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Title: Radiography Test Problem for MCNP

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Intended for: Distribution to
Transport Applications (XCP-7) and
Monte Carlo Codes (XCP-3)
Group Members

Radiography Test Problem for MCNP

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Abstract

Synthetic radiographs may be created with the Los Alamos Monte Carlo code MCNP. After creating a problem geometry, arbitrary object tilts and/or rotations about one or more axes may be considered by "coordinate transformation" entries or simply rotating a source-detector system about the object to be imaged. A simple MCNP test problem was devised to illustrate effects of various code options and is described here. A LNK3DNT mesh representation of this geometry was produced with MCNP6 to exercise that recent capability.

Introduction

The "Flux Image Radiograph", or *FIRn:p* tally in MCNP[1] parlance, is shown schematically in Figure 1 and makes synthetic radiography applications possible with MCNP. Coupled with the general source definition and other tally features, the user defines an image grid with *FSn* and *Cn* entries and has great flexibility to model source-object-detector systems. Only photon radiography is considered here but the *FIR* tally also works with neutrons.

As geometries become more complicated (e.g. through use of coordinate transformations and/or rotations), the user may find unexpected tally results if the geometry and image grid coordinate systems are misunderstood. Directions of the image-plane-defining *S*- and *T*-axes in Figure 1, for example, depend on the user-defined reference direction vector. Furthermore, post-processing tools (often used to visualize tally output) may render images in an unexpected way. A simple test problem with clear orientation features was devised to investigate radiographic image production from various code options. Similar issues and test problems have been described[2,3,4] but inputs were not provided.

Sample Problem

The sample problem is a truncated aluminum (2.7 g/cc) cone containing three tungsten (18 g/cc) spheres of 1 cm radius; within each sphere is a cylindrical void region. A steel (7.8 g/cc) sphere of 1 cm radius centered at (X,Y,Z) = (5,5,5) is included for additional orientation. The relevant MCNP input file for the radiographic test object (RTO) is shown below and two cuts through the geometry are shown in Figures 2 and 3. The latter figures are so-called YZ plots where the y-direction points to the right, the z-direction is vertical and the positive x-direction points toward the viewer. The problem origin for this right handed coordinate system, indicated by the cross-hairs in the center of Figures 2 and 3, is shown at (Y,Z) = (0,0); x = 0 and x = 5 cm, respectively.

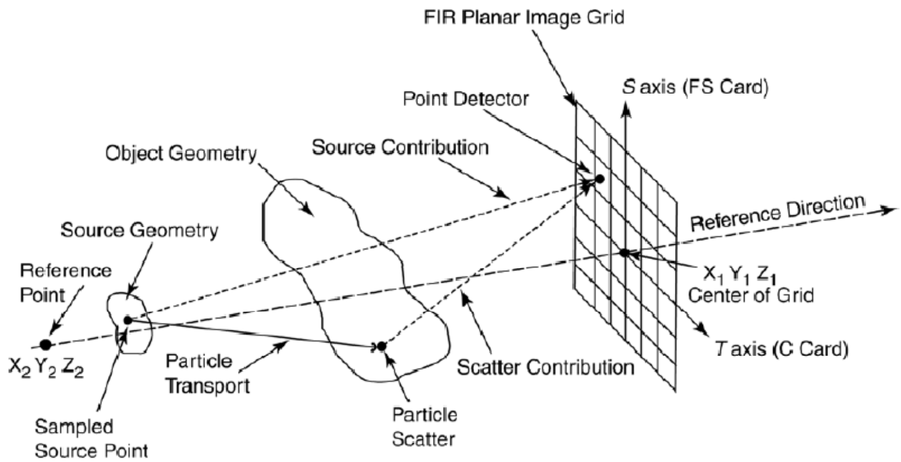

Figure 1. Diagram of the flux image radiograph (FIR) tally from Ref 1

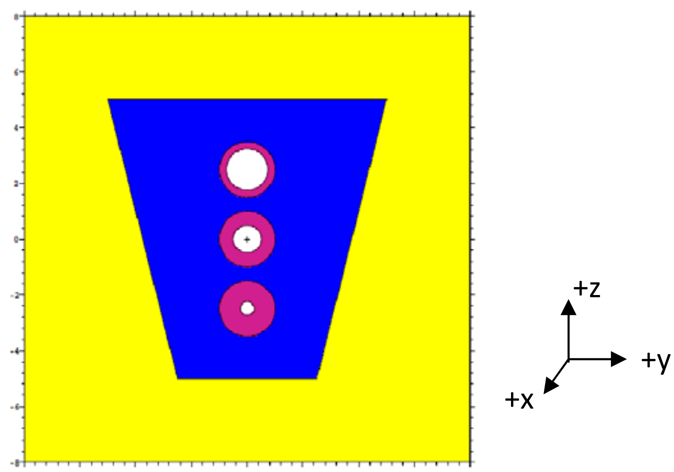

Figure 2. RTO geometry slice at x = 0 cm; dimensions are cm

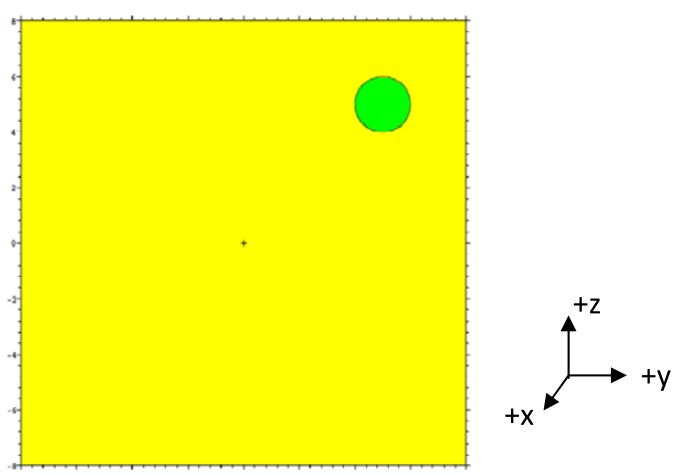

Figure 3. RTO geometry slice at x = +5 cm highlights steel sphere at (X,Y,Z)=(5,5,5)

A three-dimensional view of the RTO, created with the Los Alamos graphics package OSOLOCO[5], is shown in Figure 4 with a portion removed to visualize the interior. The three 1 cm radius tungsten spheres and their cylindrical voids of varied radii are readily visible within the aluminum cone. The external steel reference sphere, at location (X,Y,Z) = (+5,+5,+5), is shown in red.

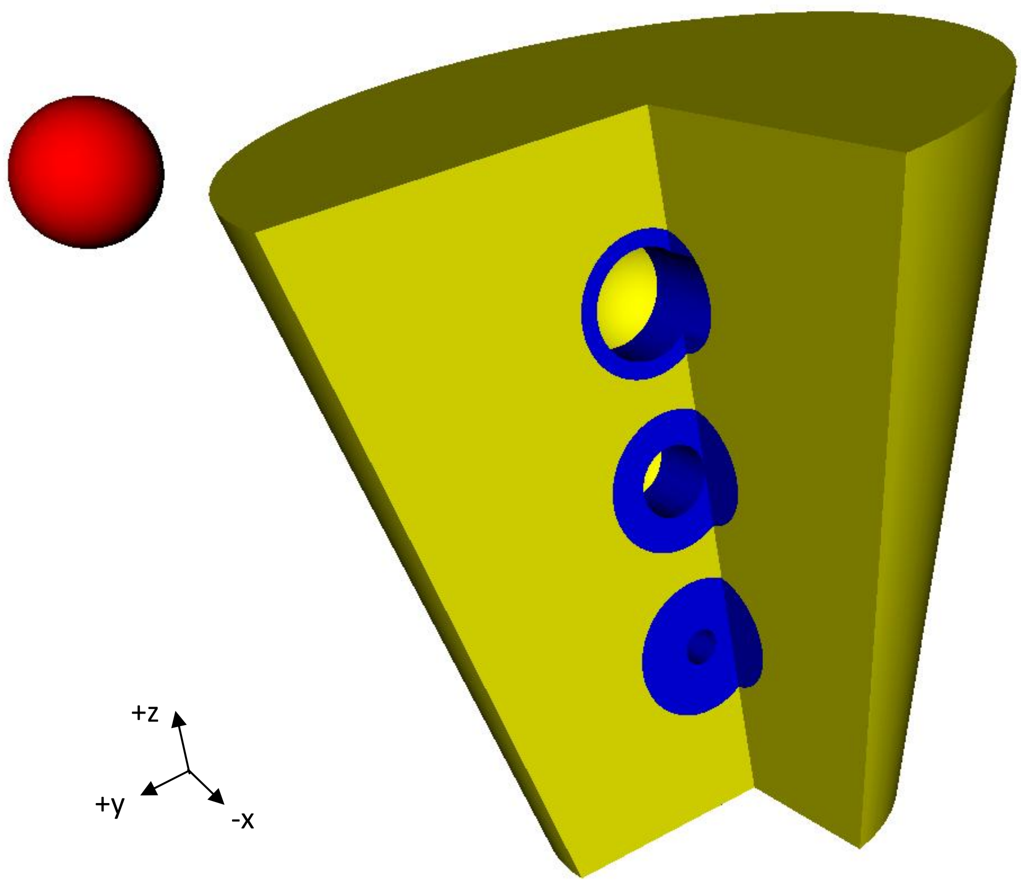

Figure 4. 3D perspective of the RTO geometry (with a portion removed) as rendered with OSOLOCO

MCNP6 Combinatorial Geometry Input File

```
Conical Test Problem
c
c This simple MCNP problem is intended to illustrate
c several radiographic projections.
c
c 05 Jan 2010
c Erik F. Shores, Duane P. Flamig and John D. Zumbro, XCP-7
c
c file = cone ; 05 Jan 10 ; problem creation
c -----------------------------------------------------------------------
c CELL CARDS
c -----------------------------------------------------------------------
1    101 -18.0  -1 10       imp:p=1 $ W sphere
2    101 -18.0  -2 11       imp:p=1 $ W sphere
3    101 -18.0  -3 12       imp:p=1 $ W sphere
4    103 -2.7   (1 2 3) -4  imp:p=1 $ Al cone
5    104 -7.8   -5          imp:p=1 $ SS sphere for orientation
6    105 -1.0e-3 4 5 -98    imp:p=1 $ air
10     0        -1 -10      imp:p=1 $ W void
11     0        -2 -11      imp:p=1 $ W void
12     0        -3 -12      imp:p=1 $ W void
80   105 -1.0e-3 98 -99     imp:p=1
99     0             99     imp:p=0
c end cells with blank space
c -----------------------------------------------------------------------

c -----------------------------------------------------------------------
c SURFACE CARDS
c -----------------------------------------------------------------------
1    so    1.0
2    sz    2.5  1
3    sz   -2.5  1
4   trc    0    0   -5    0 0 10   2.5 5
5     s    5    5    5    1
10  c/x    0    0    0.5
11  c/x    0    2.5  0.75
12  c/x    0   -2.5  0.25
98   so  900
99   so 1000
c end surfaces with blank space
c -----------------------------------------------------------------------

c -----------------------------------------------------------------------
c DATA CARDS
c -----------------------------------------------------------------------
c -8 degree rotation about y (up)*
tr3   0.                  0.        0.
      0.99026806874157036 0.       -0.13917310096006544
      0.                  1.        0.
      0.13917310096006544 0.        0.99026806874157036 1
c
c -----------------------------------------------------------------------
c MATERIAL CARDS
c -----------------------------------------------------------------------
m101   74184 1.000000 $ W
m103   13027 1.000000 $ Al
m102   73181 1.000000 $ Ta
m105    7014 0.770900  8016 0.219500 18000 0.009600 $ air
mpn105  7014 8016 18040
m104   26056 0.698000 24052 0.206000 28058 0.096000 $  SS
m106   71175 2.000000 14028 1.000000 8016 5.000000  $ LSO
mpn106 73181 14028 8016
c
c -----------------------------------------------------------------------
c SOURCE: CARDS
```

```
c -------------------------------------------------------------------
mode p
phys:p j 0 0
cut:p j 0.1
sdef pos -133 0. 0.
     vec    1 0  0
c sdef pos -131.70565314262884726 0.  -18.51002242768870332 $ small end to source
c      vec 0.99026806874157036    0.    0.13917310096006544
c sdef pos -131.70565314262884726 0.   18.51002242768870332 $ large end to source
c      vec 0.99026806874157036    0.   -0.13917310096006544
c
c -------------------------------------------------------------------
c TALLY CARDS
c -------------------------------------------------------------------
fc5 Sample Radiograph
fir5:p   392                   0.  0.   0   0. 0. 0.  0 0 0
c fir5:p 388.18508294559555880 0.  54.55585557534554954
c                                       0   0. 0. 0.  0 0 0 $ small end to source
c fir5:p 388.18508294559555880 0. -54.55585557534554954
c                                       0   0. 0. 0.  0 0 0 $ large end to source
fs5 -22.48 1123i 22.48
c5  -22.48 1123i 22.48 $ radiographic grid
talnp 5               $ don't print tally bins
nps 1                 $ histories
notrn                 $ ray trace
prdmp j 1 1 2         $ dump control
print                 $ make some output!
c for LNK3DNT file creation
mesh  geom xyz origin=-8 -8 -8  ref=0 0 0
       imesh 8
       iints 80
       jmesh 8
       jints 80
       kmesh 8
       kints 80
dawwg points=10 xsec=ndilib
```

The nominal source is positioned at (X,Y,Z) = (-133,0,0), directed through the test object in a direction orthogonal to the conical symmetry axis, and incident on a detector grid at (X,Y,Z) = (392,0,0). The input file contains an optional transformation and **an optional input block to create, via MCNP6, a LNK3DNT version of this geometry**. In this case, the binary file `efslinktest` was created with this command[6]:

```
mcnp6 m i=cone.i linkout=efslinktest
```

and the resultant mesh is essentially a 16 x 16 x 16 cm cube of 80 x 80 x 80 elements. The 2 mm (16 cm / 80 mesh elements) "grid version" of this geometry is shown in Figures 5 and 6.

The following screen output was produced during MCNP's LNK3DNT file creation and is shown here for completeness; such information may be useful in subsequent transport runs making use of the linkfile.

```
Converting MCNP Geometry to LNK3DNT Mesh
                       Start time =  07/20/11 15:37:29
 Done with conversion of MCNP Geometry to LNK3DNT Mesh
                       End time =  07/20/11 15:46:05
The ORDERED list of materials written to the LNK3DNT file is:
                                             void; material index #      0
   index #    1 listed as material card #     101; material index #      1
   index #    2 listed as material card #     103; material index #      2
   index #    3 listed as material card #     105; material index #      3
   index #    4 listed as material card #     104; material index #      4
```

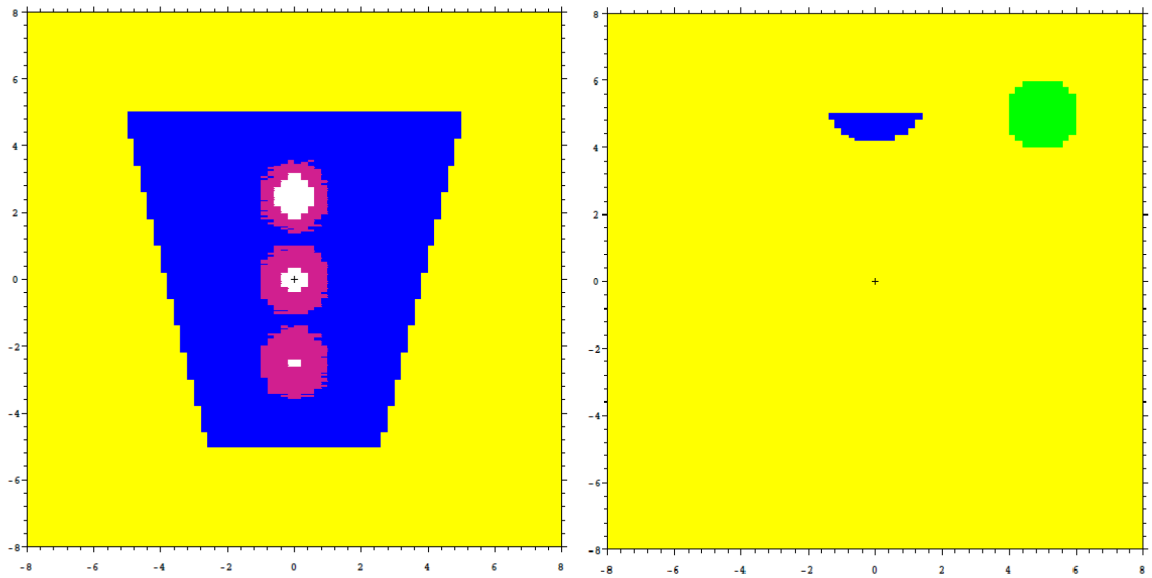

Figure 5. 2-mm LNK3DNT version of the RTO at x = 0 (left) and x =+5 cm (right); dimensions are cm

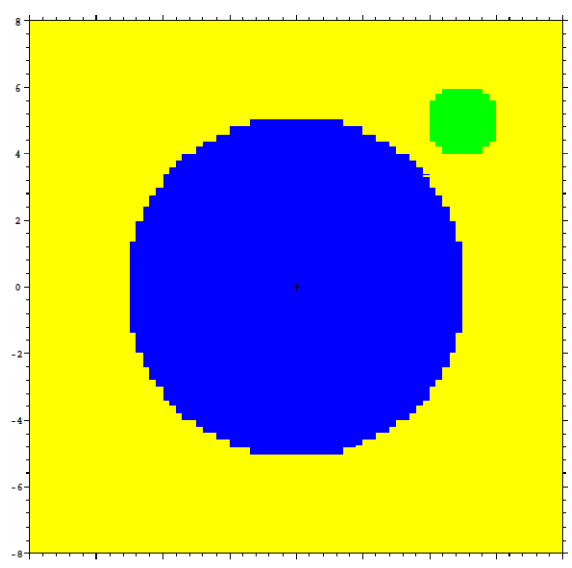

Figure 6. Cross-sectional XY plot at z = +5 cm

The geometry slice in Figure 5, unlike that in Figure 3, reveals a portion of the aluminum cone courtesy of several "mixed" cells. Inspection of Figure 6 at X = 5 or Y = 5 cm provides an alternate perspective. Mixed cells are also evident at the boundary of each tungsten sphere in Figure 5.

A 1-mm LNK3DNT version of the RTO is a factor of 8 larger than the 2-mm mesh (98.3 MB vs 12.3 MB).

The Los Alamos Monte Carlo team (XCP-3) is currently working on a Monte Carlo Application Toolkit[7] (MCATK) and, among other features, this code includes a geometry plotter intended to visualize LNK3DNT files. Material index and density (g/cc) for the 1-mm LNK3DNT version of the RTO is shown in Figure 7. MCATK is thus an alternative to interrogating this geometry with the MCNP plotter. One of the convenient features of this tool is the ability to interactively “scroll” through planar slices of the geometry and the snapshot in Figure 7 represents the center of the mesh.

Regarding the LNK3DNT file material index, 1 is the void region within each tungsten sphere, 2 is the tungsten, 3 is aluminum, 4 is air and 5, not visible in Figure 7, is the steel reference sphere.

For Los Alamos users, MCATK is found in `/usr/projects/mcatk/release`.

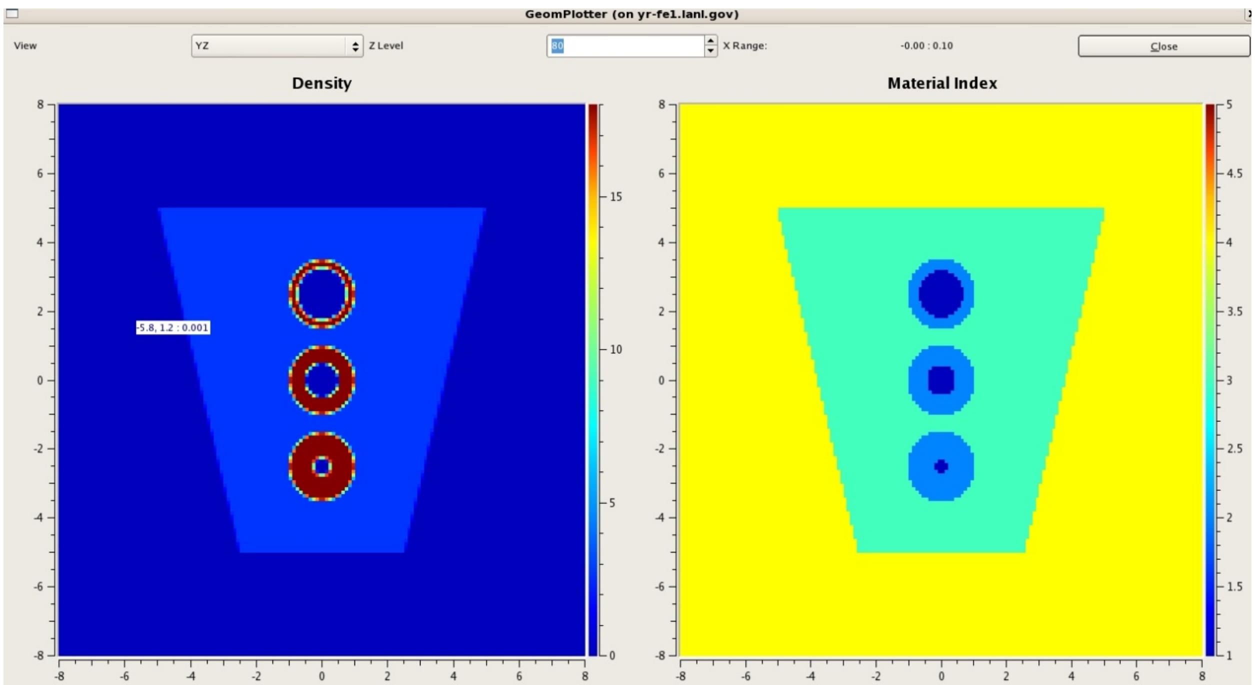

Figure 7. 1-mm LNK3DNT version of the RTO rendered in the MCATK geometry viewer

For subsequent transport runs, possibly intended for direct comparison with PARTISN (e.g. Ref 8), since that deterministic Los Alamos code also makes use of the LNK3DNT mesh, an MCNP6 input file with an embedded LNK3DNT mesh requires additional entries. Figures 5 and 6, for example, were created with the following input file and **several new entries are highlighted in bold type**.

MCNP6 input file with embedded LNK3DNT mesh

```
Conical Test Problem
c
c This simple MCNP problem is intended to illustrate
c several radiographic projections.
c
c 05 Jan 2010
c Erik F. Shores, Duane P. Flamig and John D. Zumbro, XCP-7
c
c file = conelnk.i ; 05 Aug 11 ; embedded mesh example
c -----------------------------------------------------------------
c CELL CARDS
c -----------------------------------------------------------------
10        0         0 u=e10 imp:n,p=1 $ void elements
1000    101 -18.0   0 u=e10 imp:n,p=1 $ W sphere
2000    103 -2.7    0 u=e10 imp:n,p=1 $ Al cone
4000    104 -7.8    0 u=e10 imp:n,p=1 $ SS sphere for orientation
3000    105 -1.0e-3 0 u=e10 imp:n,p=1 $ air
5000      0    -98 fill=e10 imp:n,p=1
6000      0     98 -99      imp:n,p=1
9999      0     99          imp:n,p=0
c end cells with blank space
c -----------------------------------------------------------------

c -----------------------------------------------------------------
c SURFACE CARDS
c -----------------------------------------------------------------
1    so    1.0
2    sz    2.5  1
3    sz   -2.5  1
4   trc    0    0   -5    0 0 10   2.5 5
5     s    5    5    5    1
10  c/x    0    0    0.5
11  c/x    0    2.5  0.75
12  c/x    0   -2.5  0.25
98   so  50
99   so  5000
c end surfaces with blank space
c -----------------------------------------------------------------

c -----------------------------------------------------------------
c DATA CARDS
c -----------------------------------------------------------------
c -8 degree rotation about y (up)*
tr3   0.                   0.        0.
      0.99026806874157036 0.       -0.13917310096006544
      0.                   1.        0.
      0.13917310096006544 0.        0.99026806874157036 1
c
c -----------------------------------------------------------------
c MATERIAL CARDS
c -----------------------------------------------------------------
m101   74184 1.000000 $ W
m103   13027 1.000000 $ Al
m102   73181 1.000000 $ Ta
m105    7014 0.770900  8016 0.219500 18000 0.009600 $ air
m104   26056 0.698000 24052 0.206000 28058 0.096000 $  SS
m106   71175 2.000000 14028 1.000000 8016 5.000000  $ LSO
c
```

```
c -------------------------------------------------------------------
c SOURCE: CARDS
c -------------------------------------------------------------------
mode n p
phys:p j 0 0
cut:p j 0.1
sdef pos -133 0. 0. par=1
     vec    1 0  0
c sdef pos -131.70565314262884726 0.  -18.51002242768870332 $ small end to source
c      vec 0.99026806874157036    0.    0.13917310096006544
c sdef pos -131.70565314262884726 0.   18.51002242768870332 $ large end to source
c      vec 0.99026806874157036    0.   -0.13917310096006544
c
c -------------------------------------------------------------------
c TALLY CARDS
c -------------------------------------------------------------------
fc5 Sample Radiograph
fir5:n   392                   0.  0.   0   0. 0. 0.  0 0 0
c fir5:p 388.18508294559555880 0.  54.55585557534554954
c                                       0   0. 0. 0.  0 0 0 $ small end to source
c firS:p 388.18508294559555880 0. -54.55585557534554954
c                                       0   0. 0. 0.  0 0 0 $ large end to source
fs5 -22.48 1123i 22.48
c5  -22.48 1123i 22.48 $ radiographic grid
talnp 5                $ don't print tally bins
nps 1                  $ histories
notrn                  $ ray trace
prdmp j 1 1 2          $ dump control
print                  $ make some output!
c
c for LNK3DNT file creation
c mesh  geom xyz origin=-8 -8 -8  ref=0 0 0
c        imesh 8
c        iints 80
c        jmesh 8
c        jints 80
c        kmesh 8
c        kints 80
c dawwg points=10 xsec=ndilib
c
embed10 meshgeo    = lnk3dnt
        mgeoin     = efslinktest
        matcell    = 0 10
                     1 1000
                     2 2000
                     3 3000
                     4 4000
        background = 3000        $ cell number
```

Results

The nominal synthetic radiographic image ("direct" tally from a single photon history; i.e. ignoring scatter) from our combinatorial geometry version of the RTO is shown in Figure 8. Generally, the radiographer's convention is to view an image from the source perspective and the steel sphere is thus expected in the upper left quadrant of the simulated image. The default image presentation was retained for Figure 8, however, and while it appears the viewer is looking toward the source, readers are reminded of the reference vector (1,0,0) specified on the *FIRn:p* tally entry (see Figure 1). Alternatively, the reference vector (and thus viewing perspective) could be modified by specifying the "coordinates defining outward normal to image grid' as (`400 0 0`) on the FIR entry, resulting in a reference vector of (-1,0,0), but the image would require a 180° rotation (Figure 9). In any case, post-processing tools may easily "horizontally flip" the image shown in Figure 8. Solomon's "MCTALTOOL" utility[9,10] was used to extract tally information from MCNP's Monte Carlo Tally (MCTAL) file for image production in GNUPLOT with this command:

`mctaltool -i mctalfile -o outputfile -x s -y c -n 5` [`—help` argument is available].

For Los Alamos users, this utility is located in `/users/csolomon/share/utilities`.

The synthetic images in Figures 10 and 11 are presented as a radiographer would traditionally view a piece of film—from the source perspective. In Figure 10, the source-detector system has been tilted about the geometry such that the object (cone plus reference sphere) appears tilted 8 degrees. This is an alternative to applying a TR card to the entire geometry. In other words, for Figure 10, imagine the small end of the aluminum cone has been tilted toward the source. By contrast, the large end of the cone was tilted toward the source in Figure 11. Note the position of the reference sphere in each image.

Arbitrary intensity units are shown in Figures 8-11 but are the same for each figure.

In short, for the MCNP user to understand the relationship between the geometry coordinate system and that of the detector grid, MCNP's output file should be studied. Two useful comments are those highlighting the relevant vectors:

```
direction cosines perpendicular to image grid = -1.0000E+00  0.0000E+00  0.0000E+00
```

```
image detector axes:    t (c card) axis =  0.0000  0.0000 -1.0000     s (fs card) axis
=  0.0000  1.0000  0.0000.
```

Interested readers are encouraged to explore scatter contributions in this RTO by extending photon physics and transport. Image blurring from scatter becomes readily visible with as few as 100 histories, for example. Additional options might include making contributions to each pixel with a random offset (e.g. nonzero tenth entry on the FIR tally).

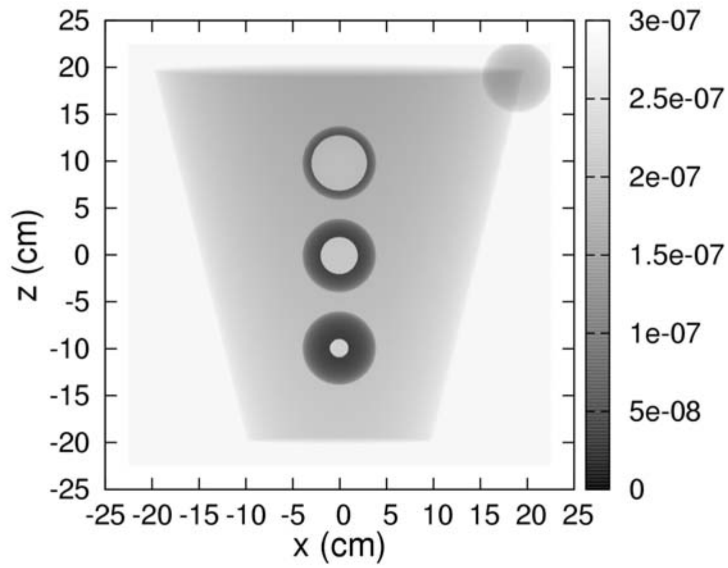

Figure 8. Nominal synthetic radiograph of the RTO requires horizontal pixels to be reversed; the reference vector is (1,0,0), s-axis is (0,1,0) and t-axis is (0,0,1)

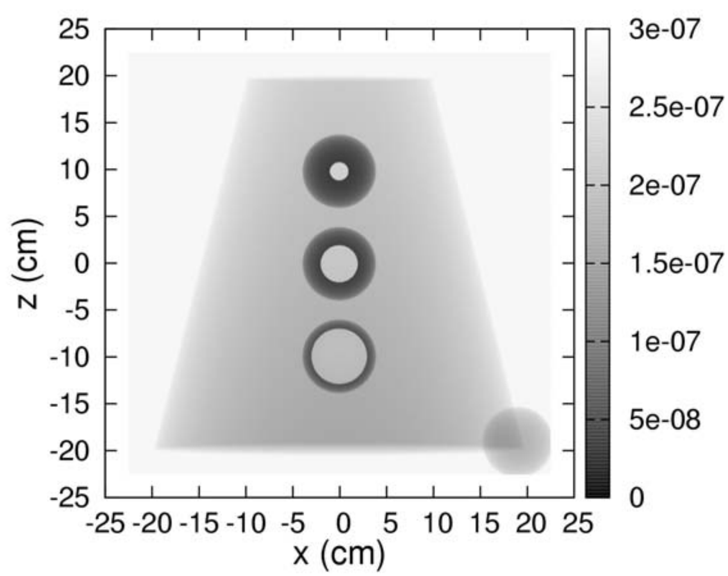

Figure 9. Synthetic radiograph of the RTO with an alternate reference vector specification requires the image to be rotated; here, the reference vector is (-1,0,0), s-axis is (0,1,0) and t-axis is (0,0,-1)

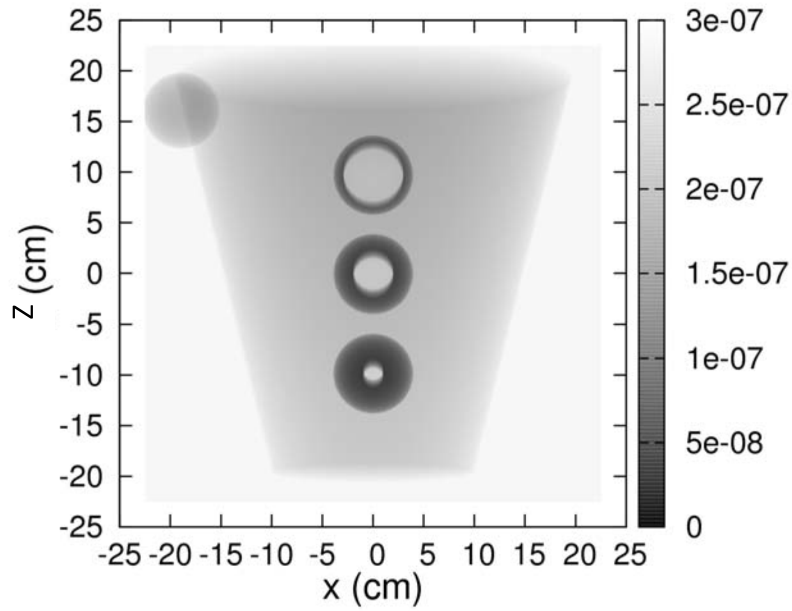

Figure 10. Synthetic radiograph of the RTO; small end of cone tilted toward source

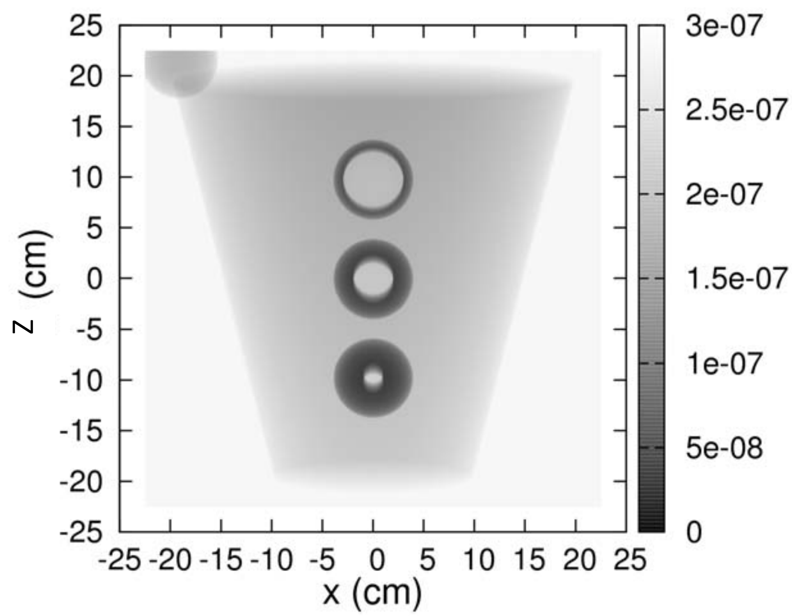

Figure 11. Synthetic radiograph of the RTO; large end of cone tilted toward source

Summary

MCNP users have great flexibility to model source-object-detector systems for radiographic applications. A sample radiographic test object (RTO) was devised to exercise MCNP's radiographic tally options and illustrate proper image orientation. In short, MCNP's output description of the *S*- and *T*- axes, coupled with the tally's reference vector, are key to understanding the *FIR*n:p tally output. This work corroborates Temple's conclusions[4] and the authors endorse his proposed modifications to the MCNP manual regarding his "better description for the radiography tally". Relative to traditional combinatorial geometry, new features in MCNP6 were used to produce analogous 1-mm and 2-mm LNK3DNT versions of the problem and this note provides a practical example.

Appendix

Further results are included as an appendix and intended for viewgraph presentation.

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Distribution

Transport Applications (XCP-7) and Monte Carlo Codes (XCP-3) group members.

EFS:efs

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