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A prototype for a plane-parallel ionization chamber for β radiation detection

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The design and manufacture of the ionizing radiation detectors is based on the deep knowledge of the physical phenomena interfering in the moment of introducing the detectors in the radiation field. Ionizing radiation detection is accomplished using different instruments or devices. The detection and measurement of the ionizing radiation field is a complex technological transfer process developing between the different stages of the chain: basic concept – realization. The detectors for different ionizing radiation types cover a large domain of applications. This work presents the design and manufacturing procedure of such ionizing radiation detectors, based on specific physical phenomena.

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1. Introduction

The detection and the measurement of the ionizing radiation is an important field of the applied nuclear physics. The devices designed to match this purpose - the ionizing radiation detection devices - are an important component of physics experiments.

The aim of this paper is to describe the basic concept together with experimental observations realized with a new ionizing chamber to detect β-radiation and to measure the absolute value of the dose rate and, respectively, of the absorption rate of the energy in a particular material during the β- radiation irradiation.

2. Ionizing radiation characteristics and their induced effects

Ionizing radiation interacts with mater by direct or indirect ionization that is seen by partial or total energy transfer, function of mater matrix. Ionizing radiation produces a wide range of effects by different interaction types through the energy left in the medium. This is the reason why the necessity for the detection of the ionizing radiation appeared and was soon followed by the need to measure the energy of these radiations release to various media.

Considering the fact that the ionizing radiations cannot be visually detected, their detection has been based always on their interaction with the medium they pass through. The result of this interaction makes the presence of radiation traceable and measurable.

The main effects of the ionizing radiation energy are the followings:

a) Electrical effects: the ionization of the atoms and molecules in the interaction medium; this leads to the formation of free electrical charges that can be collected and leading thus to the formation of an electrical signal.

b) Chemical effects: the formation of new bonds between the molecules of the irradiated medium or the braking of the existing bonds, depending on the amount of energy released.

c) Thermal effects: the increase of the interaction medium temperature due to the degradation down to the internal energy state of the energy that was released.

Variation in any of the quantities that characterize the three categories of effects mentioned above, may serve as a signal on the presence of the ionizing radiation. Combining that with a rigorous know-how of the relations that define the effects, such a variation may lead to the measurement of the released energy which produced the effects.

3. Ionizing radiation detector design

3.1 General remarks

The operating principle of the ionizing radiation detectors is based on the ionization of the sensitive gas inside the detector and the measurement of current results by collecting the electrical charges which are generated by ionization.

Depending on the detector application, its design must take into account several important aspects: the type of radiations that have to be detected; the characteristic quantity of the radiations; the detector operation conditions.

The first two requirements can be satisfied only if, from the beginning, the design is based on the physical characteristics of the radiations (e.g. particles that are or are not electrically charged), as well as on the specific processes that lead to the ionization of the sensitive gas inside the detector (e.g. the nature of the gas, the average energy required to form a pair of ions inside that gas, the rate to form a pair of ions due to the energy given by the incident radiation, the recombination velocity of the newly formed ions and the minimum intensity of the electrical field that is formed at the output of the detector).

Thus, the design of such a detector can begin only after a clear and accurate knowledge of the physical phenomena that govern the processes developing inside it. The next step in designing is to establish the functional parameters (output parameters: an electrical signal, the quantitative description of the physical phenomena involved the input and output parameter values).

Based on the relations that quantitatively describe the relationship between the input quantity (the measured quantity), the physical phenomena that take place inside the detector and the output quantity (an electrical signal that can be the counting rate for the pulses, the total number of pulses, the electrical current or the electrical ionization charge) it is now possible to calculate the values of the mechanical and electrical parameters of the detector, namely: the volume; nature and dimensions of the material the walls and electrodes of the detector will be made of ; the nature and pressure of the gas to fill the detector; the nature and dimensions of the isolating materials the components that isolate the electrodes will consist of.

3.2 Materials and methods

In order to exemplify what has already been described, here is a presentation of how the data was established for the ionization chamber designed by the Collective for Ionizing Radiation Metrology, Tests and Dosimetry (CMRID). CMRID is part of the National Institute of Physics and Nuclear Engineering "Horia Hulubei"- IFIN-HH, Magurele, Romania.

The primary data are:

a) Type of detector;
b) Type of radiations to be detected;
c) Type of measured quantity;
d) Nature of the filling gas;
e) Average value of the leakage current;
f) Minimum value that can be measured for the ionizing current.

The ionization chamber is designed to measure the absorbed dose rate of the energy deposited in the human tissue (the absorbed dose rate – D' (Gy/h)). It has been used an absolute method that implies the measurement of the ionizing current for the decreasing values of the detector volumes.

This leads to the necessity to design the electrodes in a plane-parallel type of geometry, with the possibility to vary the distance between the electrodes and to precisely measure the distance. That was indeed possible by the use of a micrometric screw tightly connected to the collecting electrode.

The method consists in a short analysis of each input data, as well as of the way these data determine the basic design activities: physical, technological and mechanical (mechanical design, electrical design, processing technology).

a) Detector type

The detector is an ionization chamber - detector, namely, the electrical charges are the result of primary ionization.

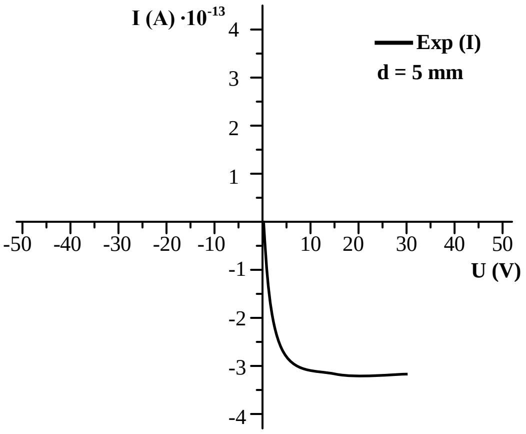

Fig. 1. I - U characteristics.

Therefore, the polarization voltage values must lie within the saturation range of the *I-U* characteristics (Fig. 1), for a given intensity.

The polarization voltage must neither go below the value of U_0, which would mean that the collection of charges would no longer be integral, nor the ionization current would leave saturation.

b) Detected radiation type

The ionization chamber is designed to detect β-radiations. This type of radiation is very easily absorbed due to its powerful interaction with the medium it passes through. This means that on the orthogonal incident direction of the ray, the detector must have a very thin window (Fig. 2). This window absorbs the β-particles (electrons) insignificantly (or in an accurately known manner). The solution to this problem is to equip the ionization chamber with a very thin window (of several µm width), made of plastic material (for example hostaphan or regular).

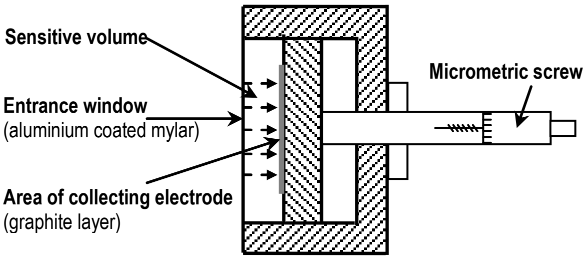

Fig. 2. General view of a plan-parallel ionization chamber.

The detector is made in a plane-parallel geometry, meaning that the electrodes have plane and parallel surfaces. Thus, the electrical field collector is obtained between the collector electrode (mobile), and the inner surface of the window (polarization electrode). Therefore, it is necessary that the 2 surfaces, be electrical conducting.

This was done as follows:

- the entrance window was made of a thin mylar film (of 7 mg/cm^2 width) covered in aluminum on one side (namely, inner surface of the window);
- the collector electrode was made by placing a continuous thin graphite film on the surface of a block of PMMA.

c) The measured quantity

The measured quantity for this detector was the absorbed dose rate by human tissue (D_{tis}).

Considering the cavity theory [1] which establishes the requirements for measuring the absorbed energy in a particular medium (tissue in the present case), this is an ionometric method [2]. The walls material should have the same elementary composition (or a very similar composition) like the medium the absorbed dose has to be measured (absorbed dose, D_{tis}, or the absorbed dose rate, $D'_{tis} = dD_{tis}/dt$).

For the chamber walls and for the block supporting the collector electrode was selected PMMA considering the similar elementary composition of the tissue, as well as its characteristic as an electrical insulator [2].

d) The filling of the detector (ionization field)

Due to the functional characteristics of the ionization chamber, it cannot be sealed, which means it can’t be filled with a gas other than air at room temperature and pressure. The value of the medium energy for producing a pair of ions is precisely known: $W_{air} = (33.97 \pm 0.6\%)$J/C.

This quantity determines the parameters of the ionization chamber in a significant manner. The parameters are: the volume of the chamber (thus the volume of the ionized air) and the number of electrical charges produced as result of the interaction with the orthogonal incident radiation.

e) Leakage current

This is an important parameter for the ionization chamber. It is the current that is formed in the detector as a result of the electrical charge leakage between the electrodes (on the surface and inside the volume between them), in the absence of any irradiation (except the natural irradiation background). The value of the leakage current is determined, primarily, by the nature of the insulating material between electrodes, but it is also determined by its shape, the degree of processing, as well as any possible blemishes that may exist on the surface. That is why the design and processing technology of the parts of an ionization chamber must consider all these aspects in order to ensure a minimum value for the parameters mentioned.

f) Minimum ionization current

The ionization current is the output electrical signal of the detector when irradiated. The ionization current is generated by collecting (integrally, in saturated conditions) the electrical charges generated inside the filling gas in the sensitive volume of the detector, through the interaction of the orthogonal incident radiation. This is the most important quantity for the use of the ionization chamber because the variation in this quantity versus the distance between the electrodes *dt/dx* (meaning the volume of the detector), determines directly the distribution of the absorbed dose $D_ß$.

$$\dot{D}_\beta = K\frac{W_{air}}{eS\rho}\left(\frac{\partial I}{\partial d}\right)_{d\to 0} \qquad (1)$$

where K - correction factor; W_{air} - average energy necessary to produce a pair of ions in air; e - elementary electrical charge; S - surface area of collector electrode; ρ - air density in the sensitive volume of the chamber.

4. Result and discussion

The above mentioned aspects, the research that has been developed regarding the physical phenomena that take place inside this type of ionization chamber and the activities in the field of engineering have all led to the design and putting into practice of the processing technology of the proper ionization chamber, with a variable volume.

The chamber was used in a series of complex experiments intended to show if it’s functioning correspond to the theory based on the running process. Among the experimental results, the paper presents the results regarding the following parameters of the detector: leakage current and ionization current.

The leakage current was measured with the experimental arrangement shown in Fig. 3.

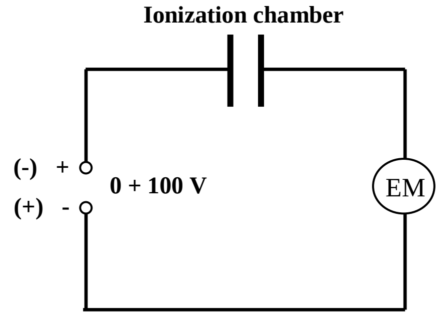

Fig. 3. Experimental arrangement.

Employing the same arrangement shown in Fig. 3 the ionization current of the chamber when the detector was irradiated with β-radiations produced by a radioactive source of (Sr+Y)^{90} with the activity Λ was measured.

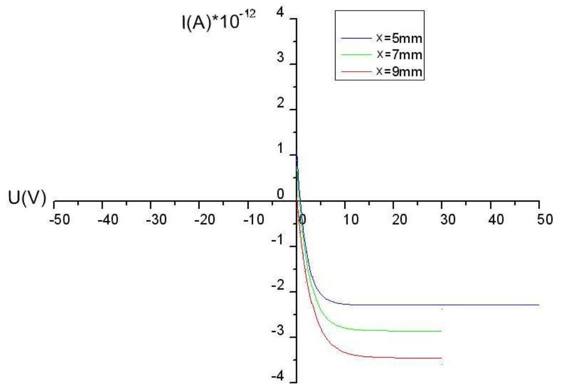

Fig. 4. The I = I (U) characteristic curve for three values of x.

Measurements done with the ionization chamber (in saturation range) had consisted of two stages:

Stage 1 – Determination of *I = I (U)* characteristic for different distances between the ionization chamber electrodes.

That was done by measuring the ionization current produced by the β-radiation (in a fixed irradiation geometry) for various values of the polarization voltage *U*.

The obtained results are presented in Fig. 4.

Stage 2 – Determination of characteristic *I = I (d)*, which is the radiation curve of the ionizing current, *I*, versus the variation of the distance between the electrodes of the ionization chamber, *d* (respectively, versus the variation of the volume of the chamber $V = S \cdot d$, *S* being the surface area of the collector electrode). The values of the ionizing current were determined by measurements using a Keithley 617 electrometer [3]. In the experimental arrangement in Fig. 3 was used in each case, the polarization voltage of the detector had the value *U = 0 ... 50 V*, which falls in the saturation range of the curve *I = I (U)*.

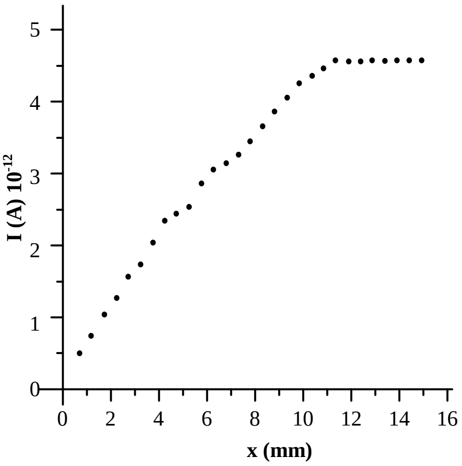

Fig. 5. The I = I (x) characteristic curve for saturation voltage.

The values obtained during the measurement of the leakage current are in the range (1×10^{-15}...3×10^{-15}) A**.** Based on these values the average value of the leakage current $I_{leak} = 2.6\times10^{-15}$ (with $u(I_{leak}) = 5\%$ uncertainty) was obtained.

The results obtained in the measurement of the ionization current versus the polarization voltage, for various values of the distance between the electrodes of the chamber, are in the curves presented in Fig. 4.

The analysis of the curves revealed that for all values of *d*, the detector characteristics *I = I (U)* with quite a wide field (saturation domain), are in good agreement with scientific literature.

This represents a primary confirmation of the fact that the design and processing method of the ionization chamber were correct. The detector operates in a saturation regime for any value of the sensitive volume, with polarization voltage greater than 15 V.

With the values of the polarization voltage within the saturation range (the range of the *I = I (U)* curves), which leads to a collector electrical field intense enough to completely collect the ions that are produced in the filling gas inside of the detector (air), the ionization current for different distances between the electrodes was measured.

The graphic representation of these various constants is given in Fig. 5 and shows that, for the value range of *d* between 1 and 10 mm, the average ionization current *I* is proportional to the distance between the electrodes, *d* therefore is proportional to the volume of the detector, $V{=}S{\cdot}d$. These results are according to scientific literature [1].

5. Conclusions

This paper presents the design and manufacturing methodology for a ionization chamber to detect the β radiation developed and applied for manufacturing a plane-parallel detector in IFIN-HH.

Starting from the basic principle of the described methodology, this paper presents the results obtained after the experimental measurements regarding: ionizing current values versus the polarizing voltage, for different values of the distance between the ionizing chamber electrodes.

The obtained experimental characteristics parameters certify that such a detector satisfies the working and measuring requirements related to an ionizing radiation detector.

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