Radiation Protection Dosimetry (2004), Vol. 108, No. 1, pp. 73–77
DOI: 10.1093/rpd/nch010

TECHNICAL NOTE

# DOSE RATE ASSESSMENT OF TERRESTRIAL GAMMA RADIATION IN THE DELTA REGION OF NIGERIA

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*Received February 18 2002, amended September 10 2003, accepted September 7 2003*

***In situ* gamma spectroscopy has been employed to characterise natural radiation in the soil at 32 locations in the Delta region of Nigeria. The outdoor gamma dose rates in the air due to $^{40}K$, $^{238}U$ and $^{232}Th$ in the soil were $1.5 \pm 0.9$ nGy h$^{-1}$, $6.9 \pm 1.6$ nGy h$^{-1}$ and $16.3 \pm 3.1$ nGy h$^{-1}$ respectively. The estimated total annual outdoor effective dose to the people in the region was 31.6 μSv y$^{-1}$.**

## INTRODUCTION

The possible effects of exposure of humans to ionising radiation due to naturally occurring radionuclides have been a cause of growing concern. It has been reported that natural radionuclides are widely distributed in the earth's crust, and that these are strongly influenced by local geology[1]. The natural environment is made up of indoor exposure to radon[2–4] and outdoor exposure to gamma radiation of both terrestrial and cosmic origin[5,6].

Unlike in other parts of the world, the data needed for the assessment of radiation hazards in most parts of Nigeria are still very sparse despite various efforts[7–14]. Most of the work carried out so far has been in major cities in Nigeria without a particular focus on rural areas where over 66% of Nigerians reside. The present work has been conducted in the Delta region where extensive oil exploration and mining activities involving the use of radioactive materials take place on a daily basis. The radioactive materials in use include radiographic sources, well logging radionuclides, radiotracers and so on, all of which can be released into the environment through accidents and improper waste disposal. This work is a pioneering effort which should yield data that will form the baseline for the determination of radioactivity level in the region.

## MATERIALS AND METHODS

### Selection of surveyed areas

The present studies were conducted in the month of March, which is the peak of the dry season in the area when most parts could be accessed with minimal difficulty. In all, 175 sites in 32 communities were surveyed and the distribution was such that all communities having one oil operational facility in the area that was accessible were covered. A few communities where oil activities were not known to be taking place were also chosen. Table 1 gives the list of communities surveyed in which there are such activities as industrial radiography, well logging, radioactive material storage, etc. They are therefore areas prone to radioactive discharge. Table 2 gives areas far from such activities, and hence these can be taken as natural environments for reference purposes. Figure 1

**Table 1. Locations with known oil exploration activities (numbers refer to locations shown in Figure 1).**

| Location no. | Communities |
|---|---|
| 3 | Mahin |
| 4 | Warri River Flow Station |
| 5 | Ovu-kokori |
| 6 | Otorugu |
| 7 | Otujeremi |
| 8 | Evwreni |
| 9 | Oroni |
| 10 | Uzede West |
| 11 | Uzede East |
| 12 | Opukushi |
| 13 | Sagbama |
| 15 | Oloibiri |
| 16 | Soku |
| 17 | Ekulama |
| 18 | Krakama |
| 19 | Abonnema Wharf |
| 20 | Elelenwo |
| 21 | Obigbo |
| 22 | Imo River Flow Station |
| 23 | Obunku |
| 24 | Afam |
| 25 | Ibibio |
| 26 | Ibeno |
| 27 | Qua Ibo River Flow Station |
| 28 | QIT (Mobil Platf.) |
| 30 | Eket |

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shows the locations where measurements were made, as listed in Tables 1 and 2.

### Measurement technique

The rapid *in situ* method of gamma spectroscopy was employed using a 7.6 cm × 7.6 cm NaI(Tl) detector placed at a height of 1 m above the ground surface. The detector has a resolution of about 8% at the 0.662 MeV line of $^{137}$Cs. As shown in a typical spectrum in the field, this resolution is sufficient to resolve the 1.460 MeV, 1.760 MeV and 2.614 MeV gamma peaks that were used to measure $^{40}$K, $^{238}$U and $^{232}$Th respectively. The detector was coupled to a Canberra Series 10 Plus multichannel analyser (MCA) (model no. 1104) through a preamplifier base. The output signals from the NaI(Tl) detector were passed to the MCA through coaxial cables of about 5 m. The same length of cable carries the high voltage necessary to bias the photomultiplier tube (PMT) of the detector from the MCA. The MCA operates on a rechargeable Cd cell battery, which can last for about 8 h when fully charged. A standby 12 V car battery was used whenever the in-built batteries ran down in the field. Counting was done for a preset time of 1000 s at five locations within each of the 32 communities and the counts per second ($N_f$) for each of the three peaks of interest were obtained for each spectrum. The count per second for each radionuclide at each location was computed using the algorithm in the memory of the MCA.

### Calibration procedure

The relevant quantity for the assessment of the radiological health effect is the absorbed dose rate and not the soil activity concentration. A conversion from activity concentration to dose rate in air (i.e. $D/A$) is therefore necessary to evaluate the impact on health. In order to do this, a uniform distribution of the radionuclides was assumed, and also all daughters including gaseous $^{222}$Rn and $^{220}$Rn from $^{238}$U and $^{232}$Th series respectively were considered to be in equilibrium with their parents and, as such, the effects of the gaseous components were not taken into account. Under this condition, the important factors in *in situ* gamma spectrometry reduce to $N_f/A$ and $N_f/D$, which relate $N_f$ to the absorbed dose rate ($D$) and soil activity concentration ($A$) of each radionuclide. The conversion factors obtained by Zombori *et al*[15] for gamma flux intensity at 1 m above the ground using a 7.6 cm × 7.6 cm NaI(Tl) are given in Table 3. The factors in this table were obtained from a combination of both theoretical and experimental values. The stated errors were therefore the errors in each of the quantities used to calculate the calibration factors.

The quantity $D/A$ is independent of the detector type and has been derived by Beck *et al*[16] for different detector types as:

$$D = 0.042A_K + 0.429A_U + 0.666A_{Th}$$

where $D$ (nGy$^{-1}$) is the total air absorbed dose rate due to the activity concentrations $A_K$, $A_U$ and $A_{Th}$ of $^{40}$K, $^{238}$U and $^{232}$Th respectively in Bq kg$^{-1}$.

**Table 2. Locations without known oil exploration activities (numbers refer to locations shown in Figure 1).**

| Location no. | Communities |
|---|---|
| 1 | Okitipupa |
| 2 | Igbokoda |
| 14 | Okoso-logan |
| 29 | Ifiayong |
| 31 | Uyo |
| 32 | Calabar |

## RESULTS AND DISCUSSION

In all the locations considered, a region of interest was created around 0.662 MeV to measure the presence of fallout $^{137}$Cs at each locality. No net count above the background was observed in this region, showing that the radionuclide was not present in any detectable amount. No peaks apart from those due to $^{238}$U, $^{232}$Th and $^{40}$K were observed at any of the localities. Using the total calibration factors obtained by Zombori *et al*[15] as presented in Table 3, the $N_f$ acquired for each peak at each location was converted to activity concentration in Bq kg$^{-1}$ shown in Table 4.[4] Using $D/A$, the absorbed dose rates at each location were calculated and the results

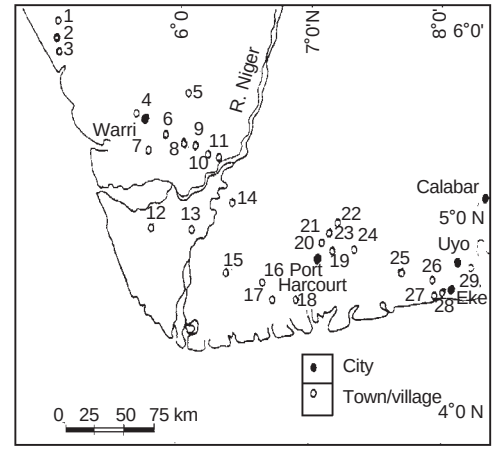


Figure 1. Map showing the locations where measurements were made. Tables 1 and 2 give the names of the numbered locations.

are presented in Table 5. The average total absorbed dose rates for the Delta region is 24.7 nGy $h^{-1}$, representing 44.9% of the world average value of 55.0 nGy $h^{-1}$.[17] The mean absorbed dose rates in air for areas where oil exploration is known to be taking place or had taken place in the past is 25.4 nGy $h^{-1}$. The mean absorbed dose rates in air for areas without any known evidence of oil extraction is 22.2 nGy $h^{-1}$. The mean absorbed dose rate in air in areas with oil exploration activity is about 14.4% higher than areas without oil exploration activity. Statistical treatment shows no significant difference between the two results.

In estimating the outdoor effective dose in any environment, the two factors of importance are the conversion factor from Gy $h^{-1}$ to Sv $h^{-1}$ and the occupancy factor. The former gives the equivalent human dose in Sv $y^{-1}$ from the absorbed dose rate in air (Gy $h^{-1}$) while the latter gives the fraction of the time that an individual is exposed to the outdoor radiation. The first factor has been recommended by the United Nations Scientific Committee on the

**Table 3. *In situ* conversion factors of natural radionuclides for a 7.6 cm × 7.6 cm NaI(Tl) detector.[15]**

| Energy (MeV) | $N_f/A$ (cps (Bq $kg^{-1})^{-1}$) | $N_f/D$ (cps (nGy $h^{-1})^{-1}$) | $D/A$ (nGy $h^{-1}$ (Bq $kg^{-1})^{-1}$) |
|---|---|---|---|
| 1.460 ($^{40}$K) | $(10.1 \pm 0.5) \times 10^{-3}$ | $0.2400 \pm 0.0070$ | $0.042 \pm 0.003$ |
| 1.760 ($^{238}$U) | $(10.5 \pm 0.5) \times 10^{-3}$ | $0.0245 \pm 0.0012$ | $0.429 \pm 0.042$ |
| 2.614 ($^{232}$Th) | $(20.5 \pm 1.0) \times 10^{-3}$ | $0.0308 \pm 0.0008$ | $0.666 \pm 0.048$ |

**Table 4. The mean specific activities of $^{40}$K, $^{238}$U and $^{232}$Th for the region.**

| Location no. | $^{40}$K (Bq $kg^{-1}$) | | $^{238}$U (Bq $kg^{-1}$) | | $^{232}$Th (Bq $kg^{-1}$) | |
|---|---|---|---|---|---|---|
| | Range | Mean | Range | Mean | Range | Mean |
| 1 | 14.3–28.8 | 19.5 ± 6.3 | 11.0–19.2 | 17.2 ± 4.3 | 7.9–17.8 | 13.9 ± 3.8 |
| 2 | 12.5–14.2 | 13.4 ± 0.7 | 19.7–11.6 | 10.8 ± 0.7 | 14.4–19.6 | 17.2 ± 2.0 |
| 3 | 11.0–22.9 | 16.4 ± 5.2 | 10.7–13.4 | 12.1 ± 1.0 | 15.7–20.0 | 18.0 ± 1.8 |
| 4 | 39.4–47.9 | 44.3 ± 3.2 | 18.3–28.5 | 24.4 ± 4.3 | 20.3–24.5 | 22.8 ± 1.6 |
| 5 | 25.9–32.8 | 28.5 ± 2.6 | 8.5–13.9 | 11.6 ± 2.0 | 8.9–14.4 | 11.0 ± 2.2 |
| 6 | 41.2–62.7 | 53.2 ± 8.0 | 18.7–27.7 | 22.1 ± 3.4 | 24.0–33.3 | 28.2 ± 4.5 |
| 7 | 50.6–67.6 | 57.5 ± 7.1 | 25.0–28.7 | 26.7 ± 1.5 | 23.5–32.2 | 29.0 ± 3.3 |
| 8 | 31.3–50.4 | 39.7 ± 7.5 | 18.5–13.9 | 18.4 ± 1.6 | 20.2–28.3 | 23.1 ± 3.1 |
| 9 | 32.9–50.1 | 41.7 ± 6.5 | 15.8–19.3 | 18.0 ± 1.4 | 22.5–29.4 | 25.9 ± 2.9 |
| 10 | 21.2–30.3 | 25.1 ± 3.4 | 10.1–12.5 | 13.1 ± 4.0 | 18.1–22.2 | 19.9 ± 1.8 |
| 11 | 21.5–31.1 | 27.5 ± 3.6 | 10.1–15.4 | 11.7 ± 2.1 | 15.3–20.3 | 18.3 ± 1.9 |
| 12 | 39.5–47.6 | 43.7 ± 3.4 | 12.5–22.5 | 15.7 ± 3.9 | 24.4–30.8 | 27.4 ± 2.8 |
| 13 | 42.2–53.9 | 49.4 ± 4.4 | 11.5–22.9 | 14.7 ± 4.7 | 20.4–31.3 | 25.5 ± 3.9 |
| 14 | 11.1–41.8 | 22.8 ± 13.0 | 19.8–23.4 | 13.7 ± 5.6 | 15.1–25.2 | 21.6 ± 4.1 |
| 15 | 44.0–55.6 | 48.8 ± 4.4 | 16.5–20.3 | 18.0 ± 1.4 | 22.6–29.8 | 27.7 ± 2.9 |
| 16 | 31.1–44.2 | 36.3 ± 5.2 | 11.5–19.1 | 15.5 ± 2.8 | 25.7–29.9 | 26.7 ± 1.8 |
| 17 | 38.5–45.7 | 42.5 ± 2.9 | 12.6–19.1 | 14.8 ± 2.6 | 28.9–33.7 | 30.5 ± 1.9 |
| 18 | 31.7–45.8 | 36.3 ± 6.0 | 19.6–25.0 | 13.9 ± 6.3 | 28.4–30.7 | 29.7 ± 0.9 |
| 19 | 32.0–39.7 | 36.1 ± 3.0 | 13.4–19.1 | 15.7 ± 2.1 | 24.5–30.8 | 26.5 ± 2.5 |
| 20 | 24.9–30.8 | 28.1 ± 2.6 | 10.1–20.6 | 14.2 ± 3.9 | 24.3–31.4 | 29.0 ± 2.9 |
| 21 | 21.2–43.6 | 32.7 ± 8.5 | 13.4–20.0 | 16.2 ± 2.8 | 21.8–29.9 | 26.0 ± 3.0 |
| 22 | 17.4–21.9 | 18.8 ± 2.2 | 7.7–13.3 | 10.8 ± 2.0 | 26.4–30.5 | 28.0 ± 1.8 |
| 23 | 21.0–37.9 | 24.9 ± 7.4 | 9.7–19.1 | 12.5 ± 3.9 | 25.2–29.8 | 27.2 ± 1.9 |
| 24 | 20.1–31.1 | 26.0 ± 5.0 | 9.1–18.2 | 13.4 ± 4.0 | 22.9–29.9 | 26.4 ± 2.6 |
| 25 | 31.6–43.8 | 36.5 ± 4.8 | 13.6–21.1 | 17.9 ± 3.2 | 25.7–30.8 | 28.0 ± 2.3 |
| 26 | 21.2–31.9 | 24.6 ± 4.3 | 18.7–25.0 | 21.1 ± 2.5 | 21.1–27.7 | 23.9 ± 2.8 |
| 27 | 19.4–22.9 | 21.2 ± 1.5 | 13.7–20.4 | 18.3 ± 2.7 | 25.2–33.8 | 29.8 ± 3.1 |
| 28 | 21.2–30.8 | 26.0 ± 3.9 | 17.5–27.7 | 21.2 ± 4.0 | 22.4–26.6 | 24.4 ± 1.9 |
| 29 | 19.2–30.6 | 22.7 ± 4.5 | 13.0–25.5 | 15.2 ± 2.5 | 20.6–25.5 | 23.6 ± 2.1 |
| 30 | 10.9–31.6 | 20.9 ± 7.3 | 10.6–22.0 | 15.6 ± 3.9 | 21.5–28.3 | 24.1 ± 2.1 |
| 31 | 14.3–32.8 | 21.9 ± 6.7 | 11.6–22.0 | 16.2 ± 4.0 | 15.9–26.9 | 22.4 ± 3.4 |
| 32 | 22.4–861.7 | 127.8 ± 0.81 | 11.6–31.8 | 19.1 ± 6.4 | 16.4–53.8 | 25.1 ± 10.5 |
| Mean ± SD | | 34.8 ± 20.4 | | 16.2 ± 3.7 | | 24.4 ± 4.7 |

**Table 5. The mean absorbed dose due to $^{40}$K, $^{238}$U and $^{232}$Th for the region.**

| Location no. | $^{40}$K (nGy h$^{-1}$) | $^{238}$U (nGy h$^{-1}$) | $^{232}$Th (nGy h$^{-1}$) | Effective dose (μSv y$^{-1}$) |
|---|---|---|---|---|
| 1 | 0.8 ± 0.3 | 7.4 ± 1.8 | 9.3 ± 2.6 | 22.4 |
| 2 | 0.6 ± 0.1 | 4.7 ± 0.3 | 11.5 ± 1.4 | 21.4 |
| 3 | 0.7 ± 0.2 | 5.2 ± 0.4 | 12.0 ± 1.2 | 22.9 |
| 4 | 1.9 ± 0.1 | 9.6 ± 1.8 | 15.2 ± 1.1 | 34.1 |
| 5 | 1.2 ± 0.1 | 5.0 ± 0.9 | 17.4 ± 1.5 | 17.3 |
| 6 | 2.2 ± 0.3 | 9.5 ± 1.5 | 18.8 ± 3.0 | 39.0 |
| 7 | 2.4 ± 0.3 | 11.4 ± 0.6 | 19.3 ± 2.2 | 42.4 |
| 8 | 1.7 ± 0.3 | 7.9 ± 0.7 | 15.4 ± 2.1 | 30.1 |
| 9 | 1.8 ± 0.3 | 7.7 ± 0.6 | 17.3 ± 2.0 | 34.1 |
| 10 | 1.1 ± 0.1 | 5.6 ± 1.7 | 13.3 ± 1.2 | 25.6 |
| 11 | 1.2 ± 0.2 | 5.0 ± 0.9 | 12.2 ± 1.3 | 23.4 |
| 12 | 1.8 ± 0.1 | 6.7 ± 1.7 | 18.3 ± 1.9 | 34.1 |
| 13 | 2.1 ± 0.2 | 6.3 ± 2.0 | 17.0 ± 2.6 | 32.5 |
| 14 | 1.0 ± 0.5 | 5.9 ± 2.4 | 14.4 ± 2.7 | 27.2 |
| 15 | 2.1 ± 0.2 | 7.7 ± 0.6 | 18.4 ± 1.9 | 35.9 |
| 16 | 1.5 ± 0.2 | 6.6 ± 1.2 | 17.8 ± 1.2 | 33.1 |
| 17 | 1.8 ± 0.1 | 6.3 ± 1.1 | 20.3 ± 1.3 | 35.9 |
| 18 | 1.5 ± 0.3 | 6.0 ± 2.7 | 19.7 ± 0.6 | 34.9 |
| 19 | 1.5 ± 0.1 | 6.7 ± 0.9 | 17.6 ± 1.7 | 33.0 |
| 20 | 1.2 ± 0.1 | 6.1 ± 1.7 | 19.3 ± 1.9 | 34.0 |
| 21 | 1.4 ± 0.4 | 6.9 ± 1.2 | 17.3 ± 2.0 | 32.7 |
| 22 | 0.8 ± 0.1 | 4.6 ± 0.9 | 18.6 ± 1.2 | 30.7 |
| 23 | 1.0 ± 0.3 | 5.4 ± 1.7 | 18.1 ± 1.2 | 31.3 |
| 24 | 1.1 ± 0.2 | 5.8 ± 1.7 | 17.6 ± 1.7 | 31.2 |
| 25 | 1.5 ± 0.2 | 7.7 ± 1.4 | 18.6 ± 1.5 | 35.5 |
| 26 | 1.0 ± 0.2 | 9.1 ± 1.1 | 15.9 ± 1.8 | 33.2 |
| 27 | 0.9 ± 0.1 | 7.8 ± 1.1 | 19.8 ± 2.1 | 36.6 |
| 28 | 1.1 ± 0.2 | 9.1 ± 1.7 | 16.3 ± 1.3 | 38.9 |
| 29 | 1.0 ± 0.2 | 6.5 ± 1.1 | 15.7 ± 1.4 | 29.7 |
| 30 | 0.9 ± 0.3 | 6.7 ± 1.7 | 16.0 ± 1.4 | 30.2 |
| 31 | 0.9 ± 0.3 | 7.0 ± 1.7 | 15.1 ± 2.2 | 29.1 |
| 32 | 5.4 ± 10.8 | 8.2 ± 2.7 | 16.7 ± 7.0 | 38.6 |
| Mean ± SD | 1.5 ± 0.9 | 6.9 ± 1.6 | 16.3 ± 3.1 | 34.6 ± 3.1 |

Effects of Atomic Radiation[17] as 0.7 Sv Gy$^{-1}$ and the second factor as 0.2, which suggests that an average individual stays outside for about 4.8 h daily. This factor suits the pattern of life in the studied area, yielding the outdoor effective dose given in Table 5. Indoor dose rates were not evaluated because the essential data on average build-up of radon gas in the indoor atmosphere were not available. The mean outdoor annual effective dose in the region is 31.6 μSv y$^{-1}$ representing 45% of the world average value of 70 μSv y$^{-1}$.[17]

## CONCLUSION

The present work has been able to establish a baseline radionuclides level for the Delta region of Nigeria, which will serve as reference for future assessment. The assessment of the radionuclide level of the area shows no significant impact of the extensive usage of radioactive materials in the region on the radiation burden of the environment. Artificial radionuclides were not detected in all the locations surveyed. The mean outdoor annual effective dose to the region is about 45% of the world average value.

## ACKNOWLEDGEMENTS

The authors wish to thank the director and staff of the Federal Radiation Protection Service, University of Ibadan, for releasing the equipment used in this study. Special thanks also go to the authority of the Federal University of Technology, Akure, for providing the travel grant for the work. We are most grateful to Professors K. M. Miller and M. Reginatto of the Department of Energy, Environmental Measurement Laboratory (EML), New York, for sending important literature materials used in this work.

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