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Setup and procedure for routine measurements of radon exhalation rates of building materials

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ABSTRACT

A practical procedure and the necessary setup for routine measurement of the exhalation rate of ^{222}Rn from building materials are described. The setup comprises a continuous radon monitor, based on an ionization chamber, and a relatively large-volume accumulation chamber. The experimentalist can interact with the setup in real time via a PC. Therefore it is possible to determine the exhalation rates by determining the optimum accumulation time before the effects of back-diffusion and radon decay set in. This, in turn, reduces the time required to test a sample and makes the setup useful for routine measurements. The exhalation rate values (Bq m^{-2} h^{-1}) for selected building materials made from gypsum, marble, ceramic, and granite were found to be 1.63, 2.29, 3.99 and 5.39 Bq m^{-2} h^{-1}, respectively. The optimal test-times for the samples ranged from 9 to 19 h.

1. Introduction

The global population – weighted average annual effective dose from exposure to natural sources of radiation is 2.4 mSv y^{-1}, out of which 1.3 mSv y^{-1} is due to radon and its decay products (UNSCEAR, 2008). The largest source of indoor radon is the pressure-driven influx from subsurface soil. In the absence of this influx, or where it has been drastically reduced through appropriate remediation, building materials can be the next most important source of indoor radon. There is concern (Al-Azmi et al., 2008) over the growing trend of covering floors and walls with tiles as it may result in higher indoor radon levels if the building materials contain high concentrations of radium and have high radon exhalation rates.

Different hazard indexes have been developed to assess the radiological significance of building materials and to decide whether or not to subject them to restrictions or further investigations. These indexes are mainly based on their ^{226}Ra, ^{4}K and ^{232}Th contents (EC, 1999). But it has been realized that hazard indexes should also account for the ^{222}Rn exhalation and emanation properties of the building materials (van der Graaf et al., 2001; Tuccimei et al., 2006). This implies that routine screening of building materials for radioactivity should include measurements of their ^{222}Rn exhalation rates, which will require simplified practical procedures and apparatus.

Designing experiments to measure the free radon exhalation rates from soil or/and building materials presents a practical challenge. Majority of the well-known methods employ accumulation chambers in association with a variety of radiation detectors, e.g. scintillation cell or Lucas cell (Sundar et al., 2003), ionization chamber (Al-Jarallah et al., 2001), electret (Righi and Bruzzi, 2006; Kotrappa and Stieff, 2008; Fathabadi et al., 2013), solid state alpha detectors (Keller et al., 1982; Tuccimei et al., 2006; Tan and Xiao, 2011), nuclear track detectors (Maged and Ashral, 2005), etc. These methods often require long accumulation times, during which the ambient or free exhalation is perturbed due to the effects of back-diffusion, which may ultimately invalidate the results unless they are subjected to further analyses (Sundar et al., 2003; Tuccimei et al., 2006). The radon measuring device used in the present study (AlphaGuard PQ2000PRO) is based on ionization chamber. One of the goals of this study is to develop a standard and fast procedure for routine determination of the free exhalation rates of radon from building materials.

2. Theory of radon exhalation rates from materials of finite dimensions

The time rate of change in the radon concentration *C(t)* inside a closed chamber containing the exhaling material is described by a linear differential equation:

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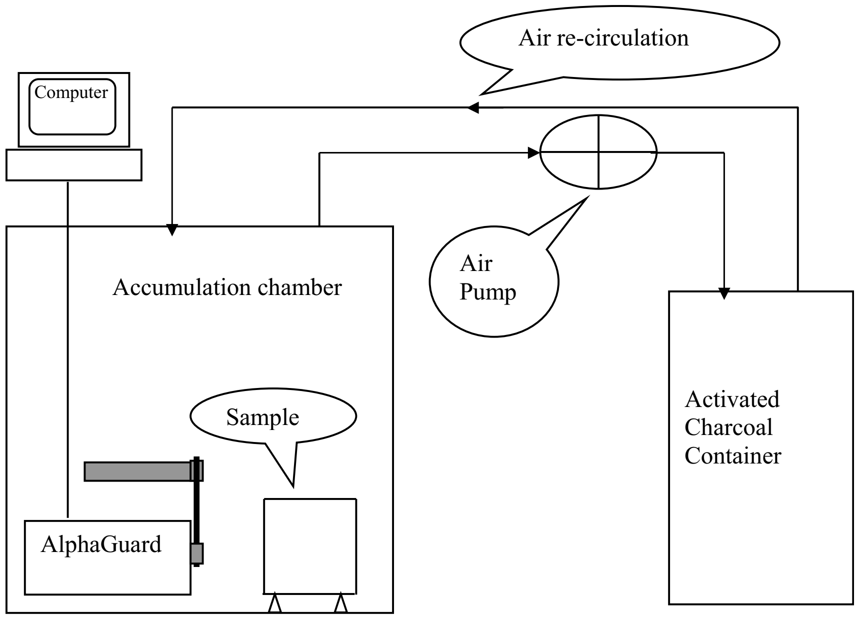

Fig. 1. Schematic diagram of the setup in the radon filtering mode.

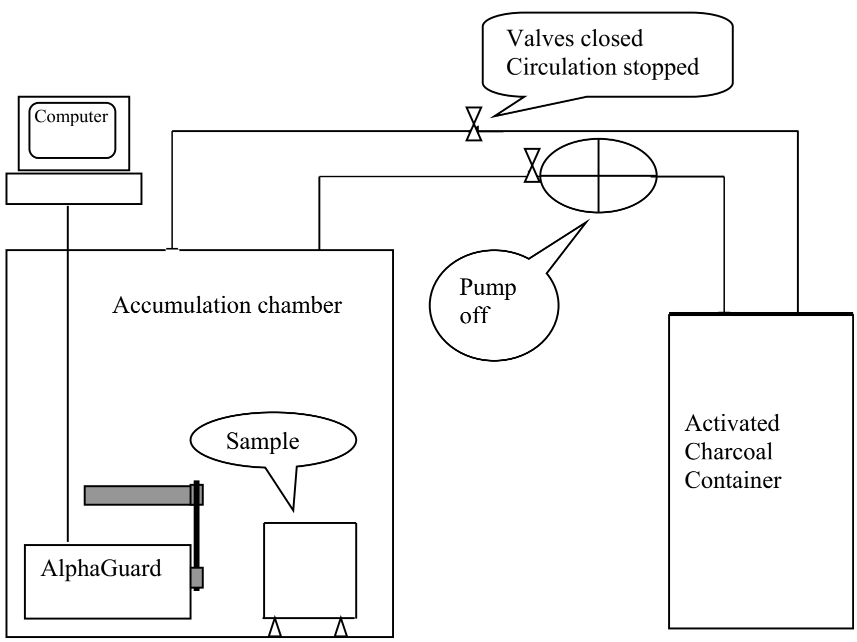

Fig. 2. Schematic diagram of the setup in the radon accumulation mode.

$$\frac{dC(t)}{dt} = J\frac{S_A}{V} - C(t)\{\lambda_{eff}\} \quad (1)$$

Where *C(t)* is the radon concentration ($Bq\ m^{-3}$) in the chamber at time *t*, *J* ($Bq\ m^{-2}s^{-1}$) is the time independent radon flux or area exhalation rate of the material of surface area S_A (m^2), *V* is the volume of air in the container (m^3), λ_{eff} is the effective radon decay rate (s^{-1}), comprising leakage between the chamber and outside air, radioactive decay of radon, and back diffusion into the exhaling material. Equation (1) assumes that the concentration of radon outside the chamber is negligibly small compared to *C(t)*, and the solution, for initial condition $C(t = 0) = 0$, is:

$$C(t) = \frac{JS_A}{V(\lambda_{eff})}\left(1 - e^{-(\lambda_{eff})t}\right) \quad (2)$$

For practical purposes the exponential term increases slowly with time, hence it can be expanded into a power series and the second and higher powers of *t* can be neglected (Keller et al., 1982). This is true for times *t* for which $(\lambda_{eff}).\ t \ll 1$ and equation (2) reduces to a linear relationship between *C*(*t*) and *t*, i.e.

$$C(t) = \frac{JS_A}{V} t \text{for}(\lambda\text{eff}).\text{t}\angle\angle 1 \quad (3)$$

A plot of *C*(*t*) versus *t* for times satisfying equation (3), i.e. the initial linear portion of the graph, will yield a slope $S = \frac{JS_A}{V}$ from which the value of *J* can be evaluated.

3. Materials and methods

3.1. Setup and procedure for radon exhalation rate measurement

The apparatus includes a radon accumulation chamber (about

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