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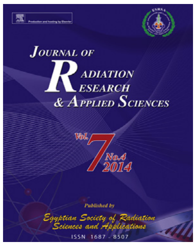

Radon exhalation rates corrected for leakage and back diffusion – Evaluation of radon chambers and radon sources with application to ceramic tile

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ABSTRACT

The natural radon decay, leakage and back diffusion are the main removal processes of radon from its container. Ignoring these processes leads to underestimate the measured value of radon related parameters like exhalation rate and radium content. This work is aimed to evaluate two different radon chambers through determining their leakage rate λ_v and evaluation of radon source by determine its back diffusion rate λ_b inside the evaluated radon chambers as well as a small sealed cup. Two different methods are adapted for measuring both the leakage rate and the back diffusion rate. The leakage rate can be determined from the initial slope of the radon decay curve or from the exponential fitting of the whole decay curve. This can be achieved if a continuous monitoring of radon concentration inside the chamber is available. Also, the back diffusion rate is measured by sealing the radon source in the chamber and used the initial slope of the buildup curve to determine λ_b and therefore the exhalation rate of the source. This method was compared with simple equation for λ_b based on the ratio of the source to the chamber volume. The obtained results are applied to ceramic tile as an important radon source in homes. The measurement is targeted the ceramic glaze before and after firing as well as the obtained tile after adhere the glaze on the tile main body. Also, six different tile brands from Egyptian market are subjected to the study for comparison.

1. Introduction

Above certain level of radon concentration, radon in homes represents a serious health hazard (WHO, 2009). The main health risk associated with long-term, elevated exposure to radon is an increased risk of developing lung cancer, which depends on the radon concentration and the length of exposure. Also, the damaging effect of radon in the blood and bone marrow was expressed as a reduction in the mitotic index and an increase in chromosome damage (Abo-Elmagd, Daif, & Eissa, 2008). Although radon is formed mainly in the soil and

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Nomenclatures

Radon concentration (Bq m^{-3})

C	radon concentration inside chamber at time t
C_∞	equilibrium radon concentration inside chamber
C_b	initial concentration of radon inside chamber in leakage measurement
C_L	non ideal radon concentration inside chamber without radon source inside (with leakage)
C_I	ideal radon concentration inside chamber without radon source inside (no leakage)
C_o	background radon concentration in the laboratory

Removal process (h^{-1})

λ	natural radon decay constant
λ_v	leakage rate
λ_b	back diffusion rate
λ^*	total removal process ($\lambda + \lambda_b + \lambda_v$)

Volume and area

V	effective volume of the test chamber (m^3)
V_s	the volume of the used radon source (m^3)
A	surface area of the radon source (m^2)

Initial slopes (Bq m^{-3} h^{-1})

M_I	initial slope of the ideal radon concentration decay curve inside chamber, without radon source inside (no leakage)
M_L	initial slope of the non ideal radon concentration decay curve inside chamber, without radon source inside (with leakage)
M_e	initial slope of the radon buildup curve inside chamber

Radon exhalation rates

E_o	initial areal radon exhalation rate (free) of radon source (areal) (at $C = 0$) (Bq m^{-2} h^{-1})
E	radon exhalation rate (bound) of radon source at concentration C (Bq m^{-2} h^{-1})
E_m	mass exhalation rate of radon source (Bq kg^{-1} h^{-1}), where
m	the mass of the used radon source (kg).

Effective Radium content

$Ra_{Eff.}$ (Bq kg^{-1})

rock upon which a house is built, exhalation from building materials is another potential source of radon in the indoor environment (UNSCEAR, 2008; WHO, 2009).

The common building materials like concrete, sandstone, brick, marble, granite and tile are the major construction and decoration materials. There is considerable public concern about radon exhalation from building materials, especially those used for interior decoration like ceramic tile which considered as an important source that contributes to indoor radon concentration through exhalation from walls and floors.

Ceramic tile has a two-piece body made up of a clay-based ceramic body covered with a glaze to provide waterproofing, durability and decoration. Glaze is a thin layer (750–500 μm) of glass or glass and crystals that adheres to the surface of the clay body to provide a smooth surface on the item. Glazes are mixtures of silica, SiO_2, and boric oxide, B_2O_3 (which form the glass), and various transition metal oxides that give the colors. Other metal oxides are also added to alter various properties of the glaze as desired (Casasola, Rincón, & Romero, 2012). Zircon, in the form of sand and/or flour, is added to the glaze as opacifier and whitening agent (15–20%). All zircon materials contain uranium and thorium in the crystal lattice. The nature of the zircon crystal is such that the removal of uranium and thorium is not easily accomplished without destruction of the crystal lattice (Verità, Righi, Guerra, & Jeyapandian, 2009). Basically two radiation exposure pathways are associated with ceramic tiles and other building materials: external exposure due to gamma-decay of naturally-occurring radionuclides, and internal exposure through inhalation of radon gas and its short-lived decay products (Abo-Elmagd, Soliman, Salman, & El-Masry, 2010).

The contribution of radon from the building materials can be expressed in term of radon exhalation rate and effective radium content which is one of the most important tools for the selection of building materials for construction (Kumar & Chauhan, 2013; Stoulos, Manolopoulou, & Papastefanou, 2003). Sealed cup technique being a simple and low cost passive technique and it is widely used to measure the exhalation rates. The sample under study is sealed inside the cup for a long period. As the radon concentration around the sample grow, radon atom diffusing back to the material due to porous nature of the materials thus lowering the equilibrium radon concentration inside the accumulator. This phenomenon was known as back diffusion and causes an underestimate of true radon exhalation rate (Petropoulos, Anagnostakis, & Simopoulos, 2001; Sahoo & Mayya, 2010). Due to this problem, the sealed cup technique suffers from some uncertainty in the results of exhalation rates. However, if the volume of sample in canister is about 10% of the volume of canister the back diffusion effect can be neglected (Samuelson, 1990). But for the materials with low radium concentration like some building material the equilibrium radon concentration of the sample are low for a precise measurement and require more than 10% volume of the sample. On the other hand the sample of high activity can be measured using the radon chamber. In this case back diffusion can be neglected but the chamber leakage can also underestimate the true exhalation rate.

This work is aimed to correct the measured exhalation rate for leakage and back diffusion using different methods and equipment.

2. Theoretical approach

2.1. Radon concentration

The radon concentration inside radon chamber can be expressed by the following radon mass transfer equation: