Study of the energy response of high pressure ionization chamber for high energy gamma-ray

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Abstract The energy response calibration of the commonly used high pressure ionization chamber is very difficult to obtain when the gamma-ray energy is more than 3 MeV. In order to get the calibration of the higher part of the high pressure ionization chamber, we use the Fluka Monte Carlo program to perform the energy response in both the spherical and the cylindrical high pressure ionization chamber which are full of argon gas. The results compared with prior study when the gamma-ray energy is less than 1.25 MeV. Our result of Monte Carlo calculation shows agreement with those obtained by measurement within the uncertainty of the respective methods. The calculation of this study is significant for the high pressure ionization chamber to measure the high energy gamma-ray.

Key words high pressure ionization chamber, Fluka program, energy response

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1 Introduction

High pressure ionization chamber as the best detector was adopted to detect the dose rate of gamma-ray in the pulsed radiation field around the Shanghai Synchrotron Radiation Facility (SSRF). According to Refs. [1, 2], the main gamma-ray energies of pulsed radiation field outside the concrete shielding wall of the Synchrotron Radiation Facility was up to 10 MeV. But the most commercial ionization chamber's energy response of gamma-ray was calibrated barely to 1.25 MeV by experimental method[3], such as using the X-ray machine and radioactive isotopes, ^{60}Co, ^{137}Cs, ^{226}Ra and ^{241}Am. It is very difficult to get the energy response of the gamma-ray with energy up to 10 MeV. And the main aim of this work is dedicated to calculate the energy response of gamma-ray with energy above 3 MeV and this is very important to gamma-ray detection at SSRF. In order to get the energy response of the higher part of high pressure ionization chamber, the Fluka Monte Carlo program was used to perform the energy response in the spherical and the cylindrical high pressure ionization chamber, which are full of argon gas with pressure 2.5 MPa. The results are compared with prior study when the gamma-ray energy is less than 1.25 MeV.

The Fluka Monte Carlo program was developed by Italian National Institute for Nuclear Physics (INFN) and European Organization for Nuclear Research (CERN). It can simulate with high accuracy the interaction and propagation in matter of about 60 different particles, including photons and electrons from 1 keV to thousands of TeV, neutrinos, muons of any energy, hadrons of energies up to 20 TeV and all the corresponding antiparticles, neutrons down to thermal energies and heavy ions. The program can also transport polarized photon and optical photons[4].

2 Calculation

The energy response of ionization chamber is that the detector sensitivity changes as a function of gamma-ray energy[5]. It also can be considered that the ratio of indicated value to reference value changes as a function of gamma-ray energy[6]. The sensitivity is the ratio of output current to fluence rate[7], which is given by

$$S = I/\varphi \,. \tag{1}$$

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Here S is the sensitivity of ionization chamber, I is the output current of ionization chamber (in A), the φ is the fluence rate of gamma-ray (in photons/cm^2/s). The output current of ionization chamber[7] is given by

$$I = n_\lambda \cdot e \cdot E/\omega \,. \tag{2}$$

There n_λ is the fluence rate (in photons/cm^2/s), e is the electronic charge (in C), E is the average energy loss per primary gamma-ray formed in the gas (in eV), and the ω is the average ionization energy of argon gas (in eV). According to the Eq. (2), the output current of ionization chamber is proportion to the average energy deposited in the gas. So the energy response of ionization chamber can be represented by

$$S = \alpha \cdot E \,. \tag{3}$$

Here α is coefficient (For a type of ionization chamber, it is a constant), the E is the average energy deposited in the gas filled in the chamber. Therefore the Fluka Monte Carlo program can be used to simulate the detector sensitivity by calculating the energy deposited in the gas of ionization chamber. The area source with the same section of ionization chamber was established by using the Fluka Monte Carlo program. The high pressure ionization chamber is exposured in the area source of monoenergetic gamma-ray. The cut-off energy of photon and electron/positron is 1 keV in the simulation.

Table 1. Factors for converting the photon fluence rate to dose equivalent.

photon energy/MeV	10 μSv/h (photon/cm^2/s)
0.05	8296
0.06	9031
0.08	8272
0.15	4173
0.20	2919
0.60	878
0.80	675
1.00	561
2.00	333
3.00	255
4.00	210
5.00	182
6.00	161
8.00	131
10.00	114

The factors for converting the photon fluence rate to dose equivalent is adopted as the reference value according to the book of Accelerator Health Physics[7], which is indicated in the Table 1. In order to compare the results with the normalized energy response from experiment, the normalized energy is set in the energy point of 0.662 MeV. The normalized energy response can be given by

$$K_i = \frac{E_i}{b_i} \cdot \frac{b_{0.662}}{E_{0.662}} \,. \tag{4}$$

There, K_i is the normalized energy response of γ-ray with energy E_i, the b_i is the reference value of γ-ray with E_i which is shown in Table 1.

2.1 Main parameters of high pressure ionization chamber

The gas-filed spherical and cylindrical high pressure ionization chambers are filled with argon gas with pressure of 2.5 MPa. The thickness of spherical ionization chamber's wall is 1.8 mm and of chamber's radius is 75 mm. The cylindrical ionization chamber consists of a hemispherical chamber with the radius of 75 mm and a cylindrical chamber with the radius of 75 mm and a height of 125 mm with the same wall thickness of 2.5 mm. The wall of the chamber is made of stainless steel with the type of 1Cr18Ni9Ti, which with the density of 7.85 g/cm^3 and the mass fraction of it is as follows: C: 0.1%, Si: 0.8%, Mn: 1.5%, P: 0.03%, S: 0.03%, Ni: 9.0%, Cr: 18.0%, Fe: 70.54%[8].

2.2 Calculation model

In order to obtain the data of the energy response of high pressure ionization chamber, the reference area source is used in the same section area as the ionization chamber. The calculation model for the energy response of the cylindrical high pressure ionization chamber is shown in Fig. 1.

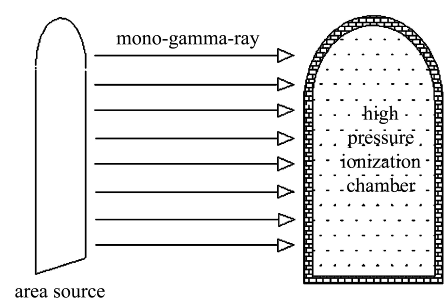

Fig. 1. The calculation model for the energy response of the cylindrical high pressure ionization chamber.

2.3 The simulation results

The simulations of normalized energy response of the spherical and the cylindrical high pressure ionization chamber which are performed by Fluka program with the gamma-ray energy range from 50 keV to 10 MeV, which can be seen in Fig. 2. There is a slightly difference between the normalized energy response curve of the spherical and cylindrical high pressure ionization chamber in low-energy part. This difference can be explained by the thickness of the chamber wall and the energy of gamma-ray. The thickness of the cylindrical chamber wall is up to 2.5 mm and the spherical chamber wall is only 1.8 mm. The spherical one is more sensitive than the cylindrical one when the gamma-ray energy is below 300 keV. Both types are over-response at the gamma-ray energy range from 55 keV to 400 keV and the gamma-ray energy above 3 MeV. And both types have their maximum response point around 80 keV.

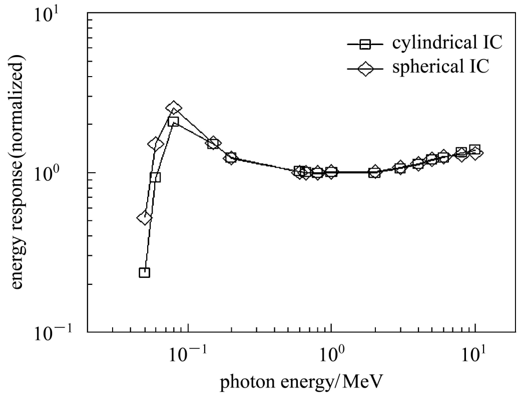

Fig. 2. The energy response of the cylindrical and the spherical high pressure ionization chambers with photon energy range from 50 keV to 10 MeV.

3 Comparison with the experimental data

The Fluka simulative results of the spherical high pressure ionization chamber use the same geometrical structure and gas pressure of argon as the published data in Ref. [3]. The experimental normalized energy response of the spherical high pressure ionization chamber with the gamma-ray energy below 1.25 MeV[3] and the simulative results are indicated in the same Fig. 3. Both results agree with each other within the uncertainties of 10%. Because it is difficult to establish the calculation model with the same geometry of actual calibration condition, such as scattering gamma-ray from concrete wall, humidity and temperature etc.

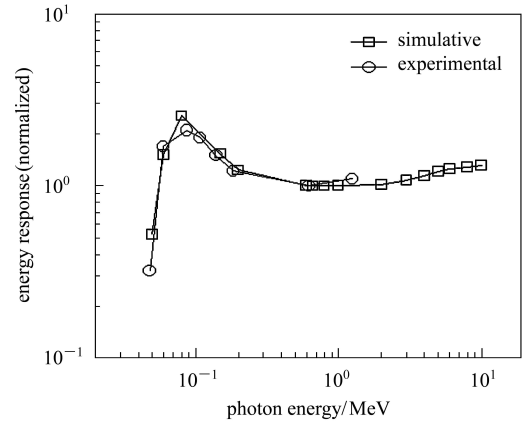

Fig. 3. A comparison of the energy response between this study and the prior measurement for the spherical high pressure ionization chamber.

4 Summary

In this study we use the Fluka Monte Carlo program to simulate the normalized energy response of the spherical and the cylindrical high pressure ionization chamber for detecting the γ-ray with energy from 50 keV to 10 MeV. The result of our study is in good agreement with the experimental data obtained by previous study. Our study shows that both of the spherical and the cylindrical high pressure ionization chamber can be used to detect the dose of gamma-ray with energy up to 10 MeV. Both types are slightly under-response when the gamma-ray energy below 55 keV and a little over-response when the gamma-ray energy ranges from 55 keV to 10 MeV. Therefore both of the spherical and the cylindrical high pressure ionization chambers are able to show proper indication when gamma-ray energy exceed to 10 MeV in the radiation fields of the Shanghai Synchrotron Radiation Facility.

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