STUDY ON THE ENERGY RESPONSE OF A MULTI-LAYER PLANAR HIGH PRESSURE IONIZATION CHAMBER USING MCNP PROGRAM

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Abstract

High pressure ionization chamber is widely used to detect various radiation fields due to its good energy response. A new Multi-layer planar high pressure ionization chamber is designed suitable for measuring directional radiation field of high dose rate, because of its high electric field strength. In this paper, MCNP program is used to simulate and calculate the energy response of this ionization chamber to obtain the energy response of high energy photons, which could not be obtained by experimental methods. The results show that this ionization chamber can measure photon radiation energy up to 10MeV.

INTRODUCTION

Accelerators produce photon radiation of wide energy range, which induced by the complex interactions of various energy charged particles with matter. To measure this kind of γ radiation field of high dose rate, a new Multi-layer planar high pressure ionization chamber was designed and manufactured. For photon radiation, it requires the energy response of ionization chamber be as flat as possible over a wide energy region. However, only a few radioactive sources and filter X-ray beams can separately provide mono-energetic and quasi-mono-energetic low energy photon radiation. It is difficult to obtain the energy response of high energy photons though experimental methods.

In this paper, MCNP program is used to simulate the energy response curve of this ionization chamber, in order to confirm the energy response of high energy photons and judge the performance of detector. MCNP, a large and multipurpose particle transport code, is developed by Los Alamos National Laboratory of the United States, which is widely applied on particle transport calculation of reactor design, shielding design, detector design and radiation dosimetry. This simulation adopts MCNP program of 4C version, which can solve transport problems of the three kinds of particles as neutron, electron, photon and coupling transport between interactions. And this version has a lot of characteristics including the capabilities of versatility and geometry processing, using precies point section parameters, suitable for calculation of various problems, abundant techniques of variance reduction.

SIMULATION METHOD AND MODEL

Theory

In the photon radiation field of certain energy, the energy response is the ratio which is between radiation value measured by detector and the true value of radiation at this point[1, 2]. The true value of radiation can be calculated though conversion coefficients for ambient dose equivalent from photon fluence, which are adopted from ICRU No.57 Report[3].

Table 1: Conversion Coefficients for Ambient Dose Equivalent From Photon Fluence

photon energy/MeV	$H^{*}(10)/\Phi$(pSv•cm^2)
0.05	0.55
0.06	0.51
0.08	0.53
0.15	0.89
0.20	1.20
0.60	3.44
0.80	4.38
1.00	5.20
2.00	8.60
3.00	11.1
4.00	13.4
5.00	15.5
6.00	17.6
8.00	21.6
10.00	25.6

The working principle of high pressure ionization chamber is that, the secondary electrons are produced by γ ray in gas of ionization chamber, which lead to ionization of gas molecular in its motion track, to produce a series of positive and negative ions. Under the electric field of sensitive volume, electron and positive ions drift toward to two electrodes respectively, which cause change of induced charge in the corresponding electrode, to form the current in the outside circuit. This current represents radiation value. Number of positive and negative ions is related to the energy deposition of particles in gas of ionization chamber, while the average energy required by a couple of ions is related to the properties of filled gas. Thus Monte Carlo method could be applied on calculating energy deposit to achieve the energy response of high pressure ionization chamber. The relationship between energy deposition and radiation value measured by detector is in the following.

$$I = \frac{E}{\omega} \cdot e \quad (1)$$

Here I is the output current of ionization chamber (in A), E is the energy deposition of γ ray in the gas (in eV), ω is the average ionization energy of argon gas (in eV), and the e is the electronic charge (in C).

During the process of simulation, high pressure ionization chamber is placed in several photon radiation fields of direction and mono-energy. The incident direction of the photon is paralleled with electrodes of ionization chamber, the scope of radiation field is larger than the size of ionization chamber. Calculate energy deposition of several energy points in the ionization chamber, and compared with radiation true value, the ratio is the photon energy response in the corresponding energy point.

Parameters and Calculation Model

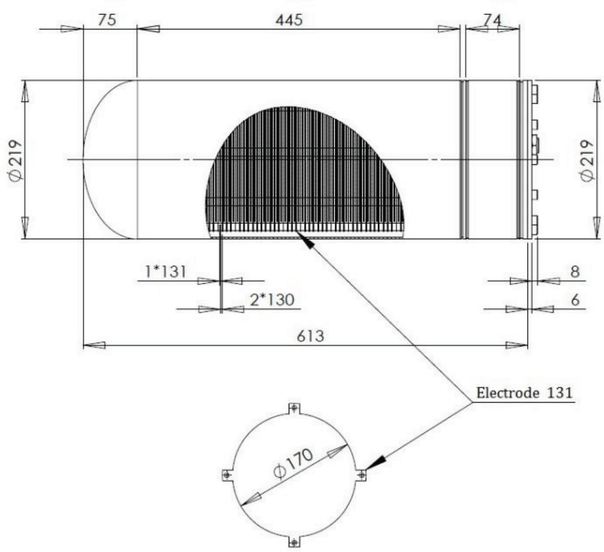

Figure 1: The schematic diagram of the ionization chamber.

The multi-layer planar high pressure ionization chamber is composed of shell of ionization chamber, shock absorption and insulation material, shell of high pressure, high voltage electrodes, passive electrodes, electrode columns, and measuring circuit, which is filled with pure argon gas with pressure of 2.5 MPa. The structure of shell of ionization chamber is a cylinder with an empty cylinder in side, thickness of the shell is 0.2 cm, radius of the cylinder is 13 cm, total height of the cylinder is 52.4 cm, material of the shell is stainless steel, which with the density of 7.86 g/cm^3. The shell of high pressure and electrodes are all made of stainless steel with the type of 1Cr18Ni8Ti, which with the density of 7.93 g/cm^3, thickness of shell is 0.2 cm, radius of electrode columns are 0.25 cm. Shock absorption and insulation material is between shell of ionization chamber and shell of high pressure, which is polyurethane with molecular formula $(C_{10}H_8N_2O_2 \cdot C_6H_{14}O_3)_x$ and the density of 0.04 g/cm^3. Sixty-six high voltage electrodes and sixty-five passive electrodes are arranged alternately, which are made of Al with the radius of 8.5 cm, the thickness of 0.1 cm, the density of 2.7 g/cm^3. The spans between electrodes are 0.2 cm, which are total of 130. The schematic diagram of the ionization chamber is shown in Fig. 1.

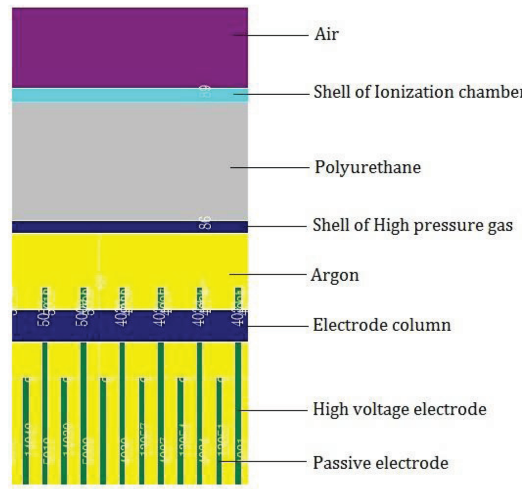

Figure 2: Center section of ionization chamber perpendicular to the electrode.

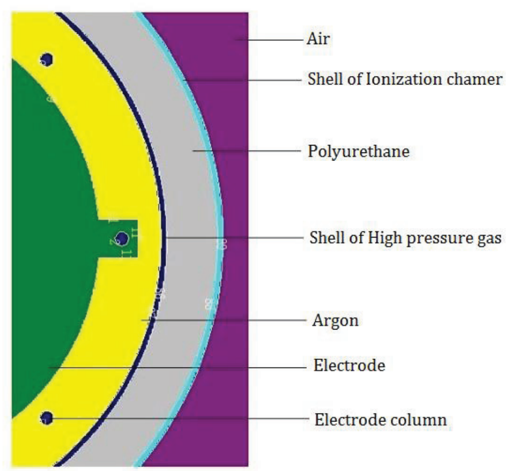

Figure 3: Section of any electrode plate parallel to electrode.

When describe the structure of ionization chamber with MCNP program[4], use real geometric model, in order to save computing time, adopt "#" operation as less as possible. When definite similar geometric structures, using LIKE BUT TRCL cards, which greatly reduce rows of description language of program and abate the possibility of errors. F6 card (the average deposition energy card) is used to count in the sensitive volume of whole ionization chamber. While the structure of this ionization chamber is complex, MCNP program can calculate neither volume nor area automatically. And it is easy to produce a fatal error, so it is useful when we take

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advantage of SD card (the sectional counting card) to provide mass of each grid element for F6 card. According to situations of different energy photons, number of particles used for simulation and calculation is greater than and equal to 10^6. The statistical errors of the results are all less than 0.6%. The graph of center section of ionization chamber perpendicular to the electrode and the graph of section of any electrode parallel to electrode, which are provided by MCNP program, are shown in Fig. 2 and Fig. 3.

THE SIMULATION RESULTS

MCNP program is used to simulate the energy response of the multi-layer planar high pressure ionization chamber from 50 keV to 10 MeV, which is shown in Fig. 4. There are twenty energy points on the curve. In order to understand energy response of ionization chamber intuitively, the results are normalized to the energy point of 0.662 MeV, the energy response of this point could be obtained by interpolation. It can be seen from Fig.3 that there are low responses to this ionization chamber when the photon energy are lower than 80keV. The relative response is only 13.3% when the photon energy is 60 keV. The reason is that ionization chamber has two shells of stainless steel outside the high pressure argon gas. The response is relatively flat when the photon energy is from 100 keV to 6 MeV. This phenomenon is different from responses of most of high pressure ionization chambers whose responses are over in the low energy part. It states planar ionization chamber has advantages. There is a little over-response when the photon energy is from 6 MeV to 10 MeV, it is an over-response of 55.4% at 10MeV. Because of plates, this kind of ionization chamber cannot satisfy the demands of isotropic photons, it is just suitable for monitoring directional radiation fields of high dose rate, such as accelerator radiation.

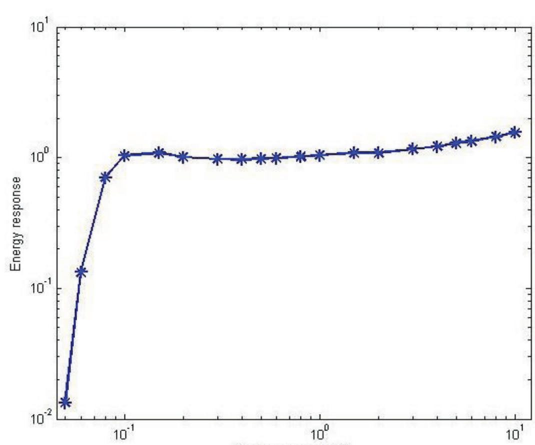

Figure 4: The energy response curve of simulation.

SUMMARY

In this study, we use MCNP program to simulate photon energy response of Multi-layer planar high pressure ionization chamber, covering the energy range from 50 keV to 10 MeV. The result of this study is in good agreement with the experimental data. Comparing with other types of high pressure ionization chamber, it does not appear the phenomenon of over-response. There is a little over-response in the high energy region, but it is smooth on the whole. It illustrates that this detector can measure the highest energy up to 10MeV. In the meanwhile, the results show MCNP program could be used to simulate the energy response of ionization chamber and optimize the design of ionization chamber.

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