Development and Evaluation of an Impactor Sampler for Radioactive Aerosol Particles

Atsuyuki Sorimachi[a*], Chutima Kranrod[a,b], Supitcha Chantrarayotha[a], Shinji Tokonami[a]

[a]National Institute of Radiological Sciences (NIRS), 4-9-1, Anagawa, Inage-ku, Chiba-shi, Chiba 263-8555, Japan.

[b]Chulalongkorn University, Payathai Road,Patumwan, Bangkok 10330, Thailand.

Abstract. This sampler consists of one impaction stage, which allows separation of airborne particles by 1 μm particle size cut-off point with a 50% probability of impaction, followed by a back-up filter at a flow rate of 1 L min^{-1}. The particles size more than and less than 1 μm-diameter are collected on the impactor plate at the nozzle side and on the filter, respectively. A CR-39 detector is mounted on the filter sides of the impaction plate; α particles emitted from the particles less than 1 μm-diameter are counted with the CR-39 detectors. In order to separate α particles emitted from radon, thoron and their progeny, the CR-39 detectors are covered with aluminum-vaporized Mylar films. The total thickness of films is adjusted to let their α particles impinge on the CR-39 detectors. Laboratory tests are going on in terms of the spectral characteristics of α particles before and after passing through the films, the count rate performance of CR-39 detectors by α particles, the actual collection efficiency of aerosol particles on the impaction plate, and so on. This sampler may be able to supply us with an interesting technique for measuring radon and thoron progeny come from the sources of natural radiation such as the naturally occurred radioactive materials.

KEYWORDS: aerosol; CR-39; impactor; Mylar film; radon; thoron.

1. Introduction

The global average annual effective dose of natural radiation is 2.4 mSv and the effective dose of radon (Rn-222) and its decay product comprises 50% of this amount [1]. Thus, radon progeny has been recognized to be one of the most important contributors to worldwide annual per caput effective dose. Generally, atmosphere aerosols of radon and thoron progeny have an aerodynamic diameter in the range of 0.1 to 1 μm [2].

In all dosimetric models for the estimation of the exposure, a considerable fraction of aerosols in the range of < 1 μm may be deposited in the extra-thoratic and bronchial regions, due to different sizes of aerosol particles [3]. On the basis of the epidemiological studies it has been established that the enhanced levels of radon and its progeny can cause health hazards and may lead to serious diseases like lung cancer [4-6].

Current Japanese laws require a lower exposure dose than 1mSv/year out of the mine, in excess of the natural background level. 1mSv/year is equivalent to 9 Bq/m^3 of equilibrium equivalent radon concentration (EECRn). It is necessary to determine the average concentration of radon progeny.

This paper describes development and evaluation of a new impactor sampler for radioactive aerosol particles, such as the aerosol-attached and unattached radon and thoron (Rn-220) progeny, based on track-etching technique with a CR-39 detector.

* Presenting author, E-mail: sorimac@nirs.go.jp

2. Experimental Method

2.1 Structure of impactor sampler

The cross section view of a new impactor sampler is shown in Figure 1. This sampler consists of one impaction stage, which allows separation of airborne particles by 1 μm particle size cut-off point with a 50% probability of impaction, followed by a back-up filter at a flow rate of 1 L min^{-1}. A CR-39 detector was mounted on the filter side of an impaction plate; α particles emitted from the particles less than 1 μm-diameter are counted with the CR-39 detectors. The nozzle side of the impactor plate was coated with grease to reduce particle rebounce [7]. In order to separate α particles emitted from radon, thoron and their progeny, the CR-39 detectors are divided into 4 channels and each channel is covered with proper aluminum-vaporized Mylar films to detect the target nuclides; CH1 is for Po-218, Po-214, Bi-212 and Po-212, CH2 is for Po-214 and Po-212, CH3 is for Po-212 and CH4 is for blank (Table 1). The total thickness of films is adjusted to let their α particles impinge on the CR-39 detectors. The arrangement of the detection channel on the filter side of an impaction plate is shown in Figure 2.

Figure 1: Schematic diagram of an impactor sampler

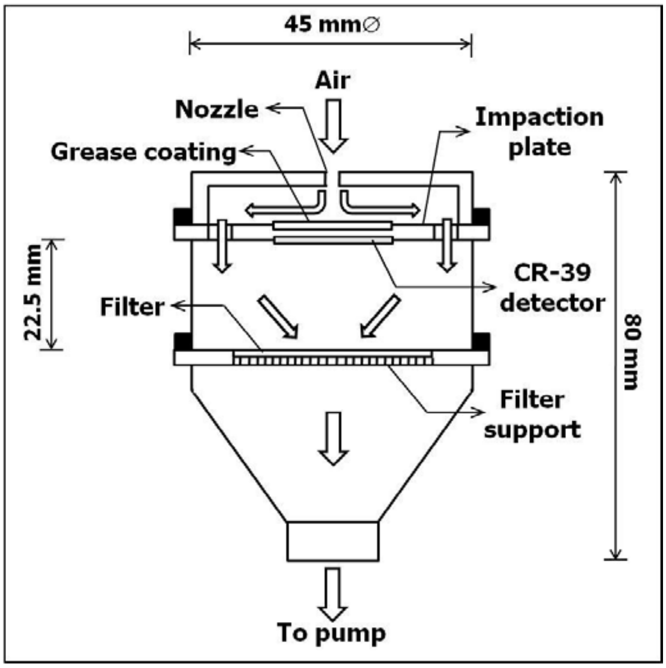


Figure 2: Arrangement of the detection channel on the filter side of an impaction plate

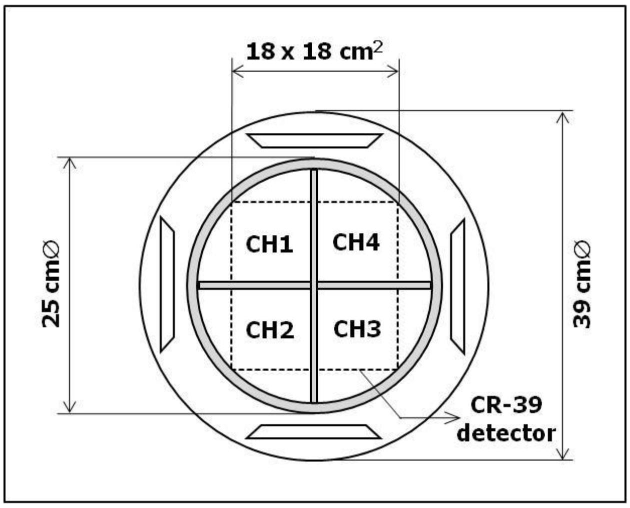


Table 1: Film area densities absorber for each channel

Channel	Film area density (mg cm^{-2})	Cutoff of alpha energy (MeV)	Radionuclide collection
CH1	1.05	4.2	Po-218, Po-214, Bi-212, Po-212
CH2	3.00	6.1	Po-214, Po-212
CH3	5.00	7.7	Po-212
CH4	Blank	—	Po-218, Po-214, Bi-212, Po-212, U-238, Th-232

In order to achieve our purpose, a NIRS radon chamber was used (about 25-m^3 inner volume) [8-9]. Radon concentrations in the chambers were continuously monitored with an interval of 10 min by a commercially available AlphaGUARD (Genitron GmbH, Germany) ionization chamber, which was calibrated by Physikalisch Technische Bundesanstalt (PTB) [10].

In order to test the influence of the detection response of the new impactor on the presence of ambient aerosols, a condensation monodisperse aerosol generator Model 3472S (TSI Inc., U.S.A.) was used [8-9]; aerosol particles were generated by the evaporation-condensation method and supplied into the chamber through the sampling port. Carnauba wax was used as the aerosol material in this study. The continuous particle size distribution was monitored by a scanning mobility particle sizer Model 3936 (TSI Inc., U.S.A.) in combination with an ultrafine condensation particle counter Model 3025A, a long-type electrical classifier Model 3081 and a personal computer [8-9].

In order to confirm the proper film area density for CH1, CH2 and CH3 to let the α particles of radon and thoron progeny impinge on the CR-39 detectors, the various area densities of aluminum-vaporized Mylar film corresponding to α particle energy of radon and thoron progeny were investigated.

The CR-39 detectors were etched for 24 hours at 60˚ C in 6N NaOH solution. The etch-pits were counted by a semi-automatic system using the image processing software. The EECRn and equilibrium equivalent thoron concentration (EECTn) were eventually determined.

2.2 Calculation method for EECRn and EECTn

The EECRn and EECTn are calculated by the equation as follows;

$$EECRn = \frac{\left(E_{\text{Po}-218} \times N_{\text{Po}-218\,\text{in}\,\text{CH1}}\right) + \left(\left(E_{\text{Po}-214} - E_{\text{Po}-218}\right) \times N_{\text{Po}-214\,\text{in}\,\text{CH2}}\right)}{\eta \times T \times V} \times 2.846 \times 10^{-5} \quad (1)$$

$$EECTn = \frac{\left[\left(E_{\text{Bi}-214} \times 0.561\right) + E_{\text{Po}-212}\right] \times N_{\text{CH3}}}{\eta \times T \times V} \times 0.215 \times 10^{-5} \quad (2)$$

where the counts of etch-pits on all channels are obtained with E_{i}, $N_{\text{i-ch}}$, T, V, and η; in which E_{i} is alpha energy of i-nuclide in MeV, $N_{\text{i-ch}}$ is number of alpha tracks due to i-nuclide in the detection area of i-channel, T is collecting period in min, V is flow rate in L min^{-1}, and η is the geometrical efficiency, which was estimated to be 1.07%. $N_{\text{Po-218 in CH1}}$ and $N_{\text{Po-214 in CH2}}$ are obtained by the following equations (3) and (4), respectively;

$$N_{\text{Po}-218\ \text{in}\ \text{CH1}} = N_{\text{CH1}} - \left(\frac{1}{0.6406}\right) N_{\text{CH3}} \quad (3)$$

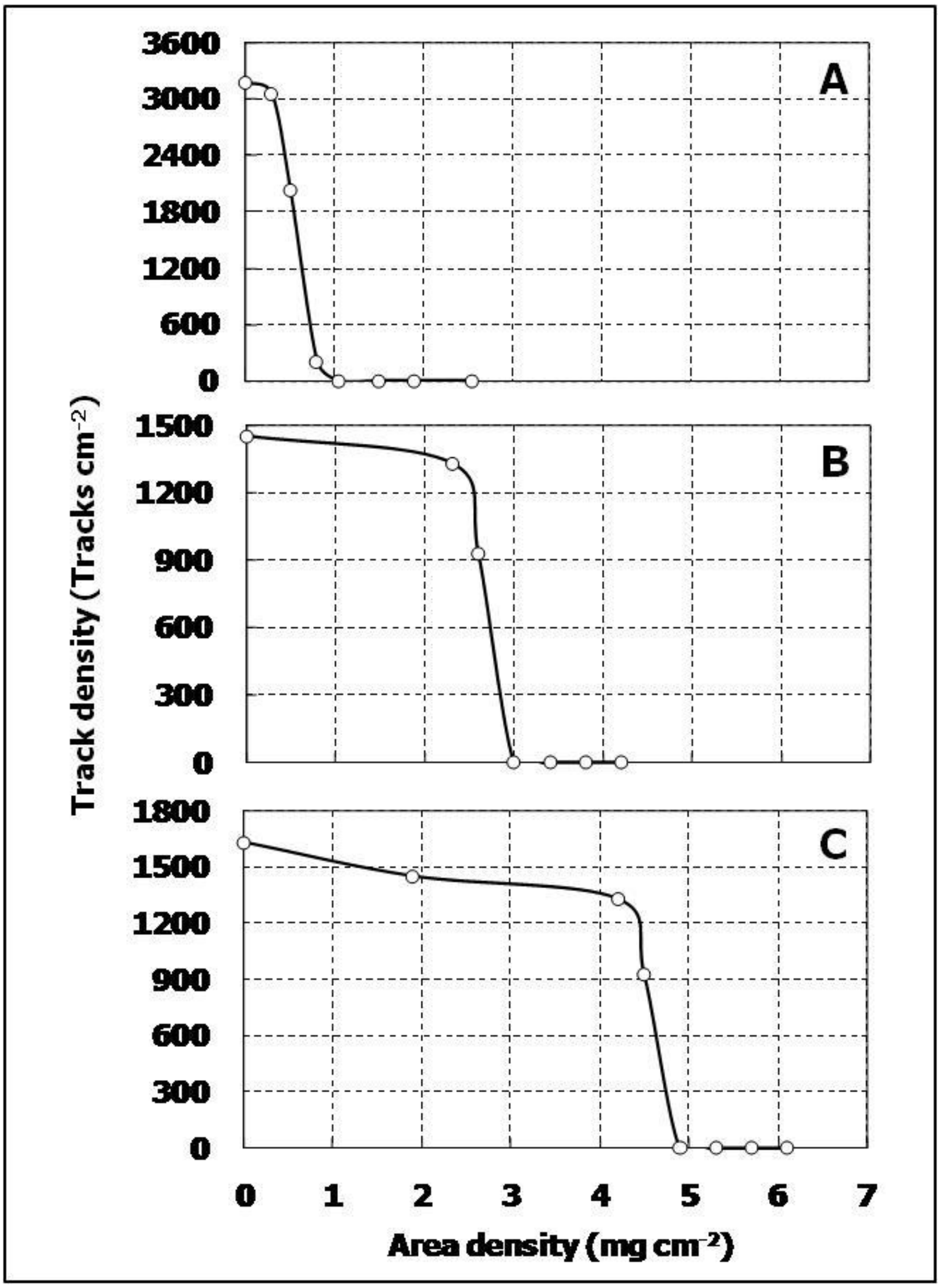
$$N_{\text{Po}-214\ \text{in}\ \text{CH2}} = N_{\text{CH2}} - N_{\text{CH3}} \quad (4)$$

where N_{CH1}, N_{CH2} and N_{CH3} mean the alpha track counts on CH1, CH2 and CH3, respectively. Therefore, $N_{\text{Po-218 in CH1}}$ and $N_{\text{Po-214 in CH2}}$ are counts per unit area of alpha track by Po-218 + Po-214 and Po-214 only, respectively.

3. Results

In order to separate Po-218, Po-214, Bi-212, and Po-212, we used the following three kinds of film area density: about 1.05 mg cm^{-2} for Po-218, Po-214, Bi-212, and Po-212 for 4.2 MeV alpha energy cutoff (from U-238 and Th-232), about 3 mg cm^{-2} for Po-214 and Po-212 for 6.1 MeV alpha energy cutoff, and about 5 MeV mg cm^{-2} for Po-212 for 7.7 MeV alpha energy cutoff. Figure 3 shows the relationship between the track density and the area density of film used for cutoff of alpha energy for 4.2, 6.1 and 7.7 MeV alpha energy. From the experiment results, the area density of each detection channel was determined, as shown in Table 1.

Figure 3: Relationship between track density and area density of film: (A) 1.05 mg cm^{-2} for cutoff alpha energy 4.2 MeV, (B) 3.0 mg cm^{-2} for cutoff alpha energy 6.1 MeV and (C) 5.0 mg cm^{-2} for cutoff alpha energy 7.7 MeV



4. Conclusion

A new impactor sampler was developed for separation and collection of airborne particles by 1 μm particle size cut-off point. This sampler collects airborne particles in 2 sizes range (more than 1 μm on the nozzle side of the impactor plate and less than 1 μm on the filter) by using a pump with a battery and detects α particles from the filter by a CR-39 detector. This device makes possible the long-term measurements of radon and thoron progeny concentration with an AC power source. Then, it is suitable for measuring the integrating radon and thoron progeny in environment. By the way, EECRn and EECTn in our study are calculated theoretically. Hence, the experimental confirmation with other measurement techniques will carry out at outdoor fields in the next study.

REFERENCES

[1] United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), Sources and Effects of Ionizing Radiations. Report to the General Assembly with Scientific Annexes, United Nations, New York (2000).

[2] Gründel, M., Porstendörfer, J., Differences between the activity size distributions of the different natural radionuclide aerosols in outdoor air, Atmos. Environ. 38, 3723 (2004).

[3] Shimo, M., Torii, T., Ikebe, Y., Measurements of unattached and attached RaA atoms in atmosphere and their deposition in human respiratory tract, J. At. Energy Soc. Jap. 23, 851 (1981).

[4] Sevc, J., Kunz, E., Placek, V., Lung cancer in uranium miners and long-term exposure to radon daughter products, Health Phys. 30, 433 (1976).

[5] Axelson, O., Cancer risks from exposure to radon in homes, Environ. Health Persp. 103: Suppl. 2, 37 (1995).

[6] Field, R.W., et al., Residential gas exposure and lung cancer: the low radon lung cancer study, Am. J. Epidemiol. 151, 101 (2000).

[7] Marple, V.A., Rubow, K.L, Behm, S.M., A microorifice uniform deposit impactor (MOUDI): description, calibration, and use, Aerosol Sci. Technol. 14, 434 (1991).

[8] Ichitsubo, H., et al., Development of a radon-aerosol chamber at NIRS – general design and aerosol performance, J. Aerosol Sci. 35, 217 (2004).

[9] Tokonami, S., et al., Intercomparison exercise of measurement techniques for radon, radon decay products and their particle size distributions at NIRS, Jpn. J. Health Phys. 40, 183 (2005)

[10] Ishimori, Y., Ishikawa, T., Tokonami, S., Radon intercomparison experiment at PTB in Germany, Jpn. J. Health Phys. 39, 263 (2004).