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Radiation environment of radon gas concentrations in serum samples of human workers in factories at Al-Najaf Governorate, Iraq

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Abstract. This study assesses the concentration of radon gas in the serum (blood) of some factory workers in Najaf Governorate, comparing the calculated values with those of healthy individuals (controls). Radon is produced during the decay process of radioactive elements such as uranium and thorium. Radon gas is a naturally occurring radioactive substance that accumulates in enclosed environments such as factories. Chronic exposure to high levels of radon increases the risk of developing diseases, most notably lung cancer. This study aims to determine whether workers in Najaf are exposed to these risks and to provide reliable data to protect their health. The study was conducted using the CR-39 detector to measure alpha particles emitted from radon gas. The total number of samples collected was 50, of which 40 were distributed to factories which are Plastic cups production factory, Water bottling factories, Dates factory and Poultry factory (10 from each factory) in addition to 10 samples for control personnel from outside the factories. After (90 days), which is the exposure period, we calculated the density of the pathways using the TASLIMAGE system. The results showed that the average radon concentration in factory workers was 28.3245 ± 30.8282 Bq/m3 while the concentration in control subjects was 20.7698 ± 11.1286 Bq/m³. The radon concentration in the factory workers' samples was slightly higher than in the control group, a result of continuous occupational exposure. The results showed that the calculated concentration values for both the factory workers and the control group were all within the permissible limit (200 Bq/m³) as defined by the International Atomic Energy Agency and the International Commission on Radiological Protection

1 Introduction

Human technological activities affect the environment in different ways. Some of these activities lead to environmental pollution; radioactive contamination plays an important role. Uranium is one of the sources of radioactive contamination [1].

Uranium is heavy, silvery and white, and is considered slightly softer than steel. Uranium and all its compounds are toxic and cause great harm to human health [2]. Uranium enters

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the human body through inhalation, drinking water, or digestion [3]. Uranium entering the bloodstream and systemic tissues cannot be simply known or measured [4]. Bones, kidneys, and liver are the main sites where uranium is deposited in the body. A number of substances are deposited in other body tissues, but at lower concentrations than the main sites, which represent the volume of soft tissue absorbed into the bloodstream [5].

During the decay process of radioactive elements such as (uranium, thorium and their decay products), radon gas is produced, which is natural. It has no smell or color. Radon is a radioactive and chemically inert substance. It is dangerous because it is an odorless and colorless gas that is emitted from rocks and soil. Three isotopes exist: Radon ^{222}Rn, (thoron) ^{220}Rn, and (actinon) ^{219}Rn, and they are in the decay series ^{238}U, ^{232}Th, and ^{235}U, respectively. Radon is the most abundant of these gases, which has a half-life of 3.82 days, compared to other very rare gases in the atmosphere such as thoron and actinon, which have very short half-lives of 55.65 seconds and 3.69 seconds, respectively [6]. Indoor radon exposure in most countries' accounts for the largest proportion of the radiation dose people receive [7]. One of the most dangerous and important risks of ionizing radiation is continuous and long-term exposure to radon gas, whether in workplaces or homes. The main ways radionuclides enter the human body are ingestion and inhalation. Open wounds can also be transmitted through. It may be accompanied by the presence of radionuclides while eating food or drinking water. In the inhalation process, radionuclides can be taken in throughout the breathing process. Not everyone who inhales radon gas develops cancer; it depends on the main factors that determine the likelihood of developing it, which are radon levels, duration of exposure, and smoking habits [8]. Determining the concentration of radon gas in the body is crucial for assessing its radioactive effects. Therefore, this study was conducted to determine radon concentration levels in the serum of factory workers and individuals outside the factory environment (a control group) in Najaf Governorate using the solid-state nuclear method, and to ascertain whether these concentrations fall within internationally permissible limits.

2 Materials and methods

Ethical Approvals: All participants in the examinations were informed of the study objectives and provided written consent before the samples were collected.

The study area includes several industrial facilities distributed across specific geographic coordinates. The plastic cup production factories are located at 32.0259° N latitude and 44.3463° E longitude. Similarly, water bottling factories are situated at the same coordinates (32.0259° N, 44.3463° E). Date processing factories are found at 32.2000° N latitude and 44.1000° E longitude. Poultry factories are positioned at 32.2488° N latitude and 44.3943° E longitude. These precise geographic locations were used to assess the environmental impact of industrial activities on surrounding areas and to correlate potential contamination sources with local human and ecological health parameters. Blood samples were collected from a group of workers at some Najaf factories and from other individuals outside the worker category (control). Blood serum was taken from the workers and control, with (10) samples taken from each group. After informing the participants of the nature of the study and the confidentiality of their information and obtaining their consent, the questionnaire was presented to the volunteers, including number of smokers, average age (in years) and average duration of work in the factory(years), as shown in Table No. 1. All blood samples were taken at four different plants, in addition to a control sample. Four milliliters of blood were collected from each group using a single-use syringe, and the sample was placed in a dry, clean test tube free of any anticoagulant, where it was left for approximately 15 minutes at room temperature to coagulate. Centrifuges spinning at 10,000 revolutions per minute were used to separate the serum from the blood within five minutes. The serum is then placed in new test tubes, which are labeled with codes. Each code represents a sample from a specific

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individual, including staff and control personnel. The serum samples are then temporarily stored at 4°C in an icebox and subsequently refrigerated until digestion time [9].

Table 1. Demographic characteristics of the four groups participating in the study.

Classification	Plastic cups production factory	Water bottling factory	Dates factory	Poultry factory
Smokers number	8/10	3/10	1/10	9/10
Age range (years)	30	28	32	31
Average duration of work in the factory(years)	5	4	1	1

To determine the concentration of radon gas, a CR-39 reagent (manufactured by Track Analysis Systems Ltd., UK), 1 mm thick and measuring 2.5 × 2.5 cm², is placed in the top of a plastic beaker, as shown in Figure 1. The samples are kept in the beakers for 90 days. Chemical etching is then performed by placing the CR-39 reagent in a chemical solution. The chemical solution is prepared by dissolving 100 grams of sodium hydroxide (6.25 M) in 400 mL of deionized water. After immersing the reagent, the beaker is heated in a water bath (HH-420, Germany) at 98 °C for one hour. The beaker is then sealed to prevent any changes in the sodium hydroxide concentration due to evaporation. The reagents are washed with distilled water. The density of the tracks detected by the CR-39 detector (tracks/cm²) is then calculated using the TASLIMAGE system (Figure 2). The track density is subtracted because the background affects it.

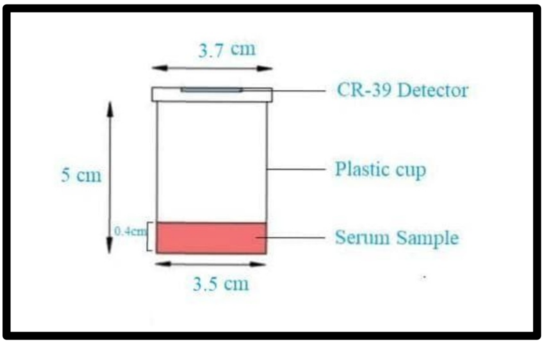

Fig. 1. Radon gas estimation by CR-39 Detector.

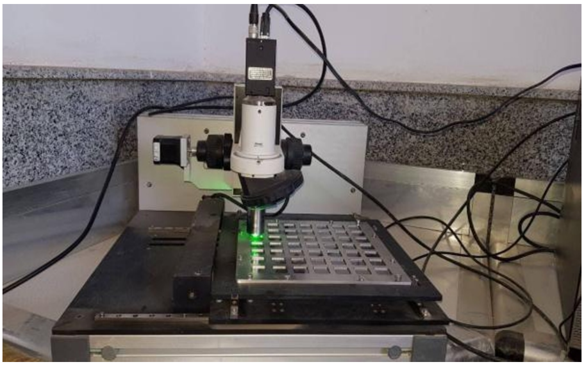

Fig. 2. TASLIMAGE system.

2.1 Calculations

The concentration of ^{222}Rn in the tubular air gap (C^{a}_{Rn}) can be calculated using equation (1) [10]:

$$C^{a}_{Rn}\left(\frac{Bq}{m^3}\right) = \frac{\rho}{K\,t} \tag{1}$$

Where ρ is the track density (Tr/cm²) on the exposed detector, the exposure time is t, which is 90 here, and K is the diffusion constant, also called the theoretical calibration factor. This factor is calculated by the equation below, which is a function of the tube parameters.

$$K = 0.25\,r\left(2cos\theta_c - \frac{r}{r_a}\right) \tag{2}$$

r represents the tubes radius and has a value of 1.75 cm, θ_c is the critical angle of the CR-39 detector and is 35° , and ra is the range of alpha particles in air ra = 4.15 cm.

From these values, the theoretical calibration factor K = 0.5733 cm² is found. The theoretical calibration factor is expressed in centimeters, while the experimental calibration factor is measured in different units (path.cm^{-2}/bcq·m^{-3}·day). These differences were unified by taking 1 becquerel = dissociation/second = track/second, 1 day = 86400 seconds, and 1 m³ = 10⁶ cm³. This gives us 1 cm = 0.0864 (Track.cm^{-2}/Bq·m^{-3}·day), and thus the relationship between $K_{theoretical}$ and $K_{experement}$ can be expressed as:

$$K_{experement}(Track.cm-2/Bq\cdot m-3\cdot day) = 0.0864 \sum iK_{itheoreticali}(cm) \tag{3}$$

By transformation, we find that the diffusion constant for CR-39 reagents is 0.049 Tr.cm^{-2}/Bq·m^{-3}·d.

3 Result and discussion

The tables below will list the radon concentration in serum samples from workers at each factory, specifying the internationally permissible range of values, along with the minimum and maximum values for each factory.

Table 2. Radon concentration in serum samples from Plastic cups production factory workers (internationally permissible range, minimum and maximum).

Factory	No.	Samples code	C^{a}_{Rn}(Bq/m³)
Plastic cups production	1	S1	67.12018
	2	S2	20.86168
	3	S3	17.91383
	4	S4	15.87302
	5	S5	6.122449
	6	S6	47.8458
	7	S7	4.081633
	8	S8	9.977324
	9	S9	13.15193
	10	S10	17.68707
Permissible limit		**200 (Bq/m³)**	
Mean (Bq/m³)			22.06349
Min			4.081633
Max			67.12018

Table 3. Radon concentration in serum samples from water bottling factory workers (internationally permissible range, minimum and maximum).

Factory	No.	Samples code	C_{Rn}^{a}(Bq/m^3)
Water bottling factories	1	S11	8.390023
	2	S12	57.14286
	3	S13	4.988662
	4	S14	4.30839
	5	S15	9.52381
	6	S16	23.58277
	7	S17	78.91156
	8	S18	53.96825
	9	S19	5.895692
	10	S20	27.6644
Permissible limit		**200 (Bq/m^3)**	
Mean (Bq/m^3)			27.43764
Min			4.30839
Max			78.91156

Table 4. Radon concentration in serum samples from Dates factory workers (internationally permissible range, minimum and maximum).

Factory	No.	Samples code	C_{Rn}^{a}(Bq/m^3)
Dates factories	1	S21	4.081633
	2	S22	80.27211
	3	S23	3.401361
	4	S24	5.895692
	5	S25	51.02041
	6	S26	11.11111
	7	S27	2.267574
	8	S28	74.14966
	9	S29	2.494331
	10	S30	39.68254
Permissible limit		**200 (Bq/m^3)**	
Mean (Bq/m^3)			27.43764
Min			2.267574
Max			80.27211

Table 5. Radon concentration in serum samples from Poultry factory workers (internationally permissible range, minimum and maximum).

Factory	No.	Samples code	C_{Rn}^{a}(Bq/m^3)
Poultry factories	1	S31	4.081633
	2	S32	1.360544
	3	S33	57.59637
	4	S34	81.4059
	5	S35	83.67347
	6	S36	3.854875
	7	S37	57.59637
	8	S38	22.90249
	9	S39	2.040816
	10	S40	86.62132
Permissible limit		**200 (Bq/m^3)**	
Mean (Bq/m^3)			40.11338
Min			1.360544
Max			86.62132

Table 6. Radon concentration in serum samples from control persons (internationally permissible range, minimum and maximum).

Control	No.	Samples code	C_{Rn}^{a}(Bq/m³)
Control	1	S41	10.88435
	2	S42	27.89116
	3	S43	34.46712
	4	S44	32.65306
	5	S45	28.79819
	6	S46	3.174603
	7	S47	8.843537
	8	S48	30.839
	9	S49	8.843537
	10	S50	21.31519
Permissible limit		**200 (Bq/m³)**	
Mean (Bq/m³)			20.71051
Min			3.174603
Max			34.46712

Using the CR-39 reagent, radon concentrations were calculated in serum samples from factory workers and control subjects. shows the mean radon concentrations in serum samples from four selected factory workers in Najaf Governorate and control persons. The results showed that the average radon concentration in factory workers was 28.3245 ± 30.8282 Bq/m3 while the concentration in control subjects was 20.7698 ± 11.1286 Bq/m³. The high levels and significant variability, as shown by the standard deviation of 30.82 among workers, indicate irregular occupational exposure, likely due to poor ventilation and radon accumulation in industrial settings. The resulting values fall within internationally permissible limits (200 Bq/m³). Radon concentration in the blood illustrates the direct pathway of internal radiation exposure.

Figure 3 shows a comparison of mean Radon concentration in the serum of workers at four factories (Plastic cups production factory, Water bottling factory, Dates factory, and Poultry factory) the numbers (1, 2, 3, and 4) in the figure represent the names of the factories respectively. versus the concentration in the control group. The figure shows that the mean radon concentration in all four factories is slightly lower than the concentration in the control group, while all values up to and including the control group are below the permissible limit of 200 Bq/m³.

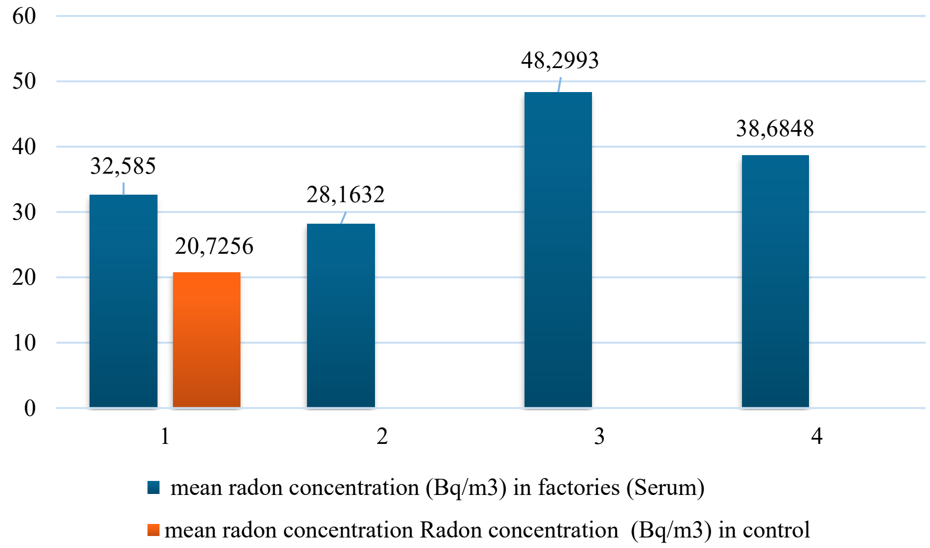

Fig. 3. Mean radon concentration (Bq/m^3) of serum samples from workers in the four factories versus mean in the control group.

3.1 Statistical analysis for radon concentration in serum

Analyses using the Shapiro-Wilk and Kolmogorov-Smirnov tests showed that the data for the plastic cup, date, and poultry factories did not meet the normality requirement ($p < 0.05$). Therefore, the non-parametric Mann-Whitney U test was used for these groups, and the independent samples t-test was adopted for the water bottling plants, which maintained a normality. The results showed no statistically significant differences between all groups compared to the control group, as in the plastic cup factory ($U = 45.00$, $p = 0.705$), the date factories ($U = 47.00$, $p = 0.821$), the poultry factories ($t(18) = 1.581$, $p = 0.131$), and the water bottling factories $t(18) = 0.722$, $p = 0.480$). This means that, within this specific data set, the observed differences between the industrial sectors and the control group remained statistically insignificant (Fig.4).

Group Statistics

	Group	N	Mean	Std. Deviation	Std. Error Mean
Water_bottling_factories1	1.00	10	27.4376	26.74455	8.45737
Control	2.00	10	20.7710	11.72589	3.70805
Dates_factories1	1.00	10	27.4376	31.25013	9.88216
Control	2.00	10	20.7710	11.72589	3.70805
Poultry_factories1	1.00	10	40.1134	36.87416	11.66063
Control	2.00	10	20.7710	11.72589	3.70805
Plastic_cups_production1	1.00	10	22.0635	19.92744	6.30161
Control	2.00	10	20.7710	11.72589	3.70805

Fig. 4. Group statistics.

The differences between groups were statistically explained according to the type of factory (water bottling, dates, poultry processing, and plastic cup production). The p-values exceeded the statistical significance threshold of 0.05 for each factory (water bottling: $p = 0.480$; plastic cups: $p = 0.705$; dates: $p = 0.821$; poultry: $p = 0.131$). No statistically significant differences were observed between the groups. This may be due to varying occupational exposures and lifestyle factors such as smoking and shared chronic health conditions among all employees, which could have a greater impact than the type of factory. These shared factors may mask any group-specific differences.

4 Conclusions

This study provides a comprehensive assessment of radon concentration levels in the blood serum of some factory workers in Najaf Governorate using CR-39 nuclear radiation trace detectors. The results showed that the workers were exposed to higher levels of radon (28.3245 ± 30.8282 Bq/m³) compared to the control group (20.7698 ± 11.1286 Bq/m³), indicating the effect of the industrial environment on internal radiation doses. The large discrepancy in worker data is due to irregular periods of occupational exposure, resulting from differences in workplace ventilation and proximity to radon-emitting materials. The recorded concentrations are within the safety limits set by international radiation protection agencies, but the presence of radon in the blood is a very important biomarker of expected long-term health risks. The results confirm the need to implement routine radiation monitoring and to monitor and improve air exchange systems within industrial facilities to protect workers' health and reduce indoor radiation pollution. Comparing the results of this study with data from other regions of Iraq and other countries reveals both environmental and physiological indicators. The results of the current study indicate that the average radon concentration in the serum of factory workers was 27.5524 Bq/m³, while the urine concentration was 33.7550 Bq/m³. When compared to other Iraqi governorates, radon levels among workers in our study were higher than those recorded in Babylon (19.22 Bq/m³), but lower than the values recorded in Basra (45.12 Bq/m³). These values are lower than those recorded in a previous study in Najaf, which found serum 54.7 Bq/m³ and urine 62.9 Bq/m³ in smokers.

Table 7. Nomenclature.

Symbol / Abbreviation	Description	Unit
^{222}Rn	Radon-222 isotope	
C_{Rn}	Radon concentration in serum samples	Bq/m^3
CR-39	Nuclear Track Detector	

Continuation of Table 7.

Symbol / Abbreviation	Description	Unit
SD	Standard Deviation	
M	Mean concentration value	
Bq/m³	Becquerel per cubic meter	Activity Unit
±	Plus-minus sign (denoting the uncertainty or range)	
ICRP	International Commission on Radiological Protection	
WHO	World Health Organization	
SSNTDs	Solid State Nuclear Track Detectors	

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