Monte–Carlo simulation of wall correction factor of graphite cavity ionisation chamber

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Abstract: The purpose of this article is to discuss the method of determining the wall correction factor of graphite cavity ionisation chamber. The method is the ‘equal effect wall thickness’ simulation and direct calculation of the wall correction factor of the std10cm\textsuperscript{3} and std30cm\textsuperscript{3} spherical graphite cavity ionisation chamber in the national air-specific kinetic energy reference group (National Institute of Standards and Technology NIST), respectively, in the NIST10cm\textsuperscript{3} and NIST30cm\textsuperscript{3} spherical graphite cavity ionisation chamber. The calculated results are in agreement with the values released by NIST in 0.1%. Conclusions of the equivalent wall thickness simulation method and the direct calculation simulation method meet each other’s requirements, which provide a new idea for the determination of wall correction factor.

1 Introduction

As the output of the international unit system, the ratio of air to kinetic energy is one of the most important physical quantities in the measurement of ionising radiation. It describes how much energy is transmitted to the physical amount of the direct ionised particles when the indirectly ionised particles interact with the substance. ICRU published the 60th report clearly which will be included in the basic ionising radiation quantities and units of the column, the unit of J/kg, the proper name Gy [1]. According to the Bragg–Gray theory, the graphite ionisation chamber for \textsuperscript{60}Co or \textsuperscript{137}Cs gamma ray air kerma measurement, modified \(\kappa_{\text{wall}}\) on weakening and scattering photons in the ionisation chamber in the wall is one of the most important modification projects, its accuracy of measurement results is an important prerequisite for absolute measurement of air kerma [2, 3] (Fig. 1).

The well-known traditional extrapolation method, which uses the ‘geometric thickness’ of the ionisation chamber wall to extrapolate linearly to zero-thickness test methods, is due to the complex physical process of ray passing through the ionisation chamber wall, extrapolating ‘geometry thickness’. Only when the parallel linear beam enters the wall of the ionisation chamber can relatively reflect its attenuation [4, 5]. For cylindrical and spherical ionisation chambers, using ‘geometrical thickness’ to describe their weakening, ionisation chamber wall thickness values will occur too low, leading to an increase in the error of the extra-thickness \(\kappa_{\text{wall}}\) value [6]. In this regard, we use the ‘equivalent wall thickness’ extrapolation method to obtain room wall corrections [7]. However, taking into account the difficulties and uncertainties of the experimental method, the same procedure as the experimental method was used to simulate the wall correction factors for \textsuperscript{60}Co or \textsuperscript{137}Cs gamma rays in the NIST10cm\textsuperscript{3} and NIST30cm\textsuperscript{3} spherical graphite chambers, and the Monte–Carlo simulation was used again. The method of direct calculation validates the results of the resulting wall correction factor [8] (Table 1).

2 Equivalent thickness of Monte–Carlo simulation

A formula for calculating the equivalent wall thickness of a spherical graphite cavity ionisation chamber is half of the total wall volume/total cross-sectional area ratio.

\[ V_R = \frac{4\pi R^3}{3} \]  
\[ V_t = \frac{4\pi r^3}{3} \]  
\[ V_{\text{wall}} = V_R - V_t \]  
\[ V_{\text{sec}} = \pi R^2 \]  
\[ \varepsilon = \frac{V_{\text{wall}}}{V_{\text{sec}}} \]

Notes: The \(R\) is the outer diameter of the ionisation chamber, the \(r\) is the inner diameter, and the epsilon is the equivalent wall thickness.

The Monte–Carlo method simulates, tracks, and records a large number of physical particles, enabling the reproduction of real physical processes. Solve the problem of particle transport on an electronic computer, that is, the source distribution sampling process, the random transportation process of the particle position, energy, and direction of motion, and the process of recording the particle transportation to complete the simulation of the entire physical process, and finally get the air kerma and the energy absorbed. By changing the parameters of an ionising radiation source, we can get the energy absorbed with a certain degree of accuracy by changing the parameters of an ionising radiation source, we can get the energy absorbed with a certain degree of accuracy.
The MC method determines the wall correction factor \( k_{\text{wall}} \) of the ionisation chamber, which has the advantages of high accuracy and science. Especially, as long as we know the basic parameters of the ionisation chamber, we can use MC to calculate the wall correction factor \( k_{\text{wall}} \) value [10]. This simulation is aimed at the study of wall correction factors for NIST standard 10 and 30 cm\(^3\) spherical graphite cavity ionisation chamber. The selected \(^{137}\text{Cs}\) or \(^{60}\text{Co}\) gamma radiation source is selected and placed at the centre 100 cm of the distance ionisation chamber. The radii of the radiation field is 25 cm. The simplified model of ionisation chamber used for calculating the energy spectrum of gamma ray incident energy using \(^{137}\text{Cs}\) or \(^{60}\text{Co}\) radiation sources is illustrated as follows [11].

In keeping with other conditions unchanged, the ionisation followed by additional outdoor different thickness of globe-shaped graphite wall sleeve (graphite cap for std10 add 1 mm for std30 add 2 mm), simulation of ionisation chamber conditions under different wall thickness for gamma rays [13] (Fig. 2).

According to the above effective wall thickness values and the simulated dose results, the extrapolation formula is obtained:

\[
K = A_e + B_e \times T_e \quad (A_e, B_e \text{ are fitted by the equivalent wall thickness dose fitting})
\]

\[
K_{\text{att}} = k_0 / k_v \quad (7)
\]

\(K_0\) is the dose of extrapolation to 0; \(K_V\) is the dose under the condition of no graphite cap (Table 2).

Attenuation factor correction of the beam will only have an excessive correction if it is represented by \(K_{\text{att}}\). Since the photonic ion interacts with the ionisation chamber wall to produce ionised electrons that cause the ionisation of the cavity, the photon only passes through a certain distance of the cavity wall, so the average electron must be considered. The location of the correction \(K_{\text{cep}}\), so get \(K_{\text{wall}} = K_{\text{att}} \times K_{\text{cep}}\).

Referring to Wyckolf's theory, the average energy generated by ionised electrons corresponds to the equivalent mass wall thickness, \(K_{\text{cep}}\) is 0.997 for \(^{60}\text{Co}\) ray source, and \(K_{\text{cep}}\) is 0.995 for \(^{137}\text{Cs}\) ray source [14] (Fig. 3).

### 3 Monte–Carlo direct calculation simulation

The EGSnrc software package was used to simulate the electron-photon coupling transport process. When using the EGSnrc program to simulate the wall correction factor of the spherical...
graphite cavity chamber, a user program is programmed to specify the relevant geometric parameters to achieve a detailed description of the shape and size of the ionisation chamber and the division of the cavity region, and at the same time radiation. The description of the source specifies the interactions that may occur and the history of each particle (including photons, electrons). The initialisation of the subroutines and main parameters used in this simulation calculation is as follows.

(i) CA VSPhrc user program. Using this subroutine to call the main program, calculations of various dosimetry values in a spherical graphite cavity chamber are achieved. These dosimetry quantities include $k_{at}$, $K_{sc}$, $K_{wall}$, and ionisation chamber absorbed doses.

(ii) Source sampling. In the CA VSPhrc subroutine, there are two types of source models: parallel beam and point source. The relative position and angle between the input source and the ionisation chamber are required, and the radiation source field size is set. It is believed that almost 30% of the photons in gamma rays come from scattered photons, and the incident energy of the particles is selected as the energy spectrum input in this simulation.

(iii) Electronic transport simulation calculations. Use the so-called PRESTAIL algorithm, the electronic step algorithm. Simulations of the electron transport process are performed to obtain more accurate results than the EGS4 program at larger step sizes under permissible geometric conditions. At the same time, a simple scattering model is used to obtain accurate boundary crossings and the electronic transport process is determined. After the correlation mode of the ionisation chamber in the longitudinal direction, all other transport parameters use the default value of the EGSnrc program.

(iv) The number of particles recorded. In the EGSnrc program, Histories are used to set the number of particles recorded during the calculation. The larger the Histories, the higher the accuracy of the calculation and the longer the calculation takes. Balance the relationship between the two, set the Histories to $10^8$, the accuracy of the calculated dose can reach 0.08% or more (Table 3).

According to the definition, the ionisation chamber $k_{wall}$ factor can be decomposed into a wall decay correction factor $k_{at}$ and a wall scattering correction factor $k_{sc}$. The formula is as follows:

$$K_{wall} = k_{at} \times k_{sc}$$  \hspace{1cm} (8)

where

$$K_{at} = \sum_{i} E_{i,0} e^{-\mu_{i} s_{i}} \sum_{j} E_{j,0}$$  \hspace{1cm} (9)

$$K_{sc} = \sum_{i} E_{i,0} \frac{R_{tot}}{R_{att}} = \sum_{i} E_{i,0} \sum_{j} (E_{j,0} + E_{j,1})$$  \hspace{1cm} (10)

Here, $E_{i,0}$ is the energy deposition of all the electrons generated by the action of the $i$th primary photon, $\mu_{i}$ is the linear attenuation coefficient of the ionisation chamber wall material, and $s_{i}$ is the primary photon travelled by the $i$th photon in the ionisation chamber. The average free path, $E_{i,0}$, is the energy deposition of electrons generated by the action of headphones or higher order scattered photons. These secondary or higher-order scattered photons are generated by the $i$th primary photon [15].

(i) Coal Section Database Generation: The main parameters involved in the cross-section database are the composition, composition, density, physical state of the coal, and the lowest maximum cut-off energy of photons and electrons in the coal.

(ii) Energy transport process: The core of the simulation of the wall correction factor is to distinguish several energy, namely primary energy, decay energy, and stimulation energy. The general energy transport process is shown in Fig. 4. The photon with energy $E$ enters the wall of the ionisation chamber. After a certain path $S_{i}$, the first interaction (compton scattering) occurs, and the primary electron and energy are $E$. The secondary scattering photons, the energy of the primary photon in the cavity gas is deposited as $E_{i,0}$, and the secondary photon scattering interacts with the wall of the ionisation chamber again. The electrons generated pass through the cavity and deposit energy $E_{i,1}$ [16].

4 Conclusion

4.1 Finding Wall Correction Factor $K_{wall}$ Values by Different Methods

Here, using the EGSnrc program, two different simulation processes are used to calculate the wall correction factors of the NIST10cm$^3$ and NIST30cm$^3$ graphite cavity ionisation chambers under two different ray sources of $^{60}$Co and $^{137}$Cs. The simulation results show that the deviation between the wall correction factor $K_{wall}$ and the NIST recommended values is <0.1% within the effective wall thickness simulation and direct simulation. Therefore, the method of ‘equivalent wall thickness’ simulation and direct simulation can be used to calculate the wall correction factor well. It provides a new road and direction for the solving process of the wall correction factor that has not yet matured, which lays the foundation for the more accurate and transparent

| $^{60}$Co ray source | NIST-std10 | NIST-std30 |
|----------------------|------------|------------|
| 'equivalent thickness' analogue extrapolation | 1.0243 | 1.0255 |
| Monte Carlo method calculation | 1.02385 | 1.0259 |
| NIST recommended value | 1.0236 | 1.026 |

| $^{137}$Cs ray source | NIST10cm$^3$ | NIST30cm$^3$ |
|----------------------|--------------|--------------|
| 'equivalent thickness' analogue extrapolation | 1.0312 | 1.0328 |
| Monte Carlo method calculation | 1.03195 | 1.0343 |
| NIST value | 1.0314 | 1.0347 |
international comparison results. However, for the same ionisation chamber, the difference of wall correction factor calculated by different programs is still about ten thousandth, which needs further research and improvement.

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6 References

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