AN AIR IONIZATION CHAMBER SIMULATION USING MONTE CARLO METHOD*

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Abstract

The CYCIAE-100 cyclotron with proton beam 200uA/100MeV and several beamlines have been developed at China Institute of Atomic Energy (CIAE) [1]. In order to protect the machine from excessive radiation activation, an uncontrolled loss criterion of 1uA is specified. Calculation for radiation shielding shows that high neutron and gamma are produced under this condition. To measure the high energy gamma -ray (about 2 MeV) [2] during machine running and void damage by the prompt radiation, an air ionization chamber is designed to fulfil this goal. A Geant4 program is developed to simulate the energy response of detectors; the EM filed data is also taken into consideration in the program. The simulation results indicate that the energy response linearity satisfies the requirement of the project specification.

INTRODUCTION

The Beijing Radioactive of Ion beam Facility (BRIF) Project has been built at CIAE. BRIF is consist of CYCIAE-100 proton cyclotron, ISOL, existing HI-13 Tandem, and super conducting linac(Tandem's booster). It is used for nuclear physics, proton therapy, materials science and application of nuclear technology etc. [3]. The driving accelerator, a 100MeV H- cyclotron, will provide high intensity stable proton beam from 75MeV to 100MeV up to 200uA. During the commissioning and operation, for the sake of beam loss, high energy neutron and photon will generate, which are harmful to staff's health and the reliability of cyclotron devices. In order to measure the actual radiation dose at real time and evaluate its hazard, a set of radiation dose monitoring system is necessary. We investigate the dose monitoring system of similar accelerators. According to the characteristics of the radiation field brought by the cyclotron, a radiation monitoring system has been constructed.

The monitoring system includes neutron detectors and γ detectors. The Monte-Carlo simulation results for shielding calculation illustrated that the energy of photon distribute from several keV to 10 MeV, the average energy is about 2 MeV yet. The maximum ambient dose equivalent rate is no more than 1Sv/h in the plane of beam transfer during beam delivering at the inner side of the wall of cyclotron vault and experiment hall. It is necessary to development a γ detector with high reliability that can work under above mentioned condition.

In consideration of the wide energy distribution of the photon, the energy response of detectors should have good linearity up to 10 MeV, furthermore working under high flux of neutron and photon, the detectors should have simple structure and less electronics to be maintained. For the reasons mentioned above, Air ionization chambers are very suitable compared with other detectors for the 100 MeV cyclotron radiation monitoring system. In order to study the characteristics of the energy response and determine the optimum size of the components of the chamber, A Geant4 code is programmed to achieve this goal; meanwhile Maxwell 3D is applied to evaluated the electrostatic electric field in the chamber.

SIMULATION TOOLS AND MODEL

Simulation Tools

There are two tools served mainly in this work, Geant4 and Maxwell 3D. The capacitance is important to the design of the preamplifier, moreover the electrostatic field distribution will influence the transit time of electron and ions generated by photon with air significantly. The Maxwell three-dimension (3D) is a set of powerful EM field simulation software; it can precisely solve different EM issue using finite element method. Geant4 is an open source framework, which can be used to simulation the interaction and transport process of particles in materials. Geant4 is widely employed in high energy physics, medical physics, detector studies, etc. [4], which is developed by CERN. It's also a huge Monte Carlo development toolkit. The data of physics models are represented as object oriented in Geant4. All the processes are built in, so the users can accomplish the whole simulation independent of external program.

The Geant4 framework provides toolkits to simulate the EM interactive processes; user can develop programs that emulate electron and photon interaction with different materials, meanwhile Geant4 provide several evaluated data library such as EPDL97, EEDL, EADL, NDL etc.

Detector Structure and Material

The main structure of the air ionization chamber can be sphere or cylinder. The sphere chamber has the most optimum performance of angular response to isometric radiation field. Due to the ionization chambers is installed at the same plane of beam, the cylinder structure is chosen according to our design, and this structure is easy to fabricate also. The sketch of the detector is shown in Figure 1. There are two parts consist in the detector, the air ionization chamber is located at upper cylinder, while the electronics circuit is seated at the bottom of the detector. The outer shell is made of metal to protect the chamber and the electronics circuit.

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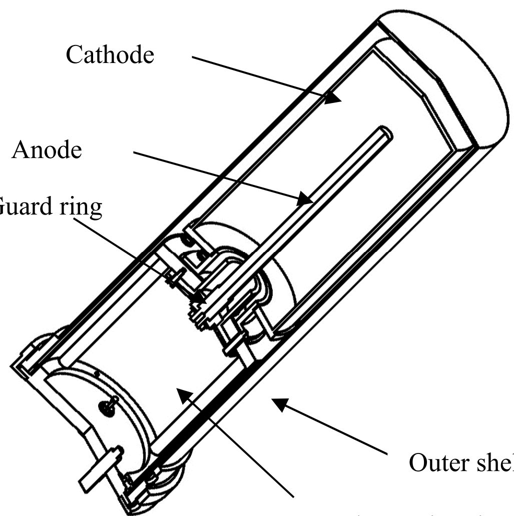


Figure 1: Structure of the detector.

The stainless steel, brass alloy and aluminium alloy are convenient for fabrication, so these materials will be considered for the chamber firstly. Though the stainless steel have the most stop capability to gamma ray among these materials [5], its mechanical strength is better than others. The SS304 is chosen for outer shell. The dimensions and materials of ionization chamber are listed in Table 1.

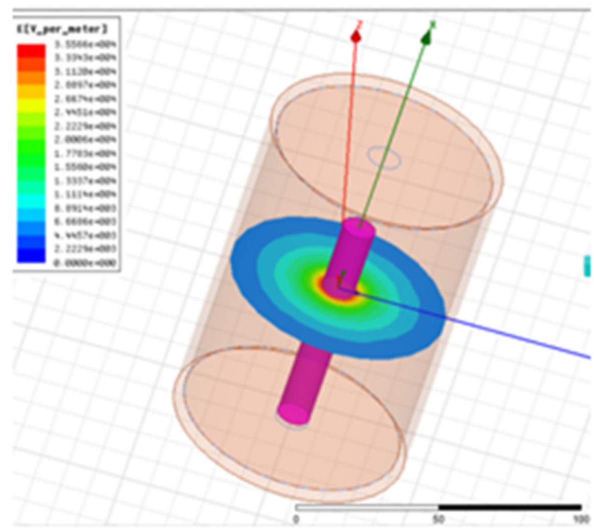
Table 1: Dimensions and Material of Ionization Chamber

Item	Inner Diameter (mm)	Outer diameter (mm)	Length (mm)	material
anode	-	12	200	brass alloy
cathode	75	77	206	Al alloy
shell	86	88	400	SS304
Guard ring	16	20	25	brass alloy

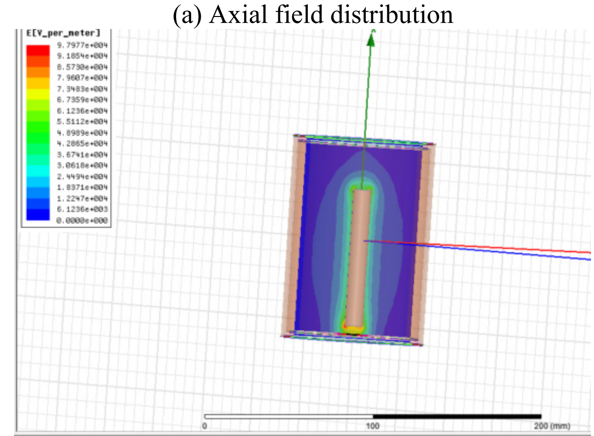
The material of cathode is aluminium alloy, which has good electric property and low stop capability for gamma ray. The anode will be made of brass alloy; this material is not easy to be corroded, this feature makes it suitable for collecting electron and negative ions long-term. This is because the output current of the air ionization chamber is very small, from tens of fA to several pA. To avoid the current leakage, a guard ring will be installed between the anode and the cathode at the bottom of the ionization chamber. The guard ring is at the same electric potential as the anode.

Electrostatic Field Simulation

The anode of the ionization chamber is connected to the input of preamplifier directly. The anode collects the electron generated by air ionization. The cathode of the chamber is connected to the negative high voltage, this bias voltage produces the electrostatic filed between the anode and the cathode. To avoid sparking in the high gradual area, Maxwell 3D is adopted to simulate the electrostatic filed distribution, furthermore, the data of field will be import into the Geant4 program in energy response analyse. The model for Maxwell 3D is simplified for fast modelling. The material of anode is brass alloy, and cathode is aluminium alloy, between the anode and the cathode is air with 1 atm. The voltage set to anode and cathode is 0 V and negative 500 V respectively. The result of electrostatic filed distribution is shown in Figure 2.



(a) Axial field distribution



(b) Transverse field distribution

Figure 2: Electrostatic field distribution of the chamber.

The post process result showed that the capacitance of the chamber is 4.324 pF. This parameter will influence the response character of the preamplifier. The gradual of voltage distribution is shown in Figure 2, the purple area is anode and the orange area is cathode. The electrostatic field is smooth at axial direction in the most regions. The maximum value of the electrostatic field occurs around the tail of the anode, about 1.14×10^4 V/m. The sparking will not generate at this voltage under 1 atm. The voltage distribution data is written to a text file, and then the file will be read by the Monte Carlo program.

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Geant4 Simulation and Analysis

The simulation program which based on the Geant4 version 4.9.2 is worked out. This program used C++ language to realize all the functions, the flow chart of the program is shown in Figure 3.

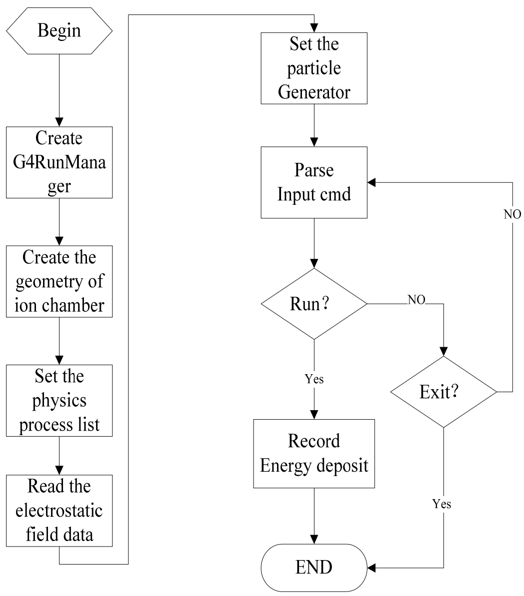

Figure 3: Flowchart of Geant4 simulation program.

There are about dozen of C++ class implement in this program. The detector construction class appoint the dimension of the components of the chamber, and assign the material to the parts. The geometry bodies are associated with the logic volume in the detector construction class also. The ionization chamber and the particle generator are located in a box named "world" in the program. The material of the world is air; the particle generator is a plane, the area of which is same as the transverse size of the chamber. The ionization chamber and the particle generator are illustrated in Figure 4.

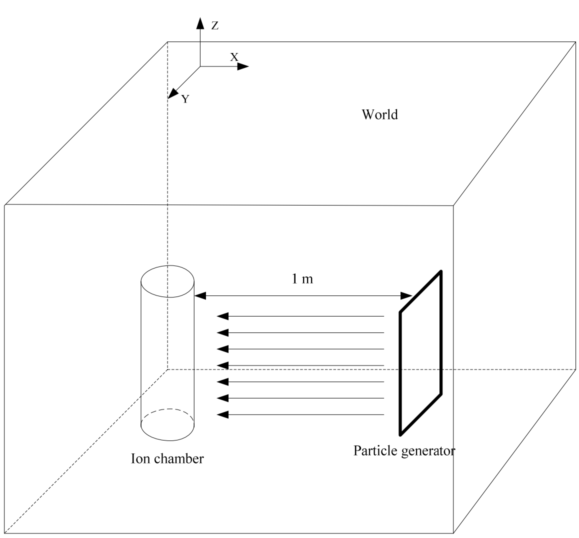

Figure 4: The Geant4 simulation model.

In this simulation program the main physics process include the photon interaction with material and electron interaction with material. The photo-electric effect, Compton scattering and gamma conversion effect are taken into account for photon. The physics processes for electron interaction include multiple scattering, ionisation and Bremsstrahlung effect.

The particle generator locate one meter far from the ionization chamber. The number of the particle can be modified at the beginning of every run. In order to minimize the statistics fluctuation, the particle number is set 10^7 presently.

The air area between the anode and the cathode act as sensitive region, the energy loss by the photon and secondary particles will be recorded in this region. The loss energy is ratio to the output current of the chamber; the normalization energy response curve is shown in Figure 5.

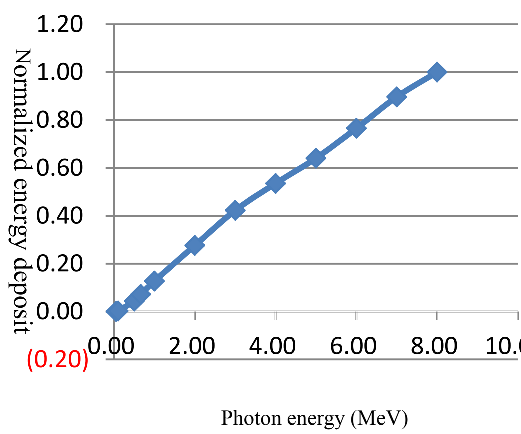

Figure 5: Energy response curve of air ionization chamber.

Figure 5 shows the curve of the energy response from 50 keV to 8 MeV of the air ionization. Though the energy response is somewhat higher at 3 MeV around, the performance of the chamber fulfils the specification of the BRIF project.

CONCLUSION

An air ionization chamber is designed for radiation monitoring system of BRIF project. To achieve the requirement of the project, the Maxwell 3D and Geant4 tools are combined to simulation the performance of the ionization chamber. The simulation result indicates that the chamber has fine linearity of energy from 50keV to 8MeV. According to the simulation, the mechanical structure of the chamber will be optimized so as to improve its performance. This chamber can be used in the BRIF project, also can be used in other similar accelerator facility as radiation monitor or beam loss detectors.

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