

Assessment of Radon Concentration, Annual Effective Dose, and Excess Lifetime Cancer Risk in Homes Constructed with Limestone, Fired Clay Bricks, and Concrete Blocks in Al-Muthanna Province

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Abstract: This study measured radon gas concentrations in three types of houses in Al-Muthanna Governorate, located in southwestern Iraq, which were built using the most common building materials in the governorate: concrete blocks, fired clay bricks, and limestone. Houses were randomly selected (20 samples for each house type to ensure comprehensive representation and determine the effect of building material type on indoor radon concentration, which helps in assessing the health risks associated with long-term exposure to this gas. It also contributes to guiding future policies towards the use of safer building materials to enhance indoor air quality and population safety. In this study, an Airthings Radon Portable Detector was used to measure radon concentrations over three consecutive days. The device was placed in living rooms at a height ranging from 60 to 100 cm above the ground, ensuring that windows and doors were closed to prevent air drafts and to provide accurate measurements. The results showed that the average radon concentration was highest in houses built of limestone (24 Bq/m^3), followed by houses constructed of concrete blocks (21 Bq/m^3), and lowest in houses built of fired clay bricks (16.25 Bq/m^3). In terms of the estimated annual effective dose, it was higher in limestone houses (0.605 mSv.y^{-1}), compared to concrete block houses (0.530 mSv.y^{-1}) and fired clay brick houses (0.410 mSv.y^{-1}). and The ELCR resulting from radon exposure was found to be higher in limestone houses (0.238%) and lower in fired clay brick houses (0.161%), suggesting that fired clay brick may be the most suitable choice in terms of radiation safety. Despite this disparity, all values remained within the safe limits and percentages recommended by the WHO and UNSCEAR. It can be concluded that the measured radon concentrations are within acceptable limits, indicating no radioactive hazard. The study reveals that the type of building material affects indoor radon concentrations, and the geological nature of limestone likely contributes to higher emissions. Accordingly, the study recommends using low-radon-emitting building materials and periodically monitoring gas levels to maintain indoor air quality and reduce long-term health risks.

Keywords: Radon Concentration, Annual Effective Dose (AED), Excess Lifetime Cancer Risk (ELCR), Building Materials, Al-Muthanna Province.

Abbreviations:

AED: Annual Effective Dose
ELCR: Excess Lifetime Cancer Risk
RCC: Radon Concentration in Concrete
RCB: Radon Concentration in Fired Clay Bricks
RCL: Radon Concentration in Limestone
UNSCEAR: United Nations Scientific Committee on the Effects of Atomic Radiation
WHO: World Health Organization

I. INTRODUCTION

Radon gas (Rn-86) is a naturally occurring radioactive noble gas that results from the radioactive decay of uranium [1], which is naturally found in rocks, soil [2], water, and some construction materials [3], such as granite. It is colourless, odourless, and tasteless [4], making it undetectable by human senses; hence, specialised devices are required for its detection and concentration measurement [5].

Due to its higher density compared to air, radon tends to accumulate in low-lying areas such as basements and ground floors. While radon disperses easily outdoors, it tends to concentrate in enclosed indoor spaces, including residential homes [6]. Radon is recognized as the second leading cause of lung cancer after smoking. When inhaled, radon particles accumulate in the lungs, emitting radiation that can damage lung tissue and cause genetic mutations that may develop into cancer over time [7].

Long-term exposure to radon, even at low or moderate levels, poses significant health risks. Radon infiltrates buildings through cracks in walls, foundations, and pipes, particularly when water sources are derived from groundwater [8]. Considering that people spend a substantial portion of their time indoors, evaluating indoor radon concentrations is critical for estimating potential health risks [9].

II. TYPE OF HOUSES

In this study, the concentration of radon gas was measured in three types of single-story houses, each with an area ranging from 150 to 200 square meters, located in Al-Muthanna Governorate, southwestern Iraq. The classification of these houses was based on the primary construction material used, as follows:

- **First type:** Houses constructed

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entirely from locally sourced limestone, abundant in the Samawah desert region (Figure 1 – Limestone). It has been reported that limestone may contain natural radionuclides, such as uranium and radium, which can contribute to radon emissions [10].

- **Second type:** Houses built entirely with fired clay bricks produced from a mixture of clay and sandy soils (Figure 2 – Fired Clay Brick). Previous studies have indicated that fired clay bricks generally exhibit lower radon exhalation rates compared to other materials, but their contribution is still measurable [11].
- **Third type:** Houses constructed using concrete blocks (Figure 3 – Concrete Block). Concrete materials exhibit variable radon exhalation rates, depending on their composition and porosity, with some studies reporting rates that range widely [12].



[Fig.1: Limestone]



[Fig.2: Fired Clay Brick]



[Fig.3: Concrete Block]

All houses shared the characteristic of having concrete flooring with a thickness ranging from 3 to 5 centimetres. All dwelling walls were coated with a mix of cement-sand-based layer approximately 1–2 cm thick. It is anticipated that the construction materials, particularly those naturally rich in uranium or its decay products, significantly contribute to the levels of radon concentration measured within these residential environments.

The significance of this study lies in its focus on the relationship between local construction materials and indoor radon emissions, thereby contributing to a deeper understanding of environmental health risks associated with indoor air quality, especially in regions with similar geological characteristics.

III. AREA OF STUDY

This study was conducted in Al-Muthanna Province, located in southern Iraq, on the edge of the alluvial valley. The Euphrates River and its tributaries flow through the region, providing the primary source of water for agricultural irrigation. Al-Muthanna is situated approximately 270 kilometres south of the capital, Baghdad, and is considered the second-largest governorate in Iraq, after Al-Anbar. It is characterized by its desert landscape, with its administrative center located in the city of Samawah.

The governorate is distinguished by the abundance of natural resources available for investment, particularly in the industrial sector, due to the presence of readily available and low-cost raw materials. These include limestone, used in the production of cement and bricks, as well as deposits of chlorine and sodium compounds in the form of saline materials, which are utilised in salt manufacturing. Additionally.

IV. MATERIALS AND METHODS

The Airthings Radon Portable Detector (Figure 4) was used to measure radon gas concentration levels in three types of residential buildings. The device was placed in an indoor living room at a height of 60 to 100 cm above ground, and continuous data acquisition was performed over three consecutive days. The device was sealed from air drafts from windows and fans to ensure the readings were accurate. Furthermore, all windows were shut for several hours before the measurements began to minimise the influence of ventilation on the measured radon levels.

The three most common construction materials — concrete blocks, fired clay bricks, and limestone — were selected to account for variations in radon concentrations with dwelling types.

Houses were haphazardly selected from various regions of existence of houses and were haphazardly chosen according to the kind of construction material (fired clay bricks, concrete blocks, and limestone) to observe the effect of construction materials on indoor radon content. The procedures taken to ensure the location and choice of sites, along with the efforts made to stabilise environmental conditions while obtaining the data, left the impression that reliable and valid information had been received. The collected data will then be interpreted and compared to assess the possible influence of different building materials on indoor radon levels.



[Fig.4: Airthing Radon Portable Detector]

In the paper, these parameters are expressed with the following symbols for research and reference: RCC (radon concentration in concrete), RCB (radon concentration in fired clay bricks), RCL (radon concentration in limestone)

A. Annual Effective Dose (AED) and Excess Lifetime Cancer Risk (ELCR) from Radon Gas

A strict scientific equation was used to calculate both the Annual Effective Dose (AED) [13] and the Excess Lifetime Cancer Risk (ELCR) [14] in this study. Due to indoor radon. These estimations were made using well-established equations that are globally acknowledged as follows:

B. Calculation of Annual Effective Dose (AED)

The annual effective dose was calculated using the following equation (1) :

$$\text{AED (mSv. y}^{-1}\text{)} = C \times F \times O \times T \times \text{DCF} \quad (1)$$

Where:

- AED = Annual effective dose (mSv. y⁻¹)
- C = Radon concentration in indoor air (Bq/m³)
- F = Equilibrium factor for radon (0.4 in residential environments)
- O = the occupancy factor (0.8)
- T = Number of hours in a year (8760 h. y⁻¹)
- DCF = Dose conversion factor (9 × 10⁻⁶ mSv. h⁻¹). (Bq/m³)⁻¹

C. Calculation of Excess Lifetime Cancer Risk (ELCR)

To assess the long-term health risk associated with continuous exposure to radon gas, the following equation (2) was applied:

$$\text{ELCR} = \text{AED (mSv. y}^{-1}\text{)} \times \text{DL (y)} \times \text{RF (Sv}^{-1}\text{)} \quad (2)$$

Where:

- ELCR = Excess lifetime cancer risk
- AED = Annual effective dose (mSv. y⁻¹)
- DL = life expectancy for Iraqis (71.5 years according to WHO data [15])
- RF = Risk factor for cancer induction due to radiation exposure (0.055 Sv⁻¹)

V. RUSTLE

Table-I: Radon Concentration, Annual Effective Dose, and Cancer Risk Probability in Samples from Houses Constructed with Different Building Materials (Fired Clay Bricks, Concrete Blocks, and Limestone)

RCC Bq/m³			ED mSv. y ⁻¹	ELCR	RCL Bq/m³		AED mSv. y ⁻¹	ELCR	RCB Bq/m³		AED mSv. y ⁻¹	ELCR
RCC1	18		4.54E-01	1.79E-03	RCL1	31	7.82E-01	3.08E-03	RCB1	13	3.28E-01	1.29E-03
RCC2	21		5.30E-01	2.08E-03	RCL2	27	6.81E-01	2.68E-03	RCB2	15	3.78E-01	1.49E-03
RCC3	17		4.29E-01	1.69E-03	RCL3	26	6.56E-01	2.58E-03	RCB3	19	4.79E-01	1.89E-03
RCC4	23		5.80E-01	2.28E-03	RCL4	22	5.55E-01	2.18E-03	RCB4	15	3.78E-01	1.49E-03
RCC5	26		6.56E-01	2.58E-03	RCL5	19	4.79E-01	1.89E-03	RCB5	20	5.05E-01	1.98E-03
RCC6	29		7.32E-01	2.88E-03	RCL6	27	6.81E-01	2.68E-03	RCB6	12	3.03E-01	1.19E-03
RCC7	15		3.78E-01	1.49E-03	RCL7	15	3.78E-01	1.49E-03	RCB7	14	3.53E-01	1.39E-03
RCC8	18		4.54E-01	1.79E-03	RCL8	18	4.54E-01	1.79E-03	RCB8	17	4.29E-01	1.69E-03
RCC9	20		5.05E-01	1.98E-03	RCL9	25	6.31E-01	2.48E-03	RCB9	18	4.54E-01	1.79E-03
RCC10	24		6.05E-01	2.38E-03	RCL10	28	7.06E-01	2.78E-03	RCB10	19	4.79E-01	1.89E-03
RCC11	16		4.04E-01	1.59E-03	RCL11	30	7.57E-01	2.98E-03	RCB11	21	5.30E-01	2.08E-03
RCC12	22		5.55E-01	2.18E-03	RCL12	29	7.32E-01	2.88E-03	RCB12	16	4.04E-01	1.59E-03
RCC13	25		6.31E-01	2.48E-03	RCL13	19	4.79E-01	1.89E-03	RCB13	18	4.54E-01	1.79E-03
RCC14	17		4.29E-01	1.69E-03	RCL14	15	3.78E-01	1.49E-03	RCB14	19	4.79E-01	1.89E-03
RCC15	23		5.80E-01	2.28E-03	RCL15	25	6.31E-01	2.48E-03	RCB15	16	4.04E-01	1.59E-03
RCC16	20		5.05E-01	1.98E-03	RCL16	27	6.81E-01	2.68E-03	RCB16	15	3.78E-01	1.49E-03
RCC17	25		6.31E-01	2.48E-03	RCL17	30	7.57E-01	2.98E-03	RCB17	17	4.29E-01	1.69E-03
RCC18	14		3.53E-01	1.39E-03	RCL18	18	4.54E-01	1.79E-03	RCB18	14	3.53E-01	1.39E-03
RCC19	25		6.31E-01	2.48E-03	RCL19	25	6.31E-01	2.48E-03	RCB19	11	2.78E-01	1.09E-03
RCC20	22		5.55E-01	2.18E-03	RCL20	24	6.05E-01	2.38E-03	RCB20	16	4.04E-01	1.59E-03

Table-II: Descriptive Statistics of Radon Concentration in Houses with Different Construction Types

Type of house	Number of Samples	Maximum reading Bq/m ³	Minimum Reading Bq/m ³	Measurement Location	Mean Radon Concentration (Bq/m ³)	AED (mSv. y ⁻¹)	ELCR
RCC	20	29	14	Living Room	21	0.530	% 0.208
RCL	20	31	15	Living Room	24	0.605	% 0.238
RCB	20	21	11	Living Room	16.25	0.410	% 0.161

VI. DISCUSSION

In this study, radon gas concentration was determined in three building materials: concrete block, limestone, and fired clay brick. The annual effective dose (AED) and excess

lifetime cancer risk (ELCR) were estimated for all materials. Table 2 presents a descriptive analysis of the radon gas concentration in three different types of houses.



The average indoor radon concentration in the concrete block houses was 21 Bq/m³, while for the limestone houses, it was 24 Bq/m³. The lowest average concentration was obtained in homes made up of fired clay brick (16.25 Bq/m³). The highest AED was in limestone houses (0.605 mSv.y⁻¹) and the lowest in fired clay brick houses (0.410 mSv.y⁻¹). While the highest ELCR was again found for limestone houses (0.238 %), the lowest was for fired clay brick houses (0.161 %), and (% 0.208) for concrete block.

It appears that limestone-built homes may have a more suitable environment for potential radon accumulation. This could be due to the geological nature of limestone, which has higher concentrations of natural radioactive isotopes, such as uranium and thorium [10]. Instead, dwellings constructed using fired clay bricks showed the lowest level of indoor radon concentration, suggesting that they might be the most suitable for home construction.

The measured radon levels were below the reference levels recommended by the World Health Organization (WHO), with a reference level at (100 Bq/m³) and an intervention level at (300 Bq/m³) [16]. Furthermore, the estimated AED doses were well below the maximum permissible dose of (1.0 mSv.y⁻¹) set by the UNSCEAR and WHO [17].

Although ELCR for all samples was low, long-term retention will contribute to a slightly higher risk of radiation-induced diseases, as reported by epidemiological studies [18]. Accordingly, it would be prudent to conduct occasional radon evaluations in ground-floor and basement buildings.

The findings suggest that using construction materials with low radon exhalation potential, such as fired clay bricks, is a necessary measure for improving indoor air quality and ensuring public safety, especially under conditions of limited ventilation.

VII. CONCLUSION

The results of this study demonstrate the range of indoor radon levels associated with various solid materials. Limestone (the material tested with the highest radon risk factor), fired clay bricks (the material with the lowest radon risk factor). While all concentrations measured, along with their associated annual effective doses, were within accepted international safety limits, the results highlight the importance of materials of construction in reducing radon exposure, mainly when indoor ventilation is restricted.

Results emphasise the importance of establishing a safety practice, indicating that regular monitoring of radon should be considered, especially in buildings made of materials associated with higher radon emission potential. Additionally, increasing the use of low-emission materials, such as fired clay bricks, could be a suitable preventive measure for mitigating long-term health issues.

Future work should measure other factors that contribute to indoor radon accumulation, including the porosity of materials, moisture dynamics, ventilation efficiency, and physical aspects of the building, to better account for these dimensions in mitigation.

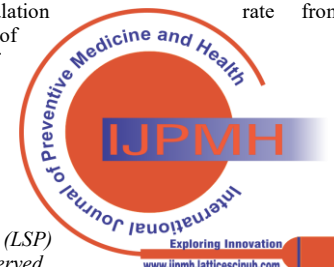
DECLARATION STATEMENT

I must verify the accuracy of the following information as the article's author.

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