Tutorial for ARTEMIS

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I. INTRODUCTION

ARTEMIS[1,2] (pArticle transport, Recombination, and Trapping in sEMiconductor Imaging Simulations) is a Monte Carlo package for X-ray, electron and electron-hole pair (EHP) transport. X-ray and secondary electron interactions in the presence of an electric field are modeled by PENELOPE 2006[3], and the locations of inelastic electron interactions are coupled in space and time to the transport routine for EHP simulation. ARTEMIS was developed at the *U. S. Food and Drug Administration (FDA), Center for Devices and Radiological Health, Office of Science and Engineering Laboratories*, Division of Imaging and Applied Mathematics.

The source code and documentation of ARTEMIS are openly distributed at the website: http://code.google.com/p/artemis/ . The following disclaimer notice applies to the code and documentation developed exclusively at the FDA (this disclaimer is provided at the beginning of each file developed at the FDA).

II. DOCUMENTATION AND REFERENCE

The ARTEMIS code was first introduced in the paper listed below, which should be referenced by researchers using this code.

- Yuan Fang, Andreu Badal, Nicholas Allec, Karim S. Karim, and Aldo Badano, "Spatiotemporal Monte Carlo transport methods in x-ray semiconductor detectors: Application to pulse-height spectroscopy in a-Se", Medical Physics 39, pp. 308–319 (2012).

Abstract:

Purpose: The authors describe a detailed Monte Carlo (MC) method for the coupled transport of ionizing particles and charge carriers in amorphous selenium (a-Se) semiconductor x-ray detectors, and model the effect of statistical variations on the detected signal.

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Methods: A detailed transport code was developed for modeling the signal formation process in semiconductor x-ray detectors. The charge transport routines include three dimensional spatial and temporal models of electron-hole pair transport taking into account recombination and trapping. Many electron-hole pairs are created simultaneously in bursts from energy deposition events. Carrier transport processes include drift due to external field and Coulombic interactions, and diffusion due to Brownian motion.

Results: Pulse-height spectra (PHS) have been simulated with different transport conditions for a range of monoenergetic incident x-ray energies and mammography radiation beam qualities. Two methods for calculating Swank factors from simulated PHS are shown, one using the entire PHS distribution, and the other using the photopeak. The latter ignores contributions from Compton scattering and K-fluorescence. Comparisons differ by approximately 2% between experimental measurements and simulations.

Conclusions: The a-Se x-ray detector PHS responses simulated in this work include three dimensional spatial and temporal transport of electron-hole pairs. These PHS were used to calculate the Swank factor and compare it with experimental measurements. The Swank factor was shown to be a function of x-ray energy and applied electric field. Trapping and recombination models are all shown to affect the Swank factor.

Some external software used by ARTEMIS includes PENELOPE and penEasy. **PENELOPE** (version 2006) is a general purpose code that performs Monte Carlo simulation of coupled electron-photon transport in arbitrary materials and in the energy range from 50 eV to 1 GeV. The standard geometry model used by PENELOPE (PENGEOM) is based on defining objects as the volume limited by a set of quadric surfaces. Despite this model can be used to describe complex geometries, it is not adequate to represent biological structures with arbitrary shapes. The PENELOPE subroutines are copyrighted by the Universitat de Barcelona and can be obtained for free at http://www.nea.fr/abs/html/nea-1525.html or at http://www-rsicc.ornl.gov/ .

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C  PENELOPE/PENGEOM (version 2006)                                      C
C  Copyright (c) 2001-2006                                              C
C  Universitat de Barcelona                                             C
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PenEasy[4] is a general-purpose simulation package for PENELOPE developed by Josep Sempau. The package contains a modular main program and several tally options and source models that facilitate the simulation of medical physics applications. The modular structure of the code makes it easy to develop additional tools that extend the applicability of PENELOPE to new fields of study. The main program of ARTEMIS is essentially a custom version of the penEasy's main program. The penEasy package is copyrighted by the Universitat Politecnica de Catalunya and distributed at http://www.upc.es/inte/downloads/penEasy.htm .

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c  penEasy                                                                      c
c  Copyright (c) 2004-2008                                                     c
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III. COMPILATION

The FORTRAN and C source files included in this distribution of ARTEMIS can be found in the Source folder. Important files include the following:

- penEasy_EMfield_EDEtally.f: main program for ARTEMIS.
- tallyEnergyDepositionEvent.f: tally program for pulse-height spectrum output.
- transEHP.c: main program for electron-hole pair transport routines.
- transEHP.h: library definition file for the electron-hole pair transport routines.
- tallyEDE.pl: perl script for PHS output and Swank noise calculations.

To compile ARTEMIS, the user needs a current FORTRAN and C compiler. For the executable in this package, Intel FORTRAN and C compilers version 11.1 are used, but the program can be compiled also with GCC (g++ and gfortran). For plotting ARTEMIS results, the distribution includes example scripts for GNUPLOT, a command-driven plotting program.

If you are not using the executable provided with the distribution, ARTEMIS can be compiled using the provide compile.sh script file in the root directory of the distribution.

Note: PENELOPE 2006 source code files penelope.f and pengeom.f are not distributed with the ARTEMIS package, but are needed for compiling. If these files are needed, please contact Yuan Fang at yuan.fang@fda.hhs.gov.

IV. DEMONSTRATION EXAMPLE

- Copy the executable ARTEMIS_v1.0.x to the \Demo directory and run the program.
- There are two demonstration examples for Mo and W spectra included in version 1.0. Both are for a 150-μm-thick a-Se detector.
- Run example for Mo spectra with an applied bias of 30 V/μm and 1e4 histories, with the following command:

  ARTEMIS_v1.0.x < Mo30V1e4.in
- Pulse-height output files:
  - tallyEDE-*.dat: contain the incident x-ray energy and number of electron-hole pairs generated and detected.
  - To get the PHS output for plotting, run the tallyEDE.pl perl script:
    - tallyEDE.pl tallyEDE-*.dat
    - the output file is: tallyEDE-*.dat.phs
- For the purpose of this demonstration example, Gnuplot scripts are provided to plot the pulse-height spectrum of both cases. Run the file PHS.gnu in the \Demo\Data folder to generate the corresponding plots seen in Figure 1. The folder contains pulse-height results for a range of simulation histories.

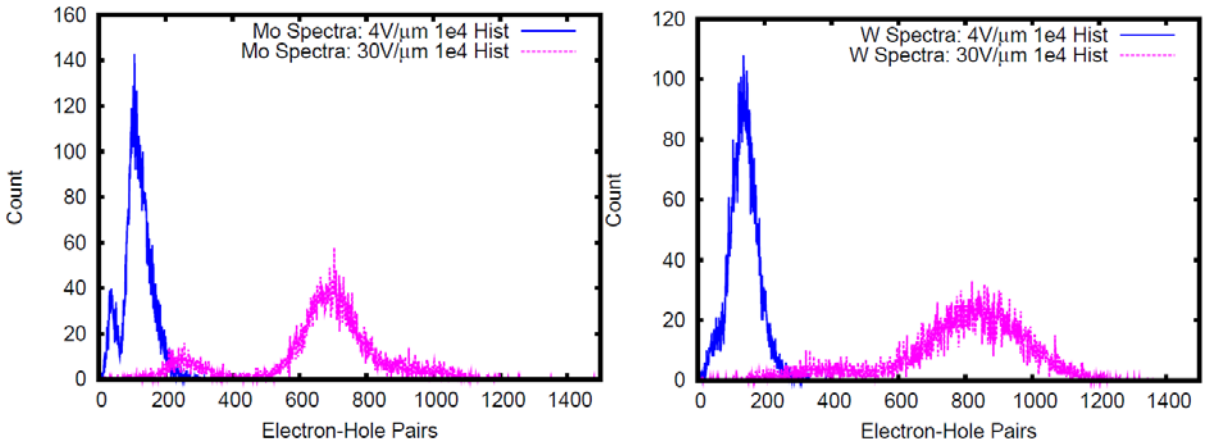

Figure 1. Sample Pulse-height simulation results for Mo and W x-ray spectra.

REFERENCE

[1] Y Fang, A. Badal, N. Allec, K.S. Karim, and A. Badano. *Spatiotemporal Monte Carlo transport methods in x-ray semiconductor detectors: Application to pulse-height spectroscopy in a-Se*, Medical Physics 39, pp. 308–319, 2012.

[2] Y Fang, K.S. Karim, and A. Badano. *Effect of burst and recombination models for Monte Carlo transport of interaction carriers in a-Se x-ray detectors on Swank noise*, Medical Physics 41, pp.011904-1, 2014.

[3] F. Salvat, J.M. Fernandez-Varea, and J. Sempau. *PENELOPE-2006, A Code System for Monte Carlo Simulation of Electron and Photon Transport.* OECD Nuclear Energy Agency, Issyles-Moulineaux, France, 2006. ISBN: 92-64-02145-0. Document available at http://www.oecd-nea.org/dbprog/penelope.pdf.

[4] J. Sempau, A. Badal and L. Brualla, *A PENELOPE-based system for the automated Monte Carlo simulation of clinacs and voxelized geometries—application to far-from-axis fields*. Medical Physics 38, pp. 5887, 2011.