Determination of ^{222}Rn Diffusion Coefficient in Japanese Soils

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ABSTRACT

Radon (^{222}Rn) diffusion coefficient as one of some important parameters of ^{222}Rn transport in the soil has been measured using soil radon diffusion monitor (SRDM). The system of SRDM consists of two scintillation detectors, sample container located between these detectors, photomultiplier tubes, amplifiers, single channel analyzers and personal computer. The source of ^{222}Rn is put in the one of the compartment, and ^{222}Rn will diffuse through the sample to other compartment. The diffusion coefficient was determined by calculating the measured data from two detectors using time-dependent diffusion model. The samples come from different places in Japan with several porosities and water contents. The diffusion coefficients were found to vary from (8.68±0.23) x10^{-7} m^2s^{-1} to (4.39±0.43) x10^{-6} m^2s^{-1}. Furthermore, the correlations between ^{222}Rn diffusion and water content and/or porosity are also discussed.

INTRODUCTION

Soil and rock are the source of most ^{222}Rn exposed to the people. An understanding of the sources and transport processes accounting for ^{222}Rn in indoor air is of considerable importance. The characteristics of soil as permeability, moisture content, porosity, and ^{222}Rn diffusion coefficients are some of important parameters used in this transport process (1,2).

The diffusion of ^{222}Rn in soil has been investigated for different purposes and by several methods. Schroeder found by surface flux measurements a ^{222}Rn diffusion coefficient of 0.02 cm^2s^{-1} for moist glacial debris, while dry, sandy alluvium showed a ^{222}Rn diffusion coefficient of 0.10 cm^2s^{-1} (3). Soogaard –Hansen and Damkjaer measured ^{222}Rn diffusion length from 160 cm to 190 cm for dry silt, and gravel, and 1 cm for wet clay (4). Cohen, et al. found by compact apparatus using scintillation detector a diffusion coefficient of 0.061 cm^2s^{-1} (5). It's well known that water in soil pore will reduce ^{222}Rn diffusion coefficient (6), so in any measurement of ^{222}Rn diffusion, the water content also determined.

This paper presents a method to determination of ^{222}Rn diffusion coefficients in a porous material, along with the measurement results of diffusion coefficients in Japanese soils.

THEORY

The present work uses a diffusion column as sketched in Figure 1. Compartment 1 has a volume V_1 and ^{222}Rn concentration C_1 and compartment 2 has a volume V_2 and ^{222}Rn concentration C_2. It is assumed that the material is of thickness, H_0, produces P_0 $Bqm^{-1}s^{-1}$ and has a diffusion constant, D_0. The basic theory of this method has been described previously by de Meijer (7).

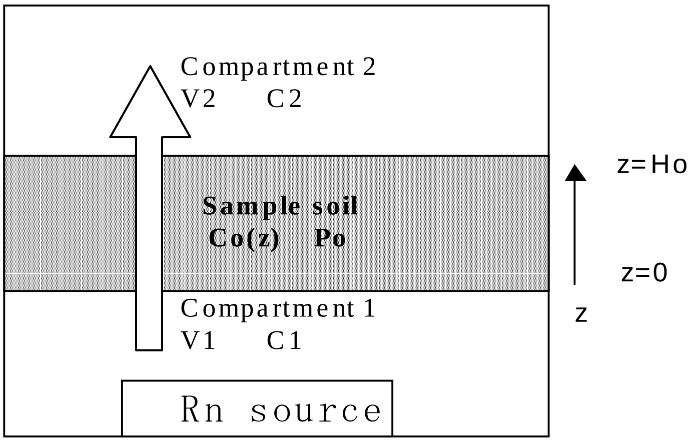

Figure 1 The schematic cross section of diffusion chamber.

The time dependent equation describing the concentration, C_0, is given by Fick's Law:

$$\frac{dC_0}{dt} = D_0 \frac{d^2 C_0}{dz^2} + P_0 - \lambda C_0 \tag{1}$$

where λ =the decay constant for ^{222}Rn.

In steady state $\frac{dC_0}{dt} = 0$ and Eq.1 transforms into:

$$\frac{d^2 C_0}{dz^2} - \frac{\lambda}{D_0} C_0 = -\frac{P_0}{D_0} \tag{2}$$

The boundary conditions at equilibrium are:

$C_0(z=0)=C_1$ and $C_0(z=H_0)=C_2$ (3)

Eq (2) becomes

$$\frac{d^2 C_0}{dz^2} - \frac{C_0}{l_0^2} = -\frac{P_0}{D_0} \tag{4}$$

with $l_0^2 = \frac{D_0}{\lambda}$, l_0 =diffusion length.

The solution of Eq.4 is given as:

$$\mathrm{C}_0(\mathrm{z}) = \mathrm{A}\sinh\left(\frac{\mathrm{z}}{\mathrm{l}_0}\right) + B\cosh\left(\frac{z}{l_0}\right) + \frac{P_0}{\lambda} \tag{5}$$

From the boundary conditions in Eq.3 it follows that:

$$A = \frac{C_2 - C_1\cosh\beta - P_0(1-\cosh\beta)/\lambda}{\sinh\beta} \tag{6a}$$

$$B = C_1 - \frac{P_0}{\lambda} \quad \text{with} \quad \beta = \frac{H_0}{l_0} \tag{6b}$$

At equilibrium, the concentration C_2 is given by :

$$E_0 A_0 = \lambda C_2 V_2 \quad (7)$$

where E_0 is the exhalation from the area A_0 and is given as:

$$E_0 = -D_0 \left[\frac{dC_0}{dz} \right]_{z=H_0} \quad (8)$$

Substitution of Eqs.5, 6 & 8 in Eq. 7 yields:

$$C_2 = \frac{A_0 l_0 \left[C_1 - \frac{P_0 (1 - \cosh \beta)}{\lambda} \right]}{V_2 \sinh \beta + A_0 l_0 \cosh \beta} \quad (9)$$

EXPERIMENTAL PROCEDURE

The Figure 2 shows the schematic diagram of soil radon diffusion monitor (SRDM). As shown in that figure, the parts of B_1 and B_2 are each a stainless steel container with a 20 cm diamater cylinder of height 16 cm. The sample plate A with a 9 cm diameter cylinder of height 16 cm is placed between these stainless steel container. The sections of C_1 and C_2 are the ZnS(Ag) scintillation detectors with diameter 5.2 cm of height 10 cm.

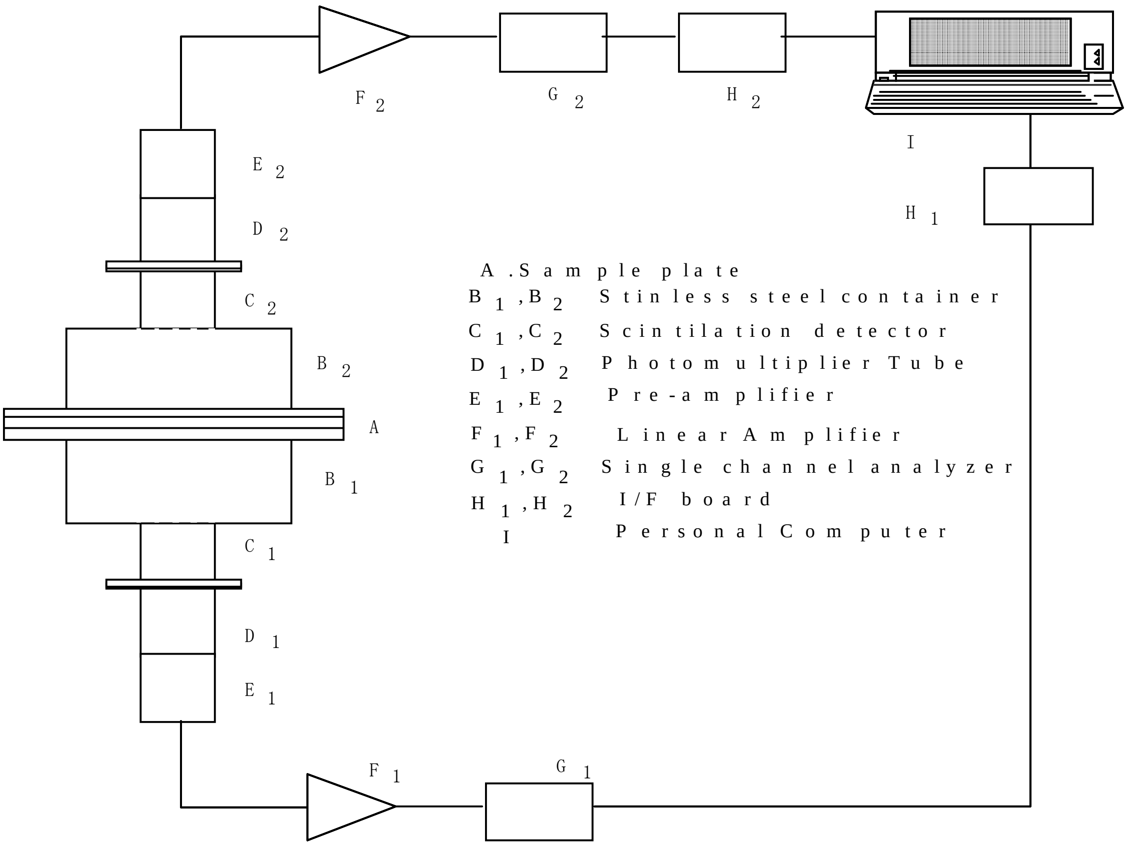

Figure 2 Schematic of experimental set up.

This SRDM was calibrated in radon calibration facility of Nagoya University. The SRDM was put in the 247.8 L calibration chamber, and ^{222}Rn concentration was measured by ionization chamber made by Ohkura Electric Co. Japan.

The sample used in this experiment come from different places in Japan with several porosities, water contents, densities, and ^{226}Ra concentration. The characteristics of soil was determined using the standard procedures as described by M.Nakano (8).

The sample to be examined was packed in the sample plate A, and ^{222}Rn source was put in the compartment 1. Then the compartment 1 and compartment 2 were tightly closed. By the time, ^{222}Rn will grow in the compartment 1, and after that it will diffuse through the sample to the compartment 2. The concentrations of ^{222}Rn in both compartments were measured every 1 hour for about 3 to 4 weeks. The diffusion coefficient of ^{222}Rn in the soil was calculated by the equation 9.

RESULTS AND ANALYSIS

Each experiment gave a curve of ^{222}Rn growth in the SRDM as shown in Figure 3, for example. This curve shows the ^{222}Rn concentration in the compartment 1 contains the ^{222}Rn source and in the compartment 2. Also it is shown the ratio between compartment 1 and compartment 2, which it is as the first indication for the calculation of diffusion coefficient.

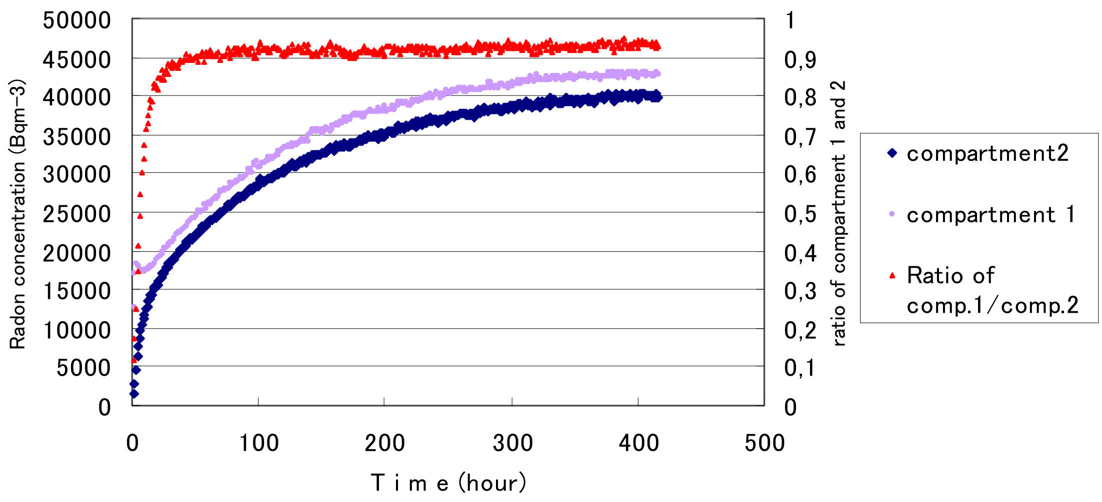

Figure 3 Radon growth of the Okayama Prefecture soil sample at SRDM.

The values of ^{222}Rn diffusion coefficients calculated from each measurement are listed in Table 1 along with the soil characteristics as porosity and water content. The q factor defined as D/D_{air} also is shown (D_{air} = 1.1×10^{-5} m^2s^{-1} (9)). The correlation between the diffusion coefficient and soil porosity and/or soil moisture is shown in Figure 4.

Table 1 The diffusion coefficients of ^{222}Rn in several Japanese soils.

No.	Material	water content (%)	Porosity (%)	Diffusion coefficient (m^2s^{-1})	q (D/Dair)
1.	Sandy, Nagoya, Aichi Pref.	6	54	(1.61+0.09)x10-6	0.147
2.	Dry sandy, Fukui Pref.	0	64	(1.53+0.12)x10-6	0.139
3.	Sandy, Fukui Pref.	12	62	(8.68+0.23)x10-7	0.079
4.	Sandy, Okayama Pref.	17	44	(3.91+0.45)x10-6	0.355
5.	Sandy, Okayama Pref.	21	46	(2.99+0.32)x10-6	0.271
6.	Sandy, okayama Pref.	11	41	(4.39+0.43)x10-6	0.399

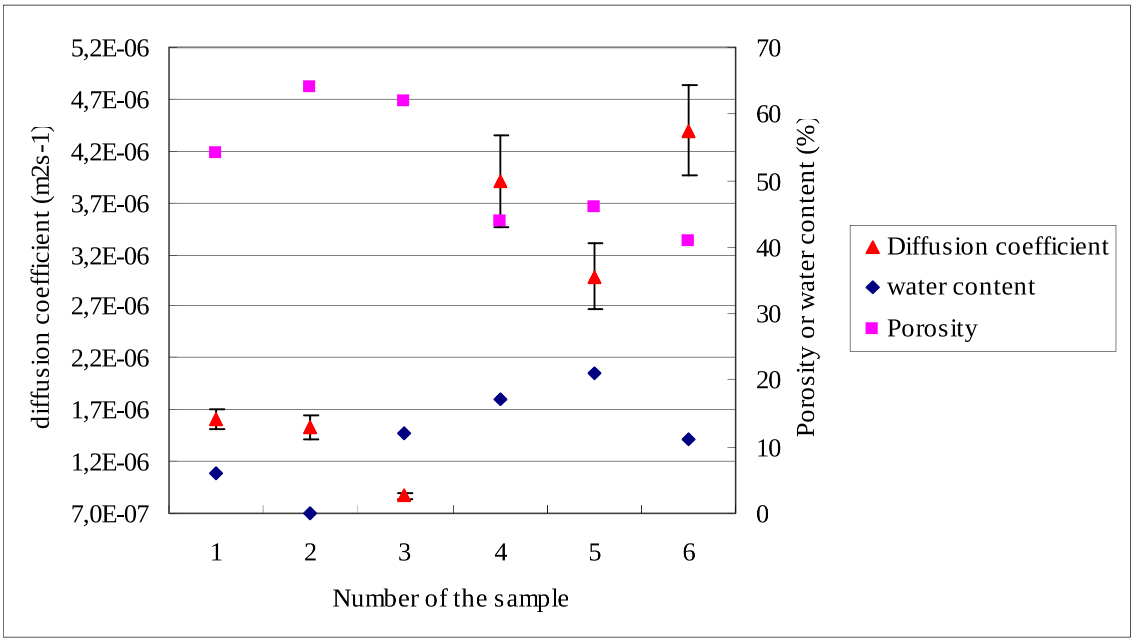

Figure 4 The correlation between diffusion coefficient and soil porosity and/or water content.

In general, the diffusion coefficients reported by V.C.Rogers (6) is in the same range with the value in Table 1, but with Schroeder (2) and Soogard Hansen (3) are slightly lower. This can be described according to the sample used in this paper was a raw materials. An examination of these results shows a correlation between water content and ^{222}Rn diffusion coefficients.

CONCLUSIONS

The method used in this experiment has shown a good result to determine ^{222}Rn diffusion coefficients in the soil and other porous materials. The ^{222}Rn diffusion coefficients in the Japanese soils were found to vary from (8.68±0.23) x10^{-7} m^2s^{-1} to (4.39±0.43) x10^{-6} m^2s^{-1}. The values depend on the characteristics of the soil as water content and porosity.

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