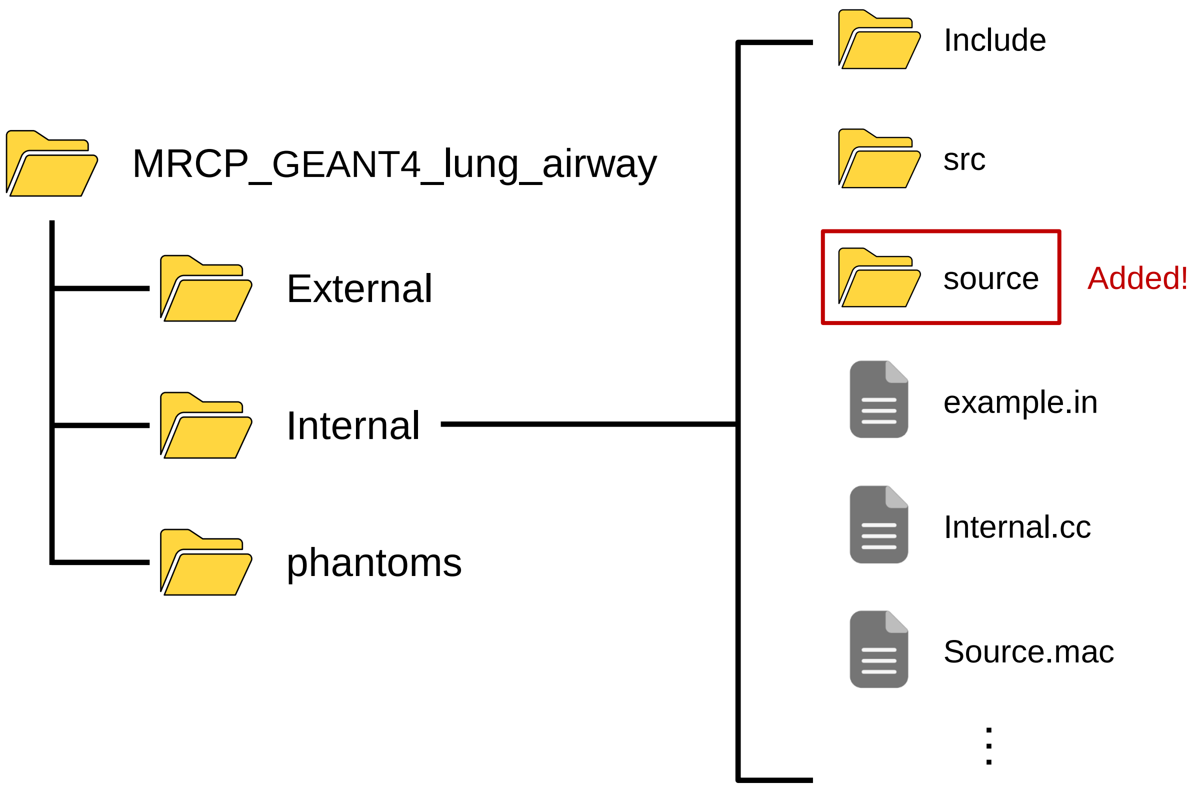
Lung Data*************************************

[mm]	#	layer0	layer1	layer2	layer3	layer4	layer5	layer6	layer7	layer8	layer9
gen-1	2	13.110	12.140	12.120	12.100	12.080	12.070	12.020	12.000	11.988	11.978
gen-2	4	9.610	8.640	8.620	8.600	8.580	8.570	8.520	8.500	8.488	8.478
gen-3	8	7.210	6.240	6.220	6.200	6.180	6.170	6.120	6.100	6.088	6.078
gen-4	16	5.510	4.540	4.520	4.500	4.480	4.470	4.420	4.400	4.388	4.378
gen-5	32	4.710	3.740	3.720	3.700	3.680	3.670	3.620	3.600	3.588	3.578
gen-6	61	4.010	3.040	3.020	3.000	2.980	2.970	2.920	2.900	2.888	2.878
gen-7	118	3.510	2.540	2.520	2.500	2.480	2.470	2.420	2.400	2.388	2.378
gen-8	217	3.110	2.140	2.120	2.100	2.080	2.070	2.020	2.000	1.988	1.978
gen-9	365	1.721	1.701	1.691	1.675	1.659	1.651	1.643	1.639	0.000	0.000
gen-10	697	1.418	1.398	1.388	1.372	1.356	1.348	1.340	1.336	0.000	0.000
gen-11	1363	1.162	1.142	1.132	1.116	1.100	1.092	1.084	1.080	0.000	0.000
gen-12	2627	0.952	0.932	0.922	0.906	0.890	0.882	0.874	0.870	0.000	0.000
gen-13	5139	0.790	0.770	0.760	0.744	0.728	0.720	0.712	0.708	0.000	0.000
gen-14	9903	0.673	0.653	0.643	0.627	0.611	0.603	0.595	0.591	0.000	0.000
gen-15	18845	0.603	0.583	0.573	0.557	0.541	0.533	0.525	0.521	0.000	0.000
gen-16		0.580	0.560	0.550	0.534	0.518	0.510	0.502	0.498	0.000	0.000

****

Source Files in "Internal" Folder

- For the internal exposure, the **"source" folder containing the location of source particles** is included in the "Internal" folder.



How to Execute Geant4 – Internal Exposure

Phantom information

Organ ID	# of Tet	vol [cm3]	d [g/cm3]	mass [g]	organ/tissue
100	2679	8.381	1.036	8.683	Adrenal_left
200	2663	8.381	1.036	8.683	Adrenal_right
300	4678	0.022	1.031	0.022	ET1(0-8)
301	4668	0.087	1.031	0.090	ET1(8-40)
302	4672	0.027	1.031	0.028	ET1(40-50)
303	5908	10.952	1.031	11.291	ET1(50-Surface)
400	8615	0.141	1.000	0.141	ET2(-15-0)
401	8613	0.378	1.031	0.390	ET2(0-40)
402	8614	0.095	1.031	0.098	ET2(40-50)
403	8614	0.048	1.031	0.049	ET2(50-55)
404	8613	0.095	1.031	0.098	ET2(55-65)
405	11326	27.942	1.031	28.808	ET2(65-Surface)
500	6495	0.082	1.050	0.086	Oral_mucosa_tongue
501	769	0.022	1.050	0.024	Oral_mucosa_mouth_floor
600	5892	0.022	1.050	0.023	Oral_mucosa_lips_and_cheeks
700	2836	10.052	1.031	10.364	Trachea
800	7422	0.025	1.000	0.025	BB(-11--6)
801	7418	0.030	1.031	0.031	BB(-6-0)
802	7426	0.050	1.031	0.052	BB(0-10)
803	7423	0.126	1.031	0.130	BB(10-35)
804	7425	0.025	1.031	0.026	BB(35-40)
805	7419	0.051	1.031	0.052	BB(40-50)
806	7421	0.051	1.031	0.052	BB(50-60)
807	7425	0.051	1.031	0.053	BB(60-70)
808	7466	2.693	1.031	2.777	BB(70-surface)
900	8205	1.419	1.060	1.504	Blood_in_large_arteries_head
910	6686	6.551	1.060	6.944	Blood_in_large_veins_head
1000	199191	182.261	1.060	193.197	Blood_in_large_arteries_trunk
1010	194214	418.901	1.060	444.035	Blood_in_large_veins_trunk
1100	79908	30.626	1.060	32.463	Blood_in_large_arteries_arms
1110	64710	157.801	1.060	167.269	Blood_in_large_veins_arms
1200	143952	102.671	1.060	108.832	Blood_in_large_arteries_legs
1210	130064	367.680	1.060	389.741	Blood_in_large_veins_legs
1300	4516	83.612	1.904	159.196	Humeri_upper_cortical
1400	1590	118.158	1.233	145.689	Humeri_upper_spogiosa
1500	1038	34.907	0.981	34.244	Humeri_upper_medullary_cavity
1600	4205	56.050	1.904	106.720	Humeri_lower_cortical
1700	1605	45.888	1.109	50.890	Humeri_lower_spongiosa
1800	793	38.121	0.981	37.397	Humeri_lower_medullary_cavity

Lung airway information

********************************Lung Information********************************

Organ ID	vol [cm3]	d [g/cm3]	mass [g]	organ/tissue
818	8.869	1.031	9.144	BB(air-surface)_2to8gen
817	0.182	1.031	0.188	BB(air--6)_2to8gen
816	0.156	1.031	0.161	BB(air-0)_2to8gen
815	0.180	1.031	0.186	BB(air-10)_2to8gen
814	0.069	1.031	0.071	BB(air-35)_2to8gen
813	0.444	1.031	0.458	BB(air-40)_2to8gen
812	0.132	1.031	0.136	BB(air-50)_2to8gen
811	1.520	1.031	1.567	BB(air-60)_2to8gen
810	0.089	1.000	0.089	BB(air-70)_2to8gen
819	12.736	0.001	0.013	BB(air)_2to8gen
826	1.963	1.031	2.024	bb(air-surface)_9to15gen
825	0.956	1.031	0.986	bb(air--4)_9to15gen
824	1.510	1.031	1.557	bb(air-0)_9to15gen
823	1.485	1.031	1.531	bb(air-4)_9to15gen
822	0.729	1.031	0.752	bb(air-12)_9to15gen
821	0.725	1.031	0.747	bb(air-20)_9to15gen
820	0.355	1.000	0.355	bb(air-25)_9to15gen
829	32.794	0.001	0.033	bb(air)_9to15gen

**************************************Lung Data**************************************

[mm]	#	layer0	layer1	layer2	layer3	layer4	layer5	layer6	layer7	layer8	layer9
gen-1	2	13.110	12.140	12.120	12.100	12.080	12.070	12.020	12.000	11.988	11.978
gen-2	4	9.610	8.640	8.620	8.600	8.580	8.570	8.520	8.500	8.488	8.478
gen-3	8	7.210	6.240	6.220	6.200	6.180	6.170	6.120	6.100	6.088	6.078
gen-4	16	5.510	4.540	4.520	4.500	4.480	4.470	4.420	4.400	4.388	4.378
gen-5	32	4.710	3.740	3.720	3.700	3.680	3.670	3.620	3.600	3.588	3.578
gen-6	61	4.010	3.040	3.020	3.000	2.980	2.970	2.920	2.900	2.888	2.878
gen-7	118	3.510	2.540	2.520	2.500	2.480	2.470	2.420	2.400	2.388	2.378
gen-8	217	3.110	2.140	2.120	2.100	2.080	2.070	2.020	2.000	1.988	1.978
gen-9	365	1.721	1.701	1.691	1.675	1.659	1.651	1.643	1.639	0.000	0.000
gen-10	697	1.418	1.398	1.388	1.372	1.356	1.348	1.340	1.336	0.000	0.000
gen-11	1363	1.162	1.142	1.132	1.116	1.100	1.092	1.084	1.080	0.000	0.000
gen-12	2627	0.952	0.932	0.922	0.906	0.890	0.882	0.874	0.870	0.000	0.000
gen-13	5139	0.790	0.770	0.760	0.744	0.728	0.720	0.712	0.708	0.000	0.000
gen-14	9903	0.673	0.653	0.643	0.627	0.611	0.603	0.595	0.591	0.000	0.000
gen-15	18845	0.603	0.583	0.573	0.557	0.541	0.533	0.525	0.521	0.000	0.000
gen-16		0.580	0.560	0.550	0.534	0.518	0.510	0.502	0.498	0.000	0.000

Output file example

```
==================================================================
 Run #0 / Number of event processed : 10000000
==================================================================
         organ ID|      Organ Mass (g)   Dose (Gy/source)      Relative Error
         BB_basal|               0.272          3.361e-17               0.238
     BB_secretory|               0.530          2.193e-17               0.218
     bb_secretory|               1.385          2.243e-17               0.130
    Lung(AI)_left|             427.256          2.314e-17               0.029
   Lung(AI)_right|             522.518          2.593e-17               0.025
==================================================================
```

Tip for Skeletal Dosimetry

Doses to Spongiosa and Medullary Cavity

- Like the ICRP-110 voxel phantoms, the skeletal target tissues [active marrow (AM, = red bone marrow) and bone endosteum (TM_{50})] are macroscopically defined as spongiosa and medullary cavity in the MRCPs.
- Therefore, **the doses to skeletal target tissues are approximated by the doses to the spongiosa and medullary cavity.**

$$D_{skel}(AM) = \sum_x \frac{m(AM,x)}{m(AM)} D(SP,x)$$

$$D_{skel}(TM_{50}) = \sum_x \frac{m(TM_{50},x)}{m(TM_{50})} D(SP,x) + \sum_x \frac{m(TM_{50},x)}{m(TM_{50})} D(MM,x)$$

- $D_{skel}(AM/TM_{50})$: Skeletal-averaged absorbed dose to AM/TM_{50}
- $m(AM/TM_{50},x)$: Masses of AM/TM_{50} in bone site x
- $m(AM/TM_{50})$: Masses of total AM/TM_{50}
- $D(SP/\mathrm{MM},x)$: Absorbed dose to spongiosa/medullary cavity

- The bone-site-specific masses of AM and endosteum can be found in **Table 4.2 of *Publication 110*.**

Fluence-to-dose Response Functions (DRFs)

- **For photon and neutron, an advanced method, called fluence-to-dose response functions (DRFs)**, can be used to estimate doses to skeletal target tissues (i.e., AM and TM_{50}).
- The AM and TM_{50} doses can be estimated only with the fluence of the photons and/or neutrons passing through spongiosa and medullary cavity.

$$D(r_T, x) = \int_E \Phi(E, r_S, x) R(r_T \leftarrow r_S, x, E) dE$$

$$D_{skel}(r_T) = \sum_x \frac{m(r_T, x)}{m(r_T)} D(r_T, x)$$

- $D(r_T, x)$: Absorbed dose to tissue r_T in bone site x
- $\Phi(E, r_S, x)$: Bone-specific energy-dependent fluence
- $R(r_T \leftarrow r_S, x, E)$: Bone-specific energy-dependent DRFs
- $D_{skel}(r_T)$: Skeletal-averaged absorbed dose to tissue r_T

- The photon and neutron fluence-to-dose response functions can be found in **Annexes D and E of *Publication 116*.**

Monte Carlo Codes – DRFs

- The DRFs can be applied to PHITS, MCNP6, and Geant4 code by using the following functions:

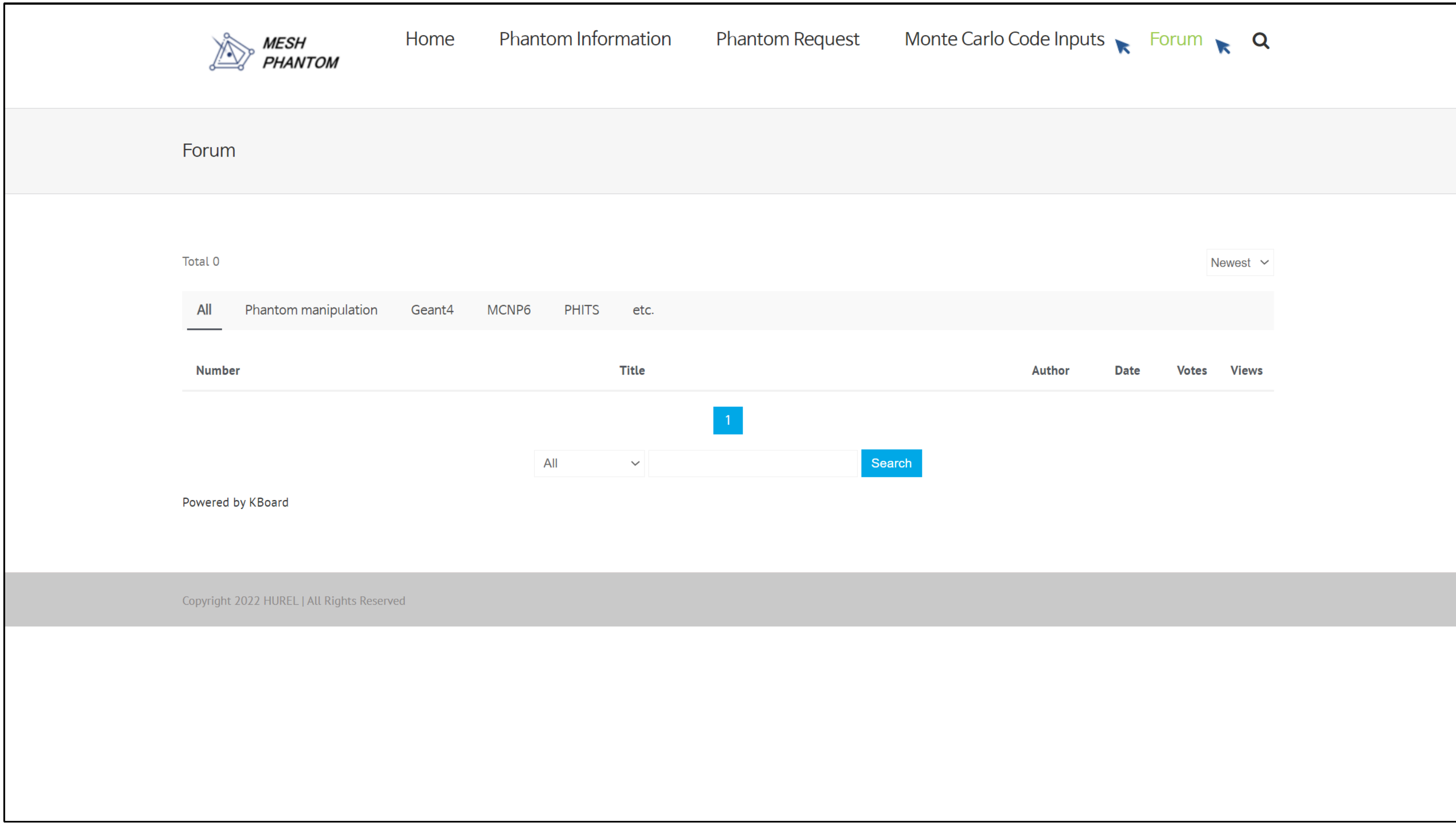
$$D(r_T, x) = \int_E \Phi(E, r_S, x) R(r_T \leftarrow r_S, x, E) dE$$

MC code	Function	Explanation
PHITS	[T-track]	Calculate particle fluence
	[Multiplier]	Apply photon/neutron DRFs
MCNP6	F4 tally	Calculate particle fluence
	DE/DF card	Apply photon/neutron DRFs
Geant4	G4VPrimitiveScorer	Calculate particle fluence and apply photon/neutron DRFs

- Input files for applying the DRFs can be downloaded through MESH-PHANTOM homepage: https://mesh-phantom.com/

MESH-PHANTOM Website

MESH-PHANTOM Website (https://mesh-phantom.com/)



Thank you!

Backup Slides

Practical Tips for Dosimetry

Effective Dose

Effective Dose

- Effective dose is a tissue-weighted sum of the equivalent doses in all specified tissues and organs of the body (***Publication 103***), given by the expression:

$$E = \sum_T w_T \sum_R w_R D_{T,R}$$

- E : Effective dose
- w_T : Tissue weighting factor (**Table 3 of *Publication 103***)
- w_R : Radiation weighting factor (**Table 2 of *Publication 103***)
- $D_{T,R}$: Mean absorbed dose from radiation R in a tissue T

Table 3. Recommended tissue weighting factors.

Tissue	w_T	$\sum w_T$
Bone-marrow (red), Colon, Lung, Stomach, Breast, Remainder tissues*	0.12	0.72
Gonads	0.08	0.08
Bladder, Oesophagus, Liver, Thyroid	0.04	0.16
Bone surface, Brain, Salivary glands, Skin	0.01	0.04
	Total	1.00

* Remainder tissues: Adrenals, Extrathoracic (ET) region, Gall bladder, Heart, Kidneys, Lymphatic nodes, Muscle, Oral mucosa, Pancreas, Prostate (♂), Small intestine, Spleen, Thymus, Uterus/cervix (♀).

Table 2. Recommended radiation weighting factors.

Radiation type	**Radiation weighting factor, w_R**
Photons	1
Electrons[a] and muons	1
Protons and charged pions	2
Alpha particles, fission fragments, heavy ions	20
Neutrons	A continuous function of neutron energy (see Fig. 1 and Eq. 4.3)

All values relate to the radiation incident on the body or, for internal radiation sources, emitted from the incorporated radionuclide(s).

[a] Note the special issue of Auger electrons discussed in paragraph 116 and in Section B.3.3 of Annex B.

Monte Carlo Codes – Weighting Factor

- The tissue and radiation weighting factors can be applied to PHITS, MCNP6, and Geant4 code by using the following functions:

$$E = \sum_T w_T \sum_R w_R D_{T,R}$$

MC code	Function	Explanation
PHITS	[T-deposit]	Calculate mean absorbed dose
	"factor" parameter	Apply weighting factors
MCNP6	+F6 tally	Calculate mean absorbed dose
	FM card	Apply weighting factors
Geant4	TETPSEnergyDeposit	Calculate mean absorbed dose
	TETRun	Apply weighting factors

Monte Carlo Codes – Binding Tissue IDs

- **Tissue IDs of the MRCPs** are more subdivided than tissues considered for the effective dose calculation; therefore, they **need to be bound for the effective dose calculation** (**Table D.1** is helpful for this).

Table D.1. List of target regions, their acronyms, and corresponding identification (ID) numbers in the tetrahedral mesh (TM) phantoms.

Target region	Acronym	ID number(s)
Red (active) marrow	R-marrow	*
Colon wall	Colon	7600, 7601, 7602, 7800, 7801, 7802, 8000, 8001, 8002, 8200, 8201, 8202, 8400, 8401, 8402, 8600
Stem cells of colon	Colon-stem	7601, 7801, 8001, 8201, 8401
RLung + LLung	Lungs	9700, 9900
Stomach wall	St-wall	7200, 7201, 7202, 7203
Stem cells of stomach	St-stem	7201
Breast-a + Breast-g	Breast	6200, 6300, 6400, 6500
ROvary + LOvary	Ovaries	11100, 11200
Testes	Testes	12900, 13000

MC code	Function	Example
PHITS	[T-deposit]	reg = (9700 9900)
MCNP6	+F6 tally	+f16 (9700 9900)
Geant4	TETRun	–

- For many cases, the entire wall can replace the thin target region (e.g., stem cells) to save the calculation time, and paragraphs (74) – (77) and the papers below may help the user decide on this.

  - Y.S. Yeom, C. Choi, H. Han, et al., Dose coefficients of mesh-type ICRP reference computational phantoms for idealized external exposures of photons and electrons, Nucl. Eng. Technol. 51 (2019) 843–852.
  - Y.S. Yeom, C. Choi, H. Han, et al., Dose coefficients of mesh-type ICRP reference computational phantoms for external exposures of neutrons, protons, and helium ions, Nucl. Eng. Technol. 52 (2020) 1545–1556.