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Measurement of Radon Activity in Soil Gas and the Geogenic Radon Potential Mapping Using RAD7 at Al-Tuwaitha Nuclear Site and the Surrounding Areas

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Abstract: In this study Soil gas radon ^{222}Rn activity was measured in different locations at Al-Tuwaitha Nuclear Site and the surrounding areas using RAD7 (radon detector). Radon activity in the soil gas varied from (866±150 to 16004±521) Bq/m^3 near Alaibtihal School and Ishtar \ Al-Ttakhi School respectively. These concentrations values are well below the allowed levels that range from (0.4 to 40) KBq/m^3. The annual effective doses related to the inhalation of radon gas and its progeny which were calculated from the Concentration of emanation in air near ground ranged from (0.0082305 to 0.152102) mSv/y. these results are less than the recommended global average dose from the inhalation of radon from all sources, which is 1 mSv/y. The Health risks originating from indoor radon concentration can be attributed to natural factors and is characterized by geogenic radon potential (GRP), The highest values were found in Ishtar \ Al-Ttakhi school which is (16.004) and The lowest values were found Near Alaibtihal school which is (0.288666667), the lowest value according to Neznal was classified as low (GRP < 10) and the highest value was classified as medium (10 < GRP < 35), according to Barnet and Pacherová low GRP causes <230 Bq m^{-3} while medium GRP causes 230-460 Bq m^{-3} indoor radon concentration. From these different values of GRP a geogenic radon risk map was created, which assists human health risk assessment and risk reduction since it indicates the potential of the source of indoor radon. The results from this study shows that the region has background radioactivity levels within the natural limits.

Keywords: Radon Gas, Al Tuwaitha Nuclear Site, RAD7

1. Introduction

In the environment, the fundamental normal source of uranium, and also of whatever other antecedent of one of the radon isotopes, is probably going to be the resuspension of tidy particles from the earth. Radon-222 exhalation starting from the earliest stage the principle wellspring of 210Pb in the air. Radon isotopes of natural origin are, separately, 222Rn (half-life t1/2 = 3.8 day), 220Rn (t1/2 = 55.6 s) and 219Rn (t1/2 = 3.96 s) [1] Radon is a noble gas with slight ability to form compounds under lab conditions. The density of radon is 9.73 g/l at °C [2].

As radon experiences radioactive decay, it emits radiation and turns into another radioactive component. This is rehashed a few times until it ends up plainly stable lead. The components that radon changes into are called radon daughters or radon descendants [3]. The major radioactive exposure of public health concern is inhalation of short-lived decay products (218Po and 214Po) of 222Rn [4]. Alpha particles released by these two radioisotopes, convey to target cells in the respiratory epithelium the energy that is considered to bring about radon-related lung-disease [5].

The original source of radon-222 is from the common radioactive decay of uranium-238 and radium-226. Certain soils and rocks that contain elevated amounts of uranium likewise store regular deposits of radon: granite, phosphate, shale, pitchblende [10]. The lower air pressure indoors gives rise to a pressure-driven flow of radon-rich soil air into the indoor environment through cracks in the bottom slab and cellar walls [11].

Radon particles situated inside solid grains are probably not going to end up noticeably accessible for discharge to the air, owing to their very low diffusion coefficients in solids. However, if they are located in the interstitial space between grains, they may diffuse to the surface. In this way, releases of radon from residue repository to the environment happen by the accompanying arrangement of procedures [12]:

(a) Emanation — radon atoms formed from the decay of radium escape from the grains (mainly because of recoil) into the interstitial space between the grains.

(b) Transport — diffusion and advective flow cause the movement of the emanated radon atoms through the residue or soil profile to the ground surface.

(c) Exhalation — radon atoms that have been transported to the ground surface and then exhaled to the atmosphere.

2. Areas of the Study

Al Tuwaitha Nuclear site filled in as the establishment of Iraq's atomic innovative work from 1967 until its closure in 2003 [6]. Al-Tuwaitha Nuclear site is the biggest, most complex and most radiological contaminated site in Iraq [7]. Substantial amounts of radioactive materials and waste related with Iraq's previous atomic facilities at Al Tuwaitha nuclear site and in addition other nuclear facilities may represent a noteworthy wellbeing and security risk to workers and inhabitants of the surrounding communities and to the earth. About the greater part of Iraq's previous atomic facilities were harmed and are presently either known to be, or are conceivably, radioactively contaminated. These nuclear facilities are all hazardous in some fashion and need disassembly and disposal, so to bolster the Government of Iraq in the assessment and decommissioning of past facilities that utilized radioactive resources, The International Atomic Energy Agency (IAEA) Board of Governors has accepted such project [8].

Twenty locations have been chosen at Al-Tuwaitha Nuclear Site and some surrounding locations also selected to be the areas of the current study to make sure that all the selected locations are safe and doesn't cause any hazards on the employees these locations varied between Administrative buildings, radiological laboratories, radiological storages and houses as shown in figure 1.

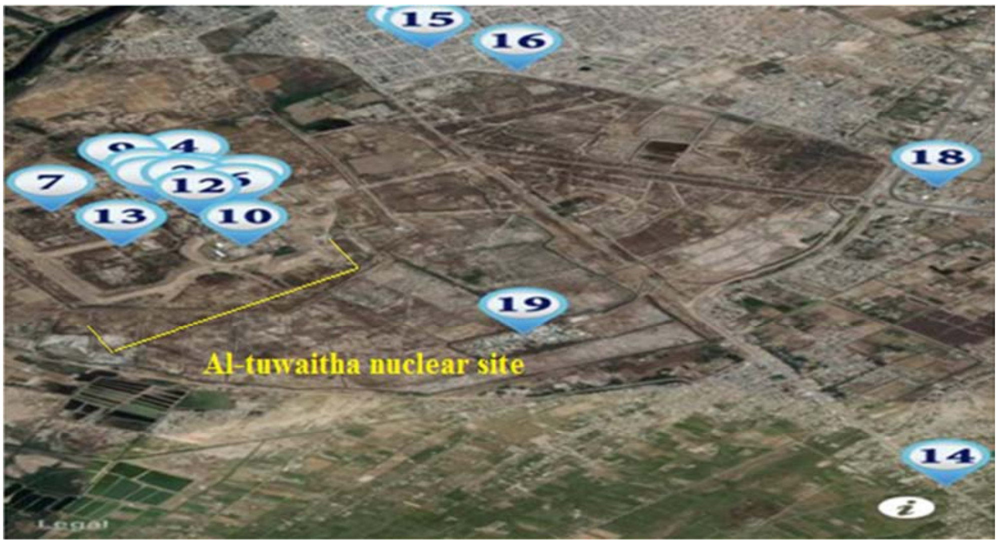

Figure 1. *A photo of Al-Tuwaitha Nuclear Site and some surrounding locations shows radon monitoring points.*

3. Airborne Radon Measurement

Radon activity concentration was measured in twenty locations at Al-Tuwaitha nuclear site and some surrounding locations using RAD7. RAD7 is continual radon measuring device from Durridge Company (USA). The RAD7 is a Sniffer that uses the 3-minute alpha decay of a radon descendant, without intrusion from other radiations, and the instantaneous alpha decay of a thoron daughter. The RAD-7 uses silicon as a semiconductor material which converts the energy of α-particles directly into electrical signals. The measuring range is between 4 to 750000 Bq m^{-3}. When the radon and thoron daughters deposited on the surface of the detector they decay and emits alpha particles of characteristic energy directly into the solid-state detector. The RAD7's microprocessor picks up the signal and stores it according to the energy of the particle. When many signals accumulate, they result in a spectrum. The RAD7 groups the spectrum's 200 channels into 8 separate "windows" or energy ranges.

The soil gas radon concentration was measured at a depth of 60 cm using a probe having diameter of 10 mm. The soil probe is immersed in the soil with gentle strokes of hammer. The soil probe is connected to drierite which is connected to the RAD-7 as shown in figure 2. In each measurement we have to keep the moisture under 10% by using the Drierite desiccant which is an important accessory which absorbs the moisture from the soil gas.

The RAD-7 can measure Radon via 9 different protocol. The protocol have been used for the soil-gas measurements is called the Grab sample protocol. The RAD-7 pumps the soil-gas for 5 minutes into the cell of the detector, and then waits for 5 minutes and count only for 5 minutes. 218Po has a half-life of 3.05 min and it takes about 3-5 half-lives for the 218Po activity to reach secular equilibrium, hence, in about 9-15 minutes. The decays of the 218Po would then be counted after 10 mins (5 min of pumping plus 5 min of waiting), in which time 95% of equilibrium would have been reached [9]. Finally, each set of readings includes four 5- min cycles that at last takes 30 min.

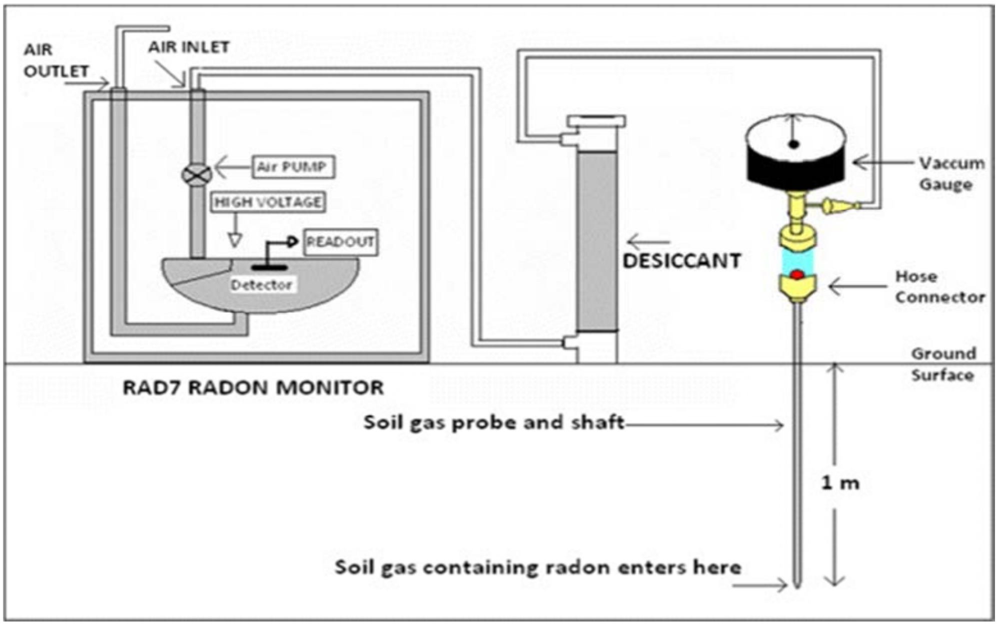

Figure 2. *The schematic diagram of the RAD7 soil-gas setup [9].*

4. Estimation the Outdoor Radon Activity and Annual Effective Dose

Let (C_{so}) be the concentration of emanation in the soil air (Bq/m^3), d its diffusion constant (cm^2/s), (a) its rate of production within the soil (Bq/m^3), which is assumed to be independent of depth and λ the radon Decay rate of Emanation which is (2.1*10^{-6}). If the soil is sufficiently porous, diffusion proceeds as if the soil are absent. From the rate of production we can find the concentration of emanation in undisturbed soil air in deeper layers [13]:

$$C_{so} = \frac{a}{\lambda} \quad (1)$$

And the exhalation rate (E) is [13]:

$$E = a\sqrt{\frac{d}{\lambda}} \quad (2)$$

The constants d and λ are fixed, d=0.05 cm^2/sec. Only a fraction of the equilibrium production of emanation escapes into the soil prior to decay within the soil particles, this fraction is found to be 10%. The concentration of emanation at the ground is given by [13].

$$C_{ao} = C_{so}\sqrt{\frac{d}{D}} \quad (3)$$

Where D is the eddy diffusion coefficient (5*10^4 cm^2/s).

For the estimation of average annual effective dose, AED (mSv/y) received by the public and workers of the studied area due to the outdoor radon and its progeny, Equation (4) was used for the calculation [19]:

$$AED\left(\frac{mSv}{y}\right) = C_{Rn} * F * O * (DCF) \quad (4)$$

Where the: AED: The annual effective dose, C_{Rn}: the activity of outdoor radon in Bq/m^3, F: The global average (0.6) of equilibrium factor for outdoor radon and its descendant, O: The global average outdoor occupancy factor (1760 h/y), DCF: The dose conversion factor (9 nSv/h per Bq/m^3)

5. Geogenic and Indoor Radon Map

Indoor radon concentration are constantly subject to human activity, natural and anthropogenic components, for example, development sorts, building materials, living propensities and meteorology, and are transiently factor and characteristic for every specific house. For example, two houses assembled contrastingly on the same land ground will have diverse normal indoor radon concentration, as will two indistinguishably manufactured houses on a similar ground, however with various living propensities for the tenants. As another case, enhancing the protection of a house can impact its indoor radon fixation. In this manner, one is keen on mapping an amount which is nearer to geogenic risk, i.e. which measures 'what earth delivers' as far as radon, on the grounds that for the most part the subsurface (soil gas Radon concentration) is the principle source for indoor radon concentration. It discovers territories, where definite indoor radon estimations are fundamental. Regardless of anthropogenic components and transiently steady over a geographical timescale [14] (see figure 3)

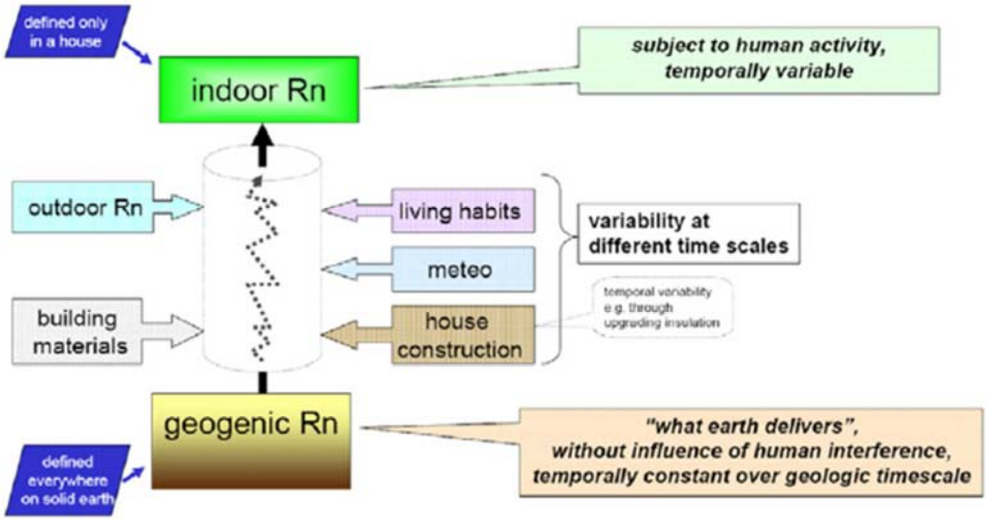

Figure 3. *From geogenic radon to indoor radon concentration–influences and definitions [14].*

The geogenic map Represent the radon potential at any location in Al-Tuwaitha Nuclear Research Center and some surrounding areas since geogenic radon potential mapping has not been performed there by using soil gas radon measurements with varying permeability of the bare earth. One suggested approach to quantify the geogenic radon potential in order to assist human health risk assessment and risk reduction which developed by Neznal [15].

$$\mathrm{GRP} = \frac{C}{-\log_{10} k - 10} \quad (5)$$

Where C is the equilibrium soil gas radon activity concentration at a definite depth (1m) (kBq m^{-3}) and k is the soil gas permeability (m^2) which we assumed it for bare earth varying from 10^{-11} to 10^{-13} (m2) [2].

6. Results and Discussion

An average value of Radon Activity in Bq/m^3 was measured for each sampling point using RAD7. All the results were listed in Table1.The radioactive level of ^{222}Rn for soil samples ranged from (866±150 Bq/m^3) in Alaibtihal School to (16004±521 Bq/m3) in Ishtar \ Al-Ttakhi school at depth 60cm under surface These concentrations values are well below the allowed levels which is range (0.4-40) KBq/m^3 [16, 17]. These values were used to calculate the Rn-222 activity of emanation in air near the ground by using equation (3) with an average value (3897). By using equation (1) we were able to calculate the Production rate (a) of emanation in soil with an average value (0.008629688) and by using equation (2) we calculated the Exhalation rate (E) with an average value (0.012630342).

Table 1. *Radon Concentrations in different locations at The Al-Tuwaitha Nuclear site.*

Sample Point no.	Date	Location	RAD eye (μ Sv/h)	GPS Coordinates E	GPS Coordinates N	Air Temreture (℃)	Soil Radon activity (Bq/m^3)
1	2016/11/1	Near the Radiological and Nuclear Safety Directorate	0.03	44.513587	33.206840	30.4	2060±648
2	2016/11/2	Near the Central Laboratories Directorate	0.03	44.512924	33.207395	27.1	3850±390
3	2016/11/3	Near the Department of Agriculture	0.03	44.515639	33.207224	21.3	2400±310
4	2016/11/6	Near the Scientific Information Center (Central Library)	0.04	44.515200	33.209671	23.1	1120±210
5	2016/11/8	Near the Decommissioning Directorate	0.04	44.51820	33.20697	21.9	2760±330
6	2016/11/23	Near The Organization presidency	0.02	44.51777	33.20607	21.3	2650±310
7	2016/11/24	Near the Nuclear applications Directorate	0.04	44.50856	33.20589	15.2	1290±220
8	2016/11/27	Near The radioisotopes production laboratories	0.04	44.51335	33.20780	16.4	4820±420
9	2016/11/28	Between former clinic and design building	0.04	44.51206	33.20932	17.6	7140±530
10	2016/11/29	Near the Treatment of Radioactive Waste	0.04	44.518099	33.202128	23.1	6690±510

Sample Point no.	Date	Location	RAD eye (μ Sv/h)	GPS Coordinates E	N	Air Temreture (℃)	Soil Radon activity (Bq/m^3)
		Management					
11	2016/12/4	Near laser building (outside berms)	0.03	44.51205	33.202128	18.2	5970±460
12	2017/1/15	The side The Organization presidency	0.03	44.51584	33.20542	15.5	1030±190
13	2017/1/24	Near electrical systems	0.03	44.31030	33.12489	27.2	1600±240
14	2017/2/1	Alwardia area /aljiearah clinic	0.02	44.55289	33.175992	17.5	2460±300
15	2017/2/6	Jisr Diyala \ Riyadh	0.05	44.52728	33.22343	15.7	3760±370
16	2017/2/9	Jisr Diyala \ area of energy storage	0.02	44.53170	33.22120	17.4	6350±480
17	2017/2/26	Near alaibtihal school	0.01	44.52646	33.22400	32.1	866±150
18	2017/2/27	Jisr Diyala / Al-alearifih	0.04	44.55246	33.20847	31	1240±200
19	2017/2/29	Ishtar \ alttakhi school	0.02	44.53205	33.19251	33.5	16004±521
Min			0.01			15.2	866±150
Max			0.05			33.5	16004±521
Average			0.03			22.3	3897.

The Soil Radon activity values seem to be safe from the point of view of health hazards because as we can see in table 2 the values of the Rn activity of emanation in air near the ground were used to calculate the annual effective dose by using equation (4) and ranged from (0.0082305 to 0.152102) mSv/y in Alaibtihal School and Ishtar \ Alttakhi School these results are less than the recommended global average dose from the inhalation of radon from all sources, which is 1 mSv/y. It is worth to mention that variation in soil radon activity during the three months can be attributed to the heterogeneity of uranium / radium distribution and mineralization in the soil / rocks and local permeability of the soil in addition to influence of lithology, soil types and structural attributes (thrusts faults and shears) in the study area. Further, the diffusion of radon through soil are governed by concentration of parent material in soil / rocks, emanation capacity of the ground, porosity of soil and rock, soil moisture because Moisture content is well known to have a strong effect on the emanation coefficient. This is because the typical ranges for recoil in water are much less than in air and therefore water is more effective at stopping radon atoms within the pore space in addition to meteorological parameters (atmospheric pressure, wind speed).

Table 2. *The Rn activity of emanation in air near the ground, a, E, AED and GRP in soil.*

Sample Point no.	Production rate (a) of emanation in soil (Bq/m^3.s)	Exhalation rate (E) (Bq/m^2.s)	Rn activity of emanation in air near the ground (Bq/m^3)	The annual effective dose (mSv/y)	GRP with Permeability 10^{-11}	10^{-12}	10^{-13}
1	0.004326	0.006675	2.06	0.0195782	2.06	1.03	0.686666667
2	0.008085	0.0124752	3.85	0.0365904	3.85	1.925	1.283333333
3	0.00504	0.0077767	2.4	0.0228096	2.4	1.2	0.8
4	0.002352	0.0036291	1.12	0.0106445	1.12	0.56	0.373333333
5	0.005796	0.0089432	2.76	0.026231	2.76	1.38	0.92
6	0.005565	0.0085868	2.65	0.0251856	2.65	1.325	0.883333333
7	0.002709	0.00418	1.29	0.0122602	1.29	0.645	0.43
8	0.010122	0.0156182	4.82	0.0458093	4.82	2.41	1.606666667
9	0.014994	0.0231357	7.14	0.0678586	7.14	3.57	2.38
10	0.014049	0.0216776	6.69	0.0635818	6.69	3.345	2.23
11	0.012537	0.0193446	5.97	0.0567389	5.97	2.985	1.99
12	0.002163	0.0033375	1.03	0.0097891	1.03	0.515	0.343333333
13	0.00336	0.0051845	1.6	0.0152064	1.6	0.8	0.533333333
14	0.005166	0.0079711	2.46	0.0233798	2.46	1.23	0.82
15	0.007896	0.0121835	3.76	0.035735	3.76	1.88	1.253333333
16	0.013335	0.0205759	6.35	0.0603504	6.35	3.175	2.116666667
17	0.0018186	0.0028061	0.866	0.0082305	0.866	0.433	0.288666667
18	0.002604	0.004018	1.24	0.011785	1.24	0.62	0.413333333
19	0.0336084	0.0518578	16.004	0.152102	16.004	8.002	5.334666667
Min	0.0018186	0.002806	0.866	0.0082305	0.866	0.433	0.288666667
Max	0.0336084	0.0518578	16.004	0.152102	16.004	8.002	5.334666667
Average	0.008629688	0.012630342	3.897894737	0.037045595	3.897894737	0.433	0.288666667

As we can see in table 2 the values of geogenic radon potential (GRP) was calculated using Eq.5. The highest values of the (GRP) was found in Ishtar \ Alttakhi School which is (16.004) with permeability (10^{-11}) and the lowest value was found near Alaibtihal School which is (0.288666667) with permeability (10^{-13}). Based on many years of extensive research in the Czech Republic, three categories of GRP were set: low (GRP < 10), medium (10 < GRP <35) and high (35 < GRP) [15], so all values of GRP are classified under the areas that have low GRP except for Ishtar \ Alttakhi school which classified under the areas that have medium GRP. According to Barnet and Pacherová [18] low GRP causes <230 Bq m^{-3}, medium GRP causes 230-460 Bq m^{-3}, high GRP causes >460 Bq m^{-3} indoor radon concentration, since the action level for IAEA (International Atomic Energy Agency) which is (1000 Bq/m^3) as a yearly average concentration for indoor radon in workplaces and Based on our results of GRP, all the chosen location are safe enough to categorize them under low radon risk areas.

7. Conclusion

From the present work, we can conclude:

All the results of radon concentrations were obtained in this study are well below the allowed levels which is range from (0.4 to 40) KBq/m^3. From the soil radon activity it has been able to calculate the Production rate (a) of emanation in soil, the Exhalation rate (E) and the radon activity of emanation in air near the ground. The annual effective dose that has been calculated from the Rn activity of emanation in air near the ground were less than the recommended global average dose from the inhalation of radon from all sources, which is 1 mSv/y.

From the values of the geogenic radon potential (GRP) that has been calculated, we predicted the indoor radon concentrations which was less than the yearly average concentration for indoor radon in workplaces (1000 Bq/m^3), by using Barnet and Pacherová classification and based on that all the chosen location are safe enough to categorize them under low radon risk areas.

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