Kuwait J.Sci., Vol.50, No.(3B),July.2023,pp(1-8)

Scattering of gamma radiation by air in the ambient environment using gamma ray spectrometry

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Abstract

The intensity of gamma radiation reduces as it traverses through matter. The gamma radiation from Earth's surface is attenuated by non-radioactive burden between the ground and the detector. The relative intensity of unscattered to scattered gamma radiation by air in ambient atmosphere is measured using in-situ gamma spectrometric method. The air thickness up to 300 cm is used for studying attenuation of terrestrial gamma radiation. No significant attenuation is measured up to 100 cm thickness of air between the detector and the ground. The attenuation by air is found to increase with increasing thickness of air. Also, the attenuation of terrestrial gamma radionuclides (^{40}K) is found higher than ^{238}U and ^{232}Th as ^{40}K has lower energy compared to them.

Keywords: Attenuation; gamma radiation; gamma spectrometry; intensity; terrestrial radionuclides.

1. Introduction

The intensity of gamma radiation reduces as it traverses matter. This is known as attenuation of gamma radiation. The attenuation is caused by scattering and absorption of gamma ray by the matter. The attenuation of gamma ray passing through a material depends upon the thickness and the type of material. Terrestrial radiation is attenuated by a material between the detector and the source. The peak of the spectra reduces with increase in attenuation. Thus, the measured spectra can be different depending on its height from the ground and on the thickness of the non-radioactive material between the ground and the detector (IAEA, 2003).

Measured radiation will be affected by about 7% by 10 meters of air. The radiation from the Earth's surface is reduced remarkably by non-radioactive material between the Earth's surface and the detector. Dense vegetation can reduce 35% of the radiation. Snow covers also attenuate radiation in significant amount from the ground. The attenuation coefficient of snow for gamma rays is around 100 times larger than due to ambient air. In ambient air, the attenuation coefficient depends on the energy of gamma rays and has almost linear dependency with density of the air. This implies that the temperature and pressure also affect the attenuation. Moisture content in the soil is another important factor to attenuate the gamma radiation. The increase in soil moisture of 10% will decrease the fluence rate measured by same amount. However, uranium ground concentrations are increased by rain (Charbonneau & Darnley, 1970). The anomalous surface activity decays away only after about three hours. The variable attenuation of gamma rays is resulted by seasonal and daily precipitation due to snow cover and soil moisture (Rubin *et al.*, 1980).

The relative intensity of the gamma radiation (unscattered) to that scattered increases with materials between the detector and the source as it depends on the material density. Linear attenuation coefficient increases with density and thus mean free path decreases, which reduces the fluence rate at the detector (Allyson, 1994). The attenuation of gamma ray is mainly due to interactions with atomic electrons and depends upon atomic number of the materials (shielding) and energy of gamma ray. The attenuation coefficient (μ) measures the quantity of attenuated radiation by an absorbing material thickness.

$$\mu = -\frac{\Delta I}{I \Delta x} \quad (1)$$

Integrating equation (1), we get

$$I = I_0 e^{-\mu x} \quad (2)$$

Attenuation of gamma rays by any media takes place by one or more of the following interaction: photoelectric absorption, Compton scattering and pair production. The photoelectric interaction occurs when the energy of incident photon is nearly equal to the binding energy of that electron. The photoelectric interaction decreases with increase in photon energy. A Compton scattering occurs when the incident photon collides with free electrons and is deflected in new direction with reduced energy. The Compton scattering decreases for higher energy photon. Pair production occurs when high energy photon (> 1.02 MeV) interact with atomic nucleus. Therefore, Compton interaction is dominating in terrestrial radiation range.

The total linear attenuation coefficient is given by equation (3),

$$\mu_{total} = \mu_{P.E.} + \mu_{C.S.} + \mu_{P.P.} \quad (3)$$

Many studies have been done on non-radioactive burden. Grasty had developed the direct determination method for estimating amount of attenuation material through suitable calibration. A snow-water equivalent thickness was estimated for airborne gamma ray spectrometry. In this method, the change in gamma spectrum shape due to gamma ray attenuation in snow mass and low energy photons built up by Compton scattering was measured (Grasty, 1982). The original photons energies are reduced in the detector, in the source and the matter between them by Compton scattering. Thus, the relative contribution of unscattered and scattered photons to the fluence rate depends on the amount of material between the detector and the source. The spectral count for NORM by removing Compton continuum counts is studied for better photo peak visibility in cases where radioisotopes is weakly present (Demir *et al.*, 2018). Martin & Gomes found daily fluctuation in the intensity of environmental gamma radiation with some increase during the rainfall (Martin & Gomes, 2021). The intensity variation is also studied theoretically (simulation) for shielding properties (Ismail *et al.*, 2021). Since, low energy photons are attenuated more easily than high energy photons, source thickness effect is more significant at lower energies. The measured gamma radiation is affected by the attenuating material's amount between the detector and the source. The aim of the study is to study the relative intensity of terrestrial gamma radiation (unscattered) to that scattered for different thickness of air by increasing the height of detector from the ground.

2. Methods

The process is carried in-situ using gamma ray spectrometer, PGIS2. The detector is equipped with 0.347 liters of NaI(Tl) crystals and is coupled with multi-channel analyzer having 512 channels. It is automated calibrated with natural radionuclides peaks ^{40}K, ^{232}Th or ^{238}U and can operate between –20°C to 50°C temperature. The energy range of detector is within 20 keV to 3 MeV. The start-up stabilization time of the instrument is less than 60 seconds and it can measure spectra per second. The data is recorded in data logger unit (android device) which has wireless communication with the detector. It is based on advanced microprocessor and mobile technologies and gives real-time navigation guidance.

The measurements are carried out for six different thickness of air in ambient environment by raising the height of detector to 50 cm, 100 cm, 150 cm, 200 cm, 250 cm and 300 cm from the ground in open field. The measurements for each thickness were taken for at least two minutes and our instrument records spectra every second. So, at least 120 measurements were taken for each thickness. The spatial variability and the land have impact on environment (Amiri & Mesgari, 2018; Al-Jiboori *et al.*, 2020). For the measurements to be comparable, the conditions on the ground and in the air for all measurements were ensured to be the same. For this, the measurements were carried at the same place within half an hour. The measurement is done using gamma ray spectrometric method. The ^{40}K is directly measured from its emission line at 1.461 MeV while the Uranium and Thorium decay series is measured from the gamma emission of ^{214}Bi at 1.764 MeV and ^{208}Tl at 2.614 MeV respectively. The example of accumulated spectra during analysis is shown in Figure 1.

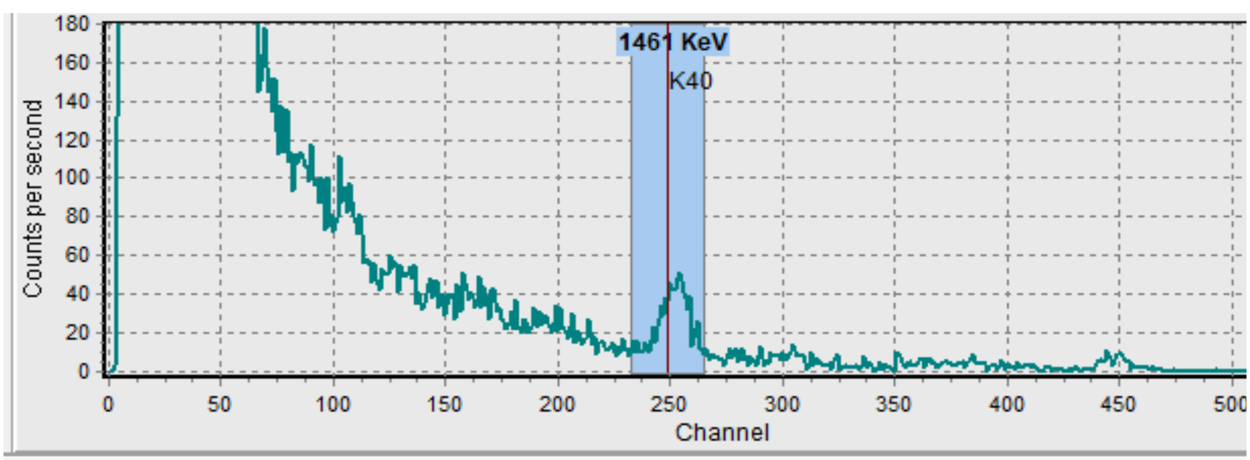

Fig. 1. Gamma ray spectra of ^{40}K

The mass attenuation coefficient of air; considering mixture of 78.08 % N_2, 20.95 % O_2, 9.34 × 10^{-3} % Ar and 3.45 × 10^{-4} % CO_2 (Allen & Cox, 2000); for 1.41 MeV (^{40}K), 1.76 MeV (^{238}U) and 2.61 MeV (^{232}Th) gamma rays were calculated using the NIST XCOM online calculator (https://physics.nist.gov/PhysRefData/Xcom/html/xcom1.html). The corresponding linear attenuation coefficients, and hence the attenuation lengths in air were calculated from linear attenuation coefficient.

3. Results and Discussion

The variation of the intensity of the environmental gamma radiation can be studied by measuring count rates (Katase *et al.*, 1982). The intensity of gamma radiation is found decreasing with the thickness of air as total count is decreasing with the height of the detector (Table 1). The decrease in total count is considerable with the change of 100 cm thickness of air as the attenuation coefficient is very low for air. The change in intensities of gamma rays from terrestrial radionuclides (^{40}K, ^{238}U and ^{232}Th) is listed in Table 2. The bar plot of total count rate is shown in Figure 2. The total count rate from ^{40}K is found higher than ^{238}U and ^{232}Th (Figure 3). The count rates from ^{238}U are found slightly greater than ^{232}Th.

Table 1. Intensity of terrestrial gamma radiation with height of detector

Thickness of air (cm)	Total count rate (cps)		
	Range	Mean	S.E.
50	91 to 130	107.0	0.1
100	86 to 130	107.7	0.1
150	82 to 127	105.6	0.1
200	71 to 126	98.1	0.1
250	71 to 115	98.2	0.1
300	65 to 109	88.9	0.1

Table 2. Intensity of particular terrestrial gamma radiation with height of detector

Thickness of air (cm)	Mean Total count (cps)		
	^{40}K	^{238}U	^{232}Th
50	9.9±0.4	2.3±0.3	1.9±0.2
100	9.8±0.4	2.0±0.3	1.9±0.2
150	10.2±0.4	2.2±0.4	1.9±0.2
200	8.5±0.5	2.2±0.3	1.7±0.2
250	8.8±0.3	2.0±0.3	1.8±0.2
300	8.7±0.4	1.8±0.3	1.7±0.2

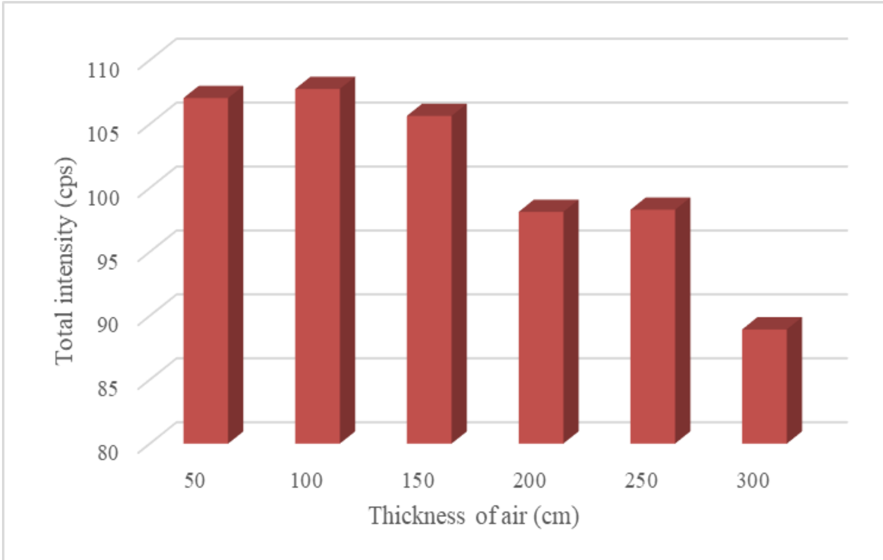

Fig. 2. Intensity of gamma ray with increasing thickness of air

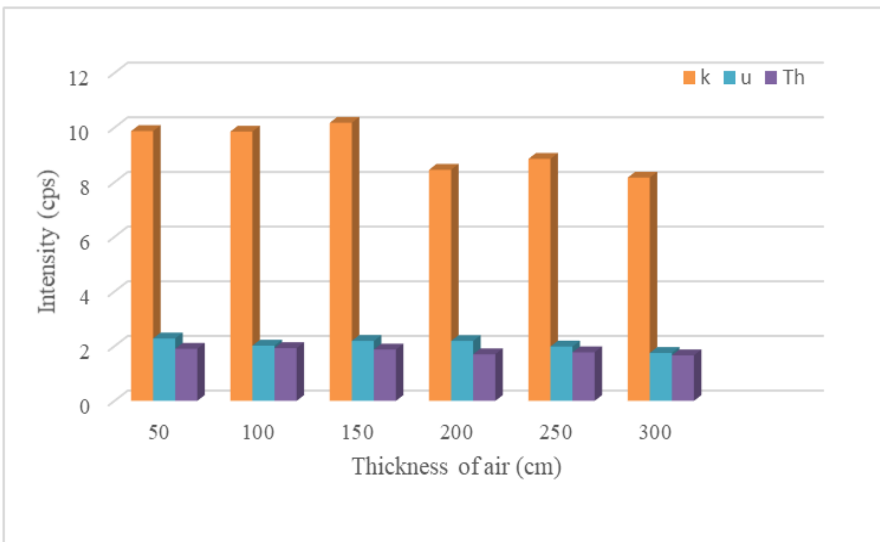

Fig. 3. Intensity of gamma ray from particular terrestrial radionuclides with increasing thickness of air

The nature of attenuation of terrestrial gamma radiations in air in ambient atmosphere is shown in Figure 4. As the detector sensitivity to primary and scatter photons are different, the detector response can affect attenuation curve in broad-beam geometries. The nature is found similar for high energy (Badawy & El-latif, 2017; Vargas *et al*., 2002). As the energy of terrestrial gamma radionuclides is high, we can say that the results are comparable.

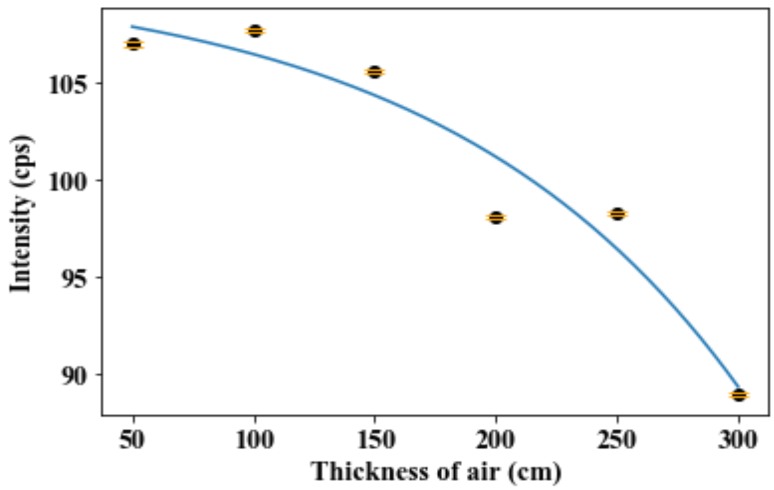

Fig. 4. Attenuation of gamma ray with increasing thickness of air

The intensity of gamma rays decreases with thickness and energy which can be seen from Figure 5. The attenuation is found higher for ^{40}K compared to ^{238}U and ^{232}Th as ^{40}K has lower energy. Also, it can be seen that attenuation is increasing exponentially with the increase in thickness of air. Since, no significant attenuation was found up to 100 cm height of detector from ground, the height of the detector from ground is always maintained below 1 m during in-situ survey. The total mass attenuation coefficient of air for 1.41 MeV (^{40}K), 1.76 MeV (^{238}U) and 2.61 MeV (^{232}Th) gamma rays were calculated 5.342×10^{-3} cm^2/g, 4.762×10^{-3} cm^2/g and 3.854×10^{-3} cm^2/g respectively. The attenuation of gamma ray in air is mainly due to scattering as absorption is very less compared to scattering. Also, coherent scattering is not considerable for high energy. The attenuation length in air for 1.41 MeV (^{40}K), 1.76 MeV (^{238}U) and 2.61 MeV (^{232}Th) gamma rays were calculated to be 10775.9 cm, 12087.9 cm and 14934.6 cm respectively. This justifies that no significant attenuation was measured up to 300 cm in air for these energy range.

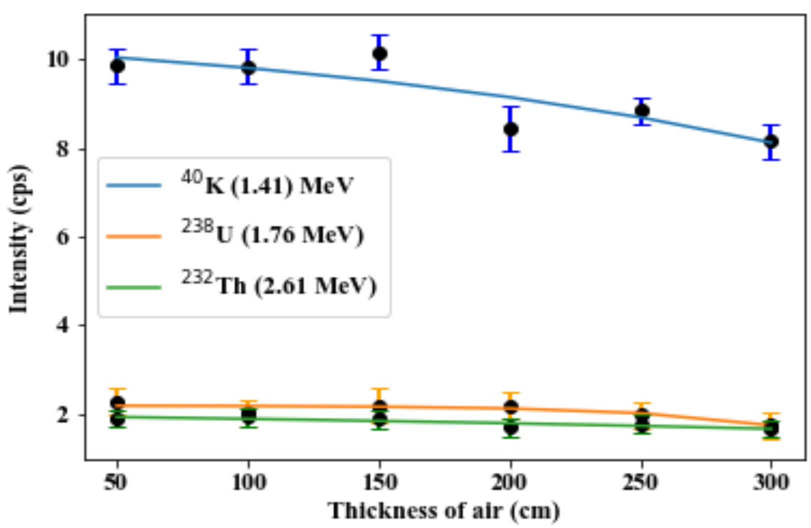

Fig. 5. Attenuation of gamma ray energy with increasing thickness of air

4. Conclusion

The relative intensity of unscattered to scattered gamma radiation by air is studied in ambient atmosphere using gamma ray spectrometric method. No considerable attenuation was found up to 100 cm thickness of air between the detector and ground. The intensity of terrestrial gamma radiation was found decreasing with thickness of air between the ground and the detector. Also, the attenuation of low gamma ray energy (^{40}K) was found higher compared to high gamma ray energy (^{238}U, ^{232}Th). The attenuation of gamma rays was considerable with 100 cm change in thickness of air as it has low attenuation coefficient. The scattering of gamma ray in air for high energy is not so significant due to their high attenuation lengths.

ACKNOWLEDGEMENTS

We would like to acknowledge the support from International Atomic Energy Agency (IAEA) through TC project NEP0002 (2014-2017), Ministry of Education, Science and Technology, Government of Nepal for coordination with IAEA, and University Grants Commission, Nepal for PhD fellowship to Anita Mishra (award number PhD- 74/75-S&T-15).

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Submitted **:** 16/11/2021
Revised **:** 14/02/2022
Accepted **:** 26/02/2022
DOI **:** 10.48129/kjs.17253