Penelope-Based User Friendly Fast Interface for Calculating Dose Distribution in Irradiated Products

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Overview

A 2017 report by Fermilab\(^1\), as well as a 2019 IAEA report\(^2\), conclude that significant impediments remain for *device manufacturers* desiring to transition from gamma-ray and ethylene-oxide sterilization modalities to electron-beam or X-ray; and that these impediments include data and education gaps.

The Office of Radiological Security (ORS) within the U.S. National Nuclear Security Administration (NNSA) asked Pacific Northwest National Laboratory (PNNL) to build a collaborative team that included major players in the medical device and biopharma production industries.

The team was charged to focus on data, education and tool gaps, as identified by the Fermilab and IAEA reports, in order to help advance X-ray and electron beam technologies, and increase their use.

This presentation covers a recently added task, which was to identify gaps in dose distribution modeling tools, and brainstorm ways in which to improve these software tools for use by non-experts.

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Team Nablo – Active Members

- Pacific Northwest National Laboratory
- Becton-Dickinson
- Stryker
- Sartorius
- Texas A&M University
- Aix Marseille University
- Steri-Tek
- IBA
- Aerial CRT
- AAMI
- Boston Scientific
- Pall
- Bayer
- Millipore Sigma
The main problem identified in our survey is that, due to its complexity and required labor, existing dose distribution software is out of reach for many potential users. As a result of the limitations of current commercial software identified by the survey, an approach is being pursued with the following features:

- The flexibility to cover simple to moderately complex product geometries.
- Wide range in input files – from images and photos, to CAD and CT scans.
- Sufficient accuracy and precision of the dose distribution so the locations of the maximum and minimum dose can be determined.
- Use by individuals who are novices at radiation modeling without the need for extensive computational resources.
- Available to any user, and at little to no cost for license and training.
Proposed Software

- The software will use PENELOPE Monte Carlo code.
- PENELOPE will be called as an external program.
- The interface will create a voxel geometry of the product.
- A 2D interface will allow for the creation of simple configurations.
  - A single block of material
  - A simple image or photo.
  - Geometry drawn by mouse.
- More complex 3D geometry information can be imported.
  - From CAD files.
  - From other Monte Carlo codes.
  - From DICOM data.
- The current task and software is being referred to as PUFFIn – Penelope User Friendly Fast Interface for electron and photon beam applications.
The PENELOPE Monte Carlo Code

- Penetration and **Energy Loss** of Positrons and Electrons.
- Used for the transport of Gammas, Electrons, and Positrons.
- Developed by the University of Barcelona, Spain.
- Available from the Nuclear Energy Agency.
- Applications include Radiotherapy, Nuclear Medicine, Dosimetry and Detectors.
- PENELOPE can be run through the PENGUIn interface.
PENELOPE Capabilities

- **Simple** – The input files are concise compared to other Monte Carlo codes. The typical input file for this application is less than 50 lines. There is a separate geometry file that will vary in size depending on the geometry specifications.

- **Gnuplot** – Data files are displayed with Gnuplot, a world standard graphics package.

- **Fast** – In comparison with other Monte Carlo codes for the same geometry – PENELOPE is shown to run substantially faster. The goal is for the calculation for a medium-complexity packaged product (for E-beam) to take less than 10 minutes with a single processor.

- **Minimal Size** – because the cross sections are part of the material definitions, it removes the need for a massive cross section data base. The complete PENELOPE distribution, including examples, tables and documentation is less than 1 GB.

- **Convenient distribution** – the PENELOPE code has already been incorporated in the GEANT4 code and the source code and executable can be distributed without additional restrictions with this software package.
PUFFIn Overview

Beam parameters

3D data display

Voxelized Image

2D data display

PENELOPE runtime messages

PENELPOE runtime messages

Beam parameters

3D data display

Voxelized Image

2D data display

PENELPOE runtime messages
**PUFFIn – Beam parameters**

### Input Parameters
- Product dimensions.
- Beam dimensions.
- Both Electron and Photon beams available.
- Foil position and thickness.
- Beam Energy.
- The beam comes from the Y direction.

<table>
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<th>Parameter</th>
<th>Value</th>
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<tr>
<td>Y length (cm)</td>
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<td>Z length (cm)</td>
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<td>Particle Type</td>
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<td>Foil 1 (cm)</td>
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<tr>
<td>Foil 2 (cm)</td>
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<tr>
<td>mil Gap (cm)</td>
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<tr>
<td>No. Electrons</td>
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</tr>
<tr>
<td>Beam centered on product</td>
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</tbody>
</table>

### Diagram
- The beam comes from the Y direction.
- Foil position and thickness.
- Beam Energy.
- Foil 1 and Air Gap.
A list of available materials is displayed.

Materials for each region can be defined.

A material and density is assigned to each color.

The color of the material region in the plot can be changed.

Standard PENELOPE materials are used.

New materials can be created in PENELOPE.
The “Run PENELOPE” button will create an input and geometry file. PENELOPE is then run as a sub-process. PLOTS are displayed and updated while running. The total Dose Uniformity Ratio (DUR) and the DUR in the direction of the beam are calculated.
2D dose distribution (eV/g). Plane I3=1

PUFFIn – Plots
PUFFIn – 3D Data Display

Options:
- Color Map.
- Transparency.
- Min and max data to display.
- Min and max X values.
- Min and max Y values.
- Min and max Z values.
PUFFIn – 3D Data Display
10 MeV Electrons in Water
PUFFIn – Boston Scientific Wallstent Yjoint
3D geometries can be created from multiple 3D data sets.

In this case a mesh tally file is used to transfer data from an existing code to a format that can be read by PUFFIn.

A voxel version of PENELOPe is being tested that can run this input.
PUFFin 3D – Bayer Stellant Dose

1 MeV Photons

10 MeV Electrons
A graphical user interface is being developed that will allow for 2D and 3D calculations of dose distribution in a product/material.

The PENELOPE code is used to do the calculations.

Users do not need extensive knowledge of PENELOPE, since the geometry and input is created by PUFFIn.

Geometry information/input can be in the form of 2D images or more complex 3D data sets.

The target users are those needing detailed dose distribution information for polymer-based products with simple to moderately complex geometries.

The software package will be available to any user at no cost.

Can be used as a training tool.
Thank you

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