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CHARACTERIZATION OF AIRBORNE RADIOACTIVITY IN URBAN KUWAIT: ACTIVITY CONCENTRATION OF SELECTED RADIONUCLIDES

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Abstract. *High-volume air samples (approximately 1800 m³) were collected from three residential areas in Kuwait with different surrounding activities (Al-Jahra, Rumaithiya, and Ahmadi) using high-volume air samplers connected to a three-stage cascade impactor. Sampling duration was three days, and the samples were collected weekly over a period of one year. Low background gamma spectrometry and chemical separation methods were used to determine the concentrations of ^{7}Be, ^{40}K, ^{210}Pb, and ^{210}Po in three particle sizes: 0.41 to 0.73 µm, 0.73 to 2.4 µm, and 2.4 to 10.2 µm. Results indicated that most of the activity was concentrated on the fine particle size fractions, except for ^{40}K, which suggests the influence of local dust sources. The activity concentration values of ^{210}Pb, ^{7}Be, and ^{40}K were consistent across all cities, while the ^{210}Po activity concentration was lower in the Al-Jahra area. Also, the ratios of $^{210}Po/^{210}Pb$ activity concentrations differ across locations; they were higher in the Ahmadi and Rumaithiya areas compared to Al-Jahra.*

Keywords: *aerosols, AMAD, ^{210}Po, ^{210}Pb, ^{7}Be, ^{40}K*

1. INTRODUCTION

Natural and artificial radionuclides, once released into the atmosphere, attach to dust, smoke, or other suspended particles, thereby forming radioactive airborne particles (RAP). Both chemical and physical properties of atmospheric aerosols affect the mobility of RAP. They can be transported over long distances, potentially posing a risk to human health and the environment [1]. The internal effective dose resulting from inhaled RAP depends on the activity median aerodynamic diameter (AMAD), the type of radionuclide attached to the aerosol, and the amount of radionuclides inhaled [2], [3]. Environmental regulatory organizations and scientific committees worldwide have conducted studies on the origins and effects of airborne fine, and ultra-fine particles ($PM_{2.5}$ and $PM_{0.1}$, respectively) on human health [3]-[6].

In Kuwait, the reported results showed the annual $PM_{2.5}$ standards of 53 µg/m³, which is five times higher than those mentioned in the guidelines of the World Health Organization (WHO) (10 µg/m³) [7]. Hence, more comprehensive studies need to be conducted to address the high concentration and health effects of $PM_{2.5}$ and PM_{10} in Kuwait and RAP in atmospheric fallout. Research has found that the natural and anthropogenic sources of $PM_{2.5}$ (e.g., sand dust, oil burning, petrochemical industry, and traffic) comprise a mix of local and regional sources [8]-[11].

This study aims to determine the radioactivity levels and distribution of select radionuclides within airborne particles of different sizes in three residential areas in Kuwait City.

2. METHODOLOGY

2.1. Sampling and sample preparation

Over the course of the year 2018, air samples were collected using high-volume air samplers connected to a three-stage cascade impactor. The samples were collected weekly for three days of sampling from three residential areas in Kuwait (Figure 1): Ahmadi area, situated near the refineries and petrochemical industries; Rumaithiya area, close to the coastal zone; and an open urban area called Al-Jahra, located northwest of Kuwait City. Each sample contained approximately 1800 m³ of air, yielding about 45 measurements for each size fraction within each area.

Figure 1. Sampling sites

The collected air filters were dried, compressed, and categorized into three groups of fraction sizes (from 0.41 to 0.73 µm, from 0.73 to 2.4 µm, and from 2.4 to

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10.2 μm) in the Radiation Measurements Laboratory (RML) in the Kuwait Institute for Scientific Research for determining the presence of radionuclides. The concentrations of alpha and gamma emitters were determined using the procedures outlined schematically in Figure 2.

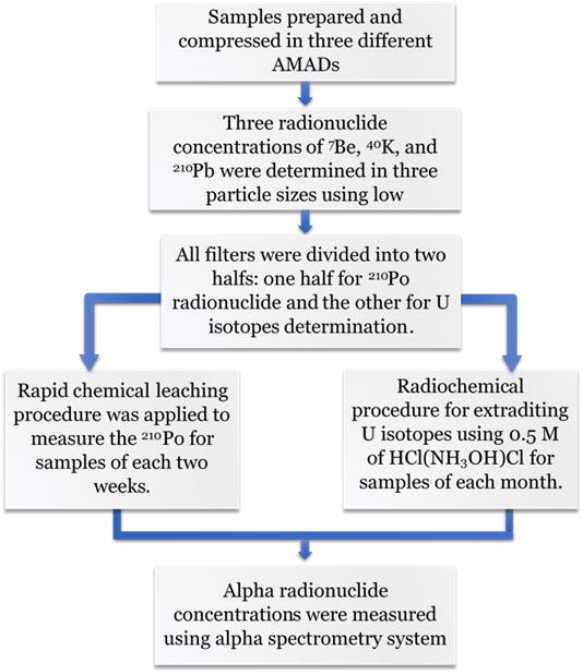

Figure 2. Schematic diagram of sample preparation and measurements

2.2. Measurements of gamma emitters

Two low background gamma spectrometry systems, equipped with broad energy germanium (BEGe) detector and an N-type HPGe detector, were used to measure the activity concentrations of ^{7}Be,^{40}K, and ^{210}Pb. Both systems exhibit high resolution at low gamma energy lines.

Laboratory Sourceless Calibration Software (LabSOCS, Canberra Inc.) was used to generate the efficiency calibration curve for the counting geometries. Such software helps calculate the activity concentrations of different gamma emitters across various geometries, accounting for the corrections required for interferences and cascade summing of gamma lines. Furthermore, to verify the derived efficiency calibration, an internal calibration air filter was prepared in the RML. This was done by spiking a compressed blank air filter with a known quantity of certified reference solution containing mixed gamma radionuclides (QCYB40+QCYB41 from Eckert & Ziegler Group).

The correction factor (1/Ks) applied for decay and build-up corrections during the sampling is as follows:

$$K_S = \frac{T_{1/2}}{Ln\,(2) * t_s}\left[1 - e^{-\frac{ln(2) * t_S}{T_{1/2}}}\right] \qquad (1)$$

where K_s are the correction factors applied, $T_{1/2}$ is the half-life of nuclide of interest, and t_s are the sampling times.

2.3. Measurements of alpha emitters

As depicted in the schematic diagram (Figure 2), all filters were halved; one half was used for determining ^{210}Po, and the other for determining U isotopes. Radiochemical separation methods, employing a twelve-chamber Canberra alpha spectrometry system equipped with a passive ion-implanted silicon detector, were used to determine the radionuclide concentrations of U isotopes and ^{210}Po (Figure 2) [12]. The required correction was made for ^{210}Po ingrowth for the period between the sampling date and the separation date of Po.

3. Results and Discussion

3.1. Activity concentration in the studied areas

^{210}Pb, ^{7}Be and ^{40}K total radioactivity concentrations (particle sizes ranging from 0.41 to 10.2) were similar across the three locations, with geometrical mean values (GM) and geometrical standard deviation (GSD) of all locations being 1.09 (1.5), 7.46 (1.5), and 2.45 (1.4) mBq/m^3, respectively. However, the concentration of ^{210}Po was lower in Al-Jahra compared to that of the other two locations [11]-[13] (Table 1). This is likely because Al-Jahra is an open area further away from potential sources of ^{210}Po, such as oil and petrochemical facilities.

Table 1. Geometrical mean (GSD) of the activity concentration in different area in Kuwait (mBq/m^3)

Radionuclides	Ahmadi	Jahra	Rumathiya
Pb-210	1.07 (1.5)	1.03 (1.5)	1.17 (1.4)
Be-7	7.3 (1.4)	6.98 (1.6)	8.0 (1.5)
K-40	2.44 (1.4)	2.67 (1.4)	2.28 (1.4)
Po-210	0.96 (1.8)	0.38 (2.0)	0.71 (2.1)

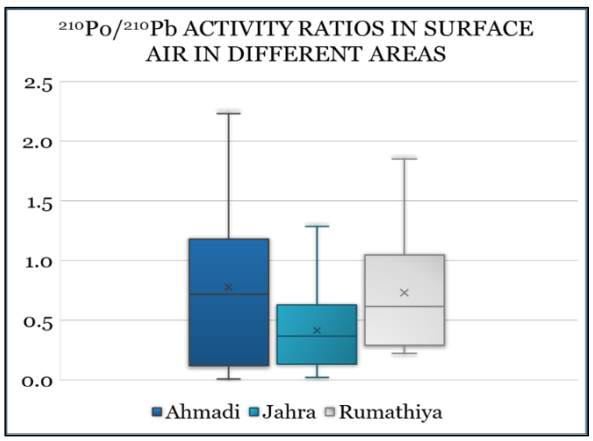

Figure 3. Activity concentration ratio between ^{210}Po and ^{210}Pb in different areas

The concentration ratio of ^{210}Po to ^{210}Pb (^{210}Po/^{210}Pb) also reflects this difference. Figure 3 shows that the interquartile range of ^{210}Po/^{210}Pb in the Al-Jahra area is lower than that in both the Rumaithiya and Ahmadi areas. The highest GM of the ratio was found in Ahmadi at 0.74 (2.1), followed by Rumaithiya at 0.59 (1.9) and then Al-Jahra at 0.38 (2.1). Notably, all three ratios were higher than the value of 0.1. reported by the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) [14].

Analysis of all collected samples revealed the ^{238}U and ^{234}U concentrations to be below their detection limits of 1.96 µBq/m^3 and 1.91 µBq/m^3, respectively.

3.2. Distribution of activity concentration on particle sizes

Approximately more than 70% of the measured radionuclides are generally attached to the finest particles (from 0.41 to 0.73 µm) except ^{40}K. Figure 4 shows that about 88% of the total ^{7}Be is attached to the finest particles. In contrast, about 81% of ^{40}K is attached to the larger particle fractions (i.e., 30% on particle sizes between 0.7 and 2.4 µm and 51% on the particle sizes between 2.4 and 10 µm). This may reflect the effects of the local dust sources [11] and the crustal origin of ^{40}K, whereas the sources of the other radionuclides are cosmogenic (^{7}Be) or naturally produced when ^{222}Rn gas diffuses from soil (^{210}Pb and ^{210}Po) [4]. A similar percentage of ^{210}Pb and ^{210}Po activity concentrations was observed in different fraction sizes of RAP.

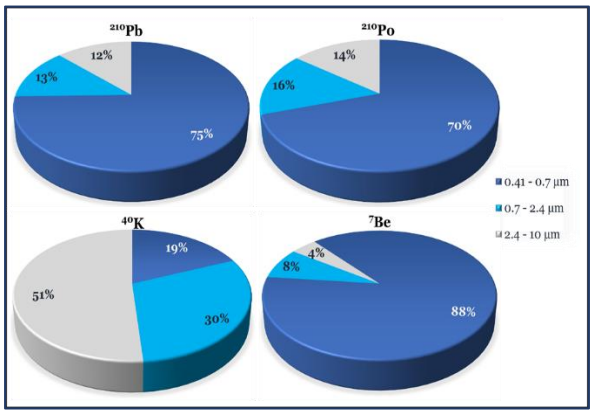

Figure 4. Percentage of the radionuclide concentration on different particle sizes

On the other hand, particle fraction sizes do not impact the extent to which ^{210}Po and ^{210}Pb concentrations contribute to the overall activity of RAP. Both radionuclides have the same activity contribution (around 5% for ^{210}Po and 9% for ^{210}Pb) to the total activity concentration of all particle sizes (Figure 5). In contrast, the contribution of ^{7}Be activity concentration significantly decreases when particle sizes increase, while ^{40}K makes the opposite contribution. Figure 5 shows that ^{40}K and ^{7}Be activity concentrations significantly contribute to the total radioactivity concentrated on the middle fraction size (0.72 to 2.4 µm), about 50% and 35%, respectively. This indicates that the fine particles onto which ^{7}Be is attached may accumulate over time, leading to the formation of larger sized particles [13].

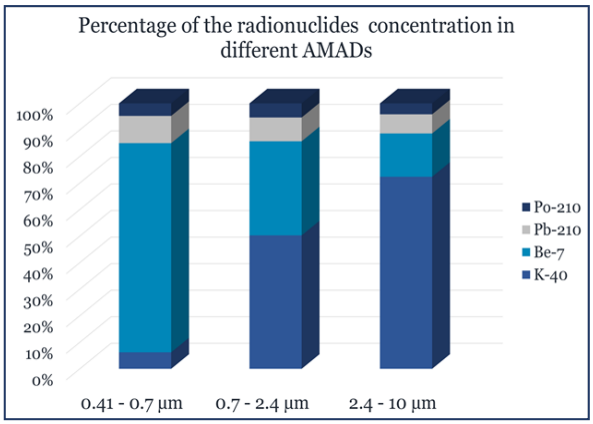

Figure 5. Percentage contribution of the radionuclide concentration in the total activity in each particle size

4. Conclusion

This study investigated the activity concentrations of ^{7}Be, ^{40}K, ^{210}Pb, ^{210}Po, ^{234}U, and ^{238}U in three size fractions of airborne aerosols. Gamma spectrometry quantified the concentration of ^{7}Be, ^{40}K, and ^{210}Pb, while alpha spectrometry, following radiochemical separation, measured ^{210}Po and U isotopes. Our findings reveal a precise size-dependent distribution of radionuclides. ^{7}Be, ^{210}Pb, and ^{210}Po are mainly associated with the smallest particles, likely due to their attachment to fine dust generated by natural processes like cosmic ray spallation and ^{222}Rn gas diffusion from the soil. Conversely, ^{40}K is attached to the largest particle fraction, reflecting its presence in soil and crustal materials. Notably, all detected radionuclides fell within expected ranges except for the ^{210}Po/^{210}Pb ratio, which exceeded the global average. This suggests the influence of anthropogenic sources on ^{210}Po, highlighting the need for further investigation into potential local emission sources and their impact on environmental health.

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