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RESEARCH ARTICLE

INNOVATIVE RADIATION SHIELDING: PERFORMANCE OF LOCALLY MADE $BaSO_4$ -COATED BUILDING BLOCKS FROM FCT, ABUJA AS LOW COST EFFECTIVE RADIATION BARRIERS

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Abstract

This study explores the innovative use of locally made blocks from four area councils (Abuja Municipal, Gwagwalada, Kuje, and Kwali) within the Federal Capital Territory of Abuja, coated with Barium Sulfate paint, as an effective shielding material against radiation. Soil samples were collected from each area, and blocks measuring 10 cm x 10 cm with varying thicknesses of 1-4 cm were molded. These coated blocks were exposed to low-energy X-rays at 100 kV and 10 mAs, and radiation doses passing through them were measured using a Raysafe Thin-X dose meter, including the free air exposure without any block. One uncoated block from Abuja Municipal area was also exposed to compare the effectiveness of barium sulfate. The Linear Attenuation Coefficients and Half-Value Layers for the blocks from each council area were determined. The block sample derived from soil collected in the Abuja Municipal Area and coated with Barium Sulfate exhibited the highest linear attenuation coefficient of 1.114 cm^{-1} and the lowest half-value layer of 6.22 mm. In contrast, an uncoated block from the same soil showed 0.702 cm^{-1} and 9.87 mm as the linear attenuation coefficient and the half-value layer respectively. Blocks from the Gwagwalada, Kuje, and Kwali Area Councils showed linear attenuation coefficients of 1.027, 0.900, and 0.968 cm^{-1} and half-value layers of 6.75, 7.70, and 7.16 mm, respectively. These values were compared with the half-value layers of concrete and lead. From the findings, Barium Sulfate coated blocks were found to be the most effective and cost-efficient alternative for radiation shielding.

Introduction:-

Radiation Physics involves the study and use of ionizing radiation, which can harm human cells. Therefore, it is important to reduce the exposure to radiation using radiation protection. Radiation protection consists of three methods: time, distance, and shielding. Shielding uses materials that can stop or absorb radiation, such as lead or concrete. However, these materials are expensive and hard to work with. Therefore, alternative materials, such as soil with barium sulfate paint, are being tested for effective and cheap shielding (De Pires et al., 2024).Radiation is broadly categorized into ionizing and non-ionizing types (Karmakar et al., 2021). Ionizing radiation, including X-rays, gamma rays, α- and β- particles has enough energy to ionize the atoms, resulting in chemical changes and

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potential damage to living tissue (Ruff, 2013). X-rays, which representthe electromagnetic radiation, can be particularly relevant in medical imaging and require effective shielding to prevent harmful exposure (Saidu et al., 2024).Ionizing radiation can be classified into two types: directly ionizing and indirectly ionizing. Direct ionizing radiation interacts with electrons within the medium, while in indirect ionizing radiation, it releases a charged particle into the medium. However, indirect ionizing radiation is more penetrating and it requires more shielding than direct ionizing radiation (Khan, 2019).Radiation is used in various fields, such as industry, agriculture, and medicine, and requires proper protection for safety. Radiation protection aims to minimize the exposure of people and devices to radiation, and to maximize the benefits of radiation applications. Research on new shielding materials and strategies is ongoing to improve radiation protection and efficiency (Shahzad et al., 2022).

X-rays can be produced when the high-energy electrons collide with a metal target within the X-ray tube, resulting in emission of photons. The energy of these photons determines their penetration power and the degree of attenuation required for effective shielding (Maier et al., 2018).Radiation shielding materials are evaluated based on their ability to attenuate ionizing radiation, which is often quantified using two parameters namely the linear attenuation coefficient and the half-value layer (HVL) (Bushberg et al., 2011). The effectiveness of a material in radiation protection is dependent on its density, thickness, and atomic number (Condori et al., 2022).

The properties of soil used in brick-making significantly influence the density and homogeneity of the bricks (Tao et al., 2018). Soil composition, including clay, silt, and sand content, affects the brick's physical properties such as strength and porosity (Akaninyene et al., 2016). These characteristics, in turn, impact the brick’s ability to attenuate radiation.

Barium Sulfate ($BaSO_4$) is a heavy compound with a high atomic number, making it highly effective in absorbing X-rays. Its use in medical radiology as a contrast agent demonstrates its ability to interact with ionizing radiation. When mixed with paint and applied to bricks, barium sulfate can enhance the radiation shielding quality of the bricks (Kim et al., 2012; Akkurt et al., 2006). Therefore, adequate shielding barriers are essential in X-ray facilities to protect workers and the public from scattered radiation. Conventional shielding materials like lead and heavy concrete are expensive and challenging to construct. This research aims to provide an alternative low-cost, lightweight, and effective shielding material. Such materials are environmentally friendly, reasonably effective in radiation absorption, and could reduce costs and construction difficulties in radiological centers, particularly in rural areas.

This study compared the attenuation coefficients and half-value layers of locally made bricks coated with $BaSO_4$ from four different Area Councils within the Federal Capital Territory (FCT), Abuja with reference values of concrete and lead (CNDE, 2016) in order to determine their ability to shield against the low-energy X-rays.

Materials and Methods:-

Wooden stool

A wooden stool with dimension 20cm x 20cm x30cm (height) was constructed to place the blocks with a small opening slit of 8cm x8cm at the middle for radiation to pass through to the detector (digital X-ray dose meter) which is placed 20 cm above the X-ray table.

Soil Samples

The Soil sample was collected from the following GPS locations from four different Area councils within the FCT, Abuja.

1. Abuja Municipal Area Council (AMAC), Jikwoyi [Sample A] 8.972045 N, 7.563714 E
2. Gwagwalada Area Council (GwAC) [Sample B] 8.900535 N, 7.088716E
3. Kuje Area Council (KuAC) [Sample C] 8.524101 N, 7.142103 E
4. Kwali Area Council (KwAC) [Sample D] 8.854785 N, 7.06536 E

The soil samples were collected by excavating of soil 35cm into the ground, this was to ensure homogeneity of samples. These sample were collected in polyethene bags and properly labeled (A, B, C & D) as above.

The bricks were molded according to standard procedures using metal molding frames of 10cm x 10cm with varying thicknesses of 1-4 cm. The dimensions of the bricks were controlled to ensure consistency in the experimental setup for adequate collimation.

Each block sample molded was exposed to the sun and dried for 14 days as shown in Fig 1. After which they were coated with Barium Sulfate and kept in the sun for 12 hours for the paint to dry properly.

Experimental Procedure

The wooden stool was placed on the X-ray table as shown in Figure 2. X-ray tube was adjusted to 100 cm FFD and the radiation dose meter, Raysafe Thin-X was placed 10 cm under the opening slit on the compartment provided in the stool. Free air exposure was taken without any molded block placing on top of the stool with a low-energy X-ray exposure settings at 100 kV and 10 mAs and the radiation dose passed through the opening slit was recorded.. Each block sample with different thickness was placed on top of the wooden stool as shown in Figure 3 and exposed at this constant exposure settings. This procedure was repeated for the remaining blocks molded from the soil collected from the other sample locations.

The exit radiation doses of X-rays were measured after passing through the block samples using a radiation dose detector, Raysafe Thin-X. The model representation(schematic) diagram of experimental set up is given in Figure 4.

Results:-

The experimental results obtained for all the samples at 100 kVp, 10 mAs are shown in the Table 1 below.

Data Analysis

In this study, linear attenuation coefficient (μ) for each of the blocks was calculated using the equation (1) below (Bushberg et al., 2011):

$$I = I_o e^{-\mu x} \qquad (1)$$

In this equation, I is the penetrated radiation dose (intensity) through the block, I_0 is the free air radiation dose (intensity), μ is the linear attenuation coefficient, and x is the vertical thickness of the block.

$I = I_o e^{-\mu x}$ is similar to the general exponential decay equation $y = ae^{-bx}$ where a and b are constants. ($a = I_o$ and $b = \mu$)

I_o = Free air exposure dose (without the block) is constant to all blocks, μ is constant (attenuation coefficient).

This equation can be written as

$\ln I = \ln I_o - \mu x \ln e$

$\ln I - \ln I_o = -\mu x$ since ($\ln e = 1$)

$$\ln(I/I_o) = -\mu x \qquad (2)$$

This is a linear equation of the type $y = -mx$ with a negative slope m.

Therefore, the slope (m) = μ

HVL was calculated from the attenuation data to compare the shielding effectiveness of different samples using the formula given in equation 3 below (Bushberg et al., 2011):

$$HVL = \frac{0.693}{\mu} \qquad (3)$$

Using the above equations, μ and HVL values for the block samples were computed and tabulated in Table 2 below. HVL values of different block samples were compared with that of lead and concrete at 100kVp (CNDE, 2016) and is shown in Table 3 below.

Discussion:-

From our study, it was found that the block sample $AMAC_1$ made from the soil sample collected from AMAC of FCT, Abuja and coated with $BaSO_4$ had the highest linear attenuation coefficient of 1.114 cm^{-1} and the lowest HVL value of 6.22 mm. However, the block made with the same soil sample from AMAC without the $BaSO_4$ coating ($AMAC_2$) had linear attenuation coefficient of 0.702 cm^{-1} and HVL of 9.87 mm. It means that a block thickness of 6.22 mm is required for the reduction of 50% of scattered radiation penetrating through the block coated with $BaSO_4$ but a thickness of 9.87 mm is required for a block without $BaSO_4$. This clearly shows that the effect of $BaSO_4$ coating on the block sample has enhanced the effectiveness of the block to be a better shielding material to block ionizing radiation. We also found that the local mud blocks made from the other Areas Councils from Gwagwalada, Kuje and Kwali had HVLs of 6.76, 7.70 and 7.16 mm respectively. From our results, a solid mud block of thickness 39.7 mm (6HVLs) coated with $BaSO_4$ from AMAC could stop scattered radiation up to 98.4%. Similarly, a block made with thickness of 46.2 mm and coated with $BaSO_4$ from Kuje Area Council could also stop scattered radiation up to 98.4%. However, it requires a concrete block of 90.6 mm thickness to stop 98.4% scattered radiation penetrating through it. This means that all the four different block samples coated with $BaSO_4$ used in this study can be effectively utilized as low-cost radiation shielding material for scattered X-rays in building an X-ray facility. From our study, it was apparent that coating the blocks with $BaSO_4$ can further enhance the effectiveness to block the penetration of low-energy scattered X-rays. Recent research suggested that materials like $BaSO_4$ have the potential to improve how well we can shield against the scattered radiation. For instance, a study evaluated silicone rubber composites with $BaSO_4$ for radiation shielding with 70% of $BaSO_4$ showed high effectiveness in reducing radiation doses from scattered diagnostic X-rays (Moonkum et al., 2022). Accordingly, recent studies focusing on cutting-edge hybrid materials, like cerium oxide nanoparticles integrated into bandages that are both flexible and moldable, have revealed encouraging findings for shielding against the scattered X-rays in medical settings. These innovative materials have proven to effectively reduce the impact of X-ray photons within the energy spectrum of 40 to 100 kVp, providing further evidence of the effectiveness of dense materials such as $BaSO_4$ in shielding against the scattered radiation (Verma et al., 2023). Furthermore, another recent study showed that use of radiation shielding concrete (RSC) by incorporating $BaSO_4$ can have an enhanced safety and it offers better radiation protection than regular concrete (Abdullah et al., 2022).This makes it a cost-effective and efficient choice for building radiation shielding structures. However, the use of concrete blocks can provide an effective radiation barrier but it is more expensive to produce because of the cost of raw materials needed.Moreover, the use of lead sheets is the best and the easiest option but it is the most expensive option among the all and hence did not consider in this study for comparison.

Conclusion:-

The findings of this study illuminate the potential of barium sulfate-coated locally-made bricks from the freely available soil as a game-changing, cost-effective solution for radiation shielding in the construction of X-ray facilities. This innovative approach is especially crucial for resource-limited settings where traditional materials are financially out of reach. By leveraging a novel combination of locally sourced raw materials and barium sulfate, this research paves the way for more accessible and affordable shielding alternatives. Ultimately, this breakthrough can significantly enhance access to safe diagnostic imaging, leading to better public health outcomes and a brighter future for the communities of developing countries around the world.

Tables

Table 1:- Radiation doses passed through the block samples A, B, C, and D.

Thickness (cm)	Sample (A) coated with $BaSO_4$ (μGy)	Sample (A) without $BaSO_4$ (μGy)	Sample(B) coated with $BaSO_4$ (μGy)	Sample (C) coated with $BaSO_4$ (μGy)	Sample (D) coated with $BaSO_4$ (μGy)
0 (free air)	812	812	812	812	812
1	345	378	264	322	310
2	55	220	115	142	116
3	33	97	42	54	44
4	10	48	12	22	17

Table 2:- Attenuation coefficients and HVLs for samples obtained from various locations.

Location(samples)Area Councils	Attenuation coefficient μ(cm^{-1})	Half value layer (mm)
$AMAC_1$ (with $BaSO_4$)	1.114	6.22
$AMAC_2$ (without $BaSO_4$)	0.702	9.87
GwAC	1.027	6.75
KuAC	0.900	7.70
KwAC	0.968	7.16

Table 3:- Comparison of HVL for block samples with lead and concrete.

Voltage				**HVL(mm)**			
kVp	Lead	Concrete	$AMAC_1$	$AMAC_2$	GwAC	KuAC	KwAC
100	0.27	15.10	6.22	9.87	6.76	7.70	7.16

Figures:

Fig 1:- Molded building blocks undergoing drying process.

Fig. 2:- Experimental set-up in the X-ray room.

Fig 3:- Barium Sulfate Coated block on the stool.

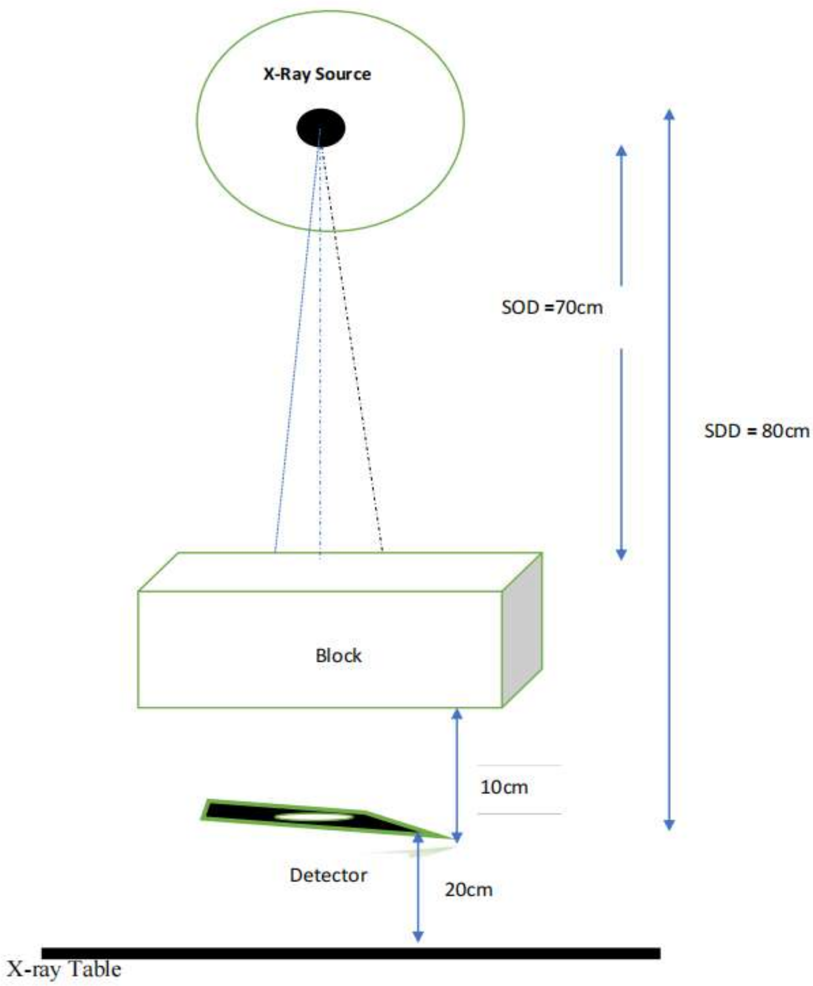

Fig 4:-The schematic diagram of the experimental set-up.

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