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ASSESSMENT OF DOSE RATE USING GAMMA RAY OBSERVATIONS IN THE MINING WASTE SAMPLES OF SIMBERI GOLD MINE IN PAPUA NEW GUINEA

DAVID KOLKOMA[1] AND *FELIX PEREIRA B.[2]

Department of Applied Physics, PNG University of Technology, Papua New Guinea

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ABSTRACT

The specific activity of natural radionuclides were measured by gamma ray spectrometry with NaI(Tl) detector in the mining waste soil samples collected from Simberi gold mine in New Ireland province of Papua New Guinea. The isotope concentrations of ^{238}U and ^{232}Th in Simberi soil samples are 10.7 and 41.3 ppm respectively whereas the world average values are 2.64 and 11.1 ppm respectively. The average Radium equivalent activity in Simberi samples is 372.2±81.4 Bq/kg which is observed to be higher than the threshold safe value of 370 Bq/kg. The average internal hazard index for Simberi samples is found to be 1.4 which is higher than the maximum permissible value of 1.0. The Excess Lifetime Cancer Risk (ELCR) is calculated to be 0.00553±0.00122 in Simberi whereas the world average value is 0.00145. Radiation in Simberi is found to be higher which may be because Simberi is situated in the volcanic region of Papua New Guinea.

KEY WORDS : Natural radionuclides, Mining waste, Radium equivalent, Hazard Index, Excess lifetime cancer risk, Volcanic region.

INTRODUCTION

Natural radioactive element distribution is a great concern to humanity because they contaminate the environment. Radioactive elements are found in rocks and soil on the Earth whose activity concentrations are generally low. The major elements present are Uranium, Thorium, Potassium and their progenies which are unevenly distributed on the Earth. Naturally occurring radioactive elements on earth are ^{238}U, ^{232}Th and ^{40}K and they are present in the earth's crust and within the tissues of all living mainly animals feeding on plants which grow in a highly concentrated ^{232}Th and ^{238}U environment (International Atomic Energy Agency, 2007). The contributors to natural background radiation doses to human are cosmic rays, gamma rays arising from rocks and soil, inhalation of radon gas and ingestion of radionuclides with food and water. Out of these, the major contributor to the external dose of the population is natural sources. Assessment of natural sources is important in this context.

Mining and other chemical processes sometimes elevate the concentration of radionuclides in the local environment. During the process of mining, materials are brought from the interior to the surface which sometimes increase the concentration of radionuclides in regions where mining waste is dumped. This elevates the ionization radiation in the environment (Kolkoma *et al.,* 2022). Activity concentration measurements from these materials are needed for the determination of dose rate to take precautionary measures whenever the dose rate is above the recommended limits. The present study is focused on the activity concentrations, absorbed dose rate, radium equivalent activity, hazard indices and Excess Lifetime Cancer Risk (ELCR) in the mining site in Papua New Guinea. Similar studies have been conducted in many parts of the world

([1]Lecturer II, [2]Associate Professor)

(Raghad and Rasha, 2017; Agbalagba, 2017; Mohammad *et al.*, 2018).

In this study, the natural radioactivity concentrations of ^{238}U, ^{232}Th, and ^{40}K are analyzed in soil samples collected from the mining site where mining wastes are dumped. The results are used to calculate the isotope contents in the soil samples. The gamma dose rate in air, the annual effective dose rate, radium equivalent and the internal and external hazard index were calculated to assess the radiation hazard associated with absorbed gamma dose rate. There have not been any past studies on natural radioactivity in this study location.

MATERIALS AND METHODS

Papua New Guinea is a country located in the south-west region of the southern hemisphere along the 'ring of fire' region. The country is blessed with natural resources such as gold, copper, oil, gas, nickel and renewable sources such as hot springs and hydro. New Ireland is a province in the north-east of Papua New Guinea which is a volcanic region. Simberi is a gold mine in Manwin Island of Tabar group of islands in the New Ireland province. The mining site is 02^0 37′ 45" South Latitude and 151° 59′ 39" East Longitude. The estimated population in this study area is estimated to be 4,000(2000 Census) inhabitants living around the mine site. Fig. 1 represents the mining location in the map.

Fig. 1. Location of Simberi gold mine in Papua New Guinea.

Twelve soil samples were collected from the mining site. The soil samples are the waste from the mills to be disposed to the dump sites. The soil samples are predominantly igneous sedimentary and metamorphic rocks. Soil samples were packed in 200 ml plastic bags and shipped to the laboratory of Applied Physics Department, PNG University of Technology for processing and analysis. The samples were dried to remove all moisture content using fluorescent bulb for one week and filtered with a mesh of 1 mm × 0.5 mm mesh. The processed soil samples are then filled into a 20 ml container and kept for a period of 30 days for the radionuclides progeny to reach equilibrium. The soil samples were then analyzed in a LB 2045 NaI (Tl) Gamma ray Spectrometer.

Experimental

Preliminary Adjustments: A Cs^{137} test source is used for calibration. The calibration function automatically modifies the high voltage until ^{137}Cs photopeak hikes on 662 keV energy line. The high voltage found is saved.

To find Background radiation: The background function is used to measure the background spectrum in the range 0 – 2048 keV. All the sources in the vicinity of the detector are removed and the background spectrum is measured for half an hour.

To get the correct activity of the sample, the background spectrum is subtracted from the total measurement result. This is done by the machine automatically. The period of counting of the sample was set at 12 hours.

Neither ^{238}U nor^{232}Th emits gamma rays. In our study, the activity of ^{238}U is estimated from the activity of ^{210}Pb, the activity of ^{232}Th is estimated from ^{228}Th. The specific activity of each sample is calculated using the formula.

$$A = \frac{P}{\varepsilon f_\gamma tm}$$

where P is the total net counts under the above-mentioned photo peak, ε is the measured photo peak efficiency, f_γ is the gamma ray intensity, t is the sample measurement time and m is the sample weight (Ayse, 2017).

RESULTS AND DISCUSSION

Specific activities of the natural radioactive elements

The specific activities of the natural radioactive elements such as ^{238}U, ^{232}Th and ^{40}K of Simberi samples are given in Table 1.

In the Simberi soil samples, the specific activity of ^{238}U varies from 53.5 to 199.0 Bq/kg with an average value of 131.7 ± 46 Bq/kg, the specific activity of ^{232}Th ranges from 121.9 to 258.2 Bq/kg with an average value of 168.1± 39.3 Bq/kg, and the specific activity of ^{40}K varies from 1.4 to 3.3 Bq/kg with an average value of 2.3 ± 0.5 Bq/kg.

The average activity of ^{238}U and ^{232}Th decay series for rock samples varies from 20-70 Bq/kg (Long *et al.*, 2012). The activities of ^{238}U and ^{232}Th in soil samples of Simberi (131.7 and 168.1 Bq/kg) were found to be much higher than this range.

Estimation of radioactive elements in soil samples using Gamma ray spectrometry

The mass of the radioisotope is estimated from the following equation.

$$m = \frac{AMB}{N_0 \lambda} \quad .. (1)$$

where m is the mass of the isotope in the given sample of mass M with activity of B (B in Bq/kg and m and M in kg), A = mass number, N_0 = Avogadro number and λ is the Decay constant (λ= 0.693/ $T_{1/2}$) (Rasha *et al.*, 2018).

The mass of ^{238}U, ^{232}Th and ^{40}K in ppm are calculated using the above formula and tabulated in Table 2. The isotope concentrations of ^{238}U, ^{232}Th and ^{40}K were observed to be higher in Simberi soil samples. The world average concentrations of ^{238}U and ^{232}Th were found to be 2.64 and 11.1 ppm respectively (Dragovic *et al.*, 2006). The concentration of ^{40}K is 0.007% which is less than the world average value of 0.012% in natural Potassium. The main contribution of radiation is from ^{238}U and ^{232}Th. The specific activities of 1ppm of ^{238}U and ^{232}Th in Simberi soil samples were 12.26 and 4.05 Bq/kg respectively. The world average values of 1 ppm of ^{238}U and ^{232}Th in rock samples are 12.35 and 4.06 Bq/kg respectively (IAEA, 1989).

Absorbed Dose rates in soil samples

The approximate values of dose rate is calculated using the specific activity of the soil samples collected from this region. The absorbed dose rate

Table 1. Specific Activities of ^{238}U, ^{232}Th and ^{40}K, Absorbed dose, outdoor and indoor Annual Effective Dose, Radium Equivalent, Radium Hazard Index and Excess Lifetime Cancer Risks for Simberi gold mine soil samples.

Sample	Specific Activity			Absorbed	Outdoor	Indoor	$Ra_{eq.}$	H_{ex}	H_{in}	$ELCR_{tot}$
	^{238}U	^{232}Th	^{40}K	Dose(out) (nGy/h)	AED (μSv/y)	AED (μSv/y)	(Bq/kg)			(×10^{-3})
1	75.5	121.9	2.2	108.6	133.1	999.3	250.0	0.7	0.9	3.68
2	105.0	161.1	1.5	145.9	178.8	1343.6	335.5	0.9	1.2	4.95
3	199.0	184.3	2.1	203.3	249.3	1893.2	462.7	1.2	1.8	6.96
4	53.5	122.2	2.5	98.6	120.9	901.7	228.4	0.6	0.8	3.32
5	148.9	258.2	1.4	224.8	275.6	2065.6	518.2	1.4	1.8	7.61
6	136.7	138.9	2.2	147.1	180.4	1367.2	335.5	0.9	1.3	5.03
7	78.4	219.9	2.6	169.1	207.4	1541.3	393.0	1.1	1.3	5.68
8	148.3	150.0	2.4	159.2	195.2	1479.5	363.0	1.0	1.4	5.44
9	193.3	154.7	3.3	182.9	224.2	1708.3	414.8	1.1	1.6	6.28
10	156.7	181.2	2.9	182.0	223.1	1685.9	416.0	1.1	1.5	6.2
11	159.3	165.1	2.5	173.4	212.6	1610.6	395.6	1.1	1.5	5.93
12	125.4	159.4	2.0	154.3	189.2	1426.7	353.5	1.0	1.3	5.25
Average	131.7 ± 45.9	168.1± 39.3	2.3 ± 0.5	162.4± 35.8	199.2 ± 43.9	1501.9 ± 333.4	372.2 ± 81.4	1.0 ± 0.2	1.4 ± 0.3	5.53 ± 1.22

Table 2. Average Specific activity and Isotope concentration of ^{238}U, ^{232}Th and ^{40}K in the soil samples of Simberi gold mine.

Element	Average Specific activity (Bq/kg)	Isotope Concentration (ppm)	World average Concentration (ppm)
^{238}U	131.7	10.7	**2.64**
^{232}Th	168.1	41.3	**11.1**
^{40}K	2.3	0.007%	**0.012%**

due to gamma radiations in air at 1m above the ground for uniform distribution of ^{238}U, ^{232}Th and ^{40}K were calculated using the guidelines of UNSCEAR 2000.

$$D_{out}(nGyh^{-1}) = 0.462A_U + 0.604A_{Th} + 0.04A_K \quad ..(2)$$

$$D_{in}(nGyh^{-1}) = 0.62A_U + 1.1A_{Th} + 0.081A_K \quad ..(3)$$

where A_U, A_{Th} and A_K are the specific activity of Uranium, Thorium and Potassium.

Outdoor Annual Estimated Dose (AED_{out}) = $D_{out}(nGyh^{-1}) \times 8760h \times 0.7(SvGy^{-1}) \times 0.2$ .. (4)

Indoor Annual Estimated Dose (AED_{in}) = $D_{in}(nGyh^{-1}) \times 8760h \times 0.7\ (SvGy^{-1}) \times 0.8$ .. (5)

Here, 0.2 and 0.8 are the outdoor and indoor occupancy index. Using equations (2), (3), (4) and (5), the outdoor dose rate and the outdoor and indoor annual effective dose rates were calculated. The absorbed dose, the outdoor and indoor Annual Effective Dose of Simberi soil samples were given in Table 1. The outdoor and indoor annual effective dose are calculated. The outdoor annual effective dose varies from 120.9 to 249.3 microSv/y with an average value of 199.2±43.9 microSv/y and the indoor effective dose varies from 901.7 to 2065.6 microSv/y with an average value of 1501.9±333.4 microSv/y. The total annual effective dose (AED_{out} + AED_{in}) is found to be 1.7 milli Sv/y. The world average value is 0.52 milli Sv/y and the criterion limit is 1 milli Sv/y as per ICRP-60.

Radium equivalent (Ra_{equ})

$$Ra_{eq} = A_U + 1.43A_{Th} + 0.07\ A_K \quad .. (5)$$

where A_U, A_{Th} and A_K are specific activities of ^{238}U, ^{232}Th and ^{40}K (Bq/kg).

The calculated values of Ra_{eq}using equation (5) are tabulated in Table 1. The average value of Ra_{eq} iscalculated to be 372.2±81.4 Bq/kg. The recommended safe maximum value of Ra_{eq} is 370 Bq/kg (UNSCEAR, 1982). The Ra_{eq} of Simberi soil samples was found to be slightly higher than the safe value.

Radiation Hazard Indices

Radiation Hazard Indices were calculated using the following equations.

$$H_{ex} = \frac{A_U}{370} + \frac{A_{Th}}{259} + \frac{A_K}{4810} \quad (6)$$

$$H_{in} = \frac{A_U}{185} + \frac{A_{Th}}{259} + \frac{A_K}{4810} \quad .. (7)$$

The values of H_{ex} and H_{in} were calculated from equations (6) and (7) and tabulated in Table 1. H_{ex} varies from 0.8 to 1.6 with an average value of 1.4±0.3 and H_{in} varies from0.6 to 1.4 with an average value of 1.0±0.2. The values of internal and external hazard indices must be less than or equal to 1 for radiation hazard to be negligible. The external and internal radiation hazard indices were found to be slightly greater in Simberi soil samples.

Excess Lifetime Cancer Risk (ELCR)

If the average life expectancy of a human being in Papua New Guinea (DL) is 65 years, then Excess Lifetime Cancer level is the probability of developing cancer over a lifetime at a given radiation exposure level. It is calculated as

$$ELCR = AED_{tot} \times DL \times RF \quad .. (8)$$

where RF is the risk factor whose value is taken as 0.05, DL is the duration of life and AED is the sum of Indoor and OutdoorAnnual Effective Doses (Qureshi *et al*., 2014).

The calculated values of ELCR for Simberi are given in Table 1. The average value of ELCR is 0.00553±0.0012. The global average value of ELCR is 0.00145 (Taskin *et al*., 2009). ELCR in Simberi is 3.81 times higher than the world average value. The radiation effects were found to be higher in Simberi gold mine andthis may be because Simberi gold mine is situated in the volcanic region of Papua New Guinea.

CONCLUSION

An LB 2045 Gamma Ray Spectrometer was used to determine the specific activity of ^{238}U, ^{232}Th, and ^{40}K from 12 soil samples collected from the waste ore of Simberi Gold mine in New Ireland Province of Papua New Guinea. The respective specific activities were then used to estimate the absorbed dose, annual indoor and outdoor effective dose, Radium Equivalent Dose, Radiation Hazard Indices and Excess Lifetime Cancer Risk. The observed mean concentrations of ^{238}U and ^{232}Th in Simberi soil samples are higher than the the world average values. The annual average effective outdoor and indoor dose rate in Simberi soil samples are 199.2±43.9 and 1501.9±333.4 microSv/y respectively. The average annual effective dose rate is higher than the maximum threshold value of 1000 microSv/y. The average value of Ra_{eq} is 372.2+81.4 Bq/kg which is slightly greater than the global average value of

370 Bq/kg. The indoor radiation hazard index is observed to be 1.4. The average ELCR is 0.00553 ± 0.0012 which is higher than the global value of 0.00145. The radiation in Simberi is observed to be higher which may be because Simberi is situated in the volcanic region of Papua New Guinea.

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