Nigerian Journal of Physics (NJP)

ISSN: 1595-0611

Volume 32(2), June 2023

Impact of Building Materials on Human Exposure to Indoor and Outdoor Background Ionizing Radiation Levels and Its Burden on the People in Makurdi Benue State

[1]Akaagerger, N. B., [2]Stanislas, A. N. and *[1]Kaki, D. K.

[1]Department of Physics Benue State University Makurdi, Benue State, Nigeria.
[2]Department of Physical Sciences, University of Mkar, Mkar. Gboko, Benue State, Nigeria

*Corresponding author's email: dkaki77@gmail.com

ABSTRACT

Exposure to ionizing radiation raises safety concerns. This necessitates monitoring of environmental radiation levels. Building materials obtained from sites with residual radioactivity are likely to increase the radiation burden. In this study, the effect of the type of building material on background levels of radiation was assessed and compared for buildings constructed with modern and traditional building materials. The indoor annual effective dose rate (IAED) and Outdoor annual effective dose rates (OAED) were found to be 1.3554±0.0445 and 0.2741±0.0029 for modern building types and 1.0115±0.0224 and 0.2505±0.068 for modern and traditional building types respectively. The Excess Lifetime Cancer Risk (ELCR) were found to be 6.2329×10^{-3} for modern and 4.7×10^{-3} for traditional building types. The difference in IAED for modern buildings was found to be statistically significant ($t = 6.0517$, $p = 0.0001$) while the OAED was not statistically significant ($t = 0.3250$, $p = 0.3745$). Modern building types were found to give rise to higher levels of radiation. It was concluded that the type of material contributed to the background levels of radiation.

Keywords:
Radiation,
Background ionization radiation,
Building materials,
Dose rate,
Annual equivalent dose rate,
General public,
Biological effects,
Indoor,
Outdoor.

INTRODUCTION

Radiation is energy in transit. This could be a bundle of energy in the form of electromagnetic waves, such as radio waves, x-rays, gamma rays, ultraviolet light or fast-moving particles, such as electrons and neutrons. Depending on energy, radiation may be classified as either ionizing or non-ionizing. Radiation with energy sufficient to eject atomic electrons from their shells is considered ionizing while those within a lower energy threshold not sufficient for ejecting atomic electrons are non-ionizing.

Ionizing radiation is of particular interest in the field of radiation protection because it alters the structure of atoms and molecules in biological systems and consequently affects their normal function. High and long-term exposure to ionizing radiation increases the risk of severe biological effects. This underpins the need for constant radiation monitoring.

Radiation is ever present in our environment even when there are no artificial radiation sources present. This is jointly due to residual amounts of primordial elements within the Earth's crust and cosmic radiation reaching the Earth from outer space (Osburn, 1965). Natural environmental radiation that is present in the environment is known as background radiation. Background levels of radiation are further increased by human activities and practices such as mining, diagnostic and therapeutic medicine, and the use of building materials obtained from sites with residual radioactivity (Dewar et al., 2013; IAEA, 2000).

The dose rate in a place, measured in Sivert per hour, quantifies the rate of energy deposition. From it, dose quantities and hazard indices such as the equivalent dose, annual effective dose rate and excess lifetime cancer risk are evaluated. They provide a means of quantifying the amount of radiation present and estimating the likelihood of developing certain health effects among an exposed population. The equivalent dose reflects the damage done in biological systems from different radiation types while the excess lifetime cancer risk gives the probability of developing cancer within a population. For example, a cancer risk level of 1×10^{-5} means one person from an exposed population of a hundred thousand is likely to develop cancer as a result of exposure to the same dose rate of radiation over a period of seventy years - the assumed mean lifetime. The world has an average background dose rate of 0.48 $mSvyr^{-1}$ and an ELCR value of 0.29×10^{-3} (Hossein *et al*., 2019). The maximum permissible dose of 1 mSv per year is considered permissible for non-radiation workers. USEPA considers an ELCR of about $1x10^{-4}$ to $1x10^{-7}$ (1 in 10,000 to 1 in 1,000,000) to be acceptable (Sadowitz & Graham, 2005).

Some results from local and international studies assessing background radiation levels found in available literature are presented in Table 1 below:

Table 1: Background Radiation Levels from Some Available Literature

S/No	Annual Effective Dose ($mSvy^{-1}$)		Excess Lifetime Cancer Risk	Location	Authors
	Indoor	Outdoor			
1	1.08	0.25	-	Keffi, Nigeria	Sadiq & Agba, 2012
2	-	0.45	-	Abeokuta Nigeria	Farai & Vincent, 2007
3	0.750 ± 0.005	0.189 ± 0.005	-	Kwali, Nigeria	
4	-	106.34 ± 15.77	20.56×10^{-3}	Port-Harcourt, Nigeria	Avwiri et al., 2014
5	-	0.92	3.21×10^{-3}	Pakistan	Qureshi et al., 2014
6	7.56	0.48	0.37×10^{-3}	Kerala, India	Monica et al., 2016
7	-	0.817	2.85×10^{-3}	Gonabad , Iran	Masoumi & Keshtkar, 2021

For this study, we sought to assess the impact of the type of building materials on background levels of radiation. Hence, buildings were broadly classified as modern and traditional. Modern buildings are those utilizing contemporary building materials such as tiles, blocks and roofing sheets while those built with traditionally available materials such as mud blocks and thatched roofs are tagged traditional. The dose rate, annual effective dose rate and excess Lifetime Cancer Risk were assessed and compared for traditional and modern building types by testing the null hypothesis – there is no significant difference in background radiation levels for modern and traditional building types in Makurdi environs.

MATERIALS AND METHODS

Fifty-two (52) buildings consisting of modern and traditional type materials were randomly sampled from Wurukum, High Level, Kanshio and Gboko Road areas of Makurdi Benue State. For each building, Dose rate measurements were taken using Inspector Exp^{+} Radiation Alert Meter (S.E inter-national, Inc U.S.A). The measurements were made with the meter held at a one-meter distance from the ground level. Five readings were taken for each indoor and outdoor location and the mean was evaluated. The mean values were then used in Equations (1) and (2) to obtain the indoor and annual effective dose rates.

$$X\left(\frac{\mu Sv}{hr}\right)\times\ 8760\left(\frac{hr}{yr}\right)\times\ 0.8\ = IAED\ \left(\frac{\mu Sv}{yr}\right) \qquad (1)$$

$$Y\left(\frac{\mu Sv}{hr}\right)\times 8760\left(\frac{hr}{yr}\right)\ X\ \ 0.2 =\ OAED\ \left(\frac{\mu Sv}{yr}\right) \qquad (2)$$

Where X and Y are the indoor and outdoor dose rates respectively, in Sievert per hour, IAED is the Annual Indoor Equivalent Dose Rate, OAED is the Annual Outdoor Equivalent Dose Rate ($\mu Svyr^{-1}$) and Eighty per cent (0.8) and twenty per cent (0.2) occupancy factors for Indoor and Outdoor Exposure situations respectively.

The Excess Lifetime risk for Cancer (ECLR) is obtained from the IAED and OAED using:

$$ELCR = (IAED + OAED)\ \times LE\ \times RF \qquad (3)$$

Where LE is the Average Life Expectancy assumed to be 70 years and RF is the Nominal risk Coefficient proposed for Lethality adjusted Cancer Risk. ICRP recommends a value of 0.055 Sv^{-1} for the whole population.

Independent samples t-test was carried out on OAEDR and IAEDR values to compare average values for modern and traditional building types.

RESULTS AND DISCUSSION

Results of the study are presented in Tables 2 to 5 with each table showing the result for modern and traditional buildings at each location within the study area. For Tables 2, 3, 4, and 5 X and Y are measured in $\mu Sv/hr$, IAED and OAED are in mSV/yr and ELCR is without dimensions.

Table 2: Annual Effective Dose Rate for Modern and Traditional Buildings at High-Level

MODERN BUILDINGS						TRADITIONAL BUILDINGS					
	X	Y	IAED	OAED	ELCR		X	Y	IAED	OAED	ELCR
H1	0.17	0.14	1.19	0.25	5.544×10^{-3}	**H9**	0.14	0.13	0.98	0.23	4.658×10^{-3}
H2	0.21	0.16	1.47	0.28	6.7375×10^{-3}	**H10**	0.15	0.13	1.05	0.23	4.928×10^{-3}
H3	0.22	0.15	1.54	0.26	7.0840×10^{-3}	**H11**	0.14	0.14	0.98	0.25	4.7355×10^{-3}
H4	0.18	0.17	1.21	0.30	6.9300×10^{-3}	**H12**	0.15	0.14	1.05	0.25	5.005×10^{-3}
H5	0.19	.15	1.33	0.26	5.8135×10^{-3}	**H13**	0.13	0.16	0.91	0.28	4.5815×10^{-3}
H6	0.23	0.19	1.61	0.33	7.469×10^{-3}	-	-	-	-	-	-
H7	0.16	0.16	1.21	0.28	5.7365×10^{-3}	-	-	-	-	-	-
H8	0.17	0.16	1.19	0.28	5.6595×10^{-3}	-	-	-	-	-	-
Average			**1.34**	**0.28**	$\mathbf{6.3718 \times 10^{-3}}$	**Average**			**0.99**	**0.25**	$\mathbf{4.7816 \times 10^{-3}}$

Table 3: Annual Effective Dose Rate for Modern and Traditional Buildings at Wurukum

MODERN BUILDINGS						TRADITIONAL BUILDINGS					
	X	Y	IAED	OAED	ELCR		X	Y	IAED	OAED	ELCR
W1	0.21	0.18	1.47	0.32	6.8915×10^{-3}	**W9**	0.14	0.15	0.98	0.26	4.7740×10^{-3}
W2	0.19	0.15	1.33	0.26	6.1215×10^{-3}	**W10**	0.17	0.16	1.19	0.28	5.6595×10^{-3}
W3	0.23	0.14	1.61	0.25	7.1610×10^{-3}	**W11**	0.15	0.13	1.05	0.23	4.9280×10^{-3}
W4	0.18	0.15	1.26	0.26	5.1861×10^{-3}	**W12**	0.17	0.17	1.19	0.30	2.3450×10^{-3}
W5	0.21	0.14	1.47	0.25	6.622×10^{-3}	**W13**	0.14	0.16	0.98	0.28	5.1205×10^{-3}
W6	0.24	0.18	1.68	0.32	7.700×10^{-3}	-	-	-	-	-	-
W7	0.20	0.16	1.40	0.28	6.468×10^{-3}	-	-	-	-	-	-
W8	0.17	0.13	1.19	0.20	5.3515×10^{-3}	-	-	-	-	-	-
Average			**1.43**	**0.27**	$\mathbf{6.4377 \times 10^{-3}}$	**Average for Traditional Houses**			**1.08**	**0.27**	$\mathbf{4.5654 \times 10^{-3}}$

Table 4: Annual Effective Dose Rate for Modern and Traditional Buildings along Gboko Road

MODERN BUILDINGS						TRADITIONAL BUILDINGS					
	X	Y	IAED	OAED	ELCR		X	Y	IAED	OAED	ELCR
G1	0.20	0.15	1.40	0.26	6.3910×10^{-3}	**G9**	0.15	0.13	1.05	0.23	4.9280×10^{-3}
G2	0.17	0.15	1.19	0.28	5.6595×10^{-3}	**G10**	0.14	0.13	0.98	0.23	4.6585×10^{-3}
G3	0.15	0.16	1.05	0.28	5.1205×10^{-3}	**G11**	0.13	0.15	0.91	0.26	4.5045×10^{-3}
G4	0.20	0.17	1.40	0.30	5.6900×10^{-3}	**G12**	0.14	0.12	0.98	0.21	4.5815×10^{-3}
G5	0.18	0.14	1.26	0.25	5.1010×10^{-3}	**G13**	0.15	0.17	1.05	0.30	5.1975×10^{-3}
G6	0.17	0.14	1.19	0.25	5.5440×10^{-3}	-	-	-	-	-	-
G7	0.15	0.14	1.05	0.25	5.0050×10^{-3}	-	-	-	-	-	-
G8	0.19	0.17	1.33	0.30	6.2575×10^{-3}	-	-	-	-	-	-
Average			**1.23**	**0.27**	$\mathbf{5.5961 \times 10^{-3}}$	**Average**			**0.99**	**0.25**	$\mathbf{4.7740 \times 10^{-3}}$

Table 5: Annual Effective Dose Rate for Modern and Traditional Buildings at Kanshio

MODERN BUILDINGS						TRADITIONAL BUILDINGS					
S/N	X	Y	IAED	OAED	ELCR	S/N	X	Y	IAED	OAED	ECLR
K1	0.22	0.17	1.54	0.30	7.0840×10^{-3}	**K9**	0.13	0.14	0.91	0.25	4.4660×10^{-3}
K2	0.23	0.17	1.61	0.30	7.3535×10^{-3}	**K10**	0.14	0.13	0.98	0.23	4.6585×10^{-3}
K3	0.17	0.13	1.19	0.23	5.4670×10^{-3}	**K11**	0.13	0.13	0.91	0.23	4.3860×10^{-3}
K4	0.23	0.19	1.61	0.33	7.4690×10^{-3}	**K12**	0.15	0.13	1.05	0.23	4.9665×10^{-3}
K5	0.17	0.15	1.19	0.26	5.5825×10^{-3}	**K13**	0.15	0.14	1.05	0.25	5.0435×10^{-3}
K6	0.16	0.14	1.12	0.25	5.2745×10^{-3}	-	-	-	-	-	-
K7	0.30	0.17	2.10	0.30	9.2400×10^{-3}	-	-	-	-	-	-
K8	0.14	0.14	0.98	0.25	4.7355×10^{-3}	-	-	-	-	-	-
Average			**1.42**	**0.28**	$\mathbf{6.5258 \times 10^{-3}}$	**Average**			**0.98**	**0.24**	$\mathbf{4.7041 \times 10^{-3}}$

Table 6: Average Values of Parameters at Different Locations in the Study Area

Parameter Average	Building Type	High Level	Wurukum	Gboko Road	Kanshio	Mean
		Locations				
INDOOR DOSE RATE (µSv/hr)	Modern	0.1913±0.0259	0.2038±0.0239	0.1763±0.0200	0.2025±0.0523	0.1935±0.0064
	Traditional	0.1420+0.0084	0.1540±0.0152	0.1420±0.0084	0.1400±0.0100	0.1445±0.0032
OUTDOOR DOSE RATE (µSv/hr)	Modern	0.1600±0.0053	0.1538±0.0185	0.1525±0.0128	0.1575±0.0205	0.1559±0.0017
	Traditional	0.1400±0.0122	0.1540±0.0152	0.1400±0.02	0.1340±0.0055	0.1420±0.0042
IAED (µSv/yr)	Modern	1.3438±0.0610	1.4263±0.1671	1.2338±0.1397	1.4175±0.3661	1.3554±0.0445
	Traditional	0.9940±0.02620	1.0780±0.1062	0.9940±0.0586	0.9800±0.0700	1.0115±0.0224
OAED (µSv/yr)	Modern	0.2800±0.0256	0.2675±0.0396	0.2713±0.0217	0.2775±0.0345	0.2741±0.0029
	Traditional	0.2480±0.0205	0.2700±0.0265	0.2460±0.0351	0.2380±0.0110	0.2505±0.0068
ELCR	Modern	$6.3718x10^{-3}$	$6.4377x10^{-3}$	$5.5961x10^{-3}$	$6.5258x10^{-3}$	$6.2329x10^{-3}$
	Traditional	$4.7816x10^{-3}$	$4.5654x10^{-3}$	$4.7740x10^{-3}$	$4.7041x10^{-3}$	$4.7063x10^{-3}$

From the summary of results presented in Table 6, the average background radiation level for modern houses is seen to have higher indoor and outdoor dose rates at all four locations within the study area. This is also reflected in the values of IAED, OAED and ELCR.

The mean value of ELCR for modern-type buildings was found to be $6.2x10^{-3}$ (0.0062±0.00100). This shows that for every one thousand members of the population exposed to background radiation level found in modern-type buildings over a period of seventy years, 6.2 persons are likely to develop cancer. The local type buildings were seen to have a lower value of $4.7x10^{-3}$ (0.0047±0.0006) - 4.7 persons per thousand. The difference was found to be statistically significant ($t = 6.1562$, $p = 0.0001$).

A test for the difference between IAED and OAED for modern and traditional building types showed a significant difference in the IAED ($t = 6.0517$, $p = 0.0001$) but no significant difference for OAED ($t = 0.3250$, $p = 0.3745$) for modern and traditional building types. This shows the type of materials used in modern type buildings significantly contributes to the indoor radiation burden and consequently the ELCR. There is therefore a need to employ measures that will reduce indoor dose rates. One such method suggested in the literature is proper ventilation of buildings. Akbari et al. (2013); Frutos et al., 2015; McCarron et al. (2020) have shown that poor ventilation results in a buildup of radon gas emitted inside enclosed buildings resulting in higher dose rates. Proper ventilation helps in reducing radon gas concentration and consequently the levels of IAED. In the study, K8 which was properly ventilated was seen to have a low value of IAED.

The ELCR in Makurdi, 6.2 persons per thousand in modern buildings and 4.7 persons per thousand for traditional type buildings, as obtained from this study, is seen to be lower than that of Port-Harcourt Nigeria reported by Avwiri, Olatunbonsun and ononugbu (2014) but higher than those for Pakistan (3.21 per thousand) and Kerala, India (0.37 per thousand) reported by Qureshi *et al.* 2014 and Monica *et al.* (2016) respectively.

The type of building materials used significantly affected the indoor background radiation levels and hence increased the radiation dose to the population. However, the fact that some of the traditional buildings also had high levels of background radiation and modern-type buildings had lower values indicates that other factors also play vital roles in the indoor levels of background radiation.

CONCLUSION

At the end of the study, it was found that there exists a difference in background radiation exposure level levels for traditional and modern building types in Markurdi modern building types having higher levels. Measurements were conducted and assessed for both indoor and outdoor exposure conditions for both building types. The average excess Lifetime Cancer risk was found to be 6.2 $x10^{-3}$ and $4.7x10^{-3}$ for modern and traditional building types respectively. Only difference in indoor exposure was found to be statistically significant. We therefore conclude that the type of material used affects background radiation levels. However, to determine the level of impact, it is recommended that further studies be carried out to:

i. Assess radionuclides in traditional and modern building materials.
ii. Conduct indoor radon gas assessment to ascertain its contribution to background radiation.

REFERENCES

Akbari, K., Mahmoudi, J., & Ghanbari, M. (2013). Influence of indoor air conditions on radon concentration in a detached house. *Journal of Environmental Radioactivity*, *116*, 166–173. https://doi.org/10.1016/j.jenvrad.2012.08.013

Avwiri, G. O., Olatubosun, S. A., & Ononugbu, C. P. (2014). Evaluation of Radiation Hazard Indices for Selected Dumpsites in PortHarcout, Rivers State, Nigeria. *International Journal of Science and Technology*, *3*(10), 663–673. https://www.ijstr.org/final-print/apr2014/Assessment-Of-Environmental-Radioactivity-In-Selected-Dumpsites-In-Port-Harcourt-Rivers-State-Nigeria.pdf

Dewar, D., Harvey, L., & Vakil, C. (2013). Uranium mining and health. *Canadian Family Physician Medecin de Famille Canadien*, *59*(5), 469–471. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3653646/

Farai, I. P., & Vincent, U. E. (2007). Out-door radiation level measurement in Abeokuta, Nigeria, by thermoluminescent dosimetry. *Nigerian Journal of Physics*, *18*(1). https://doi.org/10.4314/njphy.v18i1.38091

Frutos, B., Olaya, M., Alonso, C., & Martín-Consuegra, F. (2015). Radon concentration control by ventilation, and energy efficiency improvement. *36th AIVC Conference*, *January 2017*, 508–517. https://www.aivc.org/sites/default/files/51_0.pdf

IAEA. (2000). *Safety Series No. 115_International Basic Safety Standards for Protection Againts Ionizing Radiation and for the Safety of Radiation Sources*. 48. https://www.ilo.org/wcmsp5/groups/public/---ed_protect/---protrav/---safework/documents/publication/wcms_152685.pdf

Masoumi, H., & Keshtkar, M. (2021). Assessment of background radiation, annual effective dose and excess lifetime cancer risk in Gonabad City. *Frontiers in Biomedical Technologies*, *8*(3), 170–174. https://doi.org/10.18502/fbt.v8i3.7111

McCarron, B., Meng, X., & Colclough, S. (2020). An investigation into indoor radon concentrations in certified passive house homes. *International Journal of Environmental Research and Public Health*, *17*(11), 1–13. https://doi.org/10.3390/ijerph17114149

Monica, S., Visnu Prasad, A., Soniya, S., & Jojo, P. (2016). Estimation of indoor and outdoor effective doses and lifetime cancer risk from gamma dose rates along the coastal regions of Kollam district, Kerala. *Radiation Protection and Environment*, *39*(1), 38. https://doi.org/10.4103/0972-0464.185180

Osburn, W. S. (1965). Primordial radionuclides: Their distribution, movement, and possible effect within terrestrial ecosystems. *Health Physics*, *11*(12), 1275–1295. https://doi.org/10.1097/00004032-196512000-00005

Qureshi, A. A., Tariq, S., Din, K. U., Manzoor, S., Calligaris, C., & Waheed, A. (2014). Evaluation of excessive lifetime cancer risk due to natural radioactivity in the rivers sediments of Northern Pakistan. *Journal of Radiation Research and Applied Sciences*, *7*(4), 438–447. https://doi.org/10.1016/j.jrras.2014.07.008

Sadiq, A. ., & Agba, E. . (2012). Indoor and Outdoor Ambient Radiation Levels in Keffi , Nigeria . *Facta Universitatis*, *9*(2010), 19–26. https://www.academia.edu/2603356/Indoor_and_outdoor_radiation_levels_in_Keffi_Nigeria

Sadowitz, M., & Graham, J. D. (2005). A Survey of Residual Cancer Risks Permitted by Health , Safety and Environmental Policy. *Cancer*, *6*(1), 1–20. https://core.ac.uk/download/pdf/72057092.pdf