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Assessment of the Annual Effective Dose of Natural Radionuclides from Animal Bone Samples

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Abstract
This study aimed to assess the annual effective dose (AED) of natural radionuclides, specifically radon gas, in animal bone samples sourced from local markets in Kirkuk, Iraq. We analyzed a total of 24 samples, encompassing bones from cows, sheep, chickens, and fish.
Each sample was meticulously prepared: it was ground, and then sealed within a custom-designed exposure chamber. Radon concentrations were measured using a RAD7 detector over a 30-minute interval for each sample. The measured concentrations (in Bq/m³) were subsequently converted to Bq/kg using estimated bone density values.
Based on the data, sample SHP6 exhibited the highest radon concentration at 25.1 Bq/m³ and the highest annual effective dose at approximately 4.14×10^{-7}mSv/year. Conversely, sample SHP3 recorded the lowest values for both metrics, with a radon concentration of 4.0 Bq/m³ and an annual effective dose of roughly 0.57×10^{-7} mSv/year.
The AED was then calculated in(mSv/Year) unit Our results revealed exceptionally low annual effective doses, in the range of 10^{-7} mSv/year. These values are well below internationally accepted radiological limits. A comparative analysis with previous studies conducted in the Kirkuk region (focusing on soil and rock) indicated that animal bones exhibit significantly lower radon activity
Keywords/ Radon ^{222}Rn , Annual Effective Dose, Animal Bones, Natural Radioactivity, RAD7, Radiation Protection

Introduction
Radon (^{222}Rn) is a naturally occurring, radioactive noble gas. It originates from the decay of uranium (^{238}U), specifically through its intermediate decay product, radium (^{226}Ra). Because it's odorless, tasteless, and colorless, ^{222}Rn is impossible to detect without specialized instruments. Its high mobility in porous materials and ability to diffuse into enclosed spaces make radon a significant part of natural background radiation and a major source of internal exposure to ionizing radiation in humans[1] .

Most research on radon has concentrated on its presence in soil, water, and building materials. However, radon exhalation from biological samples, particularly animal bone samples, hasn't been widely studied. Bones, particularly those rich in calcium, can serve as reservoirs for naturally occurring radionuclides, especially Radium (^{226}Ra), which decays to produce radon gas. Measuring the concentrations of radon exhaled from bone samples offers a deeper understanding of the risks

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associated with long-term exposure and the resulting radiological health effects. Numerous studies have underscored the significance of bones as bio monitors in assessing radiation exposure [2][3]. Previous environmental radiation studies have focused on elevated background radiation, consistently reporting increased rates of radon gas exhalation from soil and building materials. These investigations have primarily centered on natural and anthropogenic sources of radioactivity [3][4].

This study seeks to bridge a significant gap in the current understanding of environmental radiation exposure. While the presence of radon and its potential for internal dose accumulation are well-documented, there is a distinct lack of data on radon emissions directly from biological samples, particularly bones.

To address this, we will employ a RAD7 detector, a highly sensitive active monitoring system, to quantify the annual effective dose attributed to the exhalation of naturally occurring radionuclides, specifically radon, from a selection of bone samples. The results of this study will contribute to a more thorough evaluation of the risks to public health by offering a more thorough understanding of radiation exposure in the area[5].

1- Materials and methods

In Kirkuk City, Iraq, 24 bone samples from cattle, sheep, poultry, and fish were collected from local markets and butchers, then meticulously cleaned, dried, and ground into fine powder before analysis , the samples underwent a meticulous preparation process : they were thoroughly cleaned, subjected to high-temperature incineration, and subsequently pulverized into a fine powder using an electric grinder.

Following preparation, a RAD7 electronic radon detector (Durridge Company Inc., USA) running in "sniff mode" for quick analysis was used to measure the radon concentrations in each bone sample. An airtight chamber measuring 25 cm by 7 cm was used to hold each sample. It was connected to the RAD7 directly using a drying unit and a nylon filter. This setup, as shown in Figure 1, ensured a sealed system for a steady transfer of radon to the detector while minimizing external interference. To guarantee accurate readings, each sample was measured for 30 minutes, allowing for equilibrium to be reached, and all measurements adhered strictly to the manufacturer's guidelines for background and relative humidity correction. [6].

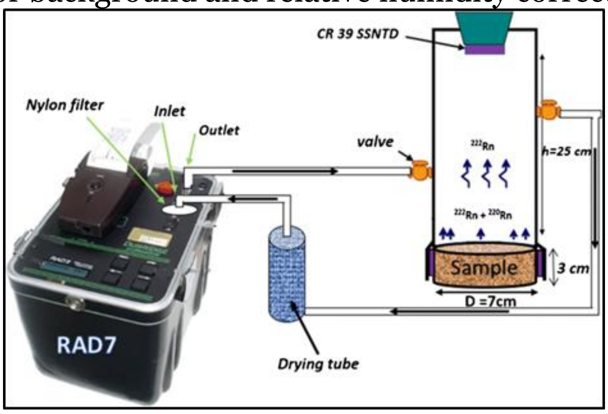

Figure1. The RAD7 detector schematic diagram for determining the amount of radon gas released from bone samples..

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The Annual Effective Dose (AED) is a key radiological metric that quantifies the biological impact of radiation exposure on human health over a one-year period. This metric integrates several critical factors, including the type and energy of the radiation, as well as the varying sensitivities of different organs and tissues to that radiation.

Typically expressed in mSv/year, the AED is a cornerstone for international organizations, such as the International Commission on Radiological Protection (ICRP), in establishing radiation safety standards. The ICRP advises that the annual maximum amount of radiation exposure for the general public from non-medical sources, such as ingestion of radionuclides, should be limited to 1 mSv, was determined using the following equation.[7] [8] :

$$E = C \times I \times D_{CF} \qquad 1$$

In this equation:

C: It shows the amount of activity present in the bone samples, expressed in (Bq/kg).

I : is used to represent the annual intake rate, which is 40 kg/year. (40kg/year).

D_{CF}: stands for the dose conversion factor, given in milliSieverts per Becquerel (mSv/Bq).

For this calculation, a D_{CF} value of$(2.8\times10\text{-}7)$ mSv/Bq was adopted, consistent with recommendations from the International Commission on Radiological Protection (ICRP).

2- Results and Discussion

This study evaluated concentration and its corresponding annual effective dose (AED) in various types of animal bones. We collected a total of 24 bone samples—including bovine, ovine, poultry, and fish bones—from local markets in Kirkuk, Iraq. We analyzed these samples using a RAD7 radon detector. The measured radon concentrations varied, ranging from 4 to 25.1 Bq/m³ ,as shows Figure 2 the distribution of radon concentrations among samples. These values were then converted to Bq/kg using the the known density of the samples ρ(Kg/m³) =679.1171 Kg/m³ .

$$C_{Bq/Kg} = \frac{C_{Bq/m^3}}{\rho} \qquad 2$$

followed by the estimation of the AED using the formula As in the table1:

$$E = C \times I \times D_{CF} \qquad 3$$

Table 1: radioactivity in units (Bq/m³), units (Bq/kg), and annual effective dose

Sample	C(Bq/m³)	C(Bq/kg)	E(mSv/Year) $\times10^{-7}$
FSH1	8.09	0.011913	1.334203
FSH2	16.1	0.023707	2.655212
CHK1	8	0.01178	1.31936
SHP2	20.1	0.029597	3.314892
SHP3	4	0.00589	0.65968
SHP4	8.04	0.011839	1.325957
CHK3	12.1	0.017817	1.995532
SHP5	16.9	0.024885	2.787148
CHK4	8.43	0.012413	1.390276

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FSH3	8.43	0.012413	1.390276
CHK5	16.9	0.024885	2.787148
CHK6	16.8	0.024738	2.770656
CHK7	8.43	0.012413	1.390276
SHP6	25.1	0.03696	4.139492
CHK8	16.8	0.024738	2.770656
CHK9	16.9	0.024885	2.787148
CHK10	8.43	0.012413	1.390276
CHK11	8.43	0.012413	1.390276
CHK12	8.43	0.012413	1.390276
CHK13	8.43	0.012413	1.390276
FSH5	16.8	0.024738	2.770656
SHP7	8.43	0.012413	1.390276
COW2	8.43	0.012413	2.770656

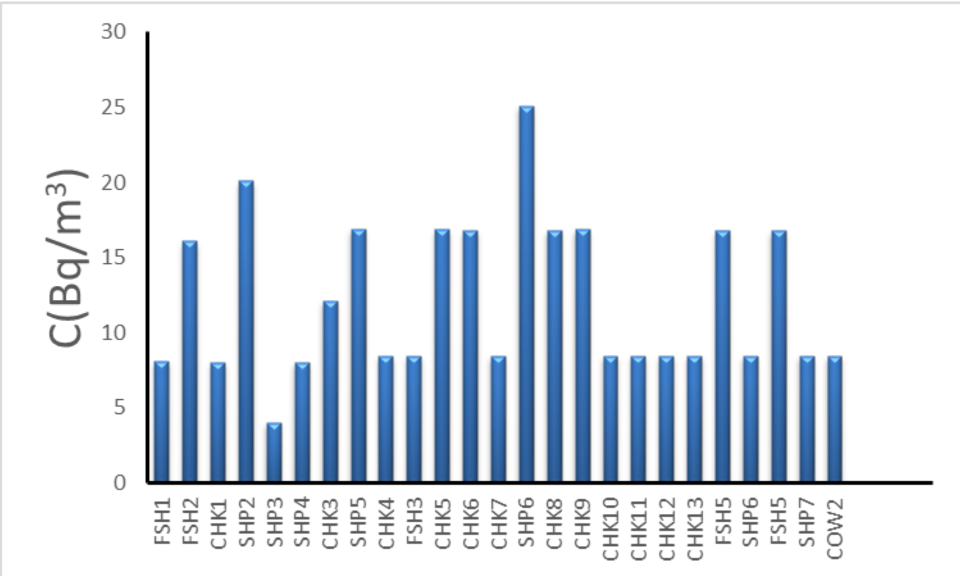

Figure 2. Radon gas concentrations in animal bone samples.

The calculated effective dose values exhibited variability, contingent upon both the radon concentration and the sample type. Notably, the highest dose was recorded for sample SHP6, with an effective dose (E) of 0.041395×10^{-5} mSv/year , as shows Figure 2.

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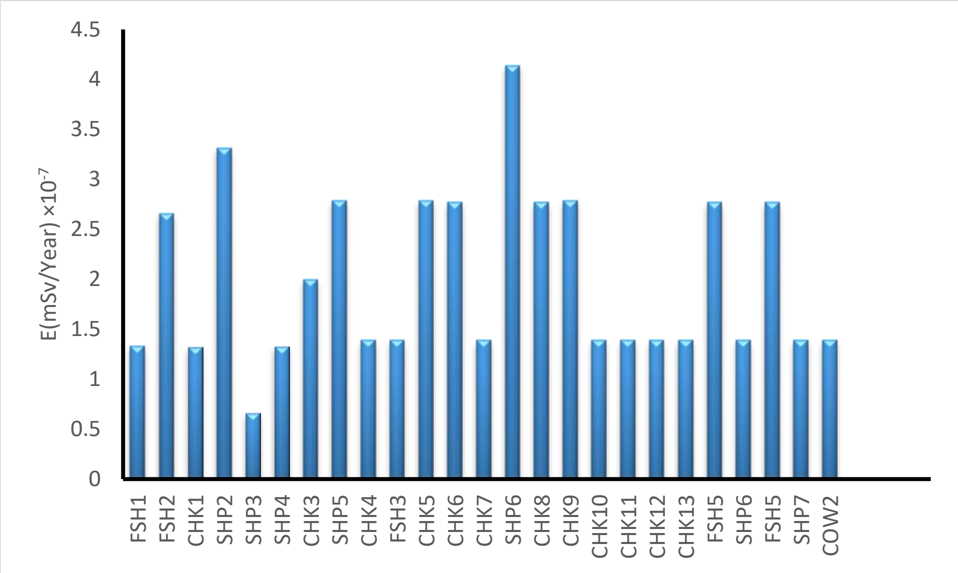

Figure 3. Annual effective dose for samples

The samples were classified into four categories according to animal type: Chicken(CHK), Cow(COW), Fish(FSH), and Sheep(SHP). The effective dose values measured using the RAD7 device are summarized in the following table: The collected samples were categorized into four distinct groups based on the animal type: Chicken (CHK), Cow (COW), Fish (FSH), and Sheep (SHP). The effective dose values determined using the RAD7 device are summarized in the table2:

Table 2 .Summary of AED by animal type.

Animal Type	Number of Samples	Mean Dose (mSv/year)	Minimum Dose	Maximum Dose
CHK	12	1.63×10^{-7}	1.31936×10^{-7}	2.787148×10^{-7}
COW	1	2.770656×10^{-7}	2.770656×10^{-7}	2.770656×10^{-7}
FSH	4	1.63×10^{-7}	1.334203×10^{-7}	2.770656×10^{-7}
SHP	6	1.95×10^{-7}	0.65968×10^{-7}	4.139492×10^{-7}

a- Sheep (SHP) bones showed the highest mean annual effective dose in this study, recording 1.95×10^{-7} mSv/year. The maximum value within this category reached 4.13×10^{-7} mSv/year.This finding might be due to a relatively higher radon concentration in some sheep bone samples. Alternatively, variations in bone density could play a role, impacting the accuracy of the conversion from Bq/m³ to Bq/kg.

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b- Chicken and Fish bones exhibited very similar mean annual effective dose values, both around 1.63×10^{-7} mSv/year. This suggests a comparable level of radon accumulation in these two types of bone.
c- Cow bone samples recorded the lowest mean annual effective dose at 2.770656×10^{-7} mSv/year. However, it's important to interpret this finding with caution due to the limited number of cow samples included in the study.
Table 3 summarizes a comparative analysis of radon concentrations and corresponding annual effective dose values reported in previous studies and the current work, which used a RAD7 detector. The findings clearly show that the radon levels in animal bone samples are significantly lower than those found in environmental media like soil, rock, and building materials As shown in Table 3 [9][10][11][12][13] .

Table 2 .Comparative Analysis of Radon Concentrations and Annual Effective Dose between the Present Study and Previous Research.

Authors & Year	Location & Sample Type	Detector Type	Radon Concentration Range (Bq/m^3)	Mean Radon Concentration (Bq/m^3)	Annual Effective Dose (mSv/year)	Remarks Compared to Present Study
Kheder & Azeez (2024)	Soil – Nineveh Province	CR-39	27.221 – 59.407	38.917	Not reported	Much higher than bone samples in the present study
Azeez et al. (2024)	Chicken tissues (meat, bones, organs) – Nineveh	CR-39	Not reported	44.96	Not reported	Much higher than bone samples in the present study
Present study (2025)	Burned animal bones (cattle, sheep, chicken, fish)	RAD7	4 – 25.1	—	$\approx 10^{-7}$	Significantly lower than all other studies
Kareem et al. (2019)	Soil – Kirkuk	CR-39 & RAD7	Not reported	32.6 (CR-39) / 35.2 (RAD7)	Not reported	Soil values several times higher than bone values
Sardar Q.	Building	CR-39 &	Not reported	Not reported	Up to 7.32	Dose

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Othmana et al. (2022)	materials (marble, granite) – Erbil	RAD7				thousands of times higher than bone samples
Arabian Journal of Geosciences (2021)	Rocks – Iraqi Kurdistan	CR-39 & RAD7	32.2 – 56.3	—	0.18 – 1.42	Much higher than bone sample values

3- Conclusions

The present study accurately quantified radon concentrations in animal bone samples—including cattle, sheep, chicken, and fish—using the active RAD7 detection system. Measured concentrations ranged from 4.0 to 25.1 Bq/m³, corresponding to extremely low annual effective dose values on the order of 10^{-7} mSv/year. These values are markedly below internationally recommended radiological safety limits and several orders of magnitude lower than those reported for environmental media such as soil, rock, and building materials in previous studies. The findings demonstrate that bone matrices exhibit a substantially reduced capacity for radon retention and exhalation compared with mineral-rich materials. Consequently, under the conditions examined, bone waste does not represent a radiological hazard from radon exposure. Further research could focus on radon behavior in non-incinerated bone tissues and other biological matrices to develop a more comprehensive understanding of natural radioactivity in animal-derived materials.

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