Applied Radiation and Isotopes 68 (2010) 665–668

Contents lists available at ScienceDirect

Applied Radiation and Isotopes

journal homepage: www.elsevier.com/locate/apradiso

On line high dose static position monitoring by ionization chamber detector for industrial gamma irradiators

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ARTICLE INFO

Keywords:
Ionization chamber
Industrial irradiator
High dose
Dosimetry

ABSTRACT

A 1 cm^3 cylindrical ionization chamber was developed to measure high doses on line during the sample irradiation in static position, in a ^{60}Co industrial plant. The developed ionization chamber showed to be suitable for use as a dosimeter on line. A good linearity of the detector was found between the dose and the accumulated charge, independently of the different dose rates caused by absorbing materials.

1. Introduction

^{60}Co gamma industrial irradiation facilities are designed for processing large amounts of materials in a short time. The irradiation is usually carried out in dynamic form (Mclaughlin et al., 1989), where the products are put inside containers and pass around a gamma source with TBq to PBq (kCi to MCi) activity. As all source radiation released is not completely absorbed by the material moving around the source during the irradiation process, it is possible to utilize the radiation to irradiate small samples in static position inside the irradiation room. In some situations, mainly for research and process validation purposes, it is required to irradiate small samples, in static position, with lower and more accurate doses than those used in dynamic irradiation. Nowadays the samples are put inside the irradiation room at a fixed distance from the source and the dose is usually determined using dosimeters, only known after the irradiation. However, containers usually with different kinds of products and different densities cross the way between samples in static irradiation position and the radioactive source. So, the dose rate varies in function of the product density inside the containers, making it difficult to reach the target dose. A suitable methodology would be to monitor the dose in real-time, measuring the dose on line with a radiation detector, which would improve the dose accuracy and avoid the exceeding of required dose. The ionization chamber is an attractive alternative to be used as a real-time dosimeter due to their no directional dependence.

However, the commercially available small ionization chambers are more suitable for low radiation level measurements. Sephton et al. (2002) tested five commercial ionization chambers to measure high-dose rates of, at least, 160 kGy/h. In this study, only two chambers survived irradiation up to 6.2 MGy without sustaining damage, apart from some stiffening of the cables. The chambers had a total size of about 14 cm^3 (Sephton et al., 2002). Chambers with large size are not appropriated for well located measurements (Sharpe et al., 2000; Sephton et al., 2002; Tanaka et al., 1985). In our previous work, a small ionization chamber of 0.9 cm^3 was developed and tested as a gamma-ray detector inside a gammacell chamber (Rodrigues et al., 2003). In this work, the developed ionization chamber was evaluated inside an industrial irradiator in static irradiation position. The ionization chamber response was studied under simulated dose rate variation caused by ^{60}Co spectrum degradation. The degradation is expected due to the absorption of the ^{60}Co photons in the material under the dynamic irradiation that goes through the source (Knoll, 1989). For an ideal performance of the ionization chamber detector as a real-time dosimeter for static position irradiation, the collected charge should have the same correlation with the dose, independently of the dose rate variation caused by the ^{60}Co spectrum degradation.

2. Materials and methods

Fig. 1 shows the schematic drawing of the developed ionization chamber. It was made with 1 mm thick stainless steel, enough for establishing the ^{60}Co γ rays electronic equilibrium (Knoll, 1989; Mclaughlin et al., 1989). The overall volume of the detector is 0.9 cm^3. To transmit the signal generated in the ionization chamber to the associated electronic and processing unit far about 20 m, a mineral insulated cable (ECIL S.A) was used. This kind of cable is not deteriorated with high-dose rates (Mcminn and Goodings, 1971); the details of the cable

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doi:10.1016/j.apradiso.2010.01.032

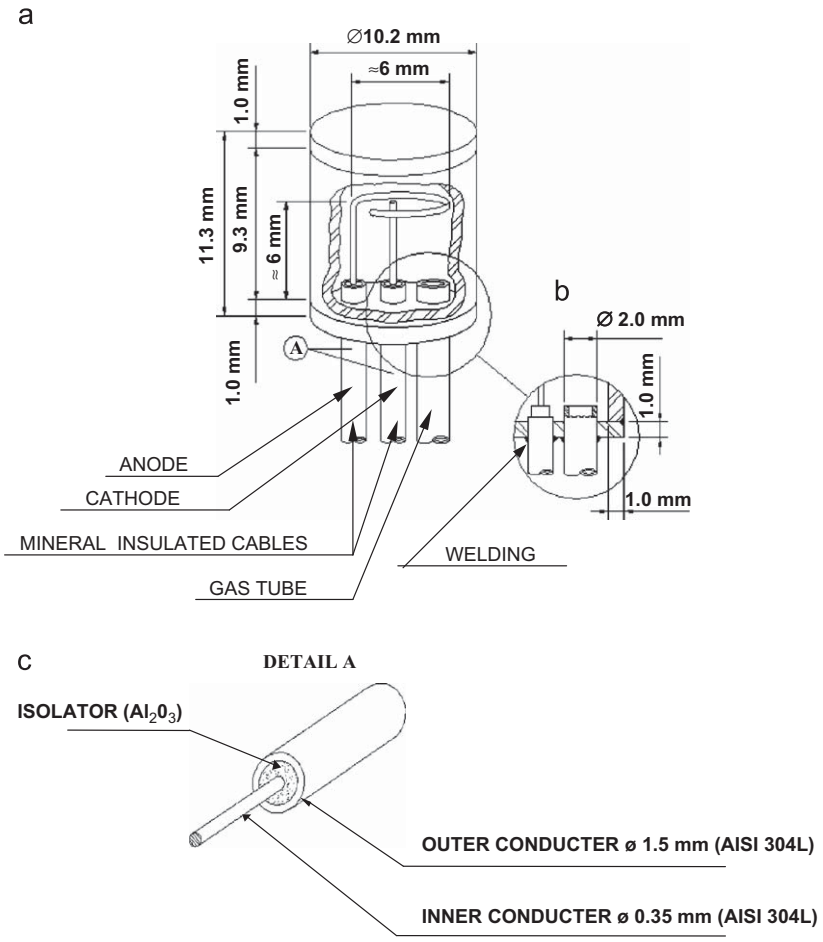

Fig. 1. Schematic drawing of the developed chamber (a). Expanded view of the cables and gas tube welding (b). Mineral insulated cable detail (c).

constituents are shown in Fig. 1(c). A pair of these cables was welded directly to the ionization chamber body as shown in Fig. 1(a). The inner wires of the cables were used as a cathode and an anode. The anode must not be a closed circle because, if there is a high radio frequency source nearby, it may induce a current inside the anode.

The ionization chamber was filled with nitrogen (34.6 eV/ion) under a pressure of 1.0 bar. In order to evaluate the developed detector, measurements of current versus voltage and accumulated charge versus dose were carried out at the static position irradiation inside the ^{60}Co industrial irradiator recently built by IPEN/CNEN-Brazil (Calvo et al., 2004) of about 3.7 PBq (100 kCi). The position is about 1 m far from the middle plane source. The dose rate variation by ^{60}Co spectrum degradation, which occurs at the static position irradiation inside a gamma irradiation facility, was simulated as closely as possible, using different absorbers placed between the radiation source and the static irradiation position.

The absorbers utilized for the simulation were a 2 cm thick lead wall and a 15.2 cm diameter polyethylene cylindrical block, with a 1.9 cm hole in the middle. Four irradiation configurations were utilized to obtain four different dose rates: (1) No absorber: 0.9 kGy/h. (2) Polyethylene block: 0.6 kGy/h (5.1 g/cm^2). (3) Lead wall: 0.3 kGy/h (22.7 g/cm^2). (4) Polyethylene block and lead wall: 0.3 kGy/h (27.8 g/cm^2). The doses were determined using Gam-

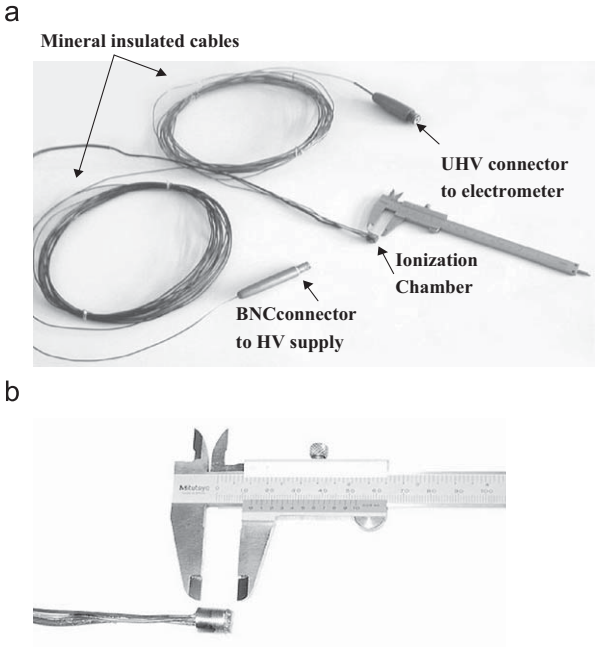

Fig. 2. Ionization chamber welded with mineral insulated cables of 20 m long (a). Expanded ionization chamber picture (b).

machrome YR (0.1–3 kGy) or Amber 3042 (1–30 kGy) perspex dosimeters (Harwell). The ionization chamber in saturation current conditions was irradiated together with the dosimeters, at static irradiation position, to verify the linearity between the accumulated charge and the dose for each configuration. The charges and currents were measured using the electrometer Keithley model 610C, supplied by a Keithley source model 247, and high voltage, ranging from 0 to 500 V.

3. Results and discussion

Fig. 2 shows the picture of the developed ionization chamber detector welded with 20 m of mineral insulated cable. The signal to noise ratio produced by the detector, at the static irradiation conditions in the industrial irradiator, was enough to be transmitted to the electrometer placed 20 m far from the detector. The ratio between signal and noise was about 100.

Table 1
Saturation currents and their minimum voltage for each absorber configuration.

Configuration	Saturation current (nA)	Minimum voltage (V)
Polyethylene block and lead wall	0.150	50
Lead wall	0.198	60
Polyethylene block	0.287	200
No absorber	0.327	200

At least three saturation currents versus voltage curve measurements were made with the ionization chamber for each configuration, varying the voltage from 0 to 500 V. The difference among curves of a same configuration was less than 1%. Very flat chamber plateaus were observed for all dose rates. Table 1 summarizes the results of the saturation current measurements and the required minimum voltages for different absorbers.

The accumulated charge measurement, in function of the dose, was performed at 400 V for all absorber configurations to ensure the saturation current stabilization. As it can be observed in Fig. 3, all curves exhibit linearity between doses and collected charge in all configurations. Table 2 shows the adjustment parameters, polynomial equations, standard deviations and adjustment verifications by the least squares method for each curve obtained. All standard deviations were below 5% which is a suitable reproducibility for a dosimetry system routine (Fairand, 2002).

For curve without absorber a significant difference of about 44% was observed compared to curves with absorbers. This is due to the spectrum degradation caused by the absorption of the ^{60}Co photons in the material under dynamic irradiation. However, as it was already mentioned in an irradiation industrial plant, a situation where there is no material crossing between the sample in the static irradiation position and the source is rather unreal.

The variation observed among all configuration curves is because the ionization chamber was designed according to the literature where the wall chamber has to be thick enough to settle the electronic equilibrium for primary photons of the radioactivity sources, in this case ^{60}Co gamma rays. Thus, the ionization chamber is less sensitive than Gammachrome and Amber perspex

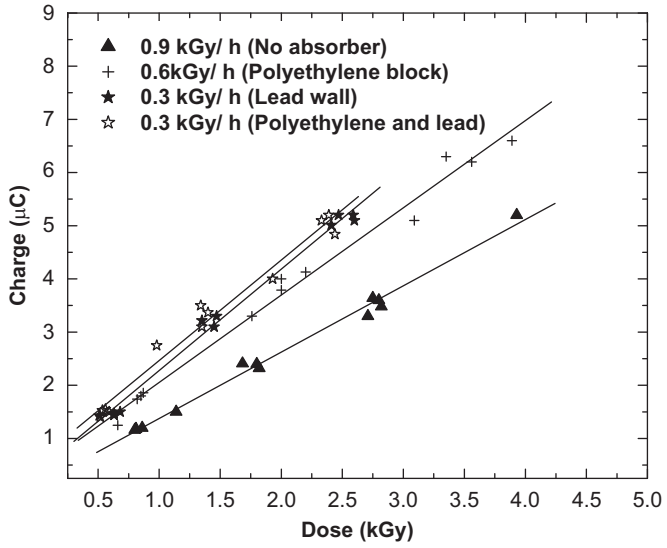

Fig. 3. Dose against charge curves measured by ionization chamber detector at the IPEN industrial ^{60}Co irradiator under different doses.

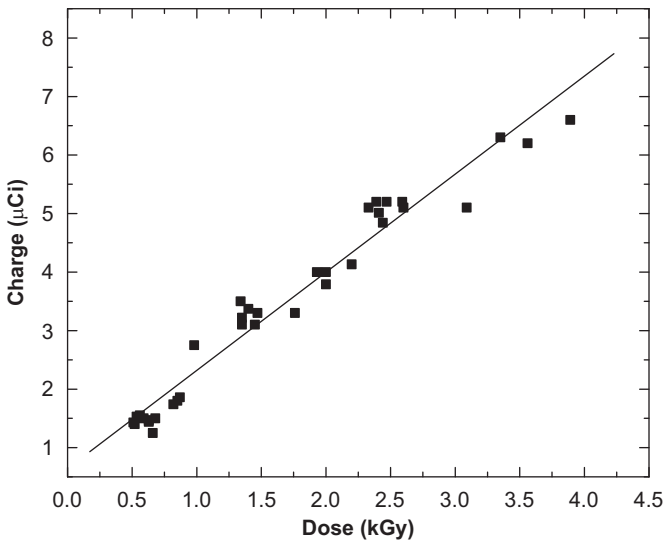

Fig. 4. Ionization chamber calibration curve for the curves obtained at the IPEN industrial irradiator, using different dose rates.

Table 2
Adjustment parameters, polynomial equations, standard deviations and adjustment verifications by least squares method for each curve in Fig. 3.

Absorber configuration	Equation $f(y)$	Adjustment parameters			Adjust verifications	
		Points	Degrees of freedom	Standard deviations (%)	λ^2	λ^2 minimal
Lead wall and polyethylene block (0.3 kGy/h)	$-0.15+0.47y$	12	10	3.5	10.20	1.02
Lead wall (0.3 kGy/h)	$-0.14+0.50y$	12	10	3.5	10.03	1.00
Polyethylene block (0.6 kGy/h)	$-0.13+0.57y$	12	10	3	9.74	0.97
No absorber (0.9 kGy/h)	$-0.13+0.81y$	12	10	3	9.77	0.98

$f(y)$=dose in kGy; y=accumulated charge in °C. λ^2=chi-square verification, should be next to number of freedom degrees. $\lambda^2_{minimal}$=minimal chi-square verification should be next to number one.

Table 3
Adjustment parameters, polynomial equations, standard deviations and adjustment verifications by least squares method for curve in Fig. 4.

Equation $f(y)$	Adjustment parameters			Adjustment verifications	
	Points	Degrees of freedom	Standard deviations (%)	λ^2	λ^2 minimal
$-0.17+0.51y$	36	34	4.5	34.72	1.02

dosimeters for ^{60}Co gamma rays spectrum degraded by absorber configurations, which is the real routine situation at an industrial irradiator static position.

An average calibration plotting all points, except those without the absorber, on a same graph, is shown in Fig. 4. The uncertainties for the obtained curve was of $\pm 4.5\%$ (Table 3), better than 5%, recommended for an industrial dosimetric system routine.

The obtained results show that the ^{60}Co spectrum degradation in the ionization chamber is an important phenomenon that should be considered for the proposed application. The developed detector can be used suitably as a real time dosimeter in an industrial irradiator, after being calibrated within a degradation spectrum range, due to the photons absorption in the dynamic irradiation material going past the ^{60}Co source.

4. Conclusion

The ionization chamber showed to be suitable for using as a real-time routine dosimeter to measure the dose range studied, from 0.7 to 3.5 kGy. A good correlation between the dose versus accumulated charge was found, independently of the spectrum degradation for absorption raging from 5.1 to 27.8 g/cm^2. For all curves in this situation, the uncertainties were $\pm 4.5\%$, being lesser than 5% recommended for a dosimetric system routine.

Acknowledgments

The authors would like to thank the FAPESP for the financial support. They also thank the staff of the IPEN ^{60}Co Irradiator Group for the valuable support in the irradiations and MSc. C. M. Napolitano for performing the dosimetry.

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