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PUFFIn Software Modeling for Quality Management

February 2025

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U.S. DEPARTMENT OF ENERGY

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Overview

PUFFIn (PENELOPE User Friendly Fast Interface) was designed as a fast and simple Monte Carlo simulation tool for the transport of photons and electrons, with a primary purpose as a learning and education tool for a broad range of static configurations in the radiation processing industry. Development of the PUFFIn software is funded by the Office of Radiological Security (ORS) within the United States National Nuclear Security Administration (NNSA). PUFFIn helps fill the education and knowledge gaps in the industry, as identified in reports by Fermilab (2017) and the IAEA (2020).

PUFFIn uses the PENELOPE (NEA-2023) physics engine to perform simulations on static configurations. PUFFIn has support for multiple geometry types from simple, single material simulations to full 3D configurations created from CAD input files or images from X-Ray Tomography scans.

PUFFin was designed to be easy for the novice user, it will generate the input and geometry files required by PENLOPE and will display the output plots within the PUFFIn interface. PUFFin is distributed for free but requires a free workshop so users can be adequately trained in its use. Workshops have been presented in the past at Texas A&M university, the Aerial-CRT facility in Strasbourg France and Jakarta Indonesia.

PUFFIn simulations have been validated by 10 MeV ebeam experiments done at Aerial-CRT in France (*Radiation Physics and Chemistry 222 (2024) 111774*). Further user experimental comparisons were made at the medical product hands on workshop at Texas A&M in October 2024.

Workshops

The first hands on workshop was held in Strasbourg, France in August of 2023 at the Aerial facility with around 15 participants. The workshop included training in the use of the PUFFIn software along with experimental validation. Experiments were made for an aluminum wedge, wood, polystyrene, and Ethafoam and compared to PUFFIn simulations for the same materials. The experiments validated the calculations that were made with the PUFFIn simulation.

In September of 2024 a workshop was hosted by the BRIN research agency in Jakarta, Indonesia. This workshop had around 30 participants and by the end of the week, participants were presenting plans on how to use PUFFIn at their facilities and institutions. This was the first onsite workshop and representatives from multiple universities, the government and private industry were in attendance. The advantage of this format is that it allows the workshop to focus on the specific needs of the country and allows for enhanced networking opportunities for users within the country after the completion of the workshop.

A one day overview of the PUFFIn code was presented at the Hands-on regional workshop in Ho Chi Minh City, Viet Nam in December of 2024. This allowed all participants in attendance to hear about the PUFFIn code and its capabilities.

In October of 2024, the first hands on PUFFIn workshop for complex medical products was held at Texas A&M University. This allowed for the comparison between PUFFIn and experimental dosimetry. Over 20 participants were trained in the use of the PUFFIn software. Dosimeters were placed in the simulated products and irradiated with the 10 MeV beam at Texas A&M National Center for Beam Research.

The attendees were divided into 6 teams and three different medical products were analyzed. Presentations were made showing the comparison between simulation and dosimetry for calculating the Dose Uniformity Ratio (DUR). The average difference between PUFFIn and dosimetry was around 5% to 7%. This workshop was confirmed that PUFFIn can be used by novice users to accurately predict dosimetry for complex geometries. It also demonstrated that novice users can be trained and become efficient with the software with a week of training.

PUFFIn for Quality Management

These workshops and corresponding experiments have shown the value of simulation along with dosimetry to assure that the correct DUR has been calculated. This is essential for quality management. It is not expected that simulation will replace dosimetry, but instead it can assure that the dosimeters are placed in the regions of interest.

Simulation will also allow for optimum packaging of a single product and the optimum arrangement of multiple products in an array. By doing this analysis through simulation a significant savings in time and money can be achieved. Once PUFFIn has determined the optimal configuration, dosimetry can be used to verify the final product array.

Since PUFFIn has been shown to compare well with dosimetry, it can be used as a vital tool for quality management. In the past it has been difficult to get an advanced simulation capability into the hands of the users because of costs, time and training needed to run a Monte Carlo simulation. To overcome these obstacles, the PUFFIn software is distributed for free and the training is offered for free. This provides a path to facilitate the training and distribution of the software to anyone who needs a simulation capability, especially those from underserved communities.

PUFFIn can simulate products with different source modalities (Co-60, E-Beam, X-Ray). This will provide an organization the tool it needs to determine the most efficient, cost effective, environmentally friendly and sustainable mode. This will further enhance the quality of operations.

For organizations or countries that do not have an E-Beam or X-ray capability, PUFFIn will allow the simulation of a proposed process to show that products can be adequately sterilized to justify the construction of the needed facility.

Future applications

PUFFIn was initially designed for the sterilization of medical products, but it can be easily adapted for other applications.

One important application is for the simulation of products with a Low Energy Electron Beam (LEEB). A PUFFIn presentation was made at the IAEA meeting in Argentina (April 2024) showing PUFFIn simulations for food/agricultural products using low-energy E-Beam (LEEB). There are significant challenges with dosimetry for low energy applications and PUFFIn can provide needed insight and verification of these dosimeters and how they can be used.

Additional potential applications include cabinet gamma-ray and orthovoltage X-ray irradiators used in research facilities and hospitals. PUFFIn could also be used for applications involving crosslinking of cables, sterilization of soil remediation and water purification. Because PUFFIn uses a general photon, electron Monte Carlo code, it can be applied to any process that involves transport of electrons or photons. The code is applicable to a wide range of energies from a few hundred eV to about 1 Gev.

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