Journal of Environmental Radioactivity 144 (2015) 9–14

Contents lists available at ScienceDirect

Journal of Environmental Radioactivity

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

Short communication

On the calibration of a radon exhalation monitor based on the electrostatic collection method and accumulation chamber

Yanliang Tan [a, *], Shinji Tokonami [b], Masahiro Hosoda [c]

[a] Department of Physics and Electronics, Hengyang Normal University, Hengyang, Hunan Province 421008, China
[b] Department of Radiation Physics, Institute of Radiation Emergency Medicine, Hirosaki University, Hirosaki, Aomori 036-8564, Japan
[c] Hirosaki University Graduate School of Health Sciences, Hirosaki, Aomori 036-8564, Japan

ARTICLE INFO

Article history:
Received 18 October 2014
Received in revised form
1 February 2015
Accepted 14 February 2015
Available online 13 March 2015

Keywords:
Radon exhalation monitor
Electrostatic collection method
Accumulation chamber
Calibration

ABSTRACT

The radon exhalation rate can be obtained quickly and easily from the evolution of radon concentration over time in the accumulation chamber. Radon monitoring based on the electrostatic collection method is not interfered with by ^{220}Rn. In this paper, we propose that the difference between radon and ^{218}Po concentrations in the measurement cell of this kind of radon exhalation monitor is the main system error, and it changes with time and different effective decay constants. Based on the results of simulation experiments, we propose that the calibration factor obtained from the suitable experiment cannot completely correct the system error, even if it is useful to reduce the measurement error. The better way for reducing measurement error is to use the new measurement model which we have proposed in recent years.

1. Introduction

The radioactive gas, radon, has become a significant indoor air pollutant (Hanson, 1989). Because most radon is from the emanation of soil, a lot of measurements of radon and radon flux have been widely performed in the world (Sheets, 1993; Atwood, 2006). Building materials are also a contributing source of indoor radon (Sahoo et al., 2011). The contribution of building materials towards indoor radon depends upon the radium content and exhalation rates and can be used as a primary index for radon levels in dwellings (Kumar et al., 2014). Radon also is a tracer for different physics and chemistry processes (Huxol et al., 2013; Evangeliou et al., 2013; Tait et al., 2013; Santos et al., 2012). Radon or radon flux anomalies are precursors for earthquakes (Reddy et al. 2004) and volcano eruptions (Tuccimei et al., 2010). The radon exhalation rate from the ground can represent the CO_2 flux (Tuccimei and Soligo, 2008). Radon exhalation measurements are useful for environmental and geophysics study (Jayaratne et al., 2011; Immé et al., 2014; Bavarnegin et al., 2013; Mahur et al., 2013; Abdallah et al., 2012). Therefore, it is important to develop an accurate, reliable, and easy method for the estimation of radon exhalation rate.

Radon exhalation can be measured by accumulation chamber technique (Tan et al., 2012; Tan et al., 2013a); this technique is also named “Sealed-can technique” (Saad et al., 2013) or “Can technique” (Kakati et al., 2013). This technique is based on the accumulation of radon gas inside a chamber, and radon exhalation rate can be obtained by radon concentration measurements. Many kinds of radon detectors can be used to perform the measurements, for example: Activated carbon (Deynse et al., 1999), Scintillation cell (Quindos-Poncela et al., 2003), solid-state nuclear track detectors (SSNTDs) (Saad et al., 2013), Pulse ionization chamber (Röttger et al., 2001), Electret Ion Chamber, Electrostatic collection (Roca et al., 2004), and so on.

If the evolution of radon concentration in the accumulation chamber can be measured with time, the radon exhalation rate can be obtained quickly and easily (Tan and Xiao, 2011a), so, the radon concentration in the accumulation chamber must be measured continuously. This kind of Radon monitor based on solid state silicon detectors and radon progeny electrostatic collection can count only the ^{218}Po decay, which means that radon measurements are not interfered with by ^{220}Rn. In previous works, we have proposed a complex model to correct data obtained with quick measurements of radon exhalation; the reason and method for non-equilibrium correction to ^{218}Po; a novel algorithm for quick and continuous tracing the change of radon concentration (Tan et al., 2011a, 2011b). Based on the principle of non-equilibrium

* Corresponding author.
E-mail address: hytyl@163.com (Y. Tan).

http://dx.doi.org/10.1016/j.jenvrad.2015.02.012
0265-931X/

correction to ^{218}Po, we developed several methods for measuring radon exhalation rate (Tan et al, 2011a, 2012, 2013a).

As we know, a radon monitor must be calibrated in a standard radon chamber. Some kinds of radon exhalation monitor are also calibrated on standard facilities simulating radon exhalation (Kotrappa et al., 1996). There is a standard facility of radon exhalation rate in the Radon Laboratory of the University of South China, and different types of radon exhalation monitors based on electrostatic collection method and accumulation chambers are calibrated on this equipment.

To the authors' knowledge, there is no commercial radon exhalation monitor based on electrostatic collection using the non-equilibrium correction to ^{218}Po in measurement. In this paper, we will present the measurement errors of calibrated radon exhalation monitors based on electrostatic collection in different conditions through mathematic simulation.

2. Materials and methods

2.1. The accumulation chamber technology

Accumulation chamber technology: An accumulation chamber covers the surface of the medium, and the radon exhaled from the material accumulates in the sealed chamber. A radon monitor is used to measure the radon concentration in the chamber continuously.

There are two ways to measure the radon concentration in the accumulation chamber. The first is to draw air from the accumulation chamber into the measurement cell of the radon monitor by a pump; the air then returns to the accumulation chamber. After a short time, the radon concentration in the accumulation chamber becomes equal to that of the measurement cell. The second is to use the measurement cell as an accumulation chamber; radon diffuses into the measurement cell directly.

For simplifying analysis, the pump rate is high to make the radon concentration in the measurement cell become equal to that in the accumulation chamber quickly. In this condition, the same model can be used for describing the radon concentration in the measurement cell, although there are two ways for measuring the radon concentration in the accumulation chamber, and it is (Ujic et al., 2008)

$$C(t) = \frac{JS}{V\lambda_{eff}}\left(1 - e^{-\lambda_{eff}t}\right) + C_0 e^{-\lambda_{eff}t} \approx \frac{JS}{V\lambda_{eff}}\left(1 - e^{-\lambda_{eff}t}\right) \quad (1)$$

where $C(t)$(Bq m^{-3}) is the radon concentration in the measurement cell; J(Bq m^{-2} s^{-1}) is radon exhalation rate; C_0(Bq m^{-3}) is the initial value of radon concentration in the chamber and equals the environmental radon concentration (which is negligible); S (m^2) is the area in the bottom of the chamber; V (m^3) is the volume of the total accumulation chamber (including the volume of the pipeline and the measurement cell); and λ_{eff}(s^{-1}) is an effective decay constant of radon, including decay constant λ, back-diffusion coefficientλ_b, and chamber leakage coefficient λ_{leak}.

A radon monitor based on the electrostatic collection method cannot measure the radon activity directly; it just measures the ^{218}Po activity which is collected on the surface of alpha detector by electrostatic field. It must be calibrated by a standard radon chamber; when the ^{218}Po activity reaches a state of equilibrium with radon activity in the internal cell of radon monitor, then the radon concentration can be expressed by the ^{218}Po concentration. Although the collection efficiency of the electrostatic field and the detection efficiency of the alpha detector is lower than 100% (Wang et al., 1999), the calibrated ^{218}Po concentration with standard radon chamber equals the radon concentration, so that, the work principle of the radon monitor based on electrostatic collection method is (Tan et al., 2011a, 2011b):

$$C_{Po} = C_R \quad (2)$$

Based on the theory of non-equilibrium correction to ^{218}Po (Tan et al., 2011a, 2011b), the ^{218}Po concentration in the measurement cell is

$$\frac{dC_{Po}}{dt} = \lambda_{Po}C(t) - \lambda_{Po}C_{Po} \quad (3)$$

$$C_{Po}(0) = 0 \quad (4)$$

Inserting Equation (1) into Equation (3), the solution of Equation (3) is

$$C_{Po}(t) = \frac{\frac{JS}{\lambda_{eff}V}\left(\lambda_{eff} - \lambda_{eff}e^{-\lambda_{Po}t} - \lambda_{Po} + \lambda_{Po}e^{-\lambda_{eff}t}\right)}{\lambda_{eff} - \lambda_{Po}} \quad (5)$$

where C_{Po} is the calibrated ^{218}Po concentration with standard radon chamber in the measurement cell; λ_{Po} is the decay constant of ^{218}Po equaling 0.0037 s^{-1}.

2.2. The difference between radon and ^{218}Po concentration in the measurement cell

Equation (1) subtracts Equation (5),

$$\Delta C = \frac{JS}{V\lambda_{eff}}\left[\left(1 - e^{-\lambda_{eff}t}\right) - \frac{\lambda_{eff} - \lambda_{eff}e^{-\lambda_{Po}t} - \lambda_{Po} + \lambda_{Po}e^{-\lambda_{eff}t}}{\lambda_{eff} - \lambda_{Po}}\right] \quad (6)$$

Fig. 1 illustrates that the difference between radon and ^{218}Po concentrations is large; it becomes approximately zero after the radon concentration reaches a steady state. The reason is the radon and ^{218}Po concentration will be steady and equal$\frac{JS}{V\lambda_{eff}}$.

The radon concentration errors from this kind of radon monitor in different measurement cycles (according the period you want the radon monitor to take a reading) result in the error of radon exhalation rate. Although the difference between radon and ^{218}Po concentration is small when measurement time is long enough, radon exhalation rate cannot be obtained from the steady radon concentration in the accumulation chamber. The reason is that the two parameters (the radon exhalation rate and effective decay

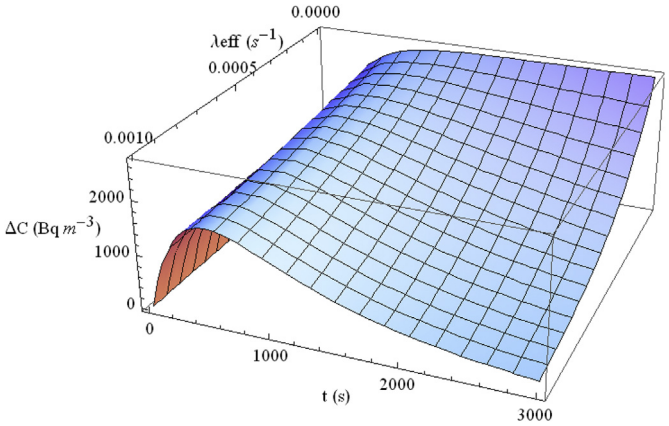

Fig. 1. The evolution of difference between radon and ^{218}Po concentrations vs. time and effective decay constant when $\frac{JS}{V} = 10Bqm^{-3}s^{-1}$.