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Investigating Radon Levels in Granite: Implications for Health and Safety

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Abstract: This study investigates radon concentration and radon exhalation rates in granite rock samples from the Eastern Desert of Egypt, utilizing the Alpha GUARD measurement system. We assessed radon levels in terms of both area (Bq/m²) and mass (Bq/kg), providing a comprehensive analysis of radon emissions from these geological materials. Additionally, we calculated the annual effective doses associated with radon exposure, highlighting the potential health risks for populations in proximity to granite formations. Our findings contribute to a better understanding of radon behavior in granite rocks and underscore the importance of continuous monitoring, especially in radon-prone regions. The results of the study have revealed that the values obtained for the studied samples are higher than the internationally accepted recommended values. Finally, it can be concluded, from the obtained results that causes high risk to humans and cannot used as a safe source in manufacturing the building materials.

Keywords: Granite- Radom - Alpha GUARD- Annual Effective Doses.

1 Introduction

Exposure to radiation from naturally occurring Radon is an odorless, colorless, inert gas with isotopes of relatively short half-lives, there are no chemical or mass spectrometric techniques with sufficient sensitivity to measure it. Consequently, it must be determined using techniques that depend on the radioactive properties either of radon itself or its decay products. The radon gas is created as the first disintegration product of ^{226}Ra. There are three radon (Rn) isotopes naturally present in the environment: ^{222}Rn, a member of the uranium decay series, ^{220}Rn, a member of the thorium decay series, and ^{219}Rn, a member of the actinium decay series. ^{220}Rn and ^{219}Rn are often referred to as thoron and actinon, respectively [1].

Beings are exposed to radon in two ways, either through inhalation, or ingestion. Radon can enter into the indoor environment of our houses through cracks and openings in the floor and walls. Groundwater constitutes an additional source of delivery of radon to the indoor environment. Radon and its short-lived decay products like ^{218}Po, ^{214}Po, and ^{214}Bi, etc. at indoor places have been pointed out to be the major sources of public exposure from the natural radioactivity, contributing to almost 50% of the worldwide mean effective dose to the community [2-3], when inhaled they emit alpha particles, which can cause damages to human tissues and organs. Everybody has significant amounts of radiation that develop according to their exposure to NORM. Radon isotopes escape from the mineral to the air when the radium decays in soil. The radon exhalation rate is known by the rate at which radon escapes from the soil into the surrounding air [4], and it can be measured per surface unit area or unit mass of soil. Long-term radiation exposure can cause harmful health effects, such as chronic lung diseases, anemia, and different cancers [5]. The emanation of radon (^{222}Rn), and α-radioactive gas, is associated with the presence of radium. The inhalation of radon and the short-lived daughter products arising from its decay exposes the subjects.

Emanation, migration, and exhalation are the three basic phases that radon goes through when it is created.

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When unsaturated rock and soils escape to interstitial space, they migrate through diffusion and follow a concentration gradient until they reach the surface. The movement of radon is caused by a transport mechanism, which is dependent on geological conditions such as number fracturing or disturbance, transport is when radon is dissolved in water and moves with it, the process is called migration [6, 7]. The radon exhalation rate is known by the rate at which radon escapes from the soil into the surrounding air [4, 8]. The inhalation of radon and the short-lived daughter products to which it decays is a major contributor to the total radiation dose to exposed subjects that may cause lung cancer.

The present work studies the radioactivity of granites in the Gable Gattar U prospect, which is located in the northeastern desert of Egypt. The Gable Gattar uranium prospect is located 35km to the west of El-Hurghada city on the Red Sea coast. It appears that Gable Gattar granite, from its uranium mineralization, has high economic potential. Gable Gattar granite is the host rock for U mineralization including seven uranium mineralization occurrences, GI–GVII [9,10]. The present study of radioactivity establishes a baseline map of radioactivity background levels in Gable Gattar II and also will be used to assess any changes in the radioactive background level due to geological processes.

The present work aims to measure the concentrations of (^{222}Rn), radiological hazards for populations in granite rock samples collected from Gabal Gatar II, Eastern Desert, Egypt. The data obtained in this study may be useful for natural radioactivity mapping and also be used as reference data for monitoring possible radioactivity pollution in the future.

2 Experimental Section

The ^{222}Rn activity concentration was measured using a radon monitoring system (Alpha GUARD PQ 2000 PRO). The Alpha GUARD is a measuring system for the continuous determination of radon- and radon progeny concentration in air as well as selected climatic parameters. During operation, this detector measures air radiation by dispersing the gas through a large glass filter area installed in the ionization chamber. It is compatible with continuous radon steps and has a measurement speed of 2.0–2.0 × 10^6 Bq m^{-3} [11].

Three hundred grams of the sample was placed in a container. The instrument is connected to a modeling device via an alpha pump; and placed in a continuous flow of 0.1 L min^{-1}. The Alpha GUARD monitor was in “flow” mode, and radon concentrations were recorded every 10 min for 1 h. Before measurement, a radon (^{222}Rn) measuring device was placed in this vessel, measured, and repeated several times to get the exact order. The background noise is subtracted from the concentration of ^{222}Rn in each sample [12]. Radon concentrations using the Alpha GUARD detector are between 2 and 2 000 000 Bq m^{-3}.

2.1 Radon Activity Concentration

The radon gas exposure shows extreme variation from one location to the other depending primarily on the exhalation rate from the rocks. The presence of radium in the rocks is the main source of indoor radon, therefore radium content measurement along with radon exhalation rate were carried out. The equilibrium concentration of radon Ceq for each sample (saturated constant concentration of radon in the room, which

$$C_{Rn} = C_{eq}(1 - \exp(-\lambda \times t)) \quad (1)$$

Where C_{Rn}, radon concentration measured at time t (Bq m^{-3}); t, the accumulation time of the released radon from a sample; and C_{eq}, radon concentration equilibrium (Bq m^{-3}) [12].

2.2 Radiological parameter estimation

The concentration of radon in the open atmosphere is governed by the source term, characterized by the exhalation rate. The transportation of Radon through the pores and then exhaled into the atmosphere is called" **exhalation**". By separating the radon exhalation rate by either the area of the exhaling surfaces or by the mass of the sample, the area (radon flux Bq/ m^2s) and mass radon exhalation rates (Bq/kgs) can be calculated. The radon surface exhalation rate and mass exhalation rate for any sample, E_a and E_m were calculated using the following:

$$E_a = \frac{Ceq \times \lambda \times V}{S} \quad (2)$$

$$E_m = \frac{Ceq \times \lambda \times V}{M} \quad (3)$$

Where V is the volume of the radon chamber, λ is the decay constant of radon (2.1 ×10^{-6}) s^{-1}, S is the total surface area of the sample surface, and M is the sample weight(kg)[12]. The process of ^{222}Rn escaping into the pore space is called emanation, the fraction of radon atoms generated that escape the solid phase in which they are formed and become free to migrate through the bulk medium is called the emanation coefficient. The emanation coefficient is calculated by:

$$F = \frac{Ceq \times V}{A_{RA} \times M} \quad (4)$$

Where f is the emanation coefficient of radon, A_{Ra} is the concentration of radium measured using HPGe detector (Bq kg^{-1}), and V is the gas empty volume (volume of chamber minus the sample volume, m^3).

The Annual Effective Dose Equivalent was calculated from the concentration of radon using UNSCEAR recommended conversion factor of 9 nSv (Bq h m^{-3})$^{-1}$ [3]. Assuming 7000 h $year^{-1}$ indoors and an equilibrium coefficient of 0.4 indoors, the effective dose for radon exposure during 1 year is calculated from [13]:

$$AEDE = \epsilon \times f_{Rn} \times T \times C_{eq} \quad (5)$$

Where, f_{Rn} is the conversion factor, T is the time spent indoors per year, ϵ is the equilibrium factor, and C_{eq} is the radon concentration.

3 Results and Discussion

The measurements of surface radon concentration, emanation coefficient, mass radon exhalation rate, and annual effective dose are listed in Table 1

Table 1: The radon concentration, surface and mass radon exhalation rate, and radon emanation coefficient.

	Radon concentration (Bq/m^3)	Surface exhalation rate(E_a) ($Bq/m^{-2}.h^{-1}$)	Mass exhalation rate(E_m) (Bq/kg^{-1} h^{-1})	radon emanation coefficient (f)	AED_{tot}
S1	6181±486	0.001±0.0002	0.00003±0.000004	0.0002±0.00007	389
S2	5410 ±430	0.003±0.0006	0.00003±0.000004	0.0001±0.00006	340
S3	46853±2758	0.03±0.004	0.0002±0.00003	0.001±0.0005	29518
S4	19774±1270	0.01±0.002	0.00009±0.00001	0.001±0.0003	1245
S5	40585 ±2503	0.02±0.004	0.0001±0.00002	0.002±0.0008	2556
S6	27204±1704	0.01±0.002	0.0001±0.00001	0.001±0.0004	17136
S7	22104±1415	0.01±0.002	0.0001±0.00001	0.0002±0.0001	1392
S8	48855±2920	0.03±0.005	0.0002±0.00003	0.004±0.001	3077
S9	29492±1861	0.02±0.003	0.0001±0.00002	0.003±0.001	1858
S10	37487±2404	0.02±0.003	0.0001±0.00002	0.003±0.001	2361
S11	15991±1224	0.01±0.001	0.00008±0.00001	0.001±0.0006	1007
S12	28884 ±1978	0.02±0.003	0.0001±0.00002	0.004±0.001	1819
S13	13453±1166	0.009±0.001	0.00006±0.00001	0.005±0.002	847
S14	15496±1307	0.01±0.001	0.00007±0.00001	0.005±0.001	976
S15	10390±890	0.007±0.001	0.00005±0.000008	0.001±0.0006	654
S16	12428±1282	0.009±0.001	0.00006±0.00001	0.001±0.0005	782
S17	11677±1054	0.008±0.003	0.00006±0.000009	0.001±0.0007	735
S18	9711±923	0.007±0.001	0.00005±0.000007	0.001±0.0006	611
S19	6318 ±650	0.004±0.0007	0.00003±0.000005	0.01±0.005	398
S20	11826±1008	0.008±0.001	0.00006±0.000009	0.02±0.008	745
S21	5257±585	0.003±0.00066	0.00003±0.000004	0.001±0.0004	331
S22	6991 ±722	0.005±0.0008	0.00003±0.000006	0.001±0.0004	440
S23	11957±971	0.008±0.001	0.00006±0.000009	0.001±0.00007	753
S24	10366±888	0.007±0.001	0.00005±0.000008	0.0004±0.0001	653
S25	36617 ±2259	0.02±0.003	0.0001±0.00002	0.001±0.0006	2306
S26	43076 ±2458	0.03±0.004	0.0002±0.00002	0.004±0.001	2713

S27	21591 ±1497	0.01±0.002	0.0001±0.00001	0.002±0.0008	1360
S28	67492±4486	0.04±0.007	0.0003±0.00004	0.006±0.002	4252
S29	51929 ±2863	0.03±0.005	0.0002±0.00003	0.08±0.03	3271
S30	47854±3358	0.03±0.005	0.0002±0.00003	0.06±0.02	3014
S31	36725±2262	0.02±0.003	0.0001±0.00002	0.0008±0.0003	2313
S32	32542±1920	0.02±0.003	0.0001±0.00002	0.0006±0.0002	2050
S33	67337 ±3847	0.04±0.007	0.0003±0.00004	0.001±0.0005	4242
S34	80218 ±4526	0.05±0.008	0.0003±0.00005	0.001±0.0005	5053
S35	976156 ±6717	0.07±0.01	0.0004±0.00006	0.02±0.007	6149
S36	104669±6976	0.07±0.01	0.0005±0.00007	0.03±0.01	6594
S37	53478±3956	0.03±0.005	0.0002±0.00003	0.4±0.1	3369
S38	46519±3480	0.03±0.005	0.0002±0.00003	0.2±0.07	2930
S39	38262±2774	0.02±0.004	0.00018±0.00002	0.009±0.003	2410
S40	23748±1732	0.01±0.002	0.0001±0.00001	0.005±0.002	1496
S41	1954±209	0.001±0.0002	0.00001±0.000002	0.0002±0.0001	123
S42	5457 ±515	0.004±0.0006	0.00003±0.000004	0.001±0.0004	343
S43	6613±590	0.004±0.0007	0.00003±0.000005	0.0007±0.0002	416
S44	30099 ±1896	0.02±0.003	0.0001±0.00002	0.004±0.001	1896
S45	33871±2372	0.02±0.003	0.0001±0.00002	0.003±0.001	21338
S46	8216 ±754	0.006±0.0009	0.00004±0.000006	0.005±0.001	517
S47	23569 ±1818	0.01±0.002	0.0001±0.00001	0.04±0.01	14840
S48	6613±590	0.004±0.0007	0.00003±0.000005	0.001±0.0006	416
S49	8435±837	0.006±0.001	0.00004±0.000007	0.002±0.0008	531
S50	4976±469	0.003±0.0005	0.00002±0.000004	0.0005±0.0001	313
S51	7361±776.	0.005±0.0009	0.00004±0.000006	0.003±0.001	463
S52	4234±458	0.003±0.0005	0.00002±0.000003	0.0009±0.0003	266
S53	9647±824	0.007±0.001	0.00005±0.000007	0.001±0.0006	607
S54	10000±966	0.007±0.001	0.00005±0.000008	0.04±0.01	630
S55	12875±1189	0.009±0.001	0.00006±0.00001	0.002±0.0007	811
S56	7465±738	0.005±0.0009	0.00004±0.000006	0.004±0.001	470
S57	7721±731	0.005±0.0009	0.00004±0.000006	0.002±0.0007	486
S58	8394±880	0.006±0.001	0.00004±0.000007	0.01±0.005	528
S59	7072 688	0.005±0.0008	0.00003±0.000005	0.001±0.0006	445

S60	23593±2157	0.01±0.002	0.0001±0.00001	0.006±0.002	1486
Min	1954 ±209	0.001±0.0002	0.00001±0.000002	0.0002±0.0001	123
Max	104669±6976	0.07±0.01	0.0005±0.00007	0.03±0.01	6594
Ave	25542±1783	0.02±0.002	0.0001±0.00002	0.02±0.01	16098

The radon activity concentration ranged from 1954±209 to 104669±6976 with an average of 25542±1783 Bq/m^3 as shown in Figure 3. The radon concentration values are higher than the permissible and recommended limit of 1000 Bq m^{-3} (UNSCEAR, 2000). The International Commission on Radiological Protection recommended the radon concentration range to be from 200 to 600 and 500 to 1500 Bq m^{-3} for public and occupation, respectively. The effective annual dose is higher than the world average value of 1.1 and 20 mSv year⁻1, for public and occupation, respectively. The commission recommended upper values for the derived reference levels of 600 Bq m^{-3} for homes and 1500 Bq m^{-3} for workplaces. The Commission reduced the upper reference level for homes to 300 Bq m^{-3} in the associated statement on radon. The radon concentration of 300 Bq m^{-3} in homes corresponds to an annual dose of approximately 10 mSv using the dose conversion convention, based on the revised nominal risk coefficient.

The Statement on Radon also referred to a level of 1000 Bq m^{-3} as an entry point for applying occupational radiological protection requirements, replacing the upper reference level of 1500 Bq m^{-3} [14].

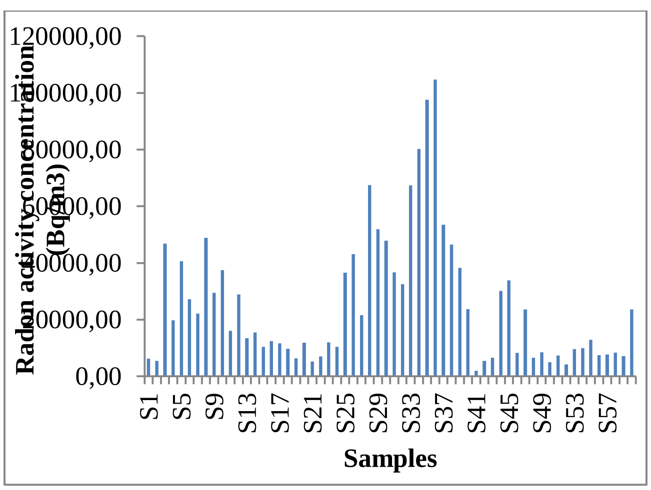

Fig.3: The activity concentration of radon in granite samples.

The measurement of indoor radon exhalation rates is of utmost importance because inhalation of radon and its

progeny contributes more than 50% of the total radiation dose from natural sources. By separating the radon exhalation rate by either the area of the exhaling surfaces or by the mass of the sample, the area (radon flux Bq/ m^2s) and mass radon exhalation rates (Bq/kgs) can be calculated.

Radon exhalation rates are listed in Table 1 The surface exhalation rate varied from 0.001±0.0002 to 0.07±0.01 with an average of 0.02±0.002(Bq/m^{-2}.h^{-1}). Mass exhalation rate ranged from 0.00001±0.000002 to 0.0005±0.00007 with an average of 0.0001±0.00002 Bq/kg^{-1} h^{-1}). The variation may be attributed to differences in radium concentration, humidity, temperature, porosity, permeability, emanation coefficient, organic matter contents, etc [15]. The radon exhalation in studied samples was found to be below the average world value of 57.6 B$qm^{-2}h^{-1}$ [16].

Radon emanation coefficient values are listed in Table 1. Its value ranged from 0.0002±0.0001% to 0.03±0.01% with an average of 0.02±0.01%. Variation in Radon emanation coefficient values. This variation could be caused by many factors, such as differences in radium concentration in the samples, radium distribution within mineral grains of the sample, the texture and size of the grains, and the permeability of the grains [17-20].

Annual effective dose equivalent indoor and outdoor values are listed in Table 10. The annual effective dose indoors ranged from 49mSv/y to 2637 mSv/y with an average of 643mSv/y, and the Annual effective dose outdoors ranged from 73 mSv/y to 3956mSv/y with an average of 965 mSv/y. The values are higher than the world average value of 1.1 and 20 mSv y^{-1}, for public and occupation, respectively [20-23].

Fig 4 and 5 illustrate the correlation between the radon concentration and surface and mass exhalation rate. It was found that the a strong relationship between the radon concentration and surface and mass exhalation rate. Which (R^2=0.99), and (R^2=1) respectively. Radon exhalation rates depend on the composition of each granite sample, which contains naturally occurring uranium and radium. These radioactive elements can lead to a rather high radon exhalation rate.

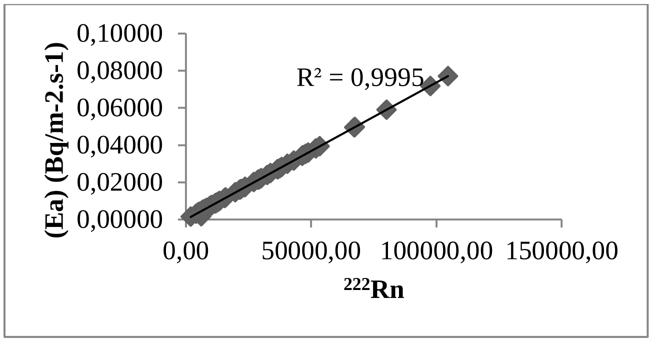

Fig. 4: The correlation between radon concentration and surface exhalation rate.

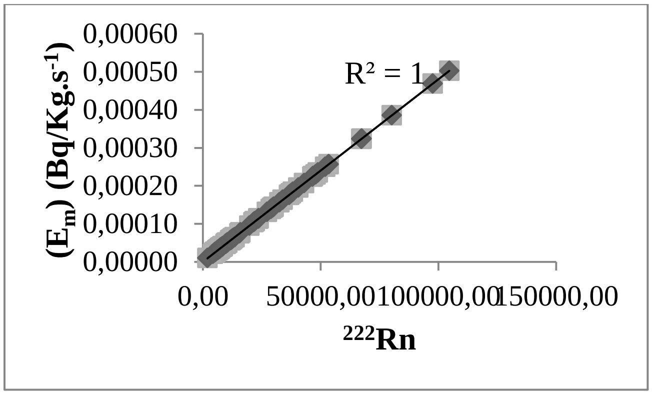

Fig.5: The correlation between radon concentration and mass exhalation rate.

Fig 6 explains the correlation between radon concentration and annual effective dose equivalent which shows the strong relationship between radon concentration and annual effective dose equivalent. The correlation coefficient (R^2=1).

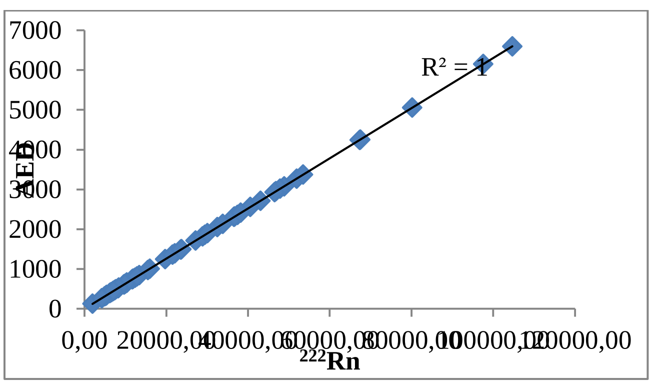

Fig. 6: The correlation between radon concentration and annual effective dose equivalent.

4 Conclusion

Radon distribution in the granitic rocks of the Gabal Gattar Eastern Desert, Egypt, was measured To assess the radiologic effect of radon concentrations, the activity concentrations have been measured and the radiological hazard parameters were calculated. When considering the average, minimum, and maximum radon activity concentration for the granites samples has the highest average concentration of ^{222}Rn we can conclude that the studied granitic rocks from the Gabal Gattar Eastern Desert cause high risk to humans, so we recommend not to use these high bearing radon rocks as ornamental, in decoration works, as building material as well as in the manufacture of household appliances. Radon gas release presents a particular hazard. It can escape from the solid rock through pores and cracks to reach the surface. It may then collect in buildings and present risks to people.

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