



Estimation rate of total alpha particle emission in blood and milk of women living in city center and rural areas of Al-Muthanna Governorate-Iraq

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Abstract. Iraq has long suffered from environmental pollution due to past wars, specifically the first and second Gulf Wars in 1990 and 2003. Al-Muthanna governorate, as part of Iraq, was directly affected by these conflicts and has experienced environmental and epidemiological changes that may increase the risk of cancer in the region. For this reason, monitoring the alpha particles emissions in human blood and milk was of significant importance. This study aims to estimate the total alpha particle emission rate (E_{α}) in blood and milk samples of women residing in different environments (rural area and city center) of Al-Muthanna Governorate, using CR-39 detectors. The results revealed that the highest, lowest, and mean E_{α} values in milk samples from city center and rural areas were (1.63, 0.68, and 1.10 mBq/ml) and (1.59, 0.56, and 1.01 mBq/ml), respectively. The maximum, minimum, and average E_{α} values in the city center and rural areas blood samples were (2.05, 0.90, and 1.31 mBq/ml) and (1.61, 0.66, and 1.12 mBq/ml), respectively. The findings indicated that the E_{α} in milk and blood samples in rural areas were lower than in the city center, which may be attributed to the reduced anthropogenic and military activities in rural areas.

Keywords: Al-Muthanna Governorate • Alpha particles • Blood • City center • CR-39 • Milk

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Introduction

Radiation pollution is one of the environmental pollution sources originating from two primary sources: natural (e.g., radioactive decay of unstable elements like uranium and thorium) and industrial (such as those produced by bombarding the nuclei of stable isotopes with different types of nuclear particles) [1–3]. In addition to these sources, the human body contains sources of internal nuclear particles such as lead-210, carbon-14, potassium-40, and other radioactive particles inside the body since birth [4–6]. Alpha particles are emitted during the decay of radionuclides, such as the uranium-238, thorium-232, and uranium-235 series, which produce multiple alpha-emitting radionuclides. This study specifically focuses on the uranium-238 decay series, as uranium constitutes over 99% of natural uranium. During this decay process, several alpha-emitting radionuclides are produced, including ^{238}U , ^{234}U , ^{230}Th , ^{226}Ra , ^{222}Rn , ^{218}Po , ^{214}Po , and ^{210}Po . Radon (^{222}Rn) and polonium (^{210}Po) are considered the most significant in terms of alpha emitting [7–10]. Numerous studies have identified ^{210}Po and ^{222}Rn as radionuclides of radiological concern due to their high toxicity once inside the human body when they enter the human body. Boryło *et al.* (2013) investigated contamination of ^{210}Po and ^{222}Rn in environmental samples and confirmed their potential health risks [11]. Alpha

Table 1. Information about the milk samples of women from the Al-Muthanna Governorate

Sample code	Job	Area classification	Location
M1	Teacher	City center	Al-Samawah
M2	Student	City center	Al-Samawah
M3	Housewife	City center	Al-Samawah
M4	Teacher	City center	Al-Samawah
M5	Employee	City center	Al-Samawah
M6	Engineer	City center	Al-Samawah
M7	Housewife	City center	Al-Samawah
M8	Radiologists	City center	Al-Samawah
M9	Student	City center	Al-Samawah
M10	Student	City center	Al-Samawah
M11	Housewife	Rural area	Al-Rumaitha
M12	Doctor	Rural area	Al-Rumaitha
M13	Student	Rural area	Al-Rumaitha
M14	Student	Rural area	Al-Warkaa
M15	Analysts	Rural area	Al-Warkaa
M16	Employee	Rural area	Al-Warkaa
M17	Teacher	Rural area	Al-Kheder
M18	Student	Rural area	Al-Kheder
M19	Employee	Rural area	Al-Majd
M20	Housewife	Rural area	Al-Majd

Table 2. Information about the blood samples of women from the Al-Muthanna Governorate

Sample code	Job	Area classification	Location
B1	Housewife	City center	Al-Samawah
B2	Teacher	City center	Al-Samawah
B3	Teacher	City center	Al-Samawah
B4	Employee	City center	Al-Samawah
B5	Radiologists	City center	Al-Samawah
B6	Teacher	City center	Al-Samawah
B7	Student	City center	Al-Samawah
B8	Housewife	City center	Al-Samawah
B9	Doctor	City center	Al-Samawah
B10	Housewife	City center	Al-Samawah
B11	Housewife	Rural area	Al-Warkaa
B12	Engineer	Rural area	Al-Warkaa
B13	Doctor	Rural area	Al-Warkaa
B14	Housewife	Rural area	Al-Rumaitha
B15	Student	Rural area	Al-Rumaitha
B16	Employee	Rural area	Al-Rumaitha
B17	Teacher	Rural area	Al-Majd
B18	Employee	Rural area	Al-Majd
B19	Teacher	Rural area	Al-Kheder
B20	Employee	Rural area	Al-Kheder

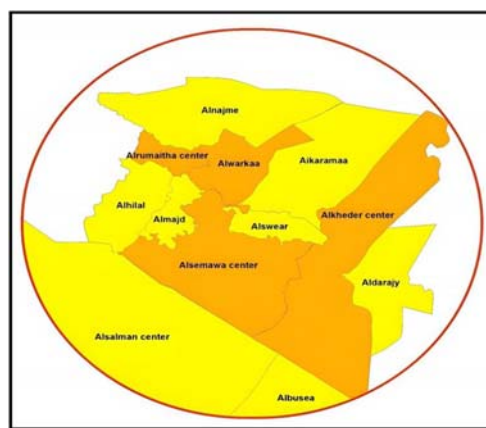
particles are among the most hazardous forms of ionizing radiation. Despite their limited penetration ability, they possess high ionizing power, especially when entering the body via inhalation or ingestion [12–15]. Once inside the body, the alpha particles are transported through the bloodstream and may accumulate in organs such as bones, kidneys, and soft tissues [16–19]. Human exposure to alpha particles poses significant risk, categorized into acute and chronic effects. Acute effects occur after exposure to high doses of radiation over short periods, affecting multiple body systems. Chronic effects arise from prolonged exposure to low doses, potentially causing leukemia, breast cancer, uterine cancer, thyroid cancer, and genetic mutations [20–23]. Therefore, detecting the rate of alpha-emitting radionuclides in biological samples, such as blood and milk provides valuable information about internal radiation exposure, especially among populations living near potential contamination sources or in different geographical environments (e.g., city center vs. rural regions). Solid state nuclear track detectors (SSNTDs), particularly CR-39 detectors, are widely used for monitoring alpha particles due to their high sensitivity and capability to record the tracks of particles emitted by radionuclides. This study aimed to measure the total alpha particle emission rate (E_α) in blood and milk samples of women residing in urban and rural areas, using CR-39 detectors.

Materials and methods

Sample collection

In this project, 20 milk and blood samples were collected from women employed in various occupations and residing in both the city center and rural areas of

Al-Muthanna Governorate, as presented in Tables 1 and 2. The samples were obtained from Al-Hussein Hospital as well as from clinics and health centers located across in different areas of the governorate. A structured questionnaire was administered to collect data from volunteers, including information on age, residence, occupation, and health status. Prior to sample collection, informed verbal consent was obtained from all participants. Al-Muthanna Governorate is located in southern Iraq. It is bordered to the east by Basra and Dhi Qar governorates, to the west by the Kingdom of Saudi Arabia and part of the Najaf desert, and to the north by Qadisiyah Governorate and part of Najaf Governorate. It is the second-largest governorate in Iraq by area, with a total area of approximately 51 740 km², but it is the least populated. Al-Muthanna Governorate consists of four districts: Al-Samawah, Al-Kheder, Al-Rumaitha, and Al-Salman, as well as Al-Warkaa, and five sub-districts: Al-Swear, Al-Hilal, Al-Majd, Al-Daraj, and Al-Karamaa, as illustrated in Fig. 1. Al-Samawah is the administrative center of the

**Fig. 1.** The map displays the districts and sub-districts of the Al-Muthanna Governorate.

governorate and has the highest population compared to other districts and sub-districts. The population of the Al-Muthanna Governorate is approximately 824 000 people [24].

Experimental method

Twenty blood and milk samples of women were collected from hospitals, health centers, and clinics. Blood samples were drawn using a syringe and placed in 5 ml tubes containing an anticoagulant. Milk samples were collected in sterile 5 ml cups using manual pressure after washing and sterilizing the breast with distilled water. To determine the total alpha emission rate ($E\alpha$) in milk and blood samples, a CR-39 detector with a thickness of 500 μm and area $1 \times 1 \text{ cm}^2$ was placed inside the Petri dishes. Then, two drops (100 μl) of the milk or blood were placed on the CR-39 detector and dried using a magnetic thermal stirrer. The samples were dried at 40°C for 5 min for blood and 3 min for milk (as milk is less dense than blood) to remove moisture. After drying, the samples were compressed with another layer of CR-39 and frozen at -20°C for 30 days [25–27]. After thirty days, the CR-39 detectors were etched in a 6.25 N of NaOH solution for 6 hours at 70°C [28, 29]. The etched reagents were then rinsed with distilled water and air-dried. An optical microscope with a magnification of 400 $\times$ was used to count the number of tracks on each CR-39 detectors [4, 17, 30].

The track density (ρ) for each detector was calculated using Eq. (1):

$$(1) \quad \rho = \frac{N_{\text{Bavg}}}{A}$$

where: ρ is the track density (tracks/ cm^2), N_{Bavg} is the average number of total tracks, and A is the area of the field of view (0.026 cm^2).

To calculate the total alpha emission rate ($E\alpha$) in blood and milk samples, was used Eq. (2) [26].

$$(2) \quad E\alpha = \frac{\varepsilon(\rho_s - \rho_b)}{T}$$

where: $E\alpha$ is the total alpha emission rate (mBq/ml), ε is the CR-39 detection efficiency (85%), T is the exposure time (30 days), and ρ_b is the background track density in the detector (5.688 tracks/ cm^2), and ρ_s is the alpha track density of the milk or blood samples.

Calibration and detector efficiency

To ensure the reliability and accuracy of the CR-39 detectors in measuring alpha particle, the detectors were calibrated using standard radioactive sources with known activity, specifically the americium isotope (Am^{241}). The source was positioned at a fixed distance from the detector in a sealed chamber to ensure uniform exposure and reduce alpha particle loss due to absorption or scattering in air. The number of alpha particles emitted toward the detector was calculated based on the known radioactivity of

the source, taking into account the solid angle (Ω) subtended by the detector surface relative to the source and assuming equal emission in all directions:

$$(3) \quad N_{\text{emitted}} = A \times t \times \Omega / 4\pi$$

where: A is the source activity in Bq, t is the exposure time in seconds, Ω is the solid angle subtended by the detector surface, and N_{emitted} is the number of alpha particles expected to reach the detector surface.

After exposure, the detectors were etched in a 6.25 N of NaOH solution for 6 hours at 70°C. The number of alpha particle traces on the detector surface was counted using an Olympus light microscope at 400 $\times$ magnification. The track density was then calculated and compared to the known activity of the standard source, allowing for the construction of a calibration curve. This curve was used to convert the measured track densities in blood and milk samples to actual alpha activity concentrations. To ensure results reliability, the calibration procedure was repeated three times, and background radiation measurements were included in the final calculations [31].

The detection efficiency (ε) of the CR-39 detectors was calculated by comparing the number of detected tracks (N_{detected}) with the estimated number of alpha particles reaching the detector surface (N_{emitted}) according to Eq. (4):

$$(4) \quad \varepsilon = N_{\text{detected}} / N_{\text{emitted}}$$

The efficiency was found to be approximately 85%, a value consistent with what is reported in the scientific literature under the etching and exposure conditions used [32].

Results and discussion

Table 3 illustrates the total alpha emission rate ($E\alpha$) in milk samples collected from women residing in the city center and rural regions of Al-Muthanna Governorate. The maximum $E\alpha$ value in the city center was recorded in sample M8 ($1.63 \pm 0.06 \text{ mBq/ml}$), which was collected from a woman working as radiologist. This elevated of $E\alpha$ may be attributed to the radiologists who work on X-ray machines, computed tomography (CT), and radiotherapy may be required to handle with radioactive materials and due to their daily work for long hours, which makes them more exposed to radiation [8]. The minimum value of $E\alpha$ in the city center was absolved in sample M10 ($0.68 \pm 0.04 \text{ mBq/ml}$), which belongs to a student. The average $E\alpha$ value in the city center was $1.10 \pm 0.05 \text{ mBq/ml}$. In contrast, for samples from rural areas, the highest $E\alpha$ was found in sample M11 ($1.59 \pm 0.03 \text{ mBq/ml}$) belong to housewife. Most women in rural areas work in farming and harvesting crops, so the reason for the high $E\alpha$ may be due to her contact with soil that contains these radioactive elements, which may be transmitted to her through open wounds or may be transmitted to her by eating vegetables and animal meat that contain these elements or due to the use of chemical fertilizers [20]. The

Table 3. The $E\alpha$ (mBq/ml) in milk samples in city center and rural areas of Al-Muthanna Governorate

Sample code	$E\alpha \pm SD$ (track/cm ² *d)	$E\alpha \pm SD$ (mBq/cm ²)	$E\alpha \pm SD$ (mBq/ml)
M1	7.903 $\pm$ 0.373	0.079 $\pm$ 0.004	0.79 $\pm$ 0.04
M2	10.518 $\pm$ 0.654	0.105 $\pm$ 0.007	1.05 $\pm$ 0.07
M3	13.570 $\pm$ 0.562	0.136 $\pm$ 0.006	1.36 $\pm$ 0.06
M4	10.736 $\pm$ 0.683	0.107 $\pm$ 0.007	1.07 $\pm$ 0.07
M5	8.230 $\pm$ 0.338	0.082 $\pm$ 0.003	0.82 $\pm$ 0.03
M6	9.756 $\pm$ 0.426	0.098 $\pm$ 0.004	0.98 $\pm$ 0.04
M7	14.768 $\pm$ 0.338	0.148 $\pm$ 0.003	1.48 $\pm$ 0.03
M8	16.294 $\pm$ 0.602	0.163 $\pm$ 0.006	1.63 $\pm$ 0.06
M9	11.499 $\pm$ 0.338	0.115 $\pm$ 0.003	1.15 $\pm$ 0.03
M10	6.813 $\pm$ 0.373	0.068 $\pm$ 0.004	0.68 $\pm$ 0.04
	Min	0.068 $\pm$ 0.004	0.68 $\pm$ 0.04
	Max	0.163 $\pm$ 0.006	1.63 $\pm$ 0.06
Mean $E\alpha$ (mBq/ml) in the city center		0.110 $\pm$ 0.005	1.10 $\pm$ 0.05
M11	15.858 $\pm$ 0.338	0.159 $\pm$ 0.003	1.59 $\pm$ 0.03
M12	12.698 $\pm$ 0.275	0.127 $\pm$ 0.003	1.27 $\pm$ 0.03
M13	8.448 $\pm$ 0.602	0.084 $\pm$ 0.006	0.84 $\pm$ 0.06
M14	5.614 $\pm$ 0.537	0.056 $\pm$ 0.005	0.56 $\pm$ 0.05
M15	10.409 $\pm$ 0.537	0.104 $\pm$ 0.005	1.04 $\pm$ 0.05
M16	8.121 $\pm$ 0.562	0.081 $\pm$ 0.006	0.81 $\pm$ 0.06
M17	11.063 $\pm$ 0.690	0.111 $\pm$ 0.006	1.11 $\pm$ 0.06
M18	6.813 $\pm$ 0.373	0.068 $\pm$ 0.004	0.68 $\pm$ 0.04
M19	9.647 $\pm$ 0.528	0.096 $\pm$ 0.005	0.96 $\pm$ 0.05
M20	13.243 $\pm$ 0.690	0.132 $\pm$ 0.007	1.32 $\pm$ 0.07
	Min	0.056 $\pm$ 0.005	0.56 $\pm$ 0.05
	Max	0.159 $\pm$ 0.003	1.59 $\pm$ 0.03
Mean $E\alpha$ (mBq/ml) in the rural areas		0.101 $\pm$ 0.005	1.01 $\pm$ 0.05
Mean $E\alpha$ (mBq/ml) in the city center and rural areas		0.106 $\pm$ 0.005	1.06 $\pm$ 0.05

SD – standard deviation

lowest $E\alpha$ value was recorded in sample M14 (0.56 $\pm$ 0.05 mBq/ml) belonging to a student. The mean value of $E\alpha$ in rural areas was 1.01 $\pm$ 0.05 mBq/ml. These results shows that the average $E\alpha$ in the city center is higher than that in rural areas, which may be explained by the population increase in addition to the increase in the number of polluting industries represented by factories and power plants, as well as the frequent use of electric generators spread in residential neighborhoods, garbage burning operations, and the increase in the number of cars and motorcycles and the various pollutants they emit, while the countryside is characterized by a cleaner and less polluted environment this is due to the low population density and the lack of industrial activities, this finding aligns with previous research [4, 11]. The overall average $E\alpha$ (combined for city center and rural area) was 1.06 $\pm$ 0.05 mBq/ml.

Table 4 presents the total alpha emission rate ($E\alpha$) in blood samples collected from women living in city center and rural areas. The highest value of $E\alpha$ in city center was recorded in sample B5 (2.05 $\pm$ 0.005 mBq/ml), which belonged to a radiologist. The elevated $E\alpha$ level was likely due to prolonged daily occupational exposure, as radiologists who work on X-ray machines, CT scanners, and radiotherapy may be required to handle radioactive material which makes them more exposed to radiation [8]. The lowest value of $E\alpha$ was 0.90 $\pm$ 0.04 mBq/ml in sample B1 belonging to the housewife. The mean value of $E\alpha$ in the city center blood samples was 1.31 $\pm$

0.10 mBq/ml. In the rural areas, the maximum value of $E\alpha$ was found in sample B13 (1.61 $\pm$ 0.04 mBq/ml), which belonged to doctor. This elevated $E\alpha$ level was likely due to long working hours and repeated exposure to radioactive elements, which may enter the body through consumption of food, inhalation of polluted air or entry through open wounds, ultimately being transported via the blood stream to internal organs [20]. The minimum value of $E\alpha$ was 0.66 $\pm$ 0.03 mBq/ml in sample B11 belongs to a housewife. The average value of $E\alpha$ in rural areas was 1.12 $\pm$ 0.08 mBq/ml. The results clearly indicate that $E\alpha$ values in the rural areas was lower than those in the city center, which may be attributed to lower population density, reduced human activities and difference in lifestyle. This result is consistent with previous research [31]. Furthermore, it was observed that blood and milk samples of women who work in the healthcare sector (including pharmacists, analysts, doctors, radiologists, and nurses) had higher $E\alpha$ compared to those from women in other professions. This suggests a correlation between $E\alpha$ levels in human blood or milk and occupational exposure [8]. The overall average of alpha emission rate in the city center and rural areas was 1.24 $\pm$ 0.09 mBq/ml.

Tables 5 and 6 represent a comparative analysis of $E\alpha$ in blood and milk of the current work with other regions. Where it found the $E\alpha$ in blood and milk samples from the current study with those in other regions. The findings indicted that the $E\alpha$ values

Table 4. The $E\alpha$ (mBq/ml) in blood samples in city center and rural areas of Al-Muthanna Governorate

Sample code	$E\alpha \pm SD$ (track/cm ² *d)	$E\alpha \pm SD$ (mBq/cm ²)	$E\alpha \pm SD$ (mBq/ml)
B1	8.993 $\pm$ 0.373	0.090 $\pm$ 0.003	0.90 $\pm$ 0.03
B2	14.332 $\pm$ 1.038	0.143 $\pm$ 0.010	1.43 $\pm$ 0.10
B3	13.134 $\pm$ 2.408	0.131 $\pm$ 0.024	1.31 $\pm$ 0.24
B4	12.916 $\pm$ 2.508	0.129 $\pm$ 0.025	1.29 $\pm$ 0.25
B5	20.544 $\pm$ 0.528	0.205 $\pm$ 0.005	2.05 $\pm$ 0.05
B6	11.717 $\pm$ 0.744	0.117 $\pm$ 0.007	1.17 $\pm$ 0.07
B7	9.102 $\pm$ 0.717	0.091 $\pm$ 0.007	0.91 $\pm$ 0.07
B8	14.877 $\pm$ 0.654	0.149 $\pm$ 0.007	1.49 $\pm$ 0.07
B9	15.531 $\pm$ 0.373	0.155 $\pm$ 0.004	1.55 $\pm$ 0.04
B10	10.409 $\pm$ 0.537	0.104 $\pm$ 0.006	1.04 $\pm$ 0.06
	Min	0.090 $\pm$ 0.004	0.90 $\pm$ 0.04
	Max	0.205 $\pm$ 0.005	2.05 $\pm$ 0.05
Average $E\alpha$ (mBq/ml) in the city center		0.131 $\pm$ 0.010	1.31 $\pm$ 0.10
B11	6.595 $\pm$ 0.275	0.066 $\pm$ 0.003	0.66 $\pm$ 0.03
B12	12.153 $\pm$ 0.820	0.122 $\pm$ 0.008	1.22 $\pm$ 0.08
B13	16.076 $\pm$ 0.426	0.161 $\pm$ 0.004	1.61 $\pm$ 0.04
B14	14.550 $\pm$ 0.570	0.146 $\pm$ 0.006	1.46 $\pm$ 0.06
B15	7.794 $\pm$ 2.021	0.078 $\pm$ 0.002	0.78 $\pm$ 0.02
B16	12.371 $\pm$ 0.844	0.124 $\pm$ 0.008	1.24 $\pm$ 0.08
B17	10.300 $\pm$ 1.147	0.103 $\pm$ 0.012	1.03 $\pm$ 0.12
B18	13.243 $\pm$ 0.934	0.132 $\pm$ 0.009	1.32 $\pm$ 0.09
B19	8.012 $\pm$ 0.384	0.080 $\pm$ 0.004	0.80 $\pm$ 0.04
B20	11.172 $\pm$ 0.373	0.112 $\pm$ 0.004	1.12 $\pm$ 0.04
	Min	0.066 $\pm$ 0.003	0.66 $\pm$ 0.03
	Max	0.161 $\pm$ 0.004	1.61 $\pm$ 0.04
Average $E\alpha$ (mBq/ml) in the rural areas		0.112 $\pm$ 0.008	1.12 $\pm$ 0.08
Average $E\alpha$ (mBq/ml) in the city center and rural areas		0.124 $\pm$ 0.009	1.24 $\pm$ 0.09

SD – standard deviation

Table 5. Comparison of $E\alpha$ (mBq/ml) in the milk of the present study with other studies

County	$E\alpha$ (mBq/ml)	References
Diwaniyah, Iraq	2.20	[26]
Al-Muthanna, Iraq	1.06	Present work

Table 6. Comparison of $E\alpha$ (mBq/ml) in the blood of the present study with other studies

County	$E\alpha$ (mBq/ml)	References
Diwaniyah, Iraq	3.30	[26]
Al-Muthanna, Iraq	1.24	Present work

in both blood and milk samples collected from city center and rural areas of Al-Muthanna Governorate were lower than those reported in Al-Diwaniyah Governorate.

Conclusion

This study revealed the total alpha emission rate ($E\alpha$) in milk and blood collected from women residing in the city center and rural regions of Al-Muthanna Governorate and engaged in various occupations. It was found that the average value of $E\alpha$ in milk samples was 1.10 ± 0.05 mBq/ml in the city center and 1.01 ± 0.05 mBq/ml in rural areas. Similarly, the average $E\alpha$ in blood samples was 1.31 ± 0.10 mBq/ml in the city center and 1.12 ± 0.08 mBq/ml in rural areas.

These results demonstrate that the mean $E\alpha$ values in both blood and milk samples in the city center were higher than in rural areas; this is due to the difference in lifestyle between the countryside and the city.

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