# A LONG-TERM FIELD TEST OF A LARGE VOLUME IONIZATION CHAMBER BASED AREA RADIATION MONITORING SYSTEM DEVELOPED AT KAERI

**HAN SOO KIM[*], JANG HO HA[*], SE-HWAN PARK[*], JUNG BOK KIM[*], YOUNG KYUN KIM[†] and HYUNG-HO JIN[‡]**

[*]Korea Atomic Energy Research Institute, [†]Department of Nuclear Engineering, Hanyang University,
[‡]Korea Hydro & Nuclear Power Co., Ltd, Young-gwang Nuclear Power site

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An Area Radiation Monitoring System (ARMS) ionization chamber, which had an 11.8 L active volume, was fabricated and performance-tested at KAERI. Low leakage currents, linearities at low and high dose rates were achieved from performance tests. The correlation coefficients between the ionization currents and the dose rates are 1 at high dose rate and 0.99 at low dose rate. In this study, an integration-type ARMS ionization chamber was tested over a year for an evaluation of its long-term stability at a radioisotope (RI) repository of the Young-gwang nuclear power plant. The standard deviation of dose rate of 1 day data and over a 100-days mean value were 6.2 μR/h and 2.9 μR/h, respectively. The fabricated ARMS ionization chamber showed stable performance from the results of the long-term tests. Design and performance characteristics of the fabricated ionization chamber for the ARMS from performance-tests are also addressed.

Keywords : ARMS (Area Radiation Monitoring System), Ionization Chamber, Long-term Stability, Linearity, Nuclear Power Plant

## 1. INTRODUCTION

Area Radiation Monitoring System (ARMS) is essential in a nuclear power plant to provide radiation level of working areas for radiation protection and safe operation. The ARMS incorporates a detector and an electronic control system to communicate with a remote monitoring system. Ionization chamber and Geiger-Muller (GM) tube are commonly selected as the detector of the ARMS. The GM tube is filled with quenching gas (butane or ethanol) to prevent avalanches and spurious pulse. Unfortunately the quenching gas causes a polymerization of electrode called as wire aging and shortens the life of GM tube. Unlike GM tube, the ionization chamber is filled with argon gas or air and results in a longer life than GM tube. However, ionization chambers are generally less sensitive to a low dose rate radiation than GM tube for the same active volume. The ARMS requires a large volume of ionization chamber to detect the dose rate as low as 10 μR/h.

A cylindrical ionization chamber was developed for the ARMS at Korea Atomic Energy Research Institute (KAERI). A guard electrode was adapted to enhance the detection sensitivity to a low dose rate of X- and gamma radiations [1]. Since current leakage from a large volume of ionization chamber is unavoidable, the current leakage must be characterized by a laboratory measurement. Linear detector response to various dose rate sources is required for an accurate radiation monitoring in multi-isotopes environmental such as a nuclear power plant repository. Since applied voltage to the ionization chamber changes the sensitivity and current leakage, an optimal applied voltage was determined by laboratory test. In addition to the laboratory tests for the detector characteristics, a long-term stability is a major characteristic of ARMS. To evaluate the long-term stability the ARMS has been placed in a reservoir room of Young-gwang nuclear power plant for a year.

This study is to address the laboratory tests and the

Corresponding author : Jang Ho Ha, jhha@kaeri.re.kr,
1045 Daedeokdaero, Yuseong, Daejeon, 305-353, Korea
Korea Atomic Energy Research Institute

long-term stability test of the ARMS with a large volume ionization chamber manufactured at KAERI.

## 2. MATERIALS AND METHOD

### 2.1 Development of Ionization Chamber Based Area Radiation Monitoring System

The ionization chamber base ARMS has been developed at KAERI for more stable radiation monitoring system in nuclear power plants than a GM counter for example. The ionization chamber is more endurable than GM tube based ARMS because of no wire aging. However, the ionization chamber is less sensitive than GM tube due to no current amplification in the chamber. Also, current leakage is easily established with a larger ionization volume due to a large surface area. A guard electrode made of brass was incorporated to minimize the leakage current, which introduces the current flow from a potential electrode to a collecting electrode in the ionization chamber. The potential electrode was made of polyethylene with a consideration of an electronic equilibrium between the electrodes and a collecting volume [2,3]. Conductivity of the electrodes was archived by a carbon coating. To eliminate an out-gassing from the carbon coating solvent, electrodes were dehumidified for 2 weeks in a fume hood. The active volume of ionization chamber was 11. 8 liters filled with highly dried air. The ionization chamber was integrated with electronics and the functional diagram as shown as Fig. 1. A preamplifier, an amplifier and an analog to digital converter (ADC) were included in electronics. And a RS-232 communication port and Ethernet card for a local communication and a remote control were also equipped in electronics. The ARMS automatically records the radiation level in every second via a local networking.

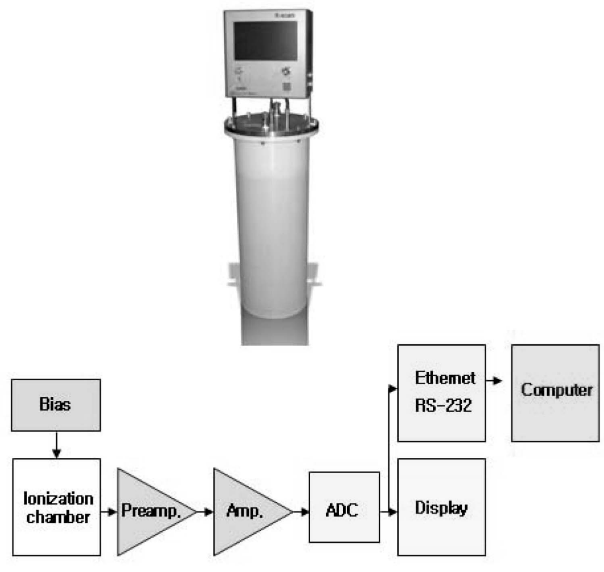


**Fig. 1.** ARMS called as R-Scan encloses a large-volume ionization chamber developed at KAERI for a long-term area radiation monitoring in a nuclear power plant. The R-scan equips a preamplifier, an amplifier, and an ADC. The R-scan also equips communication device and connected to a computer which collecting the data. An active volume of the ionization chamber was 11.8 liters.

### 2.2 Performance Tests

### 2.2.1 Current Leakage and Applied Voltage

Voltage potential deposits electric charges to the electrode and the accumulated charge is proportional to the number of ionized ions in the chamber. Also, the voltage potential removed the electric charges form the electrode to prevent the ionization chamber from becoming saturated. The ion moves by the voltage potential and becomes a current in the electrodes so called as a bias current. The bias current reaches at a point where the no more ions can be collected and saturated. The saturated voltage was measured with a 25 mCi $^{241}$Am gamma source at a 10 mm distance from the center of the ionization chamber using an experimental two-voltage method [4-6]. The saturated voltage can be determined from the calculation of the collection efficiency of the ionization chamber. The collection efficiency, *f*, at biased voltage, V, is defined as $f = 1/i_{sat}$, where $i_{sat}$ is the saturation current, and it can be determined when $i = \infty$. $i_{sat}$ can be obtained only two data sets of *i*, and *V*.

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

In Eq.(1) $i_1$ is the measured ionization current at a normal operating bias voltage $V_1$, and $i_2$, at a much lower voltage $V_2$. The reliability of the two-voltage method is

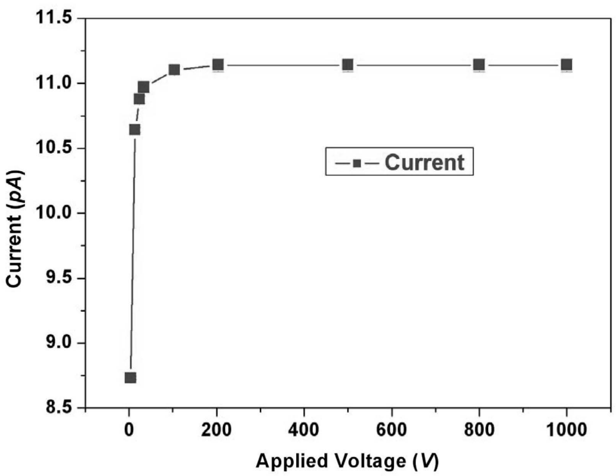


**Fig. 2.** Saturation curve of the ionization chamber against the applied voltages. 25 mCi $^{241}$Am source was located at a 10 mm distance from the ionization chamber. Dried air was filled at 1 atm. The error bars are smaller than the sizes of the symbols.

$i_2/i_{sat} > 7$ and $V_1/V_2 < 5$ [7]. This means that a voltage ratio $V_1/V_2$ from three to five allows the two-voltage method to be adequate for use in dosimetric protocols [8]. The Ortec 506 high voltage supplier (AMETEK, Oak Ridge, TN, USA) supplies the applied voltage from 0 V to 1000 V with a 100 V step. A 25 mCi $^{241}$Am gamma source was located at a 10 mm distance from the ionization chamber filled with dried air at 1 atm. The measured saturation curve is shown in Fig. 2.

The current leakage from the ionization chamber was measured using a Keithley 6517A high precision current measurer (Keithley, Cleavland, Ohio, USA) and Ortec 506 high voltage suppler (AMETEK, Oak Ridge, TN, USA) [9]. The ionization chamber was shielded from environmental radiations with lead blocks. The current leakages were automatically logged in the computer via a General Purpose Interface Bus (GPIB) communication card in a Keithley 6517A current measurer. The measured current leakage is shown in Fig. 3.

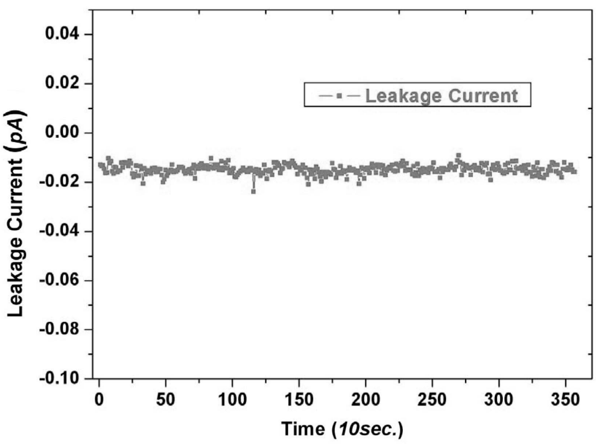


**Fig. 3.** Current leakage from the ionization chamber against elapsed time. Dried air was filled at 1 atm. Leakage currents were within the 30 fA range.

### 2.2.2 Linearity Against Dose Rates

Linearity at a relatively high dose rate was measured at Korea Research Institute of Standards and Science (KRISS). $^{137}$Cs standard source was used and the dose rates were up to $8.0 \times 10^4$ μR/h. A correlation coefficient between ionization current and applied dose rate represents the linearity of the ionization chamber.

The linearity of the ionization chamber at low dose rate was measured by a conventional show shielding technique using an NIST certified 0.906 mCi $^{226}$Ra source in the KAERI calibration laboratory [10]. A schematic of the experimental setup is shown in Fig. 4. The source was placed in a low mass holder at a height of about 1 m above the floor and at a distance of 4, 5, 6 m from the ionization chambers, which were at the same height on a low mass stand. A 30-cm thick lead shield with a cross section measuring $10 \times 10$ cm$^2$ was interposed on a low mass stand so as to intercept all the primary rays from the source to all parts of the ionization chambers through a full thickness of the shield. The current from the ionization chamber was averaged over a long period due to low dose rate source. Depending on the dose rate, the measurement time was set from 10 to 30 minutes until statistically sufficient current signals.

### 2.2.3 Long-term Stability

The ionization chamber was integrated with the ARMS system and installed in a radioisotope reservoir room of Young-gwang nuclear power plant for the long-term stability test. This place is only accessible place for long-term stability test in the nuclear power plant during the normal nuclear power plant operation. The ARMS has been operating for more than a year and has been collecting and sending the measure data over the Ethernet connections. A server computer logged the data every ten seconds into a database. Stability of the measurement can be interpreted by means of statistical measurement.

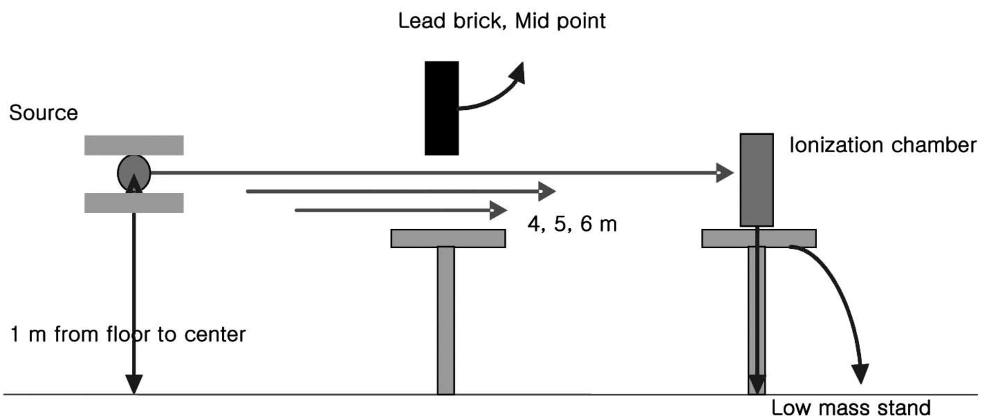


**Fig. 4.** Experimental setup for the measurement of a low dose rate in a standard radiation field.

## 3. RESULTS AND DISCUSSION

### 3.1 Applied Voltage

The current change by the applied voltage is shown in Fig. 2. The current increases as the applied voltage increases until about 200 V and becomes saturated. The applied voltage for all measurements of this study was determined at 300 V which is often used with most electrometers for ionization chamber measurement.

### 3.2 Current Leakage

The current leakage versus the elapse time is plotted in Fig. 3. Mean current leakage and standard deviation over 350 seconds were $3.1 \times 10^{-2}$ pA and $2.3 \times 10^{-4}$ pA, respectively. The range of current leakage was from $3.4 \times 10^{-2}$ pA to $2.8 \times 10^{-2}$ pA. The standard deviation confirms the current leakage can be ignored in measurement. The logged current leakages from the ionization chamber over 350 seconds are shown in Fig. 3.

### 3.3 Linearity

The current was measured against the dose rate. Fig. 5 and 6 show data points which present the current versus low dose rate and high dose rate, respectively. The linearity was examined by the correlation coefficient between points to a least-square-fitted line. The correlation coefficient of points in Fig. 5 was 1.0 presenting the perfect linearity. A 0.99 was scored by the points in Fig. 6. Both correlation coefficients results in the response of ionization chamber to low and high dose rates is linear and the ionization chamber can be used in the range of $8.0 \times 10^4$ μR/h and 20 μR/h.

### 3.4 Long-term Stability Test

The ARMS in the RI reservoir of Young-gwang nuclear power plant successfully logged the measured dose during a period of April 2007 to June 2008 every 10 seconds. As an example Fig. 7 shows the dose rate change within a day. The mean dose rate and the standard deviation during 24 hours were 490 μR/h and 6.2 μR/h, respectively. The range of dose rate during the year was 470 μR/h and 550 μR/h. Dose rates over a year were logged every 10 second. The mean value and the standard of each one day are shown in Fig. 8. Although we logged data over a year, over 100-days stabilized dose rates are shown in Fig. 9 because other days in the measurement period, there was a situational change such as a suspension of the electric power, an internal construction of RI reservoir room, and a locational change of the ARMS ionization chamber, *etc*. The mean dose rate and the standard deviation of over a 100-days

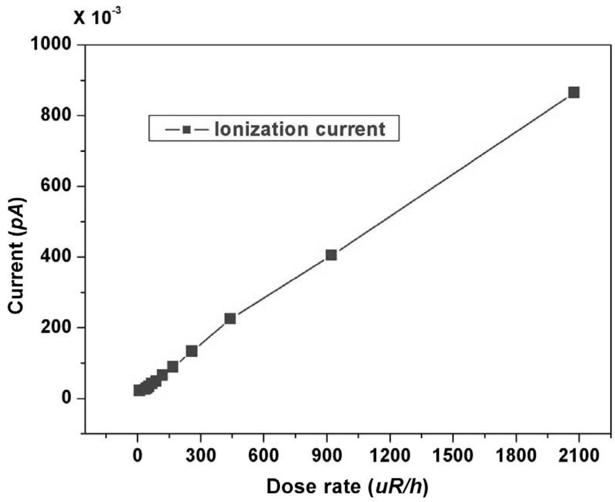


**Fig. 6.** Linearity of the ionization current plotted against the dose rate. The correlation coefficient was 0.99. The leakage current was subtracted from the ionization current. The error bars are smaller than the sizes of the symbols.

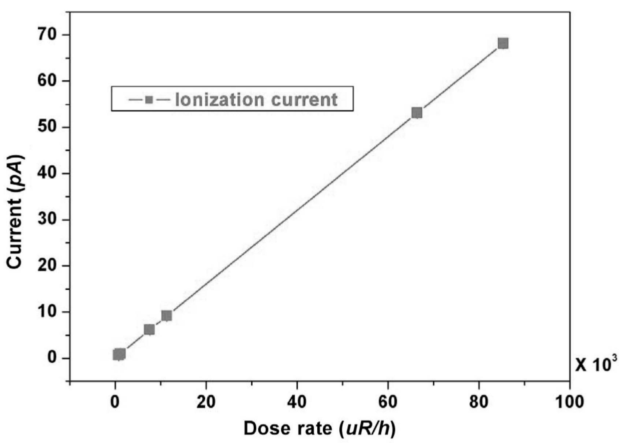


**Fig. 5.** Linearity of the ionization current plotted against the dose rate. The correlation coefficient was 1.0. The error bars are smaller than the sizes of the symbols.

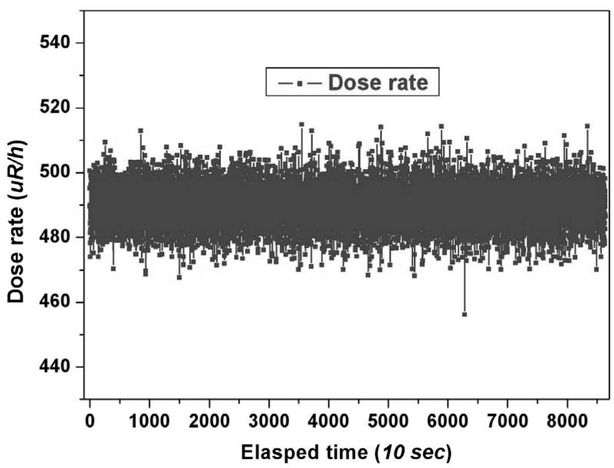


**Fig. 7.** Dose rate measured every 10 second during 1 day in the RI reservoir room at the Young-gwang nuclear power plant. The deviation of the logged data was 6.2 μR/h.

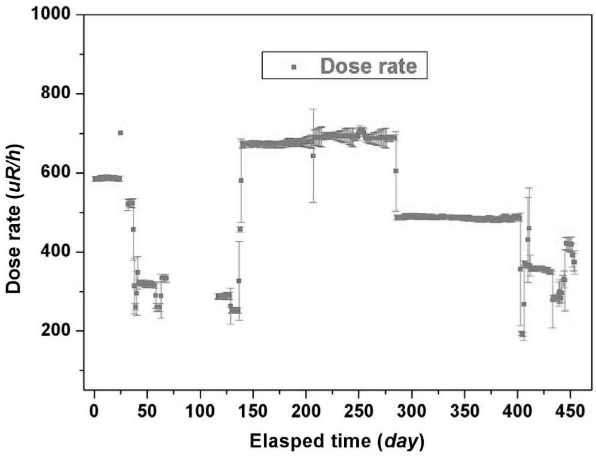


**Fig. 8.** Mean Dose rate measured over a year in the RI reservoir room of the Young-gwang nuclear power plant. There was a situational change such as a suspension of the electric power, an internal construction, a locational change of the ARMS ionization chamber, etc. Error bars represent standard deviations of dose rate within each day. Each standard deviation was calculated from each 1-day dose rates. Evaluation period was April 2007 through June 2008.

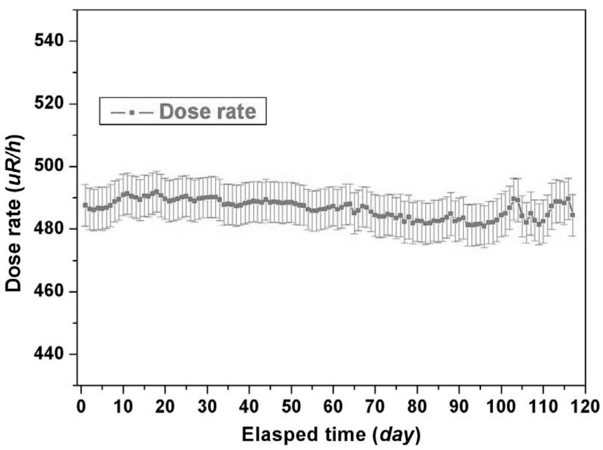


**Fig. 9.** Mean Dose rate measured over 100 days in the RI reservoir room of the Young-gwang nuclear power plant. Error bars present the standard deviations within each day data and the average deviation was 2.9 μR/h. The average deviation was calculated from the mean dose rate during over 100 days.

mean value were $4.9 \times 10^2$ μR/h and 2.9 μR/h, respectively. The value also supports the long-term stability of the fabricated ARMS ionization chamber.

## 4. CONCLUSION

An ARMS ionization chamber with integrated electronics was fabricated at KAERI. A low leakage current, a flatness of the plateau region in the saturation curve, and a linearity both at high and low dose rates were achieved from the performance tests. Long-term stability was also evaluated over a one year period in the RI reservoir room at the Young-gwang nuclear power plant. The fluctuations of 1-day acquired dose rates and over non-interrupted 100-days mean dose rate were 6.2 μR/h and 2.9 μR/h, respectively. These values show the fabricated ARMS is ready to be applied in fields such as a nuclear power plant, an accelerator facility, and other areas which need to monitor radiation.

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