ORIGINAL ARTICLE

The Effect of Various Parameters on Measuring Alpha and Beta Particles from Soil Sample; An Environmental Dosimetry

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Abstract

Purpose: The measurement of natural radioactive decay in environmental samples such as soil has received increasing importance in recent years. Proportional counters in the form of large-area planar detectors are widely used for the initial screening of α / β radioactivity in environmental samples. In this study, the affecting factors in the alpha and beta particles emitted from natural radioactive soil sample was simulated using the Monte Carlo FLUKA code.

Materials and Methods: These factors include the thickness of the sample, source-detector air gap, Mylar thickness, and gas detector density. Simulations were performed for alpha particles in 4.8 MeV and in the conventional range for the investigation of radioactive elements inside the soil sample.

Results: The final analyzed results show that the maximum number of primary particles can be measured up to 5 and 100 µm of soil sample thickness for alpha and beta particles, respectively. The maximum counting efficiencies for alpha and beta particles are 23% and 42%, respectively for our simulated sample.

Conclusion: For alpha particles, gas detector density variations have no effect on the efficiency. For beta particles, this efficiency is constant up to 0.0005 g/cm^3 density of gas. Furthermore, by increasing the air gap and Mylar thickness the efficiency will be decreased for both alpha and beta particles, while the variation of this value is remarkable for alpha particles.

Keywords: Environmental Dosimetry; Alpha and Beta Particles; Proportional Counters; Monte Carlo Simulation.

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1. Introduction

Recently, many efforts have been made to quantitatively assess the alpha and beta particles emitted from natural radioactive sources due to various applications in different fields. The most common applications are in safety against radioactive contamination, compliance management, and disposal issues for radionuclides of both alpha and beta sources [1-7].

For this aim, proportional counters have been widely used as radiation detectors [8, 9]. Proportional counters have specific advantages such as distinguishing between radiation types that make them able for alpha and beta counting. These counters exhibit little or almost no dead time which allows the counting of higher activity sources.

In the worldwide, various environmental dosimetry studies have been done on soil samples at different sites and countries. Mbonu *et al.* investigated the level of radioactivity concentration of U-238, Th-232, and K-40 natural radionuclides inside 19 soil sample gathered from several sites of factories, agricultural farming lands, and water eroded areas at Orlu Nigeria, where environmental concerns arise from human activities in the above regions. They Used NaI detecting system and their findings prove that the under-study regions are safe for human outdoor activities such as agriculture, construction, and factory operations. Missimer *et al.* performed an assessment on natural radioactivity measurement in Southern Florida USA with a focus on potential health impact. They understood that the risk of exposure to radon in indoor air in southern Florida is generally low while some areas are enriched in soil radon that migrates into structures. Ogundare *et al.* measured the mean gross alpha and beta activities in surface soil and drinkable water in the surrounding communities of a steel processing company in Nigeria using a low background Gas-less counting system with a PIPS detector. The average annual committed effective dose from intake of water was between 0.0304 mSv and 0.0678 mSv which is lower than the recommended reference level for ingested dose from drinkable water. Amanjeet *et al.* measured the natural radioactivity levels using gamma-ray spectroscopy in surface soil samples collected from Panipat City and its surrounding regions in India. They realized that the activities of radium equivalent in all gathered soil samples are lesser than the limit recommended by the Organization for Economic Cooperation and Development which is 370 Bq/kg. and the annual effective dose was at the safe level of 1 mSv/y. Durusoy *et al.* investigated the activity concentrations of naturally occurring K-40, U-238, and Th-232 radionuclides and of the artificial, Chernobyl accident-induced 137Cs radionuclide were measured in soil samples collected from Rize Province in Turkey. Rize was significantly affected by the 1986 Chernobyl nuclear reactor accident in Ukraine, and the effects have continued to today. The activity concentrations of radionuclides in 24 soil samples from the study area were measured using gamma spectrometry with a Nal(TI) detector and they finally compared their achievements with the international values reported by the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR, 2000) and previous studies on the area. Guidotti *et al.* assessed a survey study of gamma-emitting radionuclides in the Lombardia region in Italy based on the 156 agricultural soils based on Land Use/Cover Area frame statistical Survey standards. The results from this monitoring campaign are important for human radiation exposure and provide the zero point, which will be useful for assessing future effects due to external factors such as human activities [10-12].

The main purpose of this work is to investigate the effect of different parameters on the counting of alpha and beta particles emitted from a typical natural soil sample, using 2π proportional counter, while no study has been done for a long time of period. These parameters consist of the physical characteristics of 1) the radioactive source, 2) detector properties, and 3) all the influencing matters located between the source and detector such as the air gap, while emitted particles are alpha and beta. Source characteristics refer to its physical structure such as dimension, shape, and its isotropic or non-isotropic mode, density, particle type, self-absorption phenomena, activity, and the fraction of different contributed radionuclides [6-8]. The detector parameters are defined by their type and composition, detector-sensitive volume, and detector window [13-16].

Since the source and detector parameters mentioned above are varied on a wide range, an independent and comprehensive study is required to address them, case by case [17-20]. In this work, a non-isotropic soil sample source with natural background activity has been defined by emitting alpha and beta particles. The air gap distance between the source and detector, detector gas density, and the thickness of the detector window have been investigated. Moreover, the role of the stainless steel planchet as a sample holder is considered a secondary fragments producer that may reach detector-sensitive volume and affect particles counting, which is the main novelty of our work.

To do this, FLUKA as a Monte Carlo-based simulation code is utilized to investigate the effect of each parameter [17-20]. It's worth mentioning that using Monte Carlo simulation-based code is a unique option to assess the assumed parameters, numerically. FLUKA is a multi-purpose and verified code for the calculations of particles transport and their interactions with various pure and combined matters. This code covers an extended range of applications spanning from dosimetry, detector design, accelerator-driven system, space radiation, and cosmic ray showers and medical physics [21-25]. Two alpha and beta soil sample sources were simulated in this study with an energy range of natural radionuclides. Our soil sample has been simulated as a = plate-extended volumetric source located onto a stainless steel planchet at different thicknesses. The final results represent the role of each parameter in the counting process that can be helpful while doing practical experiments.

2. Materials and Methods

2.1. The Properties of the Detector and Radioactive Soil Sample

The simulated detector in this study is a 2π proportional counter as a commonly available detector for natural environmental dosimetry for alpha and beta measurement [8]. The sensitive volume of this detector is filled with gas including 90% Argon and 10% Methane in an optimum density. Figure 1 shows a schematic layout of the detector structure including a gas-filled sensitive volume between two electrodes. The detector is located upstream of the radioactive soil sample at a specific distance.

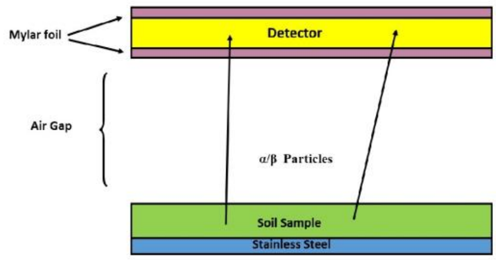

Figure 1. Schematic layout of soil sample and detector structure during the simulation process

As seen in this figure, a radioactive soil sample is put onto a stainless steel planchet at a small distance from the detector window. In practice, in order to prepare the sample, the soil is powdered and sieved. Then, a thin and uniform layer of soil is shaped on the stainless steel. It should be noted that during sample collection, statistical issues must be taken into account. In this way, around 10 samples collected from different parts of a site must be gathered and mixed together. Then, a little soil is taken as a sample from 10 mixed collected soils.

The emitted alpha and beta particles will reach the detector and deposit their energy partially or totally inside the detector sensitive volume depending on particle type and its primary energy. In the strong electric field at a proportional counter, the free electrons produce further ionizations while reaching the electrode. With the collecting of electrons and positive ions by the electrodes a pulse is generated by charge sensitive preamplifier. These pulses are then amplified to be counted and discriminated for distinguishing particle type.

2.2.Simulation Process

In this work, the geometry of the source and detector (depicted in Figure 1) has been simulated by means of Monte Carlo FLUKA code [26]. The soil sample is defined as an extended layer source in a non-isotropic volumetric fashion with 1.4 gr/cm^3 density. The source is assumed to be 1) an alpha emitter at 4.8 MeV energies and 2) a beta emitter with Sr-90 energy spectrum as common available energies utilized at environmental dosimetry. The distribution of alpha and beta is uniform inside the simulated volumetric source. Table 1 represents the elements and the fraction of each element contributed at the soil sample source.

The sample composition was chosen according to the elemental composition of the soil representing global averages.

Table 1. The elements and their fractions inside the soil sample

Element	Fraction (%)
Phosphorus	**0.008**
Oxygen	**49.38**
Aluminum	**7.1**
Silicon	**33**
Titanium	**0.46**
Sulfur	**0.09**
Calcium	**1.37**
Nitrogen	**0.1**
Magnesium	**0.63**
Iron	**3.8**
Sodium	**0.63**
Potassium	**1.36**
Carbon	**2**

It should be noted that the properties of the real proportional counter were considered during detector simulation for alpha and beta counting. In the simulation process, the thickness of the detector's sensitive volume is 0.3 cm along with particle penetration.

While simulating source and detector structures, the FLUKA Monte Carlo code can track each alpha or beta particle through the detector's sensitive volume for calculating the energy deposition of each particle on a case-by-case basis. In this work, the effects of air gap thickness between the source and detector, Mylar thickness, and detector gas density inside sensitive volume were considered during alpha and beta counting. Moreover, the effect of stainless steel and Mylar window on secondary fragments production is taken into account. The thickness of stainless steel is assumed to be 10 µm, to mimic the real condition.

3. Results

While reaching alpha and beta particles inside detector sensitive volume, they deposit their energy for ion production, known as an event. In this work, we demonstrated our results with the detector efficiency parameter as a metric tool. The detection efficiency is defined as the ratio of the number of events producing ionization inside the detector's sensitive volume to the total number of particles emitted from the simulated soil sample.

Figures 2 and 3 show the effect of the thickness of Mylar as a detector window on the = efficiency parameter for alpha and beta particles, respectively in a semi-logarithmic fashion. As seen in Figure 2, Mylar thickness is in the micrometer range, and in front of 4.8 MeV energy of alpha particles, by increasing its thickness the efficiency is reduced.

As seen in Figure 3, the range of Mylar thickness for beta particles is higher than alpha particles and this is due to beta penetration through Mylar foil. In this figure, the detector efficiency is decreased regarding with Mylar thickness increment.

Figures 4 and 5 show the effect of air gap distance (between the source and detector) on efficiency

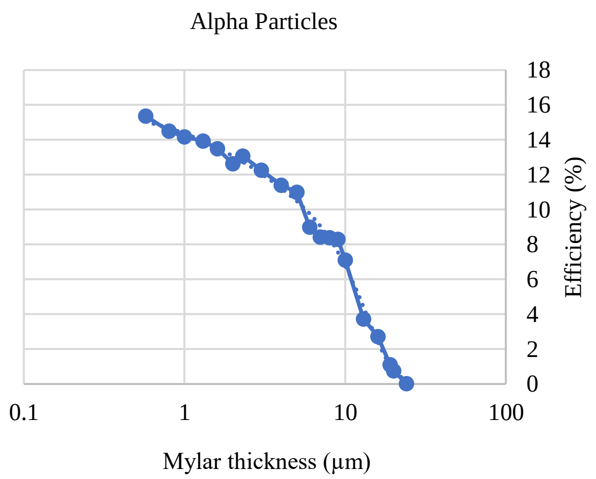

Figure 2. Detector efficiency as a function of Mylar thickness for 4.8 MeV alpha particles

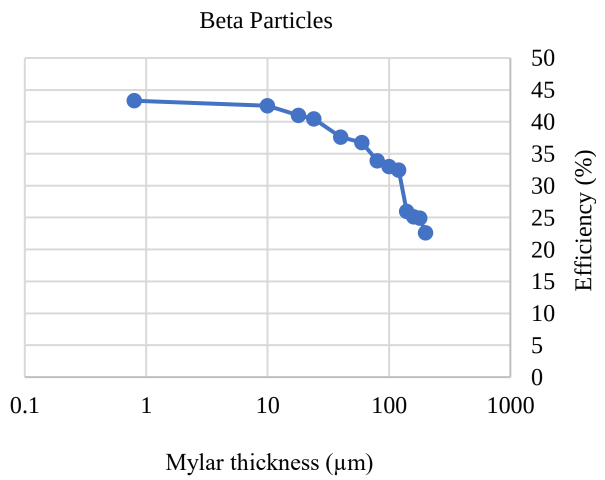

Figure 3. Detector efficiency as a function of Mylar thickness for beta particles with Sr-90 energy spectrum

parameters in semi-logarithmic plots. As seen in both figures, by increasing this distance, the number of recorded events and therefore detector efficiency is Detector efficiency will be zero if the air gap distance reaches approximately 3.5 cm and 8 cm for alpha and beta particles (with Maximum energy of beta particles), respectively.

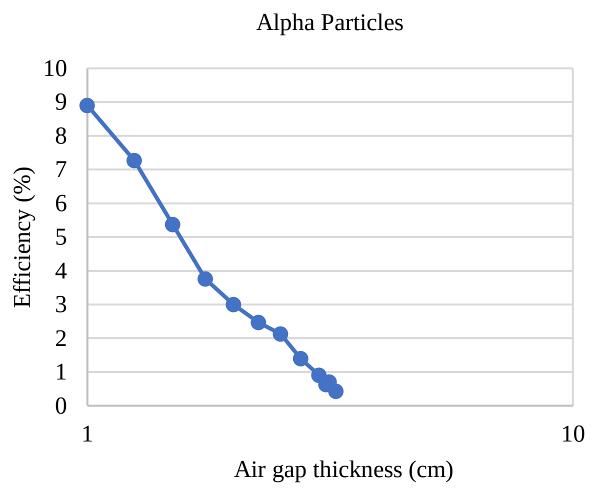

Figure 4. Detector efficiency as a function of air gap distance for 4.8 MeV alpha particles

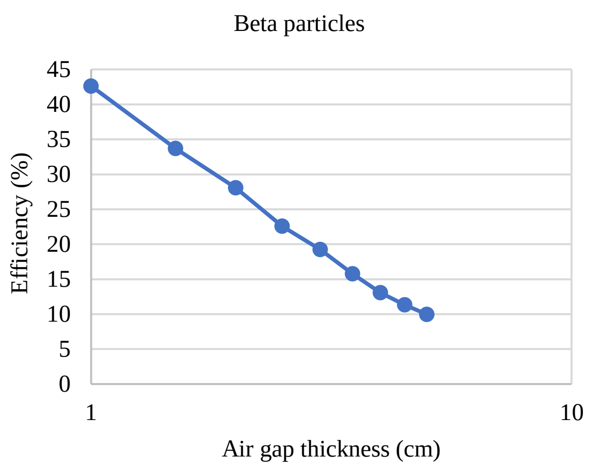

Figure 5. Detector efficiency as a function of air gap distance for beta particles with Sr-90 energy spectrum

Figures 6 and 7 demonstrate the detector efficiency variations versus the detector gas density for alpha and beta particles, respectively.

As seen in Figure 6, the detector efficiency is almost constant against the gas density increment. In contrast, for beta particles, the efficiency of the detector increases by increasing the gas density up to 0.0005 g/cm^3. After this value, the detector efficiency is almost constant that shows beta particles with maximum energies are stopped through detector-sensitive volume.

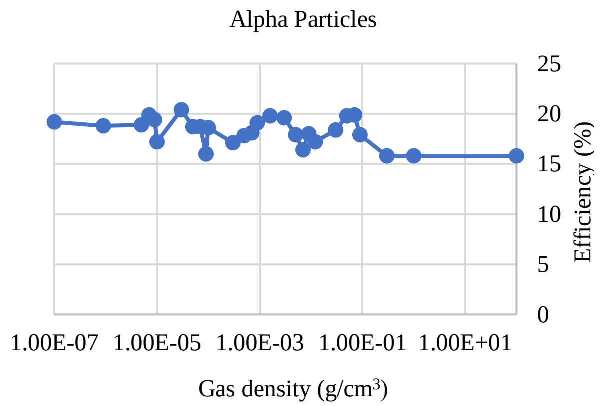

Figure 6. Detector efficiency versus detector gas density for alpha particles with 4.8 MeV

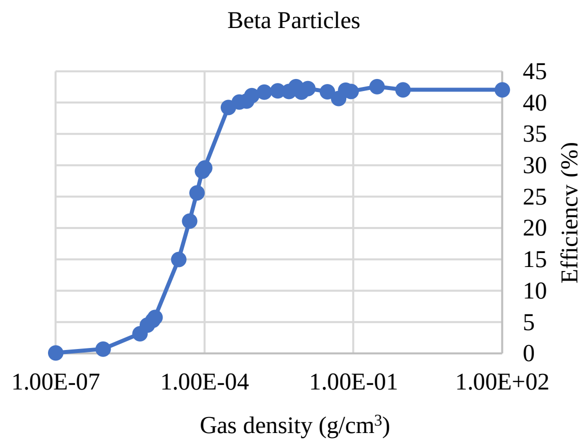

Figure 7. Detector efficiency versus detector gas density for beta particles of Sr-90

Moreover, in this study, we investigated the effect of stainless steel planchet and Mylar detector window on a secondary fragments production. The planchet is a uniform and flat plate from metal and is responsible for holding soil samples in front of the detector system. Tables 2, 3, and 4 represent our quantitative assessment of this issue in two modes while using stainless steel and Mylar and without using them. Table 2 shows detector efficiency variations affected by secondary fragments produced by alpha particles interaction with stainless steel planchet in different soil sample thicknesses. As results shown in Table 2, detector efficiency does not change significantly with secondary fragments produced by stainless steel at each given sample thickness. The same calculations have been done using beta particles and the results were reported in Table 3. In this case, at a low thickness of soil sample, efficiency parameter increases in the presence of stainless steel planchet. This is due to secondary fragments that may reach the detector-sensitive volume at a lower thickness of our sample.

Table 2. Stainless steel planchet effect on detector efficiency for 4.8 MeV alpha particles

Soil sample thickness (μm)	Detector efficiency without stainless steel planchet (%)	Detector efficiency using stainless steel planchet (%)
1	23.9	24.13
20	18.86	18.87
40	10.93	9.97
50	8.71	8.9

Table 3. Stainless steel planchet effect on detector efficiency for Sr-90 beta particles

Soil sample thickness (μm)	Detector efficiency without stainless steel planchet (%)	Detector efficiency using stainless steel planchet (%)
1	36.71	42.16
35	38.68	43.48
80	38.63	41.93
700	30.13	30.61
2400	17.53	17.31

Table 4 represents the effect of secondary fragments produced by Mylar window on detector efficiency at a given Mylar thickness that is commonly available. As seen in this table, there is no significant change in efficiency parameters by implementing alpha and beta sources. It seems the number of produced fragments by Mylar is not high enough to affect detector counting.

Table 4. Mylar effect on detector efficiency for alpha and beta particles

Type of particle	Detector efficiency without Mylar (%)	Detector efficiency with 0.572 (μm) Mylar (%)
For alpha particles	16.9	15.37
For beta particles	43.27	43.30

4. Discussion

In environmental dosimetry, there are many physical and structural parameters during experimental works that may cause measurement accuracy depending on the impact of each parameter, on a case-by-case basis. These parameters consist of detecting system structure, sample preparation, and experimental setup. In this work, the effect of various parameters affected alpha and beta counting by means of 2π proportional counter was assessed, quantitatively. In other words, this work is not a routine experimental measurement to report natural environmental radiation of a specific site or county, as mentioned in the introduction section. However, the main aim is to investigate the role of influencing parameters during a practical radiation measurement. We mainly focused on the most important parameters as the air gap distance between the source and detector, gas density, and the thickness of the detector's window. We also investigated the role of stainless steel planchet as a sample holder and Mylar as a detector window in interacting alpha/beta primary particles with them and producing secondary fragments, as the main novelty of our work. This later case was taken into account since some secondary fragments may reach detector-sensitive volume and affect the detector counting process.

To do this, the Monte Carlo FLUKA code was utilized to simulate the experimental setup. In order to investigate the effect of each parameter, detector efficiency was considered a metric tool. It should be noted that while investigating one parameter, the other parameters were assumed to be constant.

While increasing Mylar as a window, detector efficiency was reduced (Figures 2 and 3). As seen from the slope of the curves in these figures, alpha particles are more sensitive than beta particles against Mylar thickness, while this slope is falling down sharper. The alpha particles are stopped at 19 μm of Mylar thickness for 4.8 MeV energy.

We then increased the air gap distance between the source and detector starting from 1 cm. In this starting point, the detector efficiency is around 9% and 45% for alpha and beta particles, respectively. This value proves that alpha interactions with 1 cm of air molecules can significantly affect particles counting (Figures 4 and 5). Concerning the air gap, alpha particles counting can be increased remarkably if the window of the proportional detector is very close to our environmental radioactive soil sample.

Another interesting and challenging issue considered in this study was the effect of detector gas density on particle counting. As resulted, detector efficiency is almost constant by increasing the gas density for alpha particles. This is due to alpha particle penetration through detector-sensitive volume while all alpha particles are stopped at each given gas density. For beta particles, the detector efficiency is firstly increased as a function of the detector gas density and then reached a saturation condition at 0.0005 gr/cm^3 of density value. This is due to the physical properties of beta particles in interaction with gas-filled sensitive volume that is completely in a different manner against alpha particles. Beta particles deposit a fraction of their energy inside a sensitive volume and can easily pass through it. Therefore, increasing detector gas density can increase beta interactions and therefore detector efficiency will be increased.

Finally, we checked the presence of secondary fragments such as neutrons that may be produced in interacting primary alpha and beta particles with a stainless steel planchet as the sample holder and a Mylar layer as the detector window. We investigated this issue by simulating particle counting 1) with and 2) without using a stainless steel planchet and Mylar window.

As resulted, Mylar doesn’t have an effective role in producing secondary particles while interacting with alpha and beta particles. Furthermore, the stainless steel does not produce secondary fragments remarkably in interaction with alpha particles. In contrast, as a surprising achievement, for beta particles detector efficiency is a little increased while using sample holder regarding with same simulation condition, without using it. This detector efficiency difference is significant at low sample thickness, relatively. Therefore, it seems that at this thickness, secondary fragments produced in the interaction of beta particles with the sample holder may backscattered and reach detector sensitive volume and will be counted during the simulation process. It should be noted that in this work we simulated one alpha emitter with 4.8 MeV and one Sr-90 as a beta radiation source, while other alpha and beta emitters can also be considered in the next works. Moreover, future studies can be done using the same purpose in experimental mode by means of other common available detecting systems and also other liquid or gas modes of the source, since Radon gas plays an important role as natural background radiation.

5. Conclusion

In this work, we quantitatively assessed the effect of various parameters that will affect the performance accuracy of alpha and beta counting by means of a proportional counter. These parameters are detector gas density, detector window, and air gap distance between the soil sample source and detector system. Furthermore, the secondary fragments that may be produced during alpha and beta counting have been investigated, separately. The final analyzed results represent the importance degree of each parameter, quantitatively. Based on reported results, an optimum experimental condition yields to better experiment assemble for practical alpha and beta counting. The limits of the performed work refer to the number and energies of our soil-state source definition at the simulation process, while these drawbacks can be addressed by testing other radioactive sources in solid, liquid, and gas modes of natural samples, employing both simulation and experimental modes.

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