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Dose calculation using a numerical method based on Haar wavelets integration

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ABSTRACT

This paper deals with the calculation of the absorbed dose in an irradiation cell of gamma rays. Direct measurement and simulation have shown that they are expensive and time consuming. An alternative to these two operations is numerical methods, a quick and efficient way can furnish an estimation of the absorbed dose by giving an approximation of the photon flux at a specific point of space. To validate the numerical integration method based on the Haar wavelet for absorbed dose estimation, a study with many configurations was performed. The obtained results with the Haar wavelet method showed a very good agreement with the simulation highlighting good efficacy and acceptable accuracy.

1. Introduction

The dose distribution study is needed for applications in gamma ray irradiators. The direct dose measurement needs adequate equipment such as dosimeters and the reading time is relatively important to get satisfying results. An alternative to direct measurement is Monte Carlo simulation using CERN code GEANT4 [1] validated in previous works [2–5]. The increasing complexity related to shielding geometries associated with inhomogeneous materials and source makes Monte Carlo method harder to implement and increasingly computer-time intensive. The required programming capabilities make it impractical for non-experts especially when dealing with complex or multi-parameter design. Numerical methods become a suitable and attractive alternative as they can be used for fast estimation of the absorbed dose. The success of a numerical method is determined by its ability to get the required precision in the shortest time.

Haar wavelets [6,7] integration method is presented in this work and used to study dose distribution in irradiated product in the Tunisian irradiation facility. After a general description of the irradiation cell we develop the photon flux expression for a cylindrical source. Then the Haar wavelets integration method is detailed and a description of the used Monte Carlo simulation is given. A comparison between Haar wavelet method results and Monte Carlo simulation is presented and discussed in the last section.

2. The Tunisian gamma irradiation facility

The Tunisian gamma irradiator SV68 consists of a source and a source carrier. The total activity was 1.820 ± 0.18 PBq by the time the measurements were made. The source is formed by 8 radioactive pencils encapsulated in steel and zirconium to mitigate the electrons emitted by disintegration. The total length of a capsule is 450 mm and its diameter is 9.7 mm. The installation is equipped with a telescopic source holder. The upper source holder contains 4 pencils on a diameter of 140 mm and the bottom source holder contains the other 4 pencils on a diameter of 78 mm as shown in Fig. 1. This telescopic configuration gives a linear source of 900 mm length by superposing the upper and the lower pencils placed at a height of 139 mm from the floor. The source holder contains also 18 free units allowing permutation of the distribution or reloading of the source.

3. Study of the gamma ray flux from a cylindrical source

The dose rate $\dot{D}$ and the photon flux ϕ in a gamma ray irradiation cell [8] are related by:

$$\dot{D}(Gy/s) = \mu_{en}(\mathrm{cm}^2\,\mathrm{g}^{-1}) \times E(\mathrm{MeV}) \times \phi \tag{1}$$

where μ_{en} is the mass absorption coefficient of the medium and E is the gamma ray energy. In order to study the dose rate

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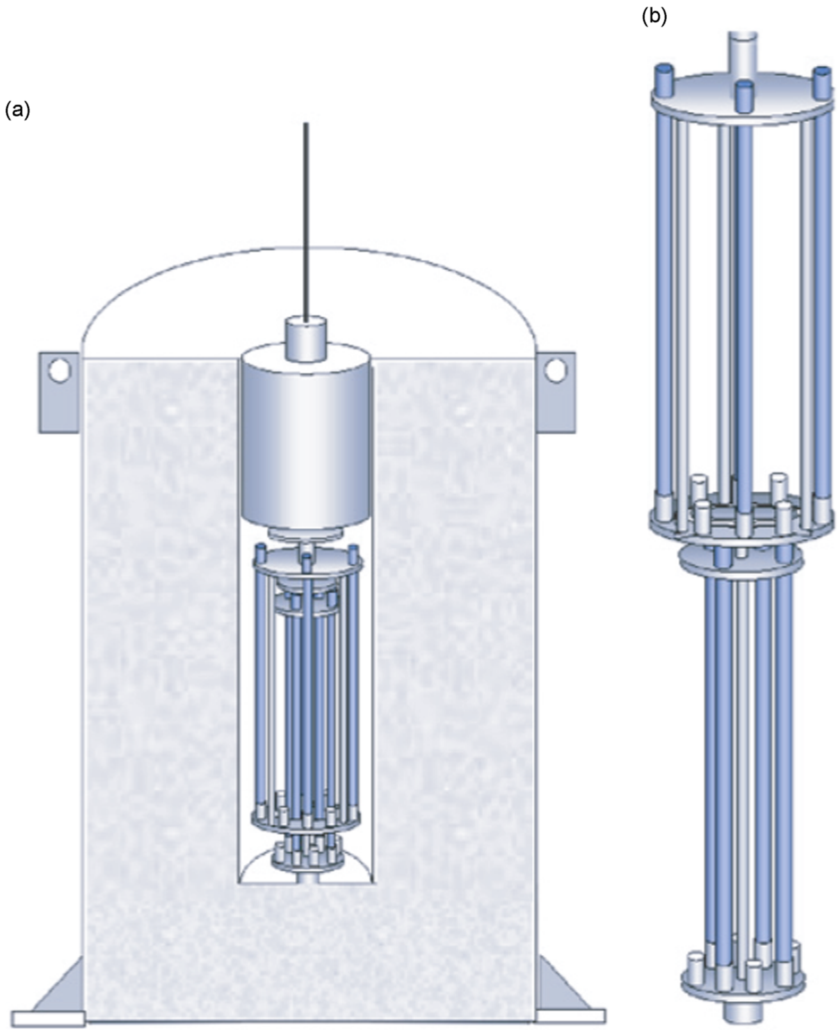

Fig. 1. (a) The telescopic source holder in storage position. (b) The 8 ^{60}Co pencils in the source holder in irradiation position.

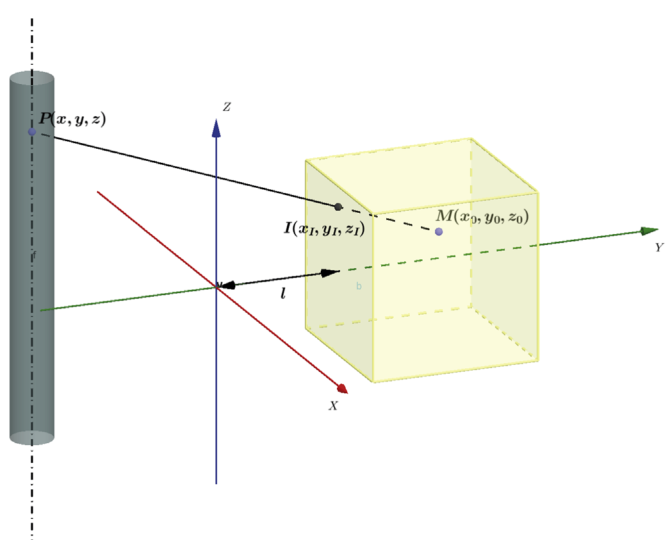

Fig. 2. A cylindrical source and a box shaped product in cartesian coordinates.

distribution in the gamma ray irradiation cell, we can study the photon flux. A thin cylindrical gamma ray source characterized by a total activity A emitting photons in isotropic directions is considered as a set of individual punctual sources placed on his axis. The flow of photons emitted from the individual point sources P and arriving up to an external point M is calculated according to Z-axis by the formula [9]:

$$\phi(M) = \frac{1}{4\pi}\int_{-h/2}^{h/2} \exp\left(-\int_P^M \mu\, dl\right)\frac{\rho(z)}{PM^2}\, dz \tag{2}$$

where h is the source height, ρ is the activity density at point P and μ is the linear attenuation coefficient. Fig. (2) shows the cylindrical source axis, an individual point-like source $P(x, y, z)$ and an external point $M(x_0, y_0, z_0)$ placed into a box shaped product. Assuming that the source has a uniform activity density ρ_0, the flux (2) can be written as:

$$\phi(M) = \frac{\rho_0}{4\pi}\int_{-h/2}^{h/2} \exp\left(-\int_P^M \mu\, dl\right)\frac{dz}{(x_0-x)^2+(y_0-y)^2+(z_0-z)^2} \tag{3}$$

3.1. First configuration: without product

In this case, the linear attenuation coefficient μ_0 is constant. The attenuation term is written as:

$$\exp\left(-\int_P^M \mu_0\, dl\right) = \exp(-\mu_0 PM) = \exp\left(-\mu_0\sqrt{(x_0-x)^2+(y_0-y)^2+(z_0-z)^2}\right) \tag{4}$$