Süleyman Demirel Üniversitesi
Fen Bilimleri Enstitüsü Dergisi
Cilt 29, Sayı 1, 62-71, 2025

Süleyman Demirel University
Journal of Natural and Applied Sciences
Volume 29, Issue 1, 62-71, 2025

DOI: 10.19113/sdufenbed.1580790

Measurements of Gamma Dose Rate in Various Working Environments and Assessment of Radiological Hazards

Aysu PULLUKYAPAN[1], Abdullah Engin ÇALIK*,[2]

[1]Department of Occupational Safety, Graduate School of Natural and Applied Sciences, Ege University, 35040, Bornova, İzmir, Türkiye

[2]Department of Physics, Faculty of Science, Ege University, 35040, Bornova, İzmir, Türkiye

(Alınış / Received: 07.11.2024, Kabul / Accepted: 24.02.2025, Online Yayınlanma / Published Online: 25.04.2025)

Keywords
Gamma rays,
Cancer risk,
Occupational health and safety,
Gamma dose rate.

Abstract: People spend most of their time in offices and schools after their homes. Workplaces can include both indoor and outdoor areas. On the Ege University campus, academic and administrative staff, students, patients and visitors occupy a variety of working environments for long periods throughout the day. In this study, gamma dose rates were measured using a portable radiation dose rate and dose meter device at a total of 30 locations (17 outdoors and 13 indoors) on the Ege University campus over a six-month period. The absorbed dose rates, the annual effective equivalent doses and the excess lifetime cancer risk were calculated from these measurements. The results were compared with the limit values established by global studies and other research conducted in Türkiye, and occupational health and safety regulations. The suitability of the findings in terms of occupational health and safety has been evaluated.

Farklı Çalışma Ortamlarında Gama Doz Hızı Ölçümleri ve Radyolojik Tehlikelerin Değerlendirmesi

Anahtar Kelimeler
Gama ışınları,
Kanser riski,
İş sağlığı ve güvenliği,
Gama doz hızı.

Öz: İnsanlar zamanlarının çoğunu evlerinden sonra işyerlerinde ve okullarda geçirmektedirler. Çalışma alanları kapalı veya açık alanları kapsayabilir. Ege Üniversitesi yerleşkesinde akademik ve idari personel, öğrenciler, hastalar ve ziyaretçiler gün içerisinde uzun süreler boyunca çeşitli çalışma ortamlarında bulunmaktadırlar. Bu çalışmada, altı aylık süre boyunca Ege Üniversitesi yerleşkesinde 17'si açık ve 13'ü kapalı olmak üzere toplam 30 noktada taşınabilir radyasyon doz hızı ve doz ölçer cihazı ile gama doz hızları ölçülmüştür. Bu ölçümlerden soğurulan doz oranları, yıllık etkin eşdeğer doz oranları ve yaşam boyu kanser riski hesaplanmıştır. Sonuçlar dünyada ve Türkiye'de yapılan diğer çalışmaların sonuçları ve iş sağlığı ve güvenliği yönetmeliklerindeki sınır değerler ile karşılaştırılmıştır. Sonuçların iş sağlığı ve güvenliği açısından uygunluğu değerlendirilmiştir.

1. Introduction

Radiation has become a natural part of life with the advancement and development of technology. Humans are exposed to radiation both indoors and outdoors. Radiation is the emission or transmission of energy in the form of waves or particles through space or a material medium. In electromagnetic spectrum, all types of radiation are categorized according to their frequencies and wavelengths.

Radiation is classified into ionizing and non-ionizing radiation. In daily life, we are more frequently exposed to non-ionizing radiation. Since non-ionizing radiation does not possess enough energy to affect the cells and tissues, it is less harmful to human health than ionizing radiation. Ionizing radiation, which has high energy, can alter genetic structures and disrupt DNA and cell integrity [1]. This type radiation has stochastic and deterministic effects [2] and is further divided into

*Corresponding author: engin.calik@ege.edu.tr

two categories: particle type and wave type. Particle type radiation includes fast electrons, free neutrons, alpha and beta particles; wave type radiation consists of cosmic, gamma and x rays. There are two sources of radiation: natural and artificial. Natural and artificial radiation sources constitute 88% and 12% of the annual absorbed radiation dose, respectively [3].

Since gamma rays have a greater range in air and can penetrate matter more effectively than alpha and beta particles, we are more exposed to their effects from both natural and artificial radiation sources, both indoors and outdoors [4]. People spend most of their time indoors, such as at home, in the workplace, or for students in school. Given that the majority of the day is spent indoors, only a portion is spent outdoors, it is important to measure the gamma dose rate (GDR) in both environments.

The concept of occupational health and safety began to gain serious attention in the early 1980s and has since become an integral part of business practices. The primary purpose of occupational health and safety is to ensure the safety of employees, the safety of manufacturing processes, and the overall safety of the enterprise. This field of science focuses on eliminating or minimizing the occupational risks and health issues that employees may encounter due to workplace conditions. It examines the factors affecting the safety and health of all individuals impacted by an organization's activities and investigates the precautions that should be implemented [5].

In Türkiye, annual dose limits are established in the Radiation Safety Regulation (Official Gazette date: 24.03.2000 and issue: 23999) [6], the Regulation on Radiation Dose Limits and Working Principles of Personnel Working with Ionizing Radiation Sources in Health Services (Official Gazette date: 05.07.2012 and issue: 28344) [7], and the Regulation on Radiation Protection in Nuclear Facilities (Official Gazette date: 29.05.2018 and issue: 30435) [8]. It is crucial to understand how much radiation exposure from daily life sources may harm individuals in the long term.

Numerous studies were conducted both globally and in Türkiye on GDR measurements in outdoor and indoor. In the world GDR measurements were primarily focused on outdoors in countries such as Vietnam [9], India [10-12], Nigeria [13-15], Iran [16, 17], Germany [18, 19], Malaysia [20], Bangladesh [21], Pakistan [22], Japan [23], France [24], Greece [25], and Spain [26]. While some studies were conducted in limited areas, others covered extensive regions, with some encompassing nearly entire countries.

In many cities across Türkiye, numerous studies were conducted on indoor and outdoor GDR measurements and calculations based on these measurements. These studies cover entire cities, their districts, or specific regions, including Yalova [27], Kahramanmaraş [28], Adıyaman [29], Tatvan, Ahlat and Adilcevaz districts of Bitlis [30], capital city Ankara [31], Digor [32] and Selim [2] districts of Kars, Ilgın district of Konya [33], Artvin [34], Isparta city centre [35], Çanakkale [36], 17 districts of Bursa [37], Trabzon [38], the city centre and districts of Şanlıurfa [39] and areas around Kütahya [40].

Indoor and outdoor GDRs were measured not only in provincial or district centres but also in schools and university campuses. Indoor and outdoor GDR measurements were taken in 12 schools in the city centre of Isparta [41]. On the Selçuk University Alaeddin Keykubat campus, indoor GDRs were measured using a NaI(Tl) detector [42]. Additionaly, outdoor GDR measurements were taken at 27 different locations on the Kütahya Dumlupınar University Evliya Çelebi campus, including areas in front of the canteen, bus stop, and faculty buildings, where students and staff spend considerable time [43]. Furthermore, GDRs were measured at 74 different indoor locations, such as various faculty buildings, the dining hall, and the library on the Kütahya Dumlupınar University Evliya Çelebi campus [44]. Indoor GDRs were also measured in several buildings at Karadeniz Technical University [45]. Natural radioactivity levels and artificial radionuclide (^{137}Cs) levels were investigated in the Istanbul University-Cerrahpasa, Avcilar region [46].

In the present study conducted on the central campus of Ege University, indoor GDRs have been measured in 17 different working environments such as the dining hall, cultural centre, pool, library, gym, museum, and various faculty and vocational school buildings. Outdoor GDRs have been measured at 13 different working locations, including the entrance gate of the campus, the student market, the front of the library, the garden, and the fronts of various faculty and vocational school buildings. The measurements have been taken periodically every week for six months using the NEB.211 model Radiation Dose Rate and Dose Meter device. The absorbed dose rate (ADR), average annual effective dose equivalent (AEDE) and excess lifetime cancer risk (ELCR) have been calculated from the measurements. The obtained results have been compared with national and international studies, as well as occupational health and safety limit values, to evaluate their suitability in terms of occupational health and safety.

2. Material and Method

Study area

Ege University is one of the leading universities in Türkiye, located in the Bornova district of İzmir. The central campus consists of buildings used for education, research, culture, sports, and social services, covering an area of 3,450,000 m^2. There are 16 faculties, 10 institutes, and 4 vocational schools within the central campus of Ege University. The number of academic and administrative staff at Ege University is approximately 10,000, while the number of students is around 70,000. In addition, since there are dental and medical faculty hospitals within the campus area, thousands of people enter the campus each day.

Since the campus is primarily located in the western part of the Aegean Region, it reflects the geological structures characteristic of this area. İzmir and its surroundings are known to be particularly tectonically active. Most parts of the Aegean Region lie within an area intersected by active fault lines that extend toward the Aegean Sea in the north. Bornova, where the Ege University campus is located, is very close to these fault lines. The area surrounding the campus generally contains alluvial soils and volcanic rocks [47].

Measurements were taken periodically every week for six months using the NEB.211 model Radiation Dose Rate and Dose Meter device at 17 indoor points and 13 outdoor points on the central campus of Ege University. The indoor and outdoor measurement points are shown in Figure 1 and Figure 2, respectively.

Figure 1. The indoor measurement points.

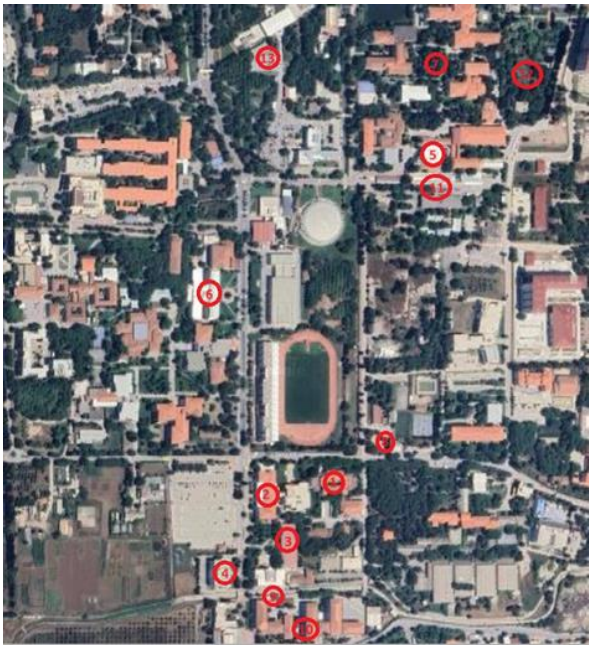

Figure 2. The outdoor measurement points.

Measurement detector

NEB.211 is a portable radiation dose rate and radiation dose measuring device, suitable for use in health physics applications, radioactive laboratories, and industrial establishments (Figure 3). A microcontroller is used in the NEB.211, reducing measurement errors at low measurement levels. Radiation dose rate and radiation dose can be measured simultaneously. The device gives a signal with each radiation or radioactive particle that reaches the detector. When the desired radiation dose intensity or radiation dose is set, the device emits an audible alarm once this level is reached. The device features a self-test function. If any malfunction occurs, it is displayed on the device's screen. Gamma and X-rays can be measured with the device. A halogen-damped, energy-compensated Geiger-Müller detector (ZP1201) is mounted on the front of the device. The device can measure radiation dose intensity between 10 mR/h and 1.99 R/h, and radiation dose between 0 and 1.99 R. It automatically switches between levels.

The device has an error margin of better than ±15%. The selectable radiation dose rate or dose level can be adjusted stepwise. The operating temperature range is -10 ºC to +50 ºC. [48].

Determination of gamma dose rates

Absorbed gamma doses originate from both terrestrial and cosmic rays. To measure the absorbed gamma dose rates in the air, the detector was positioned approximately 1 meter above the ground level. This height is significant because it reflects the radiation dose exposure in the air at a level relevant to human gonads, which are the organs most sensitive to radiation damage. The ADR and AEDE in the air were also calculated by utilizing the GDRs.

Figure 3. NEB.211 Model radiation dose rate and dose meter [48].

At each measurement point, 10 different measurements were taken at each time to minimize error. The GDR for each measurement point was determined by calculating the average of these 10 measurements, expressed in units of μRh^{-1}. The following equation was used to transition from GDR to ADR;

$$ADR(nGyh^{-1}) = GDR(\mu Rh^{-1}) \,.\, 8.7(nGy\mu R^{-1}). \qquad (1)$$

To understand the biological effect of exposure to gamma rays, the AEDE should be calculated using Eq. (2) [3, 49]:

$$AEDE\ (\mu Sv) = ADR(nGyh^{-1}).\, 0.7(SvGy^{-1}).\ (OF).\, 8760\left(\frac{h}{year}\right).\, 10^{-3}. \qquad (2)$$

Here, $0.7(SvGy^{-1})$ is defined as dose conversion factor (DCF) [3]. When calculating the effective dose equivalent, it is important to know how much humans are exposed to these rays. The occupancy factor (OF) indicates how much time a person spends indoors or outdoors in a day. According to the UNSCEAR (2000) report, adults spend an average of 20% of their day outdoors and 80% indoors. Therefore, an OF of 0.2 is used for outdoor exposure and an OF of 0.8 for indoor exposure [3].

ELCR is calculated using the formula below [50, 51];

$$ELCR = (AEDE) \,.\, (DL) \,.\, (RF), \qquad (3)$$

where, DL is the duration of life, RF is the risk factor (Sv^{-1}), which represents the fatal cancer risk per Sv, using a value of 0.05 for the public [50].

3. Results

The measurements and calculations for the 17 indoor measurement points on the central campus of Ege University are shown in Table 1, while the results for the 13 outdoor measurement points are presented in Table 2. The measurement points, along with the GDR, ADR, AEDE, and ELCR calculations, are listed in the first, second, third, fourth, and last columns of Tables 1 and 2, respectively. Equations (1), (2), and (3) were used to calculate the ADR, AEDE, and ELCR values, respectively. In the calculations, the average DL was taken as 70 years. The last line of the tables provides the averages and error rates for all measurements and calculations.

As shown in Table 1, the highest values are at measurement point 12, while the lowest values are at measurement point 10. The average values for 17 indoor measurement points on the Ege University campus (limited to the measurement points), are as follows: GDR is 15.67±0.87 μRh^{-1}, the ADR is 136.36±7.57 nGyh^{-1}, the AEDE is 668.92±37.10 μSv, and the ELCR is (2.34±0.13)×10^{-3}. In Table 2, the highest values are at measurement point 1, while the lowest values are at measurement point 5. The average values for the 13 outdoor measurement points (limited to the measurement points), are as follows: the GDR is 16.20±0.90 μRh^{-1}, the ADR is 140.98±7.83 nGyh^{-1}, the AEDE is 172.90±9.61 μSv, and the ELCR is (0.61±0.04)×10^{-3}.

Table 3 presents the measurement and calculation results regarding indoor GDR in Türkiye, along with the world average values. In addition to the studies conducted in various cities, the results from measurements taken in buildings on the campuses of Karadeniz Technical University and Kütahya Dumlupınar University, as well as measurements from 12 schools in the city center of Isparta, are also included in the table. Table 4 displays the outdoor measurement results, along with the calculated average AEDE and ELCR values in different cities across Türkiye. Finally, Table 5 outlines the radiation dose rate limits according to international regulations and those of our country, for evaluation in terms of occupational health and safety. The limit values of the International Commission on Radiological Protection (ICRP) are globally accepted and referenced values.

4. Discussion and Conclusion

As technology progresses, more detailed information about radiation has been obtained, revealing both its beneficial and harmful aspects. There has been increased exposure to ionizing artificial radiation, especially since it began to be used in imaging techniques in healthcare applications. In addition, we are constantly exposed to ionizing natural radiation, also called terrestrial radiation, which varies depending on geographical conditions. The health effects of ionizing radiation may occur in the short term if exposure is at very high doses, or in the long term if exposure is at low doses over extended

Table 1. Indoor GDR measurements and the corresponding calculations for ADR, AEDE and ELCR at Ege University.

Mea. Points	GDR (μRh-1)	ADR (nGyh-1)	AEDE (μSv)	ELCR (×10-3)
1	15.13±1.09	131.60±9.48	645.59±46.53	2.26±0.16
2	17.79±1.03	154.79±8.99	759.32±44.08	2.66±0.15
3	16.98±0.97	147.73±8.44	724.68±41.38	2.54±0.15
4	15.42±0.82	134.12±7.12	657.92±34.91	2.30±0.12
5	17.33±0.71	150.75±6.17	739.52±30.29	2.59±0.11
6	14.67±0.91	127.61±7.93	626.02±38.39	2.20±0.14
7	13.58±0.86	118.13±7.52	579.50±36.90	2.03±0.13
8	13.46±0.75	117.09±6.48	574.41±31.81	2.01±0.11
9	14.16±0.97	123.18±8.40	604.25±41.19	2.11±0.14
10	10.18±0.68	88.59±5.95	434.58±29.21	1.52±0.10
11	16.77±0.76	145.92±6.63	715.84±32.52	2.51±0.11
12	18.44±0.90	160.40±7.83	786.87±38.43	2.75±0.13
13	18.13±0.75	157.71±6.56	773.66±32.20	2.71±0.11
14	18.14±1.13	157.85±9.80	774.33±48.10	2.71±0.17
15	15.81±0.83	137.54±7.20	674.73±35.32	2.36±0.12
16	14.42±0.83	125.50±7.22	615.63±35.44	2.15±0.12
17	16.04±0.80	139.59±6.94	684.76±34.05	2.39±0.12
Av.	15.67±0.87	136.36±7.57	668.92±37.10	2.34±0.13

Table 2. Outdoor GDR measurements and the corresponding calculations for ADR, AEDE and ELCR at Ege University.

Mea. Points	GDR (μRh-1)	ADR (nGyh-1)	AEDE (μSv)	ELCR (×10-3)
1	18.85±1.08	164.03±9.42	201.17±11.56	0.70±0.04
2	13.84±0.76	120.42±6.59	147.68±8.09	0.52±0.03
3	13.93±1.00	121.20±8.70	148.64±10.67	0.52±0.04
4	16.97±1.03	147.65±8.98	181.08±11.01	0.63±0.04
5	12.14±0.74	105.65±6.41	129.56±7.86	0.45±0.03
6	17.81±0.95	154.93±8.26	190.00±10.13	0.67±0.04
7	17.70±0.98	154.02±8.50	188.89±10.43	0.66±0.04
8	15.40±0.80	133.98±6.97	164.31±8.55	0.58±0.03
9	15.91±0.61	138.40±5.30	169.74±6.49	0.59±0.02
10	16.78±1.06	145.95±9.20	178.99±11.28	0.63±0.04
11	16.38±1.03	142.49±8.96	174.75±10.98	0.61±0.04
12	18.14±0.70	157.78±6.08	193.50±7.46	0.68±0.03
13	16.81±0.97	146.25±8.47	179.37±10.39	0.63±0.04
Av.	16.20±0.90	140.98±7.83	172.90±9.61	0.61±0.04

Table 3. Indoor AEDE and ELCR values in various cities in Türkiye.

Location	AEDE (mSv)	ELCR (×10-3)
Trabzon [38]	0.33	1.16*
Isparta (Schools) [41]	0.90	3.15*
KDPU [44]	0.51	1.79*
KATÜ [45]	0.45**	1.58*
Ahmetçe-Çanakkale [52]	1.23	4.91
Nusratlı-Çanakkale [52]	1.40	5.59
World [3]	0.41	1.44
Present Study	0.67	2.34

*These calculations were performed according to Eq. (3) using the AEDE values provided in the relevant reference.
** The average indoor AEDE value for KATU was calculated based on these provided values.

periods. For this reason, it is important to understand the amount of radiation exposure in homes and workplaces where people spend significant amounts of time. Besides homes, workplaces and schools are among the places where people spend most of their time. Different workplaces have varying environments; some are indoors, while others are outdoors.

Ensuring that employees work in a healthy and safe environment forms the basis of efficient production. To this end, the Occupational Health and Safety Law (No. 6331, published in Official Gazette No. 28339 on June 20, 2012) has been enacted in our country to ensure the health and safety of not only employees but also employers, temporary workers, visitors, customers, and everyone present in the workplace. The highest dose limits to which both the public and personnel working in radiation-related jobs may be exposed are specified in the Radiation Safety Regulation (published in the Official Gazette on March 24, 2000, No. 23999).

The construction years and purposes of the buildings in the Ege University campus vary. The campus includes many different study areas. The buildings located within the Ege University campus are used not only by the staff working at the university but also by many people, especially students studying on campus. Thousands of individuals, including students, academic staff, administrative staff, visitors, patients, and their relatives, spend a significant amount of time on the Ege University Campus throughout the day. For this purpose, GDR measurements have been taken periodically over six months at 30 points—17 indoors and 13 outdoors—on the Ege University campus. From these measurements, ADR, AEDE, and ELCR have been calculated. The results are presented in Tables 1 and 2.

In Table 3, other indoor measurement results in Türkiye and world average values are presented. The results obtained in the present study are lower than those from Çanakkale and Isparta but higher than those from Karadeniz Technical University, Kütahya Dumlupınar University, and the world average. Table 4 presents the outdoor results of various studies conducted in Türkiye. As can be seen from Tables 3 and 4, the number of outdoor measurement points is considerably higher than the number of indoor ones. While the results obtained in the present study are lower than those in Adıyaman, Bitlis, Kazdağları, Isparta, Artvin, and Balıkesir, they are higher than the world average.

Table 4. Outdoor AEDE and ELCR values in various cities in Türkiye.

Location	AEDE (μSv)	ELCR ($\times 10^{-3}$)
Selim-Kars [2]	87.10	0.30
Yalova [27]	59.20	0.21
Kahramanmaraş [28]	79.50	0.40
Adıyaman [29]	177.00	0.89
Tatvan-Bitlis [30]	261.00	0.91*
Ankara [31]	71.83	0.27
Digor-Kars [32]	96.80	0.34
Ilgın-Konya [33]	132.90	0.52
Artvin [34]	214.50	0.75
Ayvacık-Çanakkale [36]	96.50	0.34*
Bursa [37]	110.40	0.45
Şanlıurfa [39]	74.70	0.26*
Kütahya [40]	78.70	0.28*
Isparta [41]	210.00	0.74*
İstanbul Univ.[46]	57.87	0.20
Kazdağları [53]	198.66	0.69
Balıkesir [54]	155.80	0.63
Trabzon [55]	73.83	0.26*
Kırklareli [56]	144.00	0.50*
Kırşehir [57]	150.00	0.29
Konya [58]	56.73	0.23
World [3]	70.00	0.25*
Present Study	172.90	0.61

* These calculations were performed according to Eq. (3) using the AEDE values provided in the relevant reference.

Indoor AEDE (668.92 ± 37.10 μSv) and ELCR (2.34 ± 0.13 × 10^{-3}) values appear significantly higher than outdoor AEDE (172.90 ± 9.61 μSv) and ELCR (0.61 ± 0.04 × 10^{-3}) values. This discrepancy is due to the OF used in the calculations. It is accepted that 80% of daily life is spent indoors and 20% outdoors (UNSCEAR, 2000). Indoor GDR (15.67 ± 0.87) μRh^{-1} and ADR (136.36 ± 7.57) nGyh^{-1} values, as well as outdoor GDR (16.20 ± 0.90) μRh^{-1} and ADR (140.98 ± 7.83) nGy/h values, are nearly equal. Since the time spent inside buildings is considered to be four times greater than the time spent outdoors, the AEDE and ELCR values differ between indoor and outdoor calculations.

ELCR values represent the probability of a person developing cancer as a result of continuous exposure to the measured and calculated dose rates over an average lifetime. For example, the value of (0.61 ± 0.04) × 10^{-3} obtained from outdoor measurements indicates that the probability of developing cancer from an AEDE value of 0.17 mSv per year is 0.061%.

In Table 5, the limit values established in regulations worldwide and in Türkiye are presented to evaluate occupational health and safety. It has been determined that the maximum AEDE value to which the public can be exposed in a year, both globally and in Türkiye, is 1 mSv. This value serves as the general dose limit, with specific limits of 15 mSv per year for the eyes and 50 mSv per year for the skin. As shown in Table 5, the AEDE values obtained in the present study, based on all measurement and calculation results for both indoor and outdoor environments, are below the limit values specified in the regulations. The values at all measurement points are below the danger limits concerning occupational health and safety.

Ege University Campus covers a very large area and includes numerous buildings and open spaces. The measurement points in the present study represent only a portion of the campus. To obtain a clearer overall assessment of the entire campus area, it would be more beneficial to conduct measurements across the whole campus for a period of 12 months or longer. The device used for measurements in the present study is a Geiger-Müller detector, which belongs to the gas detector class. Additionally, if a scintillation detector is used alongside the Geiger-Müller detector, more detailed results could be obtained by comparing the measurements from both devices.

Table 5. AEDE limits according to occupational health and safety regulations.

Regulation		AEDE (mSv)	
		Personnel	People
International Commission on Radiological Protection (ICRP), 2007 [59]	Whole Body	20	1
	Lens of an Eye	150	15
	Skin	500	50
	Hands-Feet	500	-
Radiation Safety Regulation, 2000 [6]	Whole Body	50	1
	Lens of an Eye	150	15
	Skin	500	50
	Hands-Feet	500	-
Regulation on Radiation Dose Limits and Working Principles of Personnel Working with Ionizing Radiation Sources in Health Services, 2012 [7]	Whole Body	50	-
	Lens of an Eye	-	-
	Skin	600	-
	Hands-Feet	600	-
Regulation on Radiation Protection in Nuclear Facilities, 2018 [8]	Whole Body	20	1
	Lens of an Eye	-	15
	Skin	500	50
	Hands-Feet	500	-
Present Study	Indoor	0.67 0.17	

Acknowledgment

This work was supported by Ege University Scientific Research Projects Coordination Unit. Project Number: 20754. The authors would like to thank the Rectorate of Ege University for their contributions in providing the necessary permissions for the measurements. This study is a part of the M.Sc. thesis was prepared in Graduate School of Natural and Applied Sciences, Ege University.

Declaration of Ethical Code

In this study, we undertake that all the rules required to be followed within the scope of the "Higher Education Institutions Scientific Research and Publication Ethics Directive" are complied with, and that none of the actions stated under the heading "Actions Against Scientific Research and Publication Ethics" are not carried out.

References

[1] Borrego-Soto, G., Ortiz-López, R., Rojas-Martínez, A. 2015. Ionizing radiation-induced DNA injury and damage detection in patients with breast cancer. Genet Mol Biol., 38(4), 420-32.

[2] Cengiz, G. B. 2017. Selim İlçesinin Toprak Örneklerinde Doğal Radyoaktivite Düzeyleri ve Radyolojik Etkilerinin Değerlendirilmesi. Kafkas Üniversitesi Fen Bilimleri Enstitüsü Dergisi, 10(1), 37-47.

[3] UNSCEAR. 2000. United Nations Scientific Committee on the Effects of Atomic Radiation. Exposures from Natural Radiation Sources, Report to The General Assembly Wsabnyu, Annexes B.

[4] Breithaupt, J. 2017. Physics. 4th edition. Palgrave, London, 560s.

[5] Occupational Health and Safety Law. 2012. https://www.mevzuat.gov.tr/Mevzuatmetin/1.5.6331.Pdf (Erişim Tarihi: 11.07.2024)

[6] Radiation Safety Regulation. 2000. https://www.resmigazete.gov.tr/arsiv/23999.pdf (Erişim Tarihi: 11.07.2024)

[7] Regulation on Radiation Dose Limits and Working Principles of Personnel Working with Ionizing Radiation Sources in Health Services. 2012. https://www.resmigazete.gov.tr/eskiler/2012/07/20120705-8.htm (Erişim Tarihi: 11.07.2024)

[8] Regulation on Radiation Protection in Nuclear Facilities. 2018. https://www.resmigazete.gov.tr/eskiler/2018/05/20180529-17.htm (Erişim Tarihi: 11.07.2024)

[9] Inoue, K., Fukushi, M., Van Le, T., et al. 2020. Distribution of Gamma Radiation Dose Rate Related with Natural Radionuclides in All of Vietnam and Radiological Risk Assessment of the Built-Up Environment. Scintific Reports, 10, 12428.

[10] Inoue, K., Sahoo, S. K., Veerasamy, N., Kasahara, S., Fukushi, M. 2020. Distribution Patterns of Gamma Radiation Dose Rate in the High Background Radiation Area of Odisha, India. Journal of Radio Analytical and Nuclear Chemistry, 324, 1423–1434.

[11] Shashikumar, T. S., Ningappa, C., Chandrasekhar, S. G. 2020. Studies on Gamma

Dose Rates in Indoor and Outdoor Environment of Hassan City, Karnataka. Radiation Protection Dosimetry, 188(4), 516–521.

[12] Monica, S., Visnu Prasad, A. K., Soniya, S. R., Jojo, P. J. 2018. 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), 38-43.

[13] Okeyode, C., Oladotun, I. C., Alatise, O. O., Bada, B. S., Makinde, V., Akinboro, F. G., Mustapha, A. O., Al-Azmi, D. 2019. Indoor Gamma Dose Rates in The High Background Radiation Area of Abeokuta, South Western Nigeria. Journal of Radiation Research and Applied Sciences, 12(1), 72-77.

[14] Asere, A. M., Ajayi, I. R. 2017. Estimation of Outdoor Gamma Dose Rates and Lifetime Cancer Risk in Akoko Region, Ondo State, Southwestern Nigeria. IOSR Journal of Environmental Science, Toxicology and Food Technology, 11(5), 49-52.

[15] Ononugbo, C. P., Mgbemere, C. J. 2016. Dose Rate and Annual Effective Dose Assessment of Terrestrial Gamma Radiation in Notre Fertilizer Plant, Onne, Rivers State, Nigeria. International Journal of Emerging Research in Management &Technology, 5(9), 30-35.

[16] Zarghani, H., Jafari, R. 2017. Assessment of Outdoor and Indoor Background Gamma Radiation, the Annual Effective Dose and Excess Lifetime Cancer Risk in Birjand, Iran. Jundishapur J Health Sci., 9(3), 1-4.

[17] Eslami, A., Shahsavani, A., Sagni, M. H., Akhoondi, L., Goorrani, A. 2016. Outdoor Gamma Radiation Measurment in Order to Estimate the Annual Effective Dose and Excess Lifetime Cancer Risk for Residents of Tehran, Iran. Journal of Air Pollution and Health, 1(4), 243-250.

[18] Bossew, P., Cinelli, G., Hernandez-Ceballos, M., Cernohlawek, N., Gruber, V., Dehandschutter, B. 2017. Estimating The Terrestrial Gamma Dose Rate by Decomposition of the Ambient Dose Equivalent Rate. Journal of Environmental Radioactivity, 166, 296-308.

[19] Spix, C., Grosche, B., Bleher, M., Kaatsch, P., Kreisel, P., Blettner, M. 2017. Background Gamma Radiation and Childhood Cancer in Germany an Ecological Study. Radiation Environment Biphysics, 56, 127-138.

[20] Garba, N. N., Ramli, A. T., Saleh, M. A., Sanusi, M. S., Gabdo, H. T. 2015. Terrestrial Gamma Radiation Dose Rates and Radiological Mapping of Terengganu State, Malaysia. Journal of Radioanal Nuclear Chemistry, 303, 1785-1792.

[21] Hossain, A., Nizam, Q. M. R., Rahman, M. M., 2014. Measurement of Absorbed Outdoor Dose Rate Due to Gamma Radiation in Northern Part of Chittagong City Corporation. International Journal of Scientific & Technology Research, 3(5), 98-100.

[22] Rafique, M. 2013. Ambient Indoor/outdoor Gamma Radiation Dose Rates in the City and at High Altitudes of Muzaffarabad (Azad Kashmir). Environment Earth Science, 70, 1783-1790.

[23] Furukawa, M., Shingaki, R. 2012. Terrestrial Gamma Radiation Dose Rate in Japan Estimated Before The 2011 Great East Japon Earthquake. Radiation Emergency Medicine, 1(1-2), 11-16.

[24] Billon, S., Morin, A., Caer, S., Baysson, H., Gambard, J. P., Backe, J. C., et al. 2005. French Population Exposure to Radon, Terrestrial Gamma and Cosmic Rays. Radiation Protection Dosimetry, 113(3), 314-320.

[25] Clouvas, A., Xanthos, S., Antonopulos-Domis, M. 2004. Radiological Maps of Outdoor and Indoor Gamma Dose Rates in Greek Urban Areas Obtained by in Situ Gamma Spectrometry. Radiation Projection Dosimetry, 112(2), 267-275.

[26] Quindos, L. S., Fernandez, P. L., Rodenas, C., Soto, J. 1992. Estimate of External Gamma Exposure Ourdoors in Spain. Radiation Projection Dosimetry, 45(1), 527-529.

[27] Bayrak, K., Yümün, Z. Ü., Çakar, M. 2020. Investigation of Outdoor Gamma Dose Rates in Yalova, Turkey. European Journal of Science and Technology, 18, 568-573.

[28] Karataşlı, M. 2019. Determination of Outdoor Absorbed Gamma Dose Rates of Kahramanmaraş Province, Turkey. Cumhuriyet Science Journal, 40(1), 102-107.

[29] Karataşlı, M. 2019. Assesment of Outdoor Radioactivity and Health Risk in Adıyaman Province of Turkey. Cumhuriyet Science Journal, 40(3), 772-780.

[30] Karatepe, Ş., Kuluöztürk, M. F. 2019. Gamma Dose Measurements in the Beach Sands of Tatvan, Ahlat and Adilcevaz. Sakarya University Journal of Science, 23(6), 1173-1176.

[31] Kapdan, E., Altinsoy, N., Karahan, G., Yuksel, A. 2018. Outdoor Radioactivity and Health Risk Assessment for Capital City Ankara, Turkey. Journal of Radioanalytical and Nuclear Chemistry, 318, 1033–1042.

[32] Cengiz, G. B., Öztanrıöver, E. 2018. Analysis of Natural Radioactivity Levels in Soil Samples and Dose Assessment for Digor District, Kars, Turkey, Caucasian Journal of Science, 5(1), 30-39.

[33] Erdoğan, M., Manisa, K. 2016. Assessment of Outdoor Terrestrial Gamma Dose Rates in the

Konya-Ilgın-Çavuşçu Lignite Deposit (Turkey). Süleyman Demirel University Journal of Science, 11(2), 89-93.

[34] Kobya, Y., Taşkın, H., Yeşilkanat, C. M., Çevik, U. 2015. Evaluation of Outdoor Gamma Dose Rate and Cancer Risk in Artvin Province, Turkey. Human and Ecological Risk Assessment, 21, 2077-2085.

[35] Tozun, F., Çine, A., Kürkçüoğlu, M. E. 2014. Isparta İl Merkezine Ait Gama Doz Hızı Düzeylerinin Yıllık Olarak İncelenmesi ve Haritalandırılması. Adım Fizik Günleri III, 17-18 Nisan, Süleyman Demirel Üniversitesi, Isparta.

[36] Turhan, Ş., Arıkan, I. H., Oğuz, F., Özdemir, T., Yücel, B., Varinlioğlu, A., Köse, A. 2011. Car-Bone Survey of Natural Background Gamma Dose Rate in Çanakkale Region, Turkey. Radiation Protection Dosimetry, 148(1), 45-50.

[37] Karahan, G. 2010. Risk Assessment of Baseline Outdoor Gamma Dose Rate Levels Study of Natural Radiation Sources in Bursa, Turkey. Radiation Protection Dosimetry, 142(2-4), 324-331.

[38] Kurnaz, A., Kuçukomeroglu, B., Çevik, U., Çelebi, N. 2011. Radon Level and Indoor Gamma Doses in Dwellings of Trabzon, Turkey. Applied Radiation and Isotopes, 69, 1554–1559.

[39] Bozkurt, A., Yorulmaz, N., Kam, E., Karahan, G., Osmanlıoğlu, A. E. 2007. Assessment of Environmental Radioactivity for Sanliurfa Region of Southeastern Turkey. Radiation Measurements, 42, 1387–1391.

[40] Sahin, L., Hafızoğku, N., Çetinkaya, H., Manisa, K., Bozkurt, E and Biçer, A. 2017. Assessment of radiological hazard parameters due to natural radioactivity in soils from granite-rich regions in Kütahya Province, Turkey. Isot. Environ. Health Stud., 53(2), 212-221.

[41] Kürkçüoğlu, M. E., Çine, A. 2017. Isparta İl Merkezindeki Okullarda Gama Ortam Doz Eşdeğeri Ölçümleri. Süleyman Demirel Üniversitesi Fen Bilimleri Enstitüsü Dergisi, 21(2), 549-553.

[42] Erdoğan, M., Tandırcıoğlu, T. N., Akdemir, M., Abaka, M. 2015. Selçuk Üniversitesi Alaeddin Keykubat Yerleşkesindeki Bina İçi Gama Doz Hızları. Adım Fizik Günleri IV, 28-29 Mayıs, Dumlupınar Üniversitesi, Kütahya.

[43] Deniz, K., Dönmez, A., Işık, U., Çetinkaya, H., Çalık, A.E., Manisa, K. 2015. Dumlupınar Üniversitesi Evliya Çelebi Yerleşkesinde Açık Havadaki Gama Doz Hızı Ölçümleri. Adım Fizik Günleri IV, 28-29 Mayıs, Dumlupınar Üniversitesi, Kütahya.

[44] Dönmez, A., Deniz, K., Işık, U., Çetinkaya, H., Çalık, A. E., Manisa, K. 2015. Dumlupınar Üniversitesi Evliya Çelebi Yerleşkesinde Bina İçi Gama Doz Hızı Ölçümleri. Adım Fizik Günleri IV, 28-29 Mayıs, Dumlupınar Üniversitesi, Kütahya.

[45] Çınar, H., Altundaş, S. 2015. A Preliminary Indoor Gamma-Ray Measurements in Some of the Buildings at Karadeniz Technical University (Trabzon, Turkey) Campus Area. Eastern Anatolian Journal of Science, 1(1), 10-19.

[46] Sezgin, N., Cumali, B. O., Aysal, N., Kajjumba, G. W., Nemlioglu, S. 2023. Radiological hazard assessment of natural radioactivity in Avcilar region, Turkey: a case of Istanbul University-Cerrahpasa Avcilar Campus. International Journal of Environmental Health Research, 33(12), 1443-1455.

[47] Karadaş, A. 2014. Bornova Ovası (İzmir) Holosen Paleocoğrafyası Ve Kıyı Çizgisi Değişmeleri. Ege Coğrafya Dergisi, 23(2), 37-52.

[48] TENMAK. 2024. https://nuken.tenmak.gov.tr/tr/urunlerimiz/2611-neb-211-radyasyon-doz-hizi-ve-doz-olcer-dose-rate-meter.html (Erişim Tarihi: 11.07.2024)

[49] Bilici, A., Kocak, A., Bilici, S., Kamislioglu, M., Aközcan, S., Buyuk, B. and Özden, S. 2024. Determination of Radionuclides Concentrations in Surface Soil Samples in the District of Bandirma, Balıkesir. Environmental Forensics, 25(4), 191-204.

[50] ICRP. 1990. Recommendations of The International Commission on Radiological Protection. ICRP Publication 60. Ann. ICRP, 21(1-3).

[51] Kamislioglu, M., Kocak, I., Buyuk, B., Eke, C., Ozaydın Ozkara, R. and Temiz, U. 2024. Investigation of natural and artificial radioactivity levels in travertines of the Cappadocia region in Turkey. Environ. Geochem. Health., 46, 181.

[52] Top, G., Örgün, Y., Karahan, G., Horvath, M., Kampfl, G. 2020. Effects of Local Building Materials on Indoor Gamma Doses and Related Radiological Health Risks, Ayvacık, Çanakkale, Turkey. Radiation Protection Dosimetry, 190(1), 108–117.

[53] Turgay, M. E. 2019. Cancer Risk Determination for IDA Villages by Using Annual Gamma Doses in Air, Around Edremit & Ayvacık Districts; Balıkesir & Çanakkale, Turkey. European Journal of Science and Technology, 15, 433-439.

[54] Kapdan, E., Varinlioglu, A., Karahan, G. 2012. Outdoor Radioactivity and Health Risks in Balikesir, Northwestern Turkey. Radiation Protection Dosimetry, 148(3), 301–309.

[55] Kurnaz, A., Küçükömeroğlu, B., Okumuşoğlu, N. T., Yeşilbağ, Y. Ö. 2010. Indoor and Outdoor Gamma Dose Measurements for Specific Counties of Trabzon-Turkey. 7th International Conference of the Balkan Physical Union, AIP Conference Proceedings, 1203, 379-381.

[56] Taskin, H., Karavus, M., Ay, P., Topuzoğlu, A., Hıdıroğlu, S., Karahan, G. 2009. Radionuclide Concentrations in Soil and Lifetime Cancer Risk Due to Gamma Radioactivity in Kırklareli, Turkey. Journal of Environment Radioactivity, 100, 49–53.

[57] Yamçıçıer, S., Yaşar, D. 2024. Determination of natural and artificial radioactivity levels and radiation hazard indices for soil samples in Kırşehir. Radiochimica Acta, 112(1), 53-61.

[58] Özden, S., Pehlivanoğlu, S. A., Günay, O. 2023. Evaluation of Natural Radioactivity in Soils of Konya (Turkey) and Estimation of Radiological Health Hazards. Environ. Monit. Assess, 195, 1523.

[59] ICRP. 2007. The 2007 Recommendations of The International Commission on Radiological Protection. Publication 103, 37(2-4).