The theoretical calculations of the airborne natural activities monitored in KOMAC

Sung-Kyun Park [a*], Yi-Sub Min [a], Jeong-Min Park [a]
[a] *Korea Multipurpose Accelerator Complex, Korea Atomic Energy Research Institute,*
181, Mirae-ro, Geoncheon-eup, Gyeongju-si, Gyeongsang buk-do, 780-904, Korea
[*] *Corresponding author: skpark4309@kaeri.re.kr*

1. Introduction

KOrea Multi-purpose Accelerator Complex (KOMAC) has the high-power accelerator to offer an optimum proton beam into the target rooms with the target material installed by the experimental user. Various kinds of radioactivity by-products are made by the interaction between the proton beams and nuclei of the target material. Most of radioactivity by-products produced are blocked by the shielding door located between the target-room and preparing-room for the safety of the radiation worker and experiment users worked in the radiation controlled area. The radiation monitoring system (RMS) is also monitoring the presence of these radioactivity by-products in the radiation controlled area. In order to manage systematically the radioactivity of the airborne alpha and beta particulates, the airborne contamination measurement should be performed periodically. Generally, one of the most influential factors in the alpha measurement result of the airborne contamination is the natural radioactivity, and radon and radon decay products called the radon progeny of the natural radioactivity are able to interference with the measurement of long-lived α-particle emitters.

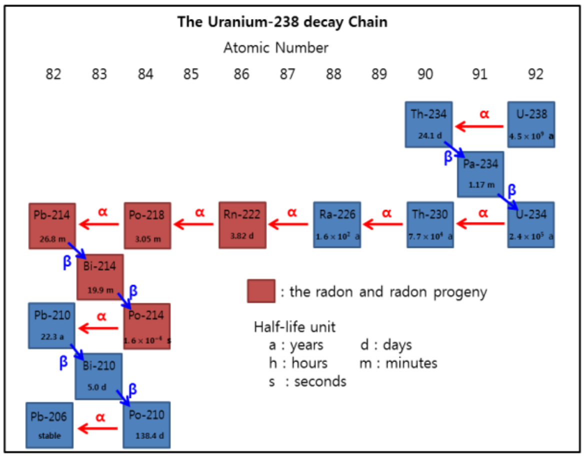

Fig. 1 The decay chain of the uranium-238. The red boxes mean the radon and radon progeny of 14 radio-nuclides of this decay chain.

Fig. 1 shows the uranium decay series with Rn-222 called radon. Since radon is the most massive of noble gases, it is chemically inert and it is not captured on the filter by the general air sampling method. Fig.1 also shows the short-lived decay products of radon, that is, Po-218, Pb-214, Bi-214, and Po-214 form the subgroup of the entire uranium series. Since the natural radioactivity has a large proportion of the measurement result of the airborne contamination, it is important to subtract the interference of the natural radioactivity effect from the measurement result. In KOMAC, the concentrations of radon in the radiation controlled and general area monitored are monitored using the RADUET [1]. In this research, the procedure to calculate the concentrations and activities of the radon progeny from the radon concentration monitored in KOMAC would be shown.

2. Concentration calculation of the radon progeny

In order to calculate the relation of the decay and ingrowth of radon and radon progeny, Bateman equation to calculate the activity or air concentration at time t of the various chain members from the decay of the initial quantity of the parent radon is used [2]. In detail, the parent isotope Rn-222 is decayed into the daughter isotope Po-218 with the decay constant, λ_0 as shown in equation (1) and the quantity decayed is added into Po-218 as shown in equation (2). The following is the real example to apply the Bateman equation:

$$\frac{dN_0}{dt} = -\lambda_0 \cdot N_0 \quad (1)$$

$$\frac{dN_1}{dt} = \lambda_0 \cdot N_0 - \lambda_1 \cdot N_1 \quad (2)$$

where N_0 and N_1 denote the number of atoms of Rn-222 and Po-218, respectively. the number of atoms of subgroups included in the radon progeny are also calculated using the same method. Since Po-214 has extremely short half-life, it can be assumed that Bi-214 decayed directly to Pb-210 emitting a α-particle and β-particle simultaneously. Also, because the half-life of Pb-210 is long compared with those of the radon progeny, it is assumed that the decay chain of the radon ends with Bi-214.

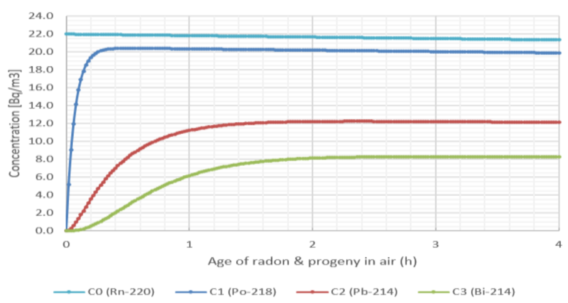

Fig. 2 Concentration change trend of radon and radon progeny when the initial concentration of radon progeny is zero.

The equations used to calculate the concentrations of the radon and radon progeny with the assumption that the initial concentrations of radon progeny in the volume of air are zero are following [3]:

$$C_0 = C_{0,0} \cdot f_{00} \quad (3)$$

$$C_1 = C_{0,0} \cdot \lambda_1 \cdot f_{01} \quad (4)$$

$$C_2 = C_{0,0} \cdot \lambda_1 \cdot \lambda_2 \cdot f_{02} \quad (5)$$

$$C_3 = C_{0,0} \cdot \lambda_1 \cdot \lambda_2 \cdot \lambda_3 \cdot f_{03} \quad (6)$$

where C_0, C_1, C_2, and C_3 are the concentrations of Rn-222, Po-218, Pb-214, and Bi-214, respectively. C_{00} is the initial concentration of Rn-222. f_{00}, f_{11}, f_{22}, and f_{33} denote $e^{-\lambda_0 \cdot t}$, $e^{-\lambda_1 \cdot t}$, $e^{-\lambda_2 \cdot t}$, and $e^{-\lambda_3 \cdot t}$, respectively. f_{01}, f_{12}, f_{23}, f_{02}, f_{13} and f_{03} mean $\frac{f_{00}-f_{11}}{\lambda_1-\lambda_0}$, $\frac{f_{11}-f_{22}}{\lambda_2-\lambda_1}$, $\frac{f_{22}-f_{33}}{\lambda_3-\lambda_2}$, $\frac{f_{01}-f_{12}}{\lambda_2-\lambda_0}$, $\frac{f_{12}-f_{23}}{\lambda_3-\lambda_1}$, and $\frac{f_{02}-f_{13}}{\lambda_3-\lambda_0}$, respectively. Fig. 2 shows the decay and ingrowth over time of radon and radon progeny when the initial concentration of Rn-222, C_{00}, measured in KOMAC is 22.0 Bq/m^3.

3. Activity calculation of radon progeny on a filter

In the real airborne contamination measurement, the air-sampler collects the air and the radon progeny is built up on the filter in the air-sampler. Using the low alpha-beta counter, the activity of the radon progeny can be measured instead of their concentration. The equation to calculate the activities from the concentrations of Fig. 2 are following [3]:

$$A_1 = F\varepsilon C_1 h_{11} \quad (7)$$

$$A_2 = F\varepsilon (C_1 \lambda_2 h_{11} + C_2 h_{22}) \quad (8)$$

$$A_3 = F\varepsilon (C_1 \lambda_2 \lambda_3 h_{13} + C_2 \lambda_3 h_{23} + C_3 h_{33}) \quad (9)$$

where A_1, A_2, and A_3 are the activities on the filter of Po-218, Pb-214, and Bi-214, respectively (Bq). F is the pump flow rate and ε is the collection efficiency. h_{11}, h_{22}, h_{33}, h_{12}, h_{23} and h_{13} mean $\frac{1-exp(-\lambda_1 t_s)}{\lambda_1}$, $\frac{1-exp(-\lambda_2 t_s)}{\lambda_2}$, $\frac{1-exp(-\lambda_3 t_s)}{\lambda_3}$, $\frac{h_{11}-h_{22}}{\lambda_2-\lambda_1}$, $\frac{h_{22}-h_{33}}{\lambda_3-\lambda_2}$, and $\frac{h_{12}-hf_{23}}{\lambda_3-\lambda_1}$, respectively.

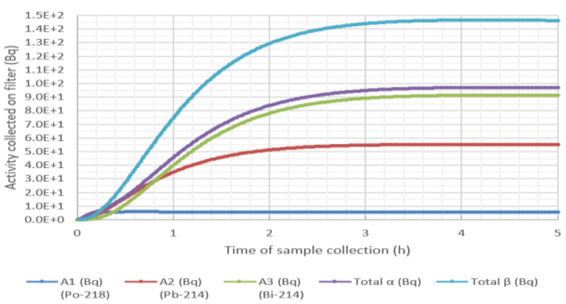

Fig. 3 Collection and ingrowth of radon progeny on filter.

When the initial concentration of Rn-222 is 22.0 Bq/m^3 and the pump flow rate of the air-sampler is 60 lpm, activities of radon progeny collected on filter can be calculated using the equation (7) ~ (9) and their results are shown in Fig. 3 as a function of sample collection time in hours. The 1-h concentrations of the radon progeny calculated are 5.77, 34.86, 39.87 Bq for Po-218, Pb-214, and Bi-214. In this case, the total α-activity is 45.64 Bq, calculated as the sum of PO-218 and Bi-214. The total β-activity is also 74.73 Bq, calculated as the sum of Pb-214 and Bi-214. In general, since the radon progeny deposit on the surface which the air encounters as the some deposition rate, the realistic concentrations of the radon progeny is changed according to this deposition rate. Fig. 4 shows activities of radon progeny collected on the filter with 1 h^{-1} as the deposition rate of all radon progeny. The 1-h concentrations of the radon progeny calculated with this deposition rate are 5.01, 17.37, 16.62 Bq for Po-218, Pb-214, and Bi-214. Their total α-activity and β-activity are 21.63 Bq and 33.99 Bq.

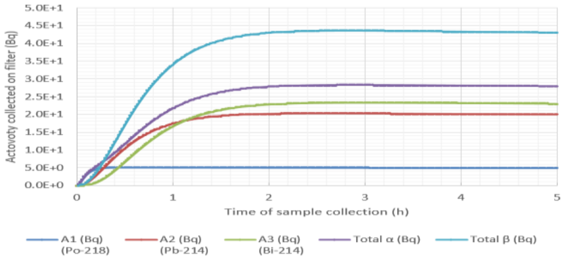

Fig. 4 Activity of radon progeny collected on filter with the time of sample collection when the deposition rate for all radon progeny is 1 h^{-1}

4. Conclusions

From the initial concentration of Rn-220, concentrations of Po-218, Pb-214, Bi-214 called as the radon progeny can be calculated using the equation (3) ~ (6) and their results are shown in Fig. 2. Activities of the radon progeny collected on the filter of the air-sampler can be calculated from concentrations of the radon progeny calculated on the previous stage using the equation (7) ~ (9), as shown in Fig. 3. Fig. 4 shows that in the case of 1 h^{-1} as the deposition rate, the total α-activity and β-activity of the 1-h concentrations should be decreased by 47% and 46%, respectively. The deposition rate of the measurement space is very important parameter to calculate realistic activities of radon progeny collected on the filter.

REFERENCES

[1] RADUET, Radosys, Ltd., Hungary
[2] Bateman, Harry, The solution of a system of differential equations occurring in the theory of radioactive transformations, In Proc. Cambridge Philos, Soc, vol. 15, no. pt V, pp. 423-427 (1910)
[3] Mark L. Maiello, Mark D. Hoover, Radioactive Air Sampling Methods, CRC Press (2010)