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

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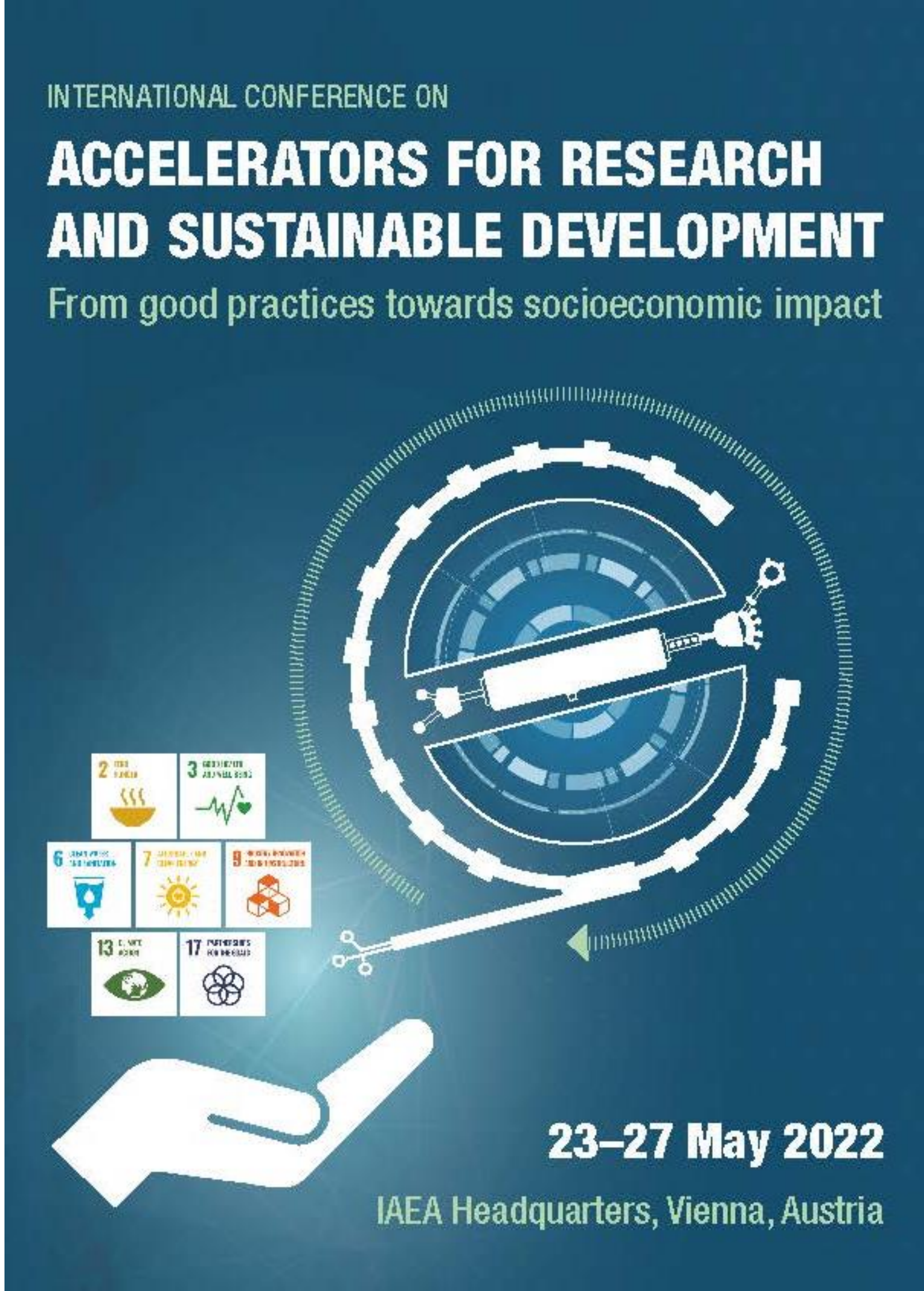


Overview

- 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.

1. FermiLab (2017). Accelerator-driven Medical Sterilization to Replace Co-60 Sources.
2. IAEA Consultancy Meeting on '"Radiation effects on polymer materials" (2019) http://www-naweb.iaea.org/napc/iachem/working_materials/IAEA%20Consultancy%20Meeting%20Final%20Report%20polymer.pdf

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

Current Approach Being Studied

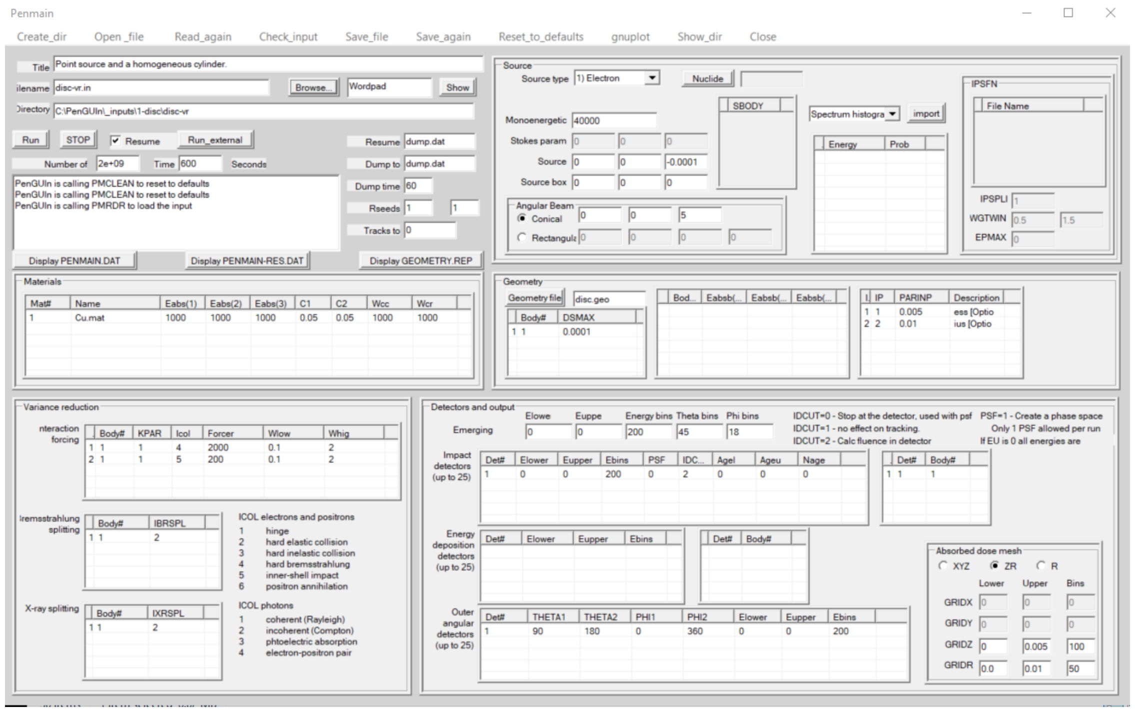
- The main problem identified in our survey is that, due to its complexity and required labor, existing dose distribution software is out of reach for many potential users.
- As a result of the limitations of current commercial software identified by the survey, an approach is being pursued with the 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 – **P**enelope **U**ser **F**riendly **F**ast **In**terface for electron and photon beam applications.

The PENELOPE Monte Carlo Code

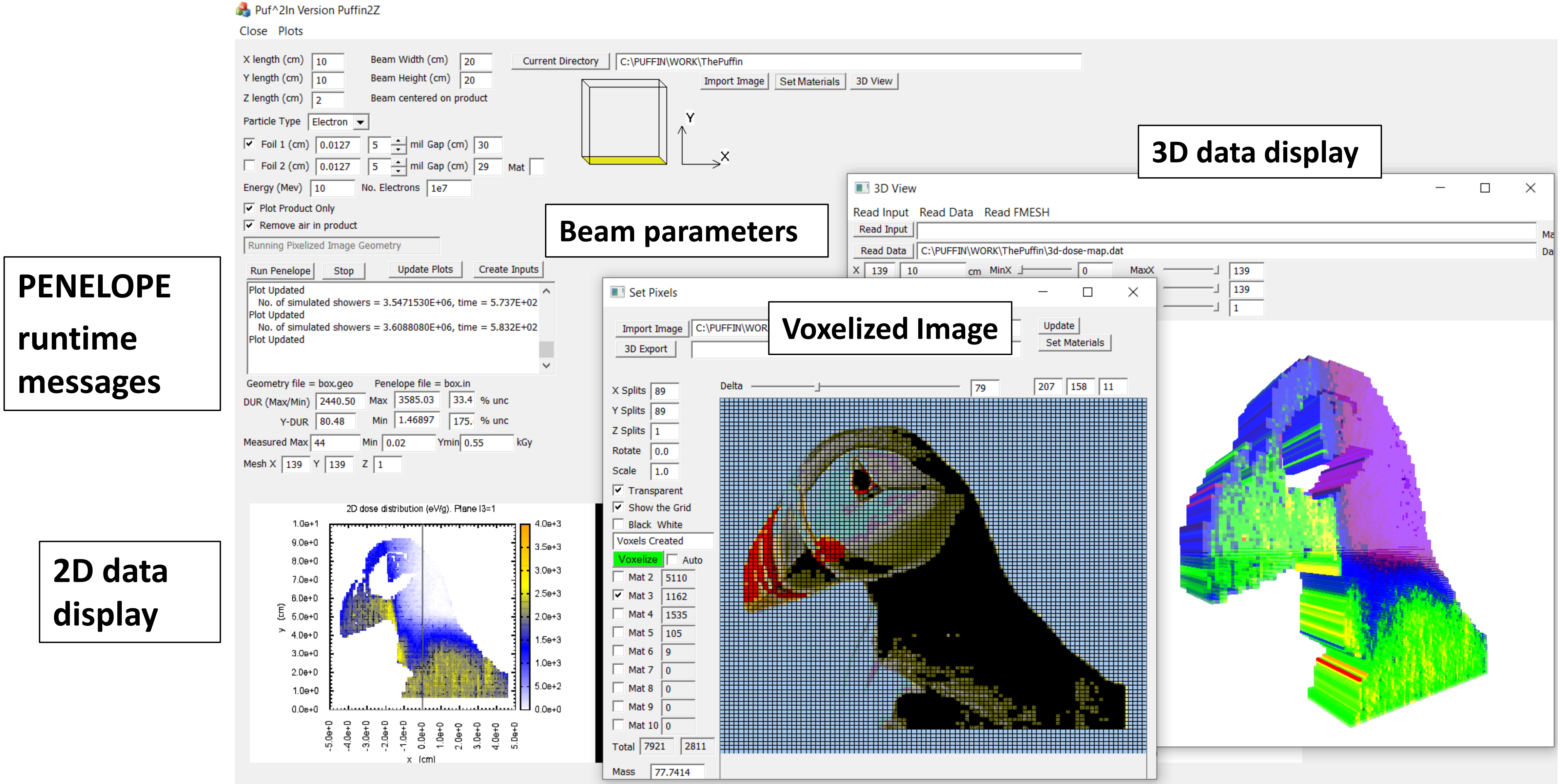
- **P**enetration and **ENE**rgy **L**oss of **P**ositrons and **E**lectrons.
- Used for the transport of Gammas, Electrons, and Positrons.
- Developed by the University of Barcelona, Spain.
- Available from the Nuclear Energy Agency.
- Applications include Radiotherapy, Nuclear Medicine, Dosimetry and 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.

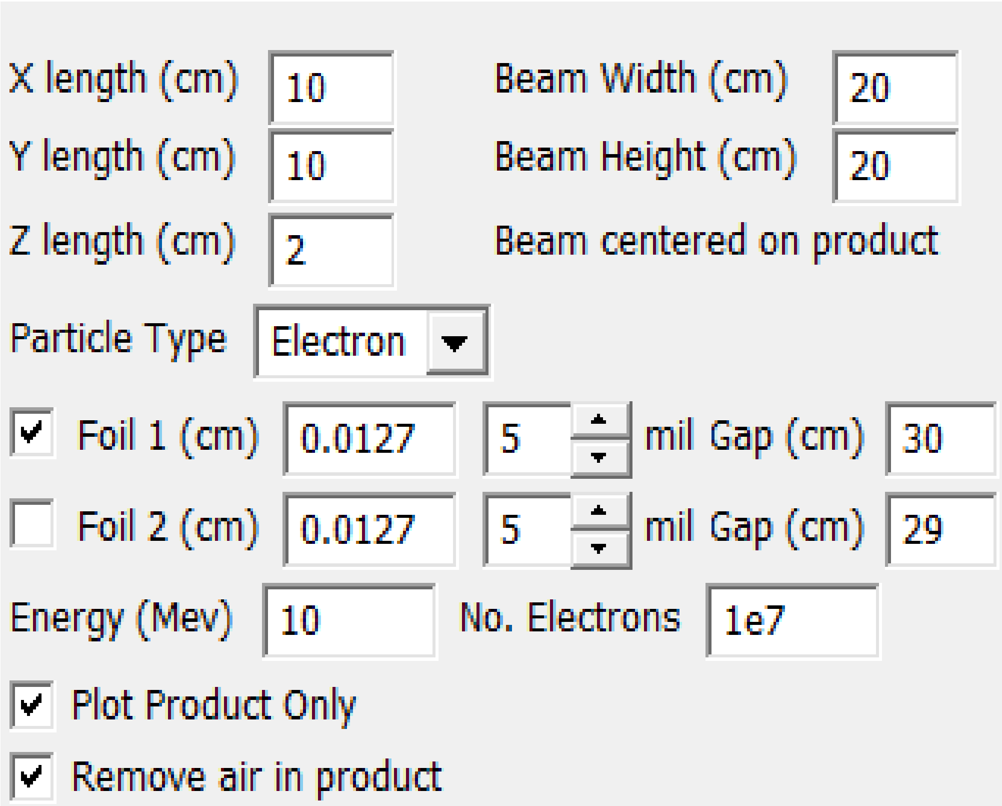
PUFFIn Overview

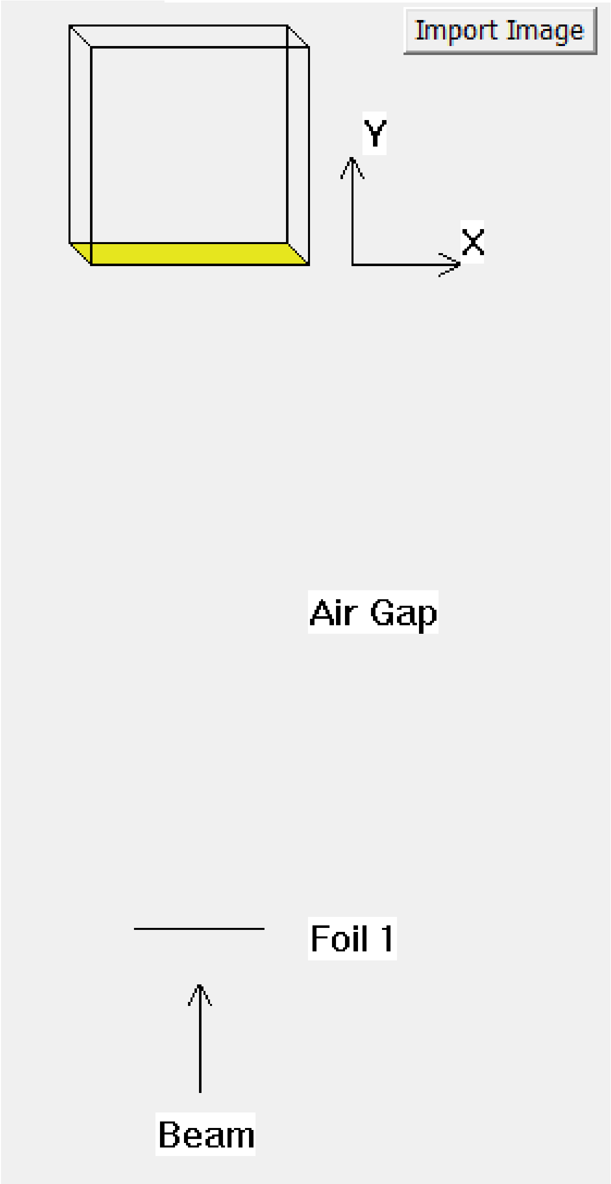


PUFFIn – Beam parameters

Input Parameters

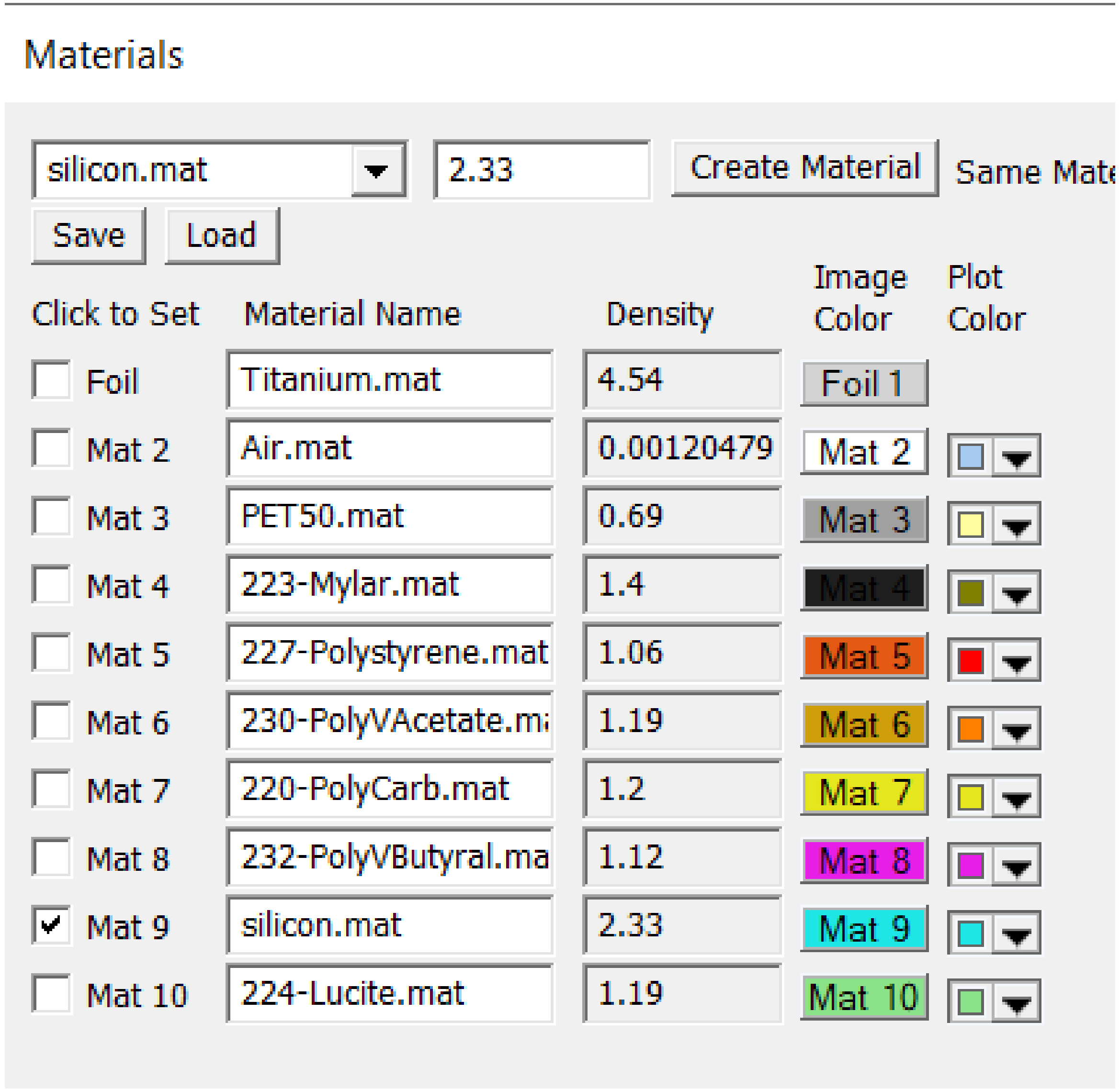
- Product dimensions.
- Beam dimensions.
- Both Electron and Photon beams available.
- Foil position and thickness.
- Beam Energy.
- The beam comes from the Y direction.





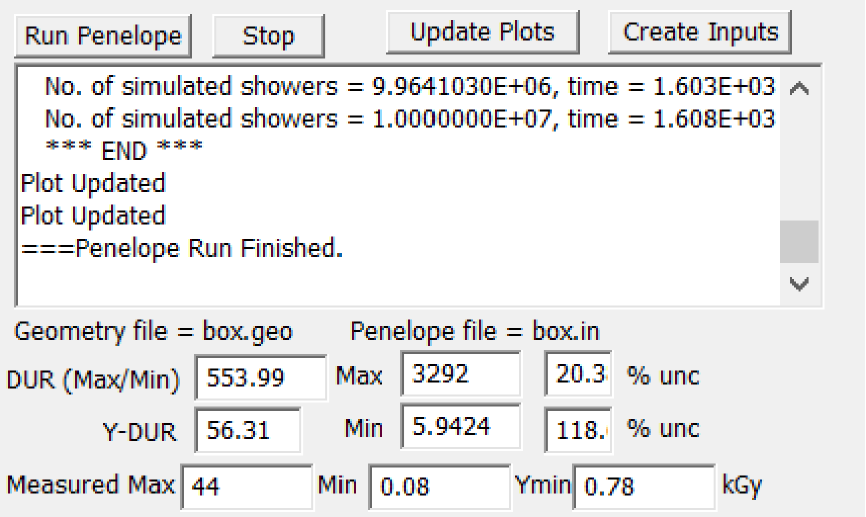
PUFFIn – Materials

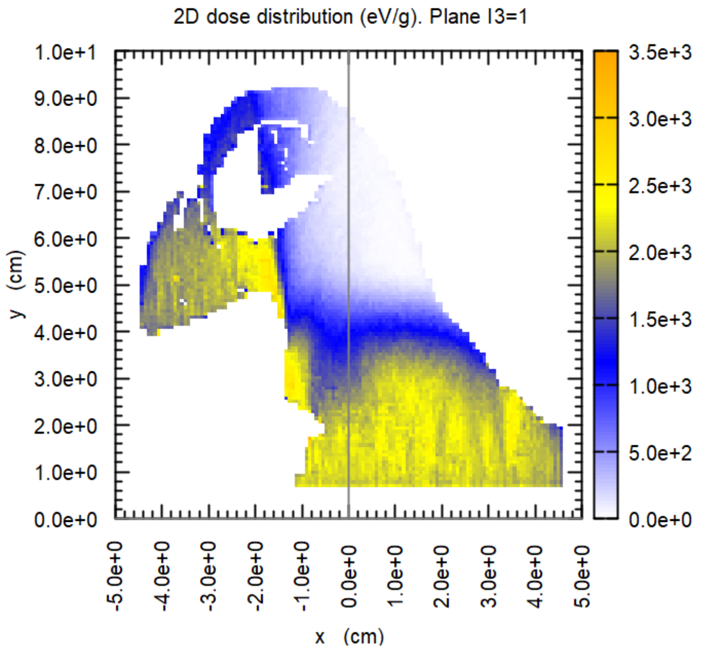
- A list of available materials is displayed.
- Materials for each region can be defined.
- A material and density is assigned to each color.
- The color of the material region in the plot can be changed.
- Standard PENELOPE materials are used.
- New materials can be created in PENELOPE.

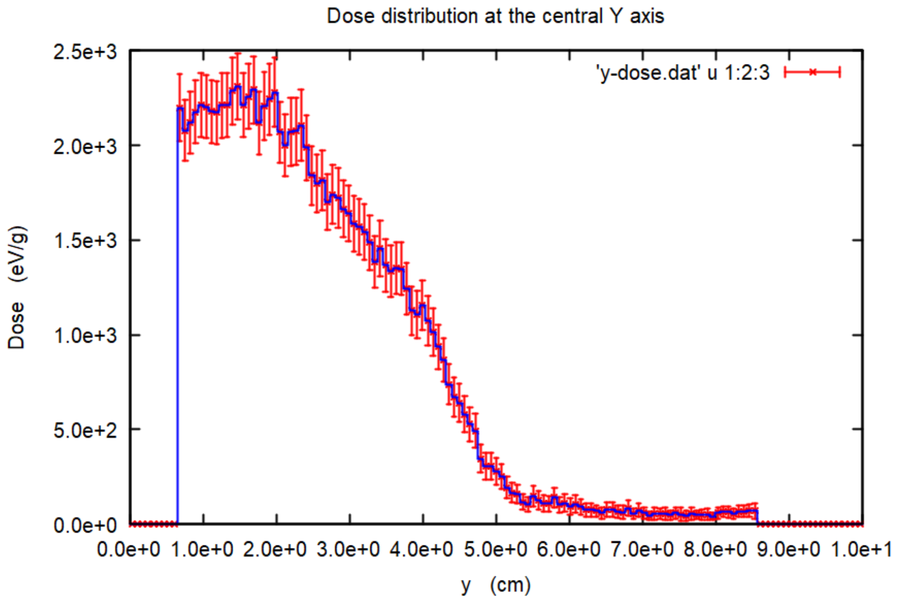


PUFFIn – Running PENELOPE

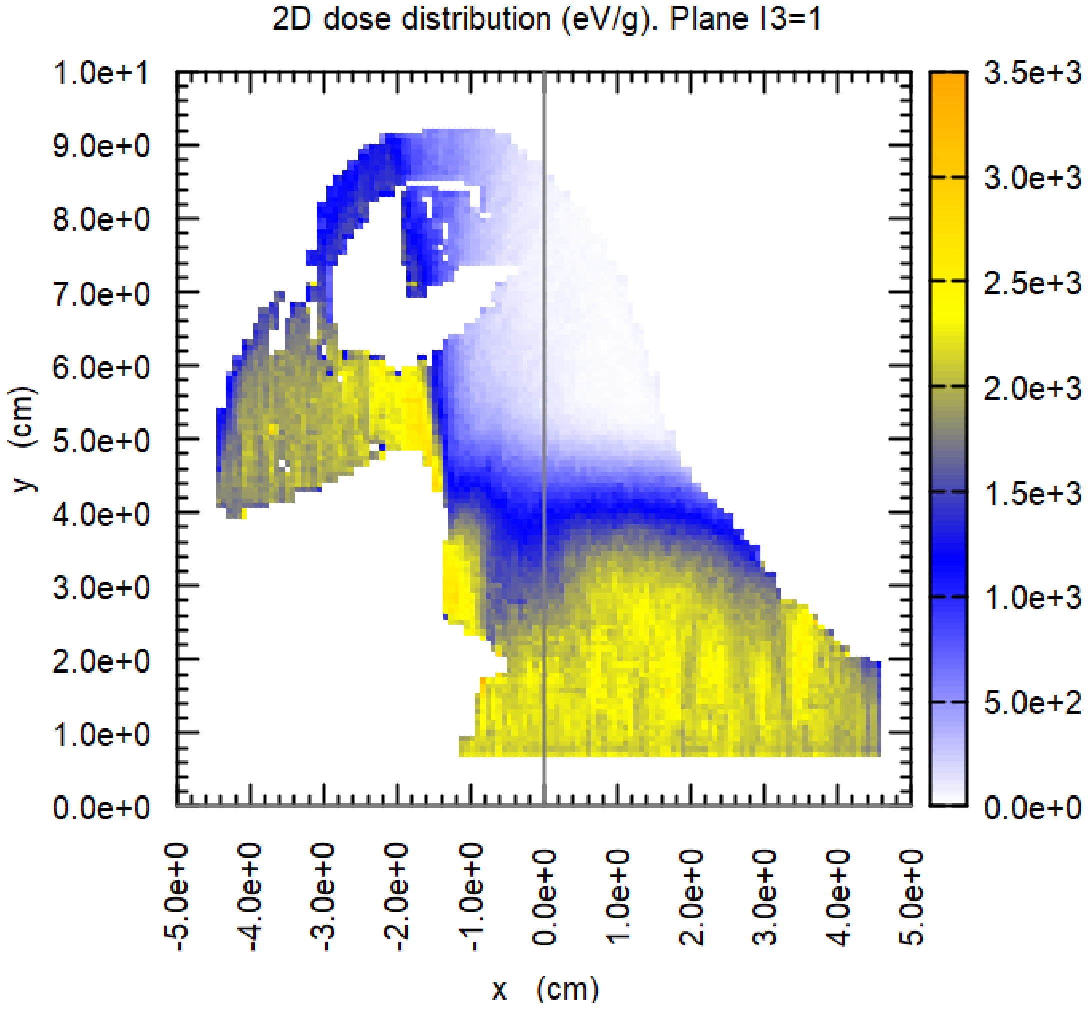
- The “Run PENELOPE” button will create an input and geometry file.
- PENELOPE is then run as a sub- process.
- PLOTS are displayed and updated while running.
- The total Dose Uniformity Ratio (DUR) and the DUR in the direction of the beam are calculated.

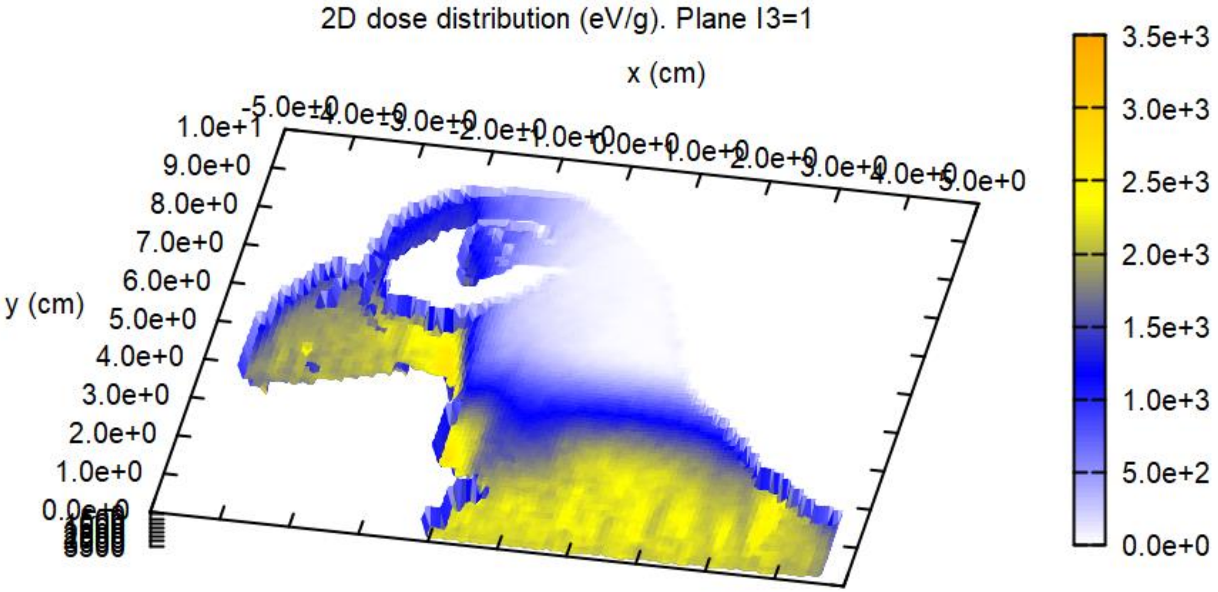






PUFFIn – Plots

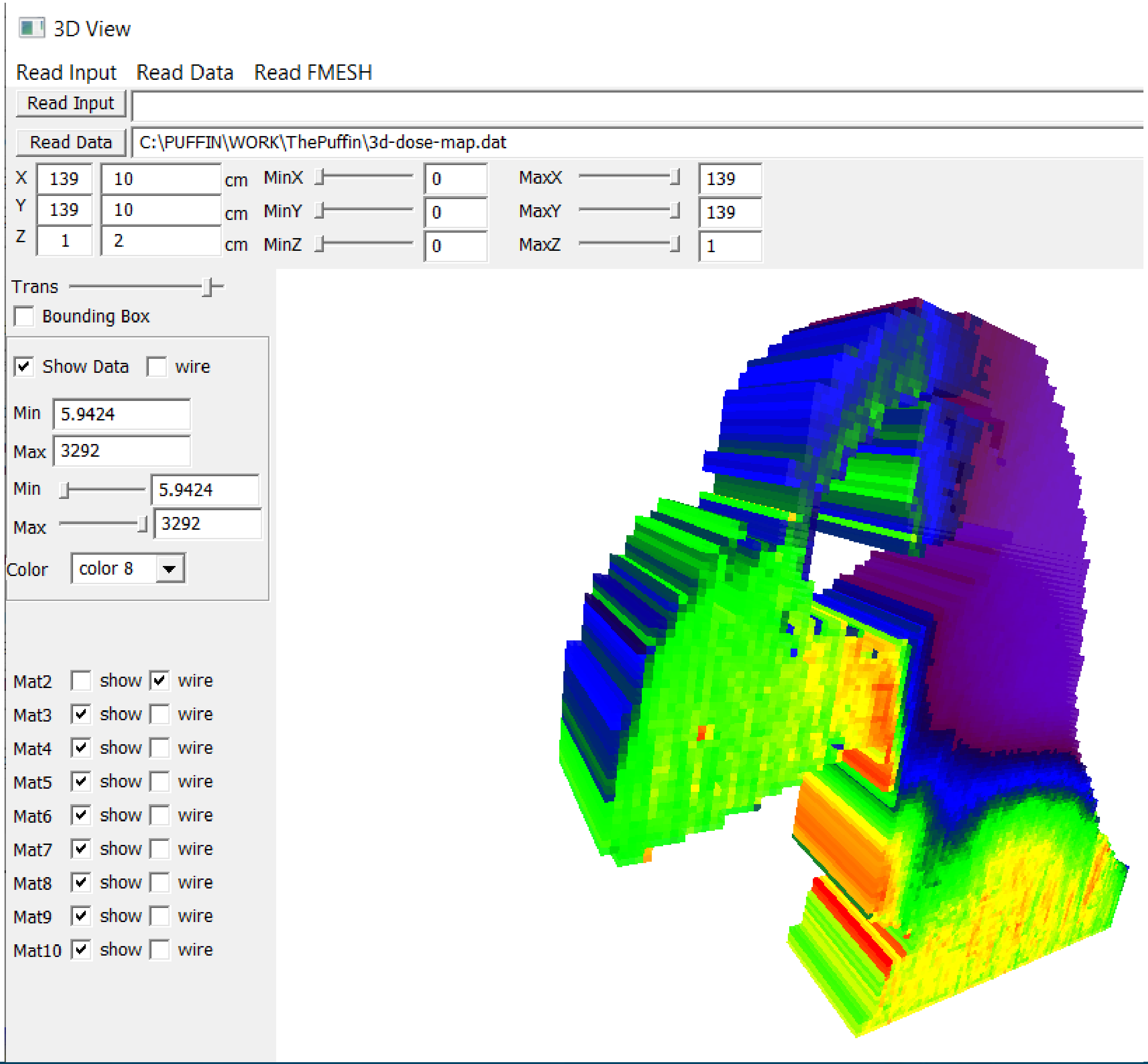




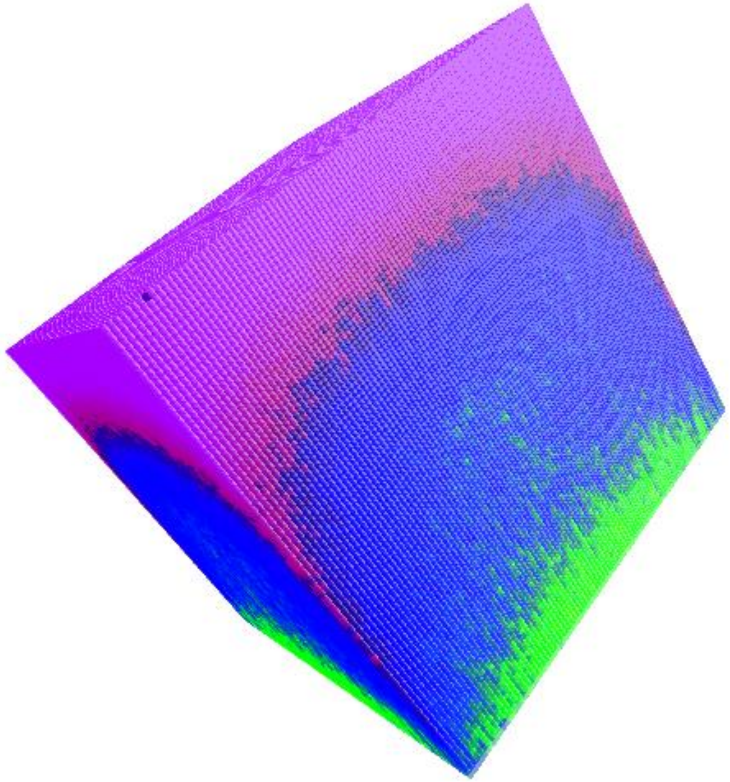
PUFFIn – 3D Data Display

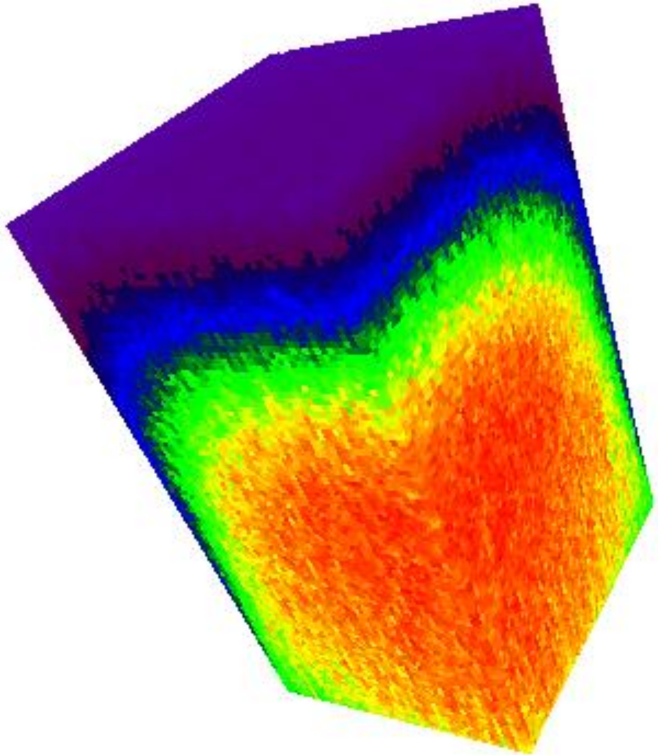
Options:

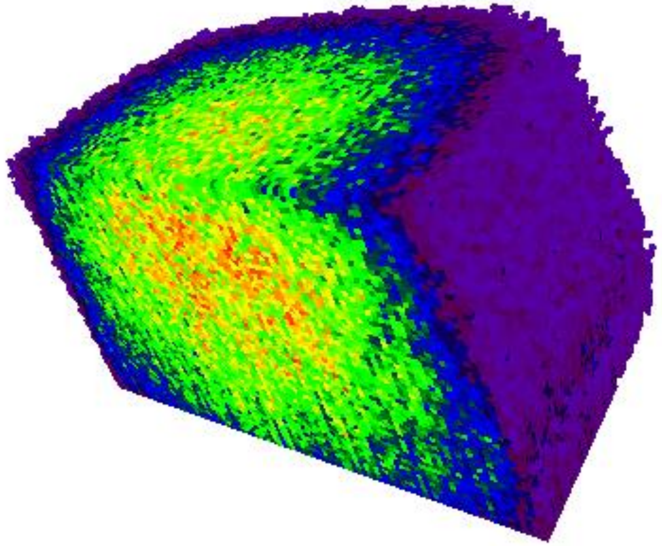
- Color Map.
- Transparency.
- Min and max data to display.
- Min and max X values.
- Min and max Y values.
- Min and max Z values.



PUFFIn – 3D Data Display
10 MeV Electrons in Water







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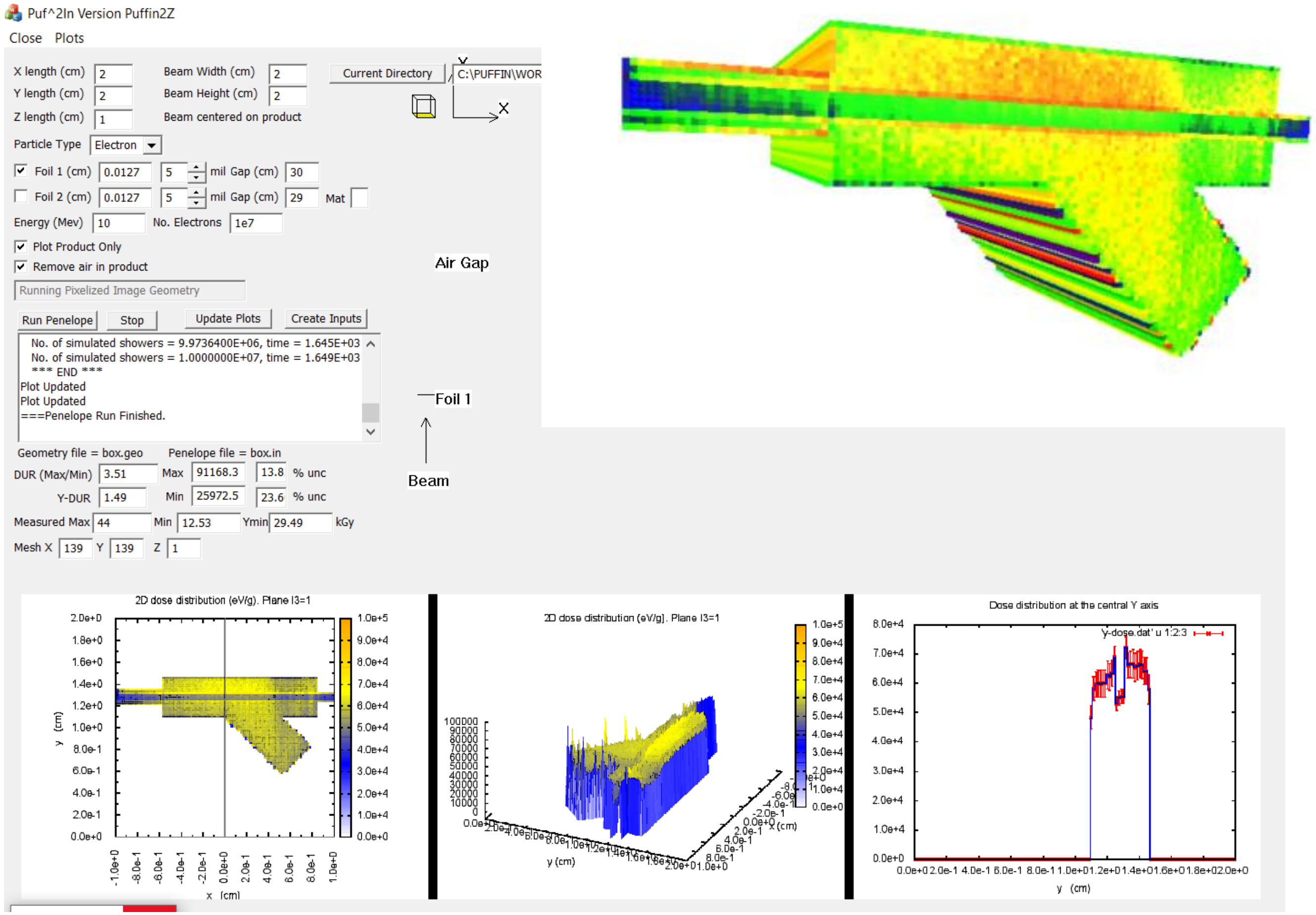
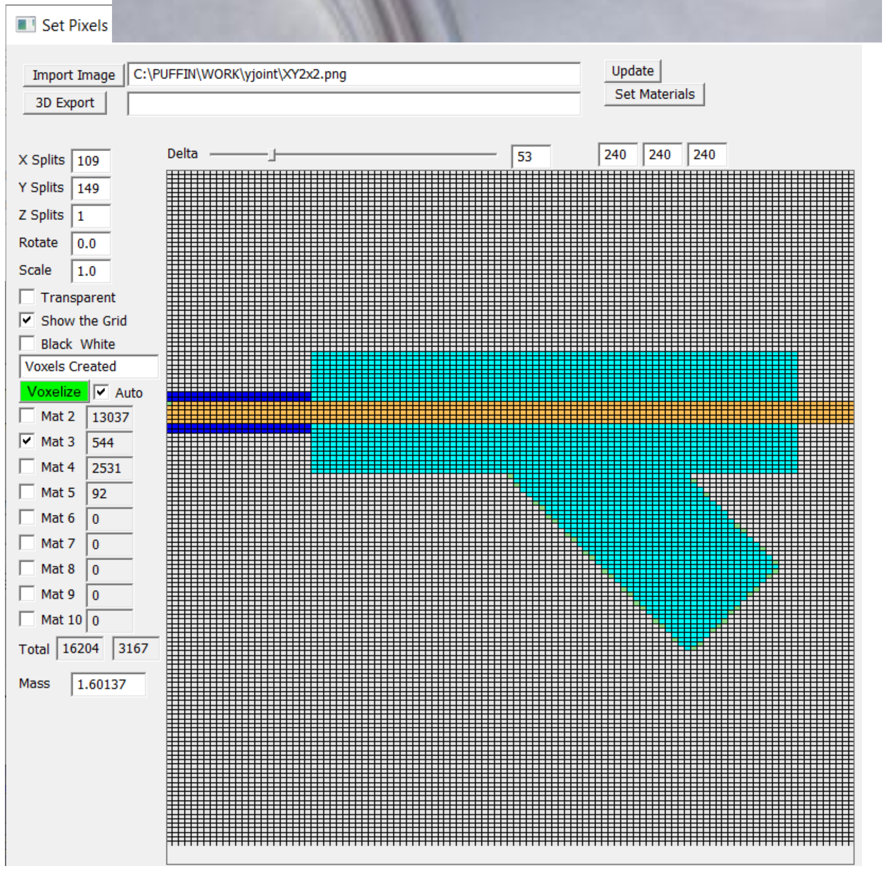


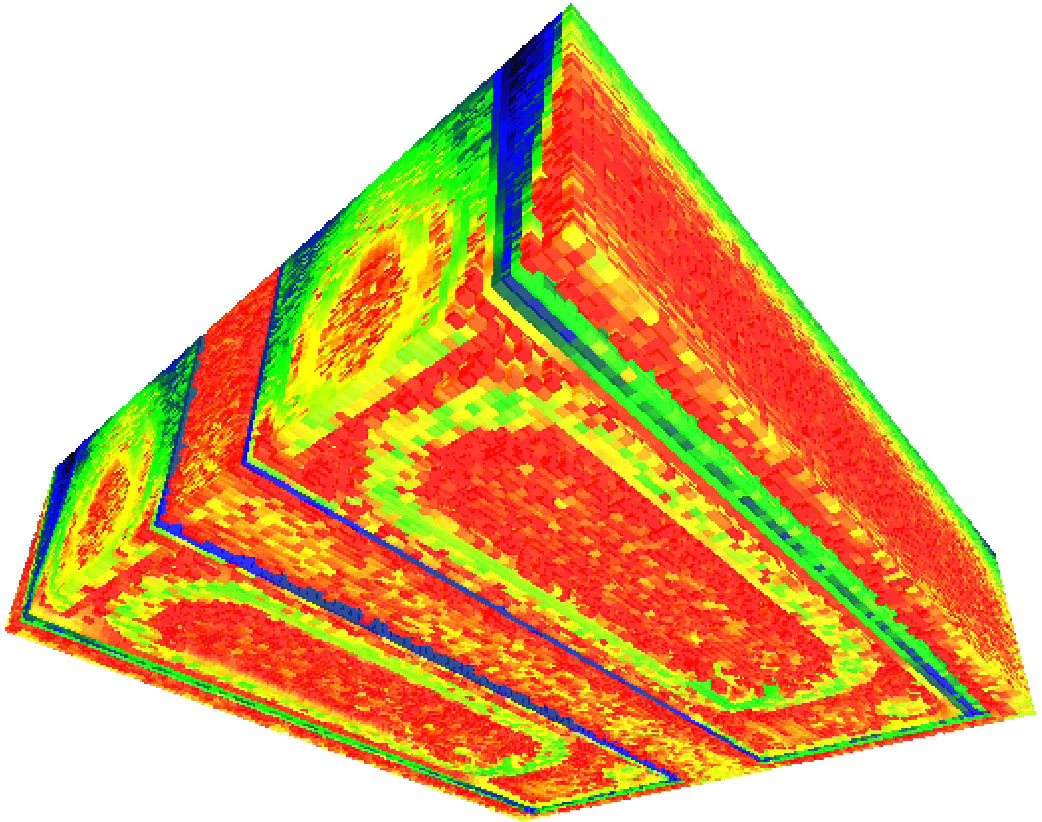


PUFFIn 3D Geometry – Bayer Stellant

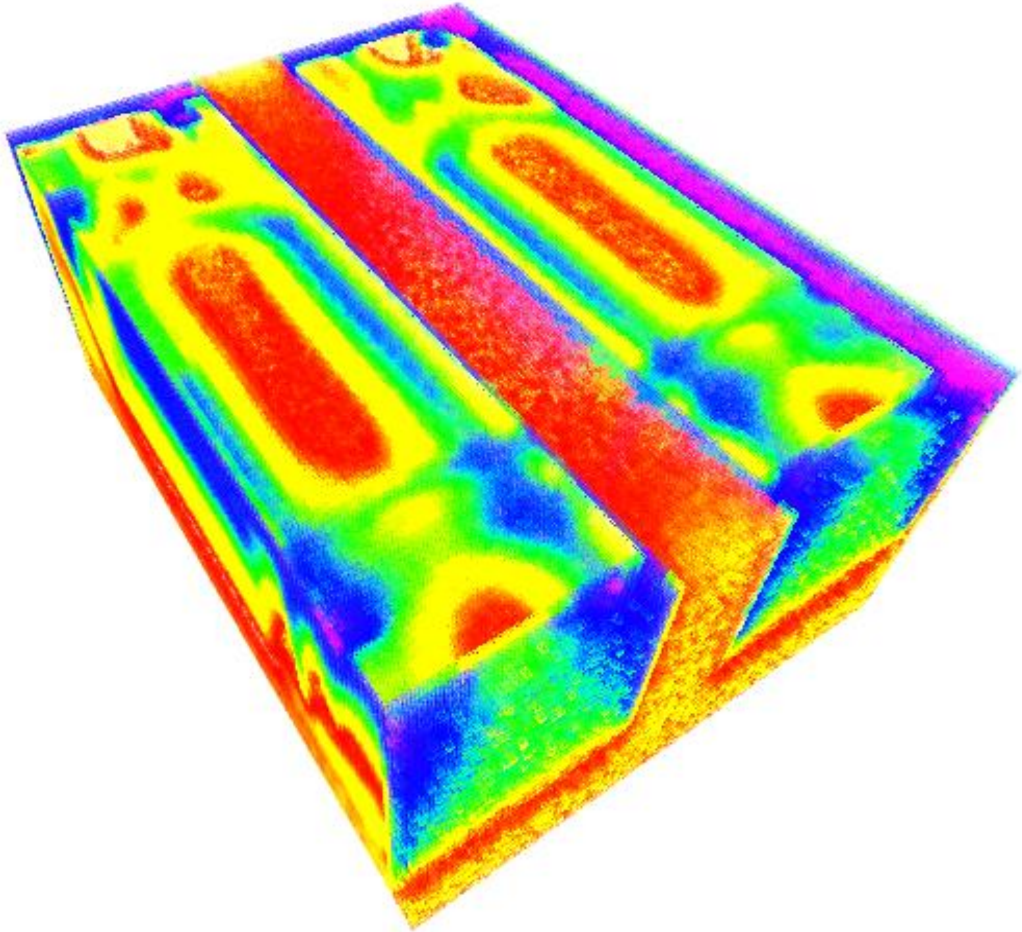
- 3D geometries can be created from multiple 3D data sets.
- In this case a mesh tally file is used to transfer data from an existing code to a format that can be read by PUFFIn.
- A voxel version of PENELOPE is being tested that can run this input.

PUFFIn 3D – Bayer Stellant Dose

1 MeV Photons



10 MeV Electrons



PUFFIn – Summary

- 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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