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Determination of absorbed and effective dose from natural occurring radionuclide around a superphosphate fertilizer factory in Nigeria

[1]Taiwo A. O., [2]Adeyemo D. J., [2]Muhammad A. and [2]Bappah I. A.

[1]Transport Technology Center, Nigerian Institute of Transport Technology Zaria, Kaduna State, Nigeria
[2]Health Physics & Radiation Biophysics Section, Centre for Energy Research and Training, Ahmadu Bello University Zaria, Nigeria

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ABSTRACT

The amount of radioactivity in soils varies widely and man is continuously being exposed to radiation. This study presents result of outdoor absorbed dose rates and estimated effective dose from the soils samples collected from different locations around a superphosphate fertilizer factory in Nigeria. An efficiency and Energy calibrated high purity germanium detector was used to carry out the study while gamma vision software was used for the spectrum analysis. The Activity Concentrations of the soil samples collected from the different locations in the factory ranges from 48.99±7.47 to 520.37±20.46 BqKg $^{-1}$ for ^{234}U, 55.32±7.59 to 215.18±8.70 BqKg $^{-1}$ for ^{232}Th, and 101.32±13.34 to 476.04±28.07 BqKg $^{-1}$ for ^{40}K respectively. The calculated absorbed dose rate and outdoor annual effective dose from the soil samples ranges from 99.18 to 282.55nGy/hr and 0.120 to 0.342mSv/yr respectively. The mean annual effective dose was calculated to be 0.217mSv/yr. The result showed the radiation exposure level from the factory activities to the public is lower than the IAEA recommended value of 1mSv/yr. Hence radiologically the operation of the factory does not appear to pose immediate threat to the factory workers.

Keywords: Absorbed Dose, Effective Dose, Naturally Occurring Radio nuclides, Superphosphate fertilizer

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INTRODUCTION

Naturally Occurring Radio nuclides [NORs] are present everywhere in the earth crust in varying amount and because of their health effect they have being subject of environmental research worldwide. The result of this research can be useful and helpful in the radiation protection programmes and policy making. The greatest interest expressed worldwide for the study of naturally occurring radiation and environmental radioactivity has led to the performance of extensive research in many countries; such as Cyprus, Syria, Greece and Japan [1]. Such investigations can be useful for both assessment of public dose [2].The Natural radioactivity is wide spread in the earth's environment and it exists in various geological formations in soils, rocks, plants, water and air. The presence of radio nuclides in soil is a source of intake by humans through direct and indirect pathways [3]. The natural radio nuclides in the earth or soil and water in the environment are present as daughters of uranium [^{238}U]; thorium [^{232}Th] isotopes distributed by natural geological and geochemical processes in addition to ^{40}K and small quantities of fission product residues such as ^{137}Cs from atmospheric weapons testing or as a result of Nuclear Power Plants accidents [4].the total amount of radioactivity in an environment should be accurately known and kept in compliance to ALARA PRINCIPLE which requires amount of dose to be As Low As Reasonable Achievable.

Studies on radiation levels and radionuclide distribution in the environment provide vital radiological baseline information. Such information is essential in understanding human exposure from natural and man-made sources of radiation and it is necessary in establishing rules and regulations relating to radiation protection [5].

Soil features, geological formations, and human activities related to radiation and radioactivity are important factors enhancing the background levels of natural radiation [6]. The continuity in increasing of these Radio nuclides in the environment may be attributed to several factors such as the successive utilization of phosphate fertilizer, burning of fossil fuels [crude oil and coal], mining and milling operations, and building materials. Ingesting and inhaling such levels of radio nuclides contribute significantly to the radiation dose that people receive [7]. In addition, exposure externally to enhanced levels of radiation can elevate the health hazard risk. The superphosphate fertilizer factory has fertilizer producing plants for different fertilizer production stages. The superphosphate fertilizer factory for this work is located in Kaduna North, Nigeria on latitude 7^{o} 24' 11'' and longitude 10^{o} 28' 41'' east of Greenwich meridian. This present study aims at measuring the absorbed dose and effective dose from soil samples collected around the superphosphate fertilizer factory. The data generated in this study will provide base line values of natural radioactivity in soils for that area and may be useful for authorities concern with implementation of radiation protection standards for the general population in the country, as well as to conduct further studies on this issue. This work has also helped in the development of a systematic procedure using high resolution gamma spectrometry activity counting system and gamma vision software for the spectrum analysis.

MATERIALS AND METHODS

The soil samples were collected from a super phosphate company in Nigeria. The factory is situated at the Northern side of Kaduna state, Nigeria. The geographical location was determined by an hand held GPS [Global positioning system]. A total number of fourteen [14] soil samples were collected using the composite sampling method around the vicinity of the factory namely the factory gate [FG],the bagging sites [BS],the church vicinity [CHV], store house [SH], vicinity of the factory laboratory[LABV], granulation unit [GPT], phosphate rock storage house [PRV], effluent treatment unit [EFT], sulfuric acid plant [SAP], alum plant unit[APT], vicinity of the power house[PHV], acidulation unit [AD] ,clinic[CLINC],residential houses Nasarrawa behind the factory [SBF]. They were all labeled appropriately. The bags samples were double bagged to prevent cross contamination of samples.

Table 1 – Sample Mass and Global Positioning System [GPS] Co-ordinates

Sample Location/Code	Mass [Kg]	Longitude	Latitude
Granulation point [GPT]	0.31042	10^{o} 28' 40'' N	7^{o} 23' 45''E
Laboratory vicinity[LABV]	0.31231	10^{o} 28' 47''N	7^{o} 24' 13''E
Sulphuric Acid plant[SAP]	0.33644	10^{o} 28' 43'' N	7^{o} 24' 15'' E
Settlement behind factory[SBF]	0.32169	10^{o} 28' 42''N	7^{o} 24' 16'' E
Acidulation[AD]	0.32493	10^{o} 28' 44''N	7^{o} 24' 18'' E
Alum plant[APT]	0.34875	10^{o} 28' 45''N	7^{o} 24' 15'' E
Store house[SH]	0.33889	10^{o} 28' 46'' N	7^{o} 24' 14'' E
Church vicinity[CHV]	0.31880	10^{o} 28' 41'' N	7^{o} 24' 13'' E
Bagging site[BS]	0.32797	10^{o} 28' 41'' N	7^{o} 24' 11'' E
Phosphate rock store[PRS]	0.33706	10^{o} 28' 43'' N	7^{o} 24' 12'' E
Power house vicinity [PHV]	0.26336	10^{o} 28' 40'' N	7^{o} 23' 59''E
Clinic[CLNC]	0.32335	10^{o} 28' 47''N	7^{o} 24' 13'' E
Factory gate [FG]	0.32283	10^{o} 28' 42''N	7^{o} 24' 14''E
Effluent treatment plant[EFT]	0.26369	10^{o} 28' 44''N	7^{o} 24' 15''E

All the samples were air-dried to avoid loss of radio nuclides [8]. The dried samples each were thoroughly grinded to ensure equal representation of samples. The samples were distinctly packed in plastic containers measuring 8.0 cm in diameter by 6.5 cm in height and width made to fit on the high purity germanium detector and labeled with codes 1, 2, 3 for each sample. The packagings in each case were triply sealed. The sealing process included smearing of the inner rims of each container lid with Vaseline jelly, filling the lid assembly gap with candle wax to block the gaps between lid and container and tight sealing lid container with masking adhesive tape. They were left for 21 days for short-lived radionuclide to allow radon and its short-lived progenies attain secular equilibrium. The activity counting was carried out using the high purity germanium detector with the gamma vision software for the computation. The system consists of a HpGe detector by Ortec Inc. connected to an Ortec series multichannel

analyzer [MCA] through a preamplifier base and coupled to a personal computer. Spectrum of every sample was collected for 29,000s. Spectrum Analysis and Activity Concentration were performed using the gamma vision software. The computer was connected to an uninterrupted power supply connection [UPS] to maintain regular voltage and safeguard the data in the system. The energy and efficiency calibration were carried out for the high purity germanium detector. The detector has high resolution and is capable of distinguishing the gamma ray energies likely to be encountered in the measurements of the samples. The absorbed dose rates [*D*] due to gamma radiations in air at 1m above the ground surface for the uniform distribution of the naturally occurring radio nuclides [^{226}Ra, ^{232}Th and ^{40}K] was calculated based on guidelines provided by UNSCEAR 2000. We assumed that the contributions from other naturally occurring radio nuclides were insignificant. Therefore, *D* was calculated according to UNSCEAR 2000 [9].

$$\mathbf{D\ [nGy/h] = 0.462\ A_{Ra} + 0.621\ A_{Th} + 0.0417\ A_{K}} \quad \mathbf{(1)}$$

Where A_{Ra}, A_{Th} and A_K are the activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K respectively.

To estimate the annual effective dose rates, the conversion coefficient from absorbed dose in air to effective dose [0.7Sv/Gy] and outdoor occupancy factor [0.2] proposed by UNSCEAR 2000[9] was used. Therefore, the annual effective dose rates [mSv/yr] were calculated by the following formula [9 -11]:

$$\mathbf{Effective\ dose\ rate\ [mSv.yr^{-1}] =}$$
$$\mathbf{D\ [nGy/h] \times 8760\ h/yr\ [hour\ per\ year] \times 0.7 \times [10^3\ mSv\ /10^9]\ nGy \times 0.2} \quad \mathbf{(2)}$$
$$\mathbf{= D \times 1.21 \times 10^{-3}\ [mSv/yr]}$$

Where the conversion coefficient from absorbed dose in air to effective dose is 0.7Sv/Gy

The outdoor occupancy factor is 0.2 proposed by UNSCEAR 2000

RESULTS AND DISCUSSION

Calibrations for energy and efficiency were done with four calibration sources; Co-60,Am-241,Ra-226,Eu-152. The findings are as shown below:

Table 2. Efficiency calibration results of High purity Germanium Detector

NUCLIDE	ENERGY	EFFICIENCY
Am-241	59.5	0.02
Eu-152	121.8	0.08
Ra-226	186.2	0.08
Ra-226	242	0.07
Ra-226	295	0.065
Co-60	1173.2	2.50E-02
Co-60	1332.5	2.50E-02

Table 3: Activity Concentration and Calculated Absorbed Dose Rates around the Factory using equation 1

Sample Location	Activity Concentration [Bq/Kg ±E]			Absorbed Dose
	^{238}U	^{232}TH	^{40}K	D[nGy/h]
GPT	312.52±12.31	67.47±5.22	401.76±24.81	203.04
AD	520.37±20.46	55.32±7.59	101.32±13.34	278.99
LABV	273.96±10.72	97.04±7.59	346.73±21.26	201.29
SAP	90.95±4.09	67.37±6.62	367.50±22.40	99.18
SBF	144.28±8.17	107.58±4.63	469.30±27.78	153.03
APT	93.24±4.05	92.33±5.50	389.74±23.42	116.67
SH	201.48±8.12	69.00±7.86	384.10±23.30	151.95
CHV	103.46±4.42	117.60±7.50	432.63±25.93	138.87
BS	275.63±11.01	78.77±5.41	417.71±25.08	193.68
PRV	484.01±19.00	74.13±5.21	309.39±20.41	282.55
PHV	251.93±10.16	94.88±6.67	419.42±26.56	192.80
CLINIC	78.84±3.72	105.85±6.27	476.04±28.07	122.00
ETP	48.99±7.47	215.18±8.70	140.10±14.56	162.10
FG	95.03±8.18	79.71±3.58	389.04±23.79	109.63
Mean				171.84

The measured absorbed gamma dose rates in air at 1m above ground level due to activity concentration of ^{238}U and ^{232}Th series and ^{40}K are presented in Table 2.0. These values range from 99.18 to 282.55n Gy/hr with the mean of 171.84nGy/hr. According to UNSCEAR [2000][9],

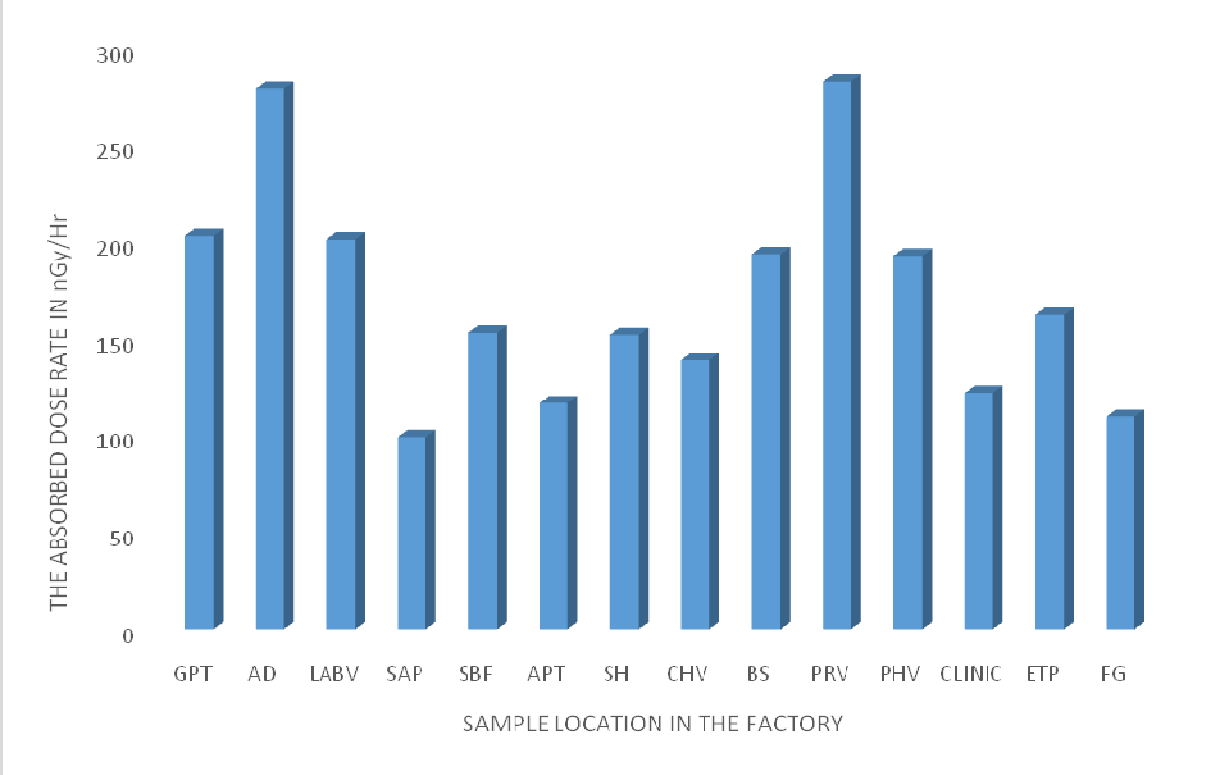

Fig 1: The Absorbed Dose Rate Distribution around the Factory

The corresponding worldwide average values range from 18-93nGy/hr and the average absorbed dose rate in air outdoor from terrestrial gamma radiation is 60nGy/hr. This shows that the mean value obtained by this study is greater than worldwide average. Of all the locations the acidulation point and the phosphate rock vicinity appear to have the highest absorbed dose rate which is due to the high contribution of ^{238}U.

Table 4: Effective Dose Rates Around the Factory using equation (2)

Sample Location	Activity Concentration [Bq/Kg ±E]			Effective Dose
	^{238}U	^{232}TH	^{40}K	[mSv/yr]
GPT	312.52±12.31	67.47±5.22	401.76±24.8	0.246
AD	520.37±20.46	55.32±7.59	101.32±13.34	0.338
LABV	273.96±10.72	97.04±7.59	346.73±21.26	0.244
SAP	90.95±4.09	67.37±6.62	367.50±22.40	0.120
SBF	144.28±8.17	107.58±4.63	469.30±27.78	0.185
APT	93.24±4.05	92.33±5.50	389.74±23.42	0.141
SH	201.48±8.12	69.00±7.86	384.10±23.30	0.184
CHV	103.46±4.42	117.60±7.50	432.63±25.93	0.168
BS	275.63±11.01	78.77±5.41	417.71±25.08	0.234
PRV	484.01±19.00	74.13±5.21	309.39±20.41	0.342
PHV	251.93±10.16	94.88±6.67	419.42±26.56	0.233
CLINIC	78.84±3.72	105.85±6.27	476.04±28.07	0.148
ETP	48.99±7.47	215.18±8.70	140.10±14.56	0.196
FG	95.03±8.18	79.71±3.58	389.04±23.79	0.133
Mean				0.217

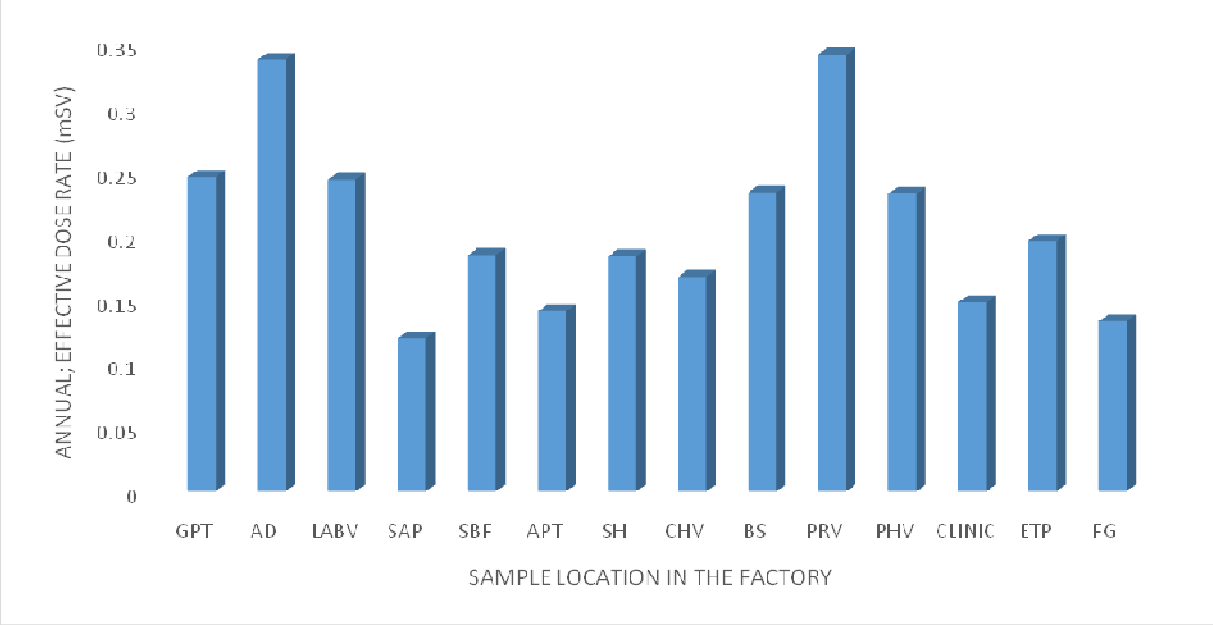

Fig. 2: Annual Effective Dose Rate distribution around the Factory

The estimated outdoor effective dose according to equation 2 for the locations as presented in table 3 range from 0.120- 0.342 mSv/yr with the mean of 0.217mSv/yr which is significantly lower than the worldwide average exposure of 0.7 mSv/yr [UNSCEAR,2000].Thus the exposure level for the public is within the recommended value of 1mSv/yr IAEA (1996)(Safety Series No.115-1).The highest and the lowest effective doses of 0.120 and 0.342 mSv/yr were recorded at sulpuric acid plant and phosphate rock vicinity respectively

CONCLUSION

In this work high resolution gamma spectrometry system [HpGe] detector using gamma vision software was utilized to develop a systematic procedure for rapid absorbed dose and effective dose determination in the vicinity of a superphosphate fertilizer factory. The average absorbed dose and annual effective dose rates were found to be 171.84 nGy/hr and 0.217mSv/yr respectively. The average annual effective dose was found to be less than the world average and the recommended limit for the public and therefore do not pose health problems to the factory workers or public.

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