RADIOLOGICAL IMPACT OF USING NIGERIAN DOLERITE (DIABASE) AS A CONSTRUCTION MATERIAL

Mokobia, C.E
Department of Physics, Delta State University, Abraka, Nigeria

ABSTRACT
The radiological impact of using natural dolerite as a construction material in Nigeria has been investigated by determining the natural radioactivity in dolerite samples collected from South West Nigeria. Gamma spectrometric measurements were carried out using a well -calibrated highly efficient Sodium doped with Iodide detector NaI (TL). Results show that the mean specific activities of ^{226}Ra, ^{228}Ra and ^{40}K contained in this mineral varied from 50.5 – 52.0, 51.9 – 52.3 and 463.1 – 467.0 Bqkg^{-1} respectively. An external hazard index of 0.4 and a mean annual effective dose equivalent of 0.1 mSvy^{-1} were obtained. Since the hazard index is less than unity and the determined dose equivalent below the internationally recommended dose equivalent limit of 1mSvy^{-1} for members of the public, it is concluded that Nigerian dolerite is a radiological friendly construction (engineering) material.

INTRODUCTION
Besides the international concern about the radiation exposure to the public from such anthropogenic sources of radiation as mining, oil exploration and exploitation, medical applications and consumer products, the radioactive contamination of geological materials has in recent times attracted great attention especially as these naturally occurring radioactive materials (NORM) are known not only to have reached hazardous levels (El – Dine *et al.,* 2001) but also have been found to have a wide availability and occurrence (WNA, 2003). Consequent upon this, they result in larger radiological exposure to the public relative to that from the nuclear industry for instance (Mokobia *et al.,* 2006).

Fundamental in the discussions of this radiation is its health implications on the populace an aspect of which has to do with ^{222}Rn (radon) the only gaseous member of the ^{238}U/^{226}Ra (Uranium) decay series part of which is shown in Figure 1 (Mokobia, 2004a). This short-lived radioactive gas (0.83days) decays into much shorter-lived ^{218}Po (Polonium) and ^{214}Pb (Lead) emitting α particle which causes cancer of the lungs if inhaled (Mokobia, 2004b).

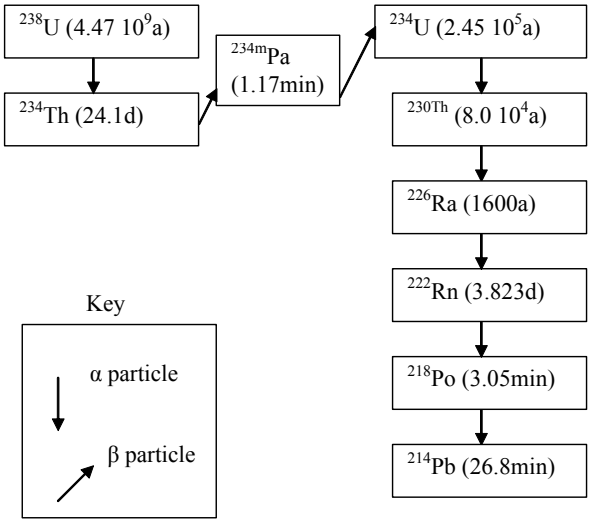

Fig. 1: *Part of the ^{238}U decay series (adapted from Mokobia, 2004a)*

Another aspect has to do with the accumulation of ^{239}Pu (Plutonium) when ^{238}U interacts with atmospheric neutrons through neutron-gamma (n, γ) nuclear reactions which result in the production of fissile materials (Mokobia *et al.,* 2006):

$$^{232}Th\,(n,\gamma)\,^{233}Th \xrightarrow{\beta^-} Pa \xrightarrow{\beta^-} {}^{233}U \qquad [1]$$

and

$$^{238}U\,(n,\gamma)\,^{239}U \xrightarrow{\beta^-} {}^{239}Np \xrightarrow{\beta^-} {}^{239}Pu \qquad [2]$$

This gradual production of ^{239}Pu is a crucial but unrecognized problem in radiation protection especially as it is reportedly toxic even in

minute quantities. The neutrons in such nuclear reactions are primarily produced by the bombardment of oxygen/ nitrogen nuclei in the atmosphere by cosmic rays. Such nuclear reactions are typified by:

$$Cosmic\ rays + {}^{17}_{8}O \Rightarrow {}^{1}_{0}n + {}^{16}_{8}O \quad [3]$$

Furthermore, several other radionuclides in the decay chain are known to be radiotoxic (Ahmed, 2004). The general NORM contamination problem has been well articulated Avwiri *et al.,* 2007).

Dolerite, a natural phosphor found in many geological formations in the world is a volcanic rock otherwise referred to as microgabbro or diabase (Research Machine, 2006). It is a potential construction (engineering) material being readily employed in road mending and for kerbstones. It is also used for monumental, masonry and as aggregate for road stone. In the phosphor form, this rock has been found to possess the potential for use as likely thermoluminescence (TL) dosimeter especially in retrospective dosimetry (Ogundare *et al.,* 2006a,b). Bell and Jermy (2000) had highlighted the potential of this phosphor as a construction material in their series of tests to determine its physical and mechanical and properties using samples obtained from a number of localities in and around Natal. They also determined its chemical and mineralogical compositions. Their investigation followed the discovery that some dolerites of that origin have been found to deteriorate within a short space of time when exposed and when used as construction materials.

This investigation is aimed at qualitatively and quantitatively determining the natural radioactivity in this local TL phosphor material from the Nigerian environment and consequently evaluating the radiological implications of using it for construction purposes in the country. The investigation primarily bothers on the radiation protection implications of its use in the construction industry.

MATERIALS AND METHODS

Dolerite samples obtained from the South Western Basement Complex of Nigeria located between latitude 7-10^{o} N and longitude 2-7^{o} E were cleaned using acetone, crushed and air dried to constant weight at room temperature in the sample preparation room of the Gamma Spectrometre laboratory at the Centre For Energy Research and development CERD, Obafemi Awolowo University, Ile Ife. Portions of these were then weighed into Marinelli beakers. These were sealed and left for a period of one month before gamma measurements were carried out. This waiting period was to ensure that secular equilibrium between ^{222}Rn (radon) on one part and ^{220}Rn (thoron) with their respective daughters hitherto disturbed during the exploration of the mineral is restored.

The experimental set-up for the gamma acquisition is composed of a Canberra model highly efficient NaI (TL) detector, a high voltage power supply, a preamplifier, an amplifier, an analog to-digital converter and a multichannel analyser. This spectrometry system which is available at the CERD and has been used by other investigators (Adesanmi *et al.,* 2000; Balogun *et al.,* 2003) had its detector enclosed in a 100 mm thick lead shield so as to screen off the interfering effect of other sources of radiation in the gamma counting environment other than the dolerite samples (Mokobia *et al.,* 2003; Mokobia *et al.,* 2006).

Gamma measurements were made using the Canberra S100 software. The energy calibration was carried out using the standard sources: ^{241}Am, ^{60}Co, ^{137}Cs and ^{152}Eu supplied by the International Atomic Energy Agency (IAEA). This facilitated the identification and subsequent quantification of the radionuclides analyzed in the same conditions. The response of the detector energy vs. channel number was linear having the equation:

$$E_{\gamma} = 8.0e^{-1}ch + 254.8keV \quad [4]$$

Eγ represents the energy while ch stands for the channel.

Using the same standard sources for efficiency calibration and considering the detection efficiency to vary significantly with energy, data pairs of efficiency vs. energy were obtained from the relationship (IAEA, 1989):

$$\varepsilon_\gamma = \frac{N_s - N_b}{tmAP_\gamma} \quad [5]$$

N_s is the total absorption peak of the radioisotope in the sample (dolerite), N_b the total absorption peak of the radioisotope in the background spectra, A is the specific activity (Bq kg^{-1}) at collection time, t is the counting time, P_γ is the probability of emission of the gamma quantum of energy and m is the mass of the sample (kg).

Radium – equivalent activity was calculated using the relationship (Tufail *et al.,* 2000 ; Khater *et al.,* 2001):

$$A_{Ra_{eq}} = A_{Ra} + 1.43A_{Th} + 0.077A_K \quad [6]$$

A_{Ra}, A_{Th} and A_K are the determined activities of ^{226}Ra, ^{232}Th and ^{40}K respectively.
This equation presupposes that 370 Bq ^{226}Ra/ kg, 259 Bq^{232}Th/kg and 4810 Bq ^{40}K/kg produce the same gamma – ray dose rate.

The external health hazard index arising from the use of dolerite was determined by employing the equation used by Tufail *et al*. (1993):

$$H_{ex} = \frac{A_{Ra}}{370} + \frac{A_{Th}}{259} + \frac{A_K}{4810} \quad [7]$$

The annual effective dose rate ($mSvy^{-1}$) was determined using the relationship found in the literature (UNSCEAR, 1988; Tufail *et al.,* 1994):

$$E = TQD_t * 10^{-6} * F_t \quad [8]$$

Dt, the outdoor dose rate in air ($nGyh^{-1}$) was obtained from the relation (UNSCEAR, 1982; Farai and Jibiri, 2000):

$$D_t = 0.446A_{Ra} + 0.662A_{Th} + 0.048A_K \quad [9]$$

In the equation [8], 10^{-6} represents a factor from nano to milli, T is 8760 hours per year, Q = 0.7 $SvGy^{-1}$ (UNSCEAR, 1988). F_t = 0.2 is the outdoor occupancy factor (Ibraheim *et al.,* 1993). Every other parameter retains its usual meaning.

RESULTS AND DISCUSSION

The range of the specific activities of the primordial radionuclides, their mean activities, radium equivalent activities and their external hazard indices as obtained in this work for each of the five samples, are presented in Table 1.

Table 1: Radionuclide detected in natural dolerite ($Bqkg^{-1}$)

Sample		^{226}Ra ($Bqkg^{-1}$)	^{228}Ra ($Bqkg^{-1}$)	^{40}K ($Bqkg^{-1}$)	Ra – eq activity	External hazard index H_{ex}
D1	Range	51.54 – 52.46	50.89 – 52.37	464.84 – 466.00		
	Mean	52.04 ± 1.45	51.96 ± 1.45	465.01 ± 2.40	162.15	0.438
D2	Range	51.05 – 52.66	51.88 – 52.58	465.55 – 468.04		
	Mean	51.87 ± 1.04	52.15 ± 1.68	467.00 ± 3.08	162.40	0.439
D3	Range	50.54 – 52.07	51.22 – 53.06	461.89 – 463.66		
	Mean	51.78 ± 1.08	51.91 ± 1.44	463.07 ± 2.00	161.67	0.437
D4	Range	50.98 – 52.55	51.46 – 53.12	464.68 – 470.34		
	Mean	52.04 ± 1.45	52.25 ± 1.08	466.03 ± 2.63	162.64	0.439
D5	Range	51.62 – 52.47	51.08 – 53.41	463.58 – 466.23		
	Mean	51.88 ± 1.32	52.04 ± 1.23	465.04 ± 1.88	162.11	0.438

The percentage contributions of the radionuclides to the total radioactivity in dolerite, the values of the absorbed dose rate in air and the effective annual dose equivalent are presented are presented in Table 2.

Table 2: % Contribution of ^{226}Ra, ^{228}Ra and ^{40}K to the total radioactivity in dolerite

Sample	^{226}Ra	^{228}Ra	^{40}K
D1	9.15	9.13	81.72
D2	9.08	9.13	81.78
D3	9.13	9.16	81.70
D4	9.12	9.16	81.71
D5	9.12	9.15	81.74
Mean	9.12	9.15	81.73

The specific activities range from 51.54 – 52.55; 50.89 – 53.41 and 461.89 – 470.34 $Bqkg^{-1}$ respectively for $^{226}Ra/^{238}U$; $^{228}Ra/^{232}Th$ and ^{40}K. The ranges of their corresponding mean values are 51.88 ± 1.32 – 52.04 ± 1.45; 51.91 ± 1.44 – 52.25 ± 1.08 and 463.03 ± 2.63 – 467 ± 3.08 $Bqkg^{-1}$.

This result shows that the radioactivity in this geological sample is largely from ^{40}K. This is in agreement with the results obtained for other building materials in the literature (Turhan *et al.,* 2008; Ngachin *et al.,* 2008). This observation from the data in Table 2 is illustrated in Figure 2, which clearly shows that the contribution of this radionuclide is nearly 82%.
The values obtained for radium equivalent

activities were high. A similar trend was observed for the specific activity values of ^{40}K.

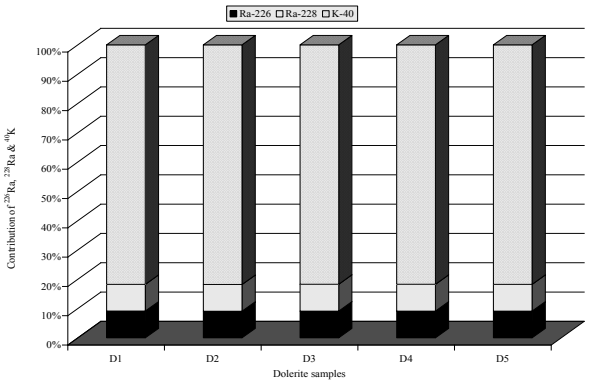

Fig. 2: *Graphical presentation of the contribution of ^{226}Ra, ^{228}Ra and ^{40}K to natural radioactivity in dolerite*

The calculated mean value for the external hazard index is 0.44. This value is less than unity indicating that this material is a radiological safe construction material.

The mean annual effective dose equivalent is 0.10 $mSvy^{-1}$. This represents just 1/10th of the radiation exposure limit of 1$mSvy^{-1}$ recommended for non radiation workers (members of the public) by the International Commission on Radiological Protection (ICRP, 1991). This also is an indication that radiation dose to members of the public resulting from the use of Nigeria dolerite is negligible, suggesting that its use as a construction material is radiation safety guaranteed.

CONCLUSION

This study shows that the external hazard index following the use of dolerite as determined in this work is 0.44. This value is less than unity. Also, the determined mean annual effective dose equivalent of 0.10 $mSvy^{-1}$ is less than the internationally recommended value for members of the public. It is therefore concluded that Nigerian dolerite is a radiological safe/friendly construction material.

Acknowledgements

The author is grateful to the Director and staff of Centre for Energy Research and Development, CERD, Obafemi Awolowo University, Ile –Ife, Nigeria for providing the facilities used in this work

REFERENCES

Adesanmi, C.A., Balogun, F.A., Fasasi, M.K., Tubosun, I.A. and Oladipo, A.A. (2000). A semi-empirical formula for HpGe detector efficiency calibration". *Journal of Radioanalytical and Nuclear Chemistry* **249**: 607.

Ahmed, N.K. (2004). Natural Radioactivity of Ground and Drinking Water in Some Areas of Upper Egypt. *Turkish Journal of Engineering and Environmental Science*. **28:** 345 – 354.

Avwiri, G.O., Tchokossa, P. and Mokobia, C.E. (2007). Natural Radionuclides in Borehole Water in Port Harcourt, Rivers State, Nigeria. *Radiation Protection Dosimetry,*. **123 (4):** 509-514

Balogun, F.A., Mokobia, C.E., Fasasi, M.K. and Ogundare, F.A. (2003). Natural Radioactivity associated with bituminous coal mining in Nigeria. *Nuclear Instruments and Methods in Physics Research* **A 505**: 444 – 448.

Bell, F. G. and Jermy, C.A. (2000). The geotechnical character of some South African dolerites, especially their strength and durability. *Quarterly Journal of Engineering Geology & Hydrogeology* 33 (1): 59-76.

El – Dine, N.W., EL-Shershaby, A., Ahmed, F. and Abdel-Haleem, A. (2001). Measurement of radioactivity and radon exhalation rate in different kinds of marble and granites. *Applied Radiation and Isotopes* **55 (6):** 853-860.

Farai, I.P. and Jibiri, N.N. (2000). Baseline Studies of Terrestrial Outdoor Gamma Dose Rate Levels in Nigeria. *Radiation Protection Dosimetry*. **88 (3):** 247 – 254.

IAEA (1989). Measurement of Radionuclides in Food and the Environment. A Guidebook. *International atomic Energy Agency,* Vienna.

Ibraheim, N.M., AbdelGhana, A.H., Shawky, S.M., Ashraf, E.M. and Farouk, M.A. (1993). Measurement of Radioactivity Levels in Soil in the Nile Delta and Middle Egypt. *Health Physics*. **64:** 620 – 627.

ICRP (1991). Radiation Protection. Publication 60. 1990. Recommendations of the International Commission on Radiologi-

cal Protection, Ann. ICRP 21 (1 – 3)

Khater, A.E.M., Higgy, R.H. and Pimpl, M. (2001). Radiological impacts of natural radioactivity in Abu – Tartor phosphate deposits, Egypt. *Journal of Environmental Radioactivity*. **55**: 255 - 267

Mokobia, C.E., Tchokossa, P., Olomo, J.B. and Balogun, F.A. (2003). Assessment of the Natural Radioactivity Content of some Liquid Paints Available in Nigeria. *Nigerian Journal of Physics*. **15(1):** 14-16.

Mokobia, C. E. (2004a). Natural Radioactivity in Nigerian Functional Coal Mines. M.Phil thesis, Obafemi Awolowo University, Ile- Ife..

Mokobia, C.E. (2004b). The effect of moisture on ^{222}Rn Emanation. *Journal of Science and Technology Research.* **3 (1):** 71-73.

Mokobia, C.E., Adebiyi, F.M., Akpan, I., Olise, F.S. and Tchokossa, P. (2006). Radioassay of prominent Nigerian fossil fuels using gamma and TXRF spectroscopy. *Fuel*. **85:** 1811-1814.

Ngachin, M., Garavagila, M., Glovani, C., Nourreddine, A., Kwato, N., Scruzzi, E. and Lagos, L. (2008). ^{226}Ra, ^{232}Th and ^{40}K contents and radon exhalation rate from materials used for construction and decoration in Cameroon. *Journal of. Radiological Protection*. **28(3):** 369-378

Ogundare, F.O., Balogun, F.A., Olowofela, J.O., Mokobia, C.E. and Fasunwon, O.O. (2006a). Thermoluminescence characteristics of natural dolerite. *Nuclear Instruments and Methods in Physics Research B.* **243:** 156- 160.

Ogundare, F.O., Mokobia, C.E. and Balogun, F.A. (2006b). Kinetic study of the thermoluminescence glow curve of natural dolerite. *Radiation Effects & Defects in Solids*. **161 (7):** 395-400

Research Machines (2006). Dolerite. Helicon Publishing division Research Machines Plc. http://www.tiscali.co.uk/reference/encyclopaedia/hutchinson/m0015239.htm

Tufail, M., Ahmad, N., Zafar, M.S., Siddiqui, M.S., Sarwar, M.S., Ali, S. and Almakky, S. (1993). Gamma activity in Lahore; Pakistani building materials. *Arabian Journal of Science and Engineering*. **18 (3):** 353 – 363.

Tufail, M., Rashid, T., Mahmood, A.B. and Ahmad, N. (1994). Radiation doses in Pakistani houses. *Science and Environment*. **142:** 171 – 177.

Tufial, M., Iqbal, M. and Mirza, S. M. (2000). Radiation doses due to natural radioactivity in Pakistan marble. *Radioprotection*. **35 (3):** 299 – 310.

Turhan, S., Baykan, U. N. and Sen, K. (2008). Measurement of the natural radioactivity in building materials used in Ankara and assessment of external doses. *Journal of Radiological Protection*.. **28 (1):** 83-91

UNSCEAR (1982). *Ionizing radiation: Sources and Biological Effects.* Report to the General assembly, New York.

UNSCEAR (1988). *Sources, effects and risks of ionization radiation*. Report to the General Assembly with Annexes, New York.

WNA (2003) *World Nuclear Association symposium on naturally occurring radioactive materials (NORM).* Energy Sustain Development. World Nuclear Association, London.