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UNATTACHED FRACTION AND THE SIZE DISTRIBUTION OF THE RADON PROGENY IN AIR OF A NUCLEAR FACILITY

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ABSTRACT

The size-distribution of the aerosol-attached radon progeny and the unattached (cluster) fraction were measured by using a low pressure cascade impactor and a single wire screen in a building of the nuclear facility. The radon concentration at the condition of ventilation "ON" was about 50 Bq m^{-3}, but it increased exponentially after ventilation "OFF" and reached to the saturated concentration of about 600 Bq m^{-3}. At the condition of low aerosol concentration without additional aerosol, the activity median aerodynamic diameter, the geometric standard deviation and the unattached fraction were, respectively, 0.3 μm, 2.7-2.9 and 0.3-0.5. On the other hand, at the condition of high aerosol concentration with burning a mosquito coil, these were, 0.3 μm, 2.1 and 0.02-0.03. These yield 2.5 times higher radiation dose conversion factors at the low aerosol condition than the high aerosol condition.

1. INTRODUCTION

The inhalation of airborne radon progeny is a major path of the radiation exposure of general population. The maximum effective dose can be estimated in all dosimetric models for the epithelium bronchi in lung. The size distribution of the aerosol-attached radon progeny and the unattached (cluster) fraction are important physical parameters to estimate this effective dose[1]. There have been very few experimental studies, because of the difficulties of their correct measurements in the environment[2]. Therefore, we measured these quantities by using a low pressure cascade impactor and a single wire screen.

2. EXPERIMENTAL

Measurements were made in a large room of the airtight building equipped with Kyoto University Critical Assembly under the condition of ventilation "ON" and "OFF", and aerosol number concentration "low" (< 500 particles cm^{-3}) without additional aerosol and "high" (about 5000 particles cm^{-3}) with additional aerosol from burning a mosquito coil.

Radon gas concentration was measured continuously by a flow through ionization chamber (effective volume : 6.6 ℓ, sensitivity : 3.3 Bq $m^{-3}fA^{-1}$). Total (unattached and attached) radon progeny were sampled by a membrane filter (pore size : 0.65 μm, flow rate : 1.2 m^3h^{-1}, face velocity : 26.5 cm s^{-1}) and measured by alpha-spectroscopy after sampling. The unattached radon progeny were sampled on a single wire screen (stainless steel, 300 mesh, flow rate : 1.2 m^3h^{-1}, face velocity : 26.5 cm s^{-1}, 50%cut-off diameter : 2.2 nm, collection efficiency : 0.95, count efficiency : 0.79) and measured by alpha-spectroscopy after sampling. Size distributions of the attached radon progeny were measured with the Andersen type low pressure impactor. Table 1 shows the collection characteristics of this impactor. The activity collected on each stage was measured with a ZnS(Ag) scintillation counter after sampling. The aerosol particle number concentration was measured continuously with a particle counter.

Table 1 Characteristics of The Andersen Low Pressure Impactor.

Stage number	Diameter of nozzle(cm)	Numbers of nossles	Pressure (mmHg)	Jet velocity (cm/sec)	50% cut-off diameter(μm)
0	0.212	98		107	9.5
1	0.121	229		141	6.2
2	0.093	229		238	4.2
3	0.073	229		380	2.9
4	0.054	229		706	1.8
5	0.036	229		1587	0.95
6	0.026	229		3043	0.55
7	0.026	134		5201	0.41
L-1	0.025	110	-75	7603	0.30
L-2	0.025	80	-195	12674	0.20
L-3	0.025	80	-350	17465	0.13
L-4	0.025	110	-550	24799	0.056

Condition ; (1) Temperature : 23 ℃, (2) Flow rate : 22.2 l/min

3. RESULTS AND DISCUSSION

The ventilator of the room was stopped from December 28, 12:00 to January 10, 16:00 and the aerosol was generated at January 3, 18:00 from burning a mosquito coil(~10 g). Fig. 1 shows variations of concentration of radon, equilibrium equivalent concentration of total (attached and unattached) radon progeny (total EEC) and equilibrium equivalent concentration of unattached radon progeny (unattached EEC) which were calculated from concentrations of individual nuclide. The equilibrium equivalent concentration of radon is defined as the activity concentration of radon in radioactive equilibrium with its short-lived progeny which has the same potential alpha energy concentration for the actual non-equilibrium mixture.

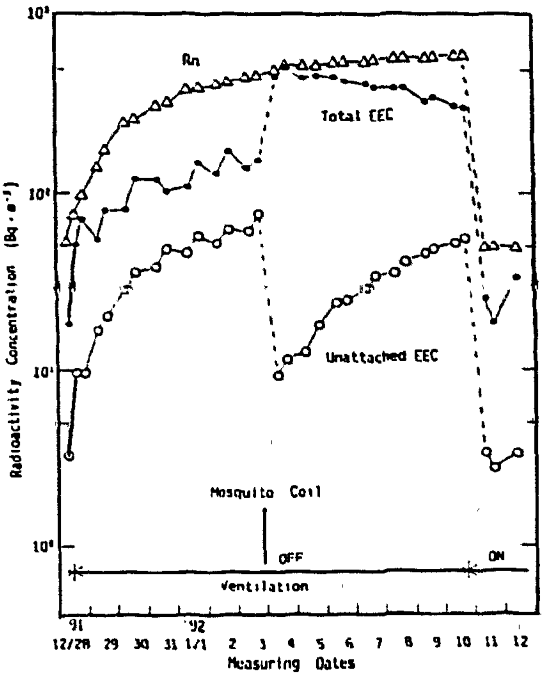

Fig. 1. Variation of concentrations of the radon and its progeny in a room.

The radon concentration at the condition of ventilation "ON" was about 50 Bq m^{-3}, but it increased exponentially after ventilation "OFF" and reached to the saturated concentration of about 600 Bq m^{-3} after two weeks. Aerosol particles did not affect to the radon concentration.

Total EEC at ventilation "ON" was 20-30 Bq m^{-3}, and it increased to 100-200 Bq m^{-3} after ventilation "OFF" with similar pattern to radon. When the aerosol particles were generated, it increased drastically to 500 Bq m^{-3} which was very close to radon concentration. And it decreased very slowly with the decrease of aerosol particles.

Unattached EEC at ventilation "ON" was 3–4 Bq m^{-3}, and it increased to 60–80 Bq m^{-3} after ventilation "OFF" with similar pattern to total EEC. But after the aerosol particles were generated, it decreased drastically to about 10 Bq m^{-3}, and it increased with the decrease of aerosol particles.

Figure 2 shows the typical size distributions of attached radon progeny at various conditions. The data at 12/29 – 1/3 was observed with the condition of the ventilator "OFF" and the aerosol number concentration "low" · without additional aerosol. The data at 1/4 – 1/5 was observed with the condition of the ventilator "OFF" and the aerosol concentration "high" with additional aerosol. On the other hand, the data at 1/11 – 1/12 was observed at the condition of the ventilator "ON". The activity size distributions of radon progeny were relatively well approximated by lognormal distributions. In this measurement, the activity median aerodynamic diameters for three cases were same value of 0.3 μm. The geometric standard deviations were dependent upon the aerosol condition, and those were, respectively, 2.7, 2.1 and 2.9 .

Figure 3 shows the variations of the unattached fraction (fp), the equilibrium factor of the radon progeny (Fp) and the number concentration of Mie particles (diameter ≥ 0.3 μm). The unattached fraction (fp) is defined as the radio of the unattached EEC to the total EEC. The equilibrium factor (Fp) is defined as the radio of total EEC to radon concentration. It is obvious from Fig. 3 that aerosol particles give very large effect to radon progeny in air. At the low aerosol condition before aerosol generation (12/29 – 1/3), Fp and fp were relatively constant, and both were 0.3–0.5. On the other hand, at the high aerosol condition after

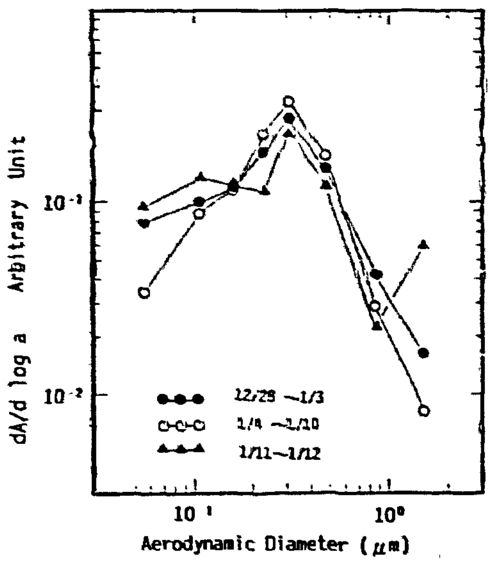

Fig. 2. Size distributions of attached progeny at differentaerosol conditions.

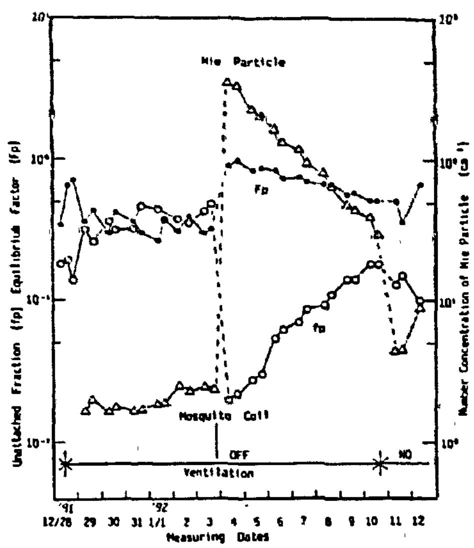

Fig. 3. Variation of unattached fraction and equilibrium factor.

aerosol generation (1/4 – 1/5), Fp was 1.0–0.9 and fp was 0.02–0.03.

4. ESTIMATION OF EFFECTIVE DOSE

The activity size distribution of the radon progeny is a very important parameter to estimate the radiation dose by inhalation. The deposition of the unattached and attached progeny in the human lung by inhalation depends on particle size. The size of unattached progeny was determined to be 1 nm (diffusion coefficient : 0.05 $cm^2\ s^{-1}$) from experiment and theretical calculation[3]. Measured size distributions at various aerosol conditions were used for attached progeny. The dose conversion factors from the intake to the effective dose by inhalation are listed in Table 2 according to Yeh-Shum lung model[4], the regional lung dose concept[5] and the quality factor of alpha particle, taking into account the different size distributions and breathing rate.

Figure 4 shows the results of estimation of the effective dose rate by inhalation with other measuring items. Effective dose rate at ventilation "ON" was 0.7–1.0 μSv/h, and it increased to 10–15 μSv/h after ventilation "OFF" with similar pattern of the other quantities. But when the aerosol particles were generated, it decreased to about 6 μSv/h by the effect of the decrease of unattached progeny. These yield 2.5 times higher radiation dose conversion factors at the low aerosol condition than the high aerosol condition.

Table 2 Dose Conversion Factor (AMD : 0.3 μm)

Deviation σg	Dose conversion factor (Sv/J)	Remarks
2.9	1.6(1−fp)+17fp	1/11~1/12
2.7	1.4(1−fp)+17fp	12/29~1/3
2.1	1.2(1−fp)+17fp	1/4~1/5

Condition of calculation
(1) Yeh-Shum lung model
(2) Regional lung dose concept
(3) Quality factor of α particle : 20
(4) Breathing rate : 1.2 m^3h^{-1}

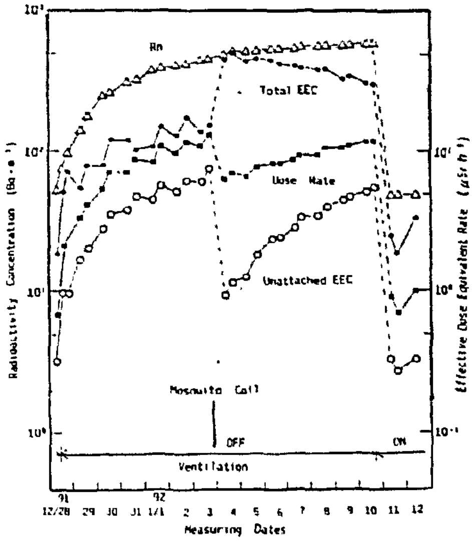

Fig. 4. Variation of effective dose equivalent based on the inhalation of radon progeny in a room.

References

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