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Concentration of Uranium and Thorium in Granite Rock in Kadugli, Sudan Using γ - ray Spectroscopy

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Author's contribution

The sole author designed, analysed, interpreted and prepared the manuscript.

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ABSTRACT

The aim of the present study is to determine the elemental concentration in (ppm) and specific activity in (Bqkg-1) of Uranium (^{238}U) and Thorium (^{232}Th) contained in the granite rock of a special geological area in Sudan (Kadugli).

The elemental concentrations and specific activity of ^{238}U and ^{232}Th in granite rock were determined by using the gross gamma counting technique (γ-ray spectroscopy). The analyses were performed for daughter decaying of ^{238}U and ^{232}Th; which are Pb-214, Bi-214 for ^{238}U and Tl-208, Ac-228 for ^{232}Th.

The experiments were carried out at the Nuclear Laboratory, Physics Department, Universiti Teknologi Malaysia using the facilities of gamma ray spectroscopy system with high purity germanium detector (HPGe) of efficiency 20%.

Granite samples were collected from Hagar El-Mlik area, 2 km from the central of Kadugli city in southern Kordofan state, Sudan. The rock was crushed and ground to fine powder and sieved with a particle size less than 120 μm. To calculate the concentrations of ^{238}U and ^{232}Th in the granite rock, standard reference materials provided by International Atomic Energy Agency (IAEA) was used.

The average of elemental concentrations and specific activity of uranium were obtained in the range (1.8 ± 0.11) to (0.80 ± 0.08) ppm, and (22.11 ± 1.30) to (9.79 ± 0.98) Bqkg^{-1} respectively,

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while (16.22±1.84) to (7.45±1.34) ppm and (65.42±7.40) to (29.50 ± 5.39) $Bqkg^{-1}$ are the average concentration and specific activity of thorium. Moreover, average activity concentrations ($Bqkg^{-1}$) for granite samples have been compared with the typical values of different countries.
^{232}Th shows high activity concentration (65.42±7.4) $Bqkg^{-1}$ whereas, ^{238}U activity value is distinctly lower than the corresponding ones obtained from other countries and, in general, all results are acceptable and fall within the range given in UNSCEAR report 1993.

Keywords: Gross gamma counting; uranium and thorium; granite rock; HPGe detector.

1. INTRODUCTION

Natural gamma radiation on the earth mainly comes from the decay of three radioactive isotopes: potassium-40 (^{40}K), uranium-238 (^{238}U) and thorium-232 (^{232}Th). The radioactive element ^{40}K decays directly to stable argon-40 (^{40}Ar), while uranium and thorium decay through long decay chains ending by the stable isotopes of lead (Pb) [1].

Gamma radiation emitted from naturally occurring radionuclides such as ^{40}K and the radionuclides from decay series of ^{238}U and ^{232}Th and their decay products, which exist at trace levels in all ground formations, represents the main external source of irradiation to the human body [2,3]. The specific levels due to naturally radionuclides are related to the types of the rock from which the soils originate. Therefore, the natural environmental radiation mainly depends on geological and geographical composition of each area. For this reason higher radiation levels are associated with igneous rocks such as granite, and lower levels with sedimentary rocks. There are exceptions, however, as some shale and phosphate rocks have relatively high content of radionuclides [3].

^{238}U and ^{232}Th are present on the Earth's crust in part per million levels [4]. Granite is usually suitable as building and ornamental material for interior and exterior use, is hard natural stone.

The aim of the present study is to determine the elemental concentration in (ppm) and specific activity in ($Bqkg^{-1}$) of uranium and thorium contain in the granite rock for special geological area in Sudan (Kadugli).

2. MATERIALS AND METHODS

2.1 Geological Feature of the Study Area

Fig. 1 shows the area of samples in Kadugli, which is situated in Southern Krodofan State of Sudan. Much of southern Kordofan is known also as Nuba Mountains a region located between 29.5ºE; 10.9ºN and 29.8ºE; 11.7ºN [5]. The geological feature of the Nuba Mountains contain almost all main rock units found in the Sudan. It consists of metamorphosed volcano-sedimentary series of rocks into which dismembered ophiolites were emplaced [6,7]. The basement rocks in Kadugli region are characterized by two types of granite outcrops (younger and older granite) protruding towards southern and western direction. In addition, the granitic – Syenitic complexes are exposed in the south east part of the area. The northern part is partly related to volcano-sedimentary series, usually thin and, persists for long distances as depicted in the geological map of the Nuba Mountains presented in Fig. 2. [8].

2.2 Sample Collection and Preparation

Four granite samples were collected from Hagar El-Mlik area, 2 km from the central of Kadugli city in state of south Kordofan state (Fig. 1). The rock was crushed and ground to fine powder and sieved to a particle size less than 120 µm. The samples were dried at 110°C for 24 h to remove the moisture [4,10] and carefully weighted with an electronic balance having sensitivity down to 0.01 mg. The powdered sample were sealed in standard Marinelli beaker. And after properly tightening the lid, the containers were left for 4 weeks before counting in order to ensure that the ^{238}U and ^{232}Th reached the secular equilibrium [4,11,12].

2.3 Standard Preparation

To calculate the concentration of ^{238}U and ^{232}Th in the granite rock, standard reference materials provided by International Atomic Energy Agency (IAEA) was used. Sample of pure quartz (silicon dioxide, SiO_2) was used for background measurements [1]. Two different weighted of standard samples were prepared by mixed 15g and 30 g of IAEA-313, with 400g of SiO_2 and sealed in Marinelli beaker and left for 4 weeks to reach the secular equilibrium [13].

2.4 Experimental Procedures

The experiments were carried out at the Nuclear Laboratory, Physics Department, Universiti Teknologi Malaysia using the facilities of gamma ray spectroscopy system with high purity germanium detector (HPGe) of efficiency 20% which connected to a multi-channel analyzer (MCA). The detector used in these measurements was, Canberra GC2018 with Genie 2000 software, P-type HPGe detectors with an energy resolution (FWHM) 1.8 keV at 1.3 MeV γ-energy of Co-60. The detector and pre-amplifier were placed inside the lead shield with 12cm thickness to reduce the background scattering, and cooled by liquid nitrogen. The energy calibration was performed using five standard gamma point sources Cs-137(661.7 keV), Co-60 (1173 and 1333 keV), Ba-133 (302.9 and 356.0 keV), Eu-152 (344.3 keV), and Am-241 (59.5 keV).

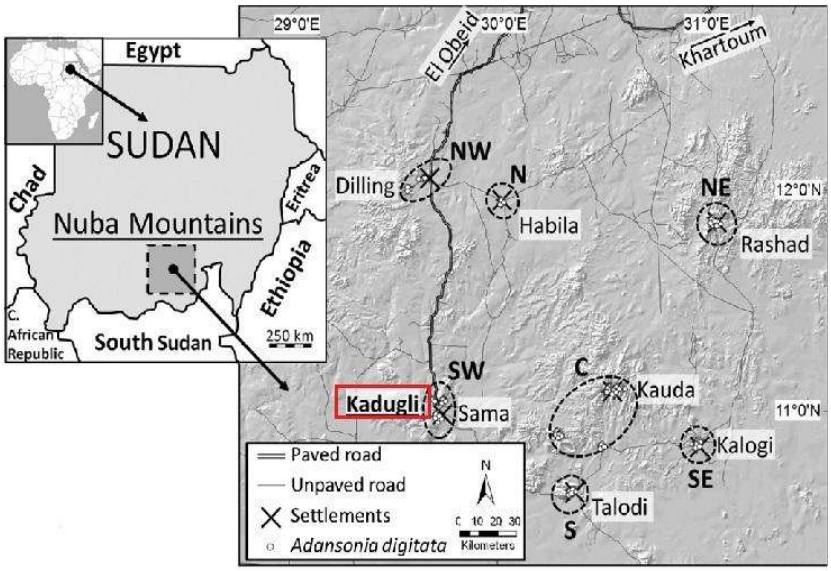

Fig. 1. Map of Sudan showing the study area (Kadugli) [9]

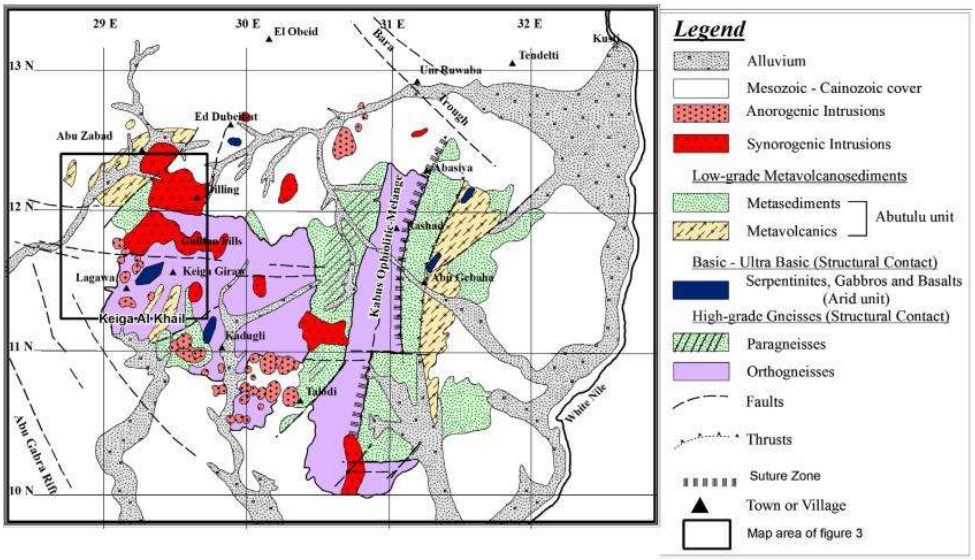

Fig. 2. Sketched geological map of the Nuba mountains [7]

In order to have better statistics, the gamma-ray of each sample was counted for 24 h. The concentration of ^{238}U and ^{232}Th were calculated from their progeny photopeaks. The gamma background level at the counting room was determined with an empty Marinelli beaker. The background was measured under the same conditions of the measurement of the samples. Finally the background was substracted from each spectrum of sample. Similar measurements were done for standard sample, which have certified values of U and Th in part per million (ppm).

2.5 Calculation of Elemental Concentrations

The concentration of uranium and thorium are obtained from the experession

$$C_{samp} = \frac{W_{std}}{W_{samp}} \times \frac{N_{samp}}{N_{std}} C_{std} \quad (1)$$

C_{samp} = the concentration of the collected sample (ppm), W_{std} = the weight of the standard sample (µg).W_{samp} = the weight of the sample collected (g), N_{samp} = the net counts of the photopeak area for the sample collected, N_{std} = the net counts of the photopeak area for the standard sample, C_{std} =the concentration of the standard (ppm).

The uncertainty of the sample concentration could be calculated by using the following formula:

$$\Delta C_{samp}(ppm) = \left(\frac{\Delta W_{std}}{W_{std}} + \frac{\Delta W_{samp}}{W_{samp}} + \frac{\Delta N_{samp}}{N_{samp}} + \frac{\Delta N_{std}}{N_{std}} \right) \times C_{samp} \quad (2)$$

ΔC_{samp} is the uncertainty of the sample concentration (ppm), ΔW_{std} is the uncertainty of the weight of the standard sample (g), ΔW_{samp} is the uncertainty of the weight of the sample collected (g), ΔN_{samp} is the uncertainty of the net counts of the photopeak area for the sample collected, ΔN_{std} is the uncertainty of the net counts of the photopeak area for the standard sample.

3. RESULTS AND DISCUSSION

Fig. 3 shows the gamma-ray peaks emitted naturally from granite sample firmly identified due to the daughters of ^{238}U and ^{232}Th. From the figure the energies of 351.9 keV from ^{214}Pb and 609.4 keV from ^{214}Bi show the daughter of uranium series, while the gamma-ray peaks 583.1 keV from ^{208}Tl and 911.4 keV, from ^{228}Ac show of daughter of thorium series. The concentration of ^{238}U and ^{232}Th were estimated using the γ-yield of energy spectra of γ-rays from ^{214}Pb and ^{214}Bi for uranium, while ^{208}Tl and ^{228}Ac for thorium by setting the area of interest in the energy spectrum. The yields for selected nuclei were estimated single gamma ray data by correcting efficiency of the detector. The background was measured under the same conditions of the measurement of the samples and was substracted from each spectrum of sample. Similar measurements were done for standard sample, which have certified values of U and Th in part per million (ppm).

The elemental and activity concentration for granite stone under this study are reported in Tables 1 and 2. The average values of elemental and activity concentrations for thorium are 7.45 ± 1.34 ppm at 15g, and 16.22±1.84 ppm at 30g and 29.50 ± 5.39 Bqkg^{-1} at 15g, 65.42 ± 7.40 Bqkg^{-1} at 30g. The average concentration of uranium is 0.80 ± 0.08 ppm at 15g, 1.80 ± 0.11 ppm at 30g and consequently activity is 9.79 ± 0.98 BqKg^{-1} and 22.11 ± 1.30 BqKg^{-1} respectively.

The activity concentrations in present study of granite are compared with previous studies and the results are reported in Table 3. It is found that the maximum activity value 78.78±2.34 Bqkg^{-1} of ^{238}U was in Egypt and maximum value 69.31±3.70 Bqkg^{-1} of ^{232}Th was found in Iran. The results obtained at present work are consistent with previous results. The ^{238}U activity value is distinctly lower than the corresponding ones obtained from other countries, however, ^{232}Th shows high activity concentration (65.42±7.4) Bqkg^{-1}. The reason could be attributed to the geological formation of the area under study; geologically this area was characterized by high younger granite [8].

The thorium and uranium in granite stones in Sudan are detected and their activity concentrations were measured by gamma ray spectroscopy system. The ^{238}U activity value is distinctly lower than the corresponding ones obtained from other countries except the results from Saudi Arabia and, in general, all results fall within the range given in UNSCEAR report 1993.

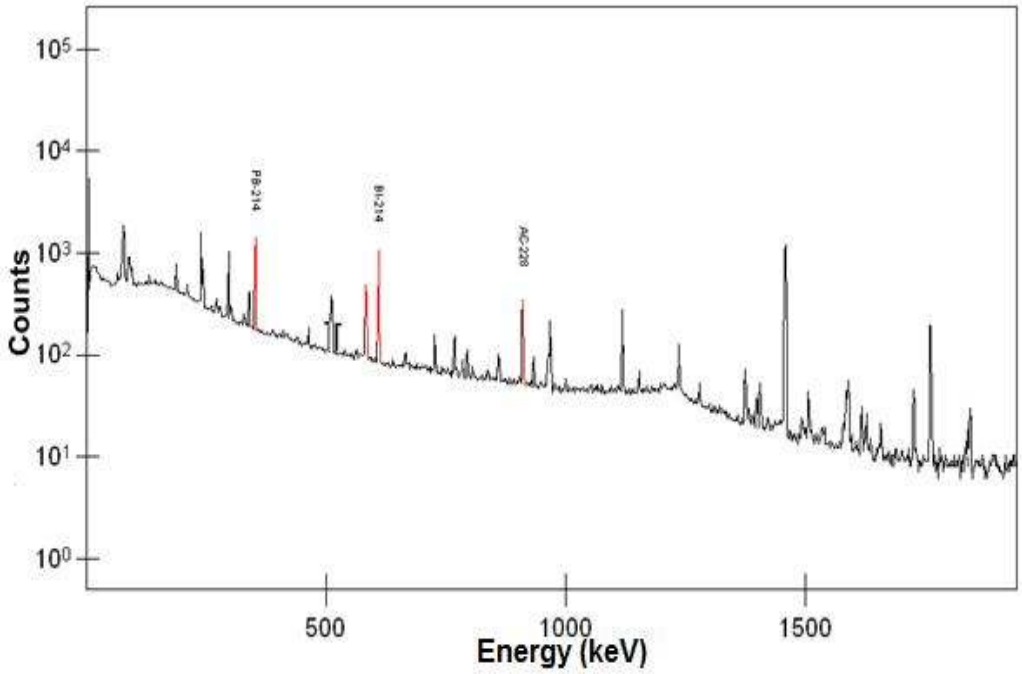

Fig. 3. γ-ray spectrum for granite samples in Sudan

Table 1. Elemental concentration of uranium and thorium in granite samples at different weight of standard (ppm)

Nuclide	Concentration (ppm)		Average of concentration	
	15 g	30 g	15 g	30 g
U-series				
^{214}Pb	0.93±0.08	1.99±0.12		
			0.80±0.08	1.8±0.11
^{214}Bi	0.67±0.08	1.60±0.09		
Th-series				
^{208}Tl	8.60±1.43	17.11±2.02		
			7.45±1.34	16.22±1.84
^{228}Ac	6.30±1.24	15.33±1.65		

Table 2. Activity concentration of uranium and thorium in granite samples for different weight of standard (Bq/kg)

Nuclide	Activity oncentration (Bq/kg)		Average of activity	
	15 g	30 g	15 g	30 g
U-series				
^{214}Pb	11.40±0.98	24.53±1.48		
			9.79±0.98	22.11±1.30
^{214}Bi	8.19±0.98	19.69±1.11		
Th-series				
^{208}Tl	34.68±5.77	69.01±8.15		
			29.50±5.39	65.42±7.40
^{228}Ac	24.32±5.00	61.83±6.65		

Table 3. Average activity concentration ($Bqkg^{-1}$) for granite sample from work conducted worldwide

Region	^{238}U	^{232}Th	Reference
Egypt	78.78±2.34	44.48±1.43	[15]
Saudi Arabi	18.7±0.08	11.5±0.13	[16]
India	44.7±0.15	34.9±0.5	[16]
Italy	72.3±0.17	41.57±0.4	[16]
Iran	--	69.31±3.7	[4]
Sudan	22.11±1.30	65.42±7.4	Present Study
Worldwide	20-120 (from ^{226}Ra)	20-80	[17]

4. CONCLUSION

In general, all results existed within the range given in UNSCEAR report 1993. According to geological composition of the Southern Kordofan, more systematic environmental monitoring studies are required, because preliminary studies in the area show radioactivity levels 10 times higher than that of more normal areas [14].

COMPETING INTERESTS

Author has declared that no competing interests exist.

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