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Penelope simulations of photon calibration fields at the LMIV-IPEN

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Abstract

In this article, the photon spectra of Eu-152 reference photon field of the detection system at LMIV-IPEN is presented, which was calculated by means of Monte Carlo simulations by using the computer transport code Penelope. The contributions from scattered photons to the spectra of the fields have been determined with regard to the quantities photon fluence. The mean photon energies calculated with respect to the mentioned quantity are listed. Differences in the design of the sources and their influence on the spectra are discussed. The dependence of the scattered photon component from the energy was examined by feeding the Penelope code with monoenergetic photons of different energies.

Keywords: Monte Carlo simulation; PENELOPE; Calibration; NaI (Tl) detector

1. Introduction

Thallium-doped Sodium Iodide (NaI(Tl)) detectors are capable of measuring the energy spectra of gamma particles (photons) emitted by radioactive nuclei with an energy resolution of a few percent. As the gamma particles emitted during the decay of specific radioactive elements have very well-defined energies, the measurement of specific energy gammas indicates what radioactive nuclei are decaying. The experimental set-up, however, requires a software calibration that converts the measured spectra versus “bin number” into the spectra versus the energy in MeV.[1]

Information about scattered photons is only accessible through an investigation of spectra by performing Monte Carlos simulations; the photon spectra at the reference point of the calibration facility will be calculated using the Monte Carlo transport code Penelope.

On PENELOPE a code system for Monte Carlo simulation, the geometry package called PENGEOM permits the generation of random electron-photon showers in material systems consisting of homogeneous bodies limited by quadric surfaces, i.e., planes, spheres, cylinders, etc.[2]

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The count rates or areas of individual peaks in the spectrum of measurement are related to the amount of radioactive material deposited in the body by a factor of efficiency. This efficiency depends on several factors including the intrinsic efficiency of the detector, the geometry of the measurement (solid angle, position, shape of the individual to be measured and the radionuclide distribution in the body) and the properties of the nuclide.

At the In Vivo Monitoring Laboratory (LMIV) of the Energy and Nuclear Research Institute (IPEN/CNEN-SP) whole-body measurements are routinely carried out in workers of the IPEN, visitors, trainees and contract workers. The frequency of measurements is established by the Radioprotection Service (SRP) and the Dose Calculation Group of IPEN. The direct measurement of body or organ activity is commonly used for radionuclides that emit radiation with energies greater than 100 keV.

We will use the Eu-152, which emits multiple gamma rays that range in energy from about 120 keV to about 1460 keV.

2. Materials and methods

The detection system of the LMIV consists of one NaI (Tl) detector (7.2 x 7.2 cm) for thyroid measurements, connected to a Ortec 556 high-voltage supply, a Canberra 2022 amplifier and an Ortec 920 Ethernim 16-input multichannel buffer. The walls of the shielded room consist of 130 mm-thick steel sheet lined with 5 mm of lead and 5 mm of copper. The internal dimensions are 2.6 m x 1.7 m x 1.85 m, with air filtration and maintained at a temperature of 25ºC.

To perform the simulation, we need the geometry file, the library containing tables of cross section with information such as chemical composition, density of mass and mean excitation of materials that will be used, the configuration file where we set parameters as the source spectrum, simulation time, number particle simulation, the output data and an executable file.

One important consideration is the efficiency with which photons may be detected. This can be defined in a number of different ways, and is categorized into absolute and intrinsic efficiency values. [3]

The absolute efficiency (ε_{ABS}) was determined by the ratio of particle counts that arrived and interacted in the detector sensitive volume and the particles emitted by the source and the intrinsic efficiency (ε_{INT}) by the ratio between the number of interacting particles and the number of incident particles in the detector.

The average of the energy deposited in the detector is the sum of contributions of energy e_i from each particle N generated,

$$\overline{E_{dep}} = \frac{1}{N}\sum_{i=1}^{N} e_i \qquad (1)$$

And the statistical uncertainty of the average energy already being in the results is given by, [4]

$$\sigma^2(\overline{E}) = \frac{\sigma^2(E)}{N} \approx \frac{1}{N}\left[\frac{1}{N}\sum_{i=1}^{N} e_i^2 - \overline{E}^2\right] \quad . \qquad (2)$$

2.1. Geometry and materials

It was constructed a simplified geometry of the detector of LMIV which has a cylindrical shape with a radius equal to 3.6 cm and 25.7 cm in height and the cylindrical wrapping of aluminum with a radius equal to 3.96 cm and 27.92 cm in height. The model of the simulator used in the experimental calibration of the detector are consisting of a acrylic cylinder with 14.9 cm in height and 14.9 cm in diameter and the Eu-152 source which has a parallelepiped shape and is located inside the simulator. The distance between the detector NaI(Tl) and the simulator was 38.9 cm according with Fig.3c.

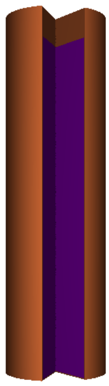

Figure 1. Geometry in 3D of the detector used: the orange region represents the aluminum hood and the purple region represents the sodium iodide

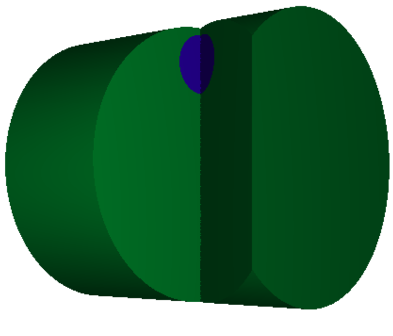

Figure 2. Geometry in 3D of the model of the simulator used

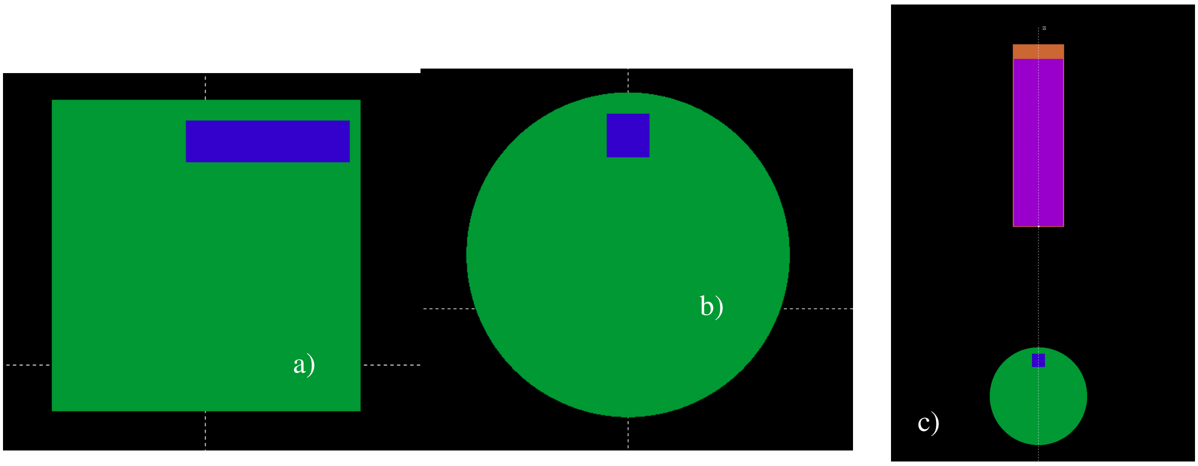

Figure 3: Geometry in 2D of the model of the simulator used: the green region represents the acrylic and the blue region represents the source of Eu-152; a) zoom xz plane, b) zoom yz plane, c) simulator and detector position

3. Results and discussion

The simulation results were obtained using the existing code PENELOPE.

Were simulated nearly 10^8 particles and the values of efficiency were ε_{INT} = 5.093.10^{-05} and ε_{ABS} =9.219.10^{-03} for an average uncertainty of the calculation performed by the subprogram penEasy of PENELOPE was 1.252%.

The simulated spectra of Eu-152 are shown in Fig. 4 that represents the deposited energy distribution.

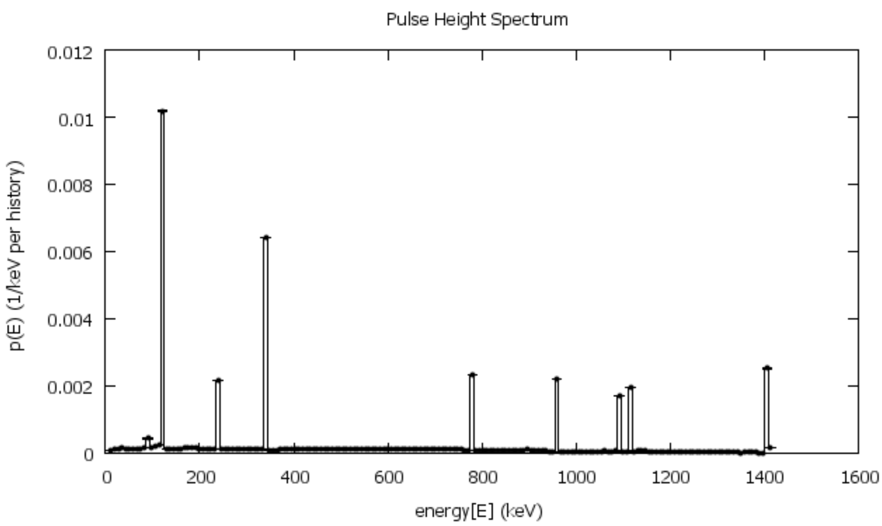

Figure 4. Simulated spectra of energy deposited in the NaI(Tl) detector.

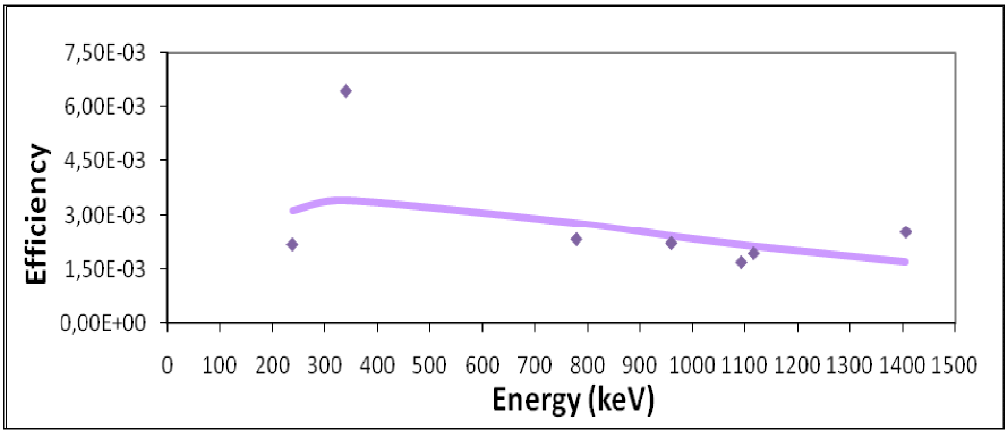

Figure 5. Simulated efficiency as a function of photon middle energy.

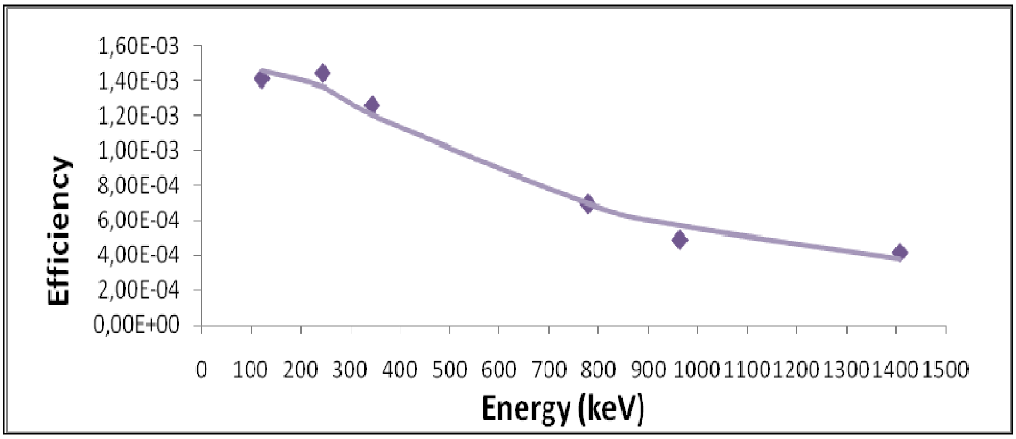

Figure 6. Experimental efficiency as a function of photon middle energy.

Analyzing the efficiency graphs in Fig.5 and Fig. 6, it can be noted that the simulated efficiency is greater than the experimental efficiency due in the simulation is not considered losses caused by electronic of detector, that is, the detection efficiency of NaI (Tl) was not considered in the calculations. In the graphs of efficiency versus energy, the points are the experimentally data and the simulation data obtained and the curves represent a fit by ordinary least squares.

For the next simulation is performed to detect the efficiency of the detector NaI (Tl) for the model to be validated. The curve of Fig 5 is almost two times higher than the curve of Fig 6.

4. References

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