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Radiological Effects of Iron-Ore Mining and Processing at Itakpe, Kogi State.

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Abstract:

Gamma spectroscopy was employed in the analysis of soil samples collected from the mine site, industrial plant site, and mill tailing dumps site of National Iron-Ore mining Project (NIOMP), Itakpe, Kogi State. The mean measured activity concentrations of ^{40}K, ^{226}Ra, and ^{232}Th were 207.6±39.4(ND-515.0), 17.6±2.4(ND-31.5), and 31.7±8.6(ND-118.0)Bqkg^{-1}, respectively, which are all less than the world mean of 370.0, 25.0, and 25 Bqkg^{-1} for ^{40}K, ^{226}Ra, and ^{232}Th, respectively. The calculated outdoor mean effective doses for the sites were respectively74.8±20.0μSv, 47.0±7.0μSv and 17.0±1.0μSv for industrial plant, mining waste and mill tailing deposit sites. These values are comparable to the control mean value of 74.3±46.2μSv (obtained from unmodified environment soil samples) which in turn is comparable to the world mean of 60μSv, thus suggesting that the mining company does not constitute radiological problem to its workers and the public. The calculated activity index, I, for the company mill tailings is 0.122, the value which is equivalent to an excess gamma dose of 0.122mSv/year over that received outdoors if used as a building material.

1. Introduction:

The process of obtaining useful minerals from the earth's crust called mining includes excavations and removal of rock and earth. Any excavation in the earth from which ore, coal, or other minerals are extracted is called a mine (Encarta, 2005). Inside the earth are Naturally Occurring Radioactive Materials (NORMs). These are long-lived and are known as primordial radionuclides because they were produced in the process that occurred when the solar system was formed. Examples of these NORMs are uranium-238 with half-life of 4.5x 10^9 years, thorium-232 with half-life of 1.4x10^9 years, actinium-235 with half-life of 7.04x10^8 years and potassium-40 with half-life of 1.28x10^9 years. All these undergo transition at a very slow rate and produce several radioactive decay products (progenies) in their respective decay chains. The NORMs and their radioactive decay progenies are responsible for the majority of radiation exposure (both external and internal) of the vast majority of people, as they are known to be emitters of alpha (α), beta (β), and gamma (γ) radiations.

The mining process therefore contributes to the dispersion of radionuclides in the environment as the NORMs and their radioactive progenies deeply located in the earth are brought to the surface along with the overburdens and the mined ore in the process of mining. The processes involved in ore beneficiation result in generation of wastes like mine tailing (resulting from the separation of ores from impurities associated with them) and mill tailings (resulting from the separation of the needed minerals from their ores). The activities of both the mine/mill tailings can be enhanced especially those resulting from radioactive ores (Ibeanu, 1999).

2. Materials and Method:

The field measurements and sampling were made at three different locations of the mining company, which are the mine, the industrial plant site and the mill tailing deposit site. For the purpose of comparison with outside environment free from the mining activities going on at the study area, field measurements and soil sampling were [1] made at five other locations namely, Ageva, Kabba-Road, Eganyi, Osara, and Lokoja, to serve as controls.

2.1 *In-situ measurements*

In-situ measurements of terrestrial gamma radiation were made based on the assumption that there exists laterally uniform distribution of natural radionuclides in the environment and that the vertical contribution from soil is limited to the first horizon (Ibeanu, 1999). These measurements were made with a portable survey meter

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(Rados model RDS 120) having sensitivity range of $0.05\mu Svh^{-1}$-$10Svh^{-1}$. At each of the three locations (the mine, the industrial plant housing and the tailing deposit) taken as sources, measurements were made at five different points at a regular interval of 0.1m beginning at the source and moving horizontally away to cover a total distance of five metres. At each point of measurement, five readings were taken. Their mean provides the exposure rate at the point while the mean of the means of the five points was recorded as the mean exposure rate of the location.

2.2 *Soil Sampling and Sample Preparation*

At each of the three locations, horizontal profile soil samples were collected at regular intervals away from each location to investigate possible change in activity concentrations of elements of interest along the profile. Possible decrease in the concentrations of such elements away from any location indicates that the location must have been responsible for such variation. At each sample point, soil sample as much as 800g was taken for gamma spectroscopy using sodium iodide thallium drifted (NaI(Tl)) detector type. Each sample collected was put into a polyethylene sampling bag, tied and labeled appropriately. Double bags were used for each sample to prevent breakage and cross contamination of samples. In addition, samples of mill tailings, mine waste, and soil from the five outside control areas were equally collected for gamma spectroscopy.

The soil samples collected were air dried for 72hrs under laboratory temperature (ambient temperature of 27^{o}C) and average relative humidity of 70% (IAEA, 1989). The samples were then grounded and packed to fill already weighed cylindrical plastic containers of dimension 7.2cm in diameter and 6.0cm high to satisfy the selected best sample container height that will adequately match the detector's dimensions, which allowed for the adequate covering of the detector shield (Ibeanu, 1999). Before sealing, the mass of each sample was determined and recorded.

The sealing of the sample containers were done in three stages, namely, vaseline wax sealing, candle wax sealing and adhesive masking tape, all done to prevent the escape of ^{222}Rn gas. The samples were then stored for a minimum period of four weeks to achieve an approximate secular equilibrium between Rn and Th, and their respective progeny before commencing their gamma spectroscopy analysis.

2.3 Gamma Spectroscopy and Analysis

In order to determine the activity concentrations of uranium, thorium, and potassium in the samples, NaI(Tl) detector was chosen. The choice was based on its cheapness, speed of analysis, relative ease of sample preparations and the simplicity of its data analysis. Each of all the samples was mounted on the surface of the detector and counted for 29000s in reproducible sample detector geometry after the calibration of the system. The high counting time was to ensure reasonable counts in the photopeaks that would give an acceptable statistical accuracy. The data acquisition and analysis of gamma spectra was made possible by a computer based MCA system with Maestro II program. The assessment of the activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K were done using 1764keV γ–line of ^{214}Bi, 2614keV γ–line of ^{208}Tl and 1460keV γ–line of ^{40}K respectively. The net peak count rate (cps) for each radionuclide in any sample was obtained by subtracting the background net peak count rate of the radionuclide from that of the sample.

All the obtained cps were converted to conventional units using the calibration factors (CF_K, CF_{Ra}, & CF_{Th}) derived by Ibeanu (1999) to determine the activity concentrations of the radionuclides of interest. The calibration factors and their values are as follows:

$$CF_K = \frac{cps(^{40}K)}{Bq(^{40}K)/kg} = 6.431\times10^{-4}\, cps/Bqkg^{-1} \qquad \text{.....2.1}$$

$$CF_{Ra} = \frac{cps(^{226}Ra)}{Bq(^{226}Ra)/kg} = 8.632\times10^{-4}\, cps/Bqkg^{-1} \qquad \text{.....2.2}$$

$$CF_{Th} = \frac{cps(^{232}Th)}{Bq(^{232}Th)/kg} = 8.768\times10^{-4}\, cps/Bqkg^{-1} \qquad \text{.....2.3}$$

3. Results and Discussion

Gamma spectroscopy results show that the mean activity concentrations of ^{40}K, ^{226}Ra, and ^{232}Th in industrial plant site soil samples are 263.0±18.6 (209.0-313.9) $Bqkg^{-1}$, 9.6±3.0 (ND-17.4) $Bqkg^{-1}$ and 69.0±13.0 (46.5-118.0) $Bqkg^{-1}$ respectively with their ranges enclosed in brackets. These results are comparable with those obtained for the control site mean values which are 451.6±333.0, 4.3±2.3, and 60.0±44.0$Bqkg^{-1}$ for ^{40}K, ^{226}Ra, and ^{232}Th respectively, which are in turn comparable with the world mean activity concentrations of 370.0, 25.0, and 25.0$Bqkg^{-1}$ for ^{40}K, ^{226}Ra and ^{232}Th, respectively (UNSCEAR, 1988). This comparison is shown in the histogram of Fig 1. However, the variation between those of the world mean values and those of the control mean values are obviously due to the much wider area of coverage and larger statistical data obtained in deriving the world mean values compared to that involved in this work.

The closeness of the mean activity concentrations of the industrial plant site samples to those obtained for the control mean values indicates that the company mining operations have not radiologically influenced the industrial plant site. Fig 2 showing the variation of activity concentrations of the three measured radioelement with distance at the industrial plant site supports this argument as the values for ^{40}K and ^{232}Th are seen to be increasing with distance away from the industrial plant site while that of ^{226}Ra shows no definite pattern, evidence that other factors such as soil nature and the topography of the environment could have contributed. This is not surprising as the nature of operation of the plant and the long distance between the plant and the tailing (both mill tailing and mine tailing) dumps do not permit much contamination of the industrial plant environment, hence the closeness of the site characteristics to those of the natural environment.

The mean activity concentrations of ^{40}K, ^{226}Ra, and ^{232}Th measured in mining waste site soil samples are displayed as part of Fig 1 as 327.6±61.5 (193.7-515.0), 15.0±2.4(8.1-22.2), and 26.2±3.0(17.9-32.2) $Bqkg^{-1}$ respectively. Their ranges are shown in the brackets. These values are also close to the control mean values only that the values are higher than those measured in the industrial plant site samples with the exception of ^{232}Th. The 26.2±3.0$Bqkg^{-1}$ mean activity concentration of ^{232}Th in the soil samples at this site is about the same with its world mean of 25.0$Bqkg^{-1}$ but lower than the values at the industrial plant site (69.0±13.1$Bgkg^{-1}$) and the control mean (60.0±44.0$Bqkg^{-1}$).

The enhanced values for ^{40}K and ^{226}Ra in the mining waste site samples over those obtained for the industrial plant site show how wastes generated by earth excavation can enhance activity concentrations of radionuclide in an environment. This is because radionuclides that are deeply located in the earth crust are brought to the surface in the process. The low value for ^{232}Th at this site should be characteristic of the mine itself, which is located on a mountain of height 1218 feet above sea level (at the time of sampling) and of a geological make-up different from those of the plains where industrial plant site and control samples were obtained.

Fig 3 shows the variations of activity concentrations of the three measured radionuclide with distance away from the mining waste site. A noticeable sharp decrease in activity concentration of ^{40}K with distance is observed along with an insignificant but noticeable decrease in activity concentration with distance for ^{226}Ra. This common decrease in values for both ^{40}K and ^{226}Ra further proves that the mining activities contribute to their values at the site. The activity concentration of ^{232}Th does not show any noticeable pattern of variation with distance. This may be due to the short distance of 5m used for the research work, which may not permit formation of a definite pattern.

The mean activity concentrations of ^{40}K,and ^{226}Ra, in the tailing deposit site soil samples are 32.2±10.8, 28.3±1.2$Bqkg^{-1}$ respectively. The value 32.2±10.8$Bqkg^{-1}$ for ^{40}K is the least mean obtained for all the locations including the control sites as seen in Fig 1. This is an indication that ^{40}K is of soil origin. Potassium generally is not an associate of iron and its ore as it has been seen to have a poor correlation coefficient with iron (Audu, 2011). This site being the place where the mill tailings of iron ore origin are deposited will definitely not show high value for mean activity concentration of ^{40}K. The low value of ^{40}K mean activity concentration also indicates low value of other isotopes of potassium at the site, which is made evident by reduction in vegetation at this tailing deposit site! Fig 4 shows the variation of ^{40}K and ^{226}Ra with distance away from tailing deposit. No definite pattern of variation for ^{40}K at this site is observed, as the site has not contributed significantly to its activity.

^{226}Ra has its mean activity concentration at the tailing deposit site to be 28.3±1.2$Bqkg^{-1}$, its highest average value measured for all the sites including control. Its fairly constant value shown in Fig 4 may be due to the prevailing

high value of its activity within the short distance of 5m, which we believe could fall in value over a much longer distance.

Comparing this 28.3±1.2Bqkg^{-1} mean activity concentration of ^{226}Ra with 25.0Bqkg^{-1} its world mean, one can say it is not bad for the environment as some other locations of the world have mean values of ^{226}Ra higher than that (Daling *et al*, 1990, Baeza *et al*, 1994 and Malanca *et al*, 1996). The enhancement of ^{226}Ra at tailing deposit site though not to hazardous level however proves further that tailings can become a source of hazard especially those obtained from radioactive ores (Ibeanu, 1999). The activity concentration of ^{232}Th at the tailing deposit site was not detected. This may still be because ^{232}Th is more from soil than from iron ore that generates the tailings.

Annual outdoor mean effective dose was calculated for the control to be 74.3±46.2μSv using a conversion factor of 0.7Sv/Gy and occupancy factor of 0.2 recommended by UNSCEAR, (1988). The difference between the above value and the world mean effective dose of 60μSv may be due to large number of data obtained in deriving that of the world mean. Similar computation made for the industrial plant, the mining waste, and the tailing deposit sites yielded 74.8±20.0μSv, 47.0±7μSv and 17.0±1.0μSv as their respective outdoor mean effective doses. These values compared to those of the control and the world mean show that the mining company sites do not constitute any external radiological problem to the workers and the public in general.

The mean activity concentrations of ^{40}K, and ^{226}Ra, in the mill tailings called 'super sound' are 128.64±5.67 (107.30-140.80) and 23.70±3.67 (13.10-34.30)Bqkg^{-1} respectively with their ranges in brackets. ^{232}Th is below detection limit of the detector. By the activity concentration index, I, recommended by European Commission, EC, (1999) in indentifying whether a dose criterion is met in building materials or not, the above mean activity concentrations resulted into an I value of 0.122. This value of I is not close to the limit of 0.5 which is for a dose criterion of 0.3mSv/yr set by EC for bulk building materials (STUK, 2003). However, in view of the enhancement level of arsenic in the same tailings as reported from a work carried out there (Audu, 2011), it is not advisable to use the mill tailings in building construction. This work being the first attempt, recommendation is hereby made for further research work on radiological effects of iron ore tailings for more investigation and certainty.

4. Conclusion and Recommendation

The study was carried out to ascertain the levels of radiological impacts (if any) caused by iron ore mining activities at the study area, knowing that taking things for granted without scientific proof could be dangerous to the environment and the people therein in line with environmental and radiation protection principles.

The pattern of variation in activity concentration of ^{40}K and ^{226}Ra measured away from the mining waste and the highest mean activity concentration of ^{232}Th at the tailing deposit site showed that the mining activities must have contributed to their presence at the sites. This therefore, is a confirmation that mining activities have considerable potential for exposure, particularly where higher activity TENORMs may have been dispersed as a result of the characteristics of the ores and the milling process in use (Ettenhuber *et al*, 1998). However, the findings resulting from this work showed that the level of waste generated at the National Iron Ore Mining Project (NIOMP), Itakpe, cannot constitute external radiological problems to its workers and the public in general.

The radioactivity index, I, of 0.122 determined for the company mill tailings seems to show that based on the European Commission and Finland criteria for building materials, it is not under any restriction as far as radioactivity is concerned. In view of the enhancement level of arsenic in the same tailings (Audu, 2011), it is however not advisable to use it in building construction. This present work being the first attempt, further radiological investigation should be carried out on the mill tailing. Also radon gas monitoring in buildings where the tailings have been used as a building material is also recommended.

Mining is too valuable a pursuit to abandon; therefore concerted efforts to minimize mining adverse impacts on the environment without undermining its economic and employment benefits should be made (NEERI, undated).

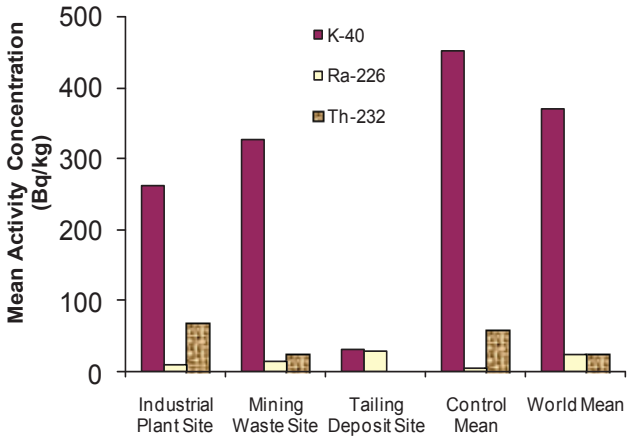

Fig 1: Comparison of Mean Activity Concentrations of the Sampled Locations with those of the Control and World Mean

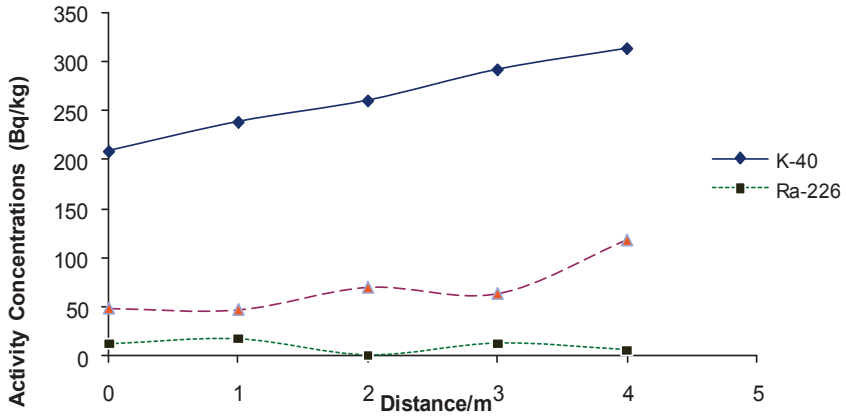

Fig 2: Radionuclide Activity Concentration Variation with Distance (Industrial Plant Site)

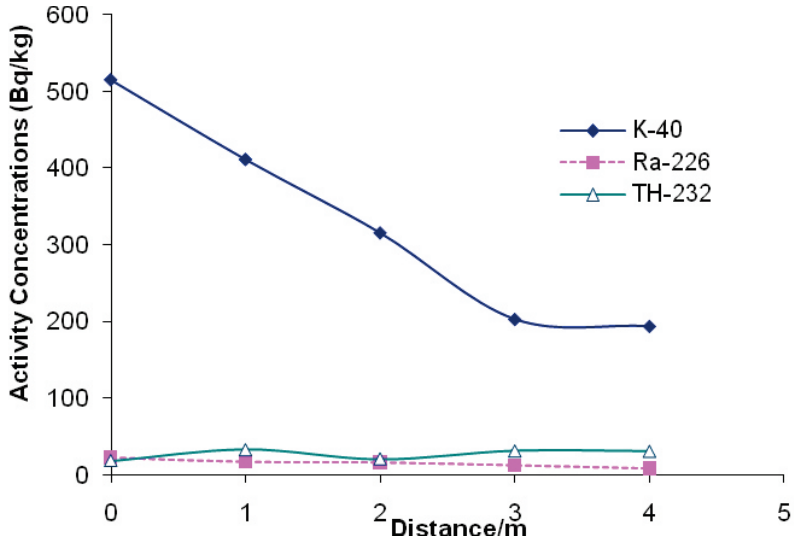

Fig 3: Radionuclide Activity Concentration Variation with Distance (Mining Waste Site)

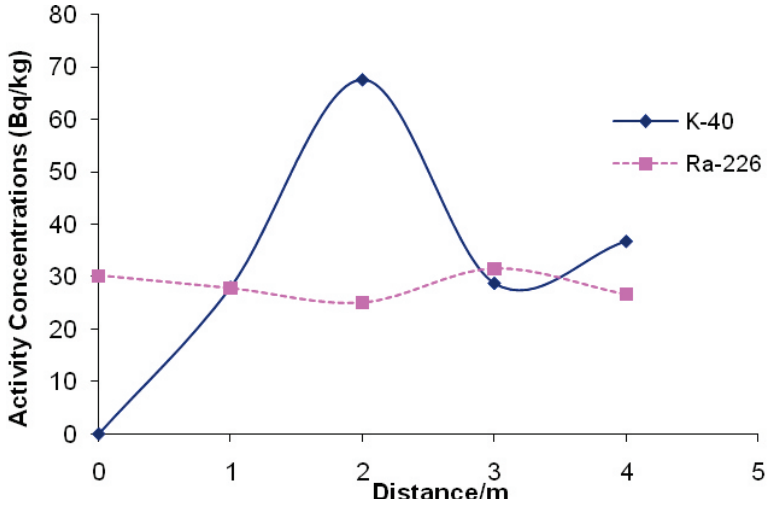

Fig: 4: Radionuclide Activity Concentration Variation with Distance (Tailing Deposit Site)

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