Radiation Protection Dosimetry (2017), Vol. 173, No. 1-3, pp. 259–262
Advance Access publication 9 December 2016 doi:10.1093/rpd/ncw333

STUDY ON A STEP-ADVANCED FILTER MONITOR FOR CONTINUOUS RADON PROGENY MEASUREMENT

Lei Zhang[1], Jinmin Yang[2] and Qiuju Guo[2,*]
[1]State Key Laboratory of NBC Protection for Civilian, Beijing 102205, China
[2]State Key Laboratory of Nuclear Science and Technology, School of Physics, Peking University, Beijing 100871, China

*Corresponding author: qjguo@pku.edu.cn

Traditional fixed-filter radon progeny monitors are usually clogged with the loading of dust and cannot be used for radon progeny continuous measurement for long period. To solve this problem, a step-advanced filter (SAF) monitor for radon progeny measurement was developed. This monitor automatically roll and stop the filter at each interview. Radon progeny is collected on a 'fresh' filter at a flowrate of 3 L/min. At the same time, alpha and beta particles emitted from filter are recorded by a PIPS detector. A newly developed alpha–beta spectrum method was used for radon progeny concentration calculation. The ^{218}Po, ^{214}Pb and ^{214}Bi concentrations as well as equilibrium equivalent concentration (EEC) could be worked out at the same time. The lower level limit detection of this monitor is 0.48 Bq m^{-3} (EEC) for 1h interval. Comparison experiments were carried out in the radon chamber at the National Institute of Metrology of China. The measurement results of this SAF monitor are consistent with EQF3220 (SARAD GmbH, Germany), and the uncertainty is smaller. Due to its high sensitivity, the periodical variation of radon progeny concentration can be easily observed by this monitor. The SAF moniter is suitable for continuous measurement in both indoor and outdoor environments.

INTRODUCTION

Radon (^{222}Rn) is an inert gas which comes from the decay of ^{226}Ra. It diffuses out from soil, water, rock as well as building materials, and decays into a series of radon decay products (^{218}Po, ^{214}Pb and ^{214}Bi). Radon and its progeny are the main contributor of natural exposure dose to human beings, and they are also important factors work on environmental natural background of radiation.

Radon can be used as an important tracer for studying on atmospheric chemistry transport models and predicting atmospheric air pollution diffusion processes[(1)]. Under the cooperation of Global Atmosphere Watch, a continuous measurement of atmospheric radon concentration was carried out in Beijing and Qingdao for more than 10 y[(2, 3)]. Recently, the variation of radon progeny concentration seems to be more interesting, and it seems to have relationship with local air pollution[(4–6)]. Continuous measurement of atmospheric radon progeny is required.

However, nearly all the commercial radon progeny measurement device use a fixed-filter method. Those fixed-filter radon progeny monitors are incapacitated by the loading of dust and the delayed detection of progeny decay, which will affect the measurement accuracy and cannot be used for radon progeny continuous measurement for long period.

To improve this problem, a step-advanced filter (SAF) monitor for radon progeny was developed in this study. For increasing the sensitivity, a new radon progeny calculation method was developed based on an alpha–beta spectrum. Comparison experiments and field measurements were also carried out.

MATERIALS AND METHODS

The step-advance radon progeny monitor

The new designed step-advanced radon progeny monitor uses a step monitor to control filter move. At the beginning of each cycle, the step monitor rolls the filter to keep a 'fresh' filter ready for collection and sampling. Then stop the rolling and start the sampling pump and record the alpha and beta particles using a 400 mm^2 PIPS detector (SARAD GmbH, Germany) at the same time. The flowrate was recorded by a mass flowmeter (Hollywell AWN43600, USA). All those moving, sampling, and recording were controlled by an inter-computer. The sketch and the picture of the SAF monitor are shown in Figure 1.

The distance between PIPS and filter was 4 mm and the flowrate was controlled to 3 L per minute using a valve. The filter is PTFE (0.8 μm, 35 mm × 5 m, Millipore, USA) and the collection efficiency is more than 99.8%. The alpha and beta pulses signals which recorded by PIPS detector are analyzed by a Multi-Channel Analyzer. The alpha detection efficiency is 26.0% and the beta detection efficiency is 16.6% which were calibrated with ^{241}Am and ^{90}Sr sources separately. A typical alpha and beta spectrum gotten by the SAF monitor is shown in Figure 2.

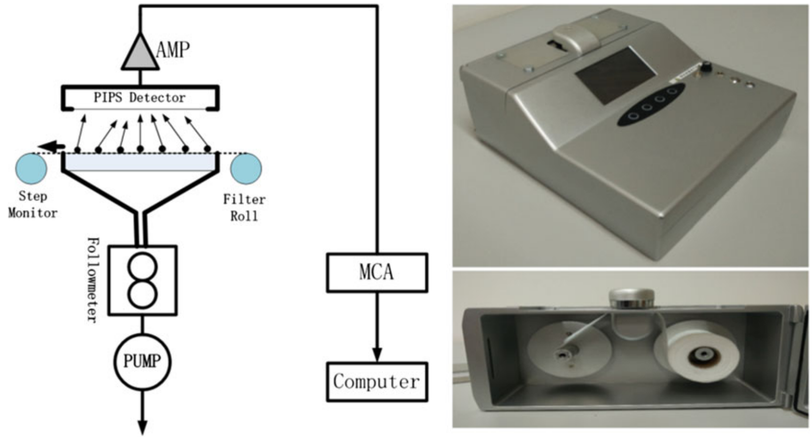

Figure 1. The sketch map (left) and the picture (right) of the step-advanced radon progeny monitor.

Radon progeny calculation method

The radon progeny concentration is usually quite low in environment and it changes fast, so to improve a monitor's sensitivity is important.

A new measurement method was developed in this work based on alpha/beta spectrum. This method is from the idea of Z. Papp and Abu Kadir[7, 8]. Separate the spectrum into three regions of interest, just as it shown in Figure 2. After each cycle (sampling and counting at the same time), three integration counts in beta channel, alpha channel I and alpha channel II can be gotten. Ignoring the thoron progeny and other alpha and beta radioactivity in environment, the RaA, RaB and RaC concentrations can be calculated as following (for 60 min cycle).

$$\begin{aligned} C_1 &= 1.1388 \times N'_{\alpha 1} \\ C_2 &= -\,0.1146 \times N'_{\alpha 1} - 0.2433 \times N'_{\alpha 2} + 0.2433 \times N'_{\beta} \\ C_3 &= 0.0028 \times N'_{\alpha 1} + 0.4139 \times N'_{\alpha 2} - 0.1349 \times N'_{\beta} \end{aligned} \quad (1)$$

Where C_1, C_2 and C_3 are RaA, RaB and RaC concentrations, respectively (Bq m^{-3}). These coefficients are calculated using Betheman equation[9]. The N'_x is defined as the normalized counting rate, which could be calculated using the following equation.

$$N'_x = \frac{N_x}{F \times \varepsilon_f \times E_x \times 10^6} \qquad x = \alpha 1, \alpha 2, \beta \quad (2)$$

Where the N_x is the integration counting in beta channel, alpha channel I and alpha channel II. F is the flowrate (L/min), ε_f is collection efficiency (= 100%), E_x is the counting efficiency of alpha and beta particle. The equilibrium equivalent concentration

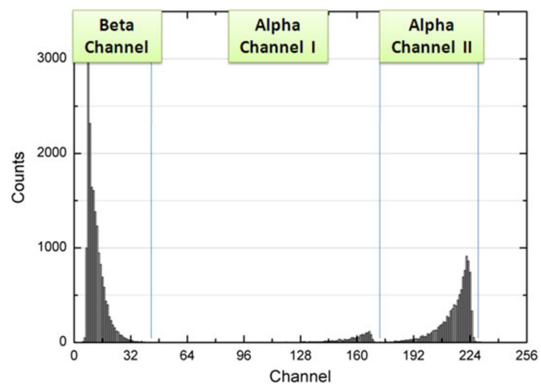

Figure 2. A typical alpha and beta spectrum from the Step-advanced radon progeny monitor.

(EEC) can be calculated from the RaA, RaB and RaC concentrations.

The background of this SAF monitor was measured for 24 h, the average background counting rate in beta channel, alpha channel I and alpha channel II are 59, 3.58 and 2.69 cph, respectively. The lower level limit of detection of this SAF monitor is 0.48 Bq m^{-3} (EEC) for 1 h interval.

RESULTS AND DISCUSSION

Comparison experiment in radon chamber

If the detection efficiency and the flowrate are calibrated, no other parameter is further needed for this SAF monitor. A series of comparison experiments were carried out in the radon chamber in NIM China[10]. The reference value of radon progeny was gotten from the EQF3220 (SARAD GmbH, Germany) that can be traced back to the Chinese radon progeny standard. The comparison results are shown in Table 1.

It is suggested by Table 1 that the EEC concentration of this SAF monitor is quite consistent with EQF3220. The RaA, RaB and RaC concentrations could also be gotten by this αβ spectrum method. The uncertainty of the SAF monitor is much lower than that of EQF3220 due to its high sensitivity.

Field measurement of outdoor radon progeny

Field measurement of atmospheric radon progeny was carried out in Peking University from 2016-1-24 to 2016-2-19. The SAF monitor was put in a thermometer shelter which is installed on the roof of the building nearly 10 m high from the ground. The continuous measurement result is shown in Figure 3.

The average value of EEC_{Rn} is 3.07 ± 0.17 Bq m^{-3} from 2016-1-24 to 2016-2-19, with a variation of 1.1 to 11.8 Bq m^{-3}. Due to its high sensitivity, the pattern of diurnal variation of radon progeny could be easily observed. The radon progeny concentration seems higher in the early morning (usually between 7:00 and 9:00), and lower in afternoon (usually between 14:00 and 17:00), which is quite clear in each day. Those results are consistent with the diurnal variation of radon gas, but have a little delay[2].

CONCLUSION

To realize the continuous measurement of atmospheric radon progeny, a SAF monitor was designed and a new alpha–beta spectrum method was developed in this research. This SAF monitor can roll the filter and avoid the interference of dust accumulation.

Table 1. The comparison results of the SAF monitor and EQF3220.

No.	The SAF monitor				EQF 3220
	RaA (Bq/m^3)	RaB (Bq/m^3)	RaC (Bq/m^3)	EEC (Bq/m^3)	EEC (Bq/m^3)
1	3459	3874	2241	3210 ± 23	3292 ± 211
2	2779	2717	2006	2455 ± 20	2613 ± 121
3	2838	3010	1768	2520 ± 20	2695 ± 218
4	2319	2779	1236	2144 ± 19	2346 ± 203

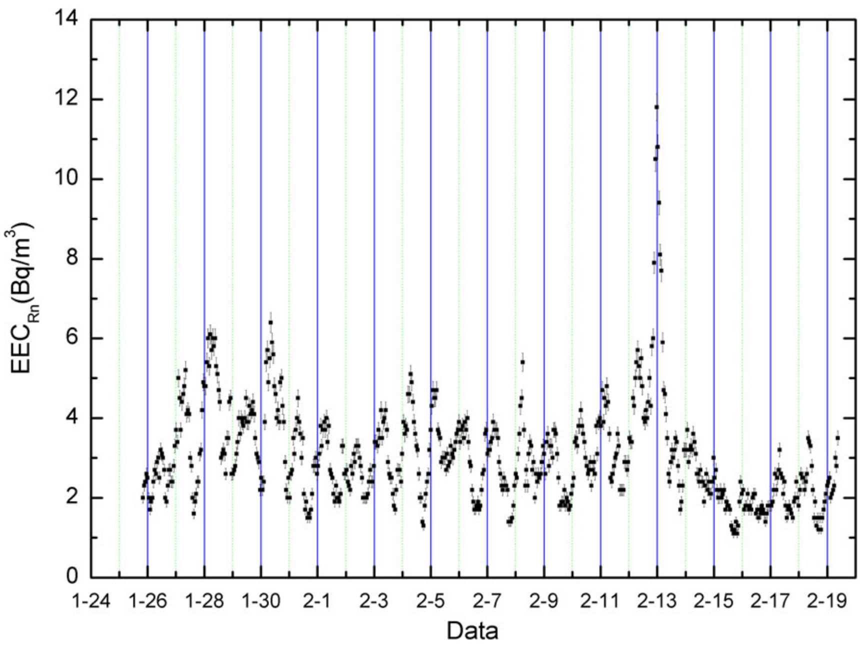

Figure 3. The continuous measurement results from the SAF monitor.

The sampling and counting are carried out at the same time in each interval, so the sensitivity is much higher. The RaA, RaB and RaC concentrations can be worked out with EEC at the same time in one interval, which is an innovation. Comparison experiment results show that this SAF monitor and this calculation method is consistent with a widely used commercial instrument EQF3220 (SARAD GmbH, Germany), and the uncertainty is quite lower. More field measurements are in progress and more results will be published in the near future.

FUNDING

This work was supported by the National Natural Science Foundation of China (Grant nos. 11205241 and 11475009).

REFERENCES

1. WMO/GAW. *First international expert meeting on sources and measurements of natural radionuclide applied to climate and air quality studies*. World Meteorological Organization Technical Document No. 1201 (2004).
2. Zhang, L.G., Guo, Q. J. and Iida, T. *Atmospheric radon levels in Beijing, China*. Radiat. Prot. Dosim. **112**(3), 449–453.
3. Zhang, L. and Guo, Q. J. *Observation and analysis of atmospheric radon in Qingdao, China*. J. Radiol. Prot. **31**, 129–134 (2011).
4. Perrino, C., Pietrodangelo, A. and Febo, A. *An atmospheric stability index based on radon progeny measurements for the evaluation of primary urban pollution*. Atmos. Environ. **35**, 5235–5244 (2001).
5. Perrino, C., Catrambone, M. and Pietrodangelo, A. *Influence of atmospheric stability on the mass concentration and chemical composition of atmospheric particles: a case study in Rome, Italy*. Environ. Int. **34**, 621–628 (2008).
6. Zhang, Z. Y., Wang, F. J., Costabile, F., Allegrini, I., Liu, F. L. and Hong, W. M. *Interpretation of ground-level ozone episodes with atmospheric stability index measurement*. Environ Sci. Pollut. Res. **19**, 3421–3429 (2012).
7. Papp, Z. *An intercomparison between gross α counting and gross β counting for grab-sampling determination of airborne radon progeny and thoron progeny*. Nucl. Instrum. Methods Phys. Res. A **558**, 569–575 (2006).
8. Kadir, A. Zhang, L. Guo, Q. J. Liang, J. C. *Efficiency analysis and comparison of different radon progeny measurement methods*. The Scientific World Journal. Article ID 269168 (2013).
9. Zhang, Z. H. Measurement Methods of Radon and its Daughters in Atmosphere (Beijing: Atomic Energy Press) (1994) (In Chinese).
10. Liang, J. C., Zheng, P. H., Yang, Z. J., Liu, H. R., Zhang, M., Li, Z. S., Zhang, L. and Guo, Q. J. *Development of calibration facility for radon and its progenies at NIM(China)*. Radiat. Prot. Dosimetry. **167**, 82–86 (2015).