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Determination of The Radiation Shielding Performance of MoO_2 Addition On PbO by Monte Carlo Simulation

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Abstract – As it is known, lead is a toxic material, although it is used in shielding material. To develop alternative materials that can be used in radiation shielding, the effect of MoO_2 additives on the mass absorption properties of PbO was investigated. 662 keV, 1173 keV, and 1332 keV gamma energies were used in the study. Radiation absorption properties of materials taken with the XCOM database and GATE simulation programs at each energy value are given comparatively. By using the obtained mass attenuation coefficient, mean free path, half-value thickness, and linear attenuation coefficients were calculated.

Keywords – Monte Carlo, MoO_2, PbO, GATE, XCOM

I. INTRODUCTION

Ionizing and non-ionizing radiation and radioactive sources are used in many areas of our daily life, from food to medicine, for treatment and diagnostic purposes. Radiation protection methods have been put forward to minimize the damage caused by its widespread use. The main purpose of diagnosis and treatment; is to gain the best quality image with the least dose. For this purpose, protection methods (As Low As Reasonably Achievable) are known as the ALARA principle. In order to biological damage caused by uncontrolled radiation exposure, acceptable dose limits were determined [1, 2]. However, especially in interventional applications, it may exceed the internationally allowed dose limits due to the prolongation of the examination period. Thus, the radiation dose received by the employee increases [3].

The trio of distance, time and shielding is the most important safety rules for protection from radiation. Especially since there are situations where distance and time cannot be prevented, shielding is done in order to shield from radiation. Concrete (or building materials) and lead materials are mostly from the shielding materials used in radiation protection [4-10]. Due to the toxic effect and transportation difficulty of these materials used, intensive studies are carried out on alternative materials. The IAEA (International Atomic Energy Agency) and WHO (World Health Organization) encouraged researchers to develop a new generation of shielding materials to replace traditional shielding materials [11].

New-generation materials are glass material coatings due to their homogeneous appearance and transparency. Many studies have focused on glass materials for gamma ray shielding [12-18]

In addition to experimental studies, simulation programs have an important place in armoring studies in terms of accessibility and ease of application. In recent years, the results obtained with the Monte Carlo simulation codes have been compared with the experimental data [19], thus accelerating the search for alternative materials [19-26].

For this reason, the purpose of the development of alternative materials that can be used in radiation shielding, absorption properties of the MoO_2, PbO, and 50%MoO_2-50%PbO investigated theoretically.

II. Materials and Method

As a measure of the absorption of a photon by the material, the mass attenuation (μ_m), linear attenuation (μ), half-value layer (HVL), and mean free path (mfp) values of the materials are taken into account. The linear attenuation coefficient is a constant for each absorber material. The attenuation coefficient determines the reduction in the number of photons per unit distance from the radiation beam passing through the materials. The attenuation coefficient increases as the matter's atomic number and physical density increase.

If an absorber is placed between the radioactive source and the detector, the emitted photons due to the Beer-Lambert law:

$I_x = I_0 e^{-\mu x}$

In this equation; I_x = intensity of monoenergetic photons passing through the material without being absorbed, I_0 = intensity of monoenergetic primary photons incident on the material μ = total linearity of the material is the absorption coefficient. HVL and mfp values are also calculated to determine the absorption property against gamma radiation. HVL is the material thickness required to reduce the radiation intensity passing through a target to half of the radiation intensity coming to the target.

$HVL = \ln 2 / \mu$

The mfp describes how far the photon passing through the material travels on average between two interactions, depending on the fundamental interactions that the incident radiation will perform in the material.

$mfp = 1/\mu$

Density values according to the materials to be used in the study and their mixing ratios are given in the table below.

Table 1. Density values according to the materials to be used in the study and their mixing ratios are given in the table below.

MATERİAL	The chemical composition (Wt%)		Density (g/cm^3)
	MoO_2	PbO	ρ
MoO_2	100	0	6,47
PbO	0	100	9,38
MoPb	50	50	7,92

The XCOM program used in our study is a computer code operating in the energy range of 1keV and 100GeV. This computer code can calculate the absorption coefficients and mass absorption coefficients of the photoelectric effect, Rayleigh and Compton scattering, electron pair formation and nuclear pair formation of both elements, compounds and mixtures [27].

GATE simulation is an software program that performs Monte Carlo calculations for use in areas such as nuclear physics, radiology, and radiotherapy. Today, GATE simulation has a wide range of uses, from the construction of new medical devices to the development of quality control protocols and medical imaging systems [28].

Comparative graphs of the μ_m values calculated using the XCOM and GATE program are shown in Figure 1-3.

Linear attenuation coefficient, half value layer, and mean free path data were obtained from the mass attenuation coefficient values obtained by XCOM and GATE program (Figure 4-12).

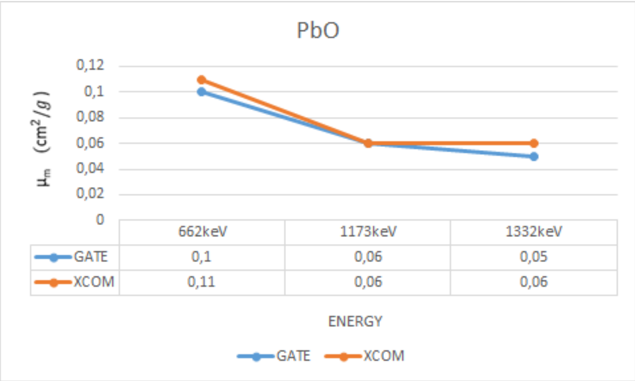

Figure 1: Mass absorption values of PbO

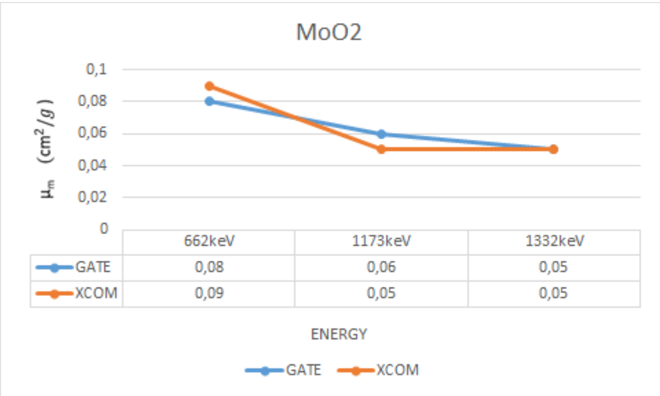

Figure 2: Mass absorption values of MoO_2

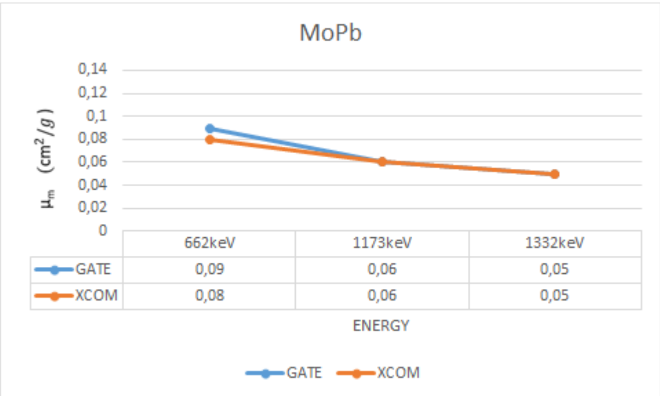

Figure 3: Mass absorption values of PbO and MoO_2 mixed in equal proportions (%50+%50)

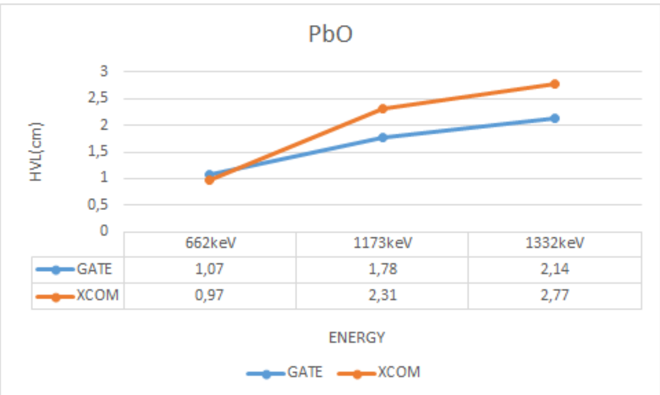

Figure 4: Half-value thickness values of PbO

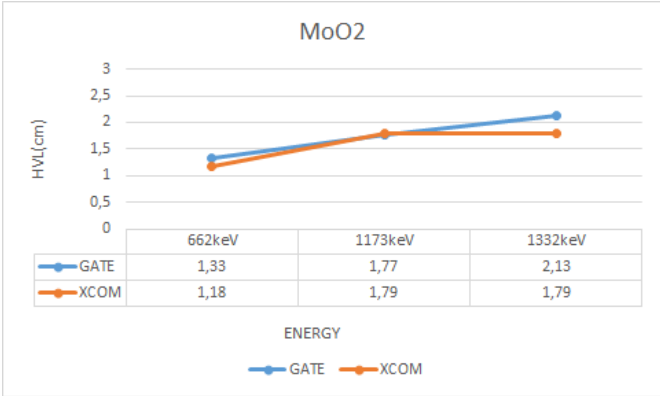

Figure 5: Half-value thickness values of MoO_2

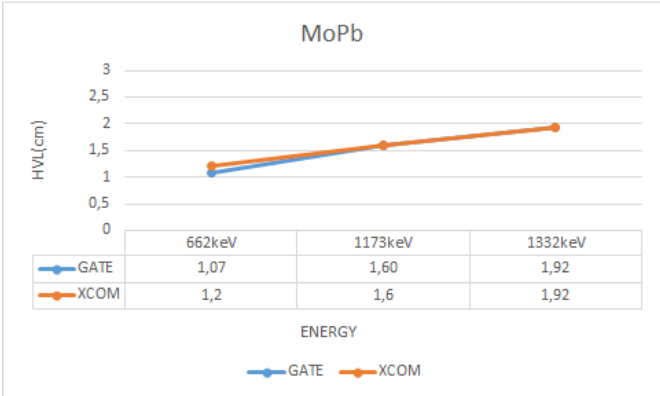

Figure 6: Half-value thickness values of PbO and MoO_2 mixed in equal proportions (%50+%50)

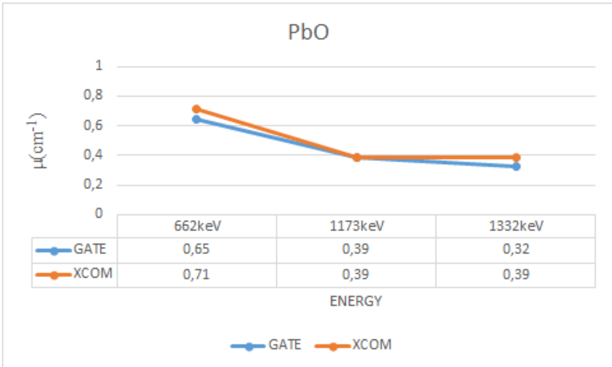

Figure 7: Variation of linear absorption coefficients of PbO

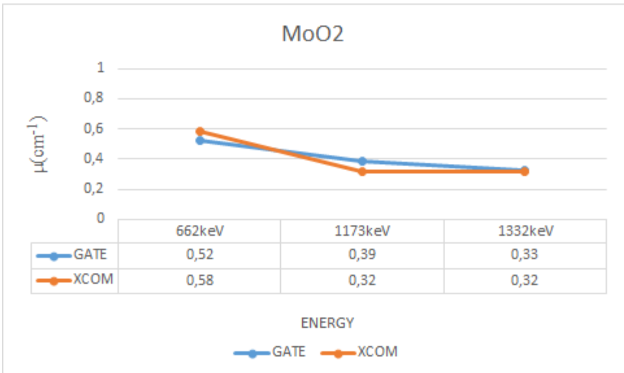

Figure 8: Variation of linear absorption coefficients of MoO_2

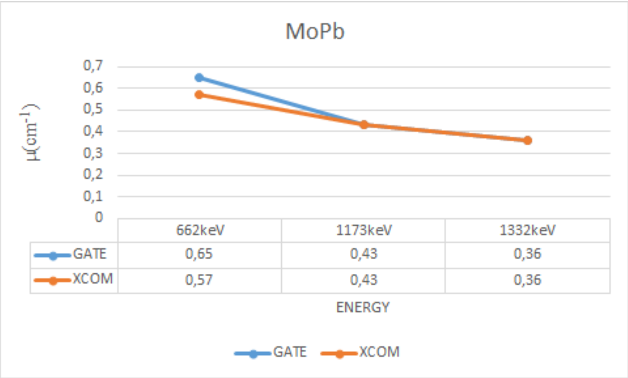

Figure 9: Variation of linear absorption coefficients of PbO and MoO_2 mixed in equal proportions (%50+%50)

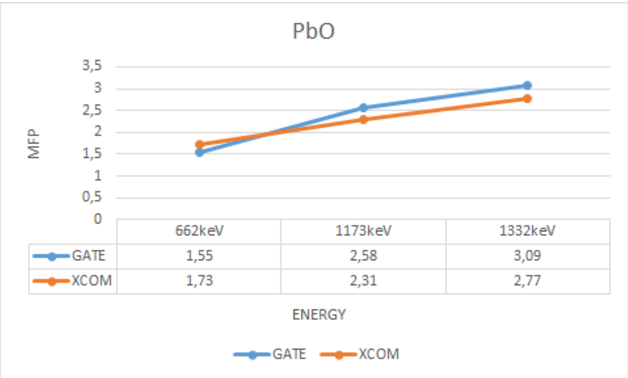

Figure 10: Mean free path variation of PbO

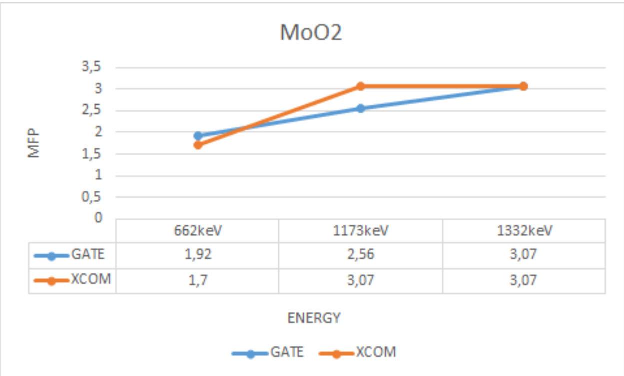

Figure 11: Mean free path variation of MoO_2

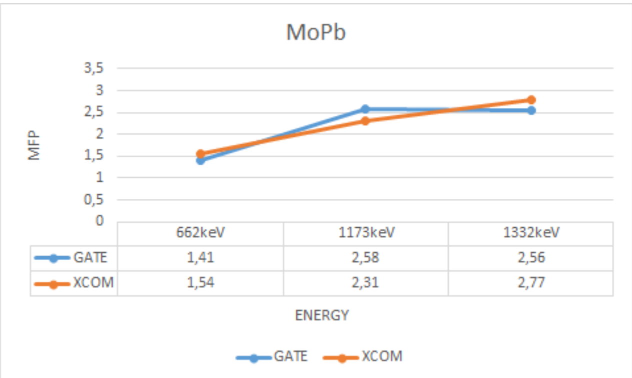

Figure 12: Mean free path variation of PbO and MoO_2 mixed in equal proportions (%50+%50)

III. DISCUSSION

In this study, the radiation attenuation properties of three compounds with PbO and MoO_2 compositions were investigated. First, the μ_m values determined by the GATE program in the photon energy range of 662, 1173, 1332 keV were theoretically compared with the XCOM software program. In addition, mfp, HVL, and linear attenuation coefficients were calculated using mass attenuation values.

In the study, it was observed that the MoO_2 contribution to PbO reduces the mass absorption feature. It was observed that the absorption property is especially high for PbO at low energy. Also, PbO due to its high density, it can be thought that its radiation attenuation feature is high. Therefore, the addition of MoO_2 with a density of 6.47 g/cm^3 decreased the absorption property. Similarly, MoO_2 decreases from 0,08 cm^2/g to 0.05 cm^2/g. All values are given in Figures 1 and 2. While the mass absorption value of the created composite was 0,11 cm^2/g in the XCOM program, it was calculated as 6.39 cm^2/g with GATE simulation. At the same time, the values decrease to 0.05 cm^2/g with the increase of energy. In Figures 4, 5 and 6 the half-value thickness values were calculated in both programs. It is observed that the values increase with the increase of energy. The highest value belongs to PbO at 1332 keV. The relationship between the linear attenuation coefficients is given in Figure 5, 6 and 7. In the binary mixture obtained in the linear absorption coefficient, it is seen that the value decreases as the energy value increases. The mfp value, which was found from the inverse of the linear attenuation coefficient according to the multiplication, is given in Figure 8, 9 and 10 increases with the increase in energy.

IV. CONCLUSION

With the study, it is seen that the use of oxide will be appropriate in order to reduce the toxic and mass effect of PbO. With the 50% contribution, it is seen that the radiation absorption feature is close to the pure PbO value at high energies.

V.RESULT

As a result of the study, it was observed that the radiation absorption property did not significantly decrease with the added of MoO_2 to PbO. However, it should not be ignored that the toxic effect of PbO will decrease thanks to this additive. In addition, it was seen that the results of both theoretical programs were compatible with each other.

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