Temperature dependence of cavity ionization chamber response

Chul-Young Yi and Hyun-Moon Kim

Center for Ionizing Radiation, Korea Research Institute of Standards and Science, 267 Gajeong-ro, Yuseong-gu, Daejeon 305-340 Rep. of Korea

Tel: +82 42 868 5370

Fax: +82 42 868 5671

E-mail: cyyi@kriss.re.kr

Website: http://www.kriss.re.kr

1. Introduction

It has normally been assumed in comparison programs that the ion chamber response would be the same if the same reference environmental conditions are used throughout (i.e., the correction for air density and humidity is applied). The starting point for this paper is the speculation that the ionization chamber response may change with temperature, even when the standard environmental correction is applied.

There might be several factors contributing to the temperature dependence of the cavity chamber response, one of which is thermal expansion. The linear thermal expansion coefficients are of the order of 10^{-6} /°C for graphite and 10^{-5} /°C for metals. It approaches 10^{-4} /°C for most plastic materials. If we assume that the spherical cavity volume of the ionization chamber expands in an isotropic manner for three mutually orthogonal directions and the volume change is small, the volume change becomes:

$$V + \Delta V = \frac{4\pi}{3}(r + \Delta r)^3 \approx \frac{4\pi}{3}(r^3 + 3r^2\Delta r) = V + 3V\frac{\Delta r}{r} \tag{1}$$

where V is the cavity volume and r the radius of the spherical cavity. In case of thermal expansion, the change of length and temperature has the following relationship:

$$\frac{\Delta l}{l} = \alpha_l \, \Delta T \tag{2}$$

where l is length, T temperature and α_l the linear thermal expansion coefficient. From Eqs. (1) and (2), we obtain the volume expansion coefficient for isotropic materials as follows:

$$\frac{\Delta V}{V} \approx 3\alpha_l \, \Delta T \equiv \alpha_V \Delta T \tag{3}$$

where α_V is the volume expansion coefficient. Eq. (3) is true regardless of the cavity shape if the expansion is isotropic and the volume change is small. The volume expansion coefficient is roughly three times the linear expansion coefficient and the resulting variation of the ionization current could be measurable in a precise measurement.

2. Cavity ionization chambers in a nitrogen gas chamber

We used four cavity ion chambers. Two chambers are Exradin model A5 and A6 chambers. One is a PTW 32002 chamber; the other is a home-made graphite chamber model SC. A constant temperature dry nitrogen gas chamber with inner dimensions of 61 cm × 38 cm × 36 cm was used during the measurements. The ionization chambers were put in the nitrogen gas chamber. The nitrogen gas chamber was placed in a ^{137}Cs gamma-ray field. The source with nominal activity of 78.1 TBq as of 2006 was fixed at a complete standstill in the irradiator. Irradiation was turned on and off using an up-down shutter. The chambers were placed at 6.5 m from the source during the measurements where the beam diameter was 75.4 cm.

Temperature in the nitrogen gas chamber was regulated from 17 ℃ to 27 ℃. The temperature was stable at the preset temperature within 0.01 ℃ during a set of measurements for a specific ionization chamber. The nitrogen gas chamber was not sealed tightly so that the chamber was being flushed out continuously with dry nitrogen gas to thrust humid air outside the chamber.

3. Ion chamber response to ^{137}Cs gamma-ray

The current created in the ionization chamber was measured using a Keithley model 6517B electrometer while the chamber was in the dry nitrogen gas chamber. If the radioactive decay is corrected, the ionization current of the ion chamber placed in the ^{137}Cs radiation field should be constant in the reference environmental conditions. The ionization current in the reference condition was obtained from the measured current by:

$$I = i_e \, k_r \, k_a \, k_d \, k_g \, k_q \tag{4}$$

where I is the ionization current in the reference condition, i_e the measured current by the electrometer, k_r the correction factor for the radioactive decay of the ^{137}Cs source during the measurement, k_a the correction factor for the attenuation of ^{137}Cs gamma-ray in air between the source and the chamber, k_d the conventional density correction factor for nitrogen gas in the cavity of the chamber, k_g the correction factor for the hygroscopic expansion or contraction of the cavity chamber and k_q the charged particle disequilibrium correction factor for the insufficiency of k_d-corrected ionization current in the cavity.

3. Results and discussion

In Fig 1, the variation of the ionization current of the Exradin A5, A6, PTW 32002 and SC graphite chambers with temperature is given. The correlation coefficients of the linear fit are excellent and better than 0.99. In the figure, the slope of the straight fit line is the temperature coefficient. The values are $4.1 \times 10^{-4}/°C$, $4.0 \times 10^{-4}/°C$, $4.3 \times 10^{-4}/°C$ and $2 \times 10^{-5}/°C$ for Exradin A5 and A6, PTW 32002 and SC graphite chambers, respectively.

The standard uncertainties of the temperature coefficients propagated from the uncertainties of the corrections, the statistical uncertainties of the ionization current measurements and the estimation of the slope in the straight line fit process are 3 parts in 10^5 for the plastic chambers and 1 part in 10^5 for the graphite chamber, respectively. The temperature coefficients of the Exradin A5 & A6 chambers are identical within 1 part in 10^5, mainly because the materials and structures of both chambers are the same. The temperature coefficient of the PTW chamber is slightly larger than those of the Exradin chambers.

Considering that the uncertainty level is greater than 2 parts in 10^3 for the primary standards

of air kerma and absorbed dose, the standard uncertainty of the temperature coefficients is minor and is essentially negligible as it is combined to obtain the overall uncertainty in the key comparison measurements with those chambers among the national metrology institutes.

It should be noted that there may be factors contributing to the temperature dependence of the cavity chamber response such as structural loosening of the cavity chamber. It may not be possible by experiment to separate the thermal expansion effect from a structural distortion. This means that in precision dosimetry we have to measure the temperature effect of the cavity chamber directly until we find evidence of structural integrity, even if we know the thermal expansion coefficient of the chamber materials.

5. Conclusion

The temperature dependence of the ionization current produced in the cavity ionization chambers was measured at room temperature in a range of 17 to 27 ℃. The temperature coefficients are 4.1×10^{-4}/℃, 4.0×10^{-4}/℃, 4.3×10^{-4}/℃ and 2×10^{-5}/℃ for Exradin A5 and A6 chambers, PTW 32002 chamber and graphite chamber, respectively.

In precision measurement, calibration and international comparison, it is recommended that measurement be made at temperature close to the reference temperature. If this is not possible, the temperature dependence of the cavity ionization chamber response should be considered. It is advisable to measure the temperature dependence directly or otherwise to add a temperature-dependent uncertainty of roughly a tenth of the net amount of the cavity gas density correction caused by the difference of the measurement temperature from the reference temperature when certain plastic chambers are used.
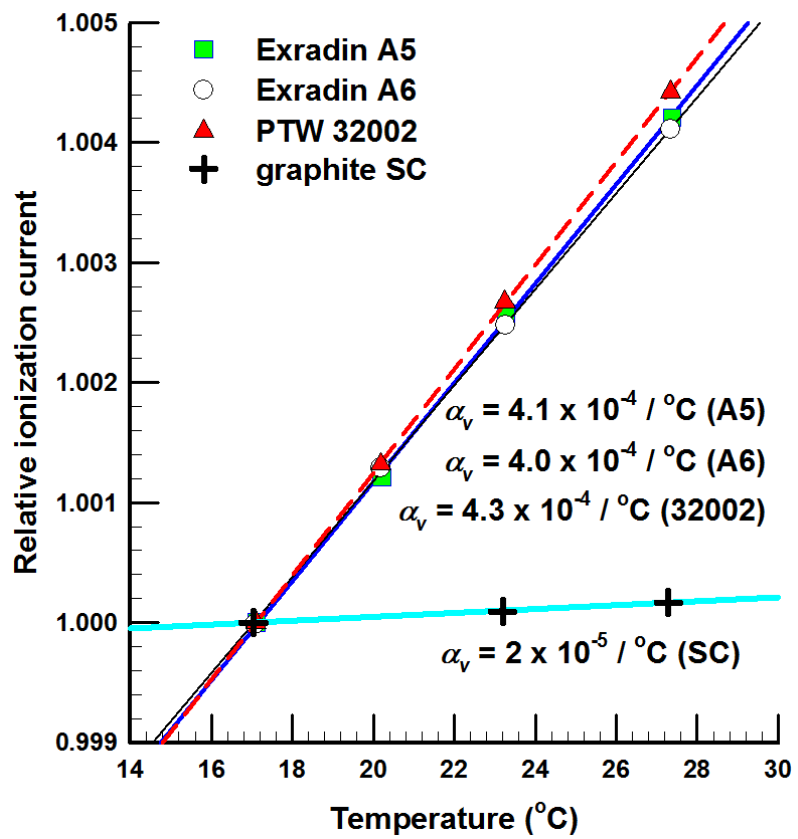
Fig. 7. Temperature coefficients of the cavity ionization chambers.