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Soil radon gas in some soil types in the rainy season in Ho Chi Minh City, Vietnam

Phong Thu Huynh Nguyen[a,b], Van Thang Nguyen[a], Ngoc Ba Vu[a], Van Dong Nguyen[c], Hao Le Cong[a,b,*]

[a] Nuclear Technique Laboratory, University of Science, VNU-HCM, 227 Nguyen Van Cu Street, District 5, Ho Chi Minh City, Viet Nam
[b] Department of Nuclear Physics and Nuclear Engineering, Faculty of Physics and Engineering Physics, University of Science, VNU-HCM, 227 Nguyen Van Cu Street, District 5, Ho Chi Minh City, Viet Nam
[c] Department of Analytical Chemistry, Faculty of Chemistry, University of Science, VNUHCM, 227 Nguyen Van Cu Street, District 5, Ho Chi Minh City, Viet Nam

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ABSTRACT

Field experiments on soil radon and radium concentrations were carried out in eighteen locations in Ho Chi Minh City, Vietnam. Soil radon depth profiles (10–100 cm) of loam, sand and clay soil samples in the rainy season were measured using RAD7 radon detector. Mean concentrations of ^{222}Rn and ^{226}Ra were found to be 28.6 ± 2.0 Bq.kg^{-1} and (1.56 ± 0.06) × 10^4 Bq.m^{-3} in clay soil while they are 31.2 ± 2.5 Bq.kg^{-1} and (1.15 ± 0.05) × 10^4 Bq.m^{-3} in loam soil. They are 30.7 ± 2.0 Bq.kg^{-1} and (9.37 ± 0.52) × 10^3 Bq.m^{-3} in sandy soil, respectively. Values of radon diffusion length and diffusion coefficient for different soils were obtained using semi-empirical fit method linked to the poor diffusion of gas in clay soil (0.2 × 10^{-6} m^2 s^{-1}), the moderate diffusion coefficient (0.9 × 10^{-6} m^2 s^{-1}) in loam and good diffusion of radon gas in sandy soil (1.4 × 10^{-6} m^2 s^{-1}). An unexpectedly unclear linear relation was found between soil radon concentration and radium content. The grain size smaller than 0.1 mm was dominant reason for the lowest (0.15 ± 0.01) and highest (0.40 ± 0.03) values emanation coefficient for sand and clay soil, respectively. A strong positive correlation was found between radon concentration and soil pH level leads to soil pH is an indirect dynamic parameter affecting the migration of radon in soil.

1. Introduction

Uranium is present in all rocks and soils, so are radium and radon because they are daughter products formed by the radioactive decay of uranium. As each atom of radium decays, an alpha particle is ejected. The newly formed radon atom recoils in the opposite direction. Alpha recoil is the most important factor affecting the release of radon from soil grains. The genealogy of thorium contains a gaseous element, radon-220. Due to the half-life of radon 220 is only ∼55 s, this form of radon is less dangerous than that released by uranium. Therefore, on top of the telluric radiations, the contribution of radon-222 (hereafter radon), as well as its radioactive progeny, should be considered as the principal natural source of exposure to radiation. Radon can move into houses because of pressure differentials, and a large concentration gradient between the building (house) and bedrock or soil (Nazaroff, 1992). The radon concentrations in houses relate closely to that in the soil, although there is no completely exactly method for estimating radon levels in individual dwellings based on soil radon data. At least 80% of the radon emitted into the atmosphere comes from the top few meters of the ground (Abumurad and Al-Tamimi, 2001). Findings have suggested that there are direct correlations between uranium, radium, radon in soil gas, and indoor radon concentrations (Forkapic at al., 2017; Mahur et al., 2013; Kitto, 2005; Vaupotic et al., 2002). So that, radon's properties can be used as a geophysical tracer for locating buried faults and geological structures, in exploring for uranium, and for predicting earthquakes (Mirhabibi et al., 2014; Zoran et al., 2012).

When radon atoms located within solid grains, they are not easily released into the atmosphere, due to their very low diffusion ability in solids (IAEA, 2013). However, if they are located in the space between the soil particles, they may completely diffuse to the surface into the atmosphere as soil gas.

The emanation coefficient of radon in soil is defined as the fraction of radon atoms generated that escape the solid phase (soil particles) and toward the intergranular space. The emanation coefficient depends on radium distribution, particle size, moisture and mineralogy (IAEA, 2013). These factors determine how many radium atoms are close

* Corresponding author. Nuclear Technique Laboratory, University of Science, VNU-HCM, 227 Nguyen Van Cu Street, District 5, Ho Chi Minh City, Viet Nam.
E-mail address: lchao@hcmus.edu.vn (H. Le Cong).

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enough to the surface of the grain to allow the radon to escape into the intergranular space. Soil moisture content can increase radon emanation. However, if the soil pores become saturated, the emission is inhibited (Strong and Levins, 1982; Bossew, 2003; Breitner et al., 2010).

Radon in the interstitial space may be transported to the surface by diffusion and convection, even during their brief lifetime. Convection may be significant in some cases owing to surface cracks or holes, gas production, transport in water or the presence of large voids. However, the dominant transport mechanism is diffusion, and therefore the transport of radon is commonly referred to as diffusion (IAEA, 2013). The radon diffusion length characterizes the radon's ability to move from the soil to the surface. It is a measure of the mean distance traveled by radon atoms in the soil matrix before their radioactive decay. The radon diffusion length depends not only on the soil type but also its pore size distribution, its water content and the degree and method of its compaction (IAEA, 2013).

Slessarev et al. (2016) stated that there is an abrupt transition from alkaline to acid soil pH that occurs at the point where mean annual precipitation begins to exceed mean annual potential evapotranspiration. Following that rapid changes in water balance caused by precipitation might leave an increasing number of soils out of equilibrium with climate. This leads to soil pH is a dynamic parameter and it is one of the important measures of soil's capacity to fulfill environmental and economic functions (Rengel, 2011). In addition, Mark Baskaran (2016) has reported that amount of precipitation can affect the transport time scale of radon from subsurface to surface. From the point of view of the link between the amount of rainfall in a region and soil pH, changes in soil pH can presumably provide useful information about soil properties and migration or transport of radon in natural soil.

With regard to radon behavior in some soil types in Ho Chi Minh City, Vietnam, the purpose of this study was to determine the activity concentrations of radon and radium and the coefficients of diffusion and emanation of radon in some soil types such as loam, clay and sandy soil in the rainy season. Some soil characters of soil samples including soil radium content, grain size, water situation and soil pH were measured for association or correlation between variables.

2. Experimental

2.1. Description of the site

Ho Chi Minh City (hereafter HCMC) is located in the south of Vietnam and is the biggest City in Vietnam. It is located from 10°10′ to 10°38′ North and 106°2′ to 106°54′ East. It is 1730 km from Hanoi and is at the crossroads of international maritime routes (Le et al., 2015). HCMC has two distinctive seasons, which is rainy and dry. The rainy season usually starts in May and ends in November. Dry season lasts from December to April, is hotter than rainy season and nearly has no rain. Mean temperature in a year is 27 °C. The concentration levels of radionuclides originated from the natural (soil, water and air) are normally low (Le et al., 2015, Le et al., 2017; Pham et al., 1994).

Fig. 1 shows the location map of the sites in Ho Chi Minh City, Vietnam. The soil of HCMC are mainly formed upon two sediment classes exposed on the surface: Pleixtoxen and Holoxen. The Pleixtoxen sediment occupies most of the North, Northwest and Northeast of the city, including Cu Chi, Hoc Mon, Northern Binh Chanh and Thu Duc districts, North and Northeastern District 9. Under the influence of natural factors and human activities, the alluvial sediment forms the specific soil group: grey soil. With more than 45 thousand hectares, or about 23.4% of the city, the grey soil in the city has three types: grey soil, grey soil with reddish-brown and scarier grey soil. The Holoxen sediment had its origin in sea, bays, rivers, mudflats … and consequently formed in some different types of soil. In this study, loam samples of 1, 2, 3, 4, 5, 7, 9 and clay samples of 1, 2, 3, 4 are presented for the Pleixtoxen sediment while loam samples of 6, 8, sand samples of 1, 2, 3, 4, 5 are presented for the Holoxen sediment.

2.2. Radon concentration measurement and determination of diffusion length

The most popular method in the in-situ category is the soil radon depth profiling method. At each site, first look for locations where the soil is uniform and generally free of rocks was conducted then hammer the pilot rod into the ground to the depth required for sampling. Soil radon depth profiles were measured at eighteen locations in HCMC. The distance between adjacent holes was about 50 cm which could be assumed to be the same place of a local environment. Soils at these locations were classified into three types: clay, loamy and sandy soils. All samples had been measured between June and December 2016.

For measurement of radon concentration, a RAD7 detector manufactured by Durridge Company, Billerica, Massachusetts, USA was used. A half hour counting time in the Grab protocol for all sampling points had been taken. In the measurement mode, the pump will run for exactly 5 min. This is followed by a five-minute equilibrium delay, after that the counting period begins. The pump does not run and soil gas will not be put into the chamber at all during the counting period (Durridge, 2017). The RAD7 uses electrostatic attraction to sweep the positively charged polonium daughters of radon to an ion-implanted silicon detector (Durridge, 2017). Soil gas was pumped through the RAD7 chamber at a flow rate of 0.5 $dm^3\,min^{-1}$. The RAD7 detector then converts alpha radiation directly to an electric signal and has the possibility of determining electronically the energy of each particle, which allows the identification of the isotopes (^{218}Po, ^{214}Po) produced by radiation, so it is possible to instantaneously distinguish between old and new radon, radon from thoron, and signal from noise (Durridge, 2017).

In order to obtain the radon concentration as a function of the soil depth, diffusion equation of radon in soil (Domis et al., 2009) should be briefly discussed as following.

$$D\frac{d^2C(z)}{d^2z} - \lambda C(z) + \lambda C_\infty = 0 \quad (1)$$

Where, C(z) ($Bq.m^{-3}$) is the radon concentration in pore-air at depth z (cm); C_∞ ($Bq.m^{-3}$) is the radon concentration at large depth in soil; D is the radon diffusion coefficient of the soil ($m^2.s^{-1}$); and λ is the decay constant of radon (s^{-1}).

The solution of Eq (1) is written:

$$C(z) = C_\infty + Ae^{-\sqrt{\frac{\lambda}{D}}z} + Be^{\sqrt{\frac{\lambda}{D}}.z} \quad (2)$$

Where, A and B are constants; For single homogeneous soil layer, radon concentration at large depth in soil is constant and

$$\left.\frac{dC}{dz}\right|_{z=\infty} = 0 \quad (3)$$

Applying the boundary equation to Eq (4), C(z) reads

$$C(z) = C_\infty + Ae^{-\sqrt{\frac{\lambda}{D}}z} = C_\infty + Ae^{-\frac{z}{L}} \quad (4)$$

Where, L (cm) is the radon diffusion length.

In order to obtain values of radon diffusion length for different soils, we have fitted the data in Figs. 2–4 functions of the type (Domis et al., 2009).

2.3. Determination of some characteristics of the soil samples

At each location, all the soil samples from 10 to 100 cm collected were packed in polyethylene bags, then transported to the laboratory where they were used for further investigations. Following that, the water content (%) is calculated from the sample weight before and after drying at 105°C-110 °C to a constant weight in the oven. Weight of dried soil is W_d. The moisture content (MC) was then calculated as Eq (5).