Measurement of Radon Gas Concentrations for different Types of Water in AL-Najaf Refinery by Using RAD7 Monitor

Mokhalad A. Mohammed[1*], Rawaa M. Obaid[2]

Abstract

In this study, the average radon gas concentration for different types of water was measured in AL-Najaf refinery by using RAD7 monitor manufactured by DURRIDGE company, USA, there are two sources of water inside the refinery, river water, and well water, at RO unit inside the refinary, they use 50% of well water (W1) and 50% of river water (W7), as drinking water after mixing and processing them, the mixed water also used as tap water (W5), or as water for oil refining process, in the refining units, the water boils before it is used in the refining process and it does not contain any concentration of radon gas as in sample (W8), and after refining process, the water becomes wastewater (W4), the other wells inside the refinery, (W3), (W9), (W4) and (W2) are used to irrigate the plants located at the borders of the refinery, the results showed that the maximum value was 471 Bq/m^3 in the well water (W1), and the minimum value was 0 Bq/m^3 in the water of the boiler at the refining units (W8), and the average of readings obtained from all water samples was of 108.6888889 Bq/m^3, also the estimation for the average of radon gas concentration in the refinery air was made with the help of EPA estimations and the annual effective dose for inhalation ($E_{inhalation}$), Lung Cancer Risk (LCR), exposure to radon and it's progenies (E_p) and Potential Alpha Energy Concentration (PAEC) were determined for the workers inside the refinary. All the results were within the accepted limits recommended by EPA and WHO.

Key Words: Radon Gas, Al-Najaf Refinery, RAD7 Monitor, Well Water, Drinking Water.

DOI Number: 10.14704/nq.2022.20.5.NQ22143 **NeuroQuantology 2022; 20(5):09-15**

Introduction

Radon is an inert gas, heavier than air with a density of 9.7 kg/m^3, as a result, it accumulates with time in poorly ventilated places. It boils at -61.8°C, it freezes at -71°C[1] and it is soluble in water, where its solubility increases with the increase of temperature, pressure, acidity, and carbon dioxide saturation[2].

Radon gas comes from radium element decay, where radium element is a member of the uranium-238 series, and it can be found in building materials, rocks, and soils with different concentrations[3]. This means, radon gas can be emitted from many products contain an amount uranium-238 or one of it's progenies before radon gas in the series such as cigarette[4].

The concentration of radium in the materials determines how many radon atoms are emitted from the material or emanated from the grains of soil, the size and permeability of the grain, temperature, and pressure also affect the rate of radon emission[5].

Corresponding author: Mokhalad A. Mohammed
Address: [1*,2]Physics Department, College of Science, Babylon University, Hilla, Iraq.
E-mail: [1*]mokhalad.aziz.scihigh82@student.uobabylon.edu.iq; [2]ashrawaa@gmail.com
Relevant conflicts of interest/financial disclosures: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.
Received: 03 March 2022 **Accepted:** 08 April 2022

The wastes resulting from the oil industry, such as sludge and scale contain an amount of radium, the radium content in sludge is not constant because the sludge has a complex chemical composition, but in the scale, the variation of radium content is relatively less than the sludge content [6]. Radon gas and its progenies participate in nearly half of the annual effective dose coming from the natural background [7]. And it is a carcinogenic gas, which is considered the second cause of lung cancer after tobacco smoking, causing 1000-2000 deaths per year in the UK, and 21000 deaths per year in the USA [8]. Where, WHO estimates that radon gas causing 3-14% of lung cancer deaths [9]. Alpha particles resulting from radon progenies decay have high energy enough to damage the cells of lung [10]. And after inhalation of radon gas progenies, these progenies get stuck to the tissue of the lung, and then, it makes damage to the cells of the lung via alpha particles, and as time runs, they lead to lung cancer [11].

The maximum concentration of radon gas in water (safe limit) according to EPA (Environmental Protection Agency) equals 11.11Bq/L (1100 Bq/m^3) [12] and WHO (World Health Organisation) determined the concentration of radon gas of drinking water to be equal to 0.4 Bq/L (400 Bq/m^3) [13].

Transfer coefficient represents the contribution of the initial average radon concentration in water to the indoor radon concentration in air, and it is given by the following relation:[14]

$$\overline{C_a} = T \times \overline{C_w} \tag{1}$$

Where:

T: is the transfer coefficient of radon gas from water to air.

$\overline{C_a}$: is the estimation of the average of radon gas concentration in indoor air.

$\overline{C_w}$: is the average radon concentration in water.

Water transfers a small amount of radon gas to the air and the coefficient of transfer lying between 0.8×10^{-4} and 1.2×10^{-4}, but The value of transfer coefficient which was adopted by EPA is 1×10^{-4} [14].

Transfer factor value can be experimentally determined or by using mathematical models, one of these models estimate the contribution of radon gas in water to air by measuring the rate of use of water per person (W), the volume of building per person (V), transfer efficiency (e), Air Exchange Rate (A.E.R.), and the average of the concentration of radon gas in water ($\overline{C_W}$), as shown in Equation(2):[14]

$$T = \frac{\overline{C_W} \times W \times e}{V \times (A.E.R.)} \tag{2}$$

Transfer efficiency (e) is referred to as the fraction of radon gas in water that is released to the air during activities related to water use such as dishwashing, cloth washing, showering, and so on[14].

The annual effective dose for inhalation ($E_{inhalation}$) can be calculated according to The Equation(3):[15]

$$E_{inhalation}(\mu Svy^{-1}) = \overline{C_a} \times T \times F \times O \times DCF \tag{3}$$

Where: $\overline{C_W}$: is the average of radon gas in water samples in kBq/m^3, T: is the transfer factor (10^{-4} according to EPA), F: is the equilibrium factor between radon gas and it's products which equals 0.4, O: is the average occupancy time per person at indoor air which equals 7000 h/y, and DFC: is the dose conversion factor for radon exposure which equals 9 nSvy^{-1} (Bq/m^3)$^{-1}$

Lung cancer risk (LCR) in (case/year.million), exposure to radon progenies(E_P) and Potential Alpha Energy Concentration (PAEC) can be calculated according to equation(4), Equation(5) and Equation(6) respectively:[16]

$$LCR = E_{inhalation}\left(\frac{mSv}{y}\right) \times (18 \times 10^{-6})\left(\frac{y}{mSv}\right) \tag{4}$$

$$E_P\left(\frac{WLM}{y}\right) = \frac{8760 \times n \times F \times \overline{C_a}}{170 \times 3700} \tag{5}$$

$$PAEC\ (WL) = \frac{F \times \overline{C_a}}{3700} \tag{6}$$

Where: (n=0.8) is the fraction of time spent indoors, 8760 is the number of hours per year, 170 is the number of working hours per month. The concentration of radon gas in Equation (4), Equation (5) and Equation (6) is in Bq/m^3.

Radon gas concentration in water depends on the material that the water is in contact with, for example, the water before entering the oil refining units is radon-free water, but after the refining process, it becomes wastewater with an amount of radon gas.

Table 1. The coordinates of samples and the description of each position in Al- Najaf refinery

Sample code	Longitude	Latitude	Description of the sample position	Type of water
W1	32°14'5.38"N	44°15'31.21"E	At the RO unit inside the refinary	Well
W2	32°13'43.17"N	44°15'33.31"E	Behind the service center	Well
W3	32°13'53.22"N	44°14'54.74"E	At the end of the refinery	Well
W4	32°13'40.81"N	44°15'18.24"E	Behind refining units	Waste
W5	32°13'52.51"N	44°15'29.40"E	At high studies unit	Tap
W6	32°14'4.20"N	44°15'30.06"E	At the RO unit inside the refinary	RO (drinking)
W7	32°14'5.24"N	44°15'27.17"E	At the RO unit inside the refinary	River water inside the refinery
W8	32°13'46.03"N	44°15'21.43"E	At the refining units	water from the boiler
W9	32°13'36.39"N	44°15'8.28"E	Near the flare	Well

Study Area

The area of study (Al-Najaf refinery) is located in AL-Najaf province, in the western part of the Republic of Iraq at a latitude 32°13'N and a longitude 44°15', Al-Najaf refinery was built in October 2006, with an area of about 887293 m^2, one hundred miles (160 km) from Baghdad the capital, and it contains three refining units[17].

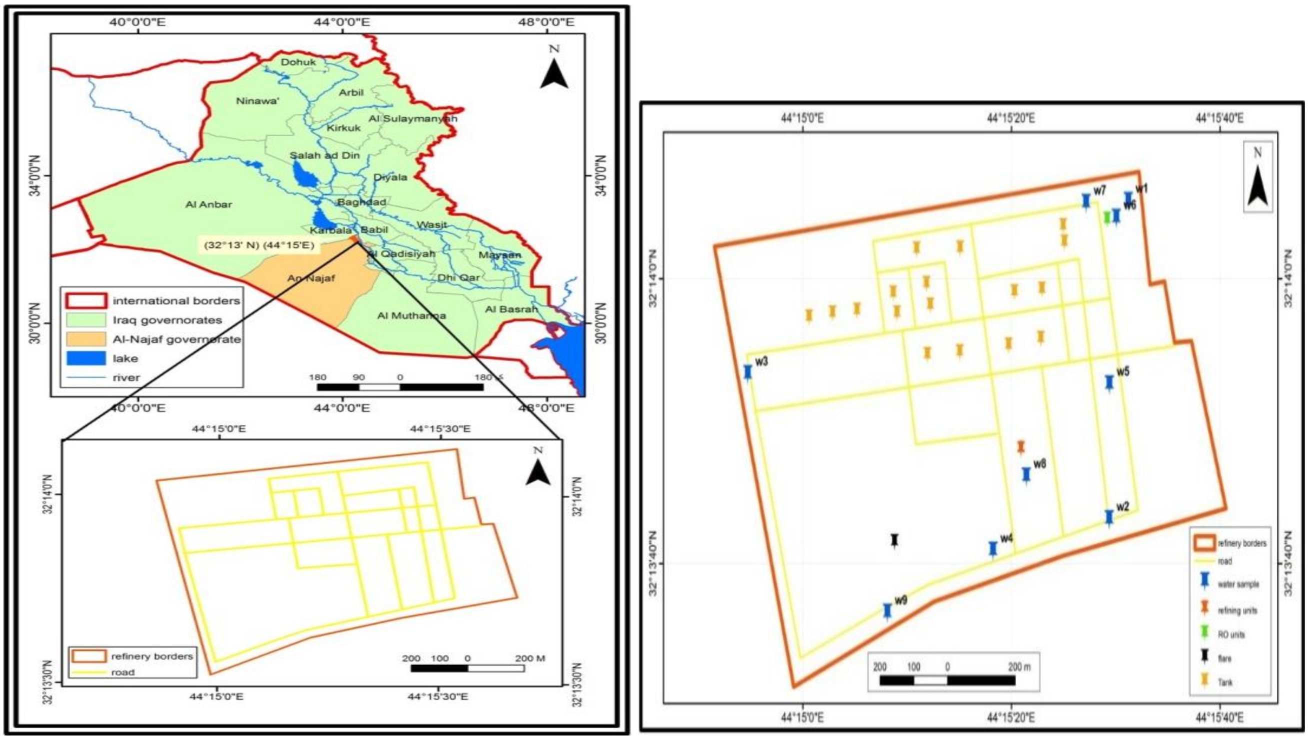

Figure 1. A map for the study area shows the position of water samples

Materials and Methods

RAD7 Monitor

It is an electronic equipment, which is designed to detect only alpha particles among all types of radiations. The RAD7 monitor contains 0.7 L cell, a hemisphere in shape, which is coated with an electrical conductor. At the center of it, a silicon detector is placed. The hemisphere is charged with a high potential of 2000 V to 2500 V relative to the detector. The potential difference will create an electric field throughout the volume of the cell, and it propels positively charged particles into the detector. Polonium-218 will be derived towards the detector after the decay of radon, and the alpha particle resulting from the decay of polonium-218 will enter the detector and produces an electrical signal proportional in strength to the energy of an alpha particle where different alpha energies, produce different responses in the detector. After signals producing, the RAD7 monitor will amplify, filter, and sort the signals according to their strength. Signals created from Polonium-218 are used to determine the concentration of radon, and which are from polonium-216 are used to determine the concentration of thoron. The other progenies effect will be neglected by the RAD7 monitor[18].

RAD H_2O

It is a set of items that are used with RAD7 monitor to calculate the concentration of radon gas in water, as shown in Fig.(1), the range of concentrations that can be measured by this system ranging between 10 pCi/L and 400000 pCi/L, and the units of measurements can be changed according to the user demand into Bq/m^3 throughout the RAD7 monitor[19].

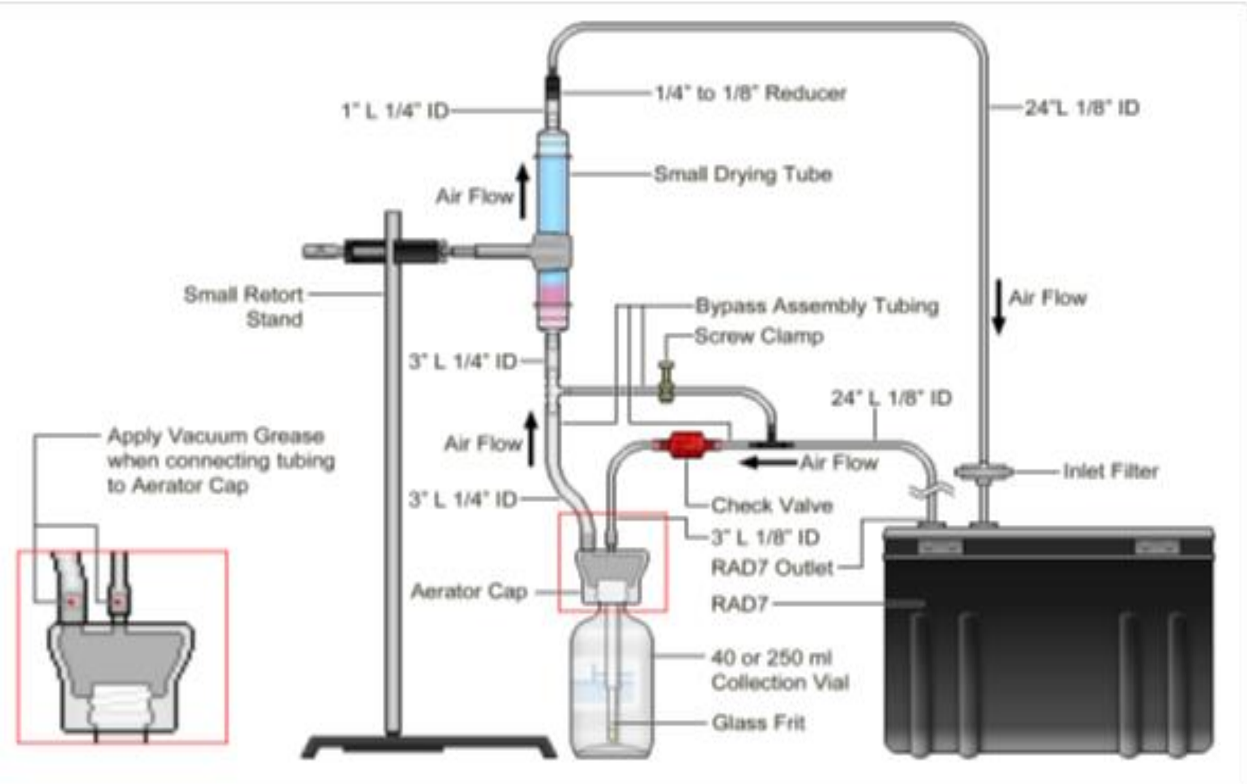

Figure 2. The components of RADH₂O connected with the RAD7 monitor[19].

Sample Collection and Test Procedures

The samples were collected from the wells after 15min. from the operating of the motor of the well to ensure that the water is come from the groundwater, as the well is with a depth of 30m, and then all water samples (well samples and the others) were brought to the lab of advanced nuclear physics in the university of Babylon/ college of science/ physics department in the next day for testing. The testing step is done, After assembling the components of RADH$_2$O and connecting it with the RAD7 monitor, as shown in Fig.(1), the test begins with the purging step, and after 10 min. of purging and reaching the humidity of less than 10%, the test is started by choosing a test start from the screen of RAD7 monitor, where the settings of the test are previously determined as the following: (protocol: WAT-250, cycle: 5minutes, recycle: 4, pump: Grab , tone: off, mode: water250mL, thoron: off), and it takes 20 min., after this step, the result is printed by the infrared printer settled on the RAD7 monitor.

Results and Discussion

Results

From the results, the maximum values of radon gas concentration were in well water sample (W1), and the concentration became lower in drinking water and wastewater, while it got vanished in the water of the boiler, because of the releasing of radon gas during the boiling period.

Table 2. The average of concentration of Radon gas for different types of water inside Al-Najaf refinery

Sample code	$\overline{C_w}$ in (Bq/m³)	Standard deviation in (Bq/m³)	$\overline{C_w}$ in (pCi/L)	Standard deviation in (pCi/L)	$\overline{C_w}$ in (kBq/m³)	Standard deviation in (kBq/m³)
W1	471	218	17427	8066	0.471	0.218
W2	72.4	145	2678.8	5365	0.0724	0.145
W3	109	72.4	4033	2678.8	0.109	0.0724
W4	72.4	83.6	2678.8	3093.2	0.0724	0.0836
W5	109	72.4	4033	2678.8	0.109	0.0724
W6	36.2	72.4	1339.4	2678.8	0.0362	0.0724
W7	36.2	72.4	1339.4	2678.8	0.0362	0.0724
W8	0	0	0	0	0	0
W9	72	83.2	2664	3078.4	0.072	0.0832
Average	108.6888889	91.04444	4021.489	3368.644	0.108689	0.091044
Maximum value	471	218	17427	8066	0.471	0.218
Minimum value	0	0	0	0	0	0

Table 3. The estimation of the average of Radon gas concentration in air inside the refinery which is calculated according to Eq.(1)

Sample code	$\overline{C_a}$ in (Bq/m3)	$\overline{C_a}$ in (pCi/L)	$\overline{C_a}$ in (kBq/m³) $\times 10^{-6}$
A1	0.0471	1.7427	47.1
A 2	0.00724	0.26788	7.24
A 3	0.0109	0.4033	10.9
A 4	0.00724	0.26788	7.24
A 5	0.0109	0.4033	10.9
A 6	0.00362	0.13394	3.62
A 7	0.00362	0.13394	3.62
A 8	0	0	0
A9	0.0072	0.2664	7.2
Average	0.010868889	0.402149	10.86889
Maximum value	0.0471	1.7427	47.1
Minimum value	0	0	0

13

Table 4. $E_{inhalation}$, LCR, PAEC and E_P as a result of inhalation of radon gas and it's progenies which comes from different types of water inside the refinary

Sample code	$E_{inhalation}$ in $(\mu Svy^{-1}) \times 10^{-6}$	LCR $\times 10^{-6}$	PAEC in (WL) $\times 10^{-6}$	E_P in (WLM/y) $\times 10^{-6}$
A1	118.692	2.13646	5.09189	209.906
A2	18.2448	0.328406	0.782703	32.2658
A3	27.468	0.494424	1.17838	48.5769
A4	18.2448	0.328406	0.782703	32.2658
A5	27.468	0.494424	1.17838	48.5769
A6	9.1224	0.164203	0.391351	16.1329
A7	9.1224	0.164203	0.391351	16.1329
A8	0	0	0	0
A9	18.144	0.326592	0.778378	32.0875
Average	27.3896	0.493013	1.175015	48.4383
Max. Value	118.692	2.13646	5.09189	209.906
Min. Value	0	0	0	0

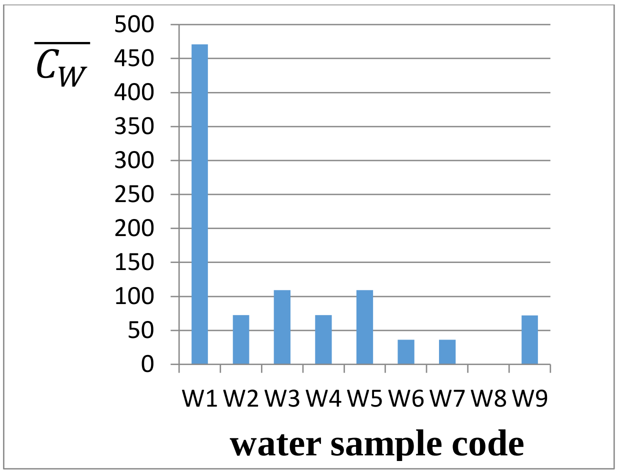

Figure 3. A bar chart shows radon gas concentrations for different types of water inside Al-Najaf refinary in (Bq/m³)

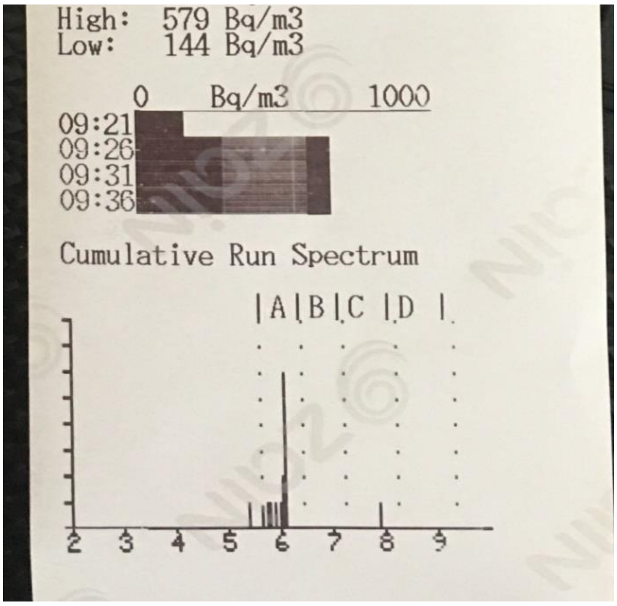

Figure 4. The spectrum of alpha particle energy and the highest and lowest values of radon gas concentration for W1 (well water sample) in the refinery

Discussion

From the results, it can be concluded that the average radon concentration of well water is the highest because it is in contact with rocks at the bottom of the well which contains an amount of radium that is come from a naturally occurring radioactive element uranium-238, and this affects the levels of radon in drinking water as the drinking water in the refinery before treating is a mixture of river water and well water, the water in the boiler is radon-free water, as the radon decayed into its progenies during storage in the reservoirs before entering the refining units, or as it is transmitted into the air while the water boils. Radon concentration in wastewater comes from oily wastes (sludge resulting from refining operations) while the water before entering the process of refining (in the boiler) is radon-free water, All the results in this work are within the accepted limits recommended by EPA and WHO.

References

B.K. Rejah and G.T. Ashoor, "Radon Gas Concentration Measurement in Air of Al - Haswaa City in Province of Baghdad," *Iraqi J. Sci.*, vol. 58, no. 2, pp. 663–668, 2017, https://www.researchgate.net/publication/321035212.

L. Pawlik-Sobecka, J. Górka-Dynysiewicz, and J. Kuciel-Lewandowska, "Balneotherapy with the use of radon-sulphide water: The mechanisms of therapeutic effect," *Appl. Sci.*, 11(6), 1–7, 2021. doi: 10.3390/app11062849.

E. Andrade, C. Miró, M. Reis, M. Santos, and M. J. Madruga, "Assessment of radium activity concentration and radon rates in Iberian peninsula building materials," *Radiat. Prot. Dosimetry*, 177(1), 1–5, 2017, doi: 10.1093/rpd/ncx128

A.M.S. Qasim, H.H. Hussain, and A.A. Abojassim, "Radon Concentrations and Annual Effective Dose in Cigarette Samples (Domestic and Importer) At the Iraqi Markets," *J. Radiat. Nucl. Appl.*, 3(2), 83–88, 2018. doi: 10.18576/jrna/030203

P. Anderson, B. Clavensjo, and G. Akerblom, "The effect of the ground on the concentration of radon and gamma radiation indoors," *Swedish Counc. Build. Res. Rep.*, 9, 1–442, 1983.

J.M. Godoy and R.P. da Cruz, "226Ra and 228Ra in scale and sludge samples and their correlation with the chemical composition," *J. Environ. Radioact.*, 70(3), 199–206, 2003.

G.K. Gillmore, P.S. Phillips, A.R. Denman, and D.D. Gilbertson, "Radon in the Creswell Crags Permian limestone caves," *J. Environ. Radioact.*, vol. 62, no. 2, pp. 165–179, 2002.

G.K. Gillmore, R.G.M. Crockett, and P.S. Phillips, "Radon as a carcinogenic built-environmental pollutant," *Geol. Soc. Spec. Publ.*, vol. 451, no. 1, pp. 7–34, 2018, doi: 10.1144/SP451.5.

I. Celikovic *et al.*, "Outdoor Radon as a Tool to Estimate Radon Priority Areas—A Literature Overview," *Int. J. Environ. Res. Public Health*, 19(2), 2022, doi: 10.3390/ijerph19020662

J.H. Jebur, R.H. Subber Abdul, and W. Tuama Saadon, "Calibration of CR-39 for different heights of radon dosimeters and application of radon concentration in Mahajran River sediment in Basra Governorate, Iraq," *J. Phys. Conf. Ser.*, 1294(2), 2019. doi:10.1088/1742-6596/1294/2/022013

S.Q. Khalaf and H.S. Hussien, "Radon concentration measurement in water reservoirs for some areas of north Baghdad by RAD7," *J. Phys. Conf. Ser.*, 2114(1), 1–8, 2021, doi: 10.1088/1742-6596/2114/1/012062

U.S. USEPA, "Environmental Protection Agency. National Primary Drinking Water Regulations for Radionuclides," EPA/570/9–91/700 US Environmental Protection Agency, 1991.

A.A. Marzaali, M.A. Al-Shareefi, and A.A. Abojassim, "Practical Study to Assess Radioactive Radon Gas in Groundwater Samples of Dhi-Qar Governorate," *IOP Conf. Ser. Earth Environ. Sci.*, 722(1), 2021. doi: 10.1088/1755-1315/722/1/012022

National Research Council (US) Committee on Risk Assessment of Exposure to Radon in Drinking Water., "Risk assessment of radon in drinking water," National Academies Press (USA), Washington, 1999. doi: 10.17226/6287.

S. Mittal, A. Rani, and R. Mehra, "Estimation of radon concentration in soil and groundwater samples of Northern Rajasthan, India," *J. Radiat. Res. Appl. Sci.*, 9(2), 125–130, 2016. doi: 10.1016/j.jrras.2015.10.006.

D.A. Salim and S.A. Ebrahiem, "Measurement of Radon concentration in College of Education, Ibn Al-Haitham buildings using Rad-7 and CR-39 detector," *Energy Procedia*, 157, no. 2018, 918–925, 2019. doi:10.1016/j.egypro.2018.11.258

"Najaf refinery gets 3rd production unit in Iraq - News | Khaleej Times." https://www.khaleejtimes.com/business/najaf-refinery-gets-3rd-production-unit-in-iraq

K.M. Opondo and K. Sims, *"Electronic Radon Detector User Manual,"* 1–94, 2021. https://durridge.com/documentation/RAD7 Manual.pdf

Durridge Company Inc., *RAD H2O user maual*, no. 978. Billerica: 2020 Durridge Company Inc, 2020.