Journal of Chemical, Mechanical and Engineering Practices
Volume 9, Number 3, December 2025
ISSN: 2141-6745
Published By
International Centre for Integrated Development Research, Nigeria
In collaboration with
Copperstone University, Luanshya, Zambia

An Assessment of Background Radiation Doses in Buildings Using a Geiger-Muller Counter across Jos-Bukuru Metropolis, North-Central Nigeria

Gata Thomas Bulus
Department of Mineral and Petroleum Resources Engineering Technology,
Federal Polytechnic Ekowe, Bayelsa State, Nigeria.
E-mail: *tomgata2000@gmail.com*

Bako Abashi
Bioresource Development Centre,
National Biotechnology Research & Development Agency,
Langtang, Plateau State, Nigeria.
E-mail: *abashi.bako@gmail.com*

ABSTRACT

An assessment of background radiation dose in buildings was carried out from different ongoing/uncompleted buildings across Jos-Bukuru metropolis and environs using a Geiger-Muller Counter (gernie39ync105po model), which has a high sensitivity and wide measurement range with GM-hose as the central sensor, which supports automatic data recording. Two hundred and twelve (212) measurements of gamma radiation readings emanating from the naturally radioactive constituents in uncompleted houses within the studied area were recorded. The data captured the average dose rate (uSv/h), which varied from one building to another. The values were then calculated and converted to determine the absorbed dose rate ranging between 1.56mSv/y (180 nGyh^{-1}) and 4.12mSv/y (470nGy/h) with a mean value of 2.45mSv/y (279.7664nGy/h), annual effective dose equivalent varied from 0.8278mSv/y to 2.1615 mSv/y, while the excess lifetime cancer risk factor ranged between 2.8974x10^{-3}Sv and 7.5654x10^{-3}Sv. These values in some buildings are higher than the recommended 1mSv/y and therefore pose some health risks for the occupants over a long period of time.

Keywords: *Radiation, Radionuclides, Dose Rate (DR), Annual Effective Dose Equivalent (AEDE), Excess Lifetime Cancer Risk (ELCR).*

INTRODUCTION

Radiation found in soils is as a result of the presence of the natural radionuclides in them, the most significant of which are ^{238}U, ^{232}Th and ^{40}K (Solomon, 2005). Radionuclides are heavy isotopes in the environment that are not stable. To be stable, these nuclides emit radiation or particles (Baxter, 1983). The radionuclides are present almost everywhere around us; in the earth's crust, air, water, plants, and so on. They may be naturally occurring or artificially produced (Beretka et al., 1985). These radionuclides all have very long half-lives and have been present in the Earth since its formation (Martins & Harbinson, 1979).

Review of Previous Work on Radiation

A review of Indoor gamma ray measurements, activity concentrations and radiation hazard assessment of residential mud buildings in Miango, North Central Nigeria (Solomom *et al*, 2018) shows that the content of ^{238}U, ^{232}Th and ^{40}K in the mud houses in the studied area varies from 3.77-10.77ppm, 27.08-73.77ppm, and 1.47-6.27% respectively, while the activity concentrations of these radioelements vary from 46.52-132.97Bq/Kg for ^{238}U, 109.76-299.49Bq/Kg for ^{232}Th, and 459.07-1961.47Bq/Kg for ^{40}K. Assessment of the natural background radiation characteristics of basalts on the Jos Plateau and the radiological implications of the use of the rocks for house construction was also carried out by Solomon *et al*. (2002). The report shows that the gamma radiation dose rate varies from 0.3225 to 0.5805mSv/yr, while dose rates due to Alpha/Beta radiation range from 1.575 to 3.15mSv/yr, making buildings constructed with the basalts radiologically relatively safe for the dwellers.

Ajayi *et al* (2013) assessed radiological hazard indices of building materials in Ogbomoso, South-West Nigeria, and reported that the activity concentration of ^{40}K was found to range from 132.76 - 276.42Bq.kg^{-1} with an average of 204.59Bq.kg^{-1}. The mean radionuclide concentration obtained for the ^{238}U range from 27.79Bq.kg^{-1} to 30.65Bq.kg^{-1} with an average of 29.22Bq.kg^{-1}. For the ^{232}Th, the range is from 16.69Bq.kg^{-1} to 22.73Bq.kg^{-1} with an average of 19.71Bq.kg-1.

Radionuclide concentration and lifetime cancer risk due to gamma radioactivity from Quarry Stone Aggregates in Jos and its Environs, North Central Nigeria were studied by Solomon *et al* (2018). The report show the concentration and specific activity of ^{238}U, ^{232}Th and ^{40}K with their respective radiological indices from the various quarries (absorbed dose rate in air, annual effective dose equivalent, radium equivalent activity, internal hazard index and excess lifetime cancer risk) were found to be generally higher within the Getegere Stone Crushing Company Bukuru, Jos and the Mararaba Jamma Quarry Bukuru, Jos with both quarries sourcing their aggregate product from biotite granite belonging to the Jos-Bukuru Complex. According to the report, the average of total Excess Lifetime Cancer Risk from the quarries (4.45x10^{-3}) is 15.34 times higher than the world average of 0.29x10^{-3}, below which there is a negligible risk of developing cancer.

ISSN: 2141-6745
Published By
International Centre for Integrated Development Research, Nigeria
In collaboration with
Copperstone University, Luanshya, Zambia

Jibiri *et al* (2009), working on farming activities on the sand situated in high background radiation (HBR) areas in Jos, recorded that farming activities enhance the radiation exposure scenarios and pathways to humans. According to this report, annual external dose values vary from 0.07mSv/y to 2.02mSv/y, while the internal dose values for the locations were reported as 9.9mSv/y for Bitsichi, 3.9mSv/y for Bukuru and 3.9mSv/y for Ropp. Ajayi (2008) reported that the radiation background values of Tin Mining sites in Jos have an equivalent dose of 3.0mSv/y due to the gamma radiation from the radionuclides ^{40}K, ^{238}U and ^{232}Th in the soil samples surrounding the mining sites. Though the value is below the average dose rate value for Radiation workers (20mSv/y), it's far above the world/global safety value of 1mSv/y for an individual as reported by the UNSCEAR (2000).

Isa *et al* (2024) assessed natural background radiation exposure in the Federal Capital Territory of Nigeria and reported the absorbed dose rate as 87.87nGy/h for Abuja Municipal Area Council, 60.03nGy/h for Kuje, 100.05nGy/h for Bwari, 164.43nGy/h for Abaji, 109.62nGy/h for Kwali and 113.10nGy/h for Gwagwalada, while the estimated annual effective dose equivalent was 0.11mSv/y for Abuja Municipal Area Council, 0.07mSv/y for Kuje, and 0.12mSv/y for Bwari. 0.20mSv/y for Abaji, 0.13mSv/y for Kwali and 0.14mSv/y for Gwagwalada.

James *et al* (2020) examined indoor and outdoor radiation levels and human health risk in Sheda Science and Technology Complex and its environment, Abuja, Nigeria. He concluded in his findings that the total dose rate (indoor and outdoor), the total annual equivalent dose (indoor and outdoor), total annual effective dose equivalent (indoor and outdoor) and the total excess lifetime cancer risk (indoor and outdoor) are 0.113±0.022 (μSv/h), 0.071±0.016 (μSv/h), 0.794±0.155 mSv/y, 0.124±0.074 mSv/y, 0.556±0.109 mSv/y, 0.087±0.020 mSv/y, 1.945±0.379, 0.304±0.104.

A review of Eke *et al* (2024) assessment of radiation hazard indices due to natural radionuclides in soil samples from Imo State University, Owerri, Nigeria showed that the dose rate ranged between 15.56 and 36.91nGy/h, while the annual effective dose ranged from 0.07156mSv/y to 0.169749mSv/y.

Geology of the Area

The rocks found within the study areas were predominantly basement rock, which comprises the gneisses, and Older Granite, which were mostly intruded by the Younger Granites. Gneiss is a banded rock formed during high-grade regional metamorphism. Gneisses found within the study area are mostly of granitic origin. There are different types of gneisses based on the type of rock from which they were formed (e.g., Granite-gneiss, Diorite-gneiss, etc.) or, in some cases, the mineral which dominates the composition of the rock (e.g., Biotite-gneiss, Hornblende-gneiss, etc.). In places around Mazah environs, the gneisses found here have a near migration into migmatites and are

ISSN: 2141-6745
Published By
International Centre for Integrated Development Research, Nigeria
In collaboration with
Copperstone University, Luanshya, Zambia

composed of more dark coloured minerals striking 232^{o}SW, whereas in places around Gold and Base, their gneiss outcrops are predominantly made up of light coloured minerals (feldspars) striking 32^{o}NE.

The Younger Granite province comprises non-orogenic granite, rhyolite, basalts, crystal-rich ignimbrite and porphyrite of the Mesozoic Era (MacLeod *et al.*, 1971). Within the study area, they include the Jos-Bukuru, Buji, Rukuba and Shere Complexes constitute the bulk of the Younger Granites suite in and around the study area. It consists essentially of biotite granite, riebeckite biotite granite, hornblende fayalite granite, hornblende biotite granite, rhyolite, syenite, gabbro, dolerites and basalts, with a significant amount of natural concentration of uranium, thorium and potassium (Solomon, 2005). The alluvial deposits of cassiterite (tin oxide, SnO2) and columbite (oxide of tantalum-niobium, iron and manganese, (Fe, Mn) (Ta, Nb)2O6), as well as radioactive mineral such as thorite (ThSiO4), zircon (ZiSiO4) and monazite (Ce, La, Yt)PO4) on the Jos Plateau are believed to have been derived from these Complexes.

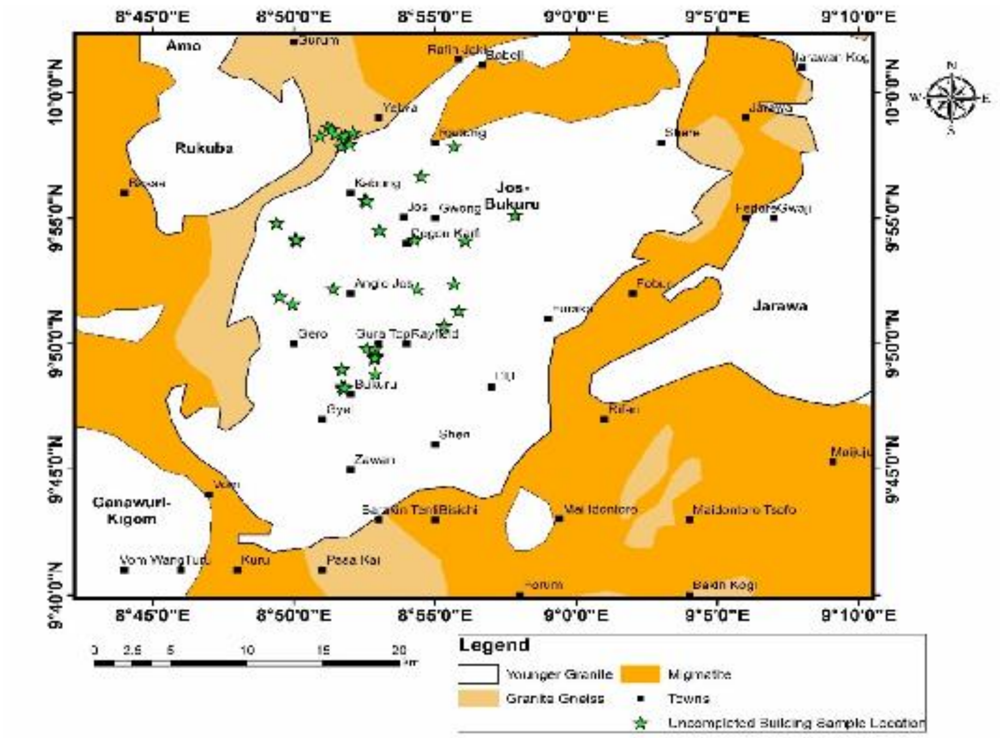

Figure: Geologic Map of the study area with the locations of the uncompleted buildings superimposed on the geology.

Journal of Chemical, Mechanical and Engineering Practices
Volume 9, Number 3, December 2025
ISSN: 2141-6745
Published By
International Centre for Integrated Development Research, Nigeria
In collaboration with
Copperstone University, Luanshya, Zambia

MATERIALS AND METHODS

For this research data collection, a GARMIN GPS map 62 model was used for taking coordinates, a compass clinometer was used for direction and a handheld Geiger-Muller counter (gernie39ync105po model) was used for taking radiation values across uncompleted houses.

Plate 1 Plate 2 Plate 3

Plate 1 = GARMIN GPSmap 62 model, Plate 2 = Geiger-Muller counter
Plate 3 = Taking background radiation reading from uncompleted buildings

METHOD

Two hundred and twelve (212) measurements of gamma radiation readings emanating from the naturally radioactive constituents in uncompleted houses within the Jos metropolis and environs were recorded using Hand-held Geiger-Muller Counter (Gernie39ync105po Model) which has a high sensitivity and wide measurement range. It uses precision GM-hose as the central sensor that supports automatic data recording. It detects and monitors indoor, outdoor and other similar environmental radiations when placed directly on the surface of the object to be studied. For better accuracy, a preset time of 8 minutes was used for the measurement per point, while the assay mode provides the average radiation absorbed dose (*uSv/h*). The values were then calculated and converted to determine the annual effective dose equivalent (*mSv/y*) and the excess lifetime cancer risk factor (*Sv*).

Journal of Chemical, Mechanical and Engineering Practices
Volume 9, Number 3, December 2025
ISSN: 2141-6745
Published By
International Centre for Integrated Development Research, Nigeria
In collaboration with
Copperstone University, Luanshya, Zambia

RESULTS AND DISCUSSION

As a way of assessing the effect of radionuclides in buildings, background radiations were measured within different ongoing/uncompleted buildings across Jos metropolis using a Geiger-Muller Counter (gernie39ync105po model). Field data captured the average dose rate in microsievert per hour (*uSv/h*)**,** which were then analyzed to determine the annual effective dose equivalent in millisievert per year (*mSv/y*) and excess lifetime cancer risk factor in sievert (*Sv*).

Table 1: Absorb dose rate, annual effective dose equivalent and excess life-time cancer risk factor recorded from analysis of random uncompleted buildings in Jos metropolis and environs.

	GPS COORDINATES				RADIOLOGICAL INDICES				
S/N	**N⁰**	**E⁰**	**ELV. (m)**	**LOCATION**	**Avg. DR (*uSv/h*)**	**Avg. DR (*nGy/h*) = DR (*uSv/h*)* 1000**	**Dose Rate (*mSv/y*)** = *uSv/h** 0.001*24*365	**AEDE*in* (*mSv/y*) = *Din(nGy/h)* * *8760* * *0.75* * *0.7(Sv/Gy)* * *0.000001***	**ELCR*in* (*Sv*) = AEDE*in* * *DL(70)* * *RF(0.05)***
1.	09 54 48.3	008 49 23.1	1268	Dong	0.23	230	2.0148	1.05777	3.70220
2.	09 54 48.5	008 49 23.4	1269	Dong	0.21	210	1.8396	0.96579	3.38027
3.	09 54 48.7	008 49 23.6	1267	Dong	0.21	210	1.8396	0.96579	3.38027
4.	09 54 48.8	008 49 23.3	1271	Dong	0.24	240	2.1024	1.10376	3.86316
5.	09 54 49.1	008 49 23.0	1266	Dong	0.24	240	2.1024	1.10376	3.86316
6.	09 54 48.9	008 49 23.6	1269	Dong Sand Heep	0.23	230	2.0148	1.05777	3.70220
7.	09 54 48.9	008 49 23.7	1268	Dong Sand Heep	0.25	250	2.19	1.14975	4.02413
8.	09 54 05.6	008 50 05.8	1301	Zoo Fence, Dong	0.23	230	2.0148	1.05777	3.70220
9.	09 54 06.5	008 50 05.5	1298	Zoo Fence, Dong	0.25	250	2.19	1.14975	4.02413
10.	09 54 07.4	008 50 05.6	1303	Zoo Fence, Dong	0.25	250	2.19	1.14975	4.02413
11.	09 54 08.9	008 50 05.0	1304	Zoo Fence, Dong	0.23	230	2.0148	1.05777	3.70220
12.	09 54 09.9	008 50 04.6	1306	Zoo Fence, Dong	0.26	260	2.2776	1.19574	4.18509
13.	09 54 10.9	008 50 04.5	1305	Zoo Fence, Dong	0.24	240	2.1024	1.10376	3.86316
14.	09 54 12.2	008 50 04.1	1300	Zoo Fence, Dong	0.26	260	2.2776	1.19574	4.18509
15.	09 54 11.8	008 50 03.8	1301	Zoo Sand Heep	0.26	260	2.2776	1.19574	4.18509
16.	09 54 08.9	008 50 04.6	1299	Zoo Sand Heep	0.23	230	2.0148	1.05777	3.70220
17.	09 51 34.5	008 49 57.3	1310	Loh-Dik, Rantya	0.32	320	2.8032	1.47168	5.15088
18.	09 51 34.6	008 49 57.4	1319	Loh-Dik, Rantya	0.3	300	2.628	1.37970	4.82895
19.	09 51 34.7	008 49 57.6	1314	Loh-Dik, Rantya	0.31	310	2.7156	1.42569	4.98992
20.	09 51 34.3	008 49 57.5	1331	Loh-Dik Stair	0.34	340	2.9784	1.56366	5.47281
21.	09 51 34.5	008 49 57.8	1324	Loh-Dik 1st floor	0.26	260	2.2776	1.19574	4.18509
22.	09 51 34.5	008 49 57.3	1322	Loh-Dik 1st floor	0.23	230	2.0148	1.05777	3.70220
23.	09 51 52.5	008 49 29.7	1293	Bwak, Rantya	0.3	300	2.628	1.37970	4.82895
24.	09 51 52.6	008 49 29.4	1294	Bwak, Rantya	0.29	290	2.5404	1.33371	4.66799
25.	09 51 52.2	008 49 29.4	1297	Bwak, Rantya	0.27	270	2.3652	1.24173	4.34606
26.	09 51 52.1	008 49 29.9	1298	Bwak, Rantya	0.28	280	2.4528	1.28772	4.50702
27.	09 51 52.3	008 49 30.0	1299	Bwak, Rantya	0.24	240	2.1024	1.10376	3.86316
28.	09 51 52.2	008 49 30.1	1295	Bwak, Rantya	0.3	300	2.628	1.37970	4.82895
29.	09 51 52.1	008 49 29.9	1294	Bwak, Rantya	0.33	330	2.8908	1.51767	5.31185
30.	09 51 52.5	008 49 30.1	1298	Bwak, Rantya	0.25	250	2.19	1.14975	4.02413
31.	09 52 11.2	008 51 23.6	1304	Opp. GJSS	0.25	250	2.19	1.14975	4.02413
32.	09 52 11.2	008 51 23.1	1297	Kufan (Amusement Park)	0.3	300	2.628	1.37970	4.82895
33.	09 52 10.9	008 54 23.1	1305	Kufan (Amusement Park)	0.3	300	2.628	1.37970	4.82895
34.	09 52 11.0	008 54 22.7	1307	Odus,	0.29	290	2.5404	1.33371	4.66799
35.	09 56 40.6	008 54 30.5	1207	Odus,	0.34	340	2.9784	1.56366	5.47281
36.	09 56 40.4	008 54 30.6	1208	Odus,	0.33	330	2.8908	1.51767	5.31185
37.	09 56 40.5	008 54 30.4	1204	Odus,	0.28	280	2.4528	1.28772	4.50702

ISSN: 2141-6745
Published By
International Centre for Integrated Development Research, Nigeria
In collaboration with
Copperstone University, Luanshya, Zambia

38.	09 56 40.7	008 54 30.4	1206	Odus,	0.36	360	3.1536	1.65564	5.79474
39.	09 56 40.4	008 54 30.0	1209	Odus,	0.26	260	2.2776	1.19574	4.18509
40.	09 56 40.6	008 54 29.8	1211	Odus,	0.27	270	2.3652	1.24173	4.34606
41.	09 56 40.7	008 54 30.3	1206	Odus,	0.28	280	2.4528	1.28772	4.50702
42.	09 54 08.7	008 54 16.5	1230	Rikko Round-about	0.27	270	2.3652	1.24173	4.34606
43.	09 54 08.5	008 54 16.7	1233	Rikko Round-about	0.25	250	2.19	1.14975	4.02413
44.	09 54 08.2	008 54 16.7	1233	Rikko Round-about	0.27	270	2.3652	1.24173	4.34606
45.	09 54 08.1	008 54 16.6	1241	Rikko Round-about	0.26	260	2.2776	1.19574	4.18509
46.	09 54 08.1	008 54 16.9	1228	Rikko Round-about	0.28	280	2.4528	1.28772	4.50702
47.	09 54 07.9	008 54 16.6	1238	Rikko Round-about	0.25	250	2.19	1.14975	4.02413
48.	09 54 07.6	008 54 16.5	1233	Rikko Round-about	0.27	270	2.3652	1.24173	4.34606
49.	09 54 06.3	008 56 03.8	1291	Beside Lamingo Dam	0.18	180	1.5768	0.82782	2.89737
50.	09 54 05.8	008 56 03.9	1290	Beside Lamingo Dam	0.2	200	1.752	0.91980	3.21930
51.	09 54 05.9	008 56 04.2	1291	Beside Lamingo Dam	0.25	250	2.19	1.14975	4.02413
52.	09 54 06.3	008 56 04.2	1294	Beside Lamingo Dam	0.2	200	1.752	0.91980	3.21930
53.	09 54 06.7	008 56 04.0	1288	Beside Lamingo Dam	0.21	210	1.8396	0.96579	3.38027
54.	09 54 06.3	008 56 03.7	1291	Beside Lamingo Dam	0.21	210	1.8396	0.96579	3.38027
55.	09 55 07.6	008 57 49.8	1333	Behind Juth Lamingo	0.32	320	2.8032	1.47168	5.15088
56.	09 55 07.6	008 57 49.9	1331	Behind Juth Lamingo	0.31	310	2.7156	1.42569	4.98992
57.	09 55 07.5	008 57 50.4	1330	Behind Juth Lamingo	0.28	280	2.4528	1.28772	4.50702
58.	09 55 07.9	008 57 50.6	1329	Behind Juth Lamingo	0.24	240	2.1024	1.10376	3.86316
59.	09 55 08.0	008 57 50.2	1333	Behind Juth Lamingo	0.31	310	2.7156	1.42569	4.98992
60.	09 55 07.1	008 57 49.2	1330	Behind Juth Lamingo	0.28	280	2.4528	1.28772	4.50702
61.	09 52 23.5	008 55 39.5	1292	Opp. Catholic Complex, Kwan	0.26	260	2.2776	1.19574	4.18509
62.	09 52 23.8	008 55 39.4	1288	Opp. Catholic Complex, Kwan	0.33	330	2.8908	1.51767	5.31185
63.	09 52 23.6	008 55 39.2	1285	Opp. Catholic Complex, Kwan	0.27	270	2.3652	1.24173	4.34606
64.	09 52 22.9	008 55 39.4	1290	Opp. Catholic Complex, Kwan	0.24	240	2.1024	1.10376	3.86316
65.	09 52 23.1	008 55 39.9	1293	Opp. Catholic Complex, Kwan	0.26	260	2.2776	1.19574	4.18509
66.	09 52 23.7	008 55 40.4	1301	Opp. Catholic Complex, Kwan	0.31	310	2.7156	1.42569	4.98992
67.	09 52 23.5	008 55 40.6	1299	Opp. Catholic Complex, Kwan	0.24	240	2.1024	1.10376	3.86316
68.	09 52 23.4	008 55 40.2	1295	Opp. Catholic Complex, Kwan	0.23	230	2.0148	1.05777	3.70220
69.	09 51 19.4	008 55 49.6	1324	Kwam Road side	0.3	300	2.628	1.37970	4.82895
70.	09 51 19.5	008 55 49.9	1323	Kwam Road side	0.3	300	2.628	1.37970	4.82895
71.	09 51 19.8	008 55 49.8	1319	Kwam Road side	0.34	340	2.9784	1.56366	5.47281
72.	09 51 19.3	008 55 49.7	1323	Kwam Road side	0.32	320	2.8032	1.47168	5.15088
73.	09 51 19.4	008 55 49.5	1322	Kwam Road side (1st floor)	0.23	230	2.0148	1.05777	3.70220
74.	09 51 19.8	008 55 49.6	1320	Kwam Road side (1st floor)	0.23	230	2.0148	1.05777	3.70220
75.	09 51 19.0	008 55 49.3	1321	Kwam Road side (1st floor)	0.18	180	1.5768	0.82782	2.89737
76.	09 51 19.1	008 55 49.5	1318	Kwam Road side (1st floor)	0.29	290	2.5404	1.33371	4.66799
77.	09 50 42.2	008 55 18.5	1332	Rayfield	0.3	300	2.628	1.37970	4.82895
78.	09 50 41.9	008 55 18.5	1336	Rayfield	0.3	300	2.628	1.37970	4.82895
79.	09 50 42.7	008 55 18.5	1328	Rayfield	0.3	300	2.628	1.37970	4.82895
80.	09 50 43.0	008 55 18.8	1332	Rayfield	0.24	240	2.1024	1.10376	3.86316
81.	09 50 43.2	008 55 18.2	1333	Rayfield	0.26	260	2.2776	1.19574	4.18509
82.	09 50 43.2	008 55 18.4	1331	Rayfield	0.32	320	2.8032	1.47168	5.15088
83.	09 50 42.8	008 55 18.6	1332	Rayfield	0.24	240	2.1024	1.10376	3.86316
84.	09 50 42.5	008 55 18.9	1330	Rayfield	0.34	340	2.9784	1.56366	5.47281
85.	09 50 42.1	008 55 19.0	1331	Rayfield	0.28	280	2.4528	1.28772	4.50702
86.	09 57 50.7	008 55 40.2	1134	Farin Gada	0.28	280	2.4528	1.28772	4.50702
87.	09 57 50.8	008 55 40.0	1138	Farin Gada	0.29	290	2.5404	1.33371	4.66799
88.	09 57 51.3	008 55 40.2	1134	Farin Gada	0.27	270	2.3652	1.24173	4.34606
89.	09 57 51.5	008 51 39.9	1131	Farin Gada (Angwan Jarawa)	0.27	270	2.3652	1.24173	4.34606
90.	09 57 51.7	008 51 40.0	1135	Farin Gada (Angwan Jarawa)	0.29	290	2.5404	1.33371	4.66799
91.	09 57 50.7	008 51 40.2	1130	Farin Gada (Angwan Jarawa)	0.3	300	2.628	1.37970	4.82895
92.	09 57 51.0	008 51 40.1	1130	Farin Gada (Angwan Jarawa)	0.38	380	3.3288	1.74762	6.11667
93.	09 57 51.3	008 51 40.1	1138	Farin Gada (Angwan Jarawa)	0.32	320	2.8032	1.47168	5.15088
94.	09 57 51.6	008 51 40.2	1136	Farin Gada (Angwan Jarawa)	0.34	340	2.9784	1.56366	5.47281
95.	09 57 50.7	008 51 40.1	1132	Farin Gada (Angwan Jarawa)	0.31	310	2.7156	1.42569	4.98992
96.	09 57 50.0	008 51 39.9	1136	Farin Gada (Angwan Jarawa)	0.26	260	2.2776	1.19574	4.18509
97.	09 57 51.2	008 51 39.8	1133	Farin Gada (Angwan Jarawa)	0.28	280	2.4528	1.28772	4.50702
98.	09 57 51.8	008 51 39.9	1134	Farin Gada (Angwan Jarawa)	0.27	270	2.3652	1.24173	4.34606
99.	09 54 31.6	008 53 01.3	1130	G.R.A Opp. Shendam Court, MTN Office	0.27	270	2.3652	1.24173	4.34606
100.	09 54 31.9	008 53 00.9	1232	G.R.A Opp. Shendam Court, MTN Office	0.34	340	2.9784	1.56366	5.47281
101.	09 54 32.4	008 53 02.0	1227	G.R.A Opp. Shendam Court, MTN Office	0.36	360	3.1536	1.65564	5.79474

ISSN: 2141-6745
Published By
International Centre for Integrated Development Research, Nigeria
In collaboration with
Copperstone University, Luanshya, Zambia

102.	09 54 32.1	008 53 02.5	1227	G.R.A Opp. Shendam Court, MTN Office	0.34	340	2.9784	1.56366	5.47281
103.	09 54 31.7	008 53 01.7	1219	G.R.A Opp. Shendam Court, MTN Office	0.35	350	3.066	1.60965	5.63378
104.	09 48 58.4	008 51 42.2	1231	Federal Low-cost Bukuru	0.39	390	3.4164	1.79361	6.27764
105.	09 48 58.6	008 51 42.1	1229	Federal Low-cost Bukuru	0.4	400	3.504	1.83960	6.43860
106.	09 48 58.4	008 51 41.7	1248	Federal Low-cost Bukuru	0.4	400	3.504	1.83960	6.43860
107.	09 48 58.0	008 51 41.3	1232	Federal Low-cost Bukuru	0.37	370	3.2412	1.70163	5.95571
108.	09 48 58.7	008 51 41.5	1231	Federal Low-cost Bukuru	0.32	320	2.8032	1.47168	5.15088
109.	09 48 58.2	008 51 41.6	1245	Federal Low-cost Bukuru	0.36	360	3.1536	1.65564	5.79474
110.	09 48 58.8	008 51 41.2	1254	Federal Low-cost Bukuru	0.37	370	3.2412	1.70163	5.95571
111.	09 48 58.6	008 51 41.9	1240	Federal Low-cost Bukuru	0.36	360	3.1536	1.65564	5.79474
112.	09 48 18.6	008 51 42.4	1247	Beside Jos-South LGA Secreteria	0.29	290	2.5404	1.33371	4.66799
113.	09 48 18.4	008 51 42.2	1249	Beside Jos-South LGA Secreteria	0.34	340	2.9784	1.56366	5.47281
114.	09 48 18.3	008 51 42.5	1255	Beside Jos-South LGA Secreteria	0.28	280	2.4528	1.28772	4.50702
115.	09 48 18.5	008 51 42.7	1253	Beside Jos-South LGA Secreteria	0.26	260	2.2776	1.19574	4.18509
116.	09 48 18.9	008 51 42.6	1254	Beside Jos-South LGA Secreteria	0.29	290	2.5404	1.33371	4.66799
117.	09 48 19.0	008 51 42.2	1258	Beside Jos-South LGA Secreteria	0.34	340	2.9784	1.56366	5.47281
118.	09 48 19.0	008 51 42.3	1257	Beside Jos-South LGA Secreteria	0.34	340	2.9784	1.56366	5.47281
119.	09 48 19.1	008 51 42.4	1266	Beside Jos-South LGA Secreteria	0.32	320	2.8032	1.47168	5.15088
120.	09 48 12.5	008 51 44.8	1262	Bukuru	0.37	370	3.2412	1.70163	5.95571
121.	09 48 12.5	008 51 44.9	1249	Bukuru	0.36	360	3.1536	1.65564	5.79474
122.	09 48 13.0	008 51 45.1	1257	Bukuru	0.47	470	4.1172	2.16153	7.56536
123.	09 48 13.0	008 51 45.0	1256	Bukuru	0.41	410	3.5916	1.88559	6.59957
124.	09 48 13.2	008 51 45.5	1258	Bukuru	0.47	470	4.1172	2.16153	7.56536
125.	09 48 12.9	008 51 45.6	1256	Bukuru	0.34	340	2.9784	1.56366	5.47281
126.	09 48 13.0	008 51 46.0	1260	Bukuru	0.4	400	3.504	1.83960	6.43860
127.	09 48 15.9	008 51 48.5	1137	Paul Gindiri Estate, Farin Gada	0.26	260	2.2776	1.19574	4.18509
128.	09 48 15.5	008 51 48.6	1136	Paul Gindiri Estate, Farin Gada	0.28	280	2.4528	1.28772	4.50702
129.	09 48 15.5	008 51 48.6	1135	Paul Gindiri Estate, Farin Gada	0.24	240	2.1024	1.10376	3.86316
130.	09 48 15.4	008 51 48.1	1138	Paul Gindiri Estate, Farin Gada	0.26	260	2.2776	1.19574	4.18509
131.	09 48 15.5	008 51 47.8	1135	Paul Gindiri Estate, Farin Gada	0.24	240	2.1024	1.10376	3.86316
132.	09 48 15.6	008 51 47.6	1142	Paul Gindiri Estate, Farin Gada	0.21	210	1.8396	0.96579	3.38027
133.	09 58 15.2	008 51 48.2	1139	Paul Gindiri Estate, Farin Gada	0.23	230	2.0148	1.05777	3.70220
134.	09 58 15.0	008 51 48.0	1131	Paul Gindiri Estate, Farin Gada	0.24	240	2.1024	1.10376	3.86316
135.	09 58 15.9	008 51 48.7	1132	Paul Gindiri Estate, Farin Gada	0.25	250	2.19	1.14975	4.02413
136.	09 58 15.9	008 51 48.9	1136	Paul Gindiri Estate, Farin Gada	0.25	250	2.19	1.14975	4.02413
137.	09 58 15.8	008 51 49.0	1137	Paul Gindiri Estate, Farin Gada	0.25	250	2.19	1.14975	4.02413
138.	09 58 16.5	008 51 48.6	1137	Paul Gindiri Estate, Farin Gada	0.25	250	2.19	1.14975	4.02413
139.	09 58 16.5	008 51 48.4	1133	Paul Gindiri Estate, Farin Gada	0.26	260	2.2776	1.19574	4.18509
140.	09 58 16.7	008 51 40.0	1134	Paul Gindiri Estate, Farin Gada	0.25	250	2.19	1.14975	4.02413
141.	09 58 16.8	008 51 47.7	1134	Paul Gindiri Estate, Farin Gada	0.26	260	2.2776	1.19574	4.18509
142.	09 58 16.7	008 51 47.5	1138	Paul Gindiri Estate, Farin Gada	0.26	260	2.2776	1.19574	4.18509
143.	09 58 16.4	008 51 47.2	1133	Paul Gindiri Estate, Farin Gada	0.22	220	1.9272	1.01178	3.54123
144.	09 55 44.0	008 52 30.2	1160	Mega Structure Polo Round About	0.33	330	2.8908	1.51767	5.31185
145.	09 55 43.5	008 52 30.5	1179	Mega Structure Polo Round About	0.28	280	2.4528	1.28772	4.50702
146.	09 55 43.6	008 52 30.2	1171	Mega Structure Polo Round About	0.27	270	2.3652	1.24173	4.34606
147.	09 55 44.1	008 52 30.2	1176	Mega Structure Polo Round About	0.25	250	2.19	1.14975	4.02413
148.	09 55 43.9	008 52 30.5	1175	Mega Structure Polo Round About	0.25	250	2.19	1.14975	4.02413
149.	09 55 44.4	008 52 30.6	1183	Mega Structure Polo Round About	0.26	260	2.2776	1.19574	4.18509
150.	09 55 43.6	008 52 30.4	1158	Mega Structure Polo Round About	0.26	260	2.2776	1.19574	4.18509
151.	09 55 41.6	008 52 33.4	1177	New Plaza Opp. Polo Club	0.31	310	2.7156	1.42569	4.98992
152.	09 55 41.9	008 52 33.8	1174	New Plaza Opp. Polo Club	0.27	270	2.3652	1.24173	4.34606
153.	09 55 41.6	008 52 33.2	1184	New Plaza Opp. Polo Club	0.25	250	2.19	1.14975	4.02413
154.	09 55 41.3	008 52 33.6	1175	New Plaza Opp. Polo Club	0.28	280	2.4528	1.28772	4.50702
155.	09 55 41.0	008 52 33.8	1171	New Plaza Opp. Polo Club	0.26	260	2.2776	1.19574	4.18509
156.	09 55 40.2	008 52 33.9	1169	New Plaza Opp. Polo Club	0.32	320	2.8032	1.47168	5.15088
157.	09 55 40.6	008 52 34.8	1178	New Plaza Opp. Polo Club	0.26	260	2.2776	1.19574	4.18509
158.	09 49 48.7	008 52 34.8	1263	Ray field (Little Rayfield)	0.26	260	2.2776	1.19574	4.18509
159.	09 49 48.4	008 52 52.5	1265	Ray field (Little Rayfield)	0.24	240	2.1024	1.10376	3.86316
160.	09 49 48.2	008 52 52.3	1265	Ray field (Little Rayfield)	0.22	220	1.9272	1.01178	3.54123
161.	09 49 48.0	008 52 52.1	1268	Ray field (Little Rayfield)	0.23	230	2.0148	1.05777	3.70220
162.	09 48 47.7	008 52 52.3	1265	Ray field (Little Rayfield)	0.25	250	2.19	1.14975	4.02413
163.	09 48 47.9	008 52 52.6	1265	Ray field (Little Rayfield)	0.25	250	2.19	1.14975	4.02413
164.	09 49 31.3	008 52 53.2	1256	Hossana Blocks Ind. Rayfield (Mai-Adiko)	0.31	310	2.7156	1.42569	4.98992
165.	09 49 31.6	008 52 53.3	1257	Hossana Blocks Ind. Rayfield (Mai-Adiko)	0.35	350	3.066	1.60965	5.63378

ISSN: 2141-6745
Published By
International Centre for Integrated Development Research, Nigeria
In collaboration with
Copperstone University, Luanshya, Zambia

166.	09 49 31.5	008 52 52.9	1259	Hossana Blocks Ind. Rayfield (Mai-Adiko)	0.27	270	2.3652	1.24173	4.34606
167.	09 49 31.4	008 52 52.6	1263	Hossana Blocks Ind. Rayfield (Mai-Adiko)	0.39	390	3.4164	1.79361	6.27764
168.	09 49 31.3	008 52 52.8	1264	Hossana Blocks Ind. Rayfield (Mai-Adiko)	0.34	340	2.9784	1.56366	5.47281
169.	09 49 31.2	008 52 53.0	1253	Hossana Blocks Ind. Rayfield (Mai-Adiko)	0.33	330	2.8908	1.51767	5.31185
170.	09 49 31.2	008 52 53.3	1258	Hossana Blocks Ind. Rayfield (Mai-Adiko)	0.33	330	2.8908	1.51767	5.31185
171.	09 49 25.3	008 52 51.4	1265	Opp. Government House, Mai-Adika	0.26	260	2.2776	1.19574	4.18509
172.	09 49 25.2	008 52 51.6	1261	Opp. Government House, Mai-Adika	0.27	270	2.3652	1.24173	4.34606
173.	09 49 25.5	008 52 51.4	1259	Opp. Government House, Mai-Adika	0.29	290	2.5404	1.33371	4.66799
174.	09 49 24.6	008 52 51.3	1254	Opp. Government House, Mai-Adika	0.26	260	2.2776	1.19574	4.18509
175.	09 49 25.1	008 52 50.3	1267	Opp. Government House, Mai-Adika	0.24	240	2.1024	1.10376	3.86316
176.	09 49 24.9	008 52 51.1	1265	Opp. Government House, Mai-Adika	0.27	270	2.3652	1.24173	4.34606
177.	09 49 24.7	008 52 51.1	1261	Opp. Government House, Mai-Adika	0.28	280	2.4528	1.28772	4.50702
178.	09 49 24.5	008 52 51.6	1266	Opp. Government House, Mai-Adika	0.27	270	2.3652	1.24173	4.34606
179.	09 49 26.7	008 52 51.4	1262	Opp. Government House, Mai-Adika	0.25	250	2.19	1.14975	4.02413
180.	09 49 26.9	008 52 51.5	1255	Opp. Government House, Mai-Adika	0.25	250	2.19	1.14975	4.02413
181	09 58 15.4	008 50 54.4	1159	Army Engineer	0.27	270	2.3652	1.24173	4.34606
182	09 58 15.7	008 50 54.5	1155	Army Engineer	0.26	260	2.2776	1.19574	4.18509
183	09 58 15.9	008 50 54.3	1163	Army Engineer	0.33	330	2.8908	1.51767	5.31185
184	09 58 16.1	008 50 54.6	1160	Army Engineer	0.26	260	2.2776	1.19574	4.18509
185	09 58 15.9	008 50 54.8	1158	Army Engineer	0.27	270	2.3652	1.24173	4.34606
186	09 58 15.6	008 50 54.6	1163	Army Engineer	0.36	360	3.1536	1.65564	5.79474
187	09 58 37.6	008 51 10.8	1160	Gamajigo	0.24	240	2.1024	1.10376	3.86316
188	09 58 37.9	008 51 10.7	1161	Gamajigo	0.22	220	1.9272	1.01178	3.54123
189	09 58 38.0	008 51 10.8	1157	Gamajigo	0.23	230	2.0148	1.05777	3.70220
190	09 58 37.8	008 51 11.0	1175	Gamajigo	0.22	220	1.9272	1.01178	3.54123
191	09 58 32.3	008 51 19.8	1158	Ajigo "A"	0.25	250	2.19	1.14975	4.02413
192	09 58 32.4	008 51 20.1	1155	Ajigo "A"	0.21	210	1.8396	0.96579	3.38027
193	09 58 32.1	008 51 20.3	1152	Ajigo "A"	0.23	230	2.0148	1.05777	3.70220
194	09 58 32.2	008 51 19.8	1149	Ajigo "A"	0.24	240	2.1024	1.10376	3.86316
195	09 58 31.8	008 51 19.9	1146	Ajigo "A"	0.23	230	2.0148	1.05777	3.70220
196	09 58 32.4	008 51 20.1	1153	Ajigo "A"	0.28	280	2.4528	1.28772	4.50702
197	09 58 32.3	008 51 19.4	1154	Ajigo "A"	0.24	240	2.1024	1.10376	3.86316
198	09 58 20.4	008 51 27.8	1147	Ajigo	0.19	190	1.6644	0.87381	3.05834
199	09 58 20.7	008 51 28.2	1152	Ajigo	0.22	220	1.9272	1.01178	3.54123
200	09 58 20.9	008 51 28.3	1134	Ajigo	0.23	230	2.0148	1.05777	3.70220
201	09 58 21.0	008 51 28.4	1145	Ajigo	0.26	260	2.2776	1.19574	4.18509
202	09 58 21.1	008 51 27.8	1139	Ajigo	0.26	260	2.2776	1.19574	4.18509
203	09 58 20.5	008 51 27.6	1148	Ajigo	0.22	220	1.9272	1.01178	3.54123
204	09 58 20.8	008 51 27.5	1148	Ajigo	0.23	230	2.0148	1.05777	3.70220
205	09 58 23.2	008 52 05.6	1128	Uliliba	0.23	230	2.0148	1.05777	3.70220
206	09 58 23.5	008 52 05.3	1124	Uliliba	0.25	250	2.19	1.14975	4.02413
207	09 58 23.4	008 52 06.3	1129	Uliliba	0.23	230	2.0148	1.05777	3.70220
208	09 58 24.1	008 52 05.3	1128	Uliliba	0.27	270	2.3652	1.24173	4.34606
209	09 57 56.7	008 51 58.6	1130	Uliliba "B"	0.32	320	2.8032	1.47168	5.15088
210	09 57 56.6	008 51 58.2	1125	Uliliba "B"	0.3	300	2.628	1.37970	4.82895
211	09 57 56.8	008 51 58.5	1129	Uliliba "B"	0.27	270	2.3652	1.24173	4.34606
212	09 57 56.5	008 51 58.6	1125	Uliliba "B"	0.31	310	2.7156	1.42569	4.98992
					Avg. DR (uSv/h)	**Avg. DR (nGy/h)**	**Dose Rate (mSv/y)**	**AEDE*in* *(mSv/y)***	**ELCR*in (Sv)***
				MINIMUM	**0.18**	**180**	**1.5768**	**0.82782**	**2.89737**
				MAXIMUM	**0.47**	**470**	**4.1172**	**2.16153**	**7.56536**
				AVERAGE	**0.2793**	**279.766**	**2.45075**	**1.28665**	**4.50326**

From the results obtained, the concentration of radiation dose varied from one building to another, with some buildings having values that fall within the safe dose limit of 1*mSv/y*, while in some buildings, the values are slightly or higher than the global permissible limit. Absorbed dose rate, annual effective dose equivalent and excess life-time cancer risk were all determined and recorded.

ISSN: 2141-6745
Published By
International Centre for Integrated Development Research, Nigeria
In collaboration with
Copperstone University, Luanshya, Zambia

Absorbed Dose Rate

From the analysis, the absorbed dose rate recorded ranges between 1.56mSvy^{-1} (180$nGyh^{-1}$) and 4.12mSv/y (470nGy/h) with a mean value of 2.45mSv/y (279.7664nGy/h) across the uncompleted buildings accessed as shown in the table above.

Annual Effective Dose Equivalent (*AEDE*)

To determine the annual effective dose equivalent (indoor), the following equation was used (Beretka & Mathew, 1985) and the UNSCEAR (2000) equation 2

$$AEDE_{indoor}\ (mSvy^{-1}) = D(nGy^{-1})\ x\ 8760hy^{-1}\ x\ 0.75\ x\ 0.7SvGy^{-1}\ x\ 10^{-6} \quad (2)$$

Where 8760 is the total number of hours in a year (24 hours *x* 365days), 0.75 is the indoor occupancy factor, which was estimated at 18 hours a day, while 0.7$SvGy^{-1}$ is the conversion coefficient from the absorbed effective dose received. Average $AEDE_{indoor}$ recorded across the area of study falls within the range of 0.8278 and 2.1615 $mSvy^{-1}$ as seen in Table 1.

Excess Lifetime Cancer Risk (*ELCR*)

This is the estimate of an additional risk for someone developing cancer as a result of exposure to toxic substances or radionuclides over a long period of time. Emelue *et al.* (2014) outlined the formula for ELCR as follows;

$$ELCR_{indoor} = AEDE_{in}\ x\ DL(70)\ x\ RF(0.05)$$

Where DL is the average duration of life, which was pegged at 70, while RF is the risk factor per sievert, which was pegged at 0.05*Sv* for the public exposure by the International Committee on Radiation Protection (ICRP), 1991. The average values obtained across the study area range between 2.8974 x 10^{-3} and 7.5654 x 10^{-3} (indoor), which were far above the recommended level set by the International Commission on Radiological Protection (ICRP) (1991).

Impact of Ionizing Radiation on Human Health

Ionizing radiation has the capacity to disrupt life processes (Solomon *et al,* 2018). As exposure to ionizing radiation increases, so does the potential for health hazards if not properly contained. When these ionizing radiations are at a very high level, acute health effects such as skin burns, nausea, etc., may occur. If the radiation dose is delivered at a low rate over a long period of time, though damaged body tissues might likely be repaired but there is still a risk of long-term effects such as cataract or cancer decades later. These

ISSN: 2141-6745
Published By
International Centre for Integrated Development Research, Nigeria
In collaboration with
Copperstone University, Luanshya, Zambia

effects are proportional to the radiation doses received over time. This risk is higher in children and adolescents as they are significantly more sensitive to radiation exposures than adults (WHO, 2023)

Summary of Findings

The summary of the findings of this study is as follows:-

1. Background radiation dose rate in buildings was assessed.
2. The levels of background radiation from each building have been measured.
3. Analyses of the radiological indices from each building were carried out to determine the average dose rate, annual effective dose equivalent and excess lifetime cancer risk from each of the buildings studied.

CONCLUSION

At the end of this study, the distribution of radionuclide concentrations and their doses from uncompleted buildings within Jos and its environs were determined. Radiological parameters and indices such as absorbed dose rate, annual effective dose equivalent and excess life-time cancer risk were all determined. Acute short-term effects of these ionizing radiation as well as long-term effects, were also carefully stated.

REFERENCES

Ajayi, I. R. (2008). An Evaluation of the Equivalent Dose due to Natural Radioactivity in the Soil around the consolidated Tin mine in Bukuru-Jos, Plateau State of Nigeria

Ajayi, J. O., Paul, J. & Bashiru, B. B. (2013). Assessment of Radiological Hazard Indices of Building Materials in Ogbomoso, South-West Nigeria. Published by the Canadian Center of Science and Education.

Baxter, M. S. (1993). Environment Radioactivity: A perspective on industrial contributions. *International Atomic Energy Agency Bulletin, 2*, 33-38.

Beretka, J. & Matthew, P. (1985). Natural radioactivity of Australian building materials, industrial wastes and by-products. *Health Phys, 48*, 87-95.

Eke B. C., Akomolafe I. R., Ukewuihe U. M. & Onyenegecha C. P. (2024). Assessment of Radiation Hazard Indices Due to Natural Radionuclides in Soil Samples from Imo State University, Owerri, Nigeria. *Environmental Health Insights, Volume 18: 1–11.*

Emelue H. U., Jibiri N. N. & Eke B. C. (2014). Excess Lifetime Cancer Risk Due to Gamma Radiation in and around Warri Refinery and Petrochemical Company in Niger Delta, Nigeria. *Journal of Advances in Medicine and Medical Research, 4* (13):2590-98

Falconer, J. D. (1921). The Geology of the Plateau Tin Fields. *Bulletin Geological Survey of Nigeria*, No.4, Kaduna.

International Commission on Radiological Protection (ICRP) (1991). Publication 60: 1990 Recommendations of the International Commission on Radiological Protection. 60. *Elsevier Health Sciences*.

Isa S., Abuh R. A. & Godwin E. (2024). Assessment of Natural Background Radiation Exposure in the Federal Capital Territory of Nigeria. *European Journal of Theoretical and Applied Sciences*, 2(1), 480-491. DOI:10.59324/ejtas.2024.2(1).40

James I. U., Moses I. F., Akueche E. C. & Kuwen R. D. (2020). Assessment of Indoor and Outdoor Radiation Levels and Human Health Risk in Sheda Science and Technology Complex and its Environ, Abuja, Nigeria.

Jibiri N.N., Alausa S. K. & Farai I. P. (2009). Assessment of External and Internal Doses due to Farming in High Background Radiation Areas in Old Tin Mining Localities in Jos-Plateau, Nigeria.

Macleod W. N., Turner D. C. & Wright E. P. (1971). The Geology of the Jos Plateau, General Geology. *Bulletin Geological Survey of Nigeria*, 1 (32)

Martins, A. & Harbison, S. (1979). An Introduction to Radiation Protection. *Chapman and Hall, London.*

Solomon, A. O. (2005). A study of Natural Radiation Levels and Distribution of Dose Rates within the Younger Granite Province of Nigeria. A thesis submitted to the School of Postgraduate Studies, University of Jos, in partial fulfilment of the requirements for the Award of the Degree of Doctor of Philosophy in University of Jos.

Solomon A. O., Ike E. E., Ashano E. C. & Jwanbot D. I. (2002): Natural Background Radiation Characteristics of Basalts on the Jos Plateau and the Radiological

Implication of the Use of the Rock for House Construction. *African Journal of Natural Sciences*, 5.43 – 46.

Solomon A. O., Nestor M. C., Alexander S. C., Ifeoma A. E., Joseph A. B., Ajol A. F., & Lukman O. A. (2018). Radionuclide Concentration and Lifetime Cancer Risk Due to Gamma Radioactivity from Quarry Stone Aggregates in Jos and its Environs, North Central Nigeria. *Journal of Environmental and Earth Science,* Vol 8, No.7.

Solomon A. O., Nestor M. C., Edafetano C. A., Paul O. O., Igah S. O. & Nansak B. R. (2018). Indoor Gamma Ray Measurements, Activity Concentration and Radiation Hazard Assessment of Residential Mud Buildings in Miango, North Central Nigeria. *Journal of Environmental and Earth Science,* Vol 8, No.6.

United Nations Scientific Committee on the Effects of Atomic Radiation, UNSCEAR. (2000). Source, Effects and Risk of Ionizing Radiation, Report to the General Assembly, United Nations, New York, USA. *Annex B*, *1*, 92- 93.

World Health Organization (WHO) (2023). Ionizing Radiation and Health Effects. Accessed from https://www.who.int/news-room/fact-sheets/detail/ionizing-radiation-and-health-effects