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Research Article

Investigation of Gamma Shielding Properties of Some Industrial Materials

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Abstract:

This paper has investigated the radiation absorption properties of some industrial materials. The most widely used for industrial purposes gamma radioisotope source is ^{60}Co. In this study, the linear attenuation coefficients of some industrial samples (Aluminium, AISI 4140 alloy steel, and AISI 4130 alloy steel) have been measured experimentally at 1173, and 1332 keV photon energies using a gamma spectrometer that contains a 3”x3” NaI (Tl) detector that is connected to Multi-Channel Analyzer (MCA) and calculated theoretically with the XCOM computer program. These results have been used to calculate the obtained radiation shielding parameters. The calculations from experimental methods were observed to be consistent with the XCOM data. As a result of this study, it was seen that AISI 4130 alloy steel has the largest linear absorption coefficients (0.487 and 0.364 cm^{-1}) at 1173 and 1332 keV energies, whereas aluminium has the lowest values (0.177 and 0.106 cm^{-1}). In addition, it was seen that the industrial samples used in this study were more suitable among radiation shielding materials compared to granite and concrete samples in previous studies.

1. Introduction

Radiation is the transfer of energy from one location to another in the form of electromagnetic waves or particles. As well as occurring spontaneously by unstable (radioactive) atoms, it can also be produced artificially.

It is possible to examine radiation in two parts: ionizing and non-ionizing radiation.

Ionizing radiation is defined as radiation that has higher energy than non-ionizing radiation, can penetrate tissues, and can create ion pairs by transferring its energy to the matter while passing through it, directly or indirectly affecting the atoms in the matter.

To protect against the harmful effects of ionizing radiation, three basic rules are recommended: time, distance, and shielding. It is a well-known fact that it is difficult for radiation workers to adhere to the first two rules. Therefore, shielding is the most appropriate method of protection against radiation, and recently, studies on the development of suitable protective materials have been rapidly increasing [1].

Many scientific investigations have been carried out regarding the radiation absorption properties of various materials, such as granite [2-5], marble [5-7], concrete [8-10], and glass [11-14].

Industrial materials such as steel and aluminium are widely utilized in modern industry, medical, construction, and transportation sector applications due to their key qualities, which include their high-temperature strength, mechanical properties, corrosion resistance, resistance to scaling, and high flexibility [15-18].

Furthermore, it has been noted that stainless steels have been employed in various nuclear reactor systems for many years and are major potential materials for structural use in fusion reactors [18-20]. Stainless steels can be preferred as shielding materials due to these superior properties.

AISI 4130 alloy steel is generally preferred in applications such as aviation, automotive, maritime, energy, and sports equipment due to its high strength and good welding ability characteristics. Because of these characteristics, it is utilized in the manufacture of pipes, bars, plates, gears, shafts, fasteners, suspension parts, and other high-strength components. AISI 4140 alloy steel is a chromium molybdenum alloy steel specification that is commonly used in general-purpose high-tensile steel components such as axles, shafts, bolts, gears, and other applications. AISI 4140 alloy steel is similar to AISI 4130, but with somewhat more carbon content. The higher carbon content of AISI 4140 steel results in greater strength and heat treatment capabilities than AISI 4130 alloy steels; however, it has lower welding ability properties.

Therefore, in order to investigate the usability of industrial materials for radiation protection purposes, the radiation absorption properties of three different samples such as Aluminium (S_1), AISI 4140 alloy steel (S_2), and AISI alloy 4130 steel (S_3) at gamma energies of 1173 and 1332 keV were investigated experimentally and theoretically.

2. Material and Methods

The XCOM program utilizes online software to determine total attenuation coefficients, cross sections, and partial cross-sections for elements, mixtures, and compounds in the photon energy range of 1keV-100GeV [21]. The linear attenuation coefficients (LAC) of industrial materials were measured at the photon energies of 1173 and 1332 keV. The shielding measurements were conducted at Amasya University Science & Arts Faculty's Radioactive Research Laboratory utilizing a gamma-ray spectrometer. The system includes a 3"x3" NaI (Tl) detector, a digital spectrum analyzer (DSPEC LF), and a Multi-Channel Analyzer (MCA) with ORTEC hardware and MAESTRO-32 software. The LAC (μ) is calculated from the Beer-Lambert's Law given by Eq.1 [22]:

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

The linear attenuation of a single-energy X or gamma photon beam per unit thickness of the material is measured in cm^{-1}.The μ is the LAC, ρ is the density, x is the sample thickness, and I and I_0 are the net counts obtained with and without the absorber, respectively. The Half-Value Layer (HVL) refers to the material thickness necessary to reduce gamma radiation by half as given Eq. 2 [2]. Half-value layer is determined by the incident photon's energy as well as the absorber material thickness.

$$HVL = \frac{In2}{\mu} \qquad (2)$$

3. Results and Discussions

Experimental LAC values were calculated according to Eq. 1 and are given in Figure 1.

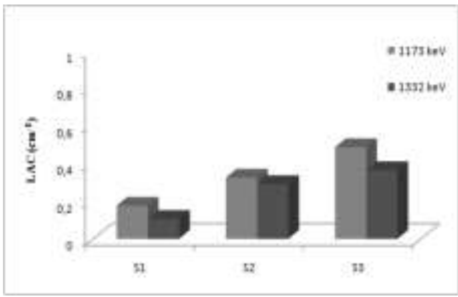

Figure 1. *Graph of the LAC values of industrial samples*

Figure 1 demonstrates that S_3 has the largest linear absorption coefficients (0.487 and 0.364 cm^{-1}) at 1173 and 1332 keV energies, whereas S_1 has the lowest values (0.177 and 0.106 cm^{-1}).

It is seen that these LAC values were higher than the LAC values of the concrete and granite studied in the previous work [2,9].

Also, Figure 1 shows that the linear absorption coefficient decreases with increasing photon energy. Experimental and theoretical LAC (μ) values are given in Figure 2- Figure 4.

It is seen from Figure 2- Figure 4, the experimental values are consistent with the theoretical values.

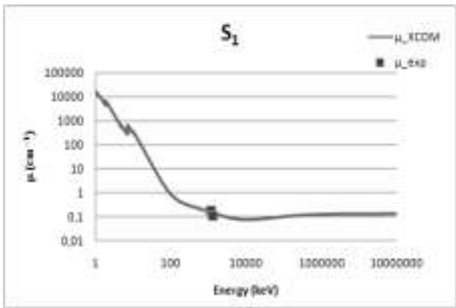

Figure 2. *Graph of the LAC values of S1*

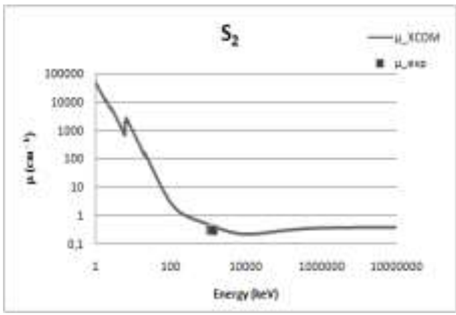

Figure 3. *Graph of the LAC values of S2*

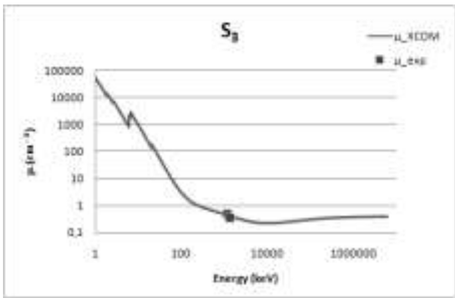

Figure 4. *Graph of the LAC values of S3*

The HVL graph derived through insertion of the LAC values into Eq. 2 is as seen in Figure 5.

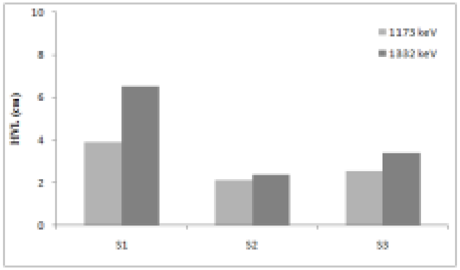

Figure 5. *Graph of the HVL values of industrial samples*

Materials with higher LAC values absorb radiation more efficiently than those with lower LAC values, which cause lower HVL values.
The transmission rate depending on the thickness of the material is shown in Figure 6.
As can be seen from Figure 6, thicker materials are needed to stop higher-energy photons.

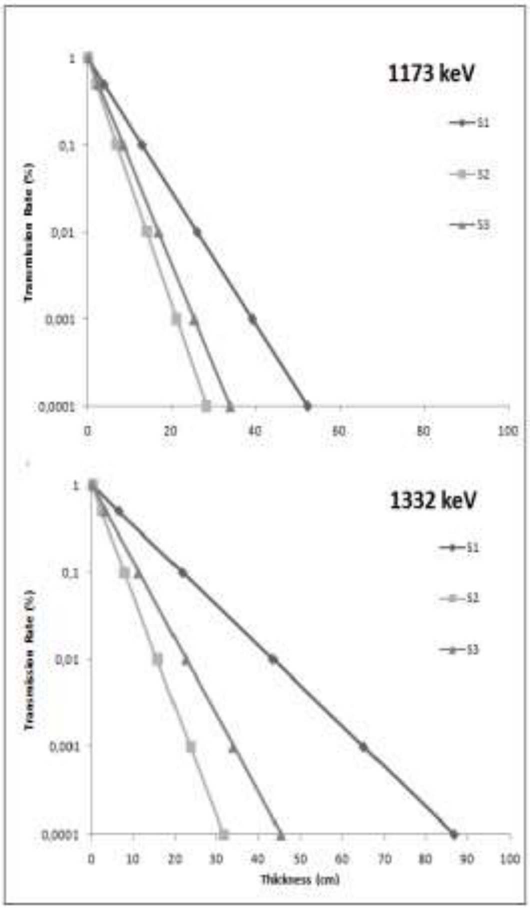

Figure 6. *Graph of the transmission rate of the samples depending on the sample thickness*

4. Conclusions

The aim of this study was to investigate the absorption properties of steel and aluminium, which have started to be used in many fields such as modern industry, medicine, construction, and transportation. For this purpose, in XCOM, the density values and chemical formulas for industrial samples were individually determined, and the LAC and HVL values representing the radiation absorption coefficients were calculated. It was observed that the calculations obtained from experimental methods were consistent with the XCOM data. Also, according to the findings obtained in the study, the industrial samples that consist of aluminium and stainless steel have been seen to be better radiation shielding materials compared to the granite and concrete samples investigated in previous articles. Even radiation shielding is well studied in the past [23-29], it should be further investigated in future.

Author Statements:

- **Ethical approval:** The conducted research is not related to either human or animal use.
- **Conflict of interest:** The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper

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- **Data availability statement:** The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

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