

Measurement Of Radon Gas In Indoor Environments Of Dwellings In Kirkuk, Iraq

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Abstract

Indoor radon (CRn) in 34 houses in Kirkuk province has been measured in multiples using CR-39 for the period of (January and February 2025). Findings from the research showed that the CRn (17.96 – 68.39) of Bq.m⁻³ Average (40.695) Bq.m⁻³ It was less than the minimum (200 - 300) Bq.m⁻³ layer (ICRP, 2009). The value of PAEC ranged from (1.94 - 7.39) mWL with a mean value of (4.39) mWL which was below the maximum value of (53.3) mWL (UNSCEAR, 1993). AEDE: The average equivalent dose (AEDE) values are between (0.453 - 1.725) (±0.867) mSv/year, the mean value (1.026) mSv/year is lower than the minimum value suggested (3 - 10) mSv/year value (IRRP, 1993). Exposures to radon offspring ranged from (0.08 to 90.30) WLMY-1 and the mean I was (0.18) WLMY-1, which was within normal 1 to 2 WLMY-1 recommended in the R, R I (NCRP, 1989). The yearly scope of the lung cancer instances per million population was (8.16 to 31.06) and the mean value was (18,480 per million population), which was less than the lower limit of the permissible range (170-230) per million population (ICRP, 1993).

Keywords: radon concentration (CRn), Indoor radon (CRn) in Kirkuk, CR-39 Solid-state nuclear track detector.

1. Introduction

Radon, a naturally occurring noble gas, boasts a non-detectable profile: it's invisible, odorless, transparent, and without taste or flavor. Its consistent generation stems from the natural breakdown of the radioactive elements ²³⁸U, ²³⁵U, and ²³²Th. ²³⁸U's decay contributes most significantly (around 55%) [1] to humans' internal radiation exposure, yielding radon gas, specifically ²²²Rn. Radon is radioactive; it releases alpha particles with 5.49 MeV of energy. ²²⁶Ra is its parent element, and ²²²Rn is its daughter element. ²²²Rn has a half-life of 3.82 days [2]. Polonium-218 (²¹⁸Po) is made right away when ²²²Rn breaks down. Alpha and beta decays then make polonium-214 (²¹⁴Po). If you breathe in these polonium isotopes, your lungs are exposed to harmful alpha radiation. A lot of radon can be absorbed from the air, and there is good evidence that these alpha-emitting decay products of ²²²Rn can cause lung cancer in people [3]. Soil, building materials like sand, rocks, and cement, waterborne transportation, and fuels like coal and gas that contain ²³⁸U are all natural sources that raise indoor radon levels. The concentration of radon indoors is determined by how quickly radon escapes from nearby objects [4], [5].

Radon-222 and its airborne children are radioactive gases that can cause lung cancer. The danger goes up when there are high levels of uranium and radium in the soil or when radon and its byproducts build up in tight spaces, like homes [3]. Radon usually gets into buildings through cracks in the foundation, mostly from the ground below. Secondary sources that help with this include building materials, water sources, and natural gas used for cooking. Most of the time, radon levels within buildings are higher than those outside. Assuming a steady flow of radon, the ventilation rate is the main factor that affects the

radon level inside a building. Radon accumulates higher in enclosed spaces than in open areas, as a reduction in ventilation can nearly double the radon concentration. The rise in radon levels in closed areas over the winter and summer is due to the fact that ventilation rate affects both radon concentration and decay rates. Individual exposure in a confined space is roughly tenfold greater than in an open space [6].

People all throughout the world get an average of 2.4 mSv of natural ionizing radiation each year. Radon exposure accounts for approximately 1.0 mSv of this total [7]. The International Agency for Research on Cancer (IARC) of the World Health Organization (WHO) says that radon is a group 1 carcinogen. This classification says that radon is just as likely to cause cancer as substances like asbestos and tobacco smoke. It is important to keep an eye on and test radon levels in buildings because we spend so much time inside [8], [9]. Regular radon concentration measurements are currently performed, and various laboratories globally have devised diverse radon radiation detectors [10]. Several methodologies are employed to ascertain radon and its decay product concentrations. Track-etch detectors, like LR-115 and CR-39, are commonly used to assess the time-integrated radon levels in residential buildings of varying types [11], [12]

2. Site Description

Kirkuk is located in the northern part of Iraq, between the Zagros Mountains and the Hamrin Mountains. It is the capital of Kirkuk Governorate, approximately 233 kilometers (145 miles) north of Baghdad. Figure 1 shows its major city as the city of Kirkuk. Positioned 44.38 d fixedline to the east of the Greenwich Line and 35.46 d fixedline below the equator, the province covers an area of 10359 square kilometres. The codes and names of the survey sites in different sites in Kirkuk Governorate are presented in Table (1).



Figure 1. An Initial Map Illustrating the Locations within the Study Area in Kirkuk Governorate.

Table 1: Location codes and names of building materials in Kirkuk Governorate

Symbol	Location	Details for buildings		
		House type	Site Detector	Building materials
K1	Elton kopri	old	Bedroom	Kashi ,Burke, Cement

K2	Elton kopri	modern	Bedroom	Plaster, Cement ,Burke
K3	Elton kopri	old		Block, Ceramics, Plaster
K4	Elton kopri	modern	Bedroom	Block, Ceramics, Burke
K5	Riyadh	old	Kitchen	Ceramics, Kashi ,Burke, Cement
K6	Riyadh	modern	bathroom	Ceramics, Burke Kashi ,
K7	Riyadh	old	bathroom	Block, Cement , Plaster
K8	Riyadh	old	Kitchen	Cement, Kashi , Block , , Burke
K9	Al- Hawija	modern	Bedroom	Brick, , Kashi , ,Burke
K10	Al- Hawija	modern	Bedroom	Block, Cement, Kashi , Burke
K11	Al- Hawija	old	Bedroom	Plaster, Kashi, Brick
K12	Kirkuk	modern	Kitchen	secondary roof, Ceramics, Kashi ,Burke
K13	Kirkuk	modern	bathroom	Kashi, Burke, Ceramics, secondary roof
K14	Kirkuk	old	Bedroom	Brick, Kashi, Burke
K15	Kirkuk	modern	Kitchen	Brick, Ceramics, secondary roof
K16	Kirkuk	old	Bathroom	Block, secondary roof , Ceramics
K17	Kirkuk	modern	Kitchen	Block, secondary roof, Kashi
K18	Kirkuk	old	Bedroom	Brick, , Cement, Plaster
K19	Kirkuk	old	Kitchen	Brick, Kashi, Burke
K20	Daquq	old	Living room	Block, Cement, Ceramics
K21	Daquq	old	Kitchen	Block, Ceramics, Cement
K22	Daquq		Kitchen	Block, secondary roof, Ceramics
K23	Daquq		Bedroom	Block, Kashi, Plaster
K24	Yaichi	modern	Kitchen	secondary roof,, Ceramics, Block
K25	Yaichi	Old	Bedroom	Brick, Kashi, Cement
K26	Yaichi	Old	Living room	Kashi, Brick, Burke
K27	Yaichi	modern	Living room	Block, Ceramics, secondary roof
K28	Taz	old	Bedroom	Kashi, Burke, Block
K29	Taz	modern	Living room	Ceramics, Kashi , Plaster
K30	Taz	Old	Living room	Marble, Burke , Brick
K31	Al- Zab	Old	Living room	Ceramics, secondary roof, Cement

K32	Al- Zab	modern	Living room	Block, secondary roof, Kashi, Ceramics
K33	Al- Zab	modern	Kitchen	Block, Ceramics, secondary roof, porcelain
K34	Al- Zab	Old	Kitchen	Kashi, cement, and brick

3. methodology

To investigate radon gas in 34 dwellings in Kirkuk Governorate, using SSNT technology, the CR-39 detector was applied. The CR-39 detectors were cut into rectangles and subsequently suspended in two houses, one with modern design and the other of an old style, and hung in bedrooms, kitchens, and bathrooms on the ground floor of each house and then suspended on the second floor at 2 m above the floor level, where most of the dwellings are typical, since the majority are constructed with cement walls and good ventilation systems. The detectors were etched using $(60 \pm 1)^\circ\text{C}$ for 300 minutes in a thermostatic water bath with a chemical etching solution at 62.5 g of NaOH analytical grade. The detectors were rinsed in cold water and then in distilled water after scraping. The detectors were then permitted to air dry for a few minutes, and the detectors were then available for counting, with the alpha lanes being counted at 400X magnification with a binocular optical search microscope.

4. Calculation

Using equation :

$$CRn (Bq \cdot m^{-3}) = \rho / K \cdot t \quad \dots\dots\dots (1)$$

The mean radon concentration (CRn) in terms of $Bq \cdot m^{-3}$ was ascertained [13] [8] Given the track density, symbolized by ρ , measured in tracks per square millimeter (track/mm^2), and incorporating K, the calibration factor, empirically determined to be $0.1278 (\text{track} \cdot \text{mm}^{-2} / Bq \cdot \text{dm}^{-3})$ - this is visually represented in Figure 2. Additionally, "t" signifies the exposure time, a period equivalent to two months.

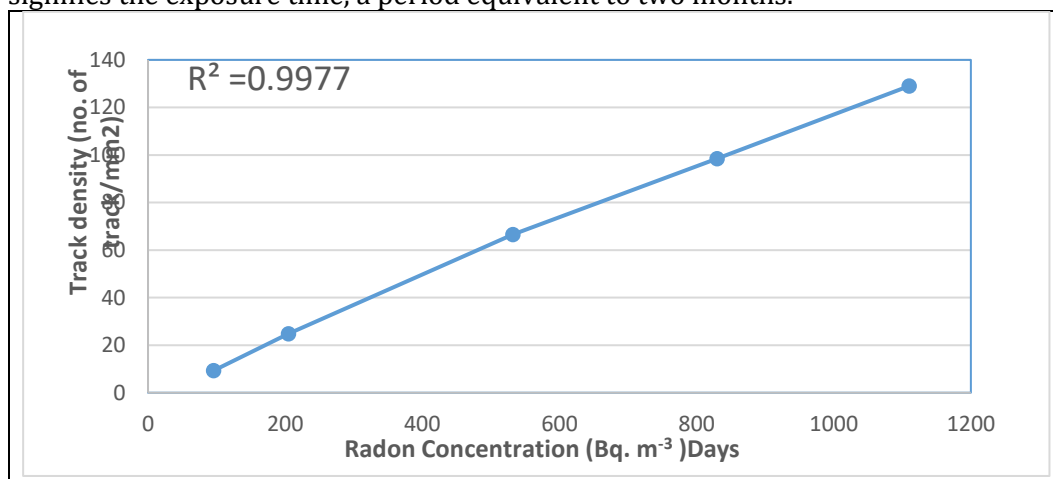


Fig. 2 The correlation of radon concentration and track density in standard specimens [14]

Using the following equation :

$$PAEC (mWL) = F \cdot CRn / 3700 \quad \dots\dots\dots (2)$$

The evaluation of potential α energy concentration (PAEC) transpires within the context of radon progeny, utilizing the Working Level (mWL) as a metric [4], [15]. Using the equation:

$$EP(WLMY - 1) = n.8760.F.CRn/170 \times 3700 \dots\dots\dots (3)$$

CRn stands for the amount of radon activity in Becquerels per cubic meter (Bq.m-3), and F stands for the equilibrium factor, which is equal to 0.4. The relationship is then established between exposure to radon progeny (EP) and the average radon concentration (CRn), a computation grounded in recognized methodology [16].

In this case, CRn is the amount of radon in Becquerels per cubic meter (Bq .m⁻³).

The variable 'n' symbolizes the proportion of time spent indoors, which is specified as 0.8. There are 8760 hours in a year. Furthermore, a working month is considered to be 170 hours long. F signifies the radon equilibrium factor; its value is given as 0.4.

To calculate the yearly effective dose rate for the population, the conversion needs to be factored in coefficient linking the absorbed dose and the indoor occupancy factor. The study group recommended a conversion factor of 9.0×10^{-6} mSv/h per Bq .m-3. The Rn-222 equilibrium factor indoors is 0.4, and the indoor occupancy factor is set at 0.8 [17]. The annual effective dose equivalent (AEDE), expressed in millisieverts per year (mSv/y), was derived using the provided equation [18], [19], [20].

$$AEDE(mSv/y) = CRn.F.H.T.D \dots\dots\dots (4)$$

The lung cancer annually per 106 individuals is estimated by utilizing the risk factor for lung cancer induction 18×10^{-6} mSv⁻¹ [4], [21].

$$CPPP = AEDE (mSv/y) \times 18 \times 10^{-6} (mSv^{-1}) \dots\dots\dots (5)$$

5. Results and discussions

CRn (Bq m⁻³) the Indoor Radon Concentration, and mean value of the indoor radon concentration is presented in Table (2), PAEC-in (mWL) for radon mass, annual effective dose in (mSv/y) and (in (WLMY-1d) of exposure to radon progeny. Kirkuk Province. Indoor radon levels: The concentration of indoor radon was between (17.96 - 68.39) Bq m⁻³ and the average value of (40.695) Bq m⁻³ (Fig.3) and kitchen, block, and cement held the greatest ones in Kashgar, Burke m. and a minimum of Kirkuk (brick bedroom, bed, cement, and gypsum). Radon concentration levels, denoted as CRn, in the region of Prince Kirkuk were observed to be below the standard range, falling within the values of 200-300 Bq.l/m³ [22]. Further investigation involved analyzing the Alpha Potential Energy Concentration (PAEC) of radon emitted from building materials. These radon blocks exhibited a range of dimensions, specifically from 1.94 to 7.39 mWL. An average value of 4.39 mWL was documented, which is visualized in Figure 4. A critical finding indicated that the PAEC readings across all indoor samples collected from the Kirkuk province remained consistently under the permissible upper limit, established as 53.30 mWL. The detected radon progeny exposure level was (0.080-0.304) WLMY⁻¹, and the mean value was (0.181) WLMY⁻¹. The annual risk of dying due to lung cancer per million was highest in Riyadh. The results, Radon levels in some closets those in the kitchen, were much higher in some of the homes the levels in the bedroom closets were examined. Kitchens, bedrooms in particular, are constructed essentially with the same architectural material used in the house (mud-brick / block-cemented / gypsum wall construction) but finishing materials in these spaces vary from finishing materials in the other parts of the house. As well as ceramic roofing and secondary roofing are replaced with a common painting material used often in kitchen and living rooms especially [22], [23].

Table 2: Presents data regarding indoor radon levels (CRn), specifically focusing on the estimated annual effective dose equivalent (AEDE), the potential alpha energy concentration (PAE), the incidence of lung cancer attributed to radon exposure, measured as cases per million individuals annually, and lastly, the overall exposure to radon progeny (EP).

Symbol	Locations	CRn (Bq. m ⁻³)	PAEC (mWL)	AEDE (mSv/y)	EP (WLMY ⁻¹)	Lung Cancer/1 0 ⁶ person
K1	Elton kopri	45.2132	4.888	1.140	0.202	20.532
K2	Elton kopri	52.169	5.639	1.316	0.232	23.690
K3	Elton kopri	33.041	3.571	0.833	0.148	15.005
K4	Elton kopri	42.895	4.638	1.089	0.191	19.479
K5	Riyadh	47.532	5.139	1.190	0.219	21.585
K6	Riyadh	42.895	4.64	1.085	0.191	19.479
K7	Riyadh	55.65	6.016	1.412	0.248	25.271
K8	Riyadh	68.398	7.394	1.733	0.304	31.061
K9	Al- Hawija	39.416	4.261	0.994	0.175	17.90
K10	Al- Hawija	30.722	3.321	0.787	0.136	13.96
K11	Al- Hawija	22.027	2.381	0.555	0.098	10.003
K12	Kirkuk	31.882	3.447	0.804	0.142	14.465
K13	Kirkuk	42.315	4.574	1.068	0.188	19.216
K14	Kirkuk	37.099	4.010	0.936	0.165	16.847
K15	Kirkuk	38.837	4.1989	0.978	0.173	17.636
K16	Kirkuk	38.24	4.136	0.965	0.1704	17.373
K17	Kirkuk	38.257	4.136	0.965	0.1704	17.373
K18	Kirkuk	17.967	1.942	0.453	0.080	8.160
K19	Kirkuk	35.359	3.823	0.892	0.157	16.057
K20	Daquq	48.691	5.264	1.228	0.217	22.112
K21	Daquq	57.965	6.266	1.462	0.258	26.323
K22	Daquq	37.098	4.011	0.935	0.165	16.846
K23	Daquq	25.505	2.758	0.643	0.113	11.582
K24	Yaichi	52.749	5.703	1.331	0.235	23.954
K25	Yaichi	35.359	3.823	0.892	0.157	16.057
K26	Yaichi	39.415	4.261	0.994	0.175	17.89
K27	Yaichi	42.315	4.574	1.067	0.188	19.214
K28	Taz	33.62	3.634	0.848	0.149	15.266
K29	Taz	45.212	4.887	1.141	0.201	20.531
K30	Taz	34.198	3.697	0.862	0.152	15.531
K31	Al- Zab	35.939	3.885	0.906	0.160	16.320
K32	Al- Zab	45.792	4.950	1.155	0.204	20.795
K33	Al- Zab	55.067	5.953	1.389	0.245	25.00
K34	Al- Zab	34.778	3.759	0.877	0.154	15.794
Average		40.695	4.399	1.027	0.181	18.480

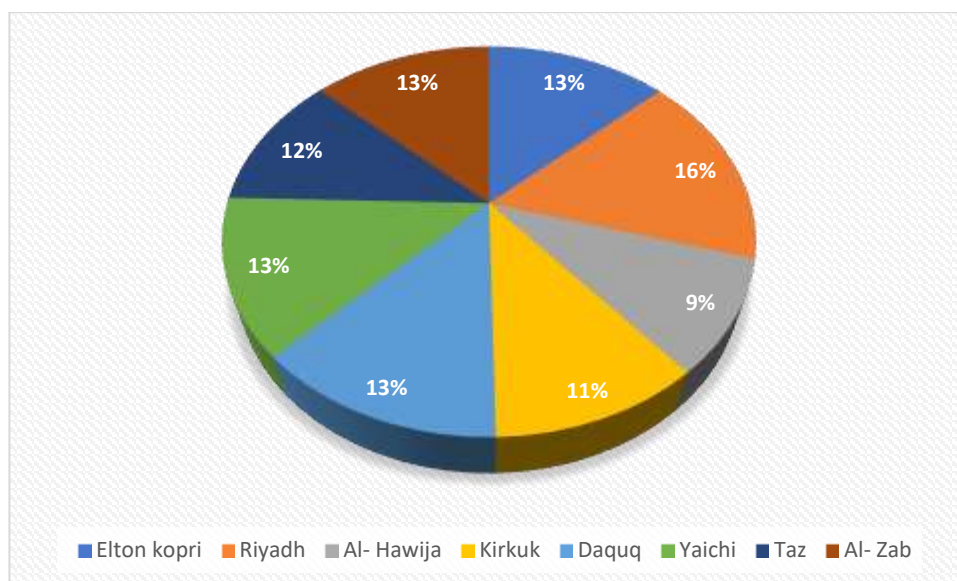


Figure 3: The Kirkuk Governorate's radon concentration histogram (CRn, Bq. m⁻³)

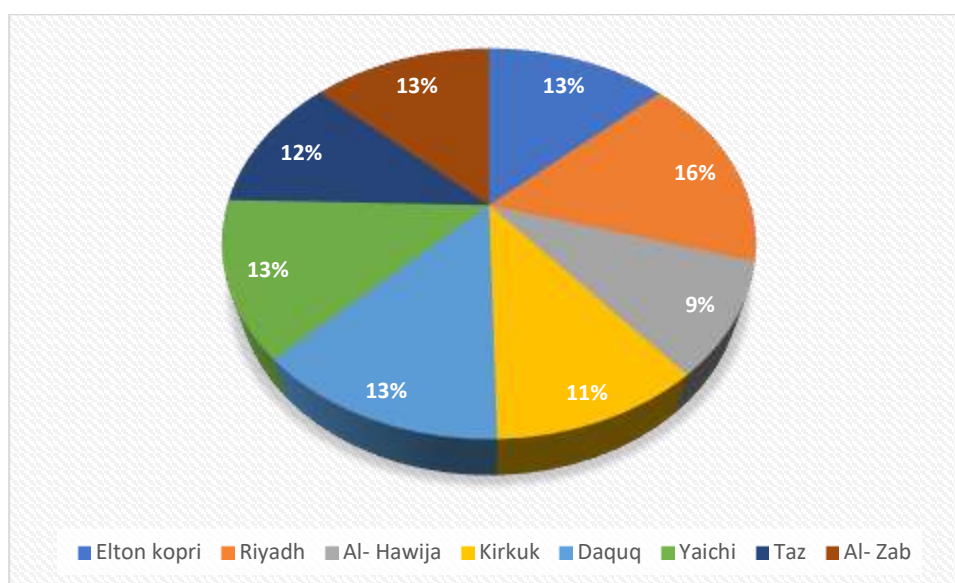


Figure 4: Potential Alpha Energy Concentration (PAEC) histogram (mWL)

6. Conclusions

This freshly gathered information will form the basis of a novel database concerning indoor radon levels within Kirkuk Governorate. The inherent radon concentrations detected all fall beneath the minimum suggested threshold for yearly internal exposure, which lies between 200 and 300 Bq.m⁻³, as stipulated by the ICRP in 2009. Therefore, a significant health risk appears to be absent.

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