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Relation between terrestrial background radiation and air dose rate

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The research is focused on the relation between terrestrial and airborne gamma radiation and their roles in the gamma radiation background development. The terrestrial gamma radiation or ambient dose equivalent rate (DER) is measured at 1m (air dose rate) and at 0.10 m (terrestrial background radiation) above the ground, in a test field located on the Black Sea coast (Port of Burgas, Bulgaria), for a period of eighteen consecutive months. The measurements were performed by “Terra” dosimeter-radiometer MKS – 05 – a portable survey meter based on energy-compensated Geiger-Mueller counter**.** The results show mean values of gamma radiation background/air dose rate at the safe values of 0.129-0.183 $\mu Sv.h^{-1}$ and positive correlation between terrestrial and air dose rate at one and the same monitoring point. It was proved that the height has a significant influence on the measured DER values and closer to the ground levels, they are higher. There is positive correlation between air temperature and air dose rate of gamma radiation, substantially expressed above 1m from the ground surface.

Keywords: gamma radiation, air dose rate, terrestrial gamma radiation, dosimeter-radiometer, ionizing radiation

INTRODUCTION

The radiation background is usually formed from radiological sources of natural origin - such as rocks, soil, the radioactive gas radon (Rn) emitted from the ground, the cosmic radiation and the radioactive elements born from the interaction between it and the chemical elements in nature, etc. Both terrestrial (0.10 m above the ground) and airborne (1 m above the ground) radiation are forming the gamma radiation background. Combining terrestrial and airborne gamma radiation data provides a comprehensive understanding of radiation distribution, which is crucial for environmental health practices and radiological risk assessments [1-4].

Natural radioactivity mainly originates from the cosmogenic radionuclides produced by the interaction of cosmic-ray particles in the Earth atmosphere and terrestrial radionuclides with half-lives comparable to the age of the Earth, such as ^{40}K, and the radionuclides from the ^{238}U and ^{232}Th series. The three naturally occurring terrestrial radioisotopes ^{238}U, ^{235}U, and ^{232}Th emit neutrons through a spontaneous fission process and contribute to neutron backgrounds, as well as neutrons produced from (α, n) reactions, although their contribution is almost negligible [5, 6]. The largest contribution to external source of irradiation of the human body stems from gamma-emitting radioactive elements in the ground [7]. Terrestrial gamma radiation (TGR) mainly depends on geological and geographical conditions [8]. Terrestrial gamma radiation in beach sand is primarily influenced by the presence of natural radionuclides such as ^{232}Th (thorium-232), ^{238}U (uranium-238) and potassium-40 (^{40}K) [9, 10]. The composition of the sand significantly influences TGR at any given place. At the Burgas beach, the sand composition is related to the geological composition of the coast of the Burgas lowland, which includes mostly senonian limestones, marls and volcanics, eocene, oligocene, sarmatian and pliocene sediments, overlain by quaternary and modern deposits [11]. The energy of cosmic gamma photons is larger than 1 MeV and the radiation survey meter, we used – “Terra” dosimeter-radiometer MKS – 05 is sensitive to gamma photons from 0.05 to 3 MeV and there is a theoretical possibility to detect cosmic gamma photons by using it [12].

EXPERIMENTAL

The present research reviews the ground monitoring of gamma radiation or ambient dose equivalent rate/air dose rate (DER) and terrestrial background radiation, measured in $\mu Sv.h^{-1}$ for a period of eighteen months, from June 2021 till November 2022. The air dose rate - gamma radiation dose absorbed by air or ambient dose equivalent rate is measured at 1 m (DER_1) and the terrestrial background radiation at 0.10 m (DER_0.10), above the ground/sand in a test field, located on the Black Sea coast (Port of Burgas, Bulgaria). The survey was focused on the Black Sea, Burgas Bay ecosystem and consists of five monitoring points – Fig. 1, including

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three points within the Burgas Port, one on the bridge platform and one on the beach coast within Burgas salt pans area.

Fig. 1. Monitoring points of the survey alongside Black Sea Burgas Bay

The measurements were performed by the “TERRA” dosimeter-radiometer MKS – 05 – a portable survey meter, based on energy-compensated Geiger-Mueller counter. The MKS-05 “TERRA” dosimeter-radiometer is designed to measure ambient dose equivalent and ambient dose equivalent rate of gamma radiation (or photon-ionizing radiation), with ±15 % accuracy in the gamma energy range from 0.05 MeV to 3 MeV. It is designed for measurement of in the range of 0.001 to 9999 mSv. To measure the gamma/photon-ionizing radiation, the dosimeter was directed with its metrological mark “+” towards the examined area at the two chosen heights -1 m and 10 cm. The final values were obtained as an arithmetic mean of the last five measurements after the LCD of the survey meter stopped blinking.

The monitoring area was determined roughly as a circle with radius of 1 m and a center - the sampling point. Within the surveyed area around the sampling point, the radiological examination included three points, for the operator to stop and measure the gamma background. The three location points were placed approximately at the vertices of an equilateral triangle, with the center - the sampling point. The area thus formed was traversed at a speed of about 5-10 cm/s). The advantage of the survey meter we used is that there is a possibility to get a fast response in the field measurements and locate hot spots or any spot where the radiation shielding is not appropriate.

The data were processed and analyzed by the SPSS statistical data processing tool.

RESULTS AND DISCUSSION

The reliability of the data gathered was analyzed and reported with Cronbach’s alpha coefficient of 0.702, which indicates good internal consistency among the items: air dose date, measured at 1m and ground–based (terrestrial) air dose rate (measured at 0.10 m above the ground). The mean values of the air dose rate at the two heights were within the safe limits (0.129-0.183 μSv.h^{-1})[1].

Mean values

The analyses of the mean values of the ambient dose equivalent rate, at 0.10 m (DER_0.10) and at 1 m (DER_1) of height showed 7 % higher values closer to the monitoring points surface (*MV DER_0.10=0.1709, MV DER_1=0.1593)* – Fig. 2.

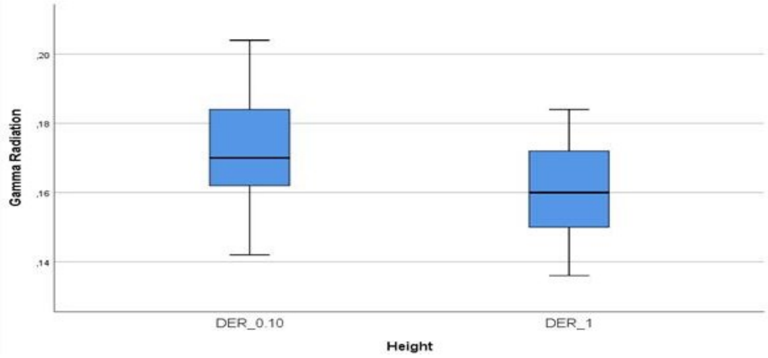

Fig. 2. Mean values of the ambient dose equivalent rate, at 0.10 m (DER_0.10) and at 1 m (DER_1)

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[1] According to the Bulgarian legislation - Ordinance on basic norms for radiation protection, adopted by the Council of Ministers №229 / 25.09.2012 on the territory of the Republic of Bulgaria the natural radiation gamma background is considered safe, while in the range from 0.06 to 0.40 μSv.h^{-1}.

Table 1. Correlation between ambient dose equivalent rate at 10 cm (DER_0.10) and at 1 m (DER_1)

DER_0.10 DER_1	1.1	1.2	1.3	1.4	1.5
1.	**0.363**	-0.289	0.094	0.305	0.502*
2.	0.034	**0.705****	0.433	-0.295	-0.231
3.	-0.043	0.145	**0.710****	0.242	-0.026
4.	0.06	-0.361	0.109	**0.920****	0.242
5.	0.618**	0.02	0.128	0.153	**0.828****

*p<0.05, ** p<0.01.

This proves the fact that terrestrial gamma radiation dose rates are higher at the source due to direct exposure to radionuclides in the monitored areas. In contrast, airborne gamma radiation is subject to attenuation as it travels through the air, resulting in lower dose rates [14, 15]. The intensity of gamma radiation decreases as it passes through the air. This attenuation increases with the thickness of the air layer. For example, significant attenuation is observed when the air thickness exceeds 1 m, with lower energy gamma radionuclides like potassium-40 (^{40}K) being more attenuated compared to higher energy radionuclides like ^{232}Th (thorium-232), ^{238}U (uranium-238) [13].

Correlation between items

The overall correlation between the values of the items assessed by Pearson correlation analysis (Table 1) shows that: air dose rate DER_1 (measured 1 m above the ground/sand) on Monitoring point 1 (1), Monitoring point 2 (2), Monitoring point 3 (3), Monitoring point 4 (4), Monitoring point 5 (5) is always positively correlated with the ground based/terrestrial dose rate DER_0.10 (measured at 0.10 m above the ground/sand) (1.1) at monitoring point 1, (2.1) at monitoring point 2, (3.1) at monitoring point 3, (4.1) at monitoring point 4 and (5.1) at monitoring point 5.

The correlation is substantial at monitoring points 2, 3, 4 and 5 ($p<0.01$), and most significant ($r > 0.75$) at monitoring points 4 and 5.

ANOVA test

A clear correlation is seen between ambient dose equivalent rate (DER) average values at 0.10 m and at 1 m (Table 1). The analysis of one-way ANOVA test ($p = 0.047$) obtained from the statistical analysis with SPSS confirmed our observation. The parameter p is less than 0.050 and it can be concluded that the height has a significant influence on DER values. Higher values are closer to the monitoring points surface. Since the p-value of 0.047 is close to the cutoff threshold, it can be interpreted as modest, and further investigation or larger sample sizes might be beneficial to confirm this relationship.

The correlation between height and DER value, shows an average statistical significance and a positive correlation ($r = 0.333$).

Monthly fluctuation

Monthly fluctuation of ambient dose equivalent rate, at 0.10 m (DER_0.10=Gamma Burgas _10) and at 1 m (DER_1=Gamma Burgas), was developed for depiction of values relation with any natural variability and certain environmental influences as temperature and its seasonal fluctuations. As seen in Fig. 3, both values are following the same trajectory trend which has its highs during the summer months, clearly expressed in June 2021 and its lows in winter months, clearly expressed in December 2021, January and February 2022.

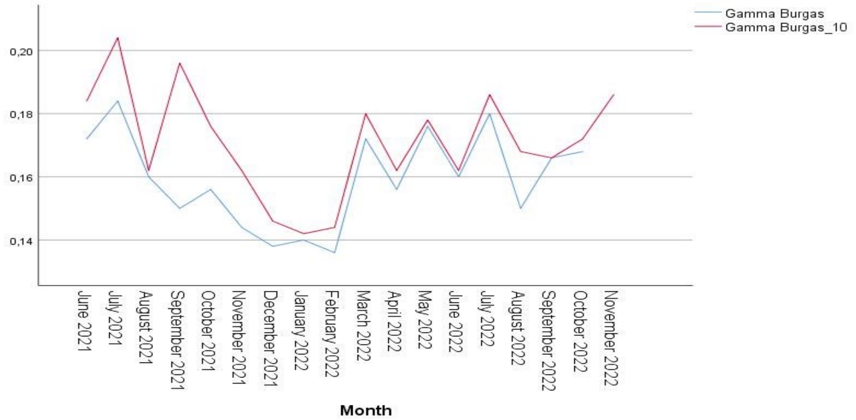

Fig. 3. Monthly fluctuation of ambient dose equivalent rate, at 0.10 m (DER_0.10=Gamma Burgas _10) and at 1 m (DER_1=Gamma Burgas)

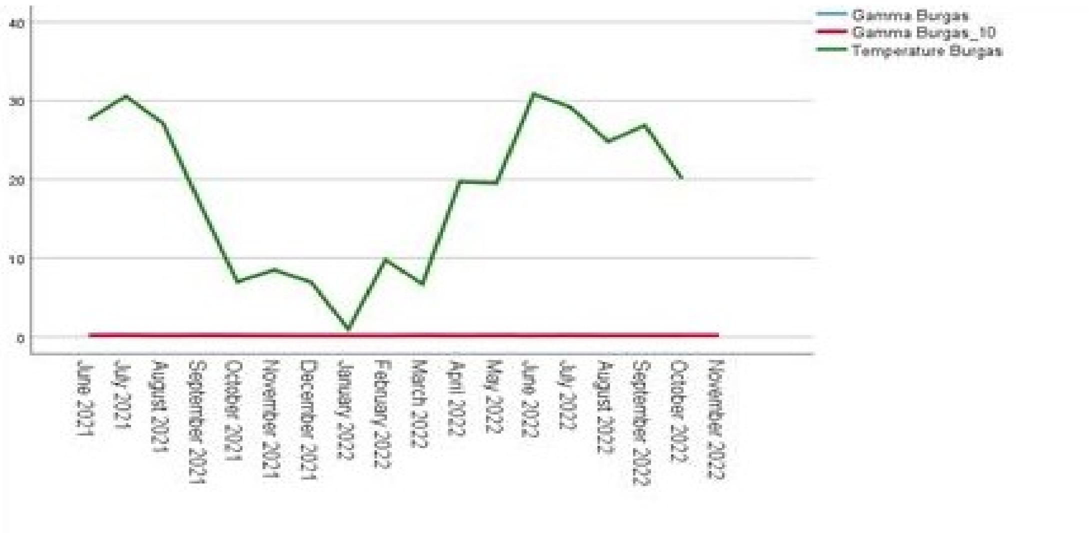

Fig. 4. Monthly fluctuation of ambient dose equivalent rate, at 0.10 m (DER_0.10=Gamma Burgas _10) and at 1 m (DER_1=Gamma Burgas) and the average temperature for the period June 2021-November 2022

Table 2. Correlation between mean values of air dose rate and ground-based dose rate

	DER_1 Gamma Burgas	DER_0.10 Gamma Burgas _10	Temperature Burgas
DER_1	1	0.771**	0.641**
DER_0.10	0.771**	1	0.488*
Temperature Burgas	0.641**	0.488*	1

*p<0.05, ** p<0.01.

Comparing the average temperature (specified in units of degrees Celsius (°C) measured with a humidity & temperature meter), of the five monitoring points and the values of the gamma radiation at DER_1 and DER_0.10 it is seen, that the temperature highs and lows are following the same trend as that of the measured gamma radiation – Fig. 4. The direct relation between these two variables could be seen also in Table 2. Both relations are positive (r=0.641, r=0.488) and substantial (p<0.01 and p<0.05). The relation between the air temperature and the gamma radiation at 1 m height is significant, which could be directly related to the sunlight and its role in heating the air and at the same time its connection with photons and gamma radiation. The values prove that temperature plays a crucial role in the observed gamma radiation level.

CONCLUSIONS

The relation between terrestrial and airborne gamma radiation helps in assessing environmental radiation background and contributes in understanding the roles of different sources in the gamma radiation background development.

Based on the above listed results, it could be concluded that:

The height has a significant influence on the measured ambient dose equivalent rate (DER) values. Since the values of the radiation measured at the two heights are different and all the monitoring points in the test field were exposed to the same cosmic radiation, there is a possibility to assess a relative contribution of terrestrial gamma radiation at the different monitoring points, due to direct exposure to radionuclides in the monitored areas.

The values prove that temperature plays a crucial role in the observed gamma radiation level. The relation between the air temperature and the gamma radiation at 1 m height is significant, which could be directly related to the sunlight and its role in heating the air.

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