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Design and study of the characteristics of a versatile ionization chamber for gamma-ray dosimetry

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Abstract

This work present the experimental characteristics study of the versatile gamma ionization chamber that is designed, developed and distinguished in our laboratory. All tests were accomplished under the International Electro-technical Commission. The saturation current curves and the linearity were plotted by determining the operating range and the sensitivity of the chamber. The response is linear up to more than 10 Sv/h. The sensitivity of the experimentally measured chamber is 2.1×10^{-8} A per Sv/h at an argon gas pressure of 0.4 MPa. In the same conditions, a comparative characterization with a reference chamber LND504 (USA) was done.

Keywords Ionization chamber · Flux gamma · Dose · Calibration · Sensitivity

Introduction

In the field of nuclear technology, instruments and sensing devices occupy a very important place. Indeed, they are the fundamental part of the whole nuclear instrumentation used in nuclear facilities, radiation protection and safety for the monitoring and control of nuclear power plants [1, 2].

The γ-rays, neutrons are a very dangerous source because they are highly penetrating, therefore around operational nuclear reactor, it is necessary to protect operators and working facilities near to prevent overexposure due to gamma radiation fields of neutrons and exceeding a certain threshold. Some types of nuclear detectors have been developed in our laboratory; among these devices, ionization chambers take a major importance.

The ionization chamber for detecting gamma radiation including a closure, made of stainless steel and filled with argon at a pressure of about 0.4 MPa [3], two electrodes positioned within the enclosure, these two electrodes being electrically insulated and separated from one another by an insulation resistance of $10^{15}\Omega$ order to create there between an electric field (E) and allowing the passage, by this electric field, of ionizing particles producing positive ions and electrons which can be collected via the cited electrodes [4].

Many applications of gamma ionization chambers in the control of nuclear reactors and radiation dosimetry [1, 5]. The operating mode of this type of detector is the current mode. In an ideal case, the amount of electric current produced in a gamma ionization chamber is directly proportional to the intensity of the radiation field. Consequently, the linearity between the intensity of the gamma radiation and the output current provides the physical parameters of

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the chamber (the sensitivity) [6]. It is noted that according to studies of the gamma ionization chamber, the problem which remains becomes even more serious when the ionization chamber is exposed to gamma rays in gamma radiation fields of high intensity where increasingly higher and higher voltages are required to reduce the recombination losses [2, 7], space and distribution expenses load.

In this paper, we have presented the design and study of current characteristics of the gamma chamber; this current is due to the primary collection charges to the electrodes. Accordingly, it has been determined that the correct and most appropriate choice of materials chamber is designed. The parts of cleaning with chemical solutions BUC-3 BRANSON GP for degreasing, pickling and passivation of the parts, this is a very important and inevitable step before assembly [8], degassing under high vacuum to 10^{-4} mPa to 600 °C temperature and fill to a pressure of about 0.4 MPa. These procedures are for the good functioning of our gamma ionization chamber [1, 2, 6, 9]. Design of the gamma ionization chamber.

Design of the gamma ionization chamber

Description of the VGIC

The ionization chamber is a versatile VGIC cylindrically shaped chamber, consisting of two stainless steel electrodes and stainless steel housing. The case closes with two flanges. The top flange is removable (screw-nut) and contains a joint with ORING throat to isolate the gas indoor and prevent leakage. A schematic cross section of the chamber is shown in VGIC Fig. 1.

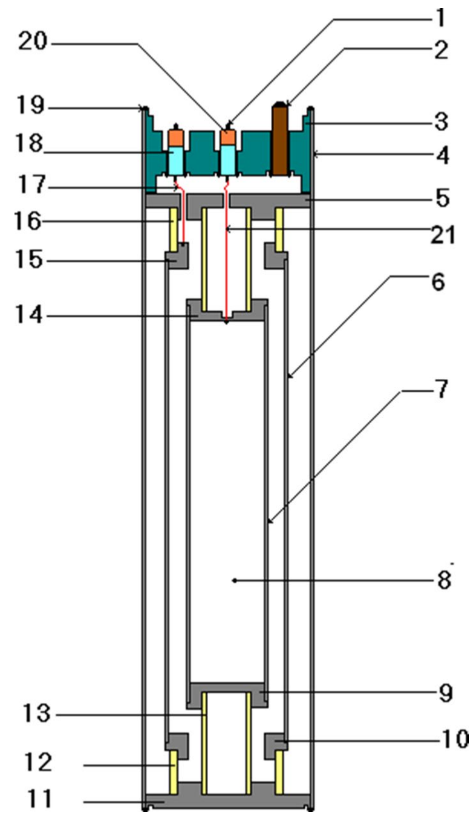

Fig. 1 View in section of prototype VGIC

Electrodes of the chamber

These are two stainless steel cylinders with a length of 25.6 cm. This length was selected to result in a sensitive volume of 500 cm^3 (0.5 L). The diameters of these two electrodes are 3.15 cm and 4.05 cm, which give us an inter-electrode distance of 0.9 cm. Their thickness was estimated to be around 2 mm. the physical and mechanical specifications of the designed chamber are summarized in Tables 1 and 2.

Table 1 Labels of prototype VGIC

No.	Designation	Material
1	Tight soldering of the signal output wire	TIG
2	Filling cap	Stainless steel
3	Upper flange	Stainless steel
4	Chamber envelope	Stainless steel
5	Upper flange	Stainless steel
6	HT external electrode (cathode)	Stainless steel
7	Internal electrode signal (anode)	Stainless steel
8	Active medium (gas)	Argon
9	Lower anode support	Stainless steel
10	Cathode support	Stainless steel
11	Sealed welded bottom flange	Stainless steel
12	Anode/ground insulator	Stainless steel
13	Cathode/mass insulator	Polyethylene
14	Upper anode support	Stainless steel
15	Upper cathode support	Stainless steel
16	Upper cathode/guard insulation	Polyethylene
17	HT power wire	Nickel
18	Watertight passage (HT)	Polyethylene
19	Joint oring	Polyethylene
20	Watertight passage (signal)	Polyethylene
21	Signal output wire	Nickel

Electrical insulators

The isolation of the high voltage (HV) signal and the mass was made with the polyethylene insulation. This material has a higher radiation resistance to gamma irradiation at 10^7 Sv.

Table 2 Physical and mechanical specifications of versatile gamma ionization chamber (VGIC)

Summary of VGIC	Value (mm)
Overall length	350
Useful length	256
Case diameter	104
Internal electrode diameter	63
Internal electrode thickness	2
External electrode diameter	81
External electrode thickness	2

Gas filling pressure

The argon gas is used in the detector, this gas was chosen because it is available and it is cheaper than the Xenon and Krypton. The filling pressure was limited to 0.4 MPa.

Electrical tests

After filling 0.4 MPa Argon, we measured all the electrical characteristics of two ionization chambers versatile gamma ionization chamber (VGIC) and LND_{405} [reference chamber (USA)].

Measurement of insulation resistance

The measurements were taken using the Keithley 617 electrometer, at voltage to 100 V. The insulation resistance of the upper signal and leakage current less than 10^{-12} A [5, 10].

Measurement of dielectric strength

The apparatus used is a dielectric strength tests post type PR 5M SEFELEC.

The chambers were submitted, respectively, at voltages of 1000 V and 1500 V, no breakdown was indicated by the meter [5].

Dose rate measurement

The nuclear tests made three gamma sources (^{60}Co: high intensity (Tables 3), low intensity (Tables 4)) and ^{137}Cs: medium intensity (Tables 5)). In the tables below gives the values of the doses according to source distance and the chamber

The essentially the main purpose of these tests is:

1. Trace the saturation characteristics of the chamber for different gamma flux to determine the operating voltage.
2. Deduce the sensitivity of the chamber.
3. Knowing the energy response of the chamber.

Table 3 Dose rate (Sv/h) of the ^{60}Co source (high intensity) as a function of distance

Distance (m)	Dose rate (Sv/h)
1.5	10.9036
2	6.1333
5	0.9813
8	0.3833
10.48	0.2451

Table 4 Dose rate (mSv/h) of the ^{137}Cs source (medium intensity) as a function of distance

Distance (m)	Dose rate (mSv/h)
1	40.25
1.5	17.33
2	9.564
2.5	6.054
3	4.173
3.5	3.044
4	2.318
4.5	1.823
5	1.465
5.5	1.207
6	1.002

Table 5 Dose rate (mSv/h) of the ^{60}Co source (low intensity) as a function of distance

Distance (m)	Dose rate (mSv/h) (10^{-2})
1	6.06
1.5	2.25
2.5	0.96
4	0.42

Saturation curves

Saturation curves representing the evolution of the current delivered by the ionization chamber VGIC and the reference chamber LND_{504} depending on the bias voltage, at different levels of gamma flux emitted by a source of ^{137}Cs are shown in Figs. 2 and 3. These gamma flux emitted by the sources of high and low to ^{60}Co intensities are in Figs. 4 and 5.

It will be noted at the outset, in the low bias voltages, the charges created in the gas are collected at all because of the effect of recombination [9]. When the bias voltage increases, the extent of the decrease to saturation, i.e. almost all charges are collected created [5, 11].

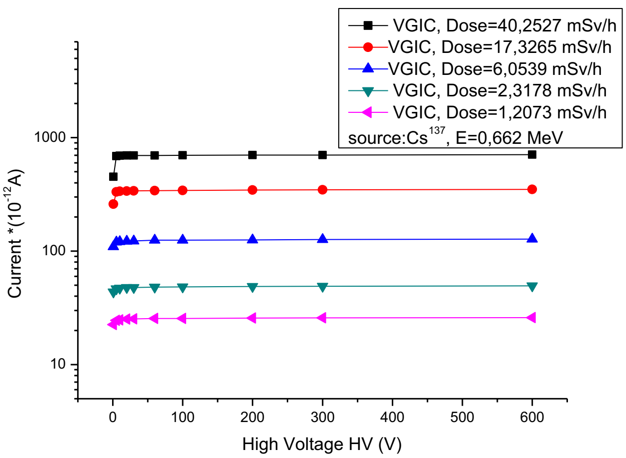

Fig. 2 Experimental saturation curves of VGIC chamber, source ^{137}Cs (medium intensity)

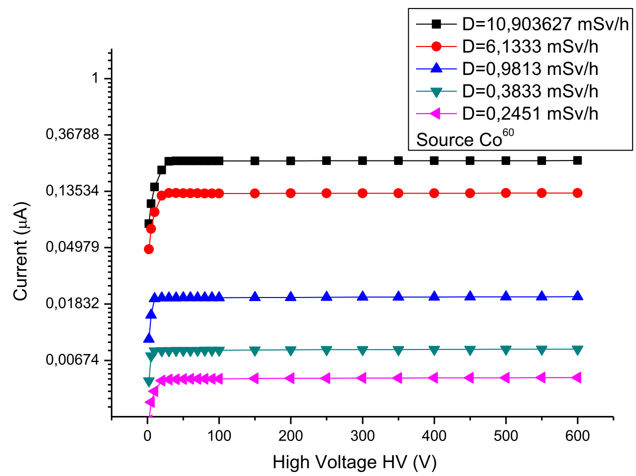

Fig. 5 Curves saturation VGIC chamber, ^{60}Co source (high intensity)

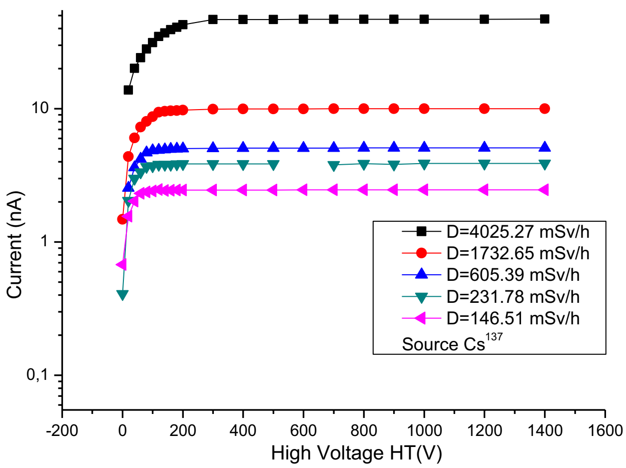

Fig. 3 Experimental saturation curves of LND_{504} chamber, ^{137}Cs source (medium intensity)

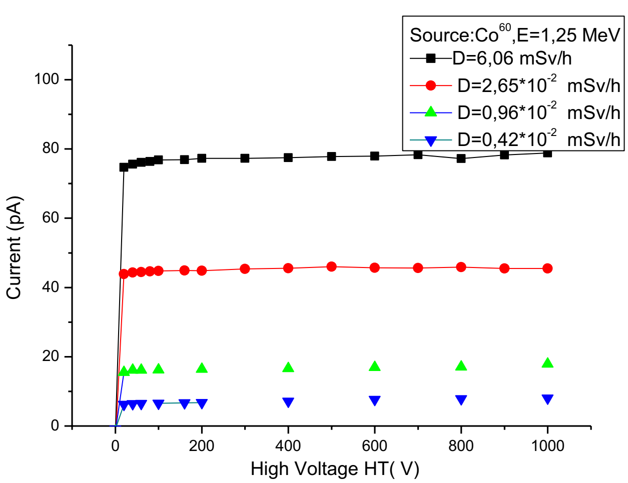

Fig. 4 Curve saturation LND_{504} chamber, ^{60}Co source (low intensity)

Figures 2, 3, 4 and 5, have of saturation curves of two ionization chambers VGIC and LND_{504} for different gamma flux emitted by gamma irradiators ^{137}Cs and ^{60}Co.

Sensitivity VGIC

The sensitivity is measured VGIC energies of 0.662 MeV (^{137}Cs) and 1.25 MeV (^{60}Co). The method used is the comparison, knowing the sensitivity of the LND_{504}.

The sensitivity of the LND_{504} ionization chamber is $S_{LND504} = 1.2.\ 10^{-6}$ A/(Sv/h) for the ^{60}Co (1.25 MeV). Experimental results establish the sensitivity was found as 2.1×10^{-8} A/(Sv/h) and was verified with sources of ^{60}Co and ^{137}Cs [5].

Effect of reversing the polarity of the backscattering phenomenon

The interaction of gamma photons with the walls of the ionization chamber produces electrons emitted in all directions. If the bias voltage is negative, electrons emitted rearward from the internal electrode will be added to the total current created inside the chamber [12, 13]. However, if the voltage is positive, the backscattered electrons will oppose the total current of the chamber and a slightly lower current is collected, especially at low photon energy. This is very apparent in Figs. 6 and 7.

The operating range

The evolution of the collected current versus γ-dose, to determine the upper and lower measurement range limit, one must trace the curve of the change of the current delivered by the ionization chamber according to the gamma ray flux. For the two chambers used (reference

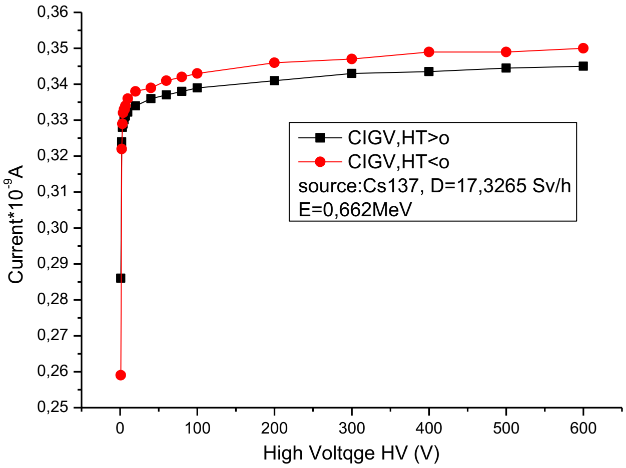

Fig. 6 Saturation curve of the chamber VGIC, Polarization positive and negative, ^{137}Cs source

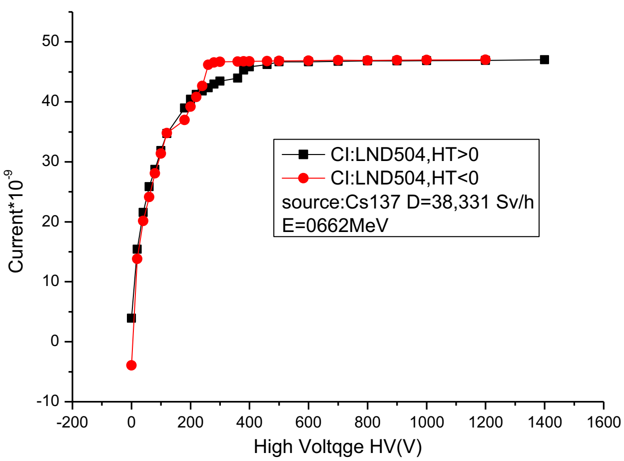

Fig. 7 Saturation curve of LND_{504} ionization chamber, Polarization positive and negative, ^{137}Cs source

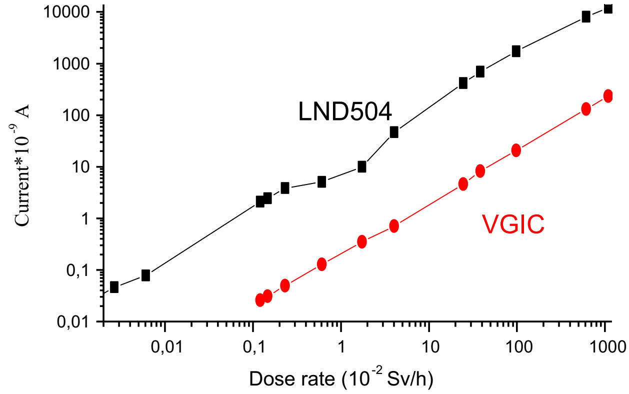

Fig. 8 Current evolution as a function of the γ Dose rate in the gamma chamber LND_{504} and VGIC

Fig. 9 Picture of versatile gamma ionization chamber prototype (VGIC) [8], [15]

chamber LND_{504} and VGIC prototype, the experimental results are shown in Fig. 8.

Knowing the proper current and sensitivity of the chamber [14], one can deduce the lower limits of the measuring range. We note that the upper limit of the VGIC can go beyond 10 Sv/h (this is what we have been in flux) but it is limited from below by its leakage current. As against the ionization chamber is limited superiorly LND about 1 Sv/h, the lower limit is less than 4×10^{-3} mSv/h. This is explained by the fact that the ionization chamber Gamma LND_{504} is more sensitive than the low dose VGIC, but our chamber VGIC is very sensitive to high doses, we conclude that there a complementation between the two ionization chambers.

Results and discussion

This work has allowed us to measure, study, and compare it with another reference chamber American (LND_{504}) the main features of the ionization chamber gamma versatile (VGIC) prototype (Fig. 9). The great advantage of versatility is the ability to change the electrodes, the gas filling and the pressure, length and volume sensitive to monitor characteristics in terms of these parameters. This helps us tremendously in the design and production of gamma ionization chambers sealed with optimal characteristics according to our needs with a suitable choice of geometry (material and dimensions). The saturation curves at different flows emitted by sources gamma ^{60}Co ($E = 1.25$ MeV) and ^{137}Cs ($E = 0.662$ MeV) provides information on the stability of the current as a function of the High voltage polarization, the choice of the latter depends on:

The saturation voltage

Can be reduced by designing gamma ionization chambers with small distances between electrodes without causing the effects of space charge, but decreasing the distance between electrodes also results in loss of sensitivity of the chamber, which usually let designers increase the fill pressure to make up for this loss. In our VGIC, from the saturation curves, deduce the high voltage i.e. the operating voltage, which we found HV = 600 V see Figs. 3 and 5.

Sensitivity

The sensitivity in the ionization chamber is directly proportional to the sensitive volume of the chamber, in our GVIC we deduce the sensitivity is 2.1×10^{-8} A/(Sv/h) for the two gamma sources ^{137}Cs and ^{60}Co. In a perspective work and to improve the sensitivity, we play on the different physical parameters, which are:

- Design a chamber with several electrodes.
- Increase the inter-electrode distance, however, this causes losses of ions not of the recombination process.
- Increase the filling pressure; this requires very good sealing of the welds. And the choice of the type of gas, the walls of the materials (materials and thickness).

The measuring range

The measuring range of an ionization chamber is the interval where the gamma collection current flow is directly proportional to the flow rate. This range is limited above by the space charge, i.e. for a certain value the total charge flow created in the chamber becomes very large and the field begins to decrease, thus losing proportionality and below by the leakage current; Thus, to increase the measurement range of a chamber, it is necessary to minimize the leakage current with good signal isolation and to increase the range of proportionality between the flow and the current collection with a minimization of the saturation voltage [7, 12].

Based on Fig. 8, where we can conclude that the measuring ranges of the VGIC and LND504 ionization chamber are:

VGIC: 1 mS/h to 10 Sv/h (this is a measuring ranges of VGIC)
LND_{504}: $0.42.10^{-2}$ Sv/h to 1 Sv/h. (this is a measuring ranges of LND_{504})

Due of the great versatility of the Versatile Gamma Ionization Chamber (VGIC), in this current work; in our laboratory, we have designed, developed and characterized a versatile gamma ionization chamber (VGIC) to study its characteristics experimentally where; The design of the VGIC is based on the different optimization parameters that have been deduced from the experimental results. In addition, to confirm our results obtained, we carried out, under the same conditions, a comparative characterization with a gamma-ionization chamber of reference type LND504 (USA), and we got a satisfactory result. In future work, we intend to take into account the effects of space charge on the charge collection process, in order to confirm a theoretical determi-nation by the experimental of the operating range, also we see that it is possible, for example, to improve the sensitivity of gamma chamber designed by a factor as high as about 25, all these can be done by replacing the two electrodes with 5 others and increasing the filling pressure up to 2.5 MPa (25 bars), and also, plan to introduce an estimate of the contribution of gaseous components to the sensitivity of the chamber.

Conclusion and perspectives

This work allowed us to measure, study and compare with another American reference chamber (LND_{504}) the main characteristics of the prototype gamma versatile ionization chamber (VGIC). The great advantage of versatility is the possibility of changing the electrodes, the filling gas and its pressure, the sensitive length and volume in order to follow the evolution of the characteristics according to these parameters. This has helped us enormously in the design and realization of the gamma ionization chamber with optimal characteristics according to our needs with a suitable choice of geometry (materials and dimensions).

The layout of the networks of saturation curves at different fluxes of gamma emitted by the sources of ^{60}Co = 1.25 MeV and ^{137}Cs (E = 0.662 MeV), informs us about the stability of the current as a function of the High voltage of polarization, the choice of the latter depends on it. The saturation voltage can be reduced by designing gamma ionization chambers with short inter-electrode distances without causing the effects of space charge; however the decrease in the inter-electrode distance also causes a loss of the sensitivity of the chamber, which generally lets the designers increase the filling pressure in order to compose this loss. The sensitivity of an ionization chamber being directly proportional to the sensitive volume of the chamber, to improve it, it is therefore necessary either:

- Design a chamber with several electrodes.
- Increase the inter-electrode distance, however, this causes ion losses, note the recombination process.
- Increase the filling pressure, which requires very good sealing of the welds.

- This, in addition to the choice of the type of gas, the walls of the materials (materials and thickness).

The measurement range of an ionization chamber is the interval of the gamma flux where the collecting current is directly proportional to this flux. This interval is upper limit by the charge of space, that is to say for a certain value of the flux the total charge created in the chamber becomes very important and begins to decrease the field, therefore to lose proportionality and lowery by the leakage current.

So in order to increase the measurement range of a chamber, we must minimize the leakage current with good signal isolation and increase the proportionality interval between the flux and the collected current with a minimization of the saturation voltage. In the context of future work, we also see that it is possible, for example, to improve the sensitivity of gamma chamber designed by a factor as high as about 25. This can be done by replacing the two electrodes with 5 others and increasing the filling pressure up to 2.5 MPa. In addition, to reduce leakage current and therefore increase the operating range chamber.

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