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Gamma Radiation Measurements of Naturally Occurring Radioactive in Igneous Rocks and Its Radiological Complications

Jamilah Al-Zahrani

Physics Department, Faculty of Science, King Abdulaziz University, Jeddah, Saudi Arabia
Email: jalzhrani@kau.edu.sa

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Abstract

The concentrations of natural radioactivity were measured in igneous rock samples collected from Albaha region in the south west of Saudi Arabia. A high purity germanium (HPGe) detector was used for analysis. The average activity concentrations for ^{226}Ra, ^{232}Th and ^{40}K were 35, 31.52 and 843.63 Bq kg^{-1}, respectively. The average absorbed dose rate was 70.86 nGy·h^{-1} with a corresponding average annual effective dose 0.09 mSv·y^{-1}. The average radium equivalent activity value was 145.84 Bq·kg^{-1}, lower than the international limit 370 Bq·kg^{-1}. The external and internal indices average values were 0.39 and 0.49, respectively. The average results obtained in this study are lower than the average national and world recommended values, therefore, there is no health risk to the populace of the area. This study provides a baseline map of background radioactivity levels in the Saudi environment and will be used as reference information to assess any changes in the level background due to geological processes.

Keywords

Natural Radioactivity, Radium, Thorium and Potassium Concentrations, Hazard Index

1. Introduction

The importance of this study is based on the igneous rocks. These rocks are divided into different types: the melting of solid rock and the crystallization of molten rock. Some igneous rocks such as granite and basalt have other purposes in industries and commercials due to their high clay mineral element. Therefore, the radioactive contents of various radionuclides in rocks may play an important role in health conditions and geoscientific research. These radionuclides create risk exposure both externally and internally due to their gamma-ray emissions, their radon and progenies. The main natural contributor to external exposure is from the original radionuclides, such as ^{40}K, and the radionuclides from ^{238}U and ^{232}Th series and their decay materials [1]. Conducting an assessment, the activity of these radionuclides in the environmental samples is necessary to control the radiation levels [2]. The radioactive elements of various radionuclides in rocks may affect the health. Thus, numerous studies have been performed in many regions of the world, and the obtained data can be used to establish if the local controls are needed [3]-[10]. The major objective of this work is to estimate the radiological effects of the specific activities of ^{226}Ra, ^{232}Th and ^{40}K in some rock samples collected from a part of the south west in Saudi Arabia (Albaha region). According to a literature survey, there are no previous data for the rock activities in the studied region. The present data are of great interest in the environmental radiation protection study and may be helpful as a baseline in making estimations of population's exposure in Saudi Arabia. These results are useful, since these types of rocks are available in the building and ornamental materials.

Description of Study Area

This study was carried out in Albaha region in the south west of Saudi Arabia. This region lies on Longitude 41˚E, 42˚E and Latitude 19˚N, 20˚N. It is the smallest of the Kingdom's provinces (11,000 square km) and has a population of 533,001. This specific region has been chosen for this study due to its rocky location where there is a variety of igneous rocks used as building materials. In addition, no previous significant work about radioactivity has been done. The studied area was illustrated in **Figure 1**.

2. Material and Methods

2.1. Samples

Thirty igneous rock samples have been collected randomly from various locations in Albaha region, southwestern part of Saudi Arabia. In the laboratory the rocks were crushed and pulverized to a uniform mixture, dried in an oven at 110˚C and sieved to a particulate size of about 2 mm. About 500 mg of powder

Figure 1. Location map of the study area.

samples were filled with Polyethylene containers, sealed for four weeks before measurement to reach secular equilibrium between ^{226}Ra and ^{232}Th and their decay products [11].

2.2. Measurements

The gamma-rays emitted by the rock samples were measured by using High Purity Germanium (HPGe) detector gamma-ray spectrometry system of 1.85 keV resolution and 25% relative efficiency with coaxial-type vertical dipstick cryostat. It is surrounded by lead and copper, which provides an efficient suppression of background gamma radiation present at the laboratory. The system has a resolution (FWHM) of (3.0 - 3.5 keV) for 1332.5 keV gamma-ray peak of ^{60}Co and a peak to a Compton ratio of 41:1. The spectra were analyzed by commercially available software GE-NIE-2000 obtained from Canberra, USA. Counting of samples and background was done for 36,000s duration. The activity concentration for ^{226}Ra was determined by using the average obtained by gamma peaks at 351.87 keV, 295.09 (214 Pb) and 609.31 keV, 1120.27 keV, 1764.49 keV (214Bi), while ^{232}Th from gamma peaks 238.63 keV (212 Pb) and 911.21 keV (228Ac), finally, ^{40}K from 1460 keV gamma peak. The radioactivity concentrations of ^{226}Ra, ^{232}Th, and ^{40}K in the environmental samples were calculated using the following relation [10] [11] [12]:

$$A = Nc/\varepsilon\gamma m \tag{1}$$

where A is the activity concentration in Bq·kg^{-1}, NC is the net gamma counting rate (counts per second), ε the detector efficiency of the definite Gamma-ray, γ is the absolute transition probability of Gamma-decay and m the mass of the sample (kg).

2.3. Calculations

The radium equivalent activity of the granite samples was calculated by using the formula [1] [11] [12]:

$$\text{Iraq} = \text{ARa} + 1.43\text{ATh} + 0.077\text{Ak} \tag{2}$$

where ARa, ATh and Ak are the activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K, respectively. This formula is based on the assumption that 370 Bq·kg^{-1} of 226 Ra, 259 Bq·kg^{-1} of ^{232}Th and 481 Bq·kg^{-1} of ^{40}K produce the same gamma-ray dose rate [13]. A value of 370 Bq·kg^{-1} corresponds to 1 mSv·y^{-1}.

The external hazard index (H_{ex}) is a radiation hazard index defined by [14]. This index value must be less than unity to keep the radiation hazard insignificant, *i.e.*, the radiation exposure due to the radioactivity of construction materials to be limited to 1.5 mSv·years^{-1} [15], based on the formula [14]:

$$H_{ex} = \text{ARa}/370 + \text{ATh}/259 + \text{Ak}/4810 \tag{3}$$

In order to address the radiation hazard to respiratory organs due to ^{222}Rn and its radiation hazard to respiratory organs due to ^{222}Rn and its progeny, the internal hazard index H_{in} which is given by [14]:

$$H_{in} = \text{ARa}/185 + \text{ATh}/259 + \text{Ak}/4810 \tag{4}$$

where ARa, ATh and Ak are the activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K, respectively. For safe, use of a material in the construction of dwellings, H_{ex} and H_{in} should be less than unity [16].

The total air absorbed dose rate ($nGy \cdot h^{-1}$) due to the activity concentrations of ^{238}U, ^{232}Th, and ^{40}K (Bq/kg) can be calculated using the activity concentration (in $Bq \cdot kg^{-1}$) of ^{40}K(AK),^{226}Ra (ARa) and ^{232}Th (ATh) substituted into the formula [1]:-

$$D = 0.0417Ak + 0.462ARa + 0.604ATh \quad (5)$$

The annual effective dose equivalent (AEDE) was calculated from the absorbed dose by applying the dose conversion factor of 0.7 $SvG \cdot y^{-1}$ with an outdoor occupancy factor of 0.2 [1]:

$$\text{AEDE}(\text{mSv/y}) = \text{D}(\text{nGy/h}) \times 8760(\text{h/y}) \times 0.7(\text{Sv/Gy}) \times 0.2 \times 10^{-6} \quad (6)$$

3. Results and Discussion

Table 1 shows the values of activity concentration of ^{226}Ra, ^{232}Th and ^{40}K and the corresponding radiological hazards were obtained from thirty rock samples collected from Albaha region in the South west of Saudi Arabia. From this Table, it can be seen that the activity concentrations of ^{40}K varied between 124.19 $Bq \cdot kg^{-1}$ in sample (R9) to 2353.19 $Bq \cdot kg^{-1}$ in sample (R27) with a mean value of 843.63 $Bq \cdot kg^{-1}$. ^{226}Ra concentrations varied from 7.39 $Bq \cdot kg^{-1}$ in sample (R21) to 82.85 $Bq \cdot kg^{-1}$ in sample (R27) with a mean of 35 $Bq \cdot kg^{-1}$. The concentrations of ^{232}Th varied from 12.09 $Bq \cdot kg^{-1}$ in sample (R15) to 82.96 $Bq \cdot kg^{-1}$ in sample (R7) with a mean value of 31.52 $Bq \cdot kg^{-1}$. The mean activity concentration values for ^{226}Ra and, ^{232}Th were lower than the recommended radioactivity levels of 50, 50 as reported by UNSCEAR 2000, while ^{40}K mean concentration was found to be greater than the global value 500 $Bq \cdot kg^{-1}$. The variations of natural radioactivity levels in different samples are due to the variation of concentrations of these elements in the geological formations. The high activity concentration of ^{40}K in some rock samples may be attributed to the presence of relatively increased amount of accessory minerals such as zircon, iron oxides, fluorite and other radioactive related minerals [17] [18]. In general, Potassium-40 is usually of limited interest because it is an isotope of an essential element, controlled in the human cells [19]. However, the ^{40}K mean value of this study is still more below the rigid control 100,000 $Bq \cdot kg^{-1}$ as given by IAEA [20]. So, the present results indicated that, the activity concentrations in the rock samples are quite uniform and do not show any considerable variation. Figure 2 shows the activity concentration of uranium, potassium and radium in the collected samples. Figure 3(a) and Figure 3(b) show that there is a good linear correlation (R^2 = 0.80 and 0.83) between the activity concentration of Ra, Th and Ra, K, respectively. Table 1 summarized the results of the hazard parameters as the following:-

The values of Raeq for all samples range from 53.72 to 339.36 $Bq \cdot kg^{-1}$ with a mean value145.84 $Bq \cdot kg^{-1}$. These obtained values were below the recommended maximum value of 370 $Bq \cdot kg^{-1}$, which is equivalent to an external dose of 1.5

Table 1. Values of radioactivity concentrations and radiation hazard parameters for rock samples under investigation.

Sample code	Activity concentrations (Bq/kg)			Radium-equivalent (Bq/kg)	External index (Hex)	Internal index (Hin)	Absorbed dose(D) (nGy/h)	Annual effective dose (AEDE)
	^{226}Ra	^{232}Th	^{40}K					
R1	20.54	17.77	522.72	86.20	0.23	0.29	42.32	0.052
R2	41.84	23.57	541.15	117.21	0.32	0.43	55.82	0.068
R3	37.12	25.69	896.81	142.91	0.39	0.49	70.42	0.086
R4	36.02	21.76	403.56	98.21	0.27	0.36	46.29	0.057
R5	53.98	38.06	829.31	172.26	0.47	0.61	82.42	0.101
R6	35.23	24.86	699.51	124.64	0.34	0.43	60.61	0.074
R7	76.64	82.96	1871.31	339.36	0.92	1.12	164.88	0.202
R8	9.69	9.25	377.65	51.99	0.14	0.17	26.14	0.032
R9	29.71	50.58	124.19	111.60	0.30	0.38	49.54	0.061
R10	8.66	12.64	350.39	53.72	0.15	0.17	26.64	0.033
R11	11.59	15.17	428.75	66.30	0.18	0.21	32.84	0.040
R12	81.38	64.36	1879.83	318.16	0.86	1.08	155.68	0.191
R13	17 .86	13.06	487.54	74.08	0.20	0.25	36.73	0.045
R14	31.49	44.46	1181.55	186.05	0.50	0.59	91.95	0.113
R15	27.65	12.09	326.86	70.11	0.19	0.26	33.39	0.041
R16	47.39	36.79	924.24	171.17	0.46	0.59	82.89	0.102
R17	43.33	34.22	1320.73	193.96	0.52	0.64	96.61	0.119
R18	66.75	54.13	1479.67	258.09	0.70	0.88	125.85	0.154
R19	45.54	35.68	1126.56	183.31	0.50	0.62	90.12	0.111
R20	23.49	30.69	620.75	115.17	0.31	0.37	55.84	0.068
R21	5.57	24.16	472.35	76.49	0.21	0.22	37.74	0.046
R22	34.54	22.96	803.35	129.23	0.35	0.44	63.60	0.078
R23	7.39	15.01	452.88	63.73	0.17	0.19	31.98	0.039
R24	20.29	21.58	835.79	115.51	0.31	0.37	58.05	0.071
R25	43.15	23.27	504.81	115.30	0.31	0.43	54.63	0.067
R26	24.79	18.39	536.27	92.38	0.25	0.32	45.10	0.055
R27	82.85	69.45	2353.19	223.46	0.98	1.21	179.83	0.221
R28	37.43	45.11	1288.81	317.94	0.54	0.64	99.50	0.122
R29	22.72	42.65	1128.25	170.58	0.46	0.52	84.79	0.104
R30	25.21	15.34	540.21	136.05	0.24	0.31	43.55	0.053
	5.57 - 82.85	12.09 - 82.96	124.19 - 2353.19	53.72 - 339.36	0.14 - 0.98	0.17 - 1.21	26.14 - 179.83	0.032 - 0.221
Mean	35	31.52	843.63	145.84	0.39	0.49	70.86	0.09
UNSCEAR2000	50	50	500	370	< 1	< 1	18 - 93	< 1

$mSv\cdot y^{-1}$. Therefore, the rock samples are within an acceptable safe limit. The external hazard (Hex) in the rock samples ranged from 0.14 to 0.98 with a mean

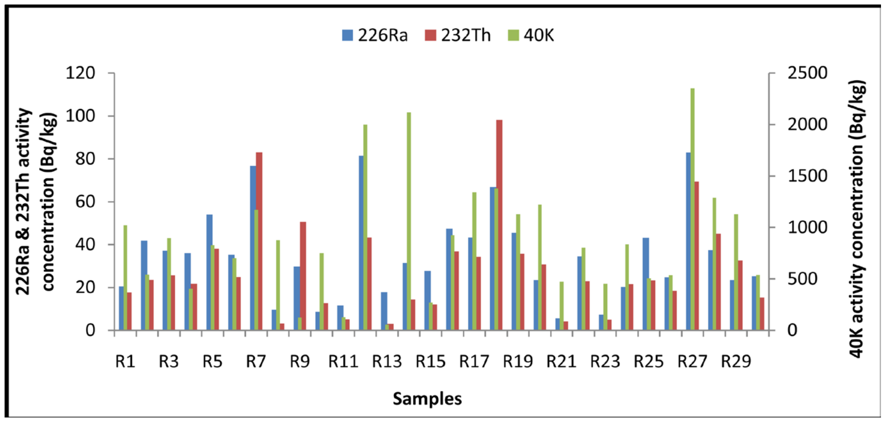
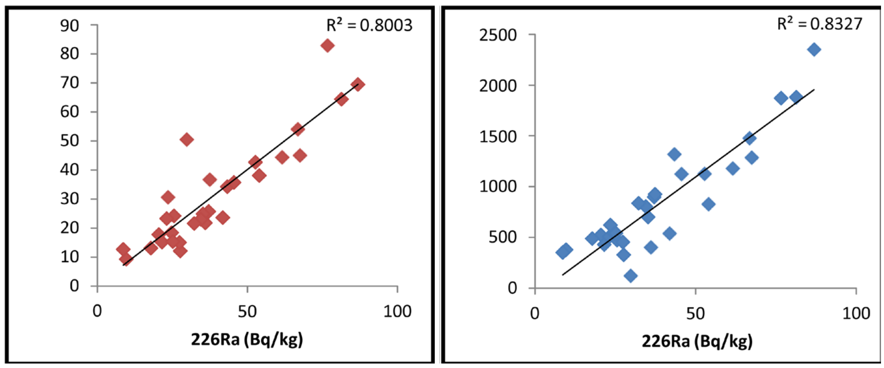


Figure 2. Activity concentrations of radionuclides ^{226}Ra, ^{232}Th and ^{40}K in rock samples from South western, Saudi Arabia.



(a) (b)

Figure 3. (a, b), Correlations between ^{226}Ra and ^{238}U and between ^{226}Ra and ^{40}K in selected rock samples.

value of 0.39. Also, the internal hazard (Hin), its values ranged from 0.17 to 1.21 with a mean value of 0.49. Three samples (R7, R12, R27) had an internal hazard values above the recommended limit of 1.0 which implies that these samples are not suitable as interior building materials and may be a source of internal radon and its progeny, while the other samples have Hin values below the recommended limit. In general, for the safe use of a material in the construction of dwellings, Hex and Hin should be less than unity. The estimated absorbed dose rate varied from 26.14 to 179.83 $nGy \cdot h^{-1}$. The mean absorbed dose rate was calculated to be 70.86 $nGy \cdot h^{-1}$ within the typical range of worldwide average values (18 - 93) reported in UNSCEAR 2000. The calculated values of annual effective dose (AEDE) ranged from 0.032 to 0.221 $mSv \cdot y^{-1}$ with a mean value 0.09 $mSv \cdot y^{-1}$. The recommended upper limit of 1 $mSv \cdot y^{-1}$ is not exceeded in all samples. This means that these rock samples are safety for human health.

Figure 4 shows a comparison between the average radium equivalent activity (Bq/kg) and the absorbed dose rate ($nGy \cdot h^{-1}$) for rock samples under investigation. Table 2 compares the average values of natural radioactivity for rocks in the present study with the obtained data for other countries. As shown in this table, the radioactivity in rock samples varied from one country to another

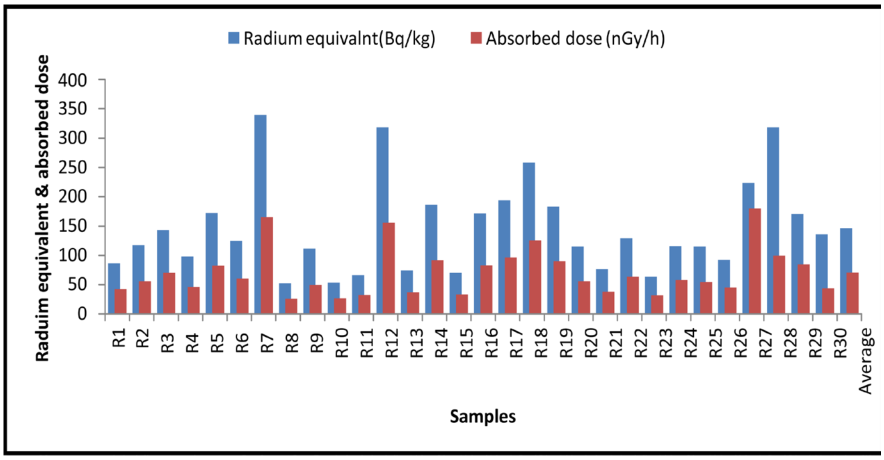


Figure 4. Radium equivalent and absorbed dose in rock samples, south western, Saudi Arabia.

Table 2. Comparison of natural radioactivity concentration (Bq/kg) in the present study with the reported values of the world.

Country	Average activity concentration (Bq/kg)			References
	226R	232Th	40K	
Saudi Arabia	35	31.57	843.63	Present work
Saudi(South of Al-Madina)	106.4	110.35	2683	[12]
Egypt	28.4	37.4	1167	[11]
Yemen (Aden)	57.086	80.26	846.21	[7]
Yemen(Sana'a,)	26.6	23.2	515.6	[9]
Italy	15 - 164	16 - 174	201 - 1350	[21]
India	41.08	86.26	869.29	[4]
Brazil	24	37	1173	[22]
Turkey	12.01 - 48.95	8.2 - 53.27	143.97 - 452.34 45444445452.34	[23]

depends on the locality geological conditions [9] [11] [16]. In general, the results of this study are comparable to the different published studies as listed in this Table.

4. Conclusion

Gamma ray spectrometry has been used to determine the radioactivity concentrations of ^{226}Ra, ^{232}Th and ^{40}K in the rock samples, collected from Albaha region in the south west of Saudi Arabia. The results show that the activity concentrations of ^{226}Ra and ^{232}Th consent with the world-wide average recommended values. The radium equivalent activity values were below the permissible limits 370 Bq/kg. The values of external, internal hazard index and outdoor effective dose were found less than unity. Therefore, the study area is still in the zones of normal radiation level. This data may provide a guideline for future measurement and assessment of possible radiological risks to human health in this region.

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