Dose Rate and Annual Effective Dose Assessment of Terrestrial Gamma Radiation in Notre Fertilizer Plant, Onne, Rivers State, Nigeria

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Abstract:

Exposure from natural background radiation to human beings is natural, continuous and inescapable feature of life on earth. This study presents the results of outdoor ambient gamma dose rates in and around Notore fertilizer plant, Onne, Rivers State, Nigeria. The fertilizer plant and it's surroundings were divided into five zones: non-plant area, utilities, production handling unit, ammonia plant area, and urea plant area. In-situ measurement of radiation exposure rate was done using well calibrated radiation detector (digilert-100). From the exposure rate cancer risk were calculated by standard method. Results showed that the outdoor absorbed dose rates in air of non-plant area, utilities, production handling unit, ammonia plants and urea plants ranges from 77.0 to 129.2 nGyh^{-1}, 95.7 to 131.37 nGyh^{-1}, 94.40 to 139.2 nGyh^{-1}, 90.05 to 134.85 nGh^{-1} and 94.40 to 254.39 nGyh^{-1} respectively. The mean annual effective dose equivalent of the five areas ranges from 0.16 to 0.20 mSvy-1 while the mean excess lifetime cancer risk of the five areas ranges from 0.55 × 10^{-3} to 0.70 × 10^{-3}. The dose rate and excess lifetime cancer risk estimated were higher than the safe limit of 84.0 nGyh^{-1} and 0.29 × 10^{-3} set by the United Nations Scientific Committee on Effect of Atomic Radiation (UNSCEAR). Urea plant and its surroundings recorded the highest dose rate due to sealed radiation source (Sprober D), in the area. This shows that the shielding material used to shield the radiation source is not effective.

Keywords: Ammonia, Digilert-100, Dose Rate, Excess Lifetime Cancer Risk, Radiation.

I. INTRODUCTION

Background ionizing radiation which was originally attributed to cosmic sources and anthropogenic sources has over the years increased due to use of radionuclides in fertilizer productions, hospitals and research institutions and this has been of great concern because of the known effects of exposure to higher doses (Okoye et al., 2012).The use of radiation sources in fertilizer productions, in medical diagnosis and therapy have contributed to increase in background radiation and the radiation dose levels of many industrial workers (Avwiri, 2011). The raw material used in production of some fertilizers is phosphate ore containing various amounts of radioactive elements (El- zakla et al., 2007). Industrial processing of rock phosphate to manufacture phosphoric fertilizer involves the production of phosphoric acid according to the following chemical reaction (Sahu et al., 2014);

$$Ca_{10}(PO_4)_6F_2 + 10H_2SO_4 + 20H_20 \rightarrow 6H_3PO_4 + 10CaSO_4.2H20 + 2HF$$

During phosphate ore processing, all ^{226}Ra gets incorporated into phosphogypsum and remains in disequilibrium status in comparison with the radioactivity levels of the raw materials (El-Zakla et al., 2007). Most of the phosphogypsum is considered waste and is stock piled or discharged into the aquatic environment (UNSCEAR, 2000).

Disposal of phosphogypsum without treatment to the environment could lead to possible impacts on the level of activity concentration of radionuclides in environmental media and the consequential ingestion by humans through the food chain and drinking water. ^{226}Ra deposited in bone tissue has the potential for causing biological damages and for prolonged exposure; it may induce bone sarcoma (El-zaklar et al., 2007). Emanation of radon gas (^{222}Rn and ^{220}Rn of lifetime 3.8 days and 55.6 seconds respectively) into the air occurs as a product of ^{238}U and ^{232}Th decay chains respectively. The short lived decay products of radon are responsible for most of the hazards due to inhalation. The health implication of radon emission comes from its radioactive progeny which attaches itself like aerosols do, trapped in the lungs and deposits alpha particle energies in the tissue producing higher ionization density than beta particles or gamma rays. Inhalation of radon decay products causes lung cancer, skin cancer and kidney diseases. The radiological implication of the above nuclides is due to radiation exposure of the body to gamma rays and irradiation of the lung tissues from inhalation of radon and its progeny (Sahu et al., 2014).

Fertilizers usually employed in agriculture contain traces of heavy metals and relatively high concentration of naturally occurring radionuclides. Phosphate containing fertilizers have been used worldwide to increase the quantities of the micro- nutrients which are being continuously taken off from the soil due to farming activities. Phosphate fertilizer industries are considered to be a potential source of natural radionuclide contamination (Sahu et al., 2014; Milica et al., 2014). Their radioactivity leading to health problems from radiation at the level of industrial processes which involves mining and transportation of phosphate ores and production of fertilizers. At the usage level, fertilizers dispersed into the geosphere and biosphere, have potential to transfer to living beings. Leaching of minerals and wastes from the plant is another potential source of radioactivity dissemination which may contribute to enhanced exposure of workers, public and the environment to these radionuclides.

Hence, this study aims at measuring the background radiation levels of the fertilizer plant and its environment and from the exposure rate, determines the absorbed dose of radiation, the annual effective dose and excess lifetime cancer risk associated with the exposure. This will help to determine the radiological burden of the environment and its health risk. The result of this study will serve as surveillance tool for radiation monitoring of the plant. The fertilizer factory is sited in Onne, Eleme, Local Government Area of Rivers State, Nigeria. Currently they produce mainly urea fertilizer that is supplied to farmers. However, the fertilizer factory is located at latitude $6^{0}25'53.29''$N and longitude $3^{0}25'28.60''$E as shown in Figure 1.

II. MATERIALS AND METHOD

Environmental radiation survey meter (Digilert-200) with halogen quenched GM tube detector with thin mica end window of density 1.5 – 2.0 $mgcm^{-1}$ was used to measure natural background radiation dose rate. Digilert-200 radiation survey meter was calibrated to read exposure rate in two ranges with measuring sensitivity of 0.1 μRh^{-1} and 1.0μRh^{-1} and exposure with measuring sensitivity of 1.0 µR and accuracy of ± 10% with ^{137}Cs (Rangaswamy *et al*., 2016). The radiation meter is designed to serve as a low radiation level survey meter in indoor and outdoor environment. The Geiger –Mueller tube generate a pulse of electrical current each time radiation passes through the tube and causes ionization. Each pulse is electronically detected and registers as a count which is in µR/h and displayed on the LCD.

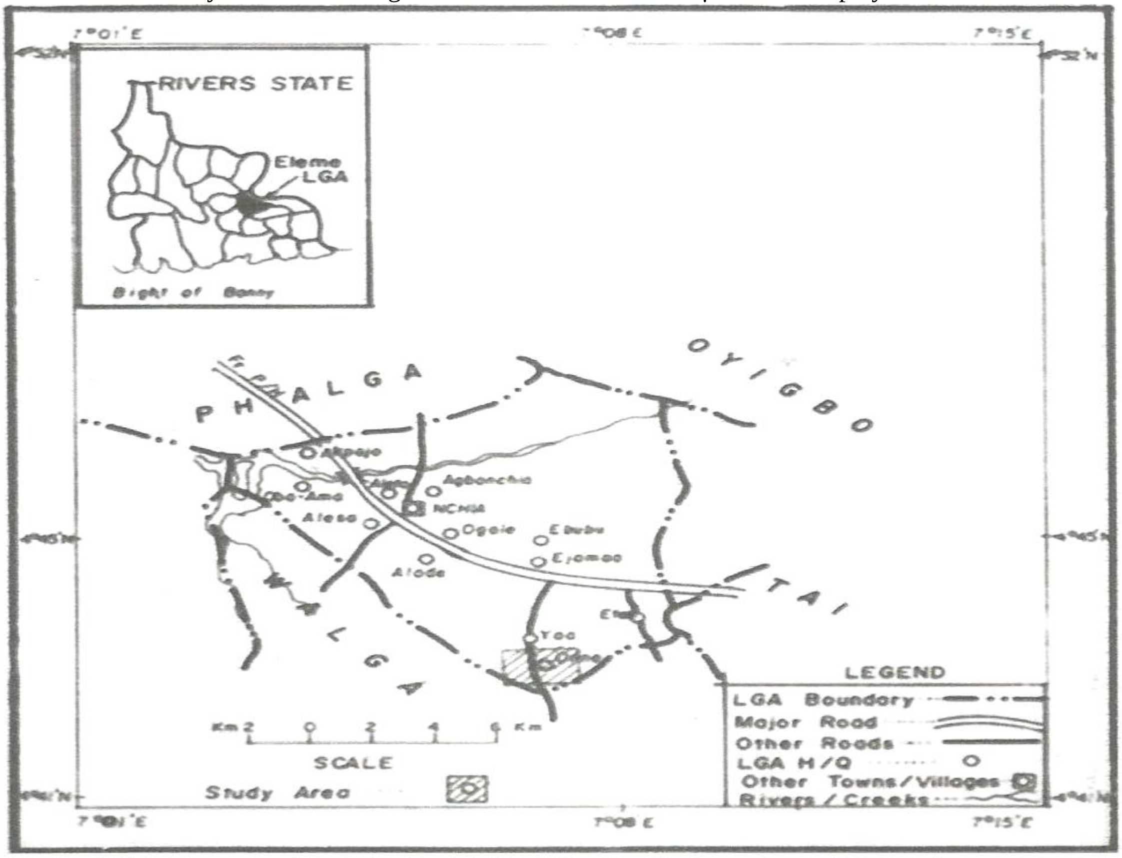

Fig. 1: Map of the study Area.

The study area (fertilizer plant and its environment) was divided into five locations and each sub-divided into five sampling points. The gamma dose rates were measured at each sampling point at the distance of 1 m above the ground. For each sampling point, four measurements were performed with 3 minutes intervals and the measured data were then averaged to a single value and used to calculate other radiological parameters. Outdoor gamma radiation exposure rate measured in µR/h was converted into absorbed dose rate in nGy/h using a conversion factor, $1\mu Rh^{-1} = 8.7\ nGyh^{-1}$ which stems from the definition of Roentgen (UNSCEAR,2000; Muhammad *et al.*, 2014).

Annual Effective Dose Equivalent (AEDE)

The estimated absorbed gamma dose rate were used to calculate the annual effective dose equivalent (AEDE) received by people of surveyed area. For calculating AEDE, we have used dose conversion factor of 0.7 Sv/Gy and the occupancy factor of 0.25 for outdoor exposure. The occupancy factor was calculated based on oral interview with workers and people of the study area. People of the area spent about 6 hours outdoor and 18 hours indoor. The AEDE for the Outdoor terrestrial radiation was calculated using the equations given (Rangaswamy et al., 2016; Muhammad *et al.*, 2014).

$$AEDE_{(outdoor)} (mSvy^{-1}) = D \times T \times OF \times CC \quad \text{-----------------------} (1)$$

Where D is the absorbed dose rate, T is time in hours for 1 year (8760h), OF is the occupancy factor (0.25) for outdoor and CC is the conversion coefficient, in the UNSCEAR,1993 report, the committee used 0.7 Sv/Gy for the conversion from absorbed dose in air to effective dose received by adult population.

Excess Lifetime Cancer Risk (ELCR)

Excess Lifetime Cancer Risk measures the additional cancer risk induced by exposure to ionizing radiations. Based on the calculated values of AEDE, ELCR is calculated using the equation;

ELCR = AEDE x DL x RF --------------------------------------- (2)

Where AEDE is the annual effective dose equivalent, DL is the average duration of life which is 70 yr, Rf is the risk factor given as 0.05 by UNSCEAR, 2000.

III. RESULTS AND DISCUSSION

Table 1: Radiation Exposure rate of Fertilizer plant and its Radiological parameters

S/N	Sampling points	Sampling code	GPS Reading	Exposure Rate (μR/h)	Absorbed dose(nGy/h	AEDE (mSv/y)	ELCR $\times 10^{-3}$
	Non-Plant Process Area						
1	Control	$NPPA_1$	$N04^0 43.938'$ $E007^{0.}669'$	12.25	106.58	0.163	0.571
2	Administrative building	$NPPA_2$	$N04^0 43.857'$ $E007^0 7.517'$	8.85	77.00	0.118	0.413
3	Laboratory	$NPPA_3$	$N04^0 34.788'$ $E007^0 07.528'$	10.85	94.40	0.144	0.0504
4	Behind maintenance	NPP_4	$N04^0 43.637'$ $E007^0 07.576'$	11.85	103.10	0.158	0.553
5	Truck yard	$NPPA_5$	$N04^0 43.637'$ $E007^0 07.650'$	14.85	129.20	0.198	0.693
	Utilities and its surroundings						
6	Gas Turbine (GT)	UT_1	$N40^0 34.730'$ $E007^0 07.434'$	15.10	131.37	0.201	0.703
7	Heat Boiler	UT_2	$N04^0 43.741'$ $E007^0 07.457'$	11.00	95.70	0.147	0.514
8	Waste Heat Boiler	UT_3	$N04^0 43.745'$ $E007^0 07.450'$	15.10	131.37	0.201	0.704
9	water treatment plant	UT_4	$N04^0 43.776'$ $E007^0 07.413'$	12.85	111.80	0.171	0.599
10	Ammonia Cooling Tower	UT_5	$N04^0 43.841'$ $E007^0 07.411'$	14.20	123.54	0.189	0.662
	Product Handling Unit and its surroundings						
11	Finished Goods	PHS_1	$N04^0 43.561'$ $E007^0 07.503'$	12.45	108.32	0.166	0.581
12	Blending plant	PHS_2	$N04^0 43.425'$ $E007^0 07.526'$	15.20	132.24	0.202	0.707
13	Jetty	PHS_3	$N4^0 43.409'$ $E007^0 07.160'$	16.00	139.20	0.214	0.749
14	The front of Burnker	PHS_4	$N04^0 43.585'$ $E007^0 07.289'$	15.35	133.55	0.204	0.714
15	Bulk storage	PHS_5	$N4^0 43.612'$ $E007^0 07.372'$	10.85	94.40	0.144	0.504
	Ammonia plant and its surroundings						
16	Ammonia storage Tank	APS_1	$N04^0 43.710'$ $E007^0 07.264'$	12.35	107.50	0.164	0.574
17	Inside Ammonia plant	APS_2	$N04^0 43.774'$ $E007^0 07.374'$	14.20	123.54	0.189	0.662
18	Primary reformer	APS_3	$N04^0 43.794'$ $E007^0 07.348'$	15.10	131.37	0.201	0.704

19	Effluent treatment site	APS_4	N04^{0}43.671′ E007^{0}07.158′	15.50	134.85	0.207	0.724
20	Scrap Yard	APS_5	N04^{0}43.734′ E007^{0}07.298′	10.35	90.05	0.138	0.483
	Urea plant and its surroundings						
21	Urea Granulator	UPS1	N04^{0}43.636′ E007^{0}07.391′	11.00	95.70	0.147	0.514
22	Urea Sprober D	UPS2	N04^{0}43.657′ E007^{0}07.392′	29.70	258.39	0.396	0.139
23	Urea Synthesis steam drum	UPS3	N04^{0}43.671′ E007^{0}07.374′	10.85	94.40	0.144	0.504
24	Urea Pump-out	UPS4	N04^{0}43.692′ E007^{0}07.354′	11.50	100.05	0.153	0.536
25	Urea Compressor	UPS5	N04^{0}43.707′ E007^{0}07.375′	11.70	101.79	0.156	0.546

Table 2: Mean exposure rates and their associated radiological parameters

S/N	Sampling Area	Exposure Rate (μR/h)	Absorbed Dose (nGy/h)	Annual Effective Dose (mSv/y)	Excess Lifetime Cancer Risk (ELCR) x 10^{-3}
1.	Non-plant process area (NPPA)	11.73	102.05	0.16	0.55
2.	Utilities (UT)	13.65	118.76	0.18	0.64
3.	Product Handling and its surrounding (PHS)	13.97	121.54	0.19	0.67
4.	Ammonia plant and its surrounding (APS)	13.50	117.45	0.18	0.63
5.	Urea plant and it's surrounding (UPS)	14.95	130.07	0.20	0.70

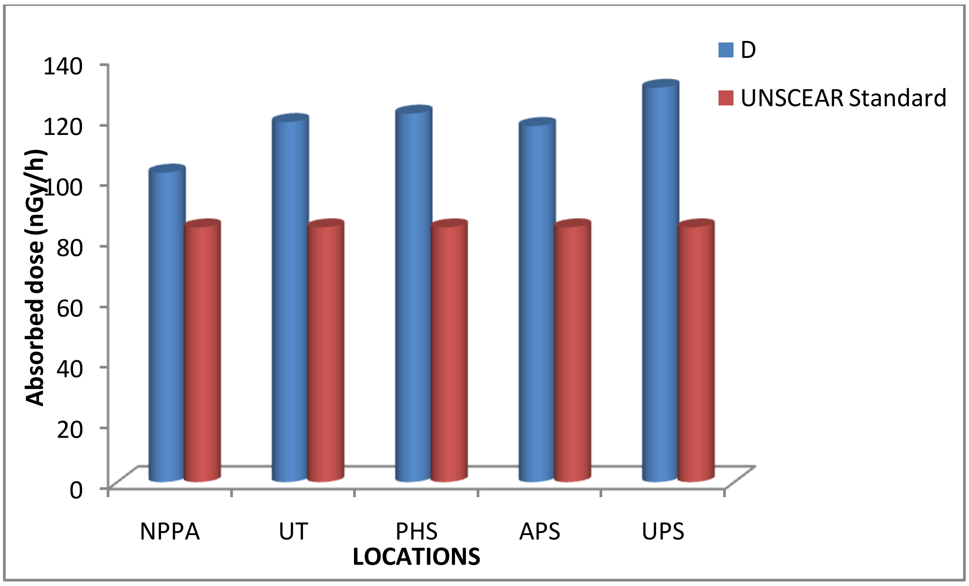

Fig.1: Comparison of absorbed dose with UNSCEAR, 2000.

Results of the outdoor gamma radiation dose rates and their associated radiological parameters are presented in Table 1. The mean exposure rate at non-plant processing area is 11.73±0.23 μRh-1 and ranges between 10.85 to 14.85 μRh^{-1}. The mean outdoor gamma dose rate at non-plant processing area is 102.05 ± 2.03 nGyh^{-1} and it ranges between 77.00 to 129.20 nGyh^{-1}. Maximum mean outdoor gamma dose rate were observed at station $NPPA_5$ (the truck yard). This might be due to its closeness to the turbine and also radiations from finished products.

The mean exposure rate measured at the Utilities and it's environ was 13.65 μRh-1 which ranges from 11.00 to 15.10 μRh^{-1}. The mean absorbed dose rate calculated was 118.76 nGyh-1 and ranges from 95.7 to131.37 nGyh^{-1}. The maximum value was recorded at the gas turbine (UT_1) and waste heat boiler plant (UT_3). This could be due to radiations from the waste stream. The mean exposure rate of 13.97 µRh-1 was recorded at the products handling unit and its environ. The exposure rate measured ranged between 10.85 and 16.00 μRh^{-1}. The absorbed dose rate ranged from 94.40 to 139.20 $nGyh^{-1}$ with an average value of 121.54 $nGyh^{-1}$. Maximum gamma dose rate was recorded at the Jetty areas. Radiations may come from the vessels depending on the content; the fertilizer itself contains radionuclide which emits radiations thereby increasing the background radiation of the area.

At Ammonia plant and it's environ, the exposure rate ranges from 10.35 to 15.50 μRh^{-1} with mean value of 13.50 μRh^{-1}. Gamma dose rate measured ranged from 90.05 to 134.85 $nGyh^{-1}$ with mean value of 117.45 $nGyh^{-1}$. The maximum dose rate was recorded at effluent treatment site (APS_4). This could be due to radiations from the waste (effluent). The mean exposure rate at Urea plant and it's environ was 14.95 μRh^{-1} . Gamma dose rate ranges from 95.7 to 258.39 $nGyh^{-1}$ with mean value of130.07 $nGyh^{-1}$. The maximum dose rate of 258.39 $nGyh^{-1}$ was recorded at Urea sprober D (UPS_2) located at latitude 443.65N and longitude 707.650E. This is due to radiation from Sprober D which is radioactive source used as raw material for the production of fertilizer. This radioactive source (Sprober D) is used in the granulator which crushes the urea crucibles into granules. Emissions from it can enhance the background radiation of the area.

The background radiation of the fertilizer producing plant, Onne measured are slightly higher than the normal environmental radiation level of 0.013 mRh^{-1} (13.0μRh^{-1}) stipulated by International Commission for Radiological Protection (ICRP, 2003) except at non-plant area. Higher radiations were recorded at product handling area and Urea process plant due to emissions from the finished products and the radioactive sources (Sprober D) used in the production process and conveyor belt to monitor the flow of the products. According to World Nuclear Association (WNA, 2015), sealed radioactive sources are used in industrial gauging applications, flow tracing and mixing measurements. This radioactive sources used during fertilizer production operations has enhanced the background radiation within the plant.

The estimated absorbed dose rate and excess lifetime cancer risk exceeded their individual safe values of 84.0 $nGyh^{-1}$ and 0.29×10^{-3} respectively stipulated by United Nations Scientific Committee on Effects of Atomic Radiation (UNSCEAR, 2008). The values of the estimated effective dose rate in the fertilizer complex are below the world acceptable value of 0.48 $mSvy^{-1}$. These sources, ^{40}K and phosphate radioisotopes from the fertilizer contributed significantly to these estimated high values. Thus the result of this study is in agreement with Taiwo *et al.,* (2014), that recorded highest absorbed dose rate at locations that are near to a radiation source.

IV. CONCLUSION

Assessment of the terrestrial gamma radiation status of fertilizer plant at Onne, Rivers state was done using well calibrated radiation meters. The exposure rate measured at the five sections of the plant exceeded the normal background radiation level. The estimated values of the absorbed dose and excess lifetime cancer risk are higher than the world acceptable value of 84 $nGyh^{-1}$ and 0.29 x 10^{-3} respectively. The estimated annual effective dose of outdoor gamma radiation in the fertilizer plant and its surroundings ranges from 0.15 $mSvy^{-1}$ to 0.19 $mSvy^{-1}$ is much lower than the world acceptable values of 0.48 $mSvy^{-1}$. The dose rate estimated at Urea plant and its environs shows that there are emissions from Sprober D sealed radiation source which is an indication that the shielding material is not effective.

The result of this study has shown that fertilizer production processes has impacted on the terrestrial gamma radiation status of the plant and its surroundings. Though there could be no immediate health hazard on the workers but prolonged exposure might lead to radiation related problems. Therefore, we suggest that routine radiation monitoring be carried out in the plant and its surroundings for possible mitigative measures.

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