Study of Applied Voltage on Ionization Chamber for Radon Detector

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1. Introduction

Radon (Rn-222) is one of Naturally Occurring Radioactive Materials (NORM), which mean radioactive materials found in environment. Among various NORM, radon accounts for 52% of the exposure dose received from natural radiation [1]. It is decay product of uranium-238 that exists in nature such as rock and soil. Radon decays with half-life 3.82 days and emit 5.5MeV alpha ray. The radon progeny also decays, emits radiation and increases lung cancer risk. So residential radon exposure should be controlled [2].

Recently indoor air quality issues including radon have been brought up in Korea. So there is an increasing need for household Radon Detector. Many continuous radon detectors are on the market using scintillators, semiconductors and gas detectors. Our purpose is making a simple and inexpensive detector, we plan to develop the ionization chamber as radon detector.

We studied about the applied voltage, which is the most affecting factor on the performance of ionization chamber. And we determine the appropriate voltage based on this study.

2. Theoretical Background

2.1. Basic principle of Ionization Chamber

Ionization chamber is one of the gas detector which collect ion pairs generated by interaction of radiation and gas molecules. Applied voltage makes electric field inside of chamber, steady-state electric current is generated by collection of ion pairs at electrode. We can deduce radon concentration in air by measuring this ionization current. In addition, pulse mode ionization chamber is generally used to separate radiation quantum. [3]

Radon gas is inert but its short-lived daughter nuclides such as Po-218 have positive charge. Since they are eliminated immediately under electric field condition, alpha particles emitted from daughter nuclides can be neglected.

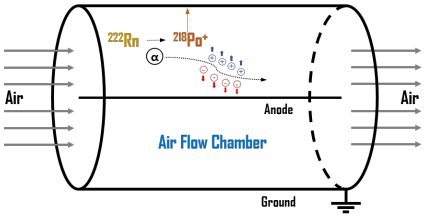

Fig. 1. Schematic diagram of Air Flow Ionization Chamber

2.2. Applied Voltage and Electric Field

Ionization chamber needs sufficient electric field to collect all ion pairs inside of chamber created by alpha particle. The current obtained this way is saturation current. Electric field is determined by applied voltage and design of chamber. It should be large enough to suppress recombination but lower than charge multiplication region (about 10^6 V/m). We choose cylinder shape chamber because of sensitivity, intensity of electric field is following Eq. (1)

$$E(r) = \frac{V}{r ln(\frac{b}{a})} \quad (1)$$

V = applied voltage
a = anode wire radius
b = chamber inner radius

Electric field makes electrons and positive ions move to each electrode. And the drift velocity of electrons and ions is following Eq. (2). Electron has small mass than positive ions, so its mobility is 1000 times greater than that of positive ion.

$$v = \frac{\mu E}{P} \quad (2)$$

v = drift velocity
μ = mobility constant
E = electric field strength
P = gas pressure

2.3. Ion loss

Efficiency of ionization chamber is mainly decreased by ion loss, which means ion pair doesn't collect on electrode. There are two main ion loss processes, which are important to gas detector: recombination and diffusion.

Recombination is a phenomenon in which ion pairs become neutral molecules by collision. There are two types of recombination. One is initial recombination that arises by ion pairs generated along the ionization track of alpha particle in column. It is independent of dose rate. The other is general recombination that occurs by ion pairs that have left the location of the ionization track immediately. It is affected by dose rate. Since alpha particle high Liner Energy Transfer (LET), it creates high density of ion pairs in its ionization track. So we should consider initial recombination as dominant recombination process in case of alpha particle.

Diffusion is random thermal motion of electron and positive ion. They tend to diffuse from high-density area to low one, also form negative ions attached on gas molecules.

3. Design of Ionization chamber

Ion losses are affected by the drift velocity of ion pair. When the size of chamber is fixed, the only factor that can change drift velocity of ion pair is intensity of electric field, which is generated by applied voltage.

3.1. Collection Efficiency

In high electric field, nevertheless, some ion pairs are lost by recombination. So many studies have been conducted about collection efficiency of ion pair according to applied voltage.

The definition of collection efficiency of ion pairs is the ratio of measured charge $Q(V)$ and saturation charge Q_{sat}, such that

$$f(V) = \frac{Q(V)}{Q_{sat}} \quad (3)$$

Collection efficiency for initial recombination (f_i) is a function of applied voltage V found by Jaffe. Collection efficiency for diffusion also can be expressed by a function of V similar with f_i. Collection efficiency for general recombination (f_g) is a function of applied voltage V^2.

$$f_i(V) = \frac{1}{1+contant/V} \quad (4)$$

$$f_g(V) = \frac{1}{1+contant/V^2} \quad (5)$$

Near the saturation region (f>0.7) and large applied voltage, the relationship between $Q(V)$ and Q_{sat} following Eq. (4).

$$\frac{1}{Q} = \frac{1}{Q_{sat}} + \frac{\alpha}{V} + \frac{\beta}{V^2} \quad (6)$$

α and β is parameters relating to initial and general recombination. Using Eq. (6), we can calculate Q_{sat} and $f(V)$ [4].

3.2. Pulse characteristics of Ionization Chamber

According to Shockley-Ramo theorem, the induced charge produced by the moving charge on the electrode only depends on the location of moving charge. We can derive velocity and drift time from Eq. (1) and Eq. (2).

$$v\ (velocity) = \frac{\mu E}{P} = \frac{\mu V}{r ln(\frac{b}{a})} \cdot \frac{1}{P} \quad (7)$$

$$\text{t (drift time)} = \int_a^r \frac{dv}{v} = \frac{P ln(\frac{b}{a})}{2\mu V} \cdot r^2 \quad (8)$$

As discussed 2.2., drift velocity of electron is much faster than that of positive ion. So the rise time of pulse depends on the collection of positive ion. In addition, at Eq. (7) and (8), we can see that the position of ion pairs determine velocity and drift time of ion pairs in cylindrical ionization chamber. We can utilize pulse rise time for circuit design and pile-up prevention.

3.3. Simulation of Designed Chamber

Our prototype ionization chamber is brass with 50mm diameter, 5 mm thickness and 220 mm length. Its volume is 432cc. Cathode is 1 mm diameter made by brass.

Electric field simulation is done by Finite Element Method Magnetic (FEMM). Voltage is applied to anode and ground is connected to inner shell of chamber. Simulation was conducted from 100 to 500 Voltage. Fig 3 shows the distribution of electric field strength inside the chamber. In addition, numerical range of electric field strengths are presented in Table I and they are well match with Eq. (1).

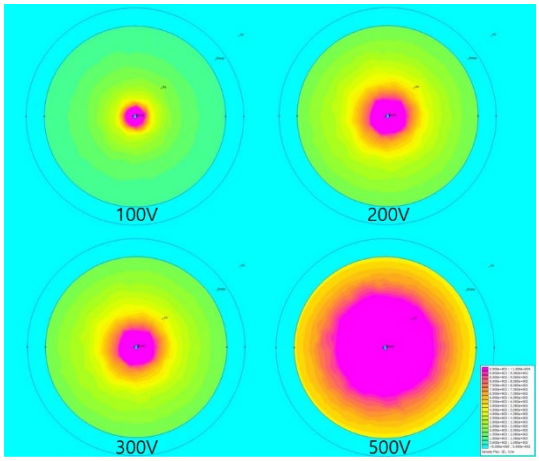

Fig. 3. The distribution of the electric field strength

Rise time of pulse can be calculated by the drift time of ions using Eq. (8). Mean mobility constant of positive ion is 1.36 $cm^2V^{-1}s^{-1}$ at STP [5]. We can obtain maximum pulse rise time suppose that ion pairs are created near the chamber surface.

Table I: Characteristics of ionization chamber according to applied voltage

Applied Voltage	Electric field (V/m)	Maximum drift time (s)
100V	1.03×10^3~5.09×10^4	~92.2 ms
200V	2.07×10^3~1.02×10^5	~44.9 ms
300V	3.10×10^3~1.54×10^5	~30.1 ms
500V	5.18×10^3~2.56×10^5	~ 18.0 ms

As checked above, high electric field strength assures less ion loss and fast pulse time. So it is appropriate for the chamber to apply voltage as high as possible assuring less than gas multiplication region.

4. Conclusion

We studied that the performance of ionization chamber is determined by behavior of ion pairs. And their movement is dependent on electric field made by applied voltage. Due to collection efficiency and pulse timing is dependent on electric field intensity, high applied voltage is needed to make good ionization chamber. But the value of electric field should lower than multiplication region.

In Further work, we will measure concentration of radon in air using ionization chamber, and find the actual operate voltage for stable measurement using saturation curve. Also, there are many components we should to design such as making guard ring, new circuit, and long air way to distinguish radon and thoron.

REFERENCES

[1] Sources and Effects of Ionizing Radiation: United Nations Scientific Committee on the Effects of Atomic Radiation 2000 Report, Volume I: SOURCES (2000)
[2] ICRP 126, Radiological Protection against Radon Exposure (2014)
[3] G. F. Knoll, Radiation Detection and Measurement, John Wiley & Sons, New York (2010)
[4] Zankowski C, Podgorsak EB. Determination of saturation charge and collection efficiency for ionization chambers in continuous beams. Med Phys. Jun;25(6):908-15 (1998)
[5] Tammet, H., H. Iher, and J. Salm, Spectrum of atmospheric ions in the mobility range 0.32-3.2 $cm^2/(Vs)$ (translated from Russian), Acta Comment. Univ. Tartu., 947, 35-49, (1992)