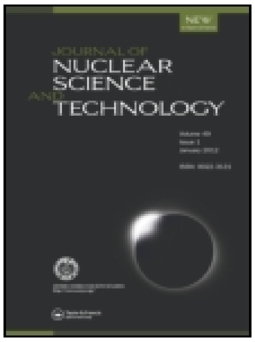

Journal of Nuclear Science and Technology

ISSN: 0022-3131 (Print) 1881-1248 (Online) Journal homepage: https://www.tandfonline.com/loi/tnst20

Operational Characteristics of Ionization Chambers for a Radiation Monitoring

Han Soo Kim, Se Hwan Park, Jang Ho Ha, Yong Kyun Kim, Jong Kyung Kim, Seung Yeon Cho, Do Hyun Kim & Eui Kwon Chung

To cite this article: Han Soo Kim, Se Hwan Park, Jang Ho Ha, Yong Kyun Kim, Jong Kyung Kim, Seung Yeon Cho, Do Hyun Kim & Eui Kwon Chung (2008) Operational Characteristics of Ionization Chambers for a Radiation Monitoring, Journal of Nuclear Science and Technology, 45:sup5, 387-390, DOI: 10.1080/00223131.2008.10875870

To link to this article: https://doi.org/10.1080/00223131.2008.10875870

Journal of NUCLEAR SCIENCE and TECHNOLOGY, Supplement 5, p. 387–390 (June 2008)

Operational Characteristics of Ionization Chambers for a Radiation Monitoring

Han Soo KIM[1], Se Hwan PARK[1], Jang Ho HA[1], Yong Kyun KIM[2*], Jong Kyung KIM[2], Seung Yeon CHO[3], Do Hyun KIM[3], and Eui Kwon CHUNG[3]

[1]*Korea Atomic Energy Research Institute, Daejeon, Korea*
[2]*Department of Nuclear Engineering, Hanyang University, Seoul, Korea*
[3]*Department of Environmental Engineering, Yonsei University, Wonju, Korea*

Ionization chambers for a Radiation Monitoring System (RMS) are required to cover a wide range of dose rates from 10^{-1} μSv/h to 10^{6} μSv/h. For a RMS, two cylindrical ionization chambers, which had active volumes of 11.8 L and 1L, were fabricated in consideration of an electronic equilibrium and a guard electrode structure. Preliminary tests such as saturation currents and leakage currents were performed with and without a 925 MBq ^{241}Am gamma source. Linearity against low dose rates was also performed by using a conventional shadow shielding technique with NIST certified 33.52 MBq ^{226}Ra source in a calibration room. A field test with 11.8 L was also performed at the Yong-kwang power plant. A Parallel Plate Ionization Chamber (PPIC) was also developed not only to measure the proton beam intensity but also to derive relevant parameters with other reference ionization chambers aimed at assisting in the quality control of a proton accelerator. Operational characteristics were investigated at high dose rates by using the X-ray generator located at the Korea Research Institute of Standards and Science (KRISS). Ion recombination, which is one of the characteristics of an ionization chamber, was evaluated with the experimental results and a theoretical model. The collection efficiencies of a PPIC were calculated by a experimental two-voltage method when the filling gases and the distance of the two electrodes were varied.

KEY WORDS: ionization chamber, radiation monitoring system (RMS), shadow shielding technique, two-voltage method

I. Introduction

Ionization chambers are still widely used in many fields such as environmental radiation monitoring and measurement of the accelerator beam intensity due to their simple designs and long operational stability[1].

Ionization chambers for RMS are required to be capable of measuring the dose rates from 10^{-1} to 10^{6} μSv/h. Ionization chambers were designed with different configurations to meet the purpose of a radiation safety and a radiation monitoring. Two cylindrical ionization chambers, which have active volumes of 11.8 L and 1 L, were designed and fabricated as radiation sensors of a RMS. The operational characteristics such as the leakage currents, saturation curve were measured. And linearity against low dose rates and high dose rates were performed by using a conventional shadow shielding technique[2] and in a standard high radiation field. The preliminary field test was also performed for a month at Young-kwang power plant in Korea.

A PPIC was developed to assist in the quality control of a proton accelerator. Before installing a proton beam line, a fabricated PPIC must be experimentally certified for its linearity and saturation characteristics in a standard radiation field. Operational characteristics of a PPIC were evaluated in terms of a saturation curve[3], its collection efficiency, and its linearity against low dose rates even if it is used for other specific purposes.

When measuring a dose rate with an ionization chamber, the observed current is always lower than the saturation current due to an ion recombination. An extrapolation method is required to obtain a saturation current, and it depends on the type of recombination inside an ionization chamber. Three different processes for the disappearance of ions can be distinguished in theory[4]. These are an initial recombination, the general recombination and a diffusion loss. An initial recombination is a recombination of the positive and negative particles formed within the track of a single ionizing particle. A general recombination refers to a process where the positive and negative particles formed by different ionizing particles meet and recombine. A diffusion loss is a process in which ions cannot reach the electrode due to their diffusion. Among these processes, only a general recombination depends on the dose rate. We considered and evaluated the recombination processes with a fabricated PPIC.

II. Experimental

1. Performance of the Cylindrical Ionization Chambers

Two cylindrical ionization chambers, which had an active volume of 11.8 L and 1 L, were designed in consideration of an electronic equilibrium. A guard electrode was inserted to minimize the leakage current flowing from the potential electrode to the collecting electrode. A potential electrode and a collecting electrode were made of carbon coated polyethylene. Insulators were made of Teflon. Two quick gas

*Corresponding Author, Tel. +82-2-2220-2354, Fax. +82-2-2296-2354, E-Mail: ykkim4@hanyang.ac.kr

connectors were installed to fill the gas such as dry air and Ar. A picture of the fabricated ionization chambers equipped with electronics is shown in **Fig. 1**.

A Keithley 6517A, an Ortec 673 high voltage supplier, and the LabVIEW program were incorporated to measure the signal of the ionization chambers. Leakage currents of the two cylindrical ionization chambers were fluctuated in the range of 30 *f*A. In order to determine the operating voltage for the 1L ionization chamber, a 925 MBq ^{241}Am gamma source was used to measure the ionization current. **Fig. 2** shows the variation of the ionization current as a function of the applied voltage, as obtained with the chamber filled with the air and Ar gas, respectively. When filled with Ar, ionization currents were about 5 times larger than when filled with air. Sensitivity of an ionization chamber can be increased by the use of a dense gas, from this result.

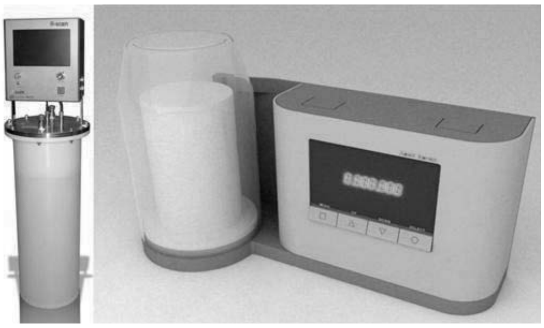

Fig. 1 Two cylindrical ionization chambers equipped with electronics. Active volumes are 11.8 L (left) and 1 L (right), respectively

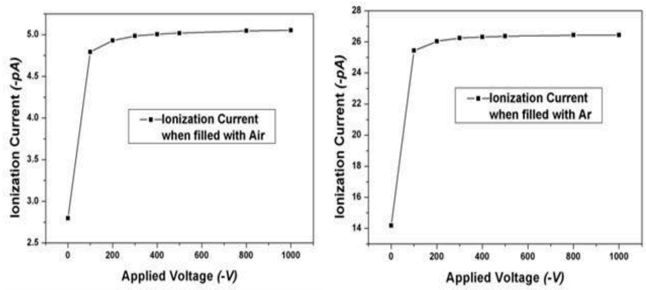

Fig. 2 Saturation curves of 1 L ionization chambers when filled with air and Ar. Distance between the 925 MBq ^{241}Am source and the center of an ionization chamber was 200 mm. The error bars are smaller than the sizes of the symbols

A current's linearity variation with the 11.8 L ionization chamber at high dose rates was measured at the voltage of a plateau region with a standard ^{137}Cs source in a calibration room at KRISS. **Fig. 3** depicts the linearity of the output current variation with respect to the dose rate. The calculated root-mean-square was 1. In low dose range, the chamber current variation was measured with a NIST-certified 33.52 MBq ^{226}Ra source using a conventional shadow shielding technique[2]. The linearity was depicted in **Fig. 3**, and the root-mean-square linearity was calculated as 0.99.

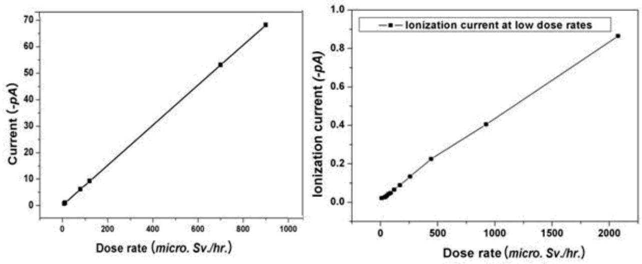

Fig. 3 Linearity against high dose rates (left) and low dose rates (right) with a 11.8 L ionization chamber when filled with air. The root-mean-square linearties were 1 and 0.99, respectively. The error bars are smaller than the sizes of the symbols

2. Performance of the Parallel Plate Ionization Chamber for Proton Beam Monitoring

A schematic of a fabricated parallel plate ionization chamber (PPIC) for a proton beam monitoring is shown in **Fig. 4**. The main considerations for designing the PPIC were reducing the leakage current to increase the sensitivity and minimizing the beam loss because the proton beams must pass through the active area of the PPIC.

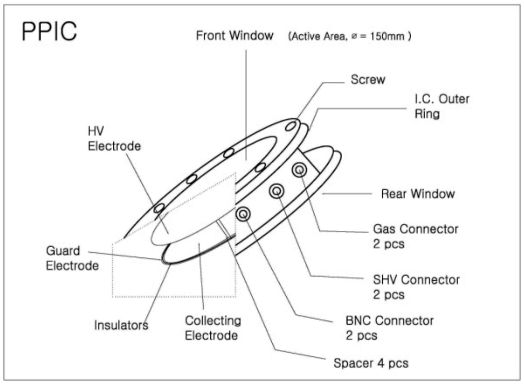

Fig. 4 Schematic of the fabricated PPIC. Double BNCs, SHVs, and gas-quick connectors were installed. Spacers were inserted between the two electrodes

The two electrodes were composed of 50-µm-thick aluminized Mylar fixed on a G-10 ring. Spacers were inserted between the two electrodes to adjust the distance of them. When a 230-MeV proton beam was passed through the PPIC, the proton beam attenuation rate due to the windows and the electrodes was 0.045% from a calculation of the stopping range of the protons in matter by using the SRIM code[5].

The leakage currents throughout the experiments were kept in the range of 20 *f*A. Saturation curves at both polarities of an applied voltage at a high dose rate and a linearity of the current are plotted against the dose rates are shown in **Fig. 5**. Saturation curves at a relatively low dose rate when the filling gas and the distance between the two electrodes were different are shown in **Fig. 6**.

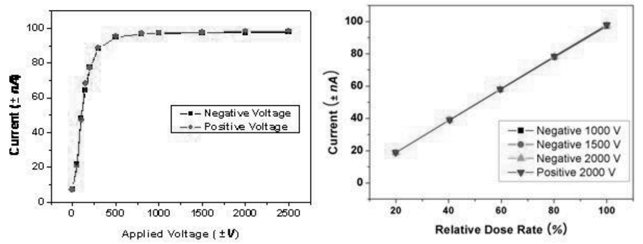

Fig. 5 Saturation curves at both polarities of an applied voltage at a high dose rate produced by the X-ray generator located at KRISS and linearity of the current plotted against the high dose rate. Dose rates were relatively varied. The error bars are smaller than the sizes of the symbols

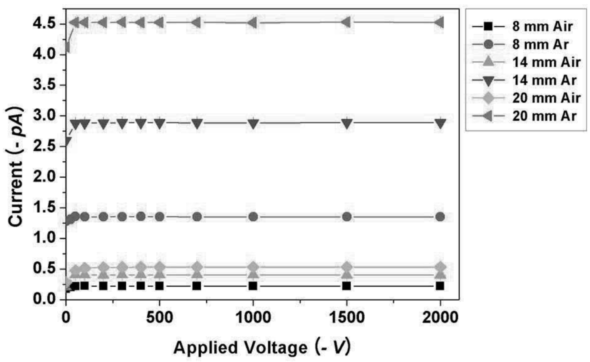

Fig. 6 Saturation curves at a low dose rate when the filling gas and the distance between the two electrodes were different. 925 MBq ^{241}Am was used. The error bars are smaller than the sizes of the symbols

III. Results and Discussion

At constant radiation intensity, the current observed in an ionization chamber is always lower than a complete saturation current mainly due to an ion recombination. Ion recombination processes are distinguished as initial and general recombinations. Initial recombination depends on the ion density along each separate track of an ionizing particle. General recombination depends on the dose rate, and refers to a recombination of the positive and negative ions formed along different ionizing particle tracks. X- and gamma-ray beams at a high dose rate, a general recombination dominates the total recombination losses. If the collection efficiency is to be evaluated, these two different recombinations must be extrapolated by using proper evaluating methods[6)-7)].

To evaluate the charge collection efficiency, we used a PPIC and extrapolated two different recombination processes. An empirical procedure formerly used to distinguish between initial and general recombinations in continuously irradiated chambers was used to plot the reciprocal of the measured ionization current i against a suitable function of the applied voltage, V, in the chamber. If an initial recombination is dominant, $1/i$ and $1/V$ in the near-saturation region have a linear relationship:

$$1/i = 1/i_0 + \text{constant}/V. \tag{1}$$

If only a general recombination is present, the relationship is:

$$1/i = 1/i_0 + \text{constant}/V^2. \tag{2}$$

At a high dose rate, a general recombination is known to be the dominant process and $1/i$ against $1/V^2$ has a linear relationship. At a low dose rate with a 925 MBq ^{241}Am source, the dominant recombination process must be determined by using an empirical extrapolation method. Plots of $1/i$ against $1/V$ and $1/V^2$ are given in **Fig. 7**.

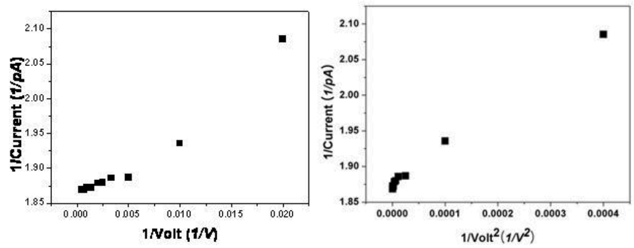

Fig. 7 Plot of i against $1/V$ and $1/V^2$ at relatively low dose rate. From these plots, the initial recombination is negligible for the total recombination

To quantify the ion recombination losses of an ionization chamber, Almond[8)] describe the use of an experimental two-voltage method when a general recombination is dominant. The collection efficiency can be derived form the ion recombination losses. The collection efficiency f at a bias voltage V is defined as $f = 1/i_{sat}$, where i_{sat} is the saturation current which can be determined when i=∞. i_{sat} can be obtained from only two data sets, i and V. Thus, the collection efficiency can be calculated by using an experimental two-voltage method:

$$f = \frac{1}{i_{sat}} - \left(\frac{(V_1/V_2)^2 - (i_1/i_2)}{(V_1/V_2)^2 - 1}\right) \tag{3}$$

where i_1 is the measured ionization current at a normal operating bias voltage V_1 and i_2 is that at a much lower voltage V_2. Almond established the reliability of a two-voltage method for $i_2/i_{sat} > 7$ and $V_1/V_2 < 5$. This means that a voltage ratio V_1/V_2 from three to five allows a two-voltage method to be adequate enough for use in dosimetric protocols[9)]. **Table 1** shows the calculated collection efficiencies and operating voltages for various dose rates and filling gases.

At a high dose rate, the case of the Ar filling was not measured because the current from the air filled ionization chamber was so large, that filling the chamber with Ar was not necessary to obtain a large current.

A preliminary field test with the 11.8L ionization chamber was performed for a month in the reserve radioactive source room at the Young-kwang power plant in Korea. The mean dose rate and the fluctuation for a day were 6.23 μSv/h and 0.07 μSv/h, respectively. This is shown in **Fig. 8**.

Table. 1 Calculated collection efficiencies and operating voltages for various dose rates and filling gases

Dose rate	Distance between the two electrodes	Filling gas	Collection efficiency	Operating voltage set
High	20 mm	Air	99%	2500 V
Low	20 mm	Air	99%	700 V
Low	20 mm	Ar	99%	700 V
Low	14 mm	Air	99%	400 V
Low	14 mm	Ar	99%	400 V
Low	8 mm	Air	99%	200 V
Low	8 mm	Ar	99%	200 V

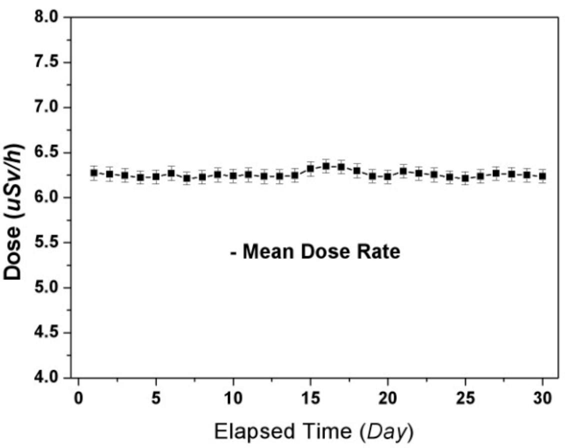

Fig. 8 A preliminary field test in the reserve RI source room at the Young-kwang power plant in Korea

IV. Conclusions

In this study, the performance of two different types of ionization chambers was tested to see if their basic characteristics meet the requirements of their intended usage. All the fabricated ionization chambers had linearity against the applied dose rates. An experimental two voltage method, which can be applied when a general recombination is dominant, was used to evaluate the operational characteristics of the PPIC in both the air filling case and the Ar filling case.

This paper will be helpful in designing and evaluating ionization chambers. Also, all the fabricated ionization chambers in this study are ready to be applied to their application fields, especially the ionization chambers for a RMS.

Acknowledgement

This work has been carried out under the nuclear R&D program of the Ministry of Science and Technology (MOST) of Korea. And we are also supported by the iTRS Science Research Center / Engineering Research Center program of MOST / Korea Science and Engineering Foundation (grant # R11-2000-067-02002-0) and partially supported by the BK21 program of Korea Research Foundation(KRF).

References

1) G. F. Knoll, Radiation Detection and Measurements, 3rd Ed., John Wiley & Sons, New York, Chap. 5 (1999).
2) A. Decampo et al., “High pressure argon ionization chamber systems for the measurement of environmental radiation exposure rates,” US. Atomic Energy Commission, New York, HASL-260 (1972).
3) J. Bohm et al., “Saturation corrections for plane-parallel ionization chambers,” Phys. Med. Biol. 21, 754 (1976).
4) S.H. Park et al., “Saturation characteristics of the ionization chamber at a low dose rate”, Radiation Physics and Chemistry, 73, 248 (2005).
5) J. Ziegler, www.srim.org.
6) J. R. Greening et al., “Saturation characteristics of parallel-plate ionization chambers,” Phys. Med. Biol. 9, 143 (1964).
7) A. Piermattei et al., “Ion-recombination correction factor ksat for spherical ion chambers irradiated by continuous photon beams,” Phys. Med. Biol. 41, 1025 (1996).
8) P. R. Almond et al., “Use of a Victoreen 500 electrometer to determine ionization chamber collection efficiencies,” Med. Phys. 8, 901 (1981).
9) IAEA Technical Report Series No. 277 (1987).