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Behaviour Analysis of Indoor Radioactive Aerosols

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Abstract

The deposition of radioactive aerosols from radon daughter, which are potentially harmful to human health. The inhalation of short-lived radon decay products (RnPs) yields the greatest contribution to natural radiation exposure. This research deals with a study carried out to improve the knowledge of the behaviour of RnPs, their interaction with particulates and the plate-out during the time. The tests confirmed that a high aerosol particle concentration increases the probability that an ion sticks to aerosol and remains long in the air, leading to both an increase in equilibrium factor (F) and a decrease of unattached fraction (f_p). The results performed in a radon calibration chamber (free of particles) showed a reduction of F (and the average of ~ 0.1 %) because in an environment the plate-out phenomenon prevails over the attachment to particulate. Besides, the high circulation fan speed (~2.9 ms^{-1}) in the radon calibration chamber has been a more significant effect on the plate-out of attached radon progeny (~0.040±0.002 Bq $cm^{-2}h^{-1}$).

Keywords: Radon decay products; Plate-out; EERC

Introduction

Radon is a naturally occurring radioactive gas, that is derived from the breakdown of uranium in the earth's crust, which provides a continuous source of radon. Radon concentration levels depend sturdily on geological and geophysical conditions, as well as on atmospheric influences. Consequently, radon escapes from the ground and accumulates in rooms according to the strength of its emanation and its reduction by ventilation. High radon concentration in indoor air, in addition to long exposure periods related to indoor habitation, makes indoor radon a potential hazard, due to most people spend nearly 90% of their life [1]. Once in the atmosphere, the radon atoms decay to produce the short-lived (^{218}Po, ^{214}Pb, ^{214}Bi, ^{214}Po) and long-lived (^{210}Pb, ^{210}Bi, ^{210}Po) radioactive decay products. They are formed as positive ions or atoms, which are able to deposit on surfaces or attach to the particles of room air. The airborne radon decay products deposit in the human respiratory tract by inhalation and damage the sensitive tissues of the respiratory tract [2-5]. It is essential to evaluate the characteristics of the radon progenies because the dose is strongly dependent on the location of radioactive aerosol deposition in the respiratory tract and hence on the aerosol size distribution of the aerosol particles [6-8]. Porstendörfer's [9] study is well described the dynamic processes of radon decay products in the air. First, the freshly produced ^{218}Po, which reacts very fast (~few seconds) with water molecules and trace gases forming small clusters which have a size diameter in the range of 0.5nm-5nm (unattached progeny). The clusters may attach to aerosol particles producing radioactive aerosol or, alternatively, to plate out on walls, floors and furniture. These two processes are in rivalry and take place over a period of a few minutes. The time period of the two processes depends on several physical parameters such as aerosol concentration, room dimensions and the nature of the furniture surface. The ^{214}Pb ion follows the same process as the parent ion. The stability time of radioactive aerosol in either r is may some hours' duration for normal aerosol. The parameter that summarises the potential risk of radon progenies defines as the Potential Alpha Energy Concentration (PAEC) (due to both attached and unattached radon progeny contributions). For the decay chain of radon, PAEC is the total alpha energy that emits from all radon decay products present in a

volume of air, along the decay chain till ^{210}Pb and it is given by the following equation:

$$PAEC = (6.003+7.687)\ C_1 + 7.687C_2 + 7.687C_3 \quad (1)$$

where PAEC is expressed in MeV/L, C_1, C_2 and C_3 are the concentrations (atoms/L) of ^{218}Po, ^{214}Pb and ^{214}Bi, respectively, and 6.003 and 7.687 the alpha energy emission (in MeV), respectively, for ^{218}Po and ^{214}Po. The concentration of ^{214}Po could be negligible due to it is very short half-life. It can be confirmed that the PAEC associated with the radon progenies in equilibrium with 1 Bq of radon is 34,700 MeV. The actual PAEC is lower than this value because many radon progenies plate out on walls, floors and furniture are removed by ventilation before decaying to ^{210}Pb. The ratio of the actual PAEC to the total potential alpha energy associated with the radon concentration in a room is called the equilibrium factor (F).

$$F = \frac{PAEC}{34.7xC_{Rn}} \quad (2)$$

where PAEC is in MeV/L and C_{Rn} is the radon activity concentration in Bq/m^3. Based on the United Nations Scientific Committee on the Effects of Atomic Radiation [10] reported the typical values of F were 0.4 and 0.6 for indoor and outdoor radon, respectively.

Material and Method

Radon calibration chamber at the Institute of Radiation Emergency Medicine (IREM)

The study was carried out in the IREM radon calibration chamber of $3.24m^3$ (the dimension of). (Total area of $12.24m^2$; dimensions of $2.25\times1.2\times1.2m^3$; surface/volume ratio of $0.26m^{-1}$), located at Hirosaki University, Japan. Radon levels may be varied in a range of ~1000-3000 Bqm^2 by the dry/humid flow-through the natural uranium rock and then input to the mixing chamber. The radon concentration is kept steady by means of continuous pumping. The schematic diagram of the calibration system was shown in Figure 1.

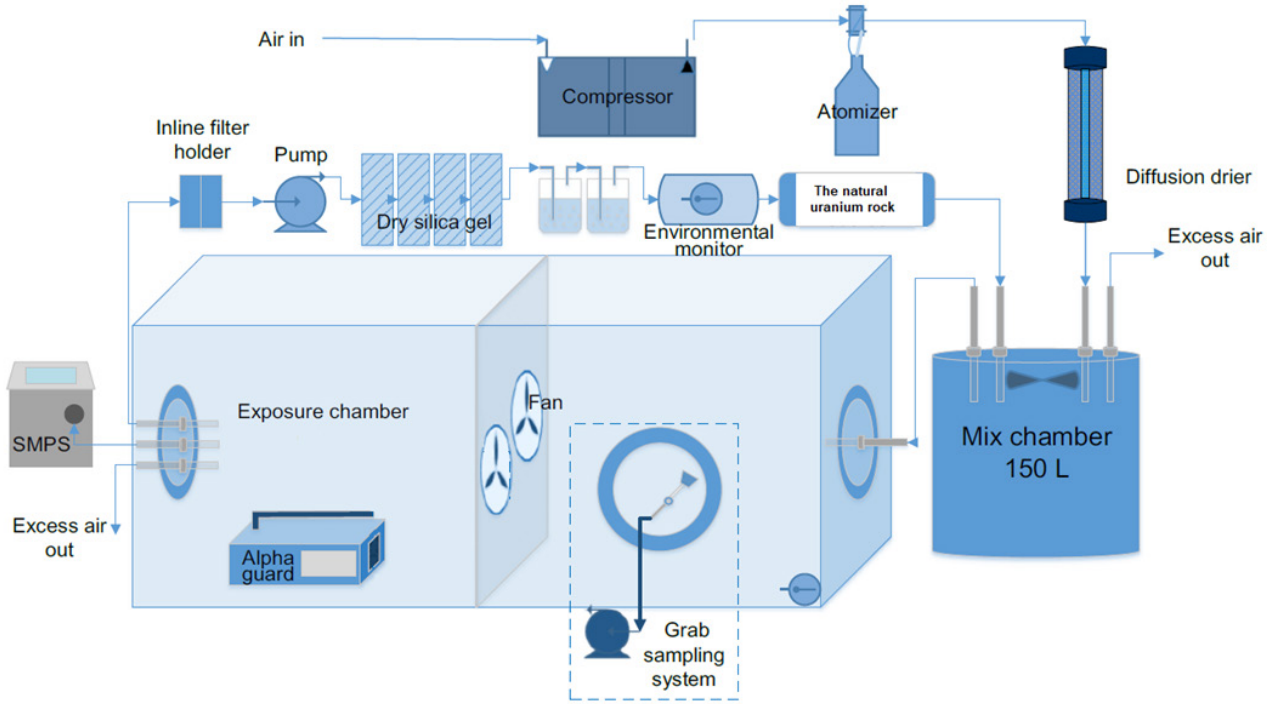

Figure 1: Schematic diagram of IREM's radon calibration chambers.

Radon and radon progeny measurement

The radon concentrations were monitored every hour by the pulse-type ionizing chamber (Alpha GUARD, PQ2000PRO, Genitron Instruments GmbH, Germany), which was calibrated by Physilalish Technische Bundesanstalt (Braunschweig, Germany). The instrument was operated with a diffusion mode, recording temperature, pressure, and relative humidity. Radon progenies were measured every hour by grab-sampling the air in the chamber through a 400 mesh-wire screen (unattached progeny) and glass fiber (attached progeny) filter (GF/F, Whatman) at a constant flow rate of $10Lmin^{-1}$. Then, counting the total activity on the wire-screen and filter by the measurement systems join Ludlum's model 2000 Scaler and Model 43-10 Alpha ZnS (Ag) Scintillator counter for specified time intervals after the end of sampling, such three time intervals proposed by J W Thomas [11,12].

Aerosol particle measurement

SMPSTM Scanning Mobility Particle Sizer produced Model 3034 by TSI® was adopted to measure the concentration of

condensation nuclei, count media diameter and its standard deviation. It measured aerosol particles in the range from ~10 to 500nm.

Aerosol generator

The effects of artificial aerosol sources on radon progeny concentration were studied by aerosol generator Model 3076 (TSI Constant Output Atomizer). In each test, radon, radon progeny and aerosol particle concentrations were monitored before and during aerosol production.

The plateout rate on the chamber wall

The plated-out activity on the surfaces of internal chamber walls was measured directly by a membrane filter (MF-Millipore 0.65 um MCE membrane) placed on the wall surfaces. After every 1 h for 5h, the filters were counted the total activity by the measurement systems joining Ludlum's model 2000 Scaler and Model 43-10 Alpha ZnS(Ag) Scintillator counter for specified time intervals. The counting of samples began 1 min after their removal from the chamber. The plateout rate was reported in Bq cm^{-2} h^{-1}.

Results and Discussion

Tests without aerosol sources

Three tests were performed in the IREM's radon calibration chamber in the non-artificial aerosol sources to evaluate the variability of F; radon levels were generally in the range of 1000-3000Bqm^3. The results are summarized in Table 1. For all the monitoring time was 10h. The equilibrium factor (F) showed a variability, from 0.0054 to 0.0073 with an average value of 0.0064±0.0013. In these conditions, the unattached fraction (f_p), defined as the ratio of $PAEC_{free}/PAEC_{total}$, ranged from 0.88 to 0.92. A low aerosol particle concentration (ranging between 150 and 400 #/cm^3 with a mode of 20nm) provided a low average value of F and a high value of fp may be due to the predominance of the plateout processes on the attachment to aerosol. However, in a small room plateout is quicker than attachment to aerosol particles, thus f_p, was higher than in the large room particles [13].

Table 1: Results obtained in the radon calibration chamber in the free-of-particle source.

Average Radon Concentration (Bq m^{-3})	F (%)	f_p (%)
860	0.73	90
2040	0.65	92
3110	0.54	88

Tests with aerosol source

The results were summarized in Table 2. During the production of aerosols at radon concentration ~2000Bqm^{-3}, the attached fraction can be observed, while the unattached fraction falls down. As the PAEC increases while $PAEC_{free}$ fell. These effects are also clearly visible of attached and unattached radon progeny. Moreover, after ~2h the aerosol concentration has a nearly stable value of 2.3 x 10^5 #cm^{-3}. The particle size distribution of aerosol is a median of 120nm.

Table 2: Result of the effect of aerosol on radon progeny's behaviour in air.

	Before Aerosol Generated	After Aerosol Generated
Radon concentration (Bq m^{-3})	2040±231	2060±248
$PAEC_{total}$ (MeV L^{-1})	543±89	16971±487
$PAEC_{free}$ (MeV L^{-1})	505±83	287±88
F (%)	0.65	38
f_p (%)	92	2
Particle average concentration (cm^{-3})	348	2.3x10^5
Average size distribution (nm)	35.2	119.7

Test the plateout rate on the chamber wall

Six tests were carried out to evaluate the plateout in the radon calibration chamber at a radon concentration of 2000Bqm^{-3}. The test conditions were free of aerosol and high aerosol conditions at the operation of fan-on (wind speed ~1.4ms^{-1} and ~2.9ms^{-1}), and fan-off (wind speed ~0.02 ms^{-1}). The plateout results were summarized in Table 3. The plateout activity of the fan-off condition at free aerosol was higher than the fan-on conditions, whereas the fan-off condition at aerosol generated was lower than the fan-on condition. These effects might cause by the plateout phenomenon of unattached progeny in the case of free-aerosol and the attached phenomenon to particulate in the case of aerosol generated at the fan-off condition (~0.02ms^{-1}), or an increase in aerosol concentrations resulting in a decrease of plateout. However, the plateout activity at free aerosol decreased when the windspeed increased, whereas the plateout activity was increased when the windspeed increased at high aerosol conditions. Therefore, the effect of windspeed has been more significant for the plateout of attached radon progeny.

Table 3: Radon progeny activity plateout.

Fan Operation (m s^{-1})	Average Plateout Rate (Bq cm^{-2} h^{-1})	
	Before Aerosol Generated	After Aerosol Generated
~0.02	0.1114±0.0038	0.0090±0.0017
~1.4	0.0669±0.0048	0.0213±0.0027
~2.9	0.0485±0.0058	0.0399±0.0017

Conclusion

In the absence of an aerosol source, the equilibrium factor (F) is variable and quite low (Average 0.0064±0.0013). The fp is slightly high (Average 0.90+0.33). The plateout rate of the unattached

fraction is high with the introduction of an aerosol source, the level of total PAEC was 30 times the initial value, while the unattached fraction is drastically reduced. In the examined conditions the interaction of radon progeny with aerosols seems to be independent of aerosol size distribution, chemical concentration, and composition. Indeed, the same increase in attached PAEC and the decrease in unattached PAEC are observed in tests with aerosols.

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