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Exploring Nile River Soil for Sustainable Gamma Radiation Shielding

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Abstract: *As is well known, Sudan is rich in Nile River bank soils that are readily available, making them an environmentally friendly option for radiation protection. Finding shields made from natural and clean environmental materials is interesting. This study aimed to evaluate the ability of Nile River bank soils to decay and avoid harmful gamma rays (conducted from February to November 2022, Department of Physics, Sudan University of Science and Technology, Khartoum). Samples were collected, dried, ground, and compressed into flat discs of uniform thickness, each measuring 0.05 mm. For the experiment, a gamma radiation source (cesium strontium) was used to measure the soil's effectiveness in attenuating gamma rays. The absorption coefficient (μ) of the soil discs was measured as a function of their thickness. The data were analyzed to produce three main graphic relationships: the correlation between gamma ray intensity, transmittance, and the transmittance coefficients as a function of soil disc thickness. The results revealed an inverse relationship between gamma ray transmittance and disc thickness, indicating that as the thickness increased, gamma ray transmittance decreased. The study concluded that increasing the thickness of the Nile River bank soil discs effectively reduces gamma radiation, indicating that this material has strong potential for use in radiation shielding systems. With further research, this environmentally friendly and cost-effective material could be developed into effective radiation shielding solutions.*

Keywords: *gamma rays, Attenuation Coefficient, Nile River soil, Radiation Protection, Shielding Materials*

1. Introduction

The discovery of gamma rays by French scientist Villard in 1900 marked a significant advancement in understanding their applications and associated risks [1]. As gamma rays have become essential in various medical and industrial technologies, concerns about their potential harm have also increased [2]. This has led to the development of guidelines and regulations for protection from ionizing radiation [3]. Radiation protection, a field combining physics and medicine, provides guidance to safeguard health when working with ionizing radiation sources such as gamma rays and X-rays [4]. These guidelines are globally adopted and incorporated into national laws to ensure safety in scientific, industrial, and medical environments [5]. Despite the beneficial uses of ionizing radiation in medicine, industry, and research, improper handling can lead to acute and long-term health effects, including cancer [6]. Gamma rays are high-energy electromagnetic waves with energies ranging from 1 million to 14 million electron volts [7]. They are produced by nuclear reactions and radioactive elements [8]. Gamma rays possess high penetrating power and are harmful to living cells due to their ionizing nature [9]. They are used in medicine for cancer treatment and in industry for inspecting pipelines and sterilizing food [10]. Due to their high intensity, effective shielding, typically with lead, is required to protect against gamma radiation [11]. Lead has been the material of choice for radiation shielding due to its excellent protective properties. However, lead is highly toxic and poses significant environmental and health risks [12]. This study explores the use of Nile River bank soil as a potential radiation shield by applying absorption and attenuation theories. The goal is to provide insights into future research and development of alternative, environmentally friendly materials for gamma radiation shielding [13]. This study aims to guide researchers and industry professionals in selecting and applying sustainable alternatives.

2. Attenuation Coefficient

The attenuation coefficient is a critical parameter in various fields such as medical imaging, materials science, and acoustics, as it quantifies how much a material can attenuate a particular type of radiation or wave [14]. Essentially, the attenuation coefficient measures the reduction in the intensity of radiation or waves as they pass through a material [15]. This parameter is influenced by the properties of the material and the nature of the radiation or wave [16]. The attenuation coefficient, often denoted by the Greek letter (μ), is defined mathematically by the following equation:

$$R=R_0.e^{-\mu x} \quad (1)$$

WhereR_0 is the original counting rate in front of the attenuator, R is the counting rate behind it, μ (cm^{-1}) is the linear attenuation coefficient and x(cm) is the linear thickness.

We can quantify the transmission of the radiation to characterize the permeability of an attenuator using:

$$T = \frac{R}{R_O} \quad (2)$$

As appeared the greater, the so-called transmittance of an attenuator, the lower its attenuating capacity [17]. The transmittance depends on the thickness of the attenuator [18]. If we assume that the properties of the incident radiation remain unchanged in spite of attenuation, an increase in the thickness x by the amount dx will cause a decrease in the transmittance T by the amount dT. The relative reduction in transmission is proportional to the absolute increase in thickness:

$$\frac{-dT}{T}=\mu.\,dX \quad (3)$$

The proportionality factor μ is referred to as the linear attenuation coefficient.

From equation (3)

$$ln\,T = -\mu X \quad (4)$$

$$\mu = \frac{-\,ln\,T}{X} \quad (5)$$

This relationship is known as Lambert’s law of attenuation [19]. The linear and mass attenuation coefficients are important parameters that are widely used in industry, agriculture, science, and technology [20]. Because the linear attenuation coefficients are influenced by beam energy and material thickness, it's possible to rewrite the mass attenuation coefficient as follows:

$$\mu_m = \frac{\mu}{\rho} \quad (6)$$

Where:

μ_m is the mass attenuation coefficient (cm^2/g) of the absorber sample. If the absorber density is (g/cm^3), then the relationship between x and is given by:

$$x_d = \rho.\,x \quad (7)$$

(g/cm^2) is the density thickness of the absorber sample [21].

3. Radiation Protection

Understanding the attenuation coefficient of materials is essential for designing shielding to protect against harmful radiation, such as in nuclear power plants or medical facilities using radiation therapy [22]. The attenuation coefficient is influenced by material composition, density, and the energy or frequency of radiation [23]. Different elements and compounds possess varying capacities to absorb or scatter radiation, directly affecting the attenuation coefficient [24]. Materials with higher densities generally have higher attenuation coefficients due to the greater number of atoms or molecules per unit volume, increasing the chances of interaction with the radiation or wave [25].

4. Attenuation Measurement

In radiation protection, accurately measuring the attenuation coefficient of various materials is crucial for determining their effectiveness as shields against gamma radiation [26]. The attenuation coefficient represents how easily a material can attenuate, or weaken, the intensity of radiation passing through it [27]. This coefficient varies based on material density and composition, as well as the energy of the gamma rays [28]. Using a gamma-ray source, such as Cobalt-60 or Cesium-137, the attenuation coefficient of materials like lead, concrete, or soil can be measured to assess their suitability for radiation shielding [29].To measure the attenuation coefficient, a known thickness of the material is placed between the gamma-ray source and a detector [30]. By comparing the intensity of gamma rays detected before and after passing through the material, the attenuation coefficient can be calculated [31]. This information is essential for designing and evaluating radiation shielding in various applications, ensuring adequate protection for workers and the public from harmful radiation exposure [32]. In practice, the attenuation coefficient helps in selecting and optimizing materials for building barriers, walls, and protective gear used in environments where gamma radiation is present, such as medical facilities, nuclear power plants, and industrial sites [33].

Lead has traditionally been used for radiation shielding due to its high density and effective attenuation properties [34]. However, lead's toxicity and environmental impact have led to the search for alternative materials [35]. Other metals, such as tungsten and bismuth, have been explored for their potential as radiation shields, offering similar attenuation properties without the toxicity concerns associated with lead [36]. Additionally, composite materials and specially engineered polymers are being developed to provide effective radiation shielding while being lighter and safer for the environment and human health [37]. In addition to metals, certain types of soil and natural materials are being investigated for their potential as radiation shields. For example, soil samples from specific regions, such as the Nile River bank, are studied to determine their attenuation coefficients and suitability for radiation protection. These natural materials could offer a sustainable and cost-effective alternative to traditional shielding materials, particularly in regions where they are readily available [38].

5. Types of Soil and their Properties

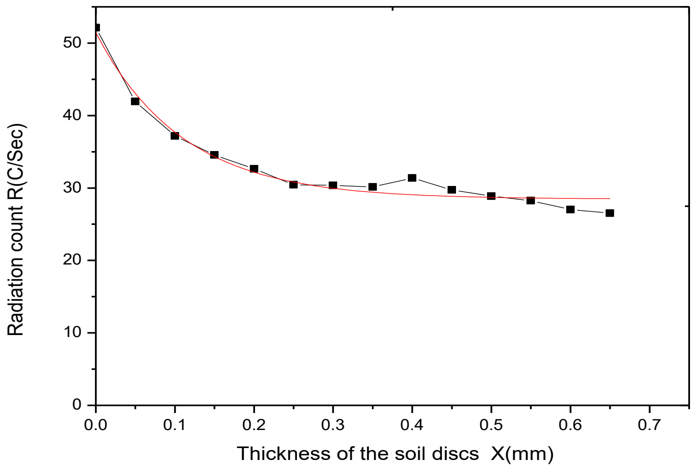
Different soil types exhibit unique properties that influence their suitability for various applications [39]. Clay soil is composed of fine mineral particles smaller than 0.002 mm in diameter and often contains significant amounts of water due to its high surface area [40]. It has a smooth texture when dry and becomes sticky when wet, with poor drainage leading to water retention. This soil type has high nutrient retention thanks to its fine particles and high cation-exchange capacity [41]. However, it is difficult to work with when wet and becomes very hard and compact when dry, exhibiting high shrink-swell capacity, which can cause significant volume changes with moisture variation [42]. Clay soil is used in pottery, ceramics, and bricks due to its plasticity and ability to harden when fired. [43].Sandy soil is primarily composed of large particles ranging from 0.05 to 2.0 mm in diameter, with fewer nutrients due to the large particle size and low surface area [44]. It has a gritty and loose texture, excellent drainage, and does not retain water well, leading to low nutrient retention and susceptibility to leaching [45]. Silt soil consists of medium-sized particles between 0.002 and 0.05 mm in diameter, with a smooth texture due to the fine particles [46]. It offers moderate drainage, better than clay but not as good as sandy soil, and has good nutrient retention [47]. Silt soil is easier to work with than clay and holds moisture better than sandy soil but is susceptible to erosion, especially in areas with little vegetation [48]. Loamy soil is a balanced mixture of sand, silt, and clay, often with organic matter, combining the beneficial properties of each soil type [49]. It has a fine-textured and crumbly structure with good drainage while retaining moisture, high nutrient content and retention, and is easy to work with and fertile [50]. Peaty soil contains a high amount of organic matter and is typically found in wetlands, characterized by a dark color due to the high organic content. It has a spongy and wet texture with poor drainage and high-water retention [51]. Calcareous soil is high in calcium carbonate (lime), characterized by a white or chalky appearance, with good drainage but poor nutrient retention due to high pH [52].

Nile River bank soil, known as Nile alluvium, is highly fertile and crucial for agriculture in Egypt and Sudan. This soil is a mix of silt and clay carried by the river from upstream and deposited during annual floods, giving it a fine and crumbly texture. The silt provides moisture and nutrient retention, while the clay enhances water-holding capacity and soil structure. Additionally, the soil is rich in organic matter from decomposed plant material and animal residues, essential for fertility. It also contains a variety of minerals, including calcium carbonate, which affects soil pH and nutrient availability. Typically, neutral to slightly alkaline in pH, Nile soil's combination of silt, clay, organic matter, and nutrients supports diverse crops and contributes to the region's agricultural productivity. [53]. It is a mix of silt and clay carried by the river from upstream and deposited during annual floods, with a fine and crumbly texture [54].

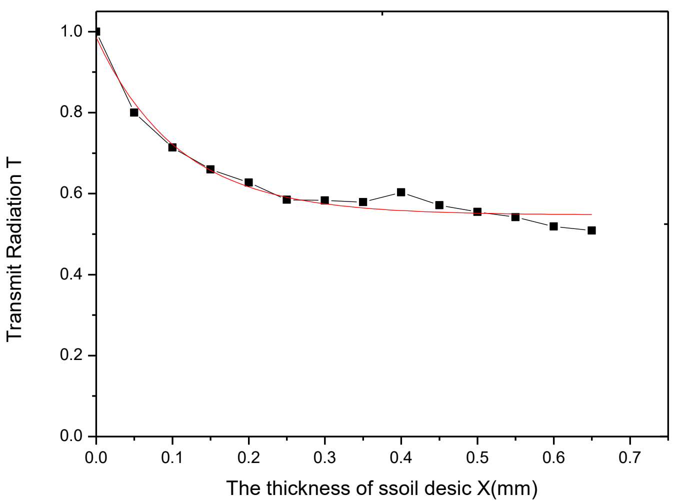
6. Materials and Methods

This studywas conducted from February to November 2022 at the Department of Physics, College of Science, Sudan University of Science and Technology in Khartoum, Sudan, Department of Physics, Faculty of Science. The aim was to determine the absorption coefficient (μ) of soil from the banks of the Nile to gamma radiation as a function of its thickness. A gamma radiation source (cesium-strontium) and a Geiger-Muller (G-M) counter or scintillation detector were used. Soil samples were collected from a dry soil sample from the Nile River bank at Tuti Island in Khartoum, Sudan, at a depth of about 20 cm below the surface. The soil was dried, ground, and compressed into uniform flat discs using a hand-held compactor. The thickness of each disc, measured with a Vernier caliper, was found to be 0.05 mm. The gamma radiation source was fixed on a stand, the detector was placed at a fixed distance from the source, and connected to a Geiger counter set at 0.99 V and timed for 60 seconds. The background radiation count rates were measured without any soil sample for a fixed period of time, repeated 5 times, and the average background count rate was calculated. The thickness was increased by adding one disc each time. Each soil disc was placed between the source and the detector, and the count rate was recorded for the same period, with the measurements repeated 5 times to calculate the average count rate. The thickness of each soil disc and the corresponding average count rate were recorded, and the background count rate was subtracted from each measured count rate to obtain the net count rate. The data were then tabulated and analyzed using Orient 6 software to produce three graphic relationships: the relationship between the thickness of the soil discs (X-axis) and the gamma ray intensity, radiant transmittance, and transmittance coefficients (Y-axis).

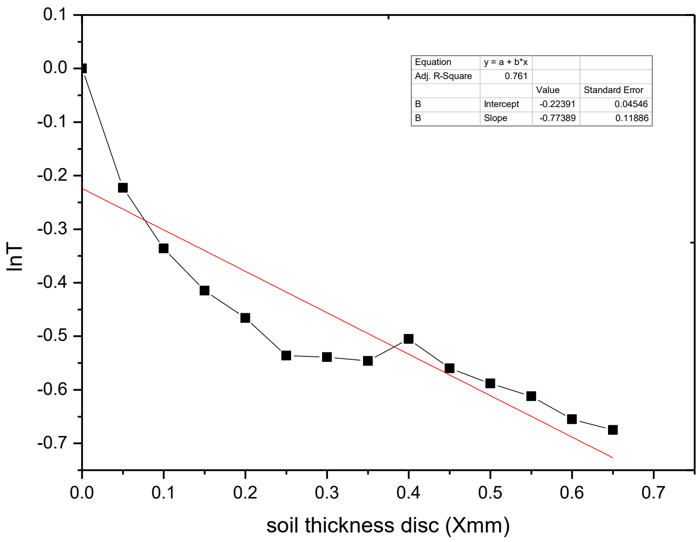
7. Results and Discussion



Figure(1). *shows the average intensity of the transmitted gamma rays (R) through the Nile River banks soil discs (X/mm).*



Figure(2). *shows the relationship between the average gamma ray transmittance intensity (T). and the thickness of the Nile River banks soil discs (X/mm) .*



Figure(3). *shows the relationship between the logarithm of the average gamma ray penetration intensity (LnT) and the thickness of the Nile River banks soil disks. (X/mm).*

8. Discussion

This study demonstrates that soil from the banks of the Nile River exhibits significant gamma radiation absorption capabilities. Specifically, it's found that the intensity of gamma radiation penetration is inversely related to the thickness of the soil discs (see figure 1). As the thickness of the soil discs increased, the intensity of the gamma radiation decreased, indicating that this soil has a high attenuation coefficient for gamma rays. The results suggest that Nile River soil can be effectively used in radiation shielding systems, offering a potential alternative to more traditional and often more hazardous shielding materials like lead. The findings of this study provide compelling evidence for the utilization of alternative materials in radiation shielding, aligning with and extending prior research.

Our results are in consistent with the work of [55], who explored the potential of local materials for radiation shielding applications. They emphasized the dual advantages of local materials: they not only effectively attenuate radiation but also offer environmental benefits. Their review underscores the feasibility of using materials that are readily available and have a lower environmental footprint compared to traditional synthetic shielding materials [55]. This aligns with our findings that Nile River soil, a natural and locally available material, can provide effective radiation shielding while supporting sustainable practices

In line with this, [56] investigated the gamma-ray attenuation properties of Polyboron, a locally developed material. Their study demonstrated that Polyboron offers substantial protection against gamma rays, showcasing its effectiveness as a radiation shield. They also highlighted the economic and environmental benefits of using locally sourced materials [56]. Our study builds upon these findings by showing that Nile River soil, with its unique mineral composition, can provide comparable or even superior radiation shielding performance. This reinforces the potential of utilizing natural and locally available materials for effective radiation protection.

The study by [57] provides further support for our results by examining the gamma-ray attenuation properties of various natural soils. They found that soils with high mineral content, such as those rich in dense and high-Z elements, exhibited significant radiation attenuation capabilities [57]. Our findings regarding Nile River soil align with this research, as the soil's mineralogical profile contributes to its effectiveness in radiation shielding. This correlation underscores the importance of mineral composition in determining the shielding properties of natural soils.

Additionally, [58] conducted a comparative analysis of alternative materials, including natural clays and soils, for radiation shielding. Their research revealed that these materials could meet or exceed the performance of conventional shielding materials, particularly in terms of cost-effectiveness and environmental sustainability [58]. This study supports our conclusion that Nile River soil, as a natural material, provides a viable alternative to traditional shielding options. The effectiveness of such materials in various contexts highlights their practical applicability and potential benefits.

[59] Further corroborates our findings by exploring the use of locally available materials in different geographic regions for radiation shielding. Their study identified that materials with specific physical and chemical properties, such as certain soil types, could achieve high radiation attenuation [59]. This research highlights the versatility of natural materials, including Nile River soil, in providing effective radiation protection across different environments.

[60] Investigated the use of composite materials that incorporate local soils for enhanced radiation shielding. Their study demonstrated that composites made from natural soils and other locally sourced materials could offer improved shielding performance compared to traditional materials [60]. This finding is particularly relevant to our study as it suggests that combining Nile River soil with other materials could further enhance its radiation shielding capabilities. The potential for creating composite materials from natural soils opens up new avenues for optimizing radiation protection strategies.

[52] Explored the engineering of polymers for gamma-ray shielding. Their findings indicated that polymers, when engineered with certain additives, could provide significant gamma-ray attenuation, offering an alternative to traditional shielding materials [52]. This supports the notion that innovative approaches to material design, including the use of locally sourced additives like Nile River soil, could enhance shielding effectiveness.

[53] discussed new trends in radiation shielding research, highlighting the importance of developing materials that not only provide effective shielding but are also environmentally friendly and cost-effective [53]. This aligns with our study's emphasis on the dual benefits of using Nile River soil for radiation protection.

Finally, [54] made a strong case for the use of natural materials in radiation shielding, focusing on soils and other readily available resources. They pointed out that these materials often have lower environmental impacts and can be more cost-effective than synthetic alternatives [54]. Our findings with Nile River soil support this perspective, suggesting a viable and sustainable solution for radiation shielding applications.

In addition to the aforementioned studies, our findings contribute to the growing body of evidence supporting the use of natural and locally available materials for radiation shielding. The demonstrated effectiveness of Nile River soil aligns with broader research trends emphasizing sustainability and cost-efficiency in radiation protection. By highlighting the practical benefits of using natural materials, this study advocates for a shift towards more sustainable and locally sourced solutions in radiation shielding applications.

The integration of natural materials like Nile River soil into radiation shielding strategies not only offers a cost-effective alternative but also promotes environmental conservation. Utilizing locally available resources reduces the need for synthetic materials, which often have higher environmental impacts and associated costs. This approach aligns with global efforts to promote sustainable practices and reduce reliance on non-renewable resources.

Future research should focus on optimizing the composition and treatment of natural materials to further enhance their radiation shielding properties. Investigating the potential for composite materials and exploring additional natural resources could provide valuable insights into improving radiation protection. Moreover, studies evaluating the long-term stability and effectiveness of these materials in various environmental conditions will be crucial for assessing their practical applicability.

This study reinforces the feasibility and advantages of using natural and locally available materials, such as Nile River soil, for radiation shielding. The alignment of our results with previous research underscores the potential for these materials to offer effective and sustainable solutions in radiation protection. By continuing to explore and optimize the use of natural materials, we can advance the field of radiation shielding and contribute to more environmentally responsible and cost-effective practices.

9. CONCLUSION

This study has demonstrated that soil from the banks of the Nile River possesses significant potential as a gamma radiation shield. The experimental results indicate a clear inverse relationship between the thickness of Nile River soil discs and the intensity of gamma radiation penetration, affirming that thicker soil discs effectively attenuate gamma rays. The calculated attenuation coefficient highlights the efficacy of this material in reducing radiation exposure, suggesting that Nile River soil is a promising candidate for radiation shielding applications.

The findings are notable for several reasons. Firstly, Nile River soil offers an environmentally friendly alternative to traditional radiation shielding materials such as lead, which poses significant health and environmental risks. By utilizing locally available soil, this study provides a cost-effective solution that leverages abundant natural resources. This approach aligns with previous research that supports the use of locally sourced and sustainable materials in radiation protection. Despite the promising results, the study acknowledges limitations that must be addressed in future research. Variability in soil composition across different regions along the Nile River could influence its shielding properties, necessitating further investigation into the consistency of these properties. Additionally, while the study focused on cesium-strontium gamma radiation, evaluating the soil's effectiveness against a wider range of gamma radiation sources is essential for broader applicability. Future research should also explore the long-term stability of Nile River soil under varying environmental conditions and compare its performance with other natural materials.

In summary, the successful demonstration of Nile River soil's potential as a radiation shield opens avenues for further exploration and development. By addressing the identified limitations and expanding the scope of research, we can advance towards more effective, sustainable, and practical solutions for radiation shielding, ultimately contributing to enhanced safety and environmental protection.

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