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Research Article

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Determination of radon concentration level and its progenies in breast cancer using Cr-39 NTD

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Abstract

Background: *Alpha particle is massive and causes a great lot of ionization when it gets into contact with a body or ingested, and causes single strand and double strand DNA breaks. Two of the alpha emitting decay products, namely 218Po, 214Po, deliver the majority of the radiogenic dose and have been identified as the primary cause of radon-induced cancer.*

Objectives: *This study aims to measure the concentration of radon in powdered blood samples of human have problem with breast cancer in Kurdistan Iraqi region*

Methods: *This study was carried out to detect and measure the concentration of radon in powdered blood samples from the human have problem with breast cancer in Kurdistan Iraqi region from (Sulaymania and Erbil) by using CR-39 NTD (passive method).*

Results: *The activity concentrations of radon of blood human suffer breast cancer ranged from highest value (27.832) Bq.m-3 in (CP3- Taslwja town) to lowest value (13.961) Bq.m-3 in (CP4- Barda qaraman town) with average value of activity concentrations of radon (24.076) Bq.m-3 in Sulamania governorate (Hewa center for cancer). Also the results showed that the activity concentrations of radon ranged from highest value (39.591) Bq.m-3 in (CP73- Taqtaq town) to lowest value (10.251) Bq.m-3 in (CP74- Kasnazan town) with average value of activity concentrations of radon (22.045) Bq.m-3 in Erbil governorate (Nana kaly center for cancer). The results showed that the radon concentration in powdered blood samples were lower than the global permissibility limiting of exposure to radon 200 Bq.m−3.*

Conclusions: *The variation in concentrations of radon in different locations may be arisen due to the difference in the nature of blood samples and nuclei content in this samples, also depending on the allergic reaction of the body to radiation. The issues in this research are very important in strengthening the link between radon, radon progeny, and blood for human have problem with cancer in Kurdistan Iraqi region*

Keywords: Human, Breast Cancer, 218Po, Radon concentration, Blood powdered

Introduction

Radon is emitted by the radioactive decay sequence of uranium-238 (238U). Radium-226, its parent radionuclide, emits alpha particles that power it (226Ra). When it breaks down into its daughter atoms, polonium-218 (218Po) and polonium-214 (214Po), it releases alpha particles [1, 2]. The distribution of radon varies from one location to another. Two of the alpha emitting decay products, namely 218Po, 214Po, deliver the majority of the radiogenic dose and have been identified as the primary cause of radon-induced cancer [3, 4]. Alpha particle is massive and causes a great lot of ionization when it gets into contact with a body or ingested, and causes single strand and double strand DNA breaks. In addition to this, it causes indirect genotoxic and nongenotoxic effects on cells, which can lead to malignancy [5].

Quantification of radiation in human's blood is a valuable technique evaluates the levels of radon naturally in blood samples. No long ago, scientists have progressively reported that specific pollutants in the circumstance may play a pivotal role, contributing at least in some cases to underlying causes of cancer problems in both genders because cancer issues are so prominent, it is important to understand the risk factor of cancer on the human's life. Then physical studies were carried out to explore the radon concentrations, radium and uranium in these samples [6].

There will be about 2 million new instances of breast cancer (BC) in women worldwide in 2020, according to a research published by the World Health Organization. It's been shown that "both hereditary predispositions and environmental reasons" contribute to the renewal of carcinogenesis, a complex process. Death rates have risen over the last three decades because of changes in our understanding of cancer's causes and the improvements in cancer registration and identification that have resulted from these shifts. Recent studies have shown that women over the age of 50 make up roughly 80% of all breast cancer patients [1,7].

Area Under Study

As can be seen in Figure 1, the research was conducted in the Kurdistan region of Iraq, which includes almost all of Iraqi Kurdistan and rural Kurdish provinces including Erbil and Sulaymaniya Governorates. This is a diverse geographical region, composes of hot plains and cooler mountainous areas with natural springs. The area of Kurdistan region is 80,000 square kilometers and its population is estimated to be more than 4.5 million people (https://www.google.com) [8, 9]. This part of Kurdistan region, the affection of uranium series and the subsequent emission of alpha particles (radon) are widespread which result in many cancer problems. Also, according to the data about the patients of cancer obtained from Nana Kaly Hospital, center of cancers in Erbil, and Hiwa hospital, center of cancers in Sulyamaniya, this region is considered suitable for studying the risk of radon on patients who have cancer.

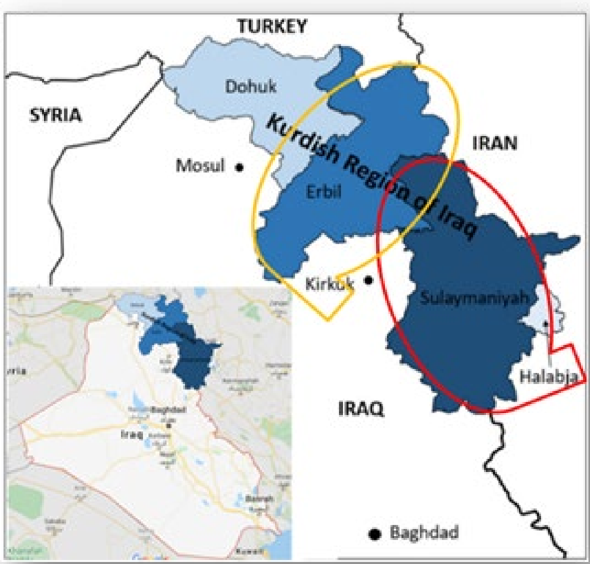

Figure 1: The map of location under study.

Materials and Methods

Blood is a circular tissue made up of fluid plasma and several different types of cells (red blood cells, white blood cells, and platelets). In the body, it carries things around by way of the circulatory system. In normal, healthy people, the circulation of their blood cells stays within a narrow range. However, illnesses, bleeding, radiation, and chemotherapy all have a deleterious effect on blood cell counts [10, 11].

CR-39 NTDs is nuclear track detector sheets are a C12 H18 O7 polymer "with a thickness of 1.22 g/cm3". and density of 100 µm tear into small parts each of (1.0 x1.0) cm2 area. These detectors got from (Pershore Moulding LTD Company, UK) were used to record fission tracks[12].

PVC tube, or polyvinyl chloride tube, is a long plastic cylinder that measures 6 cm in length, 1.5 cm in diameter, and 2 mm in thickness [12,19].

Methods

Sample collection

For the aim of this study, several samples of blood were gathered from people who have cancer problem from different patient and places in Iraqi Kurdistan that were collected appropriately for empirical study under the guidance of the medical authority from two selected (Sulaymaniya and Erbil) governorates. Afterwards, the research was conducted to examine the levels of radon in the participants' blood samples. This investigation was based on a study of 34 blood samples, randomly selected from breast cancer patients. The samples were obtained from Sulaymaniya city (Hewa Center of Cancer) and Erbil city (Nana kaly Center of Cancer), Each cancer patient had 3 mL of blood drawn using a disposable syringe and placed into a tube with ethylene diamine tetraacetic acid (EDTA) to prevent the blood from clotting, as illustrated in Tables 1 and 3 [12]. Patients' demographic details were recorded, including their names, sexes, ages, cancer diagnoses, locations, sizes, and socioeconomic standings. The blood tubes were stored in a (4°C) ice box [10]. The tubes were then taken to the research hub of the Faculty of Science and Health at Koya University, where they are now being stored in a refrigerator. Blood samples, which should be maintained at between (2-4) °C until analysis starts, were given unique identification codes and stored at 4 °C[13].

Preparation of powdered blood samples

After collecting the samples of blood required from the patients, the blood samples were put in the Perspex cup and for six hours heated at 70°C in the oven to dry, putrefy organic substance, and to remove moisture [12, 11]. Then, the samples were grinded many times, to get a powder in similar to grain size, "all samples were sieved through a fine mesh (0.5 mm)". After preparation, 0.5 g from each powdered blood were put in the end down of PVC tubes and one CR-39 track detector was placed in a container (CR-39 is a detector which had a thickness of 500 µm, with an area of (1.0 × 1.0) cm2. All the detectors were stabled to the top end of PVC tubes that have diameter (1.5 cm) and its length (6cm) [13], as shown in Figure 2, Approximately all the tubes were stored in the Research Center of Physics Laboratory in the fridge for about 90 days, after that period, the process of track visualization has been carried out in four steps

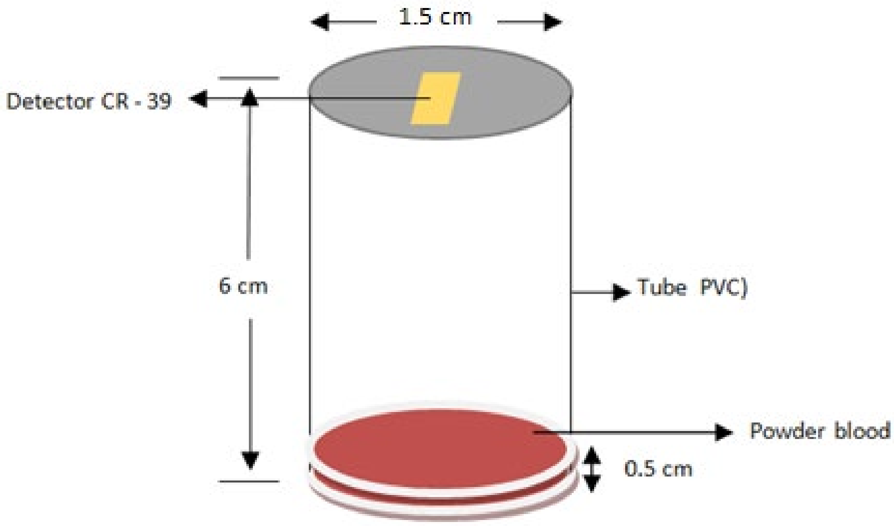

Figure 2: PVC tube with preparation of powdered blood sample and CR-39 detector

Steps of the Process of Track Visualization

The etching technique consists of four steps; [14]. include; Etching, Washing, Drying, and Observation under optical microscope. According to Durrani and Bull (1987), the four phases of an etching procedure are as follows: etching, washing, drying, and optical microscope observation.

Etching starts by heating an aqueous sodium hydroxide (NaOH) solution to 70±0.5 oC and keeping it there using a thermostatically controlled water bath so that the temperature of the solution remains consistent throughout the procedure. Suspending the CR-39 plastic detector in the NaOH solution required just taping the wire to the beaker lid [14, 15]. After that, the beaker was enclosed with rubber stopper so as to avoid rapid modifications of NaOH normality that causes evaporation that increases the concentration of NaOH, and the detector was kept there for 8 hours.

The CR-39 detector was cleaned with running cold water for 20min to halt the etching process, and then washed again with filtered water to remove any remaining traces of NaOH [17].

Drying: Having done with the washing the detector, hot air (in some cases hair dryer) was used to dry it completely in the air or by normal air [15]. Data visualization of CR-39 NTDs After carrying out the three steps of (etching, cleaning, and drying), the track density created on the CR-39 reagent was calculated by counting the alpha particles released by radon gas using an optical microscope [18, 19]. According to Figure 3, the optical microscope utilized was of the (Olympus) kind, was manufactured in Japan, and had a high precision power of (400X), optic lens of (10X), and objective lens of (40X).

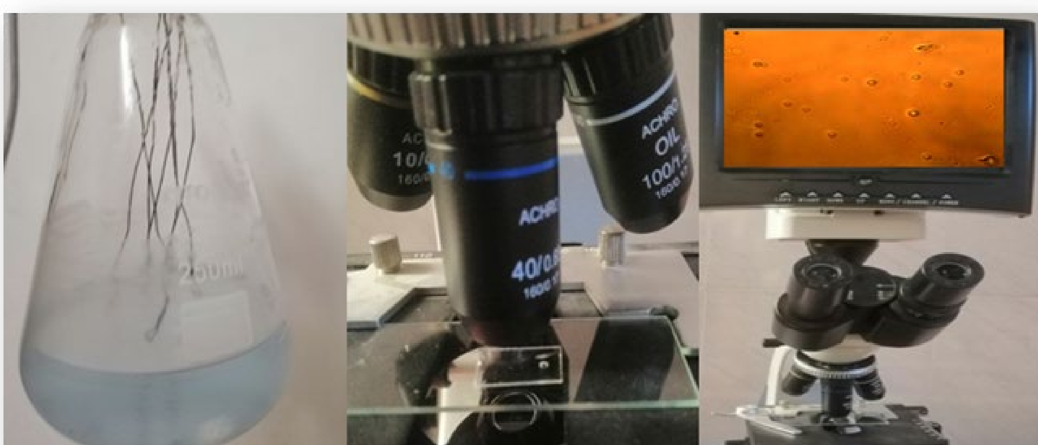

Figure 3: Steps of the process of track visualizationa

Measurement and Calculation

Measuring the density of track and concentration of radon in the powdered blood:

Track densities (ρ) were measured using the following equation after CR-39 detectors had through the four stages of the track visualization procedure (etching, washing, drying, and scanning) [20];

Track density (ρ) = Average of total pits /area of filed view (1)

Calibration factors of track density to radon concentration (0.0236 trackcm-2 per Bqm-3day) and exposure time (90 days) determine the radon concentration. In this study, this factor was calculated by equation as adapted from the studies by [20, 13].

K = 0.25 r (2cosθ_C - r/Ra) (2)

Average critical angle for CR 39 detector θC = 35°, although it varies depending on detection system geometry [21, 13], r = 0.75 cm radius of irradiation tube [12, 22] and Rα= 4.15 rα = 4.15 cm that is an average range of alpha particle in air of ^{222}Rn and the factor of calibration (K) was regarded as (0.0236 (Track.cm^{-2}. Bq.m^{-3}.day). For calculating and estimating the level of radon concentration of each blood sample, the following formula was used [16, 13].
To calculate and estimate the level of radon concentration of each sample, the following relationship was used [23, 24];

CRn(Bq.m^{-3}) = ρ/k.t ………3

Where, CRn : The radon concentration (Bq.m^{-3}), ρ : The track density (track.cm^{-2}), K: The calibration factor (track.m^{-3})/(cm^{-2}.Bq.day), t : The exposure period (day).

Estimation of the radon progenies concentration (^{214}Po, ^{218}Po)

The following formulae developed by [25] were used to determine the amount of radon progeny (polonium) deposited on the chamber walls (POW) and the detector face (POS) from alpha particles (^{214}Po and ^{218}Po)-emitting blood samples [26]; .

$$C_{po^{218}} = C_{po^{214}} = \frac{C}{4} r \left(\frac{h}{r+h}\right) \cos\theta \quad (4)$$

$$C_{po^{218}} = C_{po^{214}} = \frac{C}{4} r \left(\frac{h}{r+h}\right) \left(\cos\theta \ \frac{r}{R\alpha}\right) \quad (5)$$

Results and Discussion

Table 1 and Figure 4, demonstrated that the results of activity concentrations of radon of powdered blood of human suffer from breast cancer were ranged from highest value (CP3, 36.558 Bq.m-3, 67%, Taslwja town, Female) with age (62 year) to lowest value (CP4, 18.338 Bq.m-3, 33%, Barda qaraman town, Female) with age (41year) and average value of activity of radon concentrations (28.790) Bq.m-3 in Sulaymaniya governorate (Hewa Center of Cancer).

Table 1: The result of radon concentration in powdered blood samples for human have problem with cancer- Sulaymaniya

No.	Code	Breast Cancer	Con. of Radon (Bq.m-3)	Location	Age	Gender
1	CP1	Breast	25.118	Twymalik	58	Female
2	CP2	Breast	24.459	Kalar1	41	Female
3	CP3	Breast	36.558	Taslwja	62	Female
4	CP4	Breast	18.338	Barda qaraman	41	Female
5	CP5	Breast	20.998	Takya	47	Female
6	CP6	Breast	33.239	Sarkapkan	52	Female
7	CP7	Breast	25.767	Kalar	35	Female
8	CP8	Breast	33.489	Bazyan	71	Female
9	CP9	Breast	23.945	Zarayan	37	Female
10	CP10	Breast	27.213	Bakrajo	42	Female
11	CP11	Breast	25.297	Raparin	60	Female
12	CP12	Breast	36.347	Ashaba	36	Female
13	CP13	Breast	35.923	Sarkarez	69	Female
14	CP14	Breast	34.148	ChwarBax	56	Female
15	CP15	Breast	27.274	Kalar2	52	Female
16	CP16	Breast	35.217	Chamchamal	35	Female

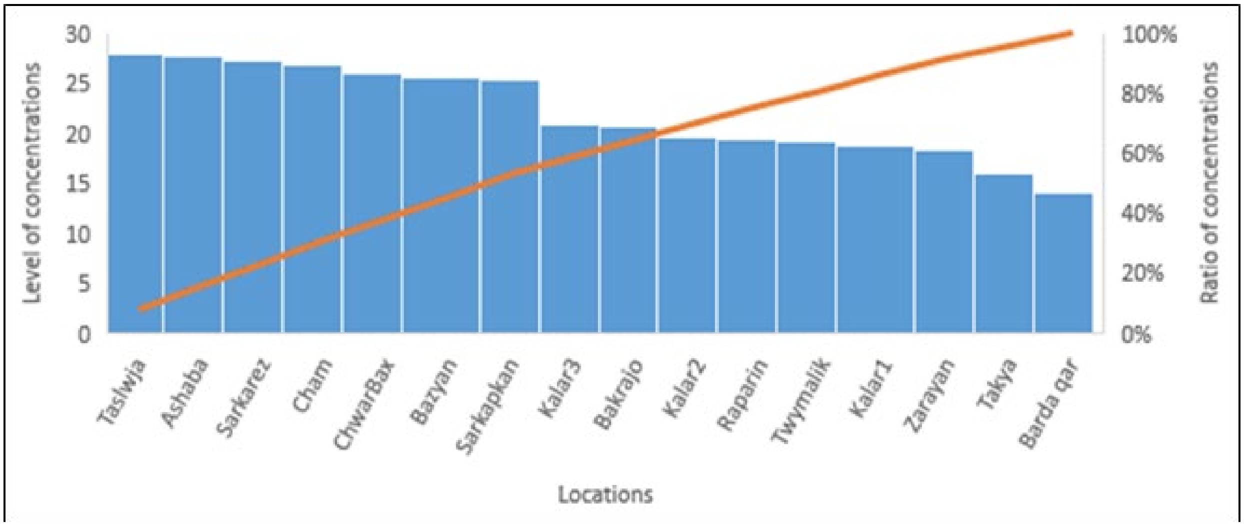

Figure 4: Relation of the level concentration of radon in blood samples with ratio of this concentration in the locations under study-Sulaymania

Patients with breast cancer had radon progenies (^{214}Po, ^{218}Po) deposited on the walls of the irradiation chamber (POW) and on the face of the detector (POS), with the highest concentrations found in the powdered blood sample CP3 (1.492 Bq.m^{-3}) and the lowest concentrations found in the blood sample CP3. According to Table 2 and Figure 5, it was also determined to be (0.135 Bq.m^{-}3) in the CP4 blood powder and (0.748 Bq.m^{-3}) in the CP4 blood sample. This depends on the typical critical angle of alpha particles hitting the CR 39 detectors [27]. The average value of concentration of polonium (POW- 0.213 Bq.m^{-3}, 15%) was higher than the average value of concentration of polonium (POS-1.175 Bq.m^{-3}, 85%) Figure 6 shows that the value of polonium concentration (POW- 0.213 Bq.m^{-3}, 15%) was greater than the average value of polonium concentration (POS-1.175 Bq.m^{-3}, 85%) because of distribution on the surface of the chamber focused on small place, making it lower than the tracks distribution on the walls of the chamber and noting that the concentration of (^{218}Po, ^{214}Po) is small and within the sampling error in the measurement of radon concentrations

Table 2: The concentration of radon progenies (^{218}Po, ^{214}Po) deposited on the walls (POW) and on the face of the detector (POS) - Sulaymaniya

No. of Sample	Code of Sam.	Breast Cancer	Con. of ^{222}Rn Bq.m^{-3}	Con. Po^{218}, Con. Po^{214} Bq.m^{-3}	
				POW	POS
1	CP1	Breast	25.118	0.186	1.025
2	CP2	Breast	24.459	0.181	0.998
3	CP3	Breast	36.558	0.271	1.492
4	CP4	Breast	18.338	0.135	0.748
5	CP5	Breast	20.998	0.155	0.857
6	CP6	Breast	33.239	0.246	1.356
7	CP7	Breast	25.767	0.191	1.051
8	CP8	Breast	33.489	0.248	1.367
9	CP9	Breast	23.945	0.177	0.977
10	CP10	Breast	27.213	0.201	1.111
11	CP11	Breast	25.297	0.187	1.032
12	CP12	Breast	36.347	0.269	1.483
13	CP13	Breast	35.923	0.266	1.477
14	CP14	Breast	34.148	0.253	1.394
15	CP15	Breast	27.274	0.202	1.113
16	CP16	Breast	35.217	0.261	1.437

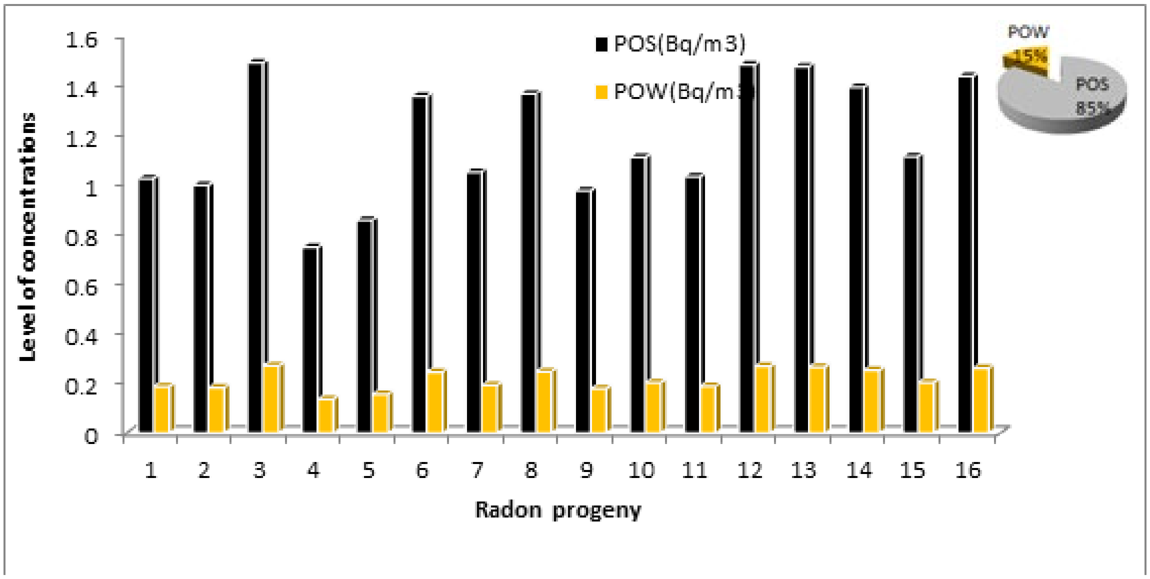

Figure 5: The relation between POW and POS of the powdered blood of breast cancer in Sulaymaniya

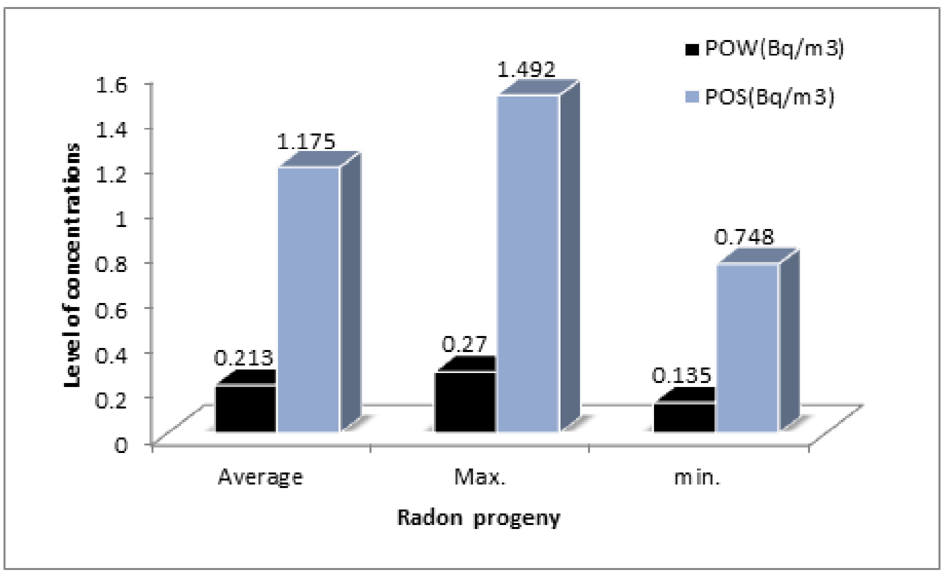

Figure 6: Average, Max., and Min. concentration of radon progenies (218Po, and 214Po)

Table 3 and Figure 7, showed that the results of activity concentrations of radon of powdered blood of human suffer breast cancer were ranged from highest value (CP73, 52.006 Bq.m-3, 79%, Taqtaq town, Female) with age 47 years old to lowest value (CP74, 13.465 Bq.m-3, 21%, Kasnazan town, Female) with age 62 years old, all patient's cancer breast are from the female with different ratio and different locations, with the value of activity of radon concentrations (30.784) Bq.m-3 in Erbil governorate (Nana kaly Center for Cancer).

The results of radon concentration in powdered blood sample for cancer patient in Erbil governorate with information were reported in Table 3.

Table 3: The result of radon concentration in blood samples for human have problem with cancer-Erbil

No.	Code	Breast Cancer	Con. of Radon ($Bq.m^{-3}$)	Location	Age	Gender
1	CP71	Breast	23.729	Segrdkan	51	Female
2	CP72	Breast	31.921	Badawan	43	Female
3	CP73	Breast	52.006	Taqtaq	47	Female
4	CP74	Breast	13.465	Kasnazan	62	Female
5	CP75	Breast	26.394	Kuran	58	Female
6	CP76	Breast	37.382	Khabat	74	Female
7	CP77	Breast	28.027	Ashty	38	Female
8	CP78	Breast	21.563	Perzin	55	Female
9	CP79	Breast	38.479	Salahadin	40	Female
10	CP80	Breast	35.405	Kani gwlan	58	Female
11	CP81	Breast	48.272	Khabat	60	Female
12	CP82	Breast	35.561	Daratw	35	Female
13	CP83	Breast	27.180	Taqtaq	34	Female
14	CP84	Breast	34.087	Kasnazan	41	Female
15	CP85	Breast	27.368	Sktan	64	Female
16	CP86	Breast	25.169	Balesan	59	Female
17	CP87	Breast	22.250	Gwer	50	Female
18	CP88	Breast	21.968	Ashty	42	Female

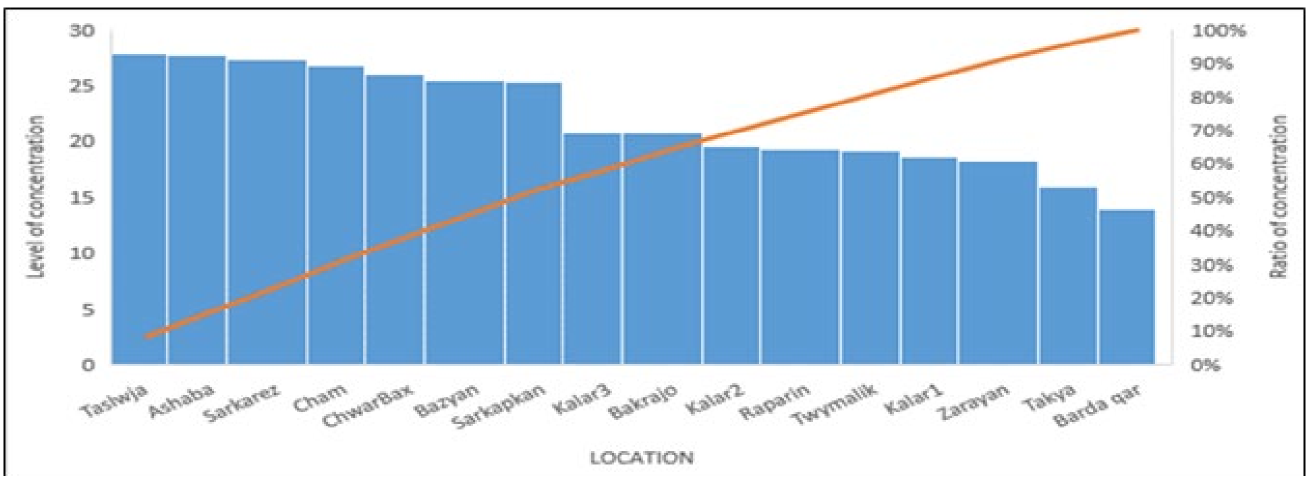

Figure 7: Relation of the level concentration of radon in blood samples with ratio of this concentration in the locations under study-Erbil

Radon concentrations in the powdered blood sample CP73 were calculated to be (0.385 $Bq.m^{-3}$) and in the blood sample CP73 were found to be (2.122 $Bq.m^{-3}$), respectively, on the surface of the irradiation chamber (POW) and on the face of the detector (POS). As can be seen in Table 4 and Figure 8, the minimum values were determined to be 0.099 $Bq.m^{-3}$ for the powdered sample CP74 and 0.549 $Bq.m^{-3}$ for the blood sample CP74, respectively. The critical angle at which the alpha particles hit the CR 39 detectors determines those numbers [27]. As can be seen in Figure 9, the average value of polonium concentration (POS - 1.256 $Bq.m^{-3}$, 85%) was considered higher than the average value of polonium concentration (POW - 0.226 $Bq.m^{-3}$, 15%) due to the fact that the distribution of the tracks on the surface of the chamber concentrated on small place, making it lower than the tracks distribution on the walls of the chamber and noting that the concentration of (^{214}Po, ^{218}Po) is low.

Table 4: The concentration of radon progeny (^{218}Po, ^{214}Po) deposited on the walls (POW) and on the face of the detector (POS)-Erbil

No. of Sample	Code of Sam.	Breast Cancer	Con. of ^{222}Rn Bq.m^{-3}	Con. Po^{218}, Con. Po^{214} Bq.m^{-3}	
				POW	POS
1	CP71	Breast	23.729	0.175	0.968
2	CP72	Breast	31.921	0.236	1.302
3	CP73	Breast	52.006	0.385	2.122
4	CP74	Breast	13.465	0.099	0.549
5	CP75	Breast	26.394	0.195	1.077
6	CP76	Breast	37.382	0.276	1.525
7	CP77	Breast	28.027	0.207	1.143
8	CP78	Breast	21.563	0.159	0.880
9	CP79	Breast	38.479	0.285	1.570.
10	CP80	Breast	35.405	0.262	1.445
11	CP81	Breast	48.272	0.357	1.970
12	CP82	Breast	35.561	0.263	1.451
13	CP83	Breast	27.180	0.201	1.109
14	CP84	Breast	34.087	0.252	1.391
15	CP85	Breast	27.368	0.202	1.117
16	CP86	Breast	25.169	0.186	1.027
17	CP87	Breast	22.250	0.164	0.908
18	CP88	Breast	21.968	0.162	0.896

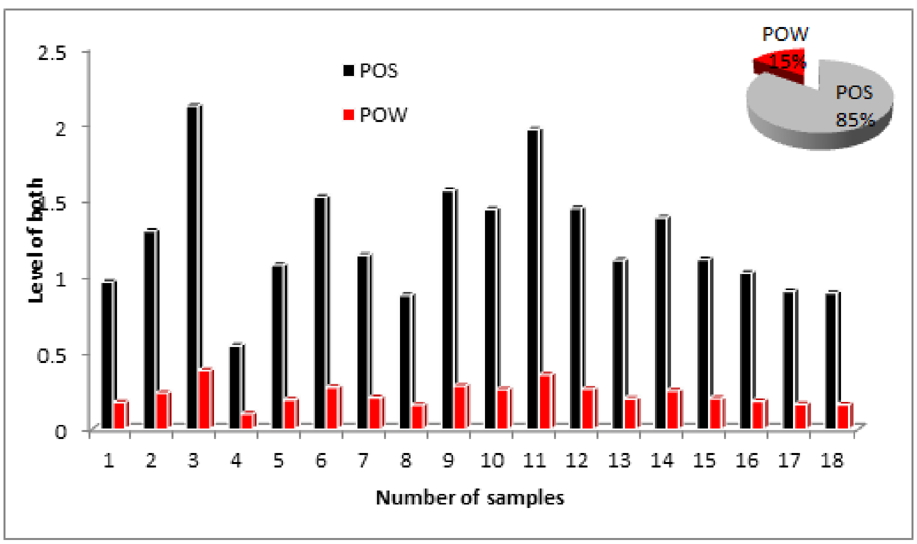

Figure 8: The relation between POW and POS of the powdered blood of breast cancer in Erbil

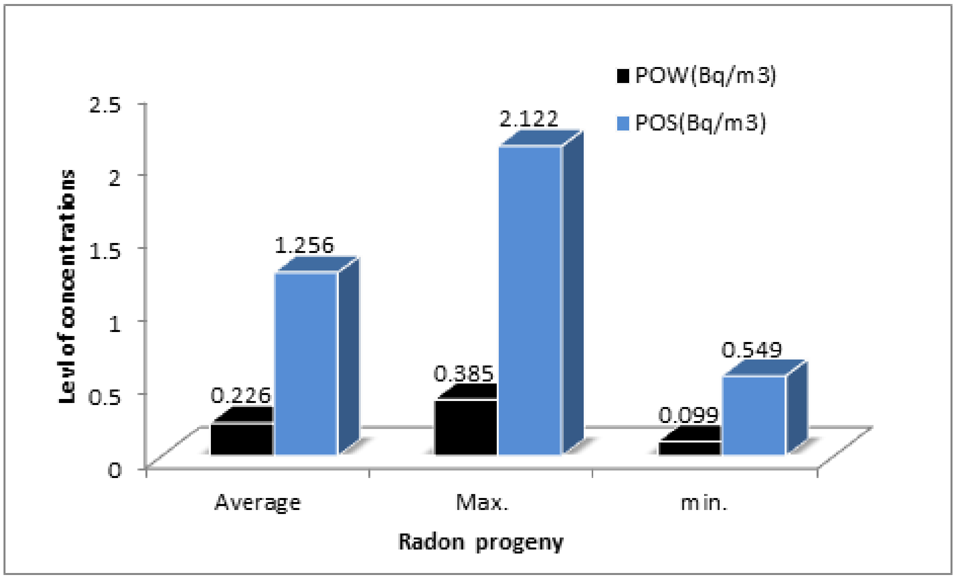

Figure 9: Average, Max., and Min. concentration of radon progenies (218Po, and 214Po)

The results showed that the radon levels in the samples from (Sulaymania and Erbil) were below the globally accepted limiting encountered to radon (200) Bq.m-3. The results also showed that the radon levels vary from cancer to cancer, patient to patient, and location to location due to the body's allergic reaction to the radiation. All the radon concentrations in the dried blood samples were found to be much below the maximum allowed by the International Commission on Radiological Protection (ICRP) and the International Atomic Energy Agency (IAEA)(200 Bq.m-3)[28].

This study's findings suggest that the radon content in powdered blood samples varies in levels for all females across geographic areas. The fact that most women remain at home for longer periods of time likely exposes them to greater levels of radiation, but the discrepancy may also be attributable to the type of the samples and the nuclei content of these samples. As the new research shows, the blood may be devoid of environmental toxins and the levels of radon-222 and radon progenies are well under global safety guidelines. When compared between the average concentrations of radon (28.790 Bq.m-3) in the powdered blood samples for human who have problem in Sulaymaniya with the average concentrations of radon (30.784 Bq.m-3) in Erbil, all results were significantly higher in Erbil governorate than in Sulaymaniya governorate. Radiation causes an allergic response in women, which may explain why radon levels are lower in them; women who remain at home for extended periods are more likely to be exposed to high levels of radiation. Reason being, people who spend more time inside have lower ventilation rates than those who spend less time inside their homes. The EPA has proposed that instant interference is needed as long as the radon concentration (222Rn) level is greater than 190 Bqm-3; Since the radon levels in all samples were found to be lower than 190 Bqm-3, there is no danger to human health. Many studies have used CR-39 NTD to diagnose the concentration of radon gas/radon progenies and alpha emitters in biological samples, allowing for a better understanding of radon and its short-lived progeny. In addition, many studies have been carried out to investigate and assess the radon concentration elements in biological samples by using various methods, such as: Ismail, et al., (2011) presented the result of radon concentration for various durations of time (221- 5.1 Bq.m-3, in PVC container with the aid of two radium (5Ci) sources, blood samples and CR-39NTD pieces are exposed (together with one another)[29].

The alpha emitter concentration in powdered blood was tested by Salih et al. (2013); the findings revealed a significant variation in radon concentration (p0.001) from (0.0036 ppm) in Eiskan to (0.0096 ppm) in Halabjay-Kon, with an average of (0.0085 ppm). Results from the Erbil Governorate showed a significant variation in concentration (p0.001), ranging from 0.0031 ppm in Shorsh to 0.0146 ppm in Sedakan, with an average of 0.0062 ppm, indicating that a significant difference in concentration ($p<0.001$). Therefore, the average concentration values in Erbil were greater than those in Sulaymaniya [12].

Salih and Jaafar (2014) conducted a study to determine the concentration of alpha/ radon in fresh blood for women with infertility issues. They found that while the results varied from (0.0029 to 0.0088) ppm in Sulaymaniya governorate, they ranged from (0.0029 to 0.0139) ppm in Erbil governorate, meaning that the mean track density of fresh was significantly higher in Erbil [10].

Women's radon exposure was investigated in a 2016 research by Salih et al. A total of "(417 to 714) Bq.m-3, with an average of 570.25 Bq.m-3" was found to be the radon concentration in the blood samples analyzed [17].
Blood cancer patients were studied by Mohsen and Abojassim (2019), who used CR-39 NTD to test 222Rn, 226Ra, and 238U levels. The findings indicated elevated levels of radon (64.325.92 Bq.m-3), radium (3.11.24 Bq.kg-1), and uranium (1.40.58 ppm) [30].

Showard, et al., (2019) reported the study about increasing prevalence of cancer, particularly leukemia, in Babylon city during (1991 – 2003) Gulf wars to assess the radon concentration in human's blood by using CR-39, the results were ranged from 13.98 Bq.m-3 to 5.24 Bq.m-3, with an average value (7.79 Bq.m-3) [31].

Abdul Wahid, et al., (2020) reported the results about blood samples which were taken from cancer patients in order to find out the contamination of (222Rn, 226Ra, and 238U) by using CN-85 NTD, showed that the results were varied from 0.39 to 2.50 Bq.kg-1 and 15.81 to 100.68 Bq.kg-1, respectively, also varied from (0.032 to 0.202) ppm [32].

Hameed, et al. (2021) evaluated the risk of alpha emitter's concentrations and measured this concentration in 60 people blood samples by using CR-39 NTD of employees in the Iraqi museum; employees in antiquities, heritage and Abd al-karim qasim museum in Baghdad, Iraq by using CR-39 NTD. Based on the results, high alpha concentrations to museum workers and archaeologists may have escalated damage to DNA and cancer more than the other workers[33].

Naji and Hassoon (2021) published a study detailing the radon levels in the serum of patients with lung cancer in the governorate of Babylon. Values for radon exposure were on average (19.2234 2.159) Bq.m-3 in patients with lung cancer[34].

Conclusions

The purpose of this research into natural radioactivity in dried blood samples was to ascertain the potential health hazards posed by the samples by measuring the amounts of radon and 222Rn in the samples. The recent data could be beneficial to observe the toxic pollution in the circumstance; also, it is of great value to decide the level of radon concentrations in blood to provide further data to rate the impact of radiation in the environment exposed to people's health. Nonetheless, majority of the samples analysed indicated generally low radon concentration level, with values generally lower than the worldwide average values reported by UNSCEAR. This study's baseline information will unquestionably be useful in estimating the proportion of the population at risk from radon exposure.

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Conflict of interest

The authors declare that they have no conflict of interest.

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