

## MCNP6 Compton Image Tally Option

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### INTRODUCTION

MCNP is a Monte Carlo nuclear particle transport code that has been under development for over half a century. Over the last decade, the development team of a high-energy offshoot of MCNP, called MCNPX, has implemented several tally enhancements important for modeling nuclear particle interactions with matter, including neutron coincidence capture tallies, variance reduction with pulse-height tallies, anticoincidence with pulse-height tallies, and tally tagging, to mention a few [1-4]. In this paper, the latest of these enhancements, a Compton Image tally option recently implemented in MCNP6 [5], is discussed.

### DESCRIPTION OF THE ACTUAL WORK

It has been possible to model coincidence and anticoincidence of multi-region pulse-height tallies in MCNPX since the release of version 2.5.0 in April of 2005 [6]. This capability, called the PHL tally option, feeds standard track-based energy deposition tallies (i.e., F6 tallies), perhaps combined from multiple particle types, into one or more pulse-height detector regions. In a dual-region application, the full coincidence/anticoincidence pulse-height matrix is produced. The F6 tallies used in this fashion can be further modified to obtain a specific detector response (e.g., light output, ion production, etc.). This PHL tally option was extended in 2010 to include triple and quadruple pulse-height regions [7]. Not long after this, the PHL tally option was combined with a Compton image algorithm, called the COM tally option, to produce a dual-panel grid of Compton coincidences (i.e., Compton image). Details of the algorithm and user interface are provided in the following two sections.

#### Compton Image Algorithm

Standard photo-atomic physics includes treatment for photoelectric, coherent (Rayleigh/Thomson), incoherent (Compton), and pair production interactions (see Fig. 1). In 1923, physicist Arthur Compton first understood and presented the well-known Compton equation [8], which relates the photon shift in wavelength to its angle of scatter:

$$\lambda' - \lambda = h/m_e c (1 - \cos \theta), \quad (1)$$

where  $h$  is the Planck constant,  $m_e$  is the electron mass, and  $c$  is the speed of light. A few decades later, this physics was exploited using multiple detectors to form Compton images of various photon sources.

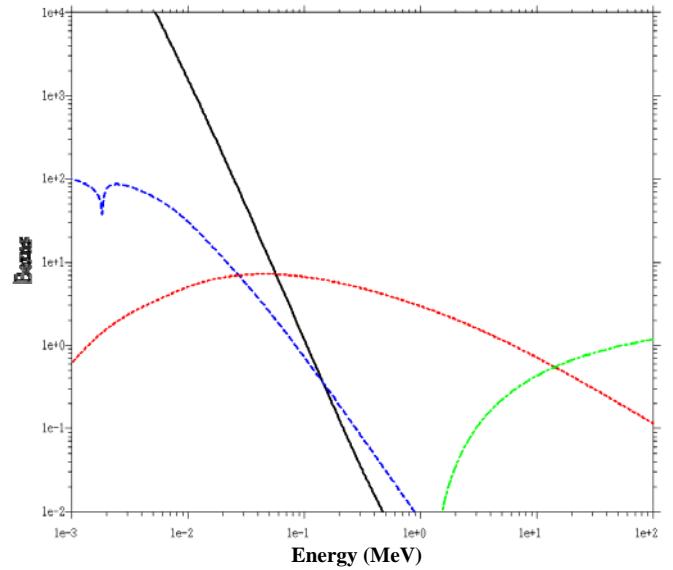


Fig. 1. The photoelectric (black), coherent (blue), incoherent (red), and pair production (green) cross sections for Si.

The new MCNP6 COM tally option produces a Compton image of the related pulse-height (i.e., F8) tally. This option is specified on the associated FT8 card and must be accompanied by the PHL tally option. The Compton image is formed from a PHL specification of dual-region coincidences of planar lattice tallies. At the end of each particle history, Compton electron energy deposition in the front panel of detectors is correlated to photoelectric energy deposition in the back panel of detectors to create a circular “image” of the incident photon on a specified image plane (see Fig. 2). A recent extension of the PHL option enables its use for lattice cells and, combined with the COM option, provides coincidences of front-panel energy deposition with back-panel energy deposition, on a voxel-by-voxel (or element-by-element) basis. For example, if the front-panel detector consists of a 5x5 lattice and the back-panel detector consists of a 10x10 lattice, then this PHL extension will produce coincident pulses for  $25 \times 100 = 2500$  voxel combinations. The Compton electron energy deposition

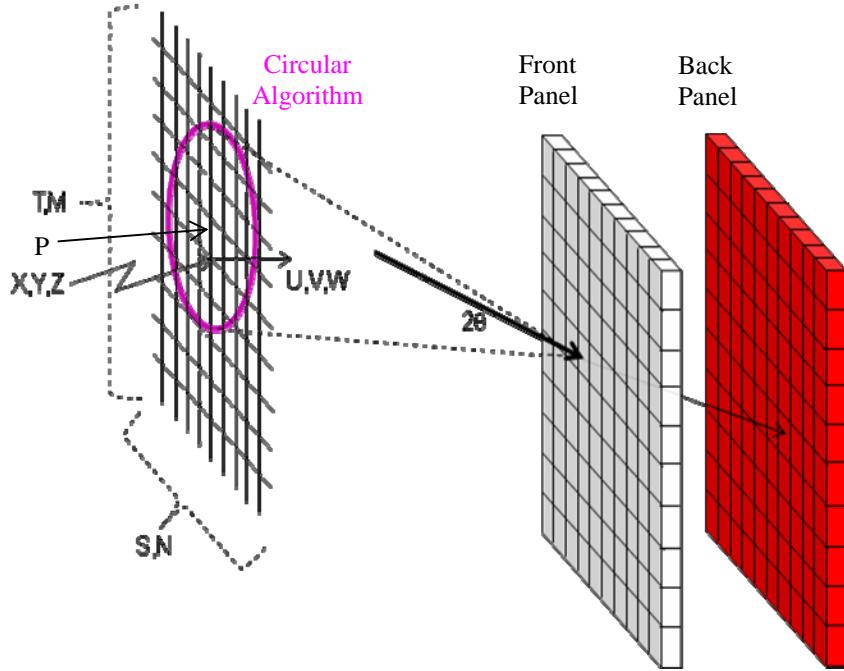


Fig. 2. Diagram of a Compton image detector, along with a circular sample on the image plane.

scored in a front-panel voxel ( $E_f$ ) is correlated to the photoelectric energy deposition in a back-panel voxel ( $E_b$ ), via the Compton equation, to produce the Compton angle of scatter and thus determine a conical angle of incidence. Here is the form of the Compton equation that is used to obtain the conical angle of incidence:

$$\cos \theta = 1 - m_e c [1/E_b - 1/(E_f + E_b)], \quad (2)$$

where  $m_e c$  is taken as 0.511 MeV. Restrictions on  $E_f$  and  $E_b$  include: (1)  $E_f < E_b$ , and (2)  $E_f > E_{ft}$  and  $E_b < E_{bt}$ , where  $E_{ft}$  and  $E_{bt}$  are threshold energies set by the user on the corresponding E8 and FU8 cards. The first of these is required to formulate a backward conical image (and helps ensure a Compton+photoelectric reaction occurred), while the latter is needed to reduce image clutter from voxel leakage (electron escape, Brems., etc.). The COM processing algorithm is currently quite simple in that it takes the centerpoint of the front-panel voxel and that of the back-panel voxel to form a line which is then intersected with the image plane (at point P). Using the equation above, a radial distance from point P is determined and scores are made to various grid elements intersected by the circle about P (see Fig. 2). A second simple algorithm is used, based on the size of the grid elements, to determine the number of sample points to score around the circle. A pulse of the source weight is scored in each image-plane grid element that overlaps a circular sample point.

### MCNP6 User Interface

The COM option is allowed only on F8 tallies and must be used with a corresponding dual-region PHL option. The tallies specified with the PHL option must involve multi-element lattices. While the lattices in the two regions can differ in size and number of elements, tallies specified within a region must tally over the same lattice cell and elements (but can include contributions from different particle types). This feature fully supports repeated-structures geometries. Table I provides a description of the eleven COM entries, which establish the orientation, size, and resolution of the image plane.

| Table I. Description of FT COM Option. |        |   |
|--|--------|---|
| Keyword                                | Values | Description*                                    |
| COM                                    | X,Y,Z  | Centerpoint of the image grid                   |
|  | U,V,W  | Normal to the image grid                        |
|  | S      | Size of the image plane in 1 <sup>st</sup> dir. |
|  | N      | No. of grid elements along S                    |
|  | T      | Size of the image plane in 2 <sup>nd</sup> dir  |
|  | M      | No. of grid elements along T                    |
|  | J      | Algorithm option (default=1)                    |

\* See Fig. 2.

The PHL option has been enhanced in the following way. The F-bin descriptor specified after each F6 tally, may be “0”, indicating that the referenced tally includes a lattice description of multiple lattice elements. When this option is specified, all tallies within that PHL region must also include the “0” descriptor and all tallies must be over

the same lattice cell and elements. When this option is used in both PHL regions, the F8 F bins are modified, with an appropriate warning message, to include  $J \times K$  bins, where  $J$  is the number of lattice elements included in PHL Region 1 and  $K$  is the number of lattice elements included in PHL Region 2. The output of Tally 8 will include coincidence results for all  $J \times K$  bins, along with appropriate cell labels (e.g.,  $1[0\ 1\ 1]+2[0\ 0\ 0]$ , which is the combination of lattice cell 1, element [0 1 1], with lattice cell 2, element [0 0 0]). Here is a simple example:

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FT8 PHL 1 16 0 1 26 0 0
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The first entry indicates there is one tally contributing to the first coincidence region, namely tally F16. The entry of “0” subsequent to this (F-bin entry) indicates F16 is a lattice tally. The fourth entry indicates there is one tally contributing to the second coincidence region, namely tally F26. Again the subsequent entry of “0” indicates F26 is also a lattice tally. The final entry of “0” indicates there are no additional coincidence regions.

## RESULTS

This simple example involves a 2-MeV isotropic photon source located off-center (-5,3,3) at 4 cm from two 1x5x5 Si panels, with the back panel 3 cm behind the front (front panel is centered at -1,0,0). The Si voxels are 2x2x2 cm, making the panels 2x10x10 cm overall in size (see Fig. 3). The image plane is coincident with the source location, so it too is ~4 cm from the front panel detector. The size of the image plane is 20 cm in each direction, with 10 grid elements along these “S” and “T” axes. The energy thresholds were set to 0.2 MeV.

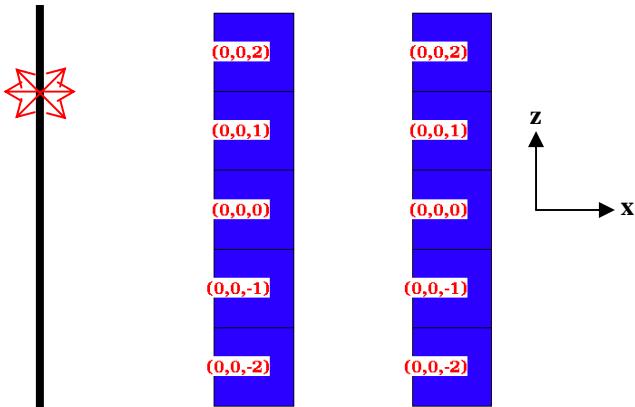


Fig. 3. Geometry plot showing the image plane (dark black line), source location (red arrows), and front and back detector panels (blue) with associated lattice indices.

Fig. 4 presents the corresponding Compton image, which indicates a source location consistent with the specified source point of  $y=3$ ,  $z=3$  (or  $S=3$ ,  $T=3$ ).

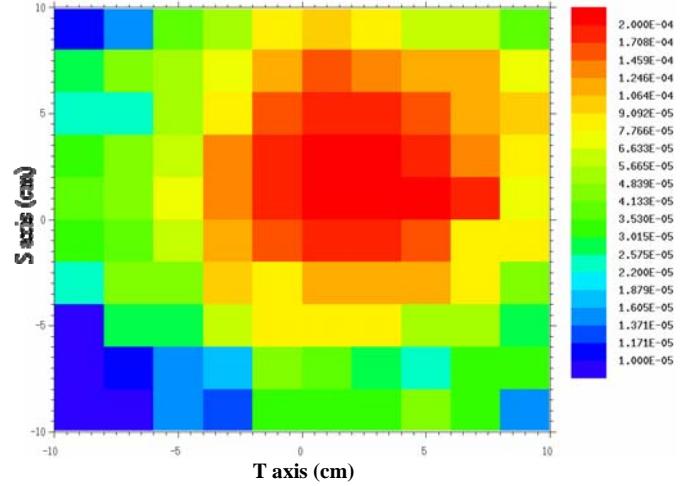


Fig. 4. Compton image of the off-center 2-MeV photon source, using a 20x20 cm image plane with 10x10 grid elements.

## ENDNOTES

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