Monte Carlo Study of the External Environment Influence on the Energy Deposited in a Cavity Ionization Chamber

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Abstract.The LNMRI is developing an ionometric determination of the absorbed dose to water for primary standardization in the ^{60}Co beam. For the characterization of the primary standard ionization chamber, it is necessary to carry out experimental measurements and simulations with sufficient statistics to reach the appropriate uncertainty levels. To optimize the CPU time of these simulations, a computational study was carried out with the PENELOPE code on the contribution to the energy deposited in the cavity, coming from the electrons generated in the air outside an ionization chamber. These electrons were discriminated to evaluate their contribution to the energy deposited in the cavity. As a result of the transport of electrons in the air outside of the chamber, a 0.015% change in the energy deposited in the cavity was obtained by an "Recommended simulation", through many simulations, all of them with $2x10^9$ events.

Considering the irrelevance of the influence of charged particles external to the cavity, three simulations were compared. The "detailed simulation", with consumes huge CPU time; the "recommended simulation", that uses the transport parameters recommended in the PENELOPE manual, and the "Optimized simulation", that disregards external electrons. The impact on CPU time was significant. The estimated CPU times for 10^9 events were 80, 3 and 1.5 hours, for the detailed, recommended and optimized simulations, respectively.

1. Introduction

The National Laboratory of Metrology of Ionizing Radiations/Institute of Radioprotection and Dosimetry (LNMRI/IRD), is the Brazilian institute designated by the National Institute of Metrology, Standardization and Industrial Quality (INMETRO), for keeping and disseminating the national standards of the SI units of physical quantities in the area of Ionizing Radiations: Kerma, fluency, dose equivalent, absorbed dose and activity [1]. The LNMRI has an ionization chamber for characterization and absolute determination of the absorbed dose in water.

This work presents results that contribute to the optimization of the CPU time of the simulations performed in the Penetration and ENErgy LOss of Positrons and Electrons (PENELOPE) code, serving as a basis for the future characterization of the CC01 Chamber model.

"The simulation of electron and positron transport is much more difficult than that of photons. The main reason is that the average energy loss of an electron in a single interaction is very small (of the order of a few tens of eV). As a consequence, high-energy electrons suffer a large number of interactions before being effectively absorbed in the medium. The evolution of an electron-photon cascade event is random in nature and can be modeled by Monte Carlo simulation", as described in [2].

This work studies the influence of external air electrons, ionized by photons of the ^{60}Co beam, on the energy deposited in the cavity of an ionization chamber.

2. Metodology

The PENELOPE code performs Monte Carlo simulations for the transport of coupled electron-photon pairs, transporting them in homogeneous material systems bounded by quadric surfaces. The PENELOPE algorithm works in a wide energy range (from a few hundred eV to approximately 1 GeV). The simulation of interactions and the "tracking" of particles is performed following the principles of the Markov process, where future interactions are statistically determined by current events and depend only on immediately preceding events [2]. This tool is being utilized to simulate the external electrons interaction in air and monitor the result of this interactions in the cavity.

2.1. Materials and Simulated Geometry

Two processors were used to simulate the system. An Intel Core i5 (3.2 GHz) and a Core i7 (3.4GHz).

The LNMRI ^{60}Co spectrum was previously determined [3], as shown in Figure 1.

The Figure 2 shows the geometric representation of Ionizing Chamber seen by Z and X axes.

The standardized field characteristics of the LNMRI are [4]: Irradiation field of 10 x 10 cm area; and source-chamber distance of 100 cm. (see Figure 2 and 3).

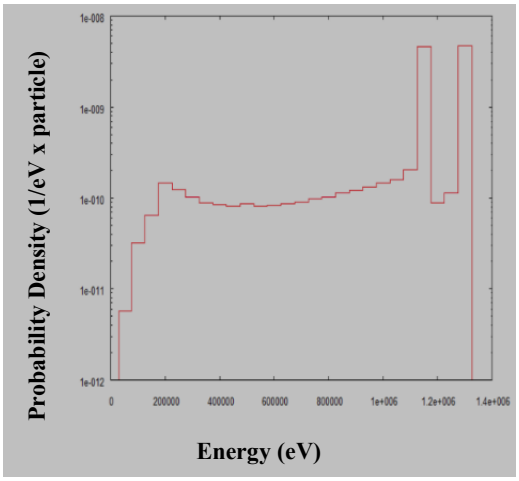

Figure 1 – ^{60}Co Spectrum
100 cm from source

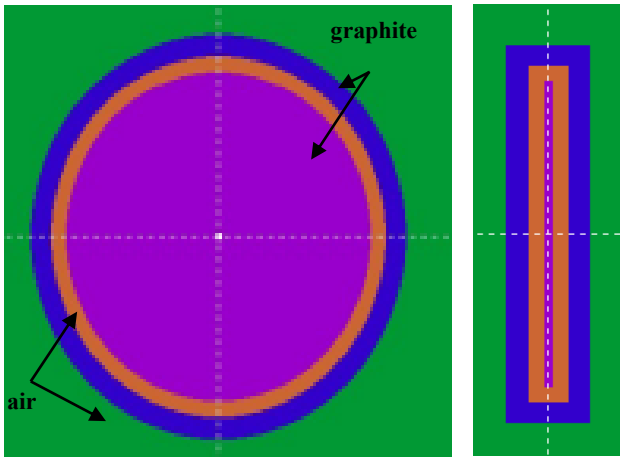

Figure 2 – chamber CH5-1:
a) Z-axis, b) X-axis

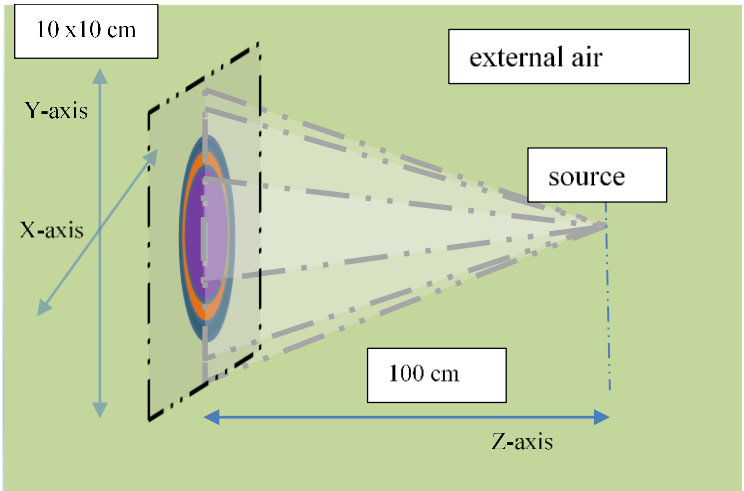

Figure 3 – Standardized field

The chamber CH5-1 is disk shaped and the center of the flat area is the beam incident direction. See details about the chamber shape below (Table 1):

Table 1. Chamber dimensions

electrode diameter	4.1 cm
cavity diameter	4.5 cm
External wall diameter	5.05 cm
electrode thickness	0.1 cm
cavity thickness	0.516 cm
wall thickness	0.283 cm

2.2. Simulation

The chamber response was simulated 104 times (each one with $2x10^9$ events) with different seeds using the "recommended simulation". Transport parameters from table 2 were used.

The fraction of the total energy deposited in the cavity, originated from the interaction of the external electrons, was determined. For this, transport parameters were selected in order to obtain a better cost-benefit between simulation time and accuracy. (see Table 2)

Table 2. Transport parameters

Material	DSmax (cm)	EABS(1,mat) (keV)	EABS(2,mat) (keV)	C1 e C2 (-----)	WCC (keV)	WCR (keV)
Graphite – electrode	0.02	10.0	1.0	0.05	10.0	1.0
Air – inner IC	0.01	10.0	1.0	0.05	10.0	1.0
Graphite –IC wall	0.05	10.0	1.0	0.05	10.0	1.0
Air – external air	1.00	10.0	1.0	0.05	10.0	1.0

Initially, a code was written in Fortran, named "Odisseu.f", which uses the PENELOPE code routines according to the logic diagram presented in the reference literature [2].

The program, Odisseu.f, follows the particles in the specified geometry and stores the energy deposited in the region of interest (cavity), discriminating the origin of the particles. To store the properties of the particles, PENELOPE has a 5-dimensional array. The positions of the ILB store characteristics such as (generation, type of originating particle, originating interaction, etc.), and the ILB(5) is defined by the user to discriminate the particles of interest [2].

The particles of interest are the electrons generated in the air outside the ionization chamber.

To demonstrate the influence of transport parameters on simulation CPU time, three simulations were performed with $1x10^9$ events and the same seeds. The "recommended simulation", that uses Table 2 transport parameters, the PENELOPE simulation by Odisseu program, that uses electron cutoff energy 1.33MeV's, and detailed simulation by selecting WCR= -1, WCC, C1 and C2 =0. In the detailed simulation, the PENELOPE code performs the "detailed transport" of each particle individually instead of using the Mixed Simulation Algorithm. The difference in corrected deposited energy is small, but the CPU time increases considerably.

3. Results

The percentage of energy deposited in the cavity, originating from the interaction of electrons outside the chamber by "recommended simulation" is 0.015%, with associated uncertainty of 1%. Result obtained with $2x10^9$ events and 104 simulations.

Interactions in the chamber cavity from external electrons are bremsstrahlung losses and electron-positron pair annihilation, phenomena that emit photons that, compared to electrons, are more likely to reach the cavity [5].

With the obtained results, we can increase the EABS parameter to locally deposit all the energy of the ionized electrons in the external air, optimizing the simulation CPU time.

For purposes of comparing the deposited energies, table 3 shows the results of the detailed, recommended and Odisseu simulations. The correction factor is applied to discounting the energy arising from electrons interactions outside the chamber, and the corrected energies are compared with that obtained in the Odisseu program.

Table 3. Deposited energies comparison and uncertainties by simulation types.
One standard deviation uncertainties are given in brackets.
(simulation with $1x10^9$ events and the same seeds)

Simulation	Total deposited energy (eV)	External influence (eV)	Correction factor	Corrected energy (eV)
Detailed simulation	2.5268(0.17%)	0.0003(10.2%)	0.9999	2.5265
Recommended Simulation	2.5349(0.16%)	0.0004(13.8%)	0.9998	2.5344
Odisseu Program	2.5239(0.11%)	-------	------	------

The CPU time for performing the detailed simulation is approximately 80 hours, while the "recommended simulation" uses the parameters in Table 2 and requires 3 hours. The simulation optimized by this study carried out on Odisseu.f, takes approximately one and a half hours.

4 Conclusion

The obtained results showed that the influence of the external air electrons is minimal, 0.015% of the total deposited energy. For this determination we can conclude that simulating electrons from outside air, unnecessarily increases CPU time.

Analyzing the table 3 we can see enormous agreement between the simulation of the deposited energy determined through the Odisseu with the detailed simulation

When applying the uncertainties in the energy values arising from the interaction of electrons external to the chamber, even with values close to 10%, there is no significant change in these values.

In the near future, at LNMRI/IRD, a Primary ionization chamber will be geometrically modeled and integrated into Odisseu.f for absolute determination of Absorbed Dose in Water.

To characterize a primary level ionization chamber, it is necessary to know its sensitive volume, and to determine some experimental and simulated factors. These factors correct, among other effects, the attenuation and scattering in the chamber. Therefore, the simulation must consider all the materials of these media and their interaction with the beam particles.

This work demonstrates that, the influence of external air electrons is irrelevant, therefore one can optimize the transport parameters to disregard them without compromising the accuracy of the results, significantly optimizing the CPU time of future simulations.

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