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Estimating Radon Excess Lung Cancer at the Babylon Cement Plant in Iraq

In this work, radon excess lung cancer (ELC) was estimated for 14 soil samples from the Babylon cement plant in Iraq. A CR-39 nuclear track detector was used to measure uranium and radon (^{222}Rn) concentrations in the soil samples. The uranium concentration varied from 0.008 to 0.05 ppm, with a mean value of 0.025 ± 0.013 ppm. The radon concentration was found to be between 31 and 92 Bq/m^3, with a mean value of 56.72 and a standard division of 17.29. The radon ELC per million persons per year has a mean value of 863 (463.81–12,082.8) and a standard division of 261.65. The annual effective dose, E (mSv/y), ranged from 0.77 to 2.32, with a mean value of 1.44 and a standard division of 0.44. [DOI: 10.1115/1.4049757]

1 Introduction

Uranium-238 is mainly distributed throughout the Earth's crust. It is naturally present in soils, rocks, and sand in different amounts, depending on the place [1–4]. Radon (^{222}Rn) is one of the most dangerous radioactive elements in the environment [5–10]. Radon is spread through the atmosphere due its nature as a noble gas. Most human natural radiation exposure is due to the inhalation of radon and its decay products indoors and in work places (about 55% of natural exposure) [4]. It can be diffused through rock cavities into the soil and surrounding material. Measuring radon is the most favorable method for detecting uranium-238.

Exposure to radon and its decay products is the second leading cause of lung cancer, with a relative risk factor of RR ∼ 2–10 (following tobacco smoke, RR ∼ 40) [11]. Radon also increases the risk of lung cancer for smokers. The carcinogenic potential of radon has been established by numerous experimental studies. In addition, the causative effect of radon on other cancers has been explored. The interaction of alpha particles from radon and its decay products with reactive oxygen species is the main causal mechanism for deoxyribonucleic acid damage and carcinogenesis. As such, radon and tobacco smoke have a synergistic effect.

The World Health Organization (WHO) states that most cancer deaths worldwide are related to lung cancer: over 1.1 million people die from lung cancer each year [12,13]. This number is continually increasing. Lung cancer is caused when the exposed cells that line the lungs suffer genetic damage. Scientists have identified several chemical and environmental factors that give rise to the kind of genetic damage which can cause lung cancer [12,13].

Excess Lung Cancer per Million Persons per Year. Excess lung cancer (ELC) risk is the excess deaths per million persons in a year owing to lung cancer per unit of exposure to radon and its short-lived daughters [2–4,14,15]

$$\mathrm{ELC} = 15.13 C_{\mathrm{Rn}} \qquad (\mathrm{Bq/m^3}) \tag{1}$$

where C_{Rn} is the concentration of radon (Bq/m^3).

The aim of this study is to estimate the radon ELC of soil samples from the Babylon cement plant in Iraq. Measured with a CR-39 tract detector, the ELC will be estimated in terms of ^{222}Rn concentration in 14 soil samples collected from the plant. The uranium content is measured in terms of neutron activation.

2 Experimental Method

Nuclear track detectors are often applied to study heavily ionized radiation like alpha particles. The number of alpha particles is measured by observing their tracks in either organic or inorganic materials. This method is used in various fields, like nuclear physics, field geology, and astrophysics. The CR-39 detector has a high-efficiency response to alpha particles. This kind of detector is used in this study to determine the uranium and Rn-222 concentrations in soil samples from the cement plant.

The Babylon cement plant is located in Babil province (Fig. 1) [16]. It was established in 1957 by the German Krupp company with two production lines. It produces Portland cement, which is resistant to salts. The total area of Babil province is 512 km^2: it

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Fig. 1 The Babylon cement plant on a map of Iraq [16]

has a population of approximately 2,000,000. In the area of interest, the dominant winds are typically oriented in an NW–SE direction toward population centers [16].

The samples were collected from different points in the cement plant area. The samples were collected at a depth of 0.15 m. They were prepared and cleaned before being dried with an oven at a temperature of 70 °C for six hours. The samples were then ground and sieved with a special sieve (250 μm in diameter) [17]. 0.01 kg from each soil sample was weighed and placed in a plastic can in order to measure the radon concentration. The dimensions of the can were designed to minimize the effect of thoron (Rn-220) as standard from International Commission on Radiological Protection (ICRP). A CR-39 detector with an area of 1×10^{-4} m^2 ($10^{-2} \times 10^{-2}$ m) was placed under the can cover. The soil samples were placed in the can, as shown in Fig. 2. The exposure time was 21 days [18].

Fig. 2 Radon gas (^{222}Rn) estimate from soil samples using the CR-39 detector

To measure the uranium concentration, 5×10^{-4} kg from each soil sample was taken as a powder and mixed with 1×10^{-4} kg of methylcellulose powder as a bonding material. Using a hydraulic instrument, the mix was compressed into pellets, each with a diameter of 12 mm and a thickness of 1.5 mm. These pellets were attached to a CR-39 detector and put on a paraffin wax plate 0.05 m away from a source of Am–Be neutrons [19]. The source flux is 5×10^7 n/(m^2 s) for thermal neutrons. This setup is shown in Fig. 3.

Chemical Etching and Microscopic Scanning. After exposure, the detectors were etched in a 6.25 normality aquatic

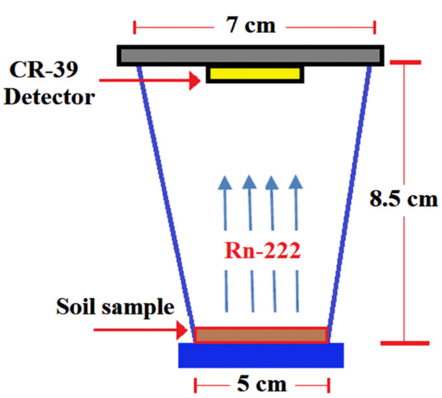

Fig. 2 Radon gas (^{222}Rn) estimate from soil samples using the CR-39 detector

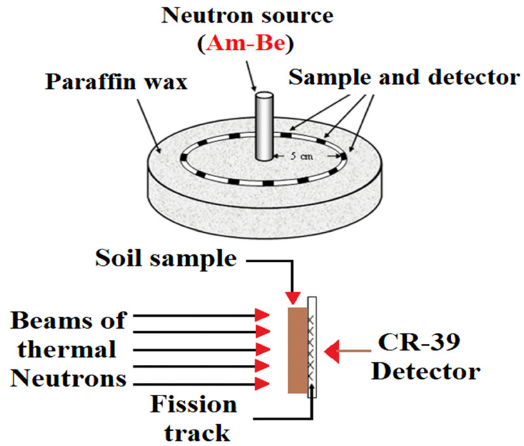

Fig. 3 Setup of the CR-39 detector for measuring uranium in soil samples

solution of NaOH. Then, the detectors were placed in a water bath with a temperature of 60 °C for 6 h. This period of time is standard for etching [17,20,21]. The detectors were then rinsed in distilled water and dried in air. The track density was recorded with an optical microscope (magnification = 400×). The track density (ρ) was estimated with the following equation:

$$\rho = \frac{N_{\text{ave}}}{A} \tag{2}$$

where ρ is the surface track density (track/mm^2), N is the average value of the total tracks (average track number is the average of three areas taken in each detector sample under microscope), and A is the area of field view (mm^2).

Radon and Uranium Concentrations. A standard geological sample was used to calculate the concentration of ^{222}Rn in the soil samples. Using the detector, the registered track densities from the soil samples and the standard geological sample were compared (see Eq. (3)). Similarly, the fission-track technique was used to determine the uranium concentration in the soil samples and the standard geological sample

$$\frac{C_S}{\rho_S} = \frac{C_{\text{sg}}}{\rho_{\text{sg}}} \tag{3}$$

where C_{sg} and C_S are the specific activities (Bq/m^3) of the standard geological sample and the soil samples, respectively. ρ_{sg} and ρ_S are the track densities (track/mm^2) of the standard geological sample and the soil samples, respectively.

From the measured radon concentration, the annual effective dose caused by radon decay products has been estimated using the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) model

$$E = C_{\text{Rn}} \times F \times O \times T \times D_{\text{Rn}} \tag{4}$$

where C_{Rn} (Bq m^{-3}) is the ^{222}Rn concentration, F (0.4, as recommended by UNSCEAR) is the equilibrium factor, O (0.8 was estimated) is the occupancy factor, T are the hours in a year (8760 h y^{-1}) and D_{Rn} equals 9.0×10^{-6} mSv Bq^{-1} m^{-3} h^{-1} (the dose conversion factor).

3 Results and Discussion

Fourteen samples are collected and measured. The radon concentrations (Bq/m^3) and uranium concentrations (ppm) for each soil sample are presented in Fig. 4 and Table 1. The radon concentration ranges from 31 to 92 Bq/m^3, while the mean value is

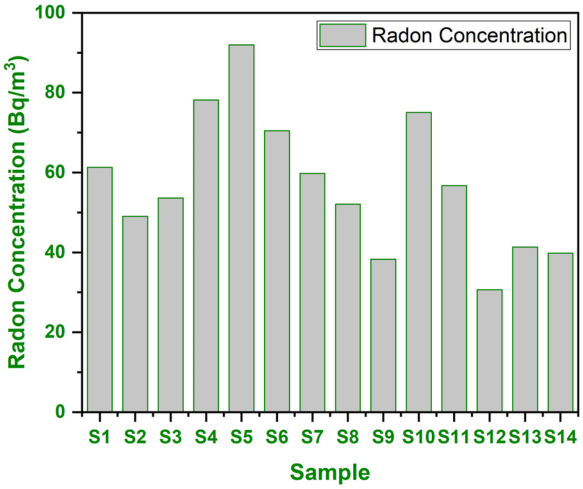

Fig. 4 Radon concentration level (Bq/m^3) in each soil sample collected from the Babylon cement plant

Table 1 Radon concentration levels (Bq/m^3), uranium concentration levels (ppm), working level month (WLM), *E* (mSv/y), and ELC per million persons per year for soil samples collected from the Babylon cement plant

	N	Mean	Standard Deviation	Sum	Min	Max
Radon concentration (Bq/m^3)	14	56.72	17.29	799	31.00	92.00
Uranium concentration (ppm)	14	0.025	0.013	0.35	0.008	0.050
WLM	14	0.32	0.096	4.44	0.17	0.51
E (mSv/y)	14	1.44	0.44	20.14	0.77	2.32
ELC	14	863	261.65	12,082.8	464	1392

56.72 Bq/m^3. The maximum concentration of uranium is 0.050 ppm and the minimum is 0.008 ppm, with a mean value of 0.025 ppm. In general, the uranium level is normal and falls within the acceptable range, below 3 ppm [22].

As can be seen in Table 1, WLM has a mean value of 0.32, with a minimum value of 0.17 and a maximum of 0.51. The annual effective dose ranged from 0.77 to 2.32 mSv/y, with a mean of 1.44 mSv/y. As stated by UNSCEAR, the global mean annual effective dose (*E*) due to radon inhalation is about 1.3 mSv/y [3]. The mean value of the annual effective dose in the

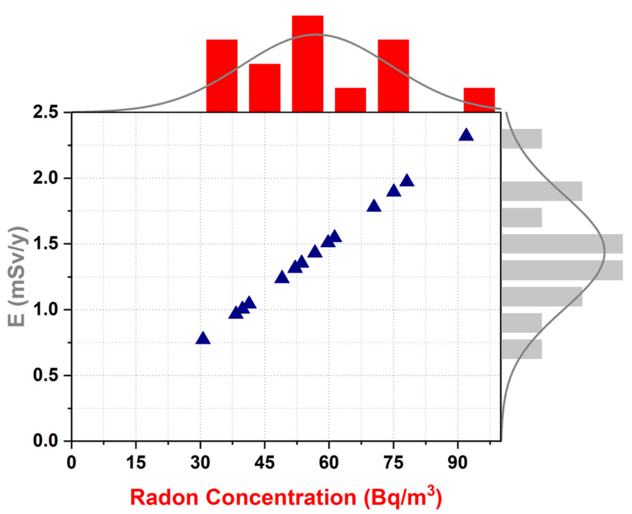

Fig. 5 Annual effective dose (mSv/y) and radon concentration (Bq/m^3) correlation and normal probability frequency

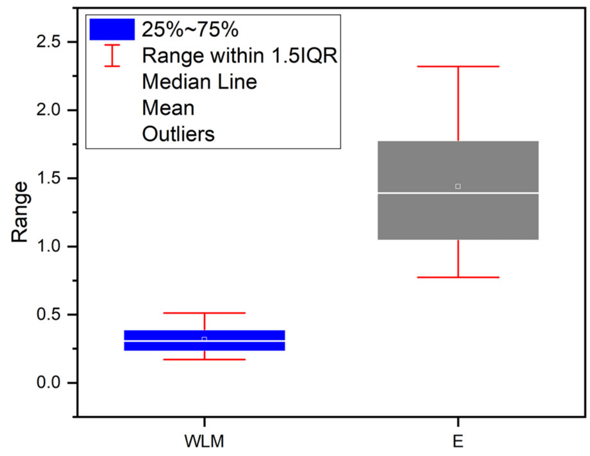

Fig. 6 WLM and *E* (mSv/y) range with a chart bar error

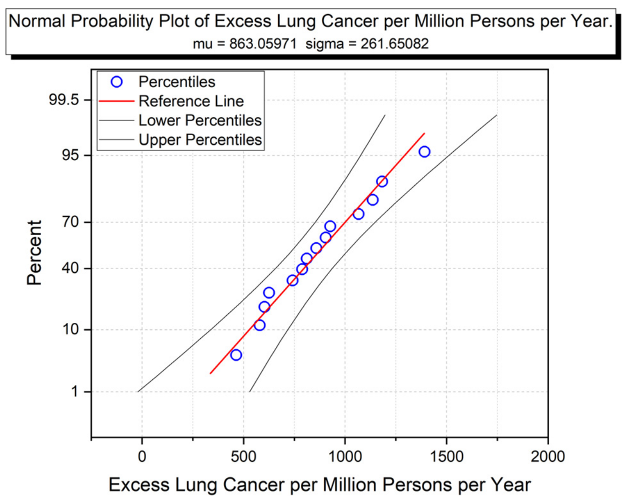

Fig. 7 Normal probability of ELC with a reference line and upper and lower limits

Babylon cement plant is higher than the global mean annual effective dose. The correlation between the annual effective dose and the radon concentration with a normal probability frequency is presented in Fig. 5. The results are normal distributed and around the mean values. Direct strong correlation is explained between annual effective dose and the radon concentration. In addition, the WLM and *E* (mSv/y) range with a chart bar error is shown in Fig. 6. The mean values of WLM and *E* (mSv/y) are inside the box and nearly touch the median line. It means that the results have a good symmetric mode.

Figure 7 shows the normal probability of ELC with a reference line and upper and lower limits. The ELC ranges from 464 to 1392, with a mean value of 863. The variance in the results may be due to the nature of the fuel for thermal stations in the cement plant. The fuel that comes to the Babylon cement plant has a different origin with different concentrations of radioactive elements inside it. As an example, the southern region in Iraq has more radioactive elements in kerosene fuel which is used in Babylon cement plant. The excess of radioactive elements in the fuel gives increasing in radon concentration and ELC more than other.

4 Conclusions

The radon ELC for soil samples from the Babylon cement plant in Iraq was estimated in terms of the ^{222}Rn activity concentration, which was measured with a CR-39 track detector. The ^{222}Rn activity concentration for the collected soil samples ranged from

31 to 92 Bq/m^3, with a mean value of 56.72 Bq/m^3. The ELC ranged from 464 to 1392, with a mean value of 864: there were no significant deviations in all the samples. These results show that the radon concentration in soil samples from the Babylon cement plant is below the ICRP's allowed limit, although the mean annual effective dose (1.44 mSv/y) is higher than the global annual effective dose recommended by UNSCEAR (1.3 mSv/y). The variance in the results may be due to the nature of the fuel for thermal stations in the cement plant.

Nomenclature

A = the area of field view (mm^2)
CR-39 = nuclear track detector
C_{Rn} = the concentration of radon
C_S = the specific activities of the soil samples (Bq/m^3)
C_{sg} = the specific activities of the standard geological sample (Bq/m^3)
D_{Rn} = the dose conversion factor 9.0×10^{-6} mSv/(Bq m^3 h)
E = the annual effective dose (mSv/y)
ELC = excess lung cancer
F = the equilibrium factor (0.4, as recommended by UNSCEAR)
ICRP = International Commission on Radiological Protection
N = the average value of the total tracks
NW–SE = north west–south east wind direction
O = the occupancy factor (0.8 was estimated)
ppm = part per million
RR = relative risk factor
T = the hours in a year (8760 h/y)
UNSCEAR = United Nations Scientific Committee on the Effects of Atomic Radiation
WHO = World Health Organization
WLM = working level month
^{220}Rn = thoron-220 gas
^{222}Rn = radon-222 gas
ρ = the surface track density (track/mm^2)
ρ_S = the track densities of the standard geological sample (track/mm^2)
ρ_{sg} = the track densities of the soil samples (track/mm^2)

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