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ScienceDirect
Applied Radiation and Isotopes 64 (2006) 1370–1374
Applied Radiation and Isotopes
www.elsevier.com/locate/apradiso

Monte Carlo calculations of calibration and geometry correction factors of a radionuclide calibrator

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Abstract

The activity of radioactive pharmaceuticals administered to patients in nuclear medicine is usually determined using well-type high-pressure ionization chambers. For the Bqmeter chamber (Consortium BQM, Czech Republic) a Monte Carlo model was created using the MCNP4C2 code. Basic chamber characteristics for two sample containers of various geometry (a vial and an ampoule) were calculated and compared with measurements. As the pharmaceuticals are often measured in various syringes, the chamber response for samples in syringes was also studied.

Keywords: Monte Carlo calculation; Radionuclide calibrator; Response function; Calibration factor

1. Introduction

The activity of radiopharmaceuticals administered to patients in nuclear medicine (NM) is usually determined using a so-called radionuclide calibrator or activimeter, i.e. a well-type ionization chamber filled with argon at a pressure of several MPa. One of the most frequently used (37%) radionuclide calibrators in the Czech Republic is the Bqmeter, manufactured by Consortium BQM, Czech Republic.

In NM departments, the activity of samples of various volumes is measured in vials or syringes. However, not only the geometry (dimensions, shape, material) of the syringes used, but also the position of a syringe in the chamber well varies. Moreover, ampoules are used for calibration in the Czech Metrology Institute, which is responsible for accuracy checks of radionuclide calibrators in the country. In order to reduce the work with radioactive material and determine suitable calibration factors or geometry correction factors for various containers and solution volumes, a Monte Carlo model of the Bqmeter chamber was created using the MCNP4C2 transport code (Briesmeister, 2000).

The chamber characteristics were studied for two particular types of vials or ampoules. The energy-dependent response function, calibration factors for several radionuclides, variation of the response with increasing volume of the source and the effect of source displacement on the response were calculated and compared with measurements. However, as standard ampoule geometry is rarely used in NM measurements, the majority of the chamber characteristics presented in this paper is for the vial geometry used in NM applications. For syringes, the variations of the chamber response with various syringe positions as well as syringe geometry, without and with various needles, were studied.

2. Monte Carlo model of the Bqmeter chamber

2.1. Geometry parameters

The Bqmeter is a well-type high-pressure ionization chamber with steel walls and aluminium electrodes, filled with argon to a pressure of 0.35 MPa, see Fig. 1. Its active volume is given by two concentric cylinders of 4.5 and 20.2 cm in diameters and 21.2 and 27.4 cm in height, respectively. The standard position for measurements is placed on the cylinder axis, with the sample centre

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doi:10.1016/j.apradiso.2006.02.047

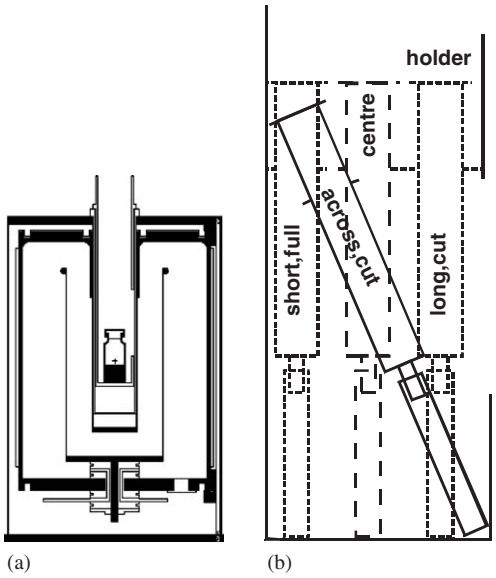

Fig. 1. Geometry parameters: (a) Bqmeter ionization chamber with a vial and (b) syringe positions within the holder.

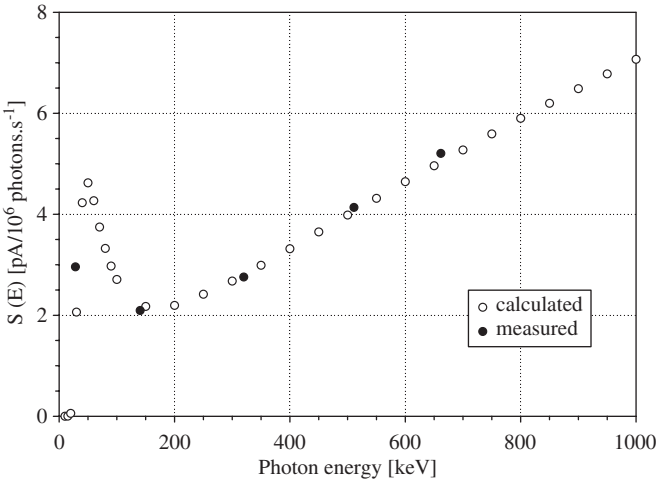

Fig. 2. Response function $S(E)$ versus photon energy E for vial geometry.

4.8 cm above the bottom of the inner cylinder. The model uses the dimensions and materials given by the chamber drawings.

The chamber response was studied for two standard borosilicate glass containers: a 1-ml ampoule and 10-ml vial with standard volumes of 1 and 5 ml, respectively. In addition, two types of 2-ml volume syringes, produced by B. Braun AG., Melsungen (Germany) and Chirana T. Injecta, a.s. (Slovak Republic), both with and without needles, were used for the chamber response study. The needles used were Sterican black 0.7×40 mm and orange 0.5×16 mm (B. Braun AG., Melsungen, Germany) and Terumo Neolus black 0.7×40 mm and purple 0.55×25 mm (Terumo Europe N.V., Belgium). The calculated response values were compared with measured ones for several radionuclides.

2.2. Parameters of Monte Carlo calculations

Compositions and densities of construction materials were taken from the tables of Gray (1972). The chemical compositions of the radioactive solutions were used as given by the manufacturer. For response calculations of monoenergetic photons, the material of the sample was assumed to be water.

In the model, the source geometry is a cylinder of the size of the standard container volume. When calculating the response as a function of sample volume, the cylinder height was changed.

For starting the calculations, the energies of the photons for each radionuclide were inserted with a discrete distribution into an MCNP4C2-input file using data from the Table of Isotopes (Firestone, 1996). The minimum energy for a generated photon to contribute to the chamber response was defined considering the response function to be calculated, see Fig. 2. Photons below this energy were omitted, in order to simplify and speed up the calculation. All photons started with a default statistical weight and directions uniformly distributed in a solid angle of 4π.

A detailed photon treatment (Briesmeister, 2000) was used over the whole energy range during their interaction history. For electrons, a Thick Target Bremsstrahlung approximation (Briesmeister, 2000) was used. The lower-energy cut-off was set to 1 keV for both, photon and electron transport. For photon and electron interactions, the data libraries supplied with the MCNP4C2 code were used.

The computation time was limited to values necessary to obtain results with a relative statistical uncertainty smaller than 0.05%.

2.3. Calculation of ionization current

The ionization current, I, produced by a source emitting N photons per second of a given energy was calculated by the formula:

$$I = E_{\mathrm{d}} N e / W_{\mathrm{i}}, \tag{1}$$

where E_{d} is the mean energy per emitted photon deposited in the active chamber volume (treated as a single region), e is the electron charge and W_{i} is the average energy for creating an ion pair in argon. A W_{i} value of 25.94 eV was adopted, which was obtained in previous calculations (Olšovcová, 2004). This value is within the limits of (23.8–26.4) eV, the experimental values cited for argon in the ICRU Report 31 (1979). The mean deposited energy, E_d, was determined using tally 6, a routine of the MCNP4C2 code, which averaged over a cell in the chamber volume.