FACTA UNIVERSITATIS
Series: **Working and Living Environmental Protection** Vol. 7, N° 1, 2010, pp. 53 - 58

ANNUAL EFFECTIVE DOSE DUE TO COMBINED CONCENTRATION OF ^{226}RA AND ^{228}RA IN THE GROUNDWATER SYSTEM: A CASE STUDY OF THE UNIVERSITY OF ILORIN MAIN CAMPUS, NIGERIA

UDC 77.026.34:631.423:539.16 (662.6)

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Abstract. *An estimation of the annual effective dose received by the population as a result of the ingestion of ^{226}Ra and ^{228}Ra in the groundwater within the Main Campus of the University of Ilorin, Nigeria has been made. Groundwater samples from existing boreholes sited inside the campus were analyzed by γ-ray spectroscopy to determine the suitability of the water for human consumption. The activity concentration values from the analysis range from 0.03±0.02 to 4.79±1.26 Bq l^{-1} for ^{226}Ra and from 0.01±0.00 to 4.79±1.82 Bq l^{-1} for ^{228}Ra. The computed annual effective dose received by the population as a result of the ingestion of ^{226}Ra and ^{228}Ra is thus estimated to range from 0 to 0.49 mSv y^{-1} and 0.003 to 1.21 mSv y^{-1} respectively. The total annual effective dose received as a result of the combined ingestion of ^{226}Ra and ^{228}Ra is consequently found to range from 0.003 to 1.45 mSv y^{-1} with an average of 0.59 mSv y^{-1}. It is therefore, observed that although the average combined contribution of ^{226}Ra and ^{228}Ra activities to the committed effective dose from a year's consumption of drinking water in the study area is less than the ICRP's recommended limit of 1 mSv y^{-1}, the groundwater from some of the boreholes is more than 1 mSv y^{-1}. For this reason, it is recommended that adequate measures should be taken to protect the young populace in the study area from consuming radiologically unsafe drinking water from the affected boreholes.*

Key words: *radioactivity, groundwater system, spectroscopy, effective dose and Nigeria*

INTRODUCTION

The activity concentration of natural radionuclides in groundwater is connected to the activity concentrations of uranium (^{238}U and ^{235}U) and thorium (^{232}Th) and their decay products in the ground and bedrock. This is due to groundwater reacting with the ground and bedrock and releasing quantities of dissolved components that depend on the mineralogical

Received October 11, 2010

and geochemical composition of the soil and rock, chemical composition of the water, degree of weathering of rock, redox conditions and the residence time of groundwater in the soil and bedrock (Vesterbacka, 2007). Out of the isotopes of uranium, ^{238}U is the predominant contributor to natural radioactivity (Ahmed, 2004). The average ^{238}U content in the Earth's crust has been estimated to be 2.7 mg/kg and concentrations may be as high as 120 mg/kg in phosphate rocks (Padam *et al*., 1996). Meanwhile, the average ^{232}Th content of the Earth's crust is about 9.6 mg/kg (Firestone *et al*., 1996). Enhanced levels of uranium, thorium and their daughter products might be present in water in areas that are rich in natural radioactivity. As groundwater moves through fractures in the bedrock that contain these deposits, radioactive minerals can leach out into the groundwater system. Wells constructed in bedrock within such areas could show levels of natural radioactivity in water quality tests. The analysis of drinking and groundwater shows that the natural radioactivity in water varies over a wide range, mainly depending on the geological characteristics of the soil (Ahmed, 2004).

Uranium isotopes (^{238}U, ^{234}U and ^{235}U) have a non-negligible radiotoxicity (WHO, 1978; Malcome-Lawes, 1979). In addition, several radionuclides in the radioactive decay chain starting from ^{238}U and ^{235}U are highly radiotoxic. The most radiotoxic and most important among them is radium, which is a known carcinogen and exists in several isotopic forms. The predominant radium isotopes in groundwater are ^{226}Ra, an alpha emitter with a half-life of 1600 years, and ^{228}Ra, a beta emitter with a half-life of 5.8 years (Iyenger, 1990; Marovic *et al*., 1996; Sidhu and Breithart, 1998). Considering the high radiotoxicity of ^{226}Ra and ^{228}Ra, their presence in water and the associated health risks require particular attention. It is known that even small amounts of a radioactive substance may produce a damaging biological effect and that ingested and inhaled radiation can be a serious health risk (Rowland, 1993). When radium is introduced into the body, its metabolic behavior is similar to that of calcium and an appreciable fraction is deposited in the bones, the remaining fraction being distributed almost uniformly in soft tissues (Wrenn *et al*., 1985). When people are exposed to very high levels of radium for a long period of time, cancer of the bone and nasal cavity may result (Ahmed, 2004). On the basis of previous studies carried out within the Main Campus of the University of Ilorin, Nigeria (Nwankwo, 2008), the objective of this study is therefore, to determine the radiological suitability of groundwater for drinking by estimating the annual effective dose received by the population as a result of the combined ingestion of ^{226}Ra and ^{228}Ra in the groundwater supply, which is more pertinent for people using the local water sources. In addition, we propose to make appropriate recommendations.

EXPERIMENTAL PROCEDURE

Water samples were collected from 5 boreholes scattered within the Main Campus of the University of Ilorin, Nigeria. About six litres of water were collected in polyethylene containers. The water samples were stored in a refrigerator and kept for 30 days for secular equilibrium to be established before gamma ray spectrometry analysis was carried out. This method has been commonly used by workers (Ajayi et al., 1995; Jubril et al., 1999; Nwankwo, 2008). The spectrometer consists of a Canberra 7.6cm by 7.6cm NaI (TI) detector coupled with a Canberra series 10 plus Multichannel Analyzer (MCA) through a pre-amplifier base. The transition lines of 1764.5 keV of ^{214}Bi and 2614.7 keV of ^{208}Tl were used to determine the concentrations of ^{226}Ra (decay series of naturally occurring radionuclide headed by ^{238}U) and ^{228}Ra (decay series of naturally occurring radionuclide headed by ^{232}Th) respectively (Ahmed, 2004; Nasirian et al. 2008; Lydie and Nemba, 2009; Ajayi and Adesida, 2009).

The samples were transferred to a one-litre Marinelli sample container, which fits into the detector. Counting was done for 10 hours because of the low natural activities of radionuclides in water. The spectrum was measured and the area under the photopeaks was computed using the algorithm of the MCA. Environmental shielding of the water was achieved using a Canberra 10cm thick lead castle (Farai and Sanni, 1992).

Each radionuclide concentration C, in each water sample was evaluated using the relation (Lydie and Nemba, 2009):

$$C = \frac{N(E_y)}{\varepsilon(E_y).I_y.V.t_c} \tag{1}$$

where $N(E_y)$ is the net peak area of the radionuclide of interest, $\varepsilon(E_y)$ is the efficiency of the detector for the energy E_y, I_y is the intensity per decay for the energy E_y, V is the volume of the water sample and t_c is the total counting time in second (36000 s).

When analyzing the total annual effective dose to the human population from natural sources, the dose received by ingestion of long-lived natural radionuclides must be considered. Effective doses resulting from the intake of ^{226}Ra and ^{228}Ra may be determined directly from external measurements of their concentrations in the body or estimated from intake concentrations of materials such as air, food and water. The intakes of the natural radionuclides ^{226}Ra and ^{228}Ra through groundwater in the campus were calculated. The contribution of ^{40}K is neglected because it is always a fixed fraction of the inactive potassium that is kept in balance by the body so that any extra potassium is eliminated by the body. The annual effective dose was calculated with the intake of individual radionuclide and ingestion dose coefficients (Sv Bq^{-1}) reported by the International Commission on Radiological Protection (ICRP, 1994). The equation for calculating the annual effective dose (AED) per person is given by:

$$AED = \sum_i I_i.365.D_i \tag{2}$$

where I_i is the daily intakes of radionuclide I (Bq d^{-1}) and the ingestion dose coefficient D_i for ^{226}Ra and ^{228}Ra is 2.8 x 10^{-7} and 6.9 x 10^{-7} SvBq^{-1} respectively (ICRP, 1994).

RESULTS AND DISCUSSION

Measured activity concentrations of ^{226}Ra and ^{228}Ra, which are the decay products of ^{238}U and ^{232}Th respectively, are presented in Table 1. The activity concentrations of ^{226}Ra and ^{228}Ra range from 0.03±0.02 to 4.79±1.26 Bq l^{-1} and 0.01±0.00 to 4.79±1.82 Bq l^{-1} respectively. Abuja Hostel has the highest concentration of ^{226}Ra while it was not detectable in the Male Hostel sample. The highest and lowest concentrations of ^{228}Ra were found in New PG Hostel sample and Male Hostel sample respectively. The mean activity concentration values were 1.51±0.44 and 1.74±0.78 Bq l^{-1} for ^{226}Ra and ^{228}Ra respectively.

Assuming the volume of drinking water for the young adults in the study area to be 1 litre/day, the daily intake per person of ^{226}Ra and ^{228}Ra through groundwater in all locations is shown in Table 2. The computed annual effective dose received by the population as a result of the ingestion of ^{226}Ra and ^{228}Ra is thus estimated to range from 0 to 0.49 mSv y^{-1} and 0.003 to 1.21 mSv y^{-1} respectively. This is shown in Table 3.

Table 1. Activity concentration of ^{226}Ra and ^{228}Ra

Sample	^{226}Ra (Bq l^{-1})	^{228}Ra (Bq l^{-1})
Lagos Hostel	0.03±0.01	0.03±0.02
Abuja Hostel	4.79±1.26	3.80±2.03
Male Hostel	0.00±0.00	0.01±0.00
New PG Hostel	2.29±0.92	4.79±1.82
LT4	0.05±0.02	0.09±0.04
Mean	1.51±0.44	1.74±0.78

Table 2. Assumed Daily intake of ^{226}Ra and ^{228}Ra

Sample	^{226}Ra (Bq d^{-1})	^{228}Ra (Bq d^{-1})
Lagos Hostel	0.03±0.01	0.03±0.02
Abuja Hostel	4.79±1.26	3.80±2.03
Male Hostel	0.00±0.00	0.01±0.00
New PG Hostel	2.29±0.92	4.79±1.82
LT4	0.05±0.02	0.09±0.04
Mean	1.51±0.44	1.74±0.78

Table 3. Estimated annual effective dose

Sample	^{226}Ra (mSv y^{-1})	^{228}Ra (mSv y^{-1})
Lagos Hostel	0.003	0.008
Abuja Hostel	0.49	0.96
Male Hostel	0	0.003
New PG Hostel	0.23	1.21
LT4	0.005	0.023
Mean	0.15	0.44

The mean annual effective dose from ^{226}Ra is found to be 0.15 mSv y^{-1} and that due to ^{228}Ra is 0.44 mSv y^{-1}. The doses from ^{226}Ra and ^{228}Ra in the water samples are found to be less than 1 mSv y^{-1} except in New PG Hostel, which has 1.21 mSv y^{-1} for ^{228}Ra. However, the total annual effective dose received as a result of the combined ingestion of ^{226}Ra and ^{228}Ra is consequently found to range from 0.003 to 1.45 mSv y^{-1} with an average of 0.59 mSv y^{-1}. Table 4 shows that the total annual effective dose received as a result of the combined ingestion of ^{226}Ra and ^{228}Ra from the Abuja Hostel and New PG Hostel samples are above 1 mSv y^{-1}, which is the recommended limit from ICRP. The comparison is shown in Fig. 1. Radium is highly radiotoxic; people who consume the water face the risk of some health effects that may result from the significant accumulation of radium in their bones and other radiosensitive soft body tissues (Ajayi and Adesida, 2009). Hence remedial measures should be taken to reduce radium from affected boreholes. Ajayi and Adesida (2009) suggested that such water sources must be treated using conventional water treatment methods that remove radium from groundwater.

Table 4. Total annual effective dose

Sample	mSv y^{-1}
Lagos Hostel	0.011
Abuja Hostel	1.45
Male Hostel	0.003
New PG Hostel	1.44
LT4	0.028
Mean	0.59

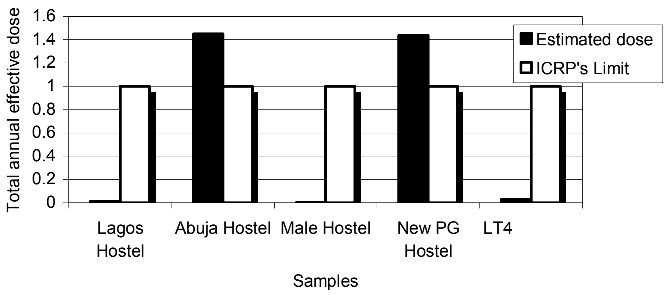

Fig. 1. Total effective dose compared to the ICRP limit.

CONCLUSION

This study has shown that although the average combined contribution of ^{226}Ra and ^{228}Ra activities to the committed effective dose from a year's consumption of drinking water in the study area is less than the ICRP's recommended limit of 1 mSv y^{-1}, the groundwater from two boreholes showed values of more than 1 mSv y^{-1}. These boreholes were taken from the Abuja Hostel and New PG Hostel. For this reason, it is recommended that adequate measures should be taken to protect the young populace in the study area from consuming radiologically unsafe drinking water from the affected boreholes.

Acknowledgement. *The author is grateful to the Centre for Energy Research and Development (CERD), Obafemi Awolowo University, Ile-Ife, Nigeria for the facilities made available for this work.*

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GODIŠNJA EFEKTIVNA DOZA USLED ZAJEDNIČKOG EFEKTA KONCENTRACIJA ^{226}RA I ^{228}RA U PODZEMNIM VODAMA: STUDIJA SLUČAJA NA UNIVERZITETU ILORIN MAIN CAMPUS, NIGERIJA

Levi I. Nwankwo

Izvršena je procena godišnje efektivne doze dobijene od stanovništva kao posledica unosa ^{226}Ra i ^{228}Ra iz podzemnih voda iz oblasti na kojoj se nalazi univerziet Ilorin u Nigeriji. Uzorci podzemnih voda iz postojećih bušotina na lokacijama u okviru samog univerziteta su analizirane upotrebom γ-zraka spektroskopije kako bi se utvrdila njihova pogodnost za ljudsku upotrebu. Vrednosti koncentracija dobijene na osnovu analize kreću se od 0.03±0.02 do 4.79±1.26 Bq l^{-1} za ^{226}Ra i od 0.01±0.00 do 4.79±1.82 Bq l^{-1} za ^{228}Ra. Izračunate godišnje efektivne doze kojima je izložena populacija kao posledica unošenja ^{226}Ra i ^{228}Ra u organizam je tako procenjena na vrednosti od 0 do 0.49 mSv y^{-1} i 0.003 do 1.21 mSv y^{-1} tim redosledom. Sveukupne godišnje efektivne doze koje se unesu kao posledica kombinovanog unošenja ^{226}Ra i ^{228}Ra se samim tim mogu naći u rasponu od 0.003 do 1.45 mSv y^{-1} sa prosečnom vrednošću od 0.59 mSv y^{-1}. Smatra se da iako prosečna kombinacija ^{226}Ra i ^{228}Ra aktivnosti u efektivnoj dozi na osnovu jednogodišnjeg unosa upotrebom pijaće vode u navedenoj oblasti je manja od vrednosti koja je propisana i koja iznosi 1 mSv y^{-1}, dok je vrednost uzorka iz nekih bušotina veća od 1 mSv y^{-1}. Upravo iz ovog razloga, preporučuje se da se adekvatne mere preduzmu kako bi se mlađe populacije zaštitile od unosa radiološki neispravne vode za piće iz kontaminiranih bušotina.

Ključne reči: *radioaktivnost, sistem podzemnih voda, spektroskopija, efektivne doze i Nigerija*