Radioactivity And Dose Assessment Of Rock And Soil Samples From Homa Mountain, Homa Bay County, Kenya

D. Otwoma[1,2,*], J. P. Patel[2] , S. Bartilol[3] and A.O.Mustapha[4]
[1] *Ministry of Energy, P. 0. Box 30582, Nairobi, Kenya*
[2] *Department of Physics, University of Nairobi, P. O. Box 30187, Nairobi, Kenya*
[3] *Institute of Nuclear Science, University of Nairobi, Nairobi, Kenya*
[4] *Department of Physics, Federal University of Agriculture, Abeokuta, Nigeria*
[*] Corresponding author: otwoma@uonbi.ac.ke *and* otwooma@gmail.com

ABSTRACT

The in situ measured average outdoor absorbed dose rate in air was found to vary from 108.4 to 1596.4 nGy h^{-1} at Homa Mountain area in southwestern Kenya. Rock and soil samples collected gave average values of the radioactivity concentrations of ^{40}K, ^{226}Ra and ^{232}Th of 915.6, 195.3 and 409.5 Bq kg^{-1}, respectively. The range of the annual effective dose for a person living in Homa Mountain area calculated varied from 28.6 to 1681.2, with a mean of 470.4 µSv. These results imply Homa Mountain have elevated levels of natural radioactivity thus the region is a high background radiation area.

INTRODUCTION

External irradiation from radionuclides naturally present in the environment is an important component of the exposure of human populations. Inescapable feature of life on earth include radiation exposure due to terrestrial from natural occurring radioactive material (NORM), cosmic and internal sources. The main sources of NORM are ^{40}K, ^{238}U (^{226}Ra) and ^{232}Th and are present in various degrees in all media in the environment, including the human body itself. In terms of NORM, the igneous rocks of granitic, carbonatite and alkaline composition are enriched in K, Th and U, compared to rocks of basaltic[1,2,3,4]. These exposures originate primarily from gamma radiation arising from decay of these radionuclides at locations outside the human body. Since these radioisotopes are not uniformly distributed in nature, knowledge of their dispersal in rocks and soils plays an important role in radiation protection and measurement. Owing to the health risks associated with the exposure to indoor radiation, many governmental and international bodies such as the International Commission on Radiological Protection (ICRP)[5] have adopted measures at minimizing such exposures.

In Kenya, Mustapha[2], Hashim[6] and Achola[7] determined the radionuclide content of NORM in building materials and radiation dose rates.

The aim of this study is to determine the activity levels of radionuclides in rock and soil around Homa Mountain area in southwestern Kenya. The annual effective dose equivalent (AEDE) from terrestrial radiation were calculated and compared to those measured in situ. The results obtained are compared with national and world average. Local authorities can use the results of this study to limit the use of building materials that can cause a significant increase in radiation exposure due to higher level external gamma exposure. This is the first study to assess the level of the background radiation in Homa Mountain area.

SURVEY AREA AND SAMPLING

Homa Mountain is a large carbonatite complex that forms a broad peninsula on the eastern shores of Lake Victoria. It is bound by latitude 0^0 30' N and 0^0 20' N and longitude 33^0 26' E and 34^0 34' E. The complex is defined as a series of cone sheets of carbonatites and breccias intrusions in the oldest rock in the Nyanzian series composed of shattered Nyanzian and ijolites as described by Le Bas[8] and Mulaha[9]. Increased human habitation is encroaching on the carbonatite hills surrounding Homa Mountain and satellite hills.

Field measurements and sample collection

Radioactivity measurements were carried out in the field using Radiagem hand held survey meters that could be coupled with NaI (Tl). The study area, shown in green in Figure 1, was traversed on foot, and ambient dose equivalent rates in air were measured 1 meter (gonad height) from the ground at suitable sites including around dwellings, farmlands, water sources and yet to be settled areas currently used for growing crops, grazing cattle or recreation. The coordinates of the readings were determined by global positioning system. At chosen sites soil was scooped while rock pieces were chipped from outcrops and transferred to the laboratory. A total of 44 samples were taken.

MATERIALS AND METHODS

Calibration of the Radiagem was done by comparing its readings to similar equipment exposed to known X-ray and ^{137}Cs gamma sources. Gamma spectroscopy was used to determine the activities of ^{40}K, ^{226}Ra and ^{232}Th with a p-type intrinsic hyper pure germanium (HpGe) coaxial detector mounted vertically and coupled to a 3 kV digital high voltage source. The HpGe detector was calibrated for energy and relative efficiency using calibration sources containing ^{133}Ba, ^{22}Na, ^{137}Cs, ^{54}Mn and ^{60}Co. A performance test using IAEA[10] standard reference material Soil-375, RGU, RGTh and RGK was used for checking the efficiency of the calibration of the system as done by Mustapha[2], Achola[7] and Hisham[6].

Sample Preparation and Analysis

In the laboratory, these samples were dried in air and then pulverized, homogenized and sieved through 100 μm mesh. 200 g samples were carefully weighed and packed in standard plastic containers which were properly tightened and hermetically sealed with aluminum foil to prevent escape of gaseous ^{220}Rn and ^{222}Rn and stored for 30 days to allow secular equilibrium between thorium and radium and their decay products.

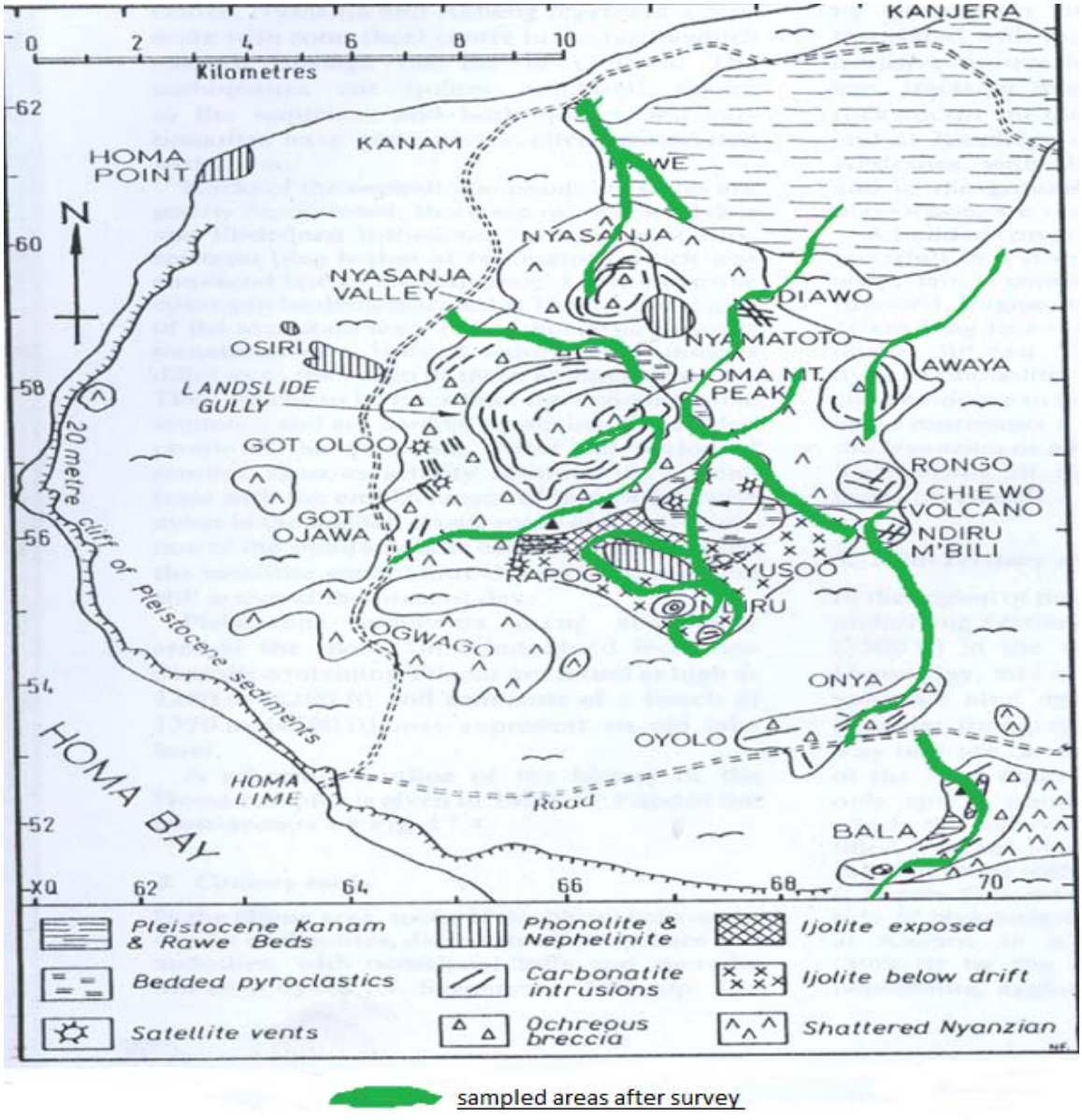

Figure 4. Sketch map of Homa Mountain area east of Homa Bay with green showing sampled areas after survey meter measurements

Radiometric and indicative Dose Analysis

The activity concentrations of ^{226}Ra and ^{232}Th were calculated assuming a secular equilibrium with their decay products. The gamma transition energies of 351.9 keV of ^{214}Pb and 609.2 keV of ^{214}Bi were used to determine the concentrations of the ^{238}U (^{226}Ra) series. The gamma transition energies of 238.6 keV of ^{212}Pb, 583.1 keV of ^{208}Tl and 911 keV of ^{228}Ac were used to determine the concentrations of the ^{232}Th series. The activity concentration of ^{40}K was determined from the peak areas of 1460 keV.

The contribution of natural radioisotopes to absorbed dose rate in air (ADRA) depends on the concentrations of the radioisotopes in the rock and soil. The contribution of terrestrial

gamma radiation to absorbed dose rate in air at 1 m above the ground (ADRA) can be calculated using the following formula[1, 3, 4, 11] .

$$\mathbf{ADRA = 0.043C_K + 0.427C_{Ra} + 0.666C_{Th}} \quad \mathbf{(1)}$$

where C_K, C_{Ra} and C_{Th} are the activity concentrations of ^{40}K, ^{226}Ra and ^{232}Th, respectively, in the rock and soil samples in units of Bq kg^{-1}. The world average annual effective dose equivalent (AEDE) from outdoor terrestrial gamma radiation for Homa Mountain region was calculated as recommended by UNSCEAR[1, 4]:

$$\mathbf{AEDE = ADRA \times DCF \times OF \times T} \quad \mathbf{(2)}$$

Where DCF is dose conversion factor (0.7 Sv Gy^{-1}), OF is outdoor occupancy factor (0.2) and T is the time factor (8766 h) taking leap year into account.

RESULTS AND DISCUSSIONS

Air Absorbed Dose Rate in Air Results from Survey in Situ Measurements

Table 1 shows the important descriptive from 210 points in and around Homa Mountain area where the Radiagem was used. This dose rates were measured directly at the sites and the survey meter gave values in n/μSv h^{-1}. The mean ADRA was 493.3 nSv h^{-1} is higher than the estimate of average global terrestrial radiation which ranges 24 to 160 nGy h^{-1}[1]. The maximum level of 1596.4 nSv h^{-1} translates to an annual dose of 14 mSv for a resident living there and possibly 70 mSv in 5 years.

Table 1. Descriptive of the Data of Absorbed Dose Rates using hand held survey meters.

Dose Rate Descriptive	**Statistic**
Mean	493.3
> 160 nGy h^{-1} (112 nSv h^{-1})	90.5%
24 to 160 nGy h^{-1} (16.8-112 nSv h^{-1})	9.5%
Median	418.7
Variance	85063.2
Standard Deviation	250.3
Minimum	108.4
Maximum	1596.4
Range	1488.0
Kurtosis	2.14

Activity Concentration, Absorbed Dose Rate And Annual Effective Dose Equivalent

The average activity concentrations in the 44 rock and soil samples from locations in and around Homa Mountain and the corresponding ADRA and AEDE are summarized in Table 2.

Table 2. Average radioactivity concentrations of ^{40}K, ^{226}Ra and ^{232}Th rock and soil samples and absorbed dose from gamma radiation

Region	^{40}K Bq kg^{-1} (mg/kg)	^{226}Ra Bq kg^{-1}	^{232}Th Bq kg^{-1}	ADRA nGy h^{-1}	AEDE µSv y^{-1}
Bala					
24b	496.0±4	80.8±5.3	439.6±1	241.57	296.5
25	2064.5±2	454.4±2	444.3±2	578.70	710.2
26b	63.9±27.1	124.3±5	ND	60.01	73.6
27	454.8±7	44.0±15.0	695.5±1	501.54	615.5
28b	872.2±3	27.5±10.6	67.4±4.1	94.13	115.5
29b	867.9±3	40.0±9.9	74.8±4.6	104.21	127.9
30b	2260.5±3	351.8±3	232.8±4	402.46	493.9
Ndiru	**Chiewo**	**Rongo**	**Awaya**	**Complex area**	
5b	1139.5±3	97.8±5.3	318.9±1	303.14	372.0
15b	514.7±4	52.4±8.2	231.0±2	198.35	243.4
16b	1279.5±2	ND	178.2±4	180.31	221.3
31	1596.4±2	85.1±11.8	140.5±3	198.55	243.7
2b	267.2±7	41.7±10.2	65.3±5.5	72.78	89.3
1b	1411.9±2	37.7±11.1	309.9±1	283.20	347.5
3b	1231.2±4	111.4±8	242.1±3	261.74	321.2
4b	197.0±11	ND	17.1±8.7	23.31	28.6
8b	1092.3±3	49.1±9.9	156.0±3	171.83	210.9
9b	216.4±13	1567.5±0	1005.4±0	1348.22	1654.6
10b	323.2±6	49.3±6.8	45.5±6.9	65.25	80.1
11b	1468.5±3	ND	111.6±4	137.47	168.7
13b	661.6±4	47.5±10.2	568.8±1	427.55	524.7
14b	279.6±9	83.5±7.8	524.9±1	397.26	487.5
22b	1253.6±2	ND	994.8±0	724.04	888.6
23b	1818.1±3	50.6±13	212.9±2	348.60	427.8
12	1405.2±3	113.2±6	421.1±1	389.21	477.6
Rawe					
6b	2672.9±2	166.3±5	564.5±2	561.9	689.6
7b	1674.2±2	95.5±6.4	456.0±1	416.46	511.1
17	186.8±11	54.3±11.2	675.1±1	480.83	590.1
18	260.1±9	44.5±13.8	476.3±2	347.4	426.3
19b	161.8±15	220.2±4	559.6±1	473.67	581.3
20b	1392.7±2	623.0±1	271.7±2	506.85	622.0
21	573.3±6	487. 9±1	564.4±1	608.87	747.2

Homa	**Mountain**				
32b	108.3±20	174.7±6	75.1±7.8	129.27	158.6
33b	138.0±18	376.9±1	54.0±7.4	202.83	248.9
34	183.5±12	421.3±5	582.4±1	283.20	347.5
35	1174.9±3	24.4±16.6	203.1±2	196.20	240.8
36	1341.2±2	124.8±4	538.8±1	469.80	576.6
38	3017.8±1	312.1±2	189.0±3	388.90	477.3
39	ND	1398.8±1	1160.1±1	1369.91	1681.2
40	333.5±6	36.8±17.2	74.0±3.3	79.33	97.3
41	920.8±3	38.3±16.0	1153.8±1	824.37	1011.7
42	670.4±4	ND	1447.0±1	992.52	1218.1
43	559.3±6	76.4±11.9	648.1±1	488.3	599.3
44	300.0±12	84.8±9.4	507.7±2	387.23	475.2
45	1382.9±2	ND	117.7±2	145.24	178.2
sum				16625.15	20403.0
mean	915.6±3	195.3±8	409.5±4	383.33	470.4
Max	3017.8±1	1567.5±0	1447.0±1	1369.91	1681.2
Min	63.9±27.1	27.5±10.6	17.1±8.7	23.32	28.6
St Dev	733.1	322.6	342.6	302.06	370.7

ND = non detectable

The cumulative mean activity concentration for the 44 Homa Mountain samples of ^{40}K, ^{226}Ra and ^{232}Th (915.6, 195.3 and 409.5 Bq kg^{-1}, respectively) are higher than the world average (400, 35 and 30 Bq kg^{-1}, respectively[(1)]). The standard deviations depict the spatial variation of the activity concentrations of the natural radionuclides in each rock and soil type. This ranged from non detectable (ND) to highest levels of 3017.8 ± 1.5, 1567.5 ± 0.4 and 1447.0 ± 0.8 Bq kg^{-1}, respectively. Uncertainties of ^{40}K, ^{232}Th and ^{226}Ra (^{238}U) activity concentrations range from 0.05 % to 31.01%.

About 80% of the rock and soil collected at Homa Mountain show ^{226}Ra (^{238}U) activity concentration that is higher than the world average value of 35 Bq kg^{-1} [(1)], and the average ^{226}Ra activity concentration value of 195.3 Bq kg^{-1} is more than 5.58 times the world average value. In 95% of the samples, the ^{232}Th activity concentrations exceed the world average value of 30 Bq kg^{-1}, and the mean ^{232}Th activity concentration value of 409.5 Bq kg^{-1} obtained in this work is 13.65 times higher than the world average value. The mean activity concentrations of ^{40}K of 915.6 Bq kg^{-1} is more than 2 times the world average value of 400 Bq kg^{-1} reported by UNSCEAR[(1)]. The highest ^{238}U (^{226}Ra) activity concentration of 1567.5 ± 0.4 Bq kg^{-1} (44 times the world average) was found from the top of Got Chiewo. The highest ^{232}Th activity concentration of 1447 ± 0.8 and highest ^{40}K activity concentration 3017.8 ± 1.5 came from carbonatite rock samples taken on top of Homa Mountain. It is about 48 times the world average for ^{232}Th and 7.5 times the world average for ^{40}K.

The average AEDE from the calculated outdoor terrestrial gamma radiation at 1 m above the ground in Homa Mountain was found to vary from 0.029 to 1.68 with the mean value of 0.47 mSv y^{-1} and a standard deviation of 0.37 mSv y^{-1}. Only one sample had a value less than

70 μSv y^{-1} which is the world average[1] out of the 44 samples showing that Homa Mountain area qualifies to be a High Background Radiation Area (HBRA). 43 samples are by a factor of 6.71, above the world average value of 0.07 mSv y^{-1}. It compares to those reported by Mustapha[3] from natural stone ranging from 0.155 to 1.559 with an average of 0.509 mSv y^{-1}.

Correlation Between In Situ And Laboratory Followed By Calculation Measurements

Calculations using equation 2 after inserting HpGe measured concentration values, yielded the mean ADRA of 383.36 nGy h^{-1} a value 6 times higher than average global terrestrial radiation. The maximum level of 1.37 μSv h^{-1} which translates to 12 mSv y^{-1} for a resident living there is way beyond the dose limit of 1 mSv y^{-1} for the general public and compares with the 20 mSv y^{-1} for radiation workers[4, 5,12].

A good correlation between the ambient dose equivalent measured with the survey meter and those estimated from the radioactivity concentrations of ^{40}K, ^{226}Ra and ^{232}Th in rock/soil samples was observed. It was noted that the estimated values, are however, lower than the measured. UNSCEAR[1] explains that data from different parts of the world showed that absorbed dose rates in air inferred from concentrations of radionuclides in soil can differ from those obtained through direct measurements by up to 50%. Several factors do influence the direct measurements of absorbed dose rates[1], the most relevant to the present study are presence of radon and its gamma emitting decay products in the atmosphere and the ground roughness. Radon and its decay products which emit gamma are dispersed in the atmosphere and will contribute to direct dose measurements, whereas the dose conversion factors used to convert the radioactivity concentrations of radionuclides to dose do not take into consideration the radon presence in air. Also the terrain around and on Homa Mountain comprises of hills, sloppy valleys, plateaus, escarpments, troughs etc., which make the ground surface quite rough rather than flat. On the average the survey meter sees more source volume than the flat interface models assumed in the dose conversation factors derivation. These factors could have contributed to making the results from direct measurements in the present study higher than those calculated. Nevertheless, both sets of results indicate the study area is a HBRA.

Comparisons with Recent Results on Natural Gamma Radioactivity

Numerous studies such as those undertaken by Nyamai[13], Mulaha[7], Patel[14], Mustapha[15], Oladele[17], Shanthi[18, 19] and Otansev[20] have shown the presence of radioactive minerals such as zircon, allanite, apatite and monazite in the rocks together with high potassium fledspar correlate well with the high activity measured comparable to the values in Homa Mountain area. A comparison of the mean activity concentration values obtained in this study with values from other regions of the world is presented in Table 3.

Table 3. Comparison of Mean Activity Concentration values (Bq kg^{-1}) of Rock and Soil Samples from different Countries

Sample ID	^{40}K	^{226}Ra	^{232}Th	Reference
Mean for 44 samples from Homa Mt area	915.6	195.3	409.5	This Study
Kenya (national average)	255.7	28.7	73.3	Mustapha[2]
Kenya (Carbonatites)	185.6	179.0	950.2	Mustapha[15]
Southwestern Region(Nigeria)	286.5	54.5	91.1	Oladele [17]
Turkey, Kestanbol	1,207.0	115.0	192.0	Otansev[20]
Turkey, Rize	105-1235	11-188	10-105	Merdanoglu[21]
HBRA, India	1585	44	215	Shanthi[18]
Kenyakumari, India	940	20	114	Shanthi[19]
Yemen (granite and gneiss)	1,742.8 and 2,341	53.6 and 22	27 and 121	AbdEl-Mageed[22]
Spain (national average)	650.0 (48 – 1570)	46.0 (13 – 165)	49.0 (7 – 204)	Baeza[23]
Punjab Province (Pakistan)	615.0	35.0	41.0	Tahir[24]
Bangalore (India)	635.1	26.2	53.1	Prasad[25]
Bangladesh	833	42	81	Chowdhury[26]
Saudi Arabia	1099	76.4	81	Alharbi[3]
World's average	400	35	30	UNSCEAR[1]

Some are the national averages while others are of specific geological rock base or an area of interest. Table 3 shows that the mean activity concentration values obtained in this study are higher than those obtained in all the countries considered, while they are lower than those obtained in India, Yemen, Saudi Arabia and Turkey for ^{40}K only. Homa Mountain area thus qualifies to join the ranks of high background radiation areas in the world. Compared with the worldwide average concentration in soils and rocks, the present study results are higher for most of the analyzed samples indicating a possible accumulation of ^{238}U (^{226}Ra), ^{232}Th and ^{40}K in Homa Mountain region, which may be due to geochemical processes.

CONCLUSION

Background radiation investigations, a major issue of environmental monitoring studies, have been done all over the world in order to determine the radioactivity in rock and soil samples. This study determined that the average activity concentrations of Homa Mountain area samples were much higher than worldwide averages. It was observed that the common geological characteristics of the areas with the high background radiations were the carbonatites of the Homa Mountain.

.

REFERENCES

(1) UNSCEAR (2000) United Nations Scientific Committee on the Effects of Atomic Radiation, Exposures from natural radiation sources, United Nations, New York.
(2) Mustapha, A.O., Patel, J.P. and Rathore, I.V.S., (1999) Assessment of human exposure to natural sources of radiation in Kenya, Radiat. Prot. Dosim, **82**, 285-292, Oxford University Press
(3) Alharbi W. R., J. H. AlZahrani and Adel G. E. Abbady (2011) Assessment of Radiation Hazard Indices from Granite Rocks of the Southeastern Arabian Shield, Kingdom of Saudi Arabia. Australian Journal of Basic and Applied Sciences, 5(6): 672-682
(4) UNSCEAR, (1988) United Nations Scientific Committee on Effects of Atomic Radiation, Sources, Effects and Risks of Ionizing Radiation, Report to the General Assembly, United Nations, New York
(5) ICRP (1984) *Principles for Limiting Exposure of the Public to Natural Sources of Radiation*. International Commission on Radiological Protection Publication 39, Annals of the ICRP **14**(1)
(6) Hashim N. O., I. V. S. Rathore, A. M. Kinyua and A. O. Mustapha (2004) Natural and artificial radioactivity levels in sediments along the Kenyan coast. Radiation Physics and Chemistry (71) pp 805 – 806
(7) Achola S. O., J. P. Patel, A. O. Mustapha and H. K. Angeyo (2012) Natural Radioactivity in the High Background Radiation Area of Lambwe East, Southwestern Kenya, Radiation Protection Dosimetry, pp 1-6, Oxford University Press
(8) Le Bas, Michael John (1977) Carbonatite – Nephelinite Volcanism. An African Case History, John Wiley & Sons Ltd, United Kingdom
(9) Mulaha Timothy O. (1989) The Ndiru Hill Carbonatite, South Nyanza District, Western Kenya. MSc thesis in Geology and Mineralogy, Department of Geology, University of Helsinki, Unpublished
(10) International Atomic Energy Agency (1987) Preparation and Certification of IAEA Gamma Spectrometry Reference Materials. IAEA/RL/148, IAEA, Vienna
(11) Kapdan E., A. Varinlioglu and G. Karahan (2012) Outdoor Radioactivity and Health Risks in Balikesir Northwestern Turkey, Radiation Protection Dosimetry, Vol. 148, No. 3, pp 301-309
(12) Kenya Government (1982) The Radiation Protection Act Cap 243 Laws of Kenya. Government Printers. Nairobi
(13) Nyamai Christopher M. (1989) The Mineralogy of Uncompahgrites and Turjaites from South Rangwa Complex, Western Kenya. MSc in Geology and Mineralogy, Department of Geology, University of Helsinki, Unpublished
(14) Patel, J.P. (1991) Environmental radiation survey of the area of high natural radioactivity of Mrima hill of Kenya, Discovery and Innovation, Vol. 3, No. 3, P 31-36
(15) Mustapha, A. O (1999) Assessment of Human Exposures to Natural Sources of Radiation in Kenya, PhD thesis, University of Nairobi, Unpublished
(16) Jibiri N. N., S. K. Alausa and I. P. Farai (2009) Assessment of external and internal doses due to farming in high background radiation area in old tin mining localities in Jos-plateau, Nigeria, Radioprotection Vol 44 139-151

(17) Oladele Samuel Ajayi (2009) Measurement of activity concentration of ^{40}K, ^{226}Ra and ^{232}Th for assessment of radiation hazards from soils of the southwestern region of Nigeria, Radiat Environ Biophys **(48)** 323-332

(18) Shanthi G., C. G. Maniyan, A. G. Raj and T. K. Thampi (2009) Radioactivity in Food Crops from High Background Radiation Area in South West India, Curr. Sci. 97(p), 1331 – 1335

(19) Shanthi G., J. Thampi, T. Kumaran, G. A. G. Raj and C.G. Maniyan (2010) Measurement of Activity Concentration of Natural Radionuclides for the Assessment of Radiological Indices. Radiation Protection Dosimetry Vol. 141 No. 1 90 - 96

(20) Otansev P., G. Karaha, E. Kan, I Barut and H. Taskin (2012) Assessment of Natural Radioactivity Concentration and Gamma Dose Rate Levels in Koyseri, Turkey. Radiation Protection Dosimetry Vol. 148 No. 2 227 – 236

(21) Merdanoglu, B and Altinsoy, N. (2006) Radioactivity concentrations and dose assessment for soil samples from Kestanbol, granite area. Radiation Protection Dosietry. 121 399-405

(22) Abd El-Mageed A.I., A.H. El-Kamel, A. Abbady, S. Harb, A. M. M. Youssef and I. I. Saleh (2010) Assessment of Natural and Anthropogenic Radioactivity levels in rocks and soils in the environs of Juban town in Yemen, Tenth Radiation Physics & Protection Conference, 27-30 November 2010, Nasr City, Egypt

(23) Baeza, A., del Rio, M., Mir, C., Paniagua, J.M.(1992) Natural Radioactivity in Soils of the Province of Caceres, Spain, Radiation Protection Dosimetry **(45)** 261-263

(24) Tahir, S. N. A., Jamil, K., Zaidi, J. H., Arif, M., Ahmed, N. and Ahmad S. A. (2005) Measurement of activity concentration of naturally occurring radionuclides in soil samples from Punjab Province of Pakistan and Assessment of Radiological hazards, Radiation Protection Dosimetry 113(4), 421 -427

(25) Prasad Shiva N. G., N. Nagaiah and N. Karunakara (2008) Concentrations of 226Ra, 232Th and 40K in the Soils of Bangalore Region, India. Health Physics (**94**) pp 264 – 271

(26) Chowdhury M. I., M. Kamal, M. N. Alam, Saleha Yeasmin and M. N. Mostafa (2005) Distribution of Naturally Occurring Radionuclides in Soils of the Southern Districts of Bangladesh. Radiation Protection Dosimetry, pp 1-5