American Journal of Sciences and Engineering Research www.iarjournals.com

*American Journal of Sciences and Engineering Research*
*E-ISSN - 2348 -703X, Volume 4, Issue 3, 2021*

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# Geological Controls Affecting on Radon Gas Concentrations in Granitic Gneisses at Wadi Abu Rushied, Southeastern Desert, Egypt

**M. A. M. Mahmoud[1], E. S. Abd El-Halim[2], S. F. Hassan[1], T. El Sayed Mohamed[1]**
[1]*Nuclear Materials Authority, Cairo, Egypt.*
[2]*Physics Department, Faculty of Women for art, science and education, Ain Shams University, Egypt.*

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**ABSTRACT:** *The radon ($Rn^{222}$) is a natural radioactive gas produced by the radioactive decay of Uranium-238. Geology is the most important factor controlling the source and distribution of radon gas in Abu Rushied area. Field and laboratory techniques for radon gas concentrations are established by CR-39 detector. In the field, Radon gas concentrations are ranged from 138.72 to 2610.09 with an average 802.7522 (Bq/m$^3$), while it ranged from 44354 to 1485 with average 8869(Bq/m$^3$) in the laboratory. The activity concentration of Radium-226 ($Ra^{226}$), Radon mass, surface exhalation rate and annual absorbed dose equivalent were measured. The main geological factors with moderate to high radon areas are described in 3D maps. The most analyzed trace elements of the studied granitic gneisses show positive correlation with Uranium content, indicating a strong relation between these elements and their U-bearing minerals. The highest radon gas concentrations in Abu Rushied area are associated with U-rich minerals. Elevated radon gas in the studied area is also increase with the fractures and other tectonic events which play a role in radon emanation.*

**Keywords**: *U-238, Radon gas, Exhalation rate, Annual effective dose, Granitic gneisses, Geological factors.*

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## I. INTRODUCTION

Because of its longer half-life, Radon gas ($Rn^{222}$) can relocate from soil and rocks to environment air before emitting a high energy alpha particle of 5.49 MeV [1]. Radon and its short-lived decay products are the most important contributors to human exposure to ionizing radiation from natural sources. This contribution represents 50% of the total dose [2].

The fraction of radon atoms that achieve the interstitial space face two processes, diffusion and transport mechanisms within the soil, which depends on the type of soil, its moisture content and the underlying geological conditions or factors. The process which happen to the flow of soil gas due to concentration gradient called diffusion and it described by Fickˈs law, while The process which happen due to pressure driven flow of soil gases and it described by Darcyˈs law [3].

The main processes that happen to radon after creation are emanation, migration and exhalation. Migration happen to unsaturated rock and soils by diffusion once it escapes to interstitial space and it follows by concentration gradient until reach up to the surface [4]. The radon move by transport mechanism but it depend on geological factors, like number fracturing or disturbance, transport is that radon dissolved in water and move with it [5].

Geology is the important factor controlling the source and distribution of radon gas. High levels of radon gas are associated with some bedrock and stream deposits such as granites, limestone, phosphatic rocks, and shales rich in organic materials [6]. The radon gas emissions from rocks and soils are controlled by the type of

 Received- 10-03-2021, Accepted- 02-05-2021

minerals in which uranium and thorium occur. In magmas, the large highly charged $U^{4+}$ ion becomes concentrated in late-stage differentiates, often in accessory minerals such as zircon and allanite. In sedimentary rocks, phosphates and organic complexes may be more important source for *uranium.*

## II. GEOLOGIC SETTING

Granitic gneisses at Abu Rushied area represent the oldest rocks exposed in this area, which formerly identified as psammitic gneisses and cataclastic rocks [7]; [8]. Abu Rusheid area is located in the Southeastern Desert of Egypt at about 45km southwest of Marsa Alam City between latitudes 24° 37′ 43" – 24° 38′ 26"N and longitudes 34° 46′ 00"– 34°46′ 35"E (Fig. 1A). It is located between a major thrust to the NE and a minor one to the SW. The rocks from oldest to youngest that exposed (Fig. 1B) in the study area are grouped as follow;

1. Granitic gneisses
2. Ophiolitic rocks (Ophiolitic mélange)
3. Intrusive rocks (Post granitic dykes and veins, Two-mica granite, and Biotite granite)

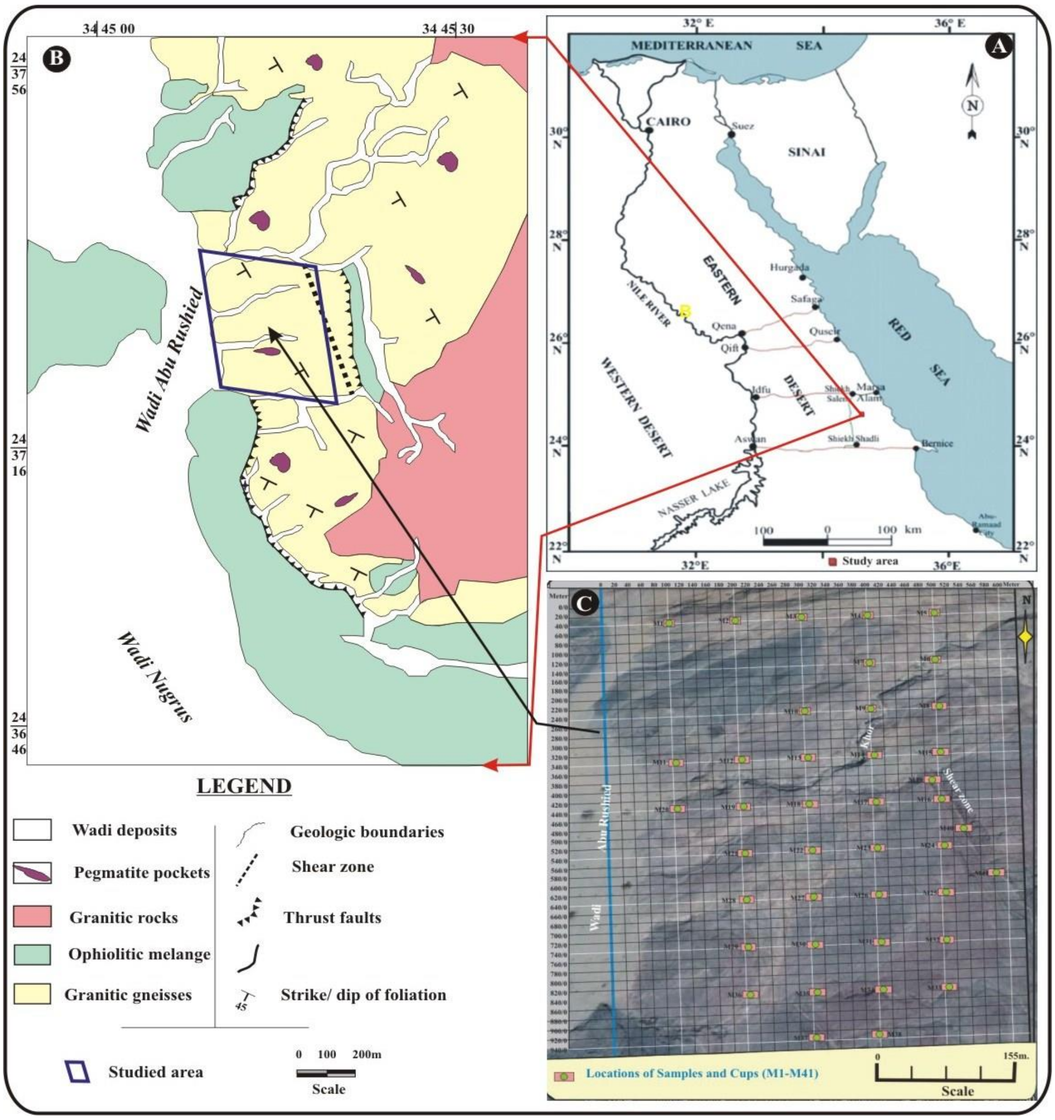


**Fig. (1): A) location map, B) Geologic map, C) and location map of samples and cup (CR), at Abu Rusheid area, South Eastern Desert, Egypt.**

Abu Rushied granitic gneisses display a range of radon potential values that relate to their age, composition and magma history. The highest radon potential values are associated with the visible uranium mineralization (Fig. 2), notably those clustered within a shear zone. The studied area consists of granitic gneisses in which the incompatible elements *U* and *Th* have become unusually highly concentrated in a range of accessory minerals, including uraninite, monazite, zircon, allanite and apatite [8]. Abu Rushied granitic gneisses also show high *U* values which are attributable to U-mineralization, and displays one of the highest radon potentials in the surrounding rocks. High-thorium uraninites and other chemically resistant minerals that are more resistant to weathering are liberate less/more radon from the parent rock, where the weathering histories of Abu Rushied area that affect the rate of release of radon. The studied area was not covered by any other rocks and exposed to multistage tectonized events (Fig. 3), which lead to permit the free migration of radon gas. Composition of the studied rock also plays a role, for example, if mineral grains of uranium-rich granites are included in superficial material, they will lead to high radon emanation.

**Fig. (2):Visible Uranium mineralization at Abu Rushied area**

**Fig. (3):Tectonic features at Abu Rushied area**

## III. RESULTS AND DISCUSSION

The studied area is divided into 41stations named M1-M41based on surveying net established by Abu Rushied project team with grid (100m x100m). Sampling and CR-39 detector are taken from these stations (Fig.1C).

**3.1-Radon gas concentration using SSNTDs**

**In the field** of the study area, each station has a solid state nuclear track detectors of CR-39 were mounted in the internal bottom of cylindrical plastic cup. The lid of each cup is punched with a hole, covered with thin piece of filter as in figure (4). After exposure period (7days), the CR-39 detectors were removed, and then etched using 6.25N NaOH under controlled conditions of temperature (70°C) and time (8hour). The detectors then washed many times by distill water and dried with tissue papers. The tracks developed in this way, were then counted by an optical microscope of 400X. The dosimeters are deployed at 41stations in the studied area.

**Fig (4): Cup technique in the field**

**In the laboratory**, forty-one samples were collected from the studied area, weighted and packed in stainless steel container, which has a volume of V=0.0005137m$^3$, area A=0.004778m$^2$ and height 0.103m as shown in figure (5). The CR-39 detector put in the top of the container and the samples were sealed well and stored for 30days. At the end of the exposure time, the radon detectors were collected, and then treated as mention before.

A Solid State Nuclear Track Detector (SSNTD) of CR-39 type was used to determine the radon concentration as well as exhalation rate measurements. The sensitive lower surface of the detector is freely exposed to the radon produced by free emanation from the sample within the container. So that it could record alpha particles resulting from the decay of radon in the remaining volume of the container and from $^{218}$Po and $^{214}$Po deposited onto its inner walls.

**Fig. (5): The cup technique used in the laboratory**

The equations used to calculate the radon gas measurements are as follows:
The value of radon concentration ($Bqm^{-3}$) at secular equilibrium is given by the equation [9];

$$C_{Rn} = \frac{\rho}{KT} \quad (1)$$

Where, $C_{Rn}$ is the radon concentration ($Bqm^{-3}$), $\rho$ is the track density (track $cm^{-2}$), $T$ is the exposure time (day) and $K$ is the calibration coefficient of CR-39 nuclear track detectors obtained from the experimental calibration 0.22 tracks. $cm^{-2}day^{-1}$/B. $qm^{-3}$ of radon.
The radium concentrations in the studied area were calculated using the following relation[10]:

$$C_{Ra} = \frac{\rho hA}{KMT} \quad (2)$$

Where $C_{Ra}$ is the radium content in ($Bqkg^{-1}$), $h$ is the distance between the detector and the top of sample, $A$ is the area of cross section of the can and $T$ is the effective exposure time (hr).
Radon exhalation rate from different samples was calculated as the following relations [11]:

$$E_{A} = \frac{CV\lambda}{A\left[T+\frac{1}{\lambda}(e^{-\lambda t}-1)\right]} \quad (3)$$

Where, $E_A$ is the surface exhalation rate in ($Bqm^{-2}h^{-1}$), $C$ is the integrated radon exposure in ($Bqm^{-3}h$), $\lambda$ is the decay constant of radon ($h^{-1}$), $V$ is the effective volume of the can ($m^3$), $A$ is the area covered by the can ($m^2$) and $T$ is the exposure time.

$$E_{M} = \frac{CV\lambda}{M\left[T+\frac{1}{\lambda}(e^{-\lambda t}-1)\right]} \quad (4)$$

Where, $E_M$ is the mass exhalation rate ($Bqkg^{-1}h^{-1}$) and $M$ is the mass of sample (kg) [11]; [12].
The annual absorbed dose equivalent due to the activity in the soil was calculated using the following equation:

$$D_{Rn} = C_{Rn} \cdot D \cdot H \cdot F \cdot T \quad (5)$$

Where, $C_{Rn}$ ($Bqm^{-3}$) is the measured radon activity concentration in air, $F$ (0.2) is the equilibrium factor. $T$ is the occupancy time (8760 hr), $H$ is the outdoor occupancy factor (0.2) and $D$ is the dose conversion factor ($9\times10^{-6}$ mSv $h^{-1}$ / $Bqm^{-3}$) [13].

Table (1), show the values of track/$cm^2$/day and radon gas concentration (Bq/$m^3$) measured in the field by cups methods. The radon concentration ranged between 138.72 to 2610 with an average 802.72 Bq/$m^3$. It is clear from table (1) that, radon concentrations in the studied samples which measured in the laboratory vary from 1485 to 44354 Bq/$m^3$ with an average 8869 Bq/$m^3$. Radium activity varies from 3.29 to 94.09 Bq/Kg with an average 17.55Bq/Kg. Radon exhalation rate in the studied samples varies from 1.2 to 36.2 Bq/$m^2$/h with an average 7.25 Bq/$m^2$/h. Radon exhalation rate in term of mass varies from 0.746 to 0.026 Bq/Kg/h with an average 0.139 Bq/Kg/h. The value of the radium content is found to be maximum in the shear zone samples (M-39, M-40 and M-41) and minimum in sample (M-37). The values of radium activity determined in the studied samples are less than the permissible value of 370 Bq/kg. The annual effective dose larger than the normal background level of 5 mSvy-1 for public and 20 $mSvy^{-1}$ for worker, as quoted by [2].
The Correlation between $Ra^{226}$ activity (Bq $kg^{-1}$) with radon surface and mass exhalation rate is very strong ($R^2$ = 0.99) and ($R^2$ = 1) as shown in (Figs. 6 & 7).

The comparison between the Values of radon concentrations in the field and the laboratory is shown in table (1). The ratio between field values and laboratory values was varied from 0.013 to 0.9549. There is a poor correlation (0.38) between radon gas concentrations in the field and in laboratory (Fig. 8), indicating that the geological factors which effect on radon gas emanation are dominate, due to ventilation process.

**Table (1):** Values of track/cm$^2$/day, activity concentration of $Rn^{222}$ (Bq/m$^3$), Rn ratio, $Ra^{226}$ (Bq/kg), radon surface and mass exhalation rates and annual absorbed dose equivalent for the studied samples in the field and laboratory. at Abu Rushied area.

| S.No. | In the Field | | | In the Lab. | | | | |
|---|---|---|---|---|---|---|---|---|
| | Track cm$^2$/day | Rn (Bq/m$^3$) | Rn ratio Field/Lab. | $C_{Rn}$ (Bq/m$^3$) | $C_{Ra}$ (Bq/kg) | $E_A$ (Bq/m$^2$/h) | $E_M$ (Bq/kg/h) | $D_{Rn}$ (mSv/y) |
| M-1 | 10223.62 | 461.15 | 0.0328 | 14069 | 26.73 | 11.5 | 0.212 | 88.73 |
| M-2 | 17277.99 | 779.34 | 0.0463 | 16831 | 32.74 | 13.8 | 0.260 | 106.16 |
| M-3 | 28841.43 | 1436.86 | 0.1380 | 10413 | 20.02 | 8.5 | 0.159 | 65.67 |
| M-4 | 18146.72 | 818.53 | 0.1061 | 7718 | 15.76 | 6.3 | 0.125 | 48.68 |
| M-5 | 8493.21 | 285.98 | 0.0311 | 9185 | 18.68 | 7.5 | 0.148 | 38.62 |
| M-6 | 16674.71 | 752.13 | 0.2385 | 3154 | 5.81 | 2.6 | 0.046 | 13.26 |
| M-7 | 5027.16 | 455.29 | 0.0701 | 6494 | 12.89 | 5.3 | 0.102 | 27.31 |
| M-8 | 16301.79 | 752.67 | 0.0915 | 8229 | 16.40 | 6.7 | 0.130 | 34.60 |
| M-9 | 17131.42 | 798.62 | 0.1353 | 5903 | 12.69 | 4.8 | 0.101 | 24.82 |
| M-10 | 19023.49 | 858.07 | 0.1823 | 4708 | 8.95 | 3.8 | 0.071 | 19.80 |
| M-11 | 6039.71 | 272.43 | 0.0218 | 12498 | 23.84 | 10.2 | 0.189 | 52.55 |
| M-12 | 12177.23 | 549.27 | 0.1037 | 5298 | 10.56 | 4.3 | 0.084 | 22.28 |
| M-13 | 16686.78 | 772.73 | 0.3028 | 2552 | 4.93 | 2.1 | 0.039 | 10.73 |
| M-14 | 27625.48 | 1246.07 | 0.1871 | 6661 | 13.16 | 5.4 | 0.104 | 28.01 |
| M-15 | 10591.33 | 474.48 | 0.0789 | 6012 | 11.12 | 4.9 | 0.088 | 25.28 |
| M-16 | 15722.87 | 709.2 | 0.0554 | 12798 | 23.41 | 10.5 | 0.186 | 53.81 |
| M-17 | 14509.15 | 654.45 | 0.2832 | 2311 | 4.66 | 1.9 | 0.037 | 9.72 |
| M-18 | 14330.07 | 666.8 | 0.1581 | 4218 | 8.44 | 3.4 | 0.067 | 17.74 |
| M-19 | 6364.02 | 273.54 | 0.0305 | 8980 | 17.40 | 7.3 | 0.138 | 37.76 |
| M-20 | 16859.46 | 751.02 | 0.1147 | 6546 | 12.63 | 5.3 | 0.100 | 27.53 |
| M-21 | 18891.25 | 982.6 | 0.1304 | 7533 | 15.38 | 6.2 | 0.122 | 31.67 |
| M-22 | 14025.39 | 651.81 | 0.0974 | 6690 | 13.95 | 5.5 | 0.111 | 28.13 |
| M-23 | 23866.52 | 1151.01 | 0.2915 | 3949 | 7.39 | 3.2 | 0.059 | 16.61 |
| M-24 | 19452.77 | 903.06 | 0.1246 | 7250 | 14.81 | 5.9 | 0.117 | 30.49 |
| M-25 | 19650.08 | 913.07 | 0.1646 | 5548 | 11.57 | 4.5 | 0.092 | 23.33 |
| M-26 | 11010.03 | 496.62 | 0.1194 | 4159 | 8.15 | 3.4 | 0.065 | 17.49 |
| M-27 | 10629.93 | 480.98 | 0.0529 | 9085 | 16.87 | 7.4 | 0.134 | 38.20 |
| M-28 | 5951.58 | 249.04 | 0.0202 | 12344 | 23.37 | 10.1 | 0.185 | 51.90 |
| M-29 | 15513.88 | 699.77 | 0.0853 | 8201 | 16.02 | 6.7 | 0.127 | 34.48 |
| M-30 | 18191.19 | 802.49 | 0.1135 | 7068 | 12.79 | 5.8 | 0.101 | 29.72 |
| M-31 | 13291.51 | 599.53 | 0.1134 | 5285 | 10.28 | 4.3 | 0.082 | 22.22 |
| M-32 | 18634.65 | 817.98 | 0.1949 | 4197 | 8.33 | 3.4 | 0.066 | 17.65 |
| M-33 | 6959.02 | 305.31 | 0.0334 | 9133 | 16.96 | 7.5 | 0.135 | 38.40 |
| M-34 | 3075.33 | 138.72 | 0.0128 | 10852 | 18.94 | 8.9 | 0.150 | 45.63 |
| M-35 | 18512.76 | 806.27 | 0.1030 | 7825 | 15.85 | 6.4 | 0.126 | 32.90 |
| M-36 | 12219.04 | 532.48 | 0.2570 | 2072 | 4.68 | 1.7 | 0.037 | 8.71 |
| M-37 | 3256.79 | 1418.01 | 0.9549 | 1485 | 3.29 | 1.2 | 0.026 | 6.24 |
| M-38 | 9585.07 | 432.36 | 0.0996 | 4336 | 9.00 | 3.5 | 0.071 | 18.23 |
| M-39 | 59946.79 | 2610.09 | 0.0738 | 44354 | 94.09 | 36.2 | 0.746 | 186.50 |
| M-40 | 58384.96 | 2542.67 | 0.0845 | 32086 | 63.93 | 26.2 | 0.507 | 134.92 |
| M-41 | 36978.67 | 1610.34 | 0.1032 | 15607 | 33.25 | 12.8 | 0.264 | 65.63 |

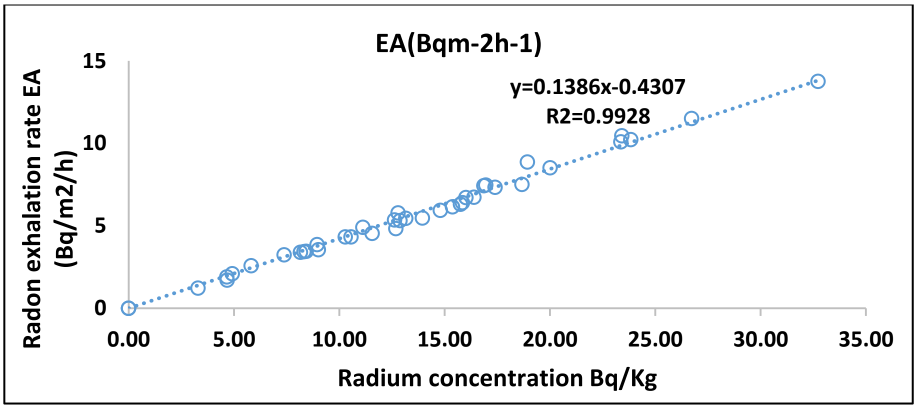


Fig. (6): Correlation between activity of Ra-226 and radon surface exhalation rate ($E_A$ ) in all Studied samples at Abu Rushied area.

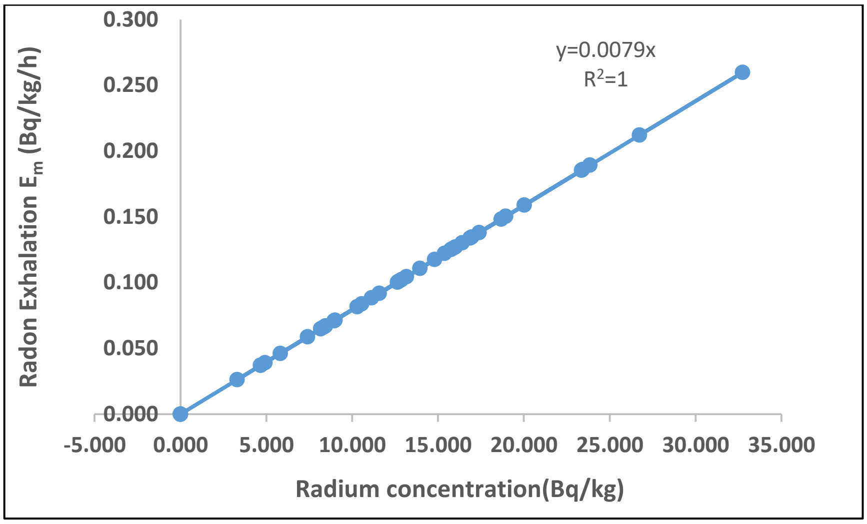


Fig. (7): Correlation between activity of $Ra^{226}$ and radon mass exhalation rate ($E_m$) in all Studied samples at Abu Rushied area.

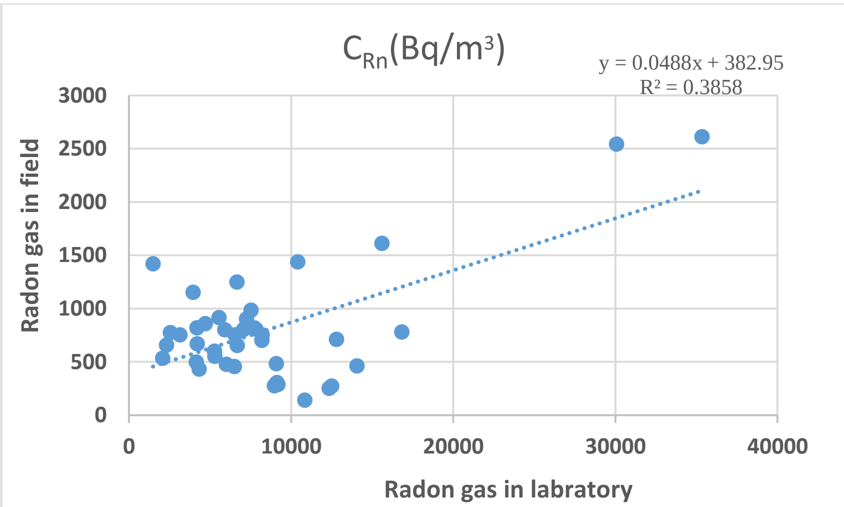


Fig. (8): The ratio of Radon concentration in the field and in laboratory for all Studied samples at Abu Rushied area.

Three maps (3D) (Fig. 9), illustrate the radon gas distribution in the studied area as follows; in the field, the highest concentrations are in the east part (red color) which ranged from 1600 to 2400 Bq/m$^3$ represented a wide range covered a small area relative to the whole studied area. The green color represents the area which has high to moderate concentrations ranged from 1000 to 1500 Bq/m$^3$. The majority of the studied area (blue color) varies from 200 to 900 Bq/m3 which represent low concentrations of radon gas. In the laboratory, the highest concentrations are in the east part (red color) which ranged from 30000 to 40000 Bq/m$^3$ represent a narrow range covered small area. The green color represents the area which has high to moderate concentrations ranged from 16000 to 28000 Bq/m3. The majority of studied area (blue color) varies from 2000 to 14000 Bq/m$^3$ which represent moderate concentration of radon gas. This means that, the area (red and blue) the high anomaly of U- mineralization.

There is a difference between the concentrations of radon gas in the field and in laboratory due to the open system, fractures, permeability of the mineral grains and mass effect are found in the field than the laboratory.

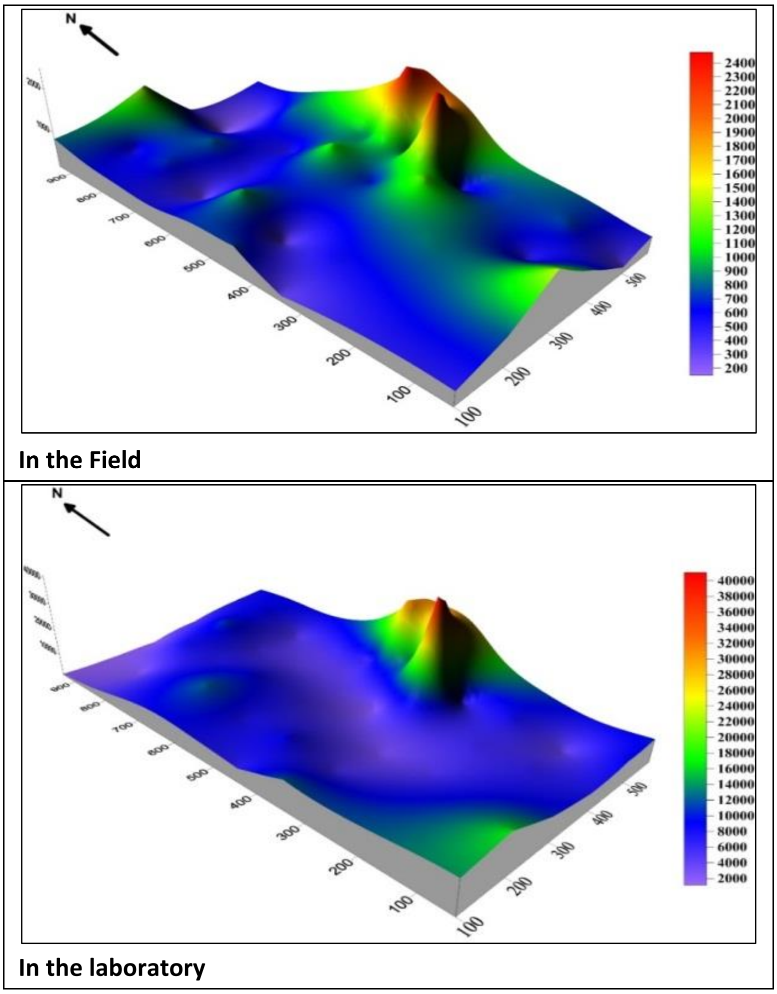


**Fig. (9): 3D maps of Rn concentration in the field and in lab. (Bq/m$^3$) of the studied area.**

**Trace elements geochemistry**

The X-ray fluorescence technique was used to determine the trace element contents for the granitic rocks using PHILIPS X'Unique-II spectrometer with automatic sample changer PW 1510, (30 positions). The trace elements concentrations are calculated from the program's calibration curves which were set up according to international reference materials (standards) as G-2 and GSP-1. Forty-one studied samples were examined to recognize some elements forming important minerals (Table 2 & Fig. 10).

**Table (2): Chemical analysis of trace elements in granitic gneisses at Abu Rushied area**

| | U | Th | Cu | Ni | Zn | Zr | Sr | Y | Rb | V | Nb | Pb |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Min.** | 16 | 10 | 3 | 2 | 22 | 73 | 149 | 30 | 9 | 2 | 5 | 23 |
| **Max.** | 311 | 285 | 320 | 98 | 5732 | 3299 | 4761 | 1227 | 1947 | 302 | 166 | 1214 |
| **Aver.** | 78.9 | 174.3 | 66.6 | 11.1 | 485.9 | 1609 | 2338 | 118.8 | 990 | 21.9 | 81.6 | 328.6 |

**Min.**: Minimum value **Max.**: Maximum value **Aver.**: Average value of 41samples

-Uranium (U) shows a positive correlation with Cu (0.7), Zn (0.7), Y (0.7), and Pb (0.7), while it shows a negative correlation with Zr (-0.1), Nb (-0.1) and Th (-0.2).

-Thorium (Th) shows a weak correlation with Zr (0.3) and Nb (0.3), while it shows a negative correlation with Cu (-0.1), Zn (-0.2), Y (-0.3) and Pb (-0.4).

-Some other trace elements like *Ni* and *V*, are observed to be lower than their respective background value, so it can be inferred that such elements are depleted in the studied area.

-It can be observed from the positive correlation between some trace elements and uranium that the very strong correlation indicating that the trace element constituents are governed by the same geochemical factors and are from the same source.

-The selected samples have high to moderate uranium content, and it is probable that some, or all, of the above-cited metallic elements that have an apparent positive relation to the uranium content of the samples were deposited contemporaneously with the uranium.

Most importantly U as the source of radon; in addition, potassium (K), yttrium (Y), zirconium (Zr), rubidium (Rb) and strontium (Sr) are considered as they can be used to assess whether U is likely to be non-labile in resistant minerals, and for the identification of evolved, highly fractionated granite plutons, which may be associated with a high radon potential.

According to the trace elements data and the previous mineralogical studies which have been performed upon granitic gneiss (cataclastic rocks) at Abu Rusheid area [8], it is interesting to give a brief account about some important minerals.

1-Uranium mineralizations: uranophane to beta-uranophane ($CaO.2UO_3.2SiO_2.6H_2O$), kasolite [Pb ($UO_2$) ($SiO_3$) $(OH)_2$], torbernite [Cu $(UO_2)_2(PO_4)_2$-8-12$H_2O$], autunite and meta-autunite [Ca $(UO_2)_2$ $(PO_4)_2$.8-12$H_2O$] &[Ca$(UO_2)_2$ $(PO_4)_2$.4-6 $H_2O$] are common in Abu Rusheid area.

2- Thorium minerals: Thorite ($ThSiO_4$) and Thorianite [Th, U, Ce) $SiO_4$]

3-U-bearing minerals: Astrocyanite (Ce)[$Cu_2(RE)_2(UO_2)$ $(CO_3)_5(OH)_2$.1.5$H_2O$], Betafite [(Ca, Na, U) (Nb, Ta) $_2O_6$.n$H_2O$], Fergusonite (Nb, Y, Ta, U, Al, Mg, REE).

4-Columbite -Tantalite Minerals: Columbite [(Fe,Mn) $(Nb,Ta)_2O_6$],Tantalite[(Fe, Mn) $(Ta, Nb)_2O_6$].

5-Base metals:Tin ($SnO_2$),Zinc–Manganese Minerals ($Zn,Mn^{+2},Fe^{+2}$)($Fe^{+3},Mn^{+3}$)$_2O_4$

6-Associated minerals: Fluorite ($CaF_2$), Xenotime ($YPO_4$), Zircon ($ZrSiO_4$), Allanite [Ce, Ca, Y) (Al, Fe)$_3(SiO_4)_3$.OH], Monazite [(Ce, La) $PO_4$]

The deposits in granitic gneiss at Abu Rushied area are particularly rich in monazite. Monazite is radioactive due to the presence of thorium and less commonly uranium. Because of its radioactive nature, monazite is used for monazite geochronology to study geological events, such as crystallization, heating, or deformation of the rocks containing monazite.

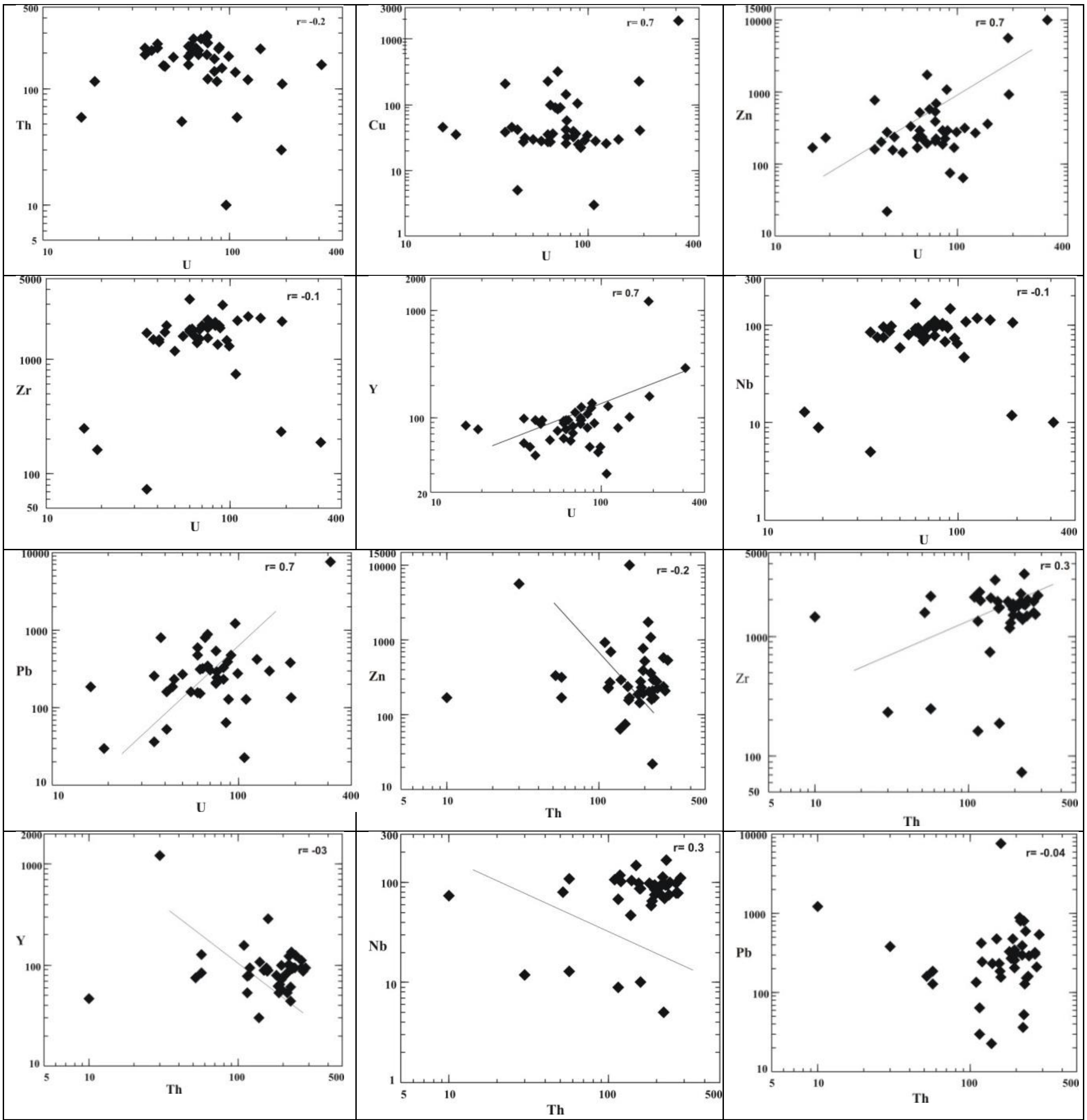


**Fig. (10): Binary Diagrams illustrate the relation of U and Th with some trace elements of granitic gneisses at Abu Rushied area.**

## IV. CONCLUSION

In the Studied area, radon gas concentrations can be explained by the mapped bedrocks and surface geology. From the field measurements, the radon gas concentrations ranged from 138.72 to 2610.09 with an average 802.7522 (Bq/m$^3$). From laboratory measurements, the radon gas concentrations ranged from 44354 to 1485 with an average 8869 (Bq/m$^3$).

Radium activity varies from 3.29 to 94.09 Bq/Kg. Radon exhalation rate in the samples in terms of area varies from 36.2 to 1.2 Bq/m$^2$/h. Radon exhalation rate in the samples in terms of mass varies from 0.746 to 0.026 Bq/Kg/h. The value of the radium content is found to be a maximum in the shear zone samples.

The values of radium activity determined in samples are less than the permissible value of 370 Bq/kg.

The role of the main geological and geochemical (trace elements) factors which effect on radon gas concentrations revealed that:

1) Most analyzed trace elements correlate strongly with U, indicating the influence of granitic or acid metamorphic source components on the studied granitic gneiss.
2) The highest radon gas concentrations are associated with high values of U in the east part of the studied area.
3) The high tectonized area and the leachable of some secondary uranium minerals that permit efficient to release of radon gas.
4) Abu Rushied granitic gneiss have a moderate to high radon gas concentrations that decrease progressively from the NE to SW direction, suggesting a lateral variation in composition and U-mineralization.

Therefore, we conclude that the studied area at Wadi Abu Rushied has a high content of uranium minerals and radon gas concentrations which cause unusual health hazards to workers.

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