Nuclear Instruments and Methods in Physics Research A 834 (2016) 10–15

Contents lists available at ScienceDirect

Nuclear Instruments and Methods in Physics Research A

journal homepage: www.elsevier.com/locate/nima

Technical notes

A new approach for the evaluation of the effective electrode spacing in spherical ion chambers

Ahmed M. Maghraby [a,*], Mohammed Shqair [b]

[a] National Institute of Standards (NIS), Ionizing Radiation Metrology Laboratory, Tersa Street 12211, Giza P.O. Box: 136, Egypt
[b] Physics Department, Faculty of Science and Humanities, Sattam Bin Abdul Aziz University, Alkharj, Saudi Arabia

ARTICLE INFO

Article history:
Received 1 February 2016
Received in revised form
26 July 2016
Accepted 30 July 2016
Available online 30 July 2016

Keywords:
Calculation
Gamma radiation
Measurement
Method of characteristics
Radiation dose

ABSTRACT

Proper determination of the effective electrode spacing (d_{eff}) of an ion chamber ensures proper determination of its collection efficiency either in continuous or in pulsed radiation in addition to the proper evaluation of the transit time. Boag's method for the determination of d_{eff} assumes the spherical shape of the internal electrode of the spherical ion chambers which is not always true, except for some cases, its common shape is cylindrical. Current work provides a new approach for the evaluation of the effective electrode spacing in spherical ion chambers considering the cylindrical shape of the internal electrode. Results indicated that d_{eff} values obtained through current work are less than those obtained using Boag's method by factors ranging from 12.1% to 26.9%. Current method also impacts the numerically evaluated collection efficiency (f) where values obtained differ by factors up to 3% at low potential (V) values while at high V values minor differences were noticed. Additionally, impacts on the evaluation of the transit time ($\boldsymbol{\tau_i}$) were obtained. It is concluded that approximating the internal electrode as a sphere may result in false values of d_{eff}, f, and $\boldsymbol{\tau_i}$.

1. Introduction

Evaluation of radiation doses using ion chambers is based on the determination of ionization in a certain volume of a gas [1–4]. Use of ion chambers in various activities is usually associated in accurate evaluation of certain quantities of ionizing radiation which involves the use of a number of correction factors in order to get correct and reliable readings [5–8].

Usually, the measured current is lower than the expected one due to incomplete charge collection which is attributed to initial recombination, volume recombination, and back-diffusion to electrodes [7–15]. Initial recombination is independent of radiation dose or dose rate, this process occurs when the positive and negative ions formed in the same charged-particle track meet and recombine [6,16]. It is highly probable in high LET while in cases of low LET radiation volume recombination dominates. Additionally, loss of ions due to diffusion is independent of radiation dose rate and considers the back diffusion of positive and negative ions to anode and cathode respectively [17–21].

Numerical evaluation of volume recombination encounters the use of the effective electrode spacing of the ion chamber as will be discussed in the following section. In plane parallel ionization chambers, effective electrode spacing represents the geometrical separation between the two parallel electrodes, while in cylindrical and spherical ion chambers it should be estimated through equations involving the radii of the internal and external electrodes [22–25].

Boag has presented a formula for the evaluation of the effective electrode spacing in spherical ion chambers assuming the spherical shape of the internal electrode [24]. Although this is true in some cases [25], in most cases the internal electrode is cylindrical in shape [24,26]. Current work provides a new trial for more accurate evaluation of the effective electrode spacing of the spherical ion chambers of cylindrical inner electrodes.

2. Materials and methods

2.1. Theoretical background

The collection efficiency of an ion chamber (f) can be evaluated according to the following relation:

$$f = f_i f_v f_d \quad (1)$$

where f_i , f_v , and f_d are collection efficiencies considering contributions of initial recombination, volume recombination, and back-diffusion loss respectively [7,8,27,28].

For continuous radiation, and according to Boag's treatment of

* Corresponding author.
E-mail address: maghrabism@yahoo.com (A.M. Maghraby).

http://dx.doi.org/10.1016/j.nima.2016.07.055
0168-9002/© 2016 Elsevier B.V. All rights reserved.

Mie's theory [24], the collection efficiency f_v can be obtained from the following formula

$$f_v = 1 - \eta^2, \tag{2}$$

where

$$\eta^2 = \frac{(M^2/6).\, d^4.\, \dot{q}}{V^2}, \tag{3}$$

And d is the effective electrode spacing, M is an empirical constant depending on the nature of the gas ($1.99 \times 10^7 \pm 1.7\%$ V m$^{1/2}$ s$^{1/2}$ C$^{-1/2}$ for air), and $\dot{q}$ denotes to the rate of charge collected per unit volume of the gas (Cm^{-3} s^{-1}), and V is the polarizing potential [21,27].

In case of pulsed radiation, f_v can be calculated using the following formula

$$f_v = \frac{\gamma}{\exp(\gamma) - 1}, \tag{4}$$

where

$$\gamma = \frac{\mu.\, d^2 q}{V}, \tag{5}$$

$$\mu = \frac{\alpha / e}{k_1 + k_2}, \tag{6}$$

where q is the initial charge density per pulse of the positive and negative ions collected by the ion chamber during irradiation, α is the ion recombination coefficient, e is the charge of electron, k_1 is the mobility of positive ions, k_2 is the mobility of the negative ions, and μ depends on the lifetime of ions in the chamber, in case of air it equals to 3.02×10^{10} mC^{-1} V [29].

The effective electrode spacing for the spherical chambers (d) can be calculated using the following formula [21,24,27,29]:

$$d_{Sph} = \frac{(a-b)}{\sqrt{3}}.\left[\frac{a}{b} + 1 + \frac{b}{a}\right]^{\frac{1}{2}}, \tag{7}$$

where a is the internal radius of the outer electrode and b is the external radius of the inner electrode, Fig. 1 represents a schematic representation of a spherical ion chamber.

On the other hand, the effective electrode spacing for the cylindrical chambers (d) can be evaluated using the following formula [24]:

$$d_{Cyl} = (a-b).\sqrt{\frac{(a+b)}{(a-b)}.\frac{\ln\left(\frac{a}{b}\right)}{2}}, \tag{8}$$

2.2. A new approach

Eq. (7) assumes the spherical ion chamber electrodes as two concentric spheres which is not the general case, usually the internal electrode is cylindrical in shape, and hence the use of Eq. (7) may result in some differences when evaluating the effective electrode spacing of the spherical ion chamber.

Instead, the chamber volume can be regarded as two hemispheres as shown in Fig. 2A. The effective electrode spacing of the upper hemisphere can be evaluated directly from Eq. (7) as the internal electrode can be regarded as a hemisphere. The lower hemisphere where the inner electrode is obviously cylindrical can be regarded as a number (m) of coaxial hemispherical segments of equal height (thickness), each one can be considered as a cylinder as shown in Fig. 2B–D, and the effective electrode spacing for each cylinder can be evaluated from Eq. (8). The total effective electrode

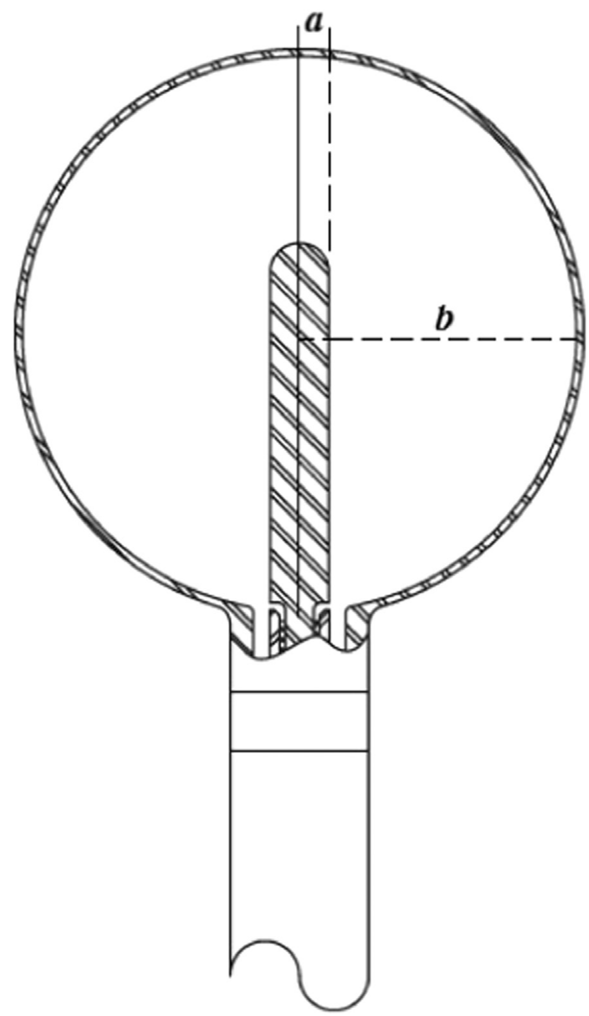

Fig. 1. Schematic representation of an ion chamber: 'a' is the radius of the internal electrode; 'b' is the radius of the external electrode.

spacing (d_{eff}) for the spherical ion chamber is the weighted average of the corresponding values obtained for the upper hemisphere (d_{Sph}) and the second one (d_{Cyl}) which is obtained by approximating the lower hemisphere as multiple coaxial cylinders:

$$d_{eff} = R_1.\, d_{Sph} + R_2.\, d_{Cyl} \tag{9}$$

where R_1 and R_2 comprising the fractional ratios of the spherical and cylindrical portions with respect to the total chamber volume, hence $R_1 + R_2 = 1$, however, for simplicity we assume a special case where $R_1 = R_2$, therefore:

$$d_{eff} = \frac{d_{Sph} + d_{Cyl}}{2}, \tag{10}$$

And d_{Cyl} can be estimated through the following relation:

$$d_{Cyl} = \sum_{i=1}^{m} w_i.\, d_{Cyl}.\,(a_i), \tag{11}$$

where w_i is the weight factor for a certain spherical segment (a_i) representing the ratio of the volume of this spherical segment (v_i) to the volume of the lower hemisphere as a whole (v_h):

$$w_i = \frac{v_i}{v_h} \tag{12}$$

As shown in Fig. 2B:2D, the larger the number of spherical segments the better simulation of the hemispherical volume. v_i