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Variation of Natural Gamma Radiation with Vertical Height

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Abstract

This paper presents the results of variations of the natural gamma radiation with vertical height. An experiment was conducted to investigate the effect of changes in vertical height on the gamma radiation absorbed dose level in the environment and its implication on Radiation hazards. The gamma radiation absorbed dose level measurements were carried out within four weeks using a Geiger-Muller(G-M) tube, the result shows that gamma radiation absorbed dose in the environment reduces with increase in vertical height.

Keywords: Gamma radiation, absorbed dose, Geiger-Muller tube (GMT).

1.0 Introduction

Measurement of natural gamma radiation is difficult because of the inclusion by the measuring device of radiation from the decay of atmospheric radon[1]. The protection of the public and workers from the harmful effects of ionising radiation has been a concern of radiation protection professionals since the early part of the 20th century when harmful effects were first observed[2]. Since that time, the detrimental effects of ionising radiation have been extensively studied: from the fundamental nature of radiation's effects on cells, organs and organisms, to the epidemiological study of large populations who have been exposed to various levels of ionising radiation. Based on these studies, over time an international system of radiation protection has been built largely through the work of the International Commission on Radiological Protection (ICRP).

Radiation is currently viewed as one of the most studied of all known carcinogens. The system of radiation protection that has been built to protect the public and workers from its harmful effects is seen as extensive and robust, but is less well developed for the protection of the environment and non-human species. The system is also viewed by some as being overly demanding of resources [2].

The amount of radiation dose depends on the intensity and energy of the radiation, the area exposed and the depth of the energy deposited. Various quantities have been introduced to specify the dose received and the biological effectiveness of a given dose. These are called the absorbed dose, the dose rate, the equivalent dose and the effective dose [3].

One might assume that only radioisotopes are significant sources of radiation. The rapid development in basic physics research and its technical applications have created a variety of possibilities for producing nearly all sufficiently long-lived elementary particles and photons in the form of radiation sources. The energy range from ultra cold particles (25meV) up to energies of 1TeV can be covered. If, in addition, cosmic rays are considered, also particles and photons with energies in excess of 1TeV are available albeit at low intensity [4].

The aim of this paper is to investigate the effect of change in vertical height on environmental gamma radiation absorbed dose level in the environment and its implication on radiation hazards (especially in living areas).

2.0 Frame Theoretical Work

2.1 Absorbed Dose

This unit is introduced for measuring the earliest effects of ionizing radiation, called the roentgen (R) and is defined as the amount of exposure that will create 2.5×10^{-4} C of a charged ion in 1kg of air at Standard Temperature Pressure (S.T.P) About 34eV of energy is needed to produce one ion air, therefore, 1R corresponding to an energy absorption per unit mass of 0.0088J/Kg. Materials other than air differ in their rate of energy absorption. The roentgen has fallen into a quantity, called the absorbed dose which specified the amount of radiation energy absorbed per unit mass of the material. Its initial unit was

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the radiation absorbed dose (rad) and is equal to 100erg of energy in 1g of absorbing medium (1 rad = 100 erg/g of medium). The SI unit of absorbed dose is the gray (Gy) and is defined as the absorption of 1J of energy per kilogram of medium [3, 5].

$$1Gy = 1\ {}^{J}\!/_{kg} = 100rads \qquad (1)$$

For a tissue average absorbed dose is defined as

$$D_T = \frac{\varepsilon_T}{M_T} \qquad (2)$$

Where ε_T is the total energy deposited in a mass of tissue or organ and $M_T$is the mass of tissue or organ

2.2 Dose Rate

The dose rate is the dose absorbed per unit time and indicates the amount of radioactive dose received by a person within a certain period of time. The dose rate in our detector is then the energy rate entering the detector, E_R, divided by the mass of the detector which is

$$D = \frac{E_R}{4\pi r^2 \rho t} \qquad (3)$$

Where ρ is thevolume density of the detector and ***t*** is the depth to which the particle penetrate

2.3 Equivalent Dose

The equivalent dose (H) is defined to indicate the biological implication of radiation exposure at level of absorbed dose encounter in normal radiation protection. If in a specific tissue, organ, or part of the body, T, the energy dose $D_{T,R}$ is caused by a radiation field of type R, then the equivalent or organ dose is given by

$$H_{T,R} = D_{T,R} \times w_R \qquad (4)$$

where $w_R$is the radiation weighting factor given in[4].

Equation(4) defined the partial-body doses T for a given radiation field R, if several different type of radiations work together, the corresponding partial-body dose is given by

$$H_T = \sum_R H_{T,R} = \sum_R w_R D_{T,R} \qquad (5)$$

The S.I unit for equivalent dose is called the Sievert (Sv) the old unit is the rem. Thus, 1(Sv) = 100rem. The weight factor is dimensionless, hence,

$$1(Sv) = 1JKg^{-1} \qquad (6)$$

2.4 Effective Dose

The effective dose equivalent$H_{eff} = (E)$ can be derived from equation (5) by weighting the different energy doses with the tissue weighting factor w_T and it's defined as$H_{eff} = \sum_T w_T H_T = \sum_T w_T \sum_R w_R D_{T,R}$ [4]. (7)

Dose units for penetrating external radiation and for radiation of low penetrating depth have been introduced in many national radiation-protection regulations.

2.5 Interaction of Gamma Rays with Matter

There are three major types of interaction mechanism for gamma rays; photoelectric absorption,

2.5.1 Photoelectric Absorption

In the photoelectric absorption process, a photon undergoes an interaction with an absorber atom and one of the atomic electrons, known as a photoelectron, is released. The most probable origin of the photoelectron is the most tightly bound or k shell of the atom. The photoelectron appears with an energy given by

$$E_e = hv - E_b \qquad (8)$$

where $E_b$represents the binding energy of the photoelectron in its original shell[5, 6].

The photoelectric process is the predominant mode of interaction for gamma rays (or X- rays). The process is also enhanced for absorber materials of high atomic number Z. To the best of our knowledge there is no single expression that is valid for the probability of photoelectric absorption per atom over all ranges of $E_\gamma$and Z, but a rough approximation is given by

$$\tau \equiv C\frac{Z^n}{E_\gamma^{3.5}} \qquad (9)$$

Where C is constant and the power n varies between 4 and 5 over the gamma-ray energy region.

2.5.2 Compton Scattering

The interaction process of Compton scattering takes place between the incident gamma - ray photon and an electron in the absorbing material. In Compton scattering, the incoming gamma - ray photon is deflected through an angle θ with respect to its original direction. The photon transfer gives a share of its energy to the electron (assumed to be initially at rest), which is then known as a recoil electron. An expression that relates the energy transfer and the scattering angle for any given interaction is given by

$$hv' = \left(\frac{hv}{1+\frac{hv^2}{m_0C^2}(1-\cos\theta)}\right) \qquad (10)$$

Where $\boldsymbol{m_0}$ is the rest mass energy of the electron (0.511MeV), the probability of Compton scattering per atom of the absorber depends on the number of electrons available as scattering targets and therefore increase linear with Z.

2.5.3 Pair Production

The process of pair production is energetically possible if the gamma rays energy exceed twice the rest-mass energy of an electron. In the interaction (which must take place in the coulomb field of a nucleus), the gamma ray photon disappears and is replaced by an electron- position pair. All these excess energy carried in by the photon above the 1.02MeV required to create the pair goes into kinetic energy shared by the positron and electron. The positron subsequently annihilate after slowing down in the absorbing medium. Practically, the probability of this interaction remains very low until the gamma-ray energy approaches several MeV and therefore, pair production is predominantly confined to high energy of gamma-rays [6, 7].

3.0 Methodology

3.1 Theory

Natural background radiation comes from cosmic radiation and some from food and drink. The greatest fraction is from the sources in the earth’s crust. Cosmic rays are energetic charged particles (mainly protons and α particle) which rain down on the earth from the outer surface, interact in the upper atmosphere and produces showers of rays and electrons, a fraction of which penetrates to the earth’s surface[5].

The concentration of atmospheric radon of terrestrial origin contributes about 60% to the gamma radiation absorbed dose in the environment while cosmic rays account for less than 10%. The passage of gamma ray energy through matter is governed by the Beer Lambert exponential decay low given by

$$I = I_0e^{-\mu x} \qquad (11)$$

Whereμ is the energy absorption coefficient of the medium and x is the distance of propagation.

Hence, the attenuation of gamma-ray energy in a medium depends largely on the magnitude of energy radiation from the source and absorption coefficient of the medium. The intensity reduces through one or a combination of the process of photoelectric effect, Compton scattering and pair productions which continue until the energy is completely absorbed. High intensity of radiation in the environment may have damaging effect on human health[8].

3.2 Procedure

An experiment was conducted to investigate the effect of changes in vertical height of the environmental gamma radiation absorbed dose level in the environment. The gamma radiation absorbed dose level measurement were carried out Within four weeks interval between 28th of December, 2014 and 27th of January, 2015 by using a Geiger-Muller(G-M) tube, Decade scalar with variable EHT supply, stop watch and a meter rule.

The experiment was at Bayero University Kano, Nigeria. The ground level was assumed to be (0 meter) were the first experiment was conducted; the procedure was repeated using different heights (3, 6 and 9 meters)from the ground level. The decade scalar was placed one meter above the ground level on each floor and the radiation levels were measured by noting the amount of ionization produced in the air. The decade scalar recorded changes in the cumulative ionization counts in air with time and the readings were taken every 10 minutes for a period of 3 hours during each day of measurement. Hence, the variation of the cumulative absorbed dose in air with time and the dose rate were determined.

4.0 Results and Discussion

The result obtained from our experiment was tabulated and presented below:

Table 1: The values of the cumulative gamma radiation absorbed dose and cumulative absorbed dose rate in air with regular time intervals at the ground floor (0m).

S/N	Time(minute)	Cumulative Dose (E-8) Gy	Cumulative Dose Rate (E-8)Gy/hr
1	10	0.397	2.38
2	20	0.784	4.71
3	30	1.19	7.14
4	40	1.635	9.82
5	50	2.049	12.29
6	60	2.464	14.79
7	70	2.885	17.32
8	80	3.272	19.64
9	90	3.682	22.1
10	100	4.09	24.55
11	110	4.56	27.37
12	120	4.978	29.88
13	130	5.4	32.41
14	140	5.774	34.66
15	150	6.184	37.12
16	160	6.623	39.75
17	170	7.023	42.15
18	180	7.435	44.63

Table 2: The values of the cumulative gamma radiation absorbed dose and cumulative absorbed dose rate in air with regular time intervals at the first floor(3m).

S/N	Time(minute)	Cumulative Dose (E-8)Gy	Cumulative Dose Rate (E-8)Gy/hr
1	10	0.328	1.97
2	20	0.653	3.92
3	30	0.968	5.81
4	40	1.287	7.73
5	50	1.585	9.51
6	60	1.918	11.51
7	70	2.244	13.47
8	80	2.55	15.31
9	90	2.854	17.13
10	100	3.168	19.02
11	110	3.487	20.93
12	120	3.802	22.82
13	130	4.114	24.69
14	140	4.417	26.51
15	150	4.748	28.5
16	160	5.063	30.39
17	170	5.399	32.41
18	180	5.702	34.23

Table 3: The values of the cumulative gamma radiation absorbed dose and cumulative absorbed dose rate in air with regular time intervals at the second floor(6m).

S/N	Time(minute)	Cumulative Dose (E-8)Gy	Cumulative Dose Rate (E-8)Gy/hr
1	10	0.315	1.89
2	20	0.614	3.69
3	30	0.916	5.49
4	40	1.196	7.16
5	50	1.491	8.95
6	60	1.794	10.77
7	70	2.112	12.68
8	80	2.401	14.41
9	90	2.69	16.15
10	100	2.982	17.9
11	110	3.3	19.81
12	120	3.62	21.73
13	130	3.937	23.63
14	140	4.295	25.78
15	150	4.591	27.56
16	160	4.91	29.47
17	170	5.237	31.43
18	180	5.54	33.25

Table 4: The values of the cumulative gamma radiation absorbed dose and cumulative absorbed dose rate in air with regular time intervals at the third floor (9m).

S/N	**Time(minute)**	**Cumulative Dose (E-8)Gy**	**Cumulative Dose Rate (E-8)Gy/hr**
1	10	0.301	1.81
2	20	0.661	3.97
3	30	0.95	5.7
4	40	1.347	8.09
5	50	1.662	9.98
6	60	1.938	11.64
7	70	2.195	13.18
8	80	2.41	14.47
9	90	2.641	15.85
10	100	2.861	17.17
11	110	2.92	17.53
12	120	3.038	18.24
13	130	3.188	19.14
14	140	3.338	20.04
15	150	3.482	20.9
16	160	3.584	21.51
17	170	3.731	22.39
18	180	3.853	23.13

4.1 Graphical Representation of Data

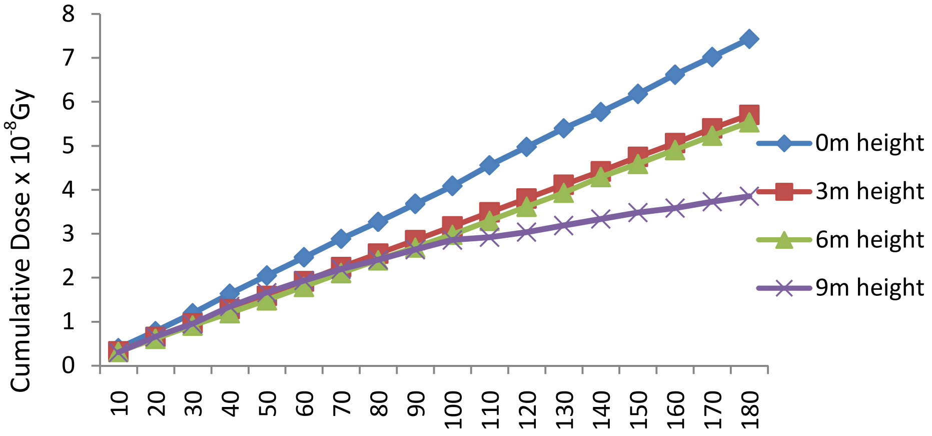

Figure 1: Variation of the cumulative gamma radiation absorbed dose with time

Time (min)

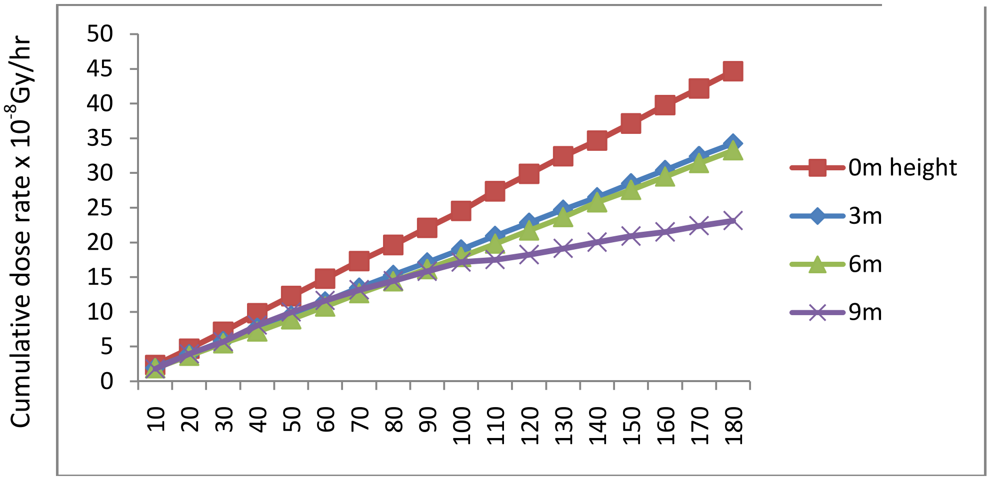

Figure 2: Variation of the cumulative gamma radiation absorbed dose rate with time

Time (min)

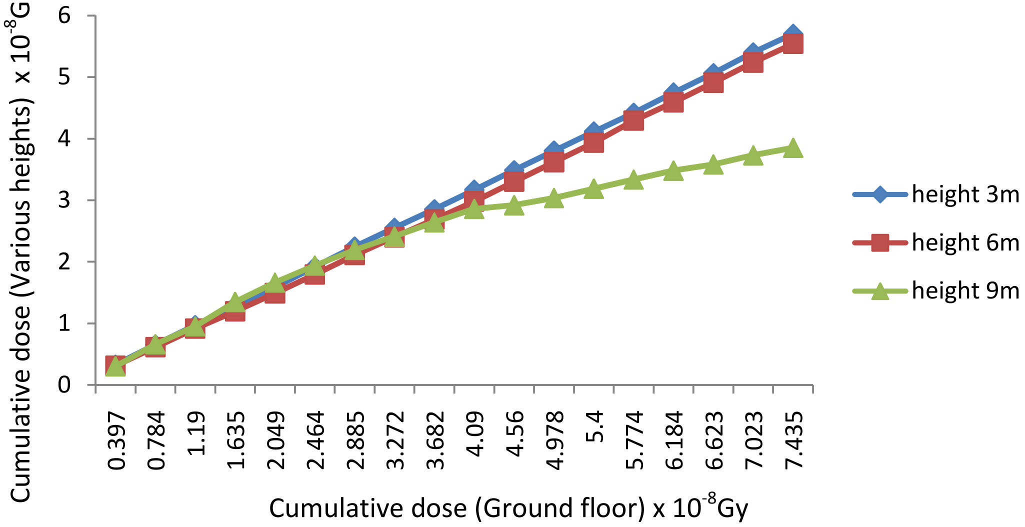

Figure 3: Correlation of the cumulative gamma radiation absorbed dose at heights 3m, 6m, and 9m respectively with that of the ground floor

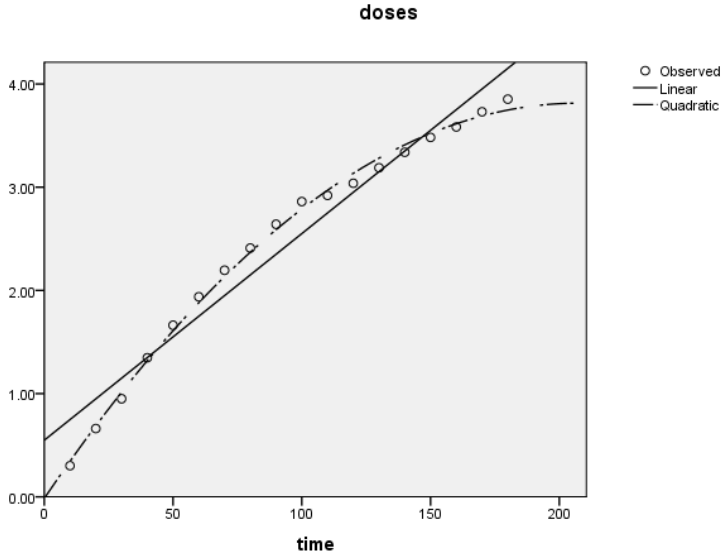

Figure 4: Variation of the cumulative gamma radiation absorbed dose with time at 9m height

4.2 Discussion

The results obtained were tabulated and used to plots our graphs. Table 1 gives the values of the cumulative gamma radiation absorbed dose and cumulative absorbed dose rate in air with regular time intervals at the ground level (assumed zero meter). Table 2 shows the values of the cumulative gamma radiation absorbed dose and cumulative absorbed dose rate in air with regular time intervals at the height three meters above the ground level (3meter).Table 3 shows the values of the cumulative gamma radiation absorbed dose and cumulative absorbed dose rate in air with regular time intervals at the height six meters above the ground level (6meter). Table 4 gives the values of the cumulative gamma radiation absorbed dose and cumulative absorbed dose rate in air with regular time intervals at the height nine meters above the ground level (9 meter).

Looking at these tables (Table 1,Table 2,Table 3, and Table 4) one observed that the cumulative gamma radiation absorbed dose increased with increased in time, though maximum absorbed dose in table 1 is higher than maximum absorbed dose in table 2.And maximum absorbed dose in table 2 is higher than maximum absorbed dose in table 3.and also maximum absorbed dose in table 3 is higher than maximum absorbed dose in table 4. These shows that cumulative gamma radiation absorbed dose is higher at ground level with value of $7.435 \times 10^{-8} Gy$and also it is least at nine meters above the ground level with value of $3.853 \times 10^{-8} Gy$.

Also from these tables (Table 1,Table 2,Table 3, and Table 4) we observed that the cumulative gamma radiation absorbed dose rate increased with increased in time, also maximum absorbed doserate in table 1 is higher than maximum absorbed dose rate in table 2. And maximum absorbed dose rate in table 2 is higher than maximum absorbed dose rate in table 3.and also maximum absorbed dose rate in table 3 is higher than maximum absorbed doserate in table 4. These shows that cumulative gamma radiation absorbed dose rate is higher at ground level with value of $44.63 \times 10^{-8} Gy/hr$and also it is least at nine meters above the ground levelwith value of$23.13 \times 10^{-8} Gy/hr$.

These results obtained were used to plots our graphs. Figure1 shows the graph of variation of the cumulative gamma radiation absorbed dose in air with time at ground level and also at the vertical height of 3m, 6m and 9m respectively.

We observed that at time equals to ten minutes (10 minute) the cumulative absorbed doses are the same for all three different heights. As the time increases the graphs start diverging from each other this is due to the variation of gamma radiation with height.

Figure2 shows the graph of variation of the cumulative gamma radiation absorbed dose rate in air with time at various vertical heights (0, 3, 6 and 9meters) respectively.

We observed that at time equals to ten to twenty minutes (10-20 minute) the cumulative absorbed doses rate are approximately the same for all three different heights. As the time increases the graphs start diverging from each other this is due to the variation of gamma radiation with height.

From the graphs of figure1 and figure 2 it could be observed that the cumulative absorbed dose and cumulative absorbed dose rate are highest on the ground level (0m height) and decreases with height as shows from 9m height which has the least value of the cumulative absorbed dosecumulative absorbed dose rate. This is due to the fact that gamma radiation emitted from the earth's surface by radioactive elements is considered to be maxima. Because, the elemental content and the natural radioactivity of building materials used for constructing houses are increasing exposure to radiations to our environment. The presence of these radioisotopes in materials causes external exposure to the people who are living in the building especially ground level. For example ^{226}Ra and ^{232}Th can increase the concentration of ^{222}Rn and^{220}Rnand of its daughter's product in the building. The^{40}K radionuclide causes external exposure while the inhalation of^{222}Rn,^{220}Rn and their short lived progeny leads to internal exposure of the respiratory tract to alpha particles [9, 10].

Considering the nature of the graphs in figure1and figure 2, one observed that the graphs follow linear relation describing cumulative dose and dose rate with time, except one at 9m height. The line representing 9m height obeys quadratic relations, the reason for this is that the contribution of radioactive elements from earth's surface are decreases as we go away few meters from the ground level because the contribution of terrestrial's gamma radiation is decreases. If we can keep increasing the height a state will be reached were the contribution of radioactive elements from earth's crust will be negligible.

Figure 3 shows the correlation of the cumulative gamma radiation absorbed dose at heights 3m, 6m, and 9m respectively with cumulative gamma radiation absorbed dose at ground level.

Because of the nature of the graphs at nine meter height (9 m) in both figure 1 and figure 2.we introduced Figure 4 and shows that Variation of the cumulative gamma radiation absorbed dose with time disobey linear relations and follows quadratic relations.

The linear equation that can describe the relations between the cumulative gamma radiation absorbed doses in air with time is

$$\gamma = \alpha t + \beta \qquad (12)$$

γCumulative gamma radiation absorbed dose, t is time,α and β are constants that obtained using regression analysis.

Table 5: Model summary of regression analysis using SPSS 16.0 of the gamma radiation absorbed dose rate in air at different height(m)

Vertical height (m)	Mean dose rate (x 10^{-8}) Gy/hr	Regression Parameters		
		α	β	R^2
0	23.48	0.249	--0.214	1.000
3	18.10	0.189	0.118	1.000
6	17.32	0.185	-0.230	1.000
9	14.71	0.120	3.296	0.956

Table 6: Two different statistical modelsof equation obtained using SPSS16.0 at height 9m.

Linear relations coefficient and regression parameter			Quadratic relations coefficient and regression parameter			
α	β	R^2	α	β	δ	R^2
0.120	3.296	0.956	0.222	0.000	-0.930	0.997

Table 5 shows the model summary of regression analysis using SPSS 16.0 of the gamma radiation absorbed dose rate in air at different height (m), it provided the values of coefficient of linear relations and constant α and β respectively, using experimental data. It also shows that mean dose rate is decreases with increases in height.

Table 6 is the two different statistical models of equation obtained using SPSS16.0 at height 9m.that islinear relations coefficient and regression parameter andquadratic relations coefficient and regression parameter in order to investigate which model equation can best describe the nature of our graph as the vertical height increase. Therefore at 9m height the quadratic relation is best equation to describe the relation, and its

$$\gamma = \alpha t^2 + \beta t + \delta \qquad (13)$$

Where α, β and δ are constants that are obtained using regression analysis

The statistical result shows that regression parameter R^2 is closer to unity in quadratic relation than in linear relation. These differences can be seen in the table 6.since the regression parameter in quadratic relation is higher than in linear relation we can conclude that quadratic relation is best equation that can describe the nature of variation of natural gamma radiation with height at vertical distance of 9m.

5.0 Conclusion

Due to the health risks associated with the exposure to indoor radiation, many governmental and international bodies such as the International Commission on Radiological Protection (ICRP), the World Health Organization (WHO) etc. have adopted strong measures aimed at minimizing such exposures [11].

Within the limit of experimental error, we show that the mean dose rate at 9m height has the least value compares to others below it. This is due to the fact that gamma radiation emitted from the earth's surface by radioactive elements is considered to be maxima. Because, the elemental content and the natural radioactivity of building materials used for constructing houses are increasing exposure to radiations to our environment. The presence of these radioisotopes in materials causes external exposure to the people who are living in the building especially ground level. For example ^{226}Ra and ^{232}Th can increase the concentration of ^{222}Rn and ^{220}Rnand of its daughter's product in the building. The ^{40}K radionuclide causes external exposure while the inhalation of^{222}Rn,^{220}Rn and their short lived progeny leads to internal exposure of the respiratory tract to alpha particles.

These results has shown that gamma radiation absorbed dose in the environment reduces with increasing in vertical height.

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