DETERMINATION OF RADIOACTIVITY IN MAIZE AND MUNG BEANS GROWN IN THE NEIGHBOURHOOD OF MINJINGU PHOSPHATE MINE, TANZANIA

Leonid L. Nkuba and Najat K. Mohammed*
Department of Physics, University of Dar es Salaam, P. O. Box 35063, Dar es Salaam, Tanzania.
E-mail addresses: leonid_nkuba@yahoo.co.uk; najat@udsm.ac.tz
** Corresponding author*

ABSTRACT

Two staple foods (maize and mung beans) which were cultivated in Minjingu village, where there are phosphate deposits in Tanzania, were collected directly from the farms. The activity concentrations of ^{226}Ra, ^{228}Th and ^{40}K were determined in the maize and mung beans samples using γ-ray spectrometry employing HPGe detector of relative efficiency of 51.0%. The mean radioactivity levels in the food samples were found to be 21.01 ± 0.8 Bq/kg (mung beans), 25.6 ± 0.7 Bq/kg (maize) for ^{226}Ra, 62.6 ± 1.1 Bq/kg (mung beans), 72.9 ± 1.0 Bq/kg (maize) for ^{228}Th and 542.9 ± 8.6 Bq/kg (mung beans), 434.6 ± 18.7 Bq/kg (maize) for ^{40}K. The radioactivity contents of the maize and mung beans from Minjingu village were higher than that of similar food samples collected from Bukombe district in Geita Region in Tanzania. The total annual effective dose for consumption of ^{226}Ra and ^{228Th} by adults was found to be 2.003 ± 0.044 mSv/year, which is higher than the annual dose limit of 1 mSv/year recommended by the ICRP for the general public. Hence a conclusion could be made that food crops cultivated at Minjingu village might expose the population to high radiation doses which might be detrimental to their health.

Keywords: Radioactivity, annual effective dose, Minjingu Phosphate mine, High Background Radiation Area

INTRODUCTION

Food crops from contaminated environment may accumulate radioactivity that could form a direct route of exposure to human population when consumed. Therefore, the knowledge of radioactivity levels in grown food crops is very important in order to establish the doses received by populations. The main radioactive environmental contaminations in Tanzania are from the natural radioactive materials that could enter the environment either through uncontrolled mining activities or from the uses of phosphate fertilizers which are manufactured from phosphate rocks (Banzi et al. 2002). Phosphate rocks are reported to contain radioactivity in order of magnitude higher than normal soil and other rocks (Shukla et al. 1982).

The phosphate rocks from Minjingu have shown to have higher activities of ^{238}U (4641 Bq/kg) and ^{226}Ra (5022 Bq/kg) and ^{232}Th in contrast to many other rocks found in the world (Shukla et al. 1982, Banzi et al. 2002, Ogunleye et al. 2002). Because of that, Minjingu was termed as a high background radiation area in Tanzania (Bianconi 1987, Banzi et al. 2000, 2002). The phosphate in Minjingu is mined to be exported to the neighbouring countries as well as be used to manufacture fertilizer for local uses. The mine, which is also carrying the processing of the phosphate, is within the village of Minjingu, which is located in semi-arid zone with approximately 11,000 inhabitants (Nkaiti Ward Census 2010). The soil in Minjingu, which might have high activities due to phosphate deposits in the area may as well be contaminated through ore dust resulting from mining processes. Therefore, food crops grown in the neighbourhood of the Minjingu phosphate mine may also be contaminated.

The radioactivity levels in soil can plausibly be used to show the magnitude of contamination in locally grown food crops, but they cannot describe the biological effects of radiation exposure to individuals who consume that food. Therefore, the estimation of doses is usually carried out for assessing health safety of an individual undergoing radiation exposure through ingestion of contaminated food. The intake of radionuclides within food is dependent on the concentrations of radionuclides in various food crops and on the food consumption rates. The risks associated with intake of radionuclides in the body are proportional to the total doses delivered by radionuclides while staying in various organs. In general, it is assumed that stochastic effects occur linearly with doses and usually the annual effective dose quantities ($E_{(\tau)}$) are usually used to define those risks when prolonged exposure to a single individual from a single intake of a radionuclide is being considered. Therefore, the present study determined the specific activities from maize and mung beans grown in the neighbourhood of Minjingu phosphate mine and from the activities the annual effective doses received by population were calculated.

Materials and Methods

Description of the study area

The Minjingu phosphate mine in Minjingu village is located to the east of the saline Lake Manyara along the rift valley escapement in Manyara region in the northern Tanzania at latitude 03°42′30.9″ S and longitude 035°54′ 56.3″ E (Figure 1). The Minjingu village occupies approximately a land area of 24,000 hectares with a population of about 11,000 people (URT 2012). The phosphate rocks at Minjingu are mined by the open dry process, a method that can lead to the dispersion of large amounts of dust to the environment. Such emission may give rise to enhanced exposure to naturally occurring radionuclides through air, soil, vegetation and water.

Agriculture, pastoralism and phosphate mining are the land uses developments in Minjingu village. Crops cultivated for subsistence living in the area include maize, mung beans and cowpeas, while for income generation the crops include watermelon, cotton and sesame.

Sample collection and preparation

In this study, samples were collected in farms within an area covered with a radius of 6.82 km from the Minjingu phosphate mine to the north and west of the village. Maize and mung beans were identified as the main staple foods, hence were collected for analysis. A total of 20 samples of maize (mass 1000 g each) and 13 samples of mung beans (mass of 1000 g each) were collected from the farms in different locations within an area covered with a radius of 6.82 km from the Minjingu phosphate mine to the north and west of the village. Two samples (one for maize and the other for mung beans) taken from Bukombe district in Geita Region, which is far from Minjingu area were used as controls to make comparisons.

Samples were sun dried for 2 days and then oven dried at 45–50 °C for 48 hours (Holynsca and Jasion 1986). They were then crushed into small grains using mortar and pestle, and by using Monomill pulverizer, the samples were pulverized into powder, then sieved to reduce particle sizes to the recommended size of 2 mm (IAEA 1989), and finally the samples were homogenized. The homogeneous powdered samples were packed (100 g for maize and 130 g for mung beans) into cylindrical stainless steel canister to a height of 1.8 cm. They were then sealed using glycerine and wrapped by using gas tightness insulation tape to avoid escape of radon gas and stored for more than 21 days to allow attainment of the radioactive equilibrium stage between ^{226}Ra and its short-lived decay products (Banzi et al. 2000).

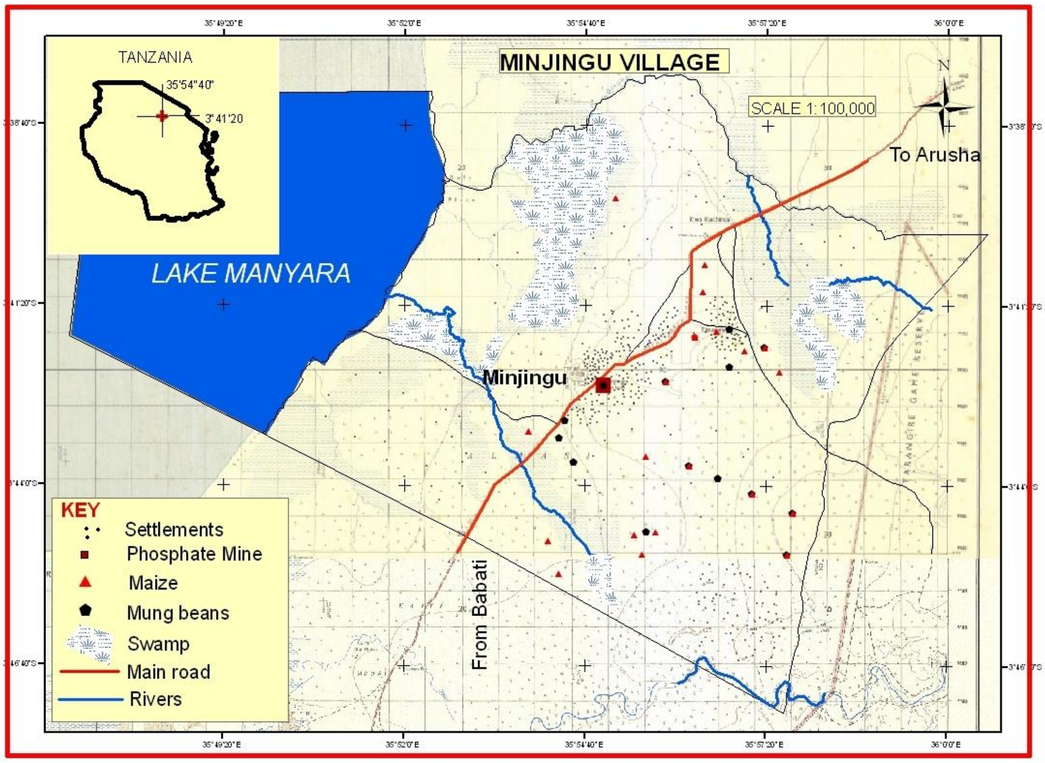

Figure 1: The map of Minjingu Village showing the sampling sites.

Selection of γ-lines

The activity of ^{226}Ra was obtained through the peak intensities of γ-lines of ^{214}Pb (295.21 keV and 351.92 keV) and ^{214}Bi (609.31 keV and 1120.29 keV), respectively. The activities of ^{228}Ac (338.32 keV, 911.60 keV and 969.11 keV), and ^{208}Tl (583.19 keV and 860.50 keV) were considered to represent the ^{228}Th activities. Measurements of ^{40}K activity concentrations were determined directly by 1460.81 keV γ-line emissions.

Accuracy and precision of results

For quality assurance, the IAEA Soil 375 standard reference material (SRM) was weighed (164 g) in the same method as the samples and packed in cylindrical stainless steel canister at a height of 1.8 cm. As Table 1 shows, the experimental values agreed well with the recommended values approximately within ± 7 % accuracy for ^{226}Ra, ± 11% for ^{228}Th and ± 10% for ^{40}K.

Results and Discussion

Radioactivity of maize samples

The mean values of natural radionuclide activity concentrations in maize samples collected from Minjingu Village are reported in Table 2. Specific activities concentrations of ^{226}Ra, ^{228}Th and ^{40}K are reported in Bq/kg dry weight and the errors are the statistical uncertainties of 20 maize samples.

The radionuclides ^{226}Ra, ^{228}Th and ^{40}K were detected in all the samples of maize analysed in this study. As it is seen in Table 2, the mean activity concentrations of ^{226}Ra, ^{228}Th in maize samples from Minjingu Village were higher than the concentrations in control samples collected from Bukombe district in Geita Region. These values were higher by factors of 3 and 12 for ^{226}Ra and ^{228}Th, respectively, than their concentrations in control samples. Whilst for ^{40}K, the activity concentration value of control was within the range found in maize cultivated in Minjingu.

Table 1: The standard reference values and experimental values of the IAEA Reference Soil 375

Radionuclides	Experimental activity (Bq/kg)	Certified values (Bq/kg)
^{226}Ra	21.5	20.0
^{228}Th	22.7	20.5
^{40}K	466.4	424

Table 2: The activity concentrations (Bq/kg ± SEM) of ^{226}Ra ^{228}Th and ^{40}K on maize samples collected from Minjingu Village

Radionuclides	Mean activity	Minimum activity	Maximum activity	Standard deviation (SD)	Control activity
^{226}Ra	25.6 ± 0.7	21.2	31.8	3.0	6.5
^{228}Th	72.9 ± 1.0	64.1	79.8	4.4	5.3
^{40}K	434.6 ± 18.7	260.7	548.4	83.8	346.7

The activity concentrations in maize samples collected from Minjingu village ranged from 21.2 Bq/kg to 31.8 Bq/kg, 64.1 Bq/kg to 79.8 Bq/kg and 260.7 Bq/kg to 548.4 Bq/kg with standard deviations values of 3.0 Bq/kg, 4.4 Bq/kg and 83.8 Bq/kg for ^{226}Ra, ^{228}Th and ^{40}K, respectively. The concentrations of radionuclides in the food crops depend on the concentrations in the soil (Jibiri *et al.* 2007). Therefore, low SD values for both ^{226}Ra and ^{228}Th in maize samples might indicate even distribution of the radionuclides in the soil within the big area of Minjingu involved in this study.

The activity concentrations of all three radionuclides in this study were higher than the concentrations reported in maize samples collected in other areas of Tanzania. The mean activity of ^{226}Ra was 8 times higher than the mean value reported in maize from Likuyu Village (Mohammed and Mazunga 2013). However, the lower extreme value of the range obtained in this study was similar to the upper value of the range reported in maize from Mbeya cultivated with the extensive applications of phosphate fertilizer from Minjingu (Mlwilo et al. 2007). The activity concentrations of ^{228}Th in samples analysed in the present study were higher than its values in maize from other places in Tanzania reported by Mlwilo et al. (2007) and Mohammed and Mazunga (2013) by factors of 15 and 18, respectively. ^{40}K in maize from Minjingu had higher activity concentrations by a factor of 9 than the mean activity in maize samples collected from Mbeya region reported by Mlwilo et al. (2007) and 16 times higher than the values reported from Likuyu Village (Mohammed and Mazunga 2013).

Moreover, the mean concentration for ^{226}Ra in maize from Minjingu was higher than the values reported in 4 out of 5 literatures surveyed in this work (Asefi et al. 2005, Romilton dos Santos et al. 2005, Jibiri and Abiodun 2012). The mean activity value was 14 times higher than the mean activity concentration reported in maize samples from Southwestern Nigeria (Jibiri and Abiodun 2012). This activity value of ^{226}Ra in maize from Minjingu was also about 20 times higher than the values reported in maize from Bangladesh, Iran and Brazil (Asefi 2005, Romilton dos Santos et al. 2005). At the same time, the concentrations of ^{226} Ra found in maize samples from Minjingu were lower than the value of 34.1 ± 14.2 Bq/kg reported by Jibiri et al. (2007) in maize samples from a high background area (HBRA) of Bitsichi, Josh Plateau in Nigeria.

Radioactivity of mung beans samples

Natural radioactivity concentrations in mung beans samples collected from Minjingu Village are reported in Table 3. The errors shown in the results are the statistical uncertainties of 13 mung beans samples and are expressed as the standard errors of the mean (SEM).

Table 3: The activity concentrations (Bq/kg ± SEM) of ^{226}Ra ^{228}Th and ^{40}K on mung beans samples collected from Minjingu Village

Radionuclides	Mean activity	Minimum activity	Maximum activity	Standard deviation (SD)	Control activity
^{226}Ra	21.0 ± 0.8	16.2	26.7	2.8	5.5
^{228}Th	62.6 ± 1.0	53.2	68.2	3.8	4.5
^{40}K	542.9 ± 8.5	453.7	574.3	30.8	423.1

The radionuclides ^{226}Ra, ^{228}Th and ^{40}K were detected in all 13 samples of mung beans analysed in this work. The activity concentrations in mung beans samples were higher than the concentrations in the control samples collected from Bukombe, Geita Region. It was found that the minimum activity values of mung beans sample from Minjingu was higher by factors of 3 and 12 for ^{226}Ra and ^{228}Th, respectively, than that of control sample. Whilst the value of ^{40}K was approximately the same as control samples for mung beans.

Table 4 shows the comparison of concentrations obtained in this study with those obtained in food samples inside and outside Tanzania. Minjingu is reported to be High Background Radiation Area (Bianconi 1987). Hence the maize and mung beans cultivated in this area were expected to have elevated concentrations of radionuclides than maize and mung beans cultivated from other regions in Tanzania. However, the mean concentration values for ^{226}Ra in both maize and mung beans analysed in this study were much lower than the mean value in edible vegetation from Minjingu reported by Banzi et al. (2000).

The activity concentrations of ^{226}Ra and ^{228}Th in mung beans from this study were higher than the activities of beans collected in Likuyu Village by factors of 7 and 20, respectively (Mhammed and Mazunga 2013). In surveyed literature outside Tanzania, concentrations of ^{226}Ra in mung beans collected from Minjingu were also higher than the means reported elsewhere. Mung beans from Minjingu had activity concentrations 2 times higher than that from Bitsichi, Jos plateau in Nigeria, 39 times higher than that reported from HBRA of the Posos de Caldas Plateau in Brazil (Amaral et al. 1992, Jibiri et al. 2007). The mean concentration of ^{228}Th in maize was found to be higher than the values reported in maize from Likuyu and from Mbeya (Mlwilo et al. 2007).

Table 4: Activity levels (Bq/kg) of ^{226}Ra, ^{228}Th, and ^{40}K on maize and beans samples from Minjingu and similar samples from other areas (around the world)

Study	Maize			Beans		
	Ra-226	Th -228	K-40	Ra-226	Th -228	K-40
Average Range Present Study	25.6 ± 3.1 21. 2– 31.8	72.9 ± 4.3 64.1 -79.8	434.6 ± 84 261 – 548	21.0 ± 2.8 16.2 – 26.7	62.6 ± 3.4 53.2 - 60.2	542.9 ± 31 454 - 574
Mbeya-Tanzania (Mlwilo *et al.* 2007)	9.7 ± 5 6.2 – 20.0	17.5 ± 5.5 MDL – 23.0	--	--	--	--
Dar es Salaam-Tanzania (Mlwilo *et al.* 2007)	11 ± 7.2 4.0 – 22.0	MDL	--	--	--	--
Likuyu Village-Tanzania (Mohammed and Mazunga, 2013)	3.2 ± 0.2	5.0 ± 0.3	--	2.93 ± 0.18	3.12 ± 0.31	--
Nigeria (Jibiri *et al.* 2007)	34.1 ±14.2	MDL	243.3 ± 21.2	9.4 ± 2.4	18.9 ± 6.4	453.6 ± 28.6
Nigeria (Jibiri *et al.* 2012)	1.8 ± 0.7	6.6 ± 0.7	386.3 ± 34.3	--	--	--
Minjingu edible leaf (Banzi *et al.* 2000)	393 ± 9	318 ± 2.6	1568.0 ± 73.3			

The natural radioactivity of ^{226}Ra ^{228}Th and ^{40}K in maize and mung beans samples from Minjingu analyzed in this study were found to be higher than those reported in the surveyed literature. This might be because the Minjingu phosphate rocks have shown higher activities of ^{226}Ra ^{228}Th and ^{40}K in contrast to many other rocks found in the world (Shukla et al. 1982, Banzi et al. 2002, Ogunleye et al. 2002). Banzi et al. (2000) reported concentrations of ^{226}Ra in the Minjingu phosphate rocks as 5760 ± 107 Bq/kg. The activity concentrations of ^{40}K in both maize and mung beans were found to be higher compared to the concentrations of ^{228}Th and ^{226}Ra in samples from Minjingu. These values were also above the world range of 40 Bq/kg to 240 Bq/kg of ^{40}K in food crops reported by Maul and O'Hara (1989). High concentrations of ^{40}K in the food samples might be attributed to concentrations of ^{40}K in the soil, which may be associated with the geological properties of the area (Saidou et al. 2010).

The radioactivity in foods depends on many factors such as the concentrations of radionuclides in soil, the means of agriculture (such as the use of fertilizer) and the uptake of radionuclides by the plant, which is a dependant of the plant species (Jibiri et al. 2007). There are always variations in the accumulation of radionuclides among different species that grow under the same conditions (Kuo et al. 1997). Hence, the differences in radioactivity in the two foods found in this work might be influenced by the differences in uptake of radionuclides.

Dose assessment

In this study, a small survey was conducted to collect food consumption patterns specifically for Minjingu population in order to estimate the food consumption rates for the selected food crops. The food consumption rates were found to be 151.2 kg capita^{-1} year^{-1} and 11.9 kg capita^{-1} year^{-1} for maize and mung beans, respectively. Therefore, using the annual effective dose per intake (dose conversion factors) provided by ICRP (1996), food consumption rates for Minjingu population and the radioactivity concentration found in the analysed food samples as input to equation 1, the annual committed effective dose, $E_{(\tau)\ ing,\ p}$ is the annual committed effective dose from consumption of nuclide *i* in foodstuff *p* (mSv/year), from food crops were calculated and presented in Table 5.

$$E_{(\tau)ing,p} = D_{ing} F_p C_{p,i} \qquad (1)$$

Where; $E_{(\tau)\ ing,\ p}$ is the annual effective dose from consumption of nuclide *i* in foodstuff *p* (mSv/year), $C_{p,\ i}$ is the concentration of radionuclide *i* in foodstuff *p* at the time of consumption (Bq/kg), F_p is the consumption rate for foodstuff *p* (kg/year), and D_{ing} is the dose coefficient for ingestion of radionuclide *i* (mSv Bq^{-1}) given by ICRP (1996), which varies with both radionuclides and the age of individuals. The total effective dose to an individual from radionuclide *i* in food crop *p* was established by summing contributions from all radionuclides present in food crop.

Table 5: Total annual effective doses from ^{226}R and ^{228}Th, for adults of age > 17, calculated using Minjingu food consumption rates.

Radionuclide	Effective Dose (mSv/year ± SEM)		
	Maize	Mung beans	Total
^{226}Ra	1.08 ± 0.03	0.070 ± 0.003	1.15 ± 0.03
^{228}Th	0.79 ± 0.01	0.054 ± 0.001	0.85 ± 0.01
Total	1.87 ± 0.04	0.124 ± 0.004	2.00 ± 0.04

The dose calculation in this study takes into account only two radionuclides ^{226}Ra and ^{228}Th, as ^{40}K it is an essential biological element distributed throughout the body and its concentrations in human tissue are under metabolic (homeostatic) control. Thus its levels in humans are not normally affected by variations in the environmental levels, and as a result, its radiation dose within the body remains constant (Shanthi et al. 2009, UNSCEAR 2000).

The total calculated annual effective dose for adults (> 17 years) in this paper is 2.003 ± 0.044 mSv/year (Table 5). This dose value is higher than the reported annual effective dose from HBRAs in Asia from the dietary intake of these two radionuclides (Iyengar et al. 2004, Pradyumna et al. 2012). The dose value is also higher than the annual dose limit of 1 mSv/year recommended by the ICRP for the general public. However, high dose value of 2.38 mSv/year was reported by Jibiri et al. (2007) in HBRA of Bitsichi, Josh Plateau in Nigeria. Among the analysed radionuclides ^{226}Ra was found to be the major contributor to the dose from maize (Table 5).

About 93.8% the total effective dose for adults (age group > 17 years) due to consumption of the two staple foods was contributed by maize. This is because maize is consumed much more than mung beans. ^{226}Ra contributed to about 57.7% of the total committed effective dose, whilst ^{228}Th contributed 42.3% of the total committed effective dose.

The total annual effective dose calculated in this work might be overestimated. This is because; the calculation of food consumption rates assumed no importation of maize and mung beans from outside the Minjingu Village. However, in some cases depending on the climatic conditions of a particular year, the harvest might become insufficient to cover for the whole year, and the village had to import food from other areas. Hence, the annual effective doses received by the population from the food crops grown in Minjingu might be variable.

CONCLUSION

The radioactivity concentrations for ^{226}Ra and ^{228}Th in analysed maize and mung beans samples from Minjingu were higher than those of controls. This might be because Minjingu village is close to the phosphate mine. In this study, ^{226}Ra is accumulated more in maize than in mung beans cultivated in the same area. The annual effective dose for adults (> 17 years) calculated in this paper is 2.003 ± 0.044 mSv/year. This dose value is higher than the reported annual effective dose from HBRAs in Asia from the dietary intake of these two radionuclides (Iyengar et al. 2004, Pradyumna et al. 2012). The dose value is also higher than the annual dose limit of 1 mSv/year recommended by the ICRP for the general public. Hence a conclusion could be made that maize and mung beans cultivated at Minjingu Village expose the population to high radiation doses, which might be detrimental to their health.

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