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Determination of Attenuation Properties for gamma rays of some Commercial Materials used Radiation Shielding

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الملخص

في هذه الدراسة تم تعيين بعض الخواص النووية لبعض سبائك المواد التجارية (Pb ،Cu ،Fe ،Al)، الألومنيوم و الحديد و النحاس والرصاص المستخدمة كدروع نووية في الوقاية من الإشعاع (أشعة جاما) , حيث تم الحصول عليها من السوق الليبي من خلال إعادة تدوير المخلفات المعدنية وصهرها بواسطة فرن وصبها في قوالب اسطوانية الشكل وتللك العملية تمت في إحدى الورش في مدينة ليبية . ومن ثم تم تشعيع العينات بواسطة مصادر مختلفة الطاقات لأشعة جاما لمدة ساعتين، حيث أشعة جاما لها طول موجي قصير وطاقة عالية وكثافة عالية وتتفاعل أشعة جاما مع المادة بعدة طرق. يجب أن تؤخذ ثلاث تفاعلات فقط في نظر الاعتبار في مسائل الإشعاع النووي. هذه التفاعلات هي التأثيرات الكهروضوئية، وإنتاج الأزواج، وتأثير كومبتون. اشتملت الدراسة على بعض الخصائص النووية مثل معامل التوهين الخطي الكلي (μ) ، سمك نصف القيمة ($X_{1/2}$) ، معامل التوهين الكتلي الكلي (μ /ρ) ، المقطع العرضي الكلي (σ_t) ، متوسط المسار الحر (λ) وكثافة الاصطدام الكلية (F) عند طاقات مختلفة لأشعة جاما γ-ray تبلغ 0.511 ، 0.662 ، 1.17 ، 1.274 ، 1.33 ميغا إلكترون فولت. تم استخدام ثلاثة مصادر مشعة في هذه الدراسة. هي نظير الكوبالت ^{60}Co مع طاقتين 1.17 و 1.33 MeV، نظير الصوديوم ^{22}Na مع طاقتين 0.511 و 1.274 MeV ، وكذلك نظير السيزيوم ^{137}C بطاقة 0.662 MeV. ووجد أن الرصاص التجاري له خصائص نووية مثلى بالمقارنة مع السبائك التجارية (النحاس والحديد والألمنيوم) , كما هو معلوم لدينا ولكن بسبب أن نقطة انصهار الرصاص منخفضة تمت دراسة باقي السبائك لأن نقطة انصهارها أعلى فيمكن استخدامها أيضا كدروع وقاية من الاشعاع في جدران الغرف والأسطح التي قد تتعرض لدرجات حرارة عالية, وبالمقارنة مع الرصاص وجد أن النحاس أفضل من الحديد والألومنيوم من حيث الخواص النووية.

Abstract

In this study, some nuclear characteristics of some commercial material alloys were identified. (Al, Fe, Cu, Pb), aluminum, iron, copper and lead used as nuclear shields in radiation protection. It was obtained from the Libyan market through the recycling and smelting of metal waste in a furnace and pouring it into cylindrical forms. The samples were then irradiated by various sources of gamma ray energies for two hours, where the rays had short wavelengths, high energy, high density and gamma rays interacting with the material in several ways. Only three interactions should be taken into account when considering nuclear radiation issues. These interactions are photoelectric effects, pair production and

Compton effect. The study covered some nuclear characteristics, such as total linear attenuation coefficient(μ), half value thickness ($X_{1/2}$), total mass attenuation coefficient(μ/ρ), total cross section (σ_t), mean free path (λ) and the total collision density (F) at different energies for γ-ray energies of (0.511, 0.662, 1.17, 1.274, 1.33) MeV. Three radioactive sources were used in this study. They are Cobalt Isotope Co 60 with 1.17 and 1.33 MeV and Sodium Isotope 22 Na with 0.511 and 1.274 MeV plus Cesium Isotope C137 with 0.662 MeV. It was found that commercial lead has optimum nuclear properties compared to commercial alloys (copper, iron and aluminum) as we know, but because the melting point of lead is low, the rest of the alloys have been studied because their melting point is higher, so they can also be used as radiation protection shields in the walls of rooms and surfaces that may be exposed For high temperatures, compared to lead, it was found that copper is better than iron and aluminum in terms of nuclear properties

Keywords: nuclear properties, attenuation coefficient, mean free path, collision density, Gamma rays.

1.Introduction

Ionizing radiation has become very important in our routine lives, especially in medical applications. This radiation interacts with matter in two ways, by ionization and by excitation. Studies on the interaction of gamma rays with shielding materials have been the subject of interest over the past several decades in the field of radiation protection [1].

Appropriate shielding materials play a very important role for safer use of highly penetrating gamma rays photons. Radiation-shielding materials are examined for their shielding properties by defining the linear attenuation coefficient as the probability of radiation interaction with the material in a unit path length [4], [5].

The degree to which gamma ray radiation is attenuated depends on the energy of the incident gamma rays radiation, the atomic number and density of elements in the shielding material, and the thickness of the shielding material. Usually, the protection design of radiation facilities, protective equipment and clothing is mainly based materials. [6], [7].

The created beam from the removal of the interacting photons will experience attenuation. This occurs by its intensity and energy attenuation. As intensity decreases with the length of the path [8].

It is important to measure the radioactive attenuation properties of any protective material and to demonstrate that the radiation protection effectiveness complies with the requirements set forth in international and national standards [15] -[17].

Many materials used in construction have been studied by many scientists in terms of protective properties from gamma rays [9] -[14].

2. Material and Methods

Commercial aluminum, iron, copper and lead were obtained from the available Libyan market by recycling and melting metal waste in a furnace and casting it into cylindrical

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forms. Atomic number, atomic weight, melting point, and specific gravity of commercial alloys aluminum, iron, copper, and lead [3]. As shown in Table 1.

Table1: The atomic number, atomic weight and the specific gravity for Commercial alloys Aluminum, Iron, Copper and Lead

Commercial alloy	Atomic number	Atomic weight	Melting point in Celsius scale (^{0}C)	Specific gravity(20^{0}C)
Aluminum	13	26.982	660	2.752
Iron	26	55.845	1204	7.85
Copper	29	63.546	1084	8.96
lead	82	207.2	328	11.35

The samples were then irradiated by various sources of gamma rays energies for two hours. The sources of γ-rays used in this study are Cs-137, Co-60 and Na-22, where their half-life are 30.04, 5.2714, and 2.6 years respectively. The γ-ray energies emitted from used sources are: 0.662 MeV, (1.17 MeV and 1.33 MeV), and (0.511 MeV and 1.274 MeV) respectively. Attenuation relations were used to derive the total linear attenuation coefficient (μ), for the investigated materials, in addition to mass attenuation coefficient (μ/ρ) In addition to this the half value thickness($X_{1/2}$), the total cross section (σ_t), mean free path (λ) and the total collision density(F) were calculated using the gamma spectrometer system, which contains a sodium Iodide (NaI) detector to detect the radiation. All the measurements were carried out at the nuclear laboratory at Omar Al-Mukhtar University in El Beida, Libya.

The absorption studies of γ-rays were made through measurements of its transitions through the alloys samples under investigation. the arrangement for measuring transmitted intensities of the beam which reaches the detector was according to Beer-Lambert's rule[2]. Where narrow beam linear attenuation coefficient (μ) in units cm^{-1}, can be described by the following relation:

$$I = I_0 \, e^{-\mu x}$$

$$Or \qquad \mu = \frac{\ln (I_0 / I)}{x} \qquad (1)$$

Where: I_0 = photon intensity through shield material.

I= transmitted intensity

X= thickness of sample in (cm).

The total mass attenuation coefficient (μ/ρ) in units $cm^2.gm^{-1}$, can be commuted by dividing the total linear attenuation coefficient by the density for these samples. and the half value thickness**[2]**, Was obtained from the relation:

$$X_{\frac{1}{2}} = \frac{lin2}{\mu} \cong \frac{0.693}{\mu} \quad (2)$$

where $X_{\frac{1}{2}}$ is the half value thickness.

The total cross section (σ_t) is equal:

$$\sigma_t = \sigma_{pe} + \sigma_{pp} + \sigma_c \quad (3)$$

where σ_{pe} is the photoelectric cross section which depends strongly on Z, varying as $\sigma_{pe} \sim Z^n$, n is a function of E.

σ_{pp} is the cross section for pair production increases steadily with increasing energy E.

The Compton cross section per atom**,** σ_c , is equal to the number of electrons in the atom, namely Z, multiplied by the Compton cross section per electron ${}_e\sigma_c$. Thus $\sigma_c = Z\ {}_e\sigma_c$,

We can calculate the total cross section (σ_t) from the relation:

$$\sigma_t = \frac{\mu}{N} \quad (4)$$

Where *N* is the atom density and is given by the formula:

$$N = \frac{\rho N_A}{M} \quad (5)$$

Where N_A is Avogadro's number , *M* is the gram atomic weight and ρ is the density.

The mean free path (λ) of the γ-rays can be calculated by the relation:

$$\lambda = \frac{1}{\mu} \quad (6)$$

Where μ is equal to the probability per unit path that a γ-rays will have a collision in a medium, and the total collision density (F) at a point where the γ-rays intensity is I, and is given by:

$$F = I\mu \quad (7)$$

Where μ is the total liner attenuation coefficient **[2].**

3. Results and Discussions:

The total liner attenuation coefficient (μ):

The total liner attenuation coefficient μ measured for commercial (aluminum, iron, copper and lead), are shown in figure (1) which displays the effect of γ-rays energies on the total linear attenuation coefficient (μ) is found that (μ) decreases with increasing the γ-rays energies, and the total linear attenuation coefficient (μ) for commercial lead seems to be high compared with commercial aluminum, Iron and copper at all different energies. However, the commercial lead (μ) has the highest value. while commercial copper higher from iron and aluminum.

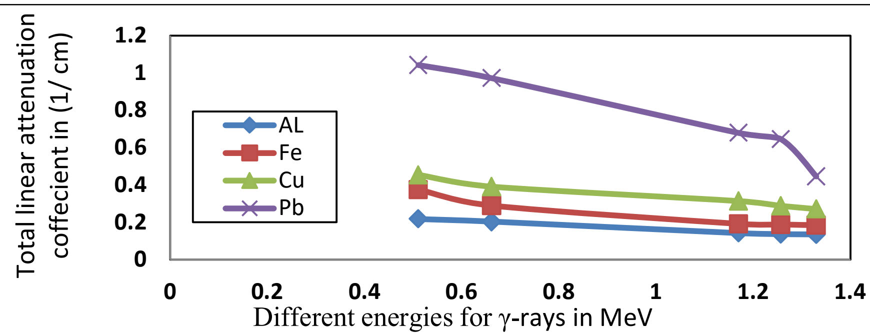

Fig.1: Effect of γ-rays energies in MeV on total Linear attenuation cofficient (μ) for commerical alloys AL, Fe, Cu, Pb

The half value thickness ($X_{1/2}$):

The half value thickness $X_{1/2}$ for all commercial alloys (Al, Fe, Cu, Pb) is shown in figure(2) which shows the effect of γ-rays energies in MeV (0.511, 0.662, 1.17, 1.274, and 1.33), on the half value thickness ($X_{1/2}$). From this figure it is seen that the half value thickness increases with increasing the γ-rays energies. It is also seen that the magnitude of $X_{1/2}$ decreases with increasing the atomic number for these samples.

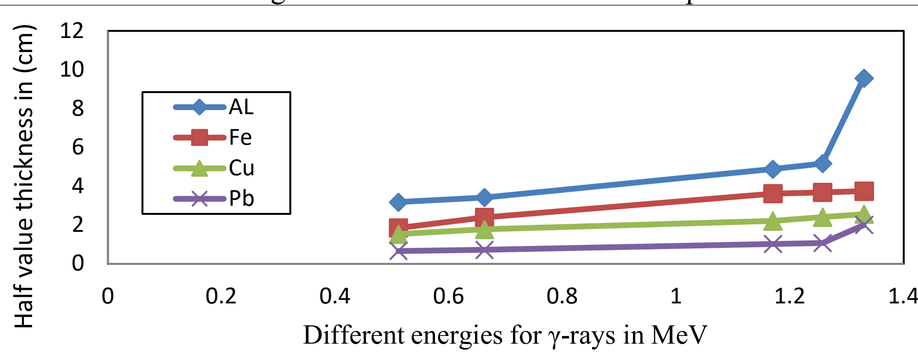

Fig.2: Effect of γ-rays energies in MeV on half value thicknes $X_{1/2}$ in for commercial Al, Fe, Cu, Pb

The total mass attenuation coefficient (μ/ρ):

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The total mass attenuation coefficient (μ/ρ) for all commercial alloys (Al, Fe, Cu, Pb) is given in figure (3), which represents the effect of γ-rays energies on total mass attenuation coefficient (μ/ρ) in (cm^2/gm). From this figure it is seen that the total mass attenuation coefficient (μ/ρ) decreases with increasing the γ-rays energies.

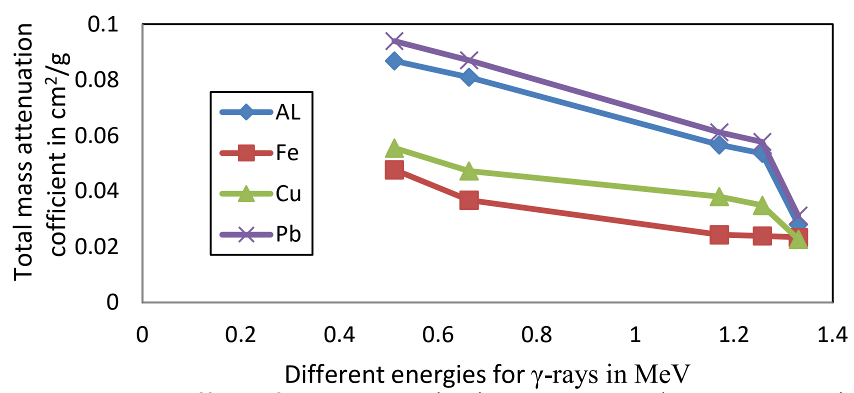

Fig.3: Effect of γ-rays energies in MeV on total mass attenuation coeffecient μ/ρ of commercial Al, Fe, Cu, Pb

The total cross section (σ_t):

The total cross section (σ_t) for all commercial alloys (Al, Fe, Cu, Pb) is shown in figure (4), which represents the effect of γ-rays energies on the total cross section (σ_t). From this figure, it is found that there is an inverse relation between the γ-ray energies and the total cross section. For energy ranges between 0.5 MeV to 1 MeV, the dominant interaction is the Compton scattering. Thus for energies 0.511 MeV and 0.662 MeV, the main interaction in Compton scattering. For energies 1.17 MeV, 1.274 MeV, and 1.33 MeV, the main interaction is pair production. For defined energy, it is also found that the total cross section (σ_t) increases with increasing the atomic number. However, at commercial lead is high compared with commercial aluminum, commercial iron and commercial copper at all different energies.

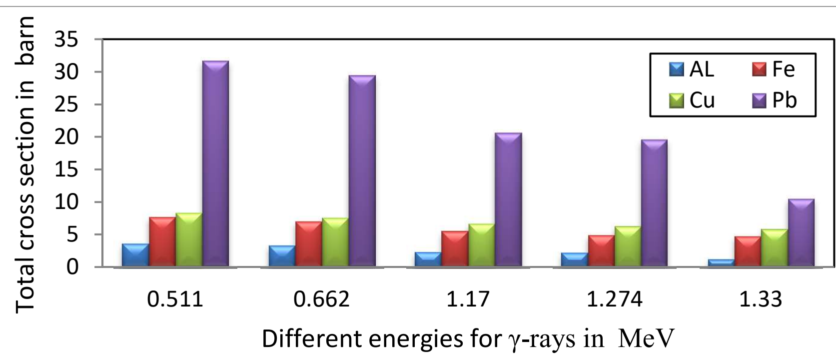

Fig.4: Effect of different energies for γ-rays on total crossection

The mean free path (λ) and the total collision density(F):

The mean free path (λ) and the total collision density(F) for all commercial alloys (Al, Fe, Cu, Pb) are shown in figure (5) and (6), respectively.

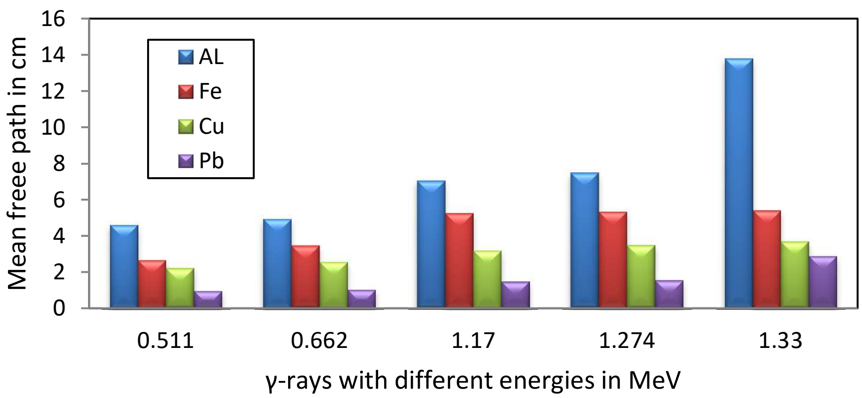

Fig.5: Effect different energies for γ-rays on mean free pathin cm

Figure(5) shows the effect of γ-rays energies in MeV (0.511, 0.662, 1.17, 1.274, and 1.33) on the mean free path (λ) for commercial aluminium, commercial copper and commercial lead. From this figure it is seen that the mean free path (λ) increases with increasing the γ-rays energies. It is also seen that the mean free path (λ) increases with decreasing the atomic number for alloy samples.

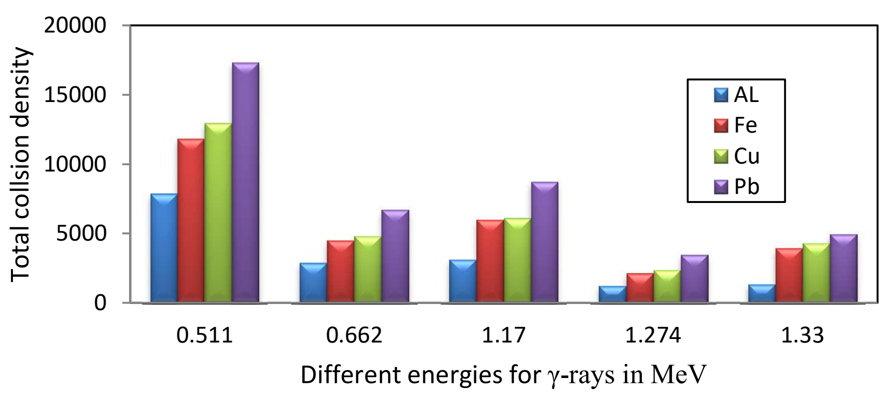

Fig.6: Effect different energis for γ-rays in MeV on total collision density

Figure(6) shows the effect of γ-rays energies in MeV (0.511, 0.662, 1.17, 1.274, and 1.33) on the total collision density(F) for commercial aluminum, commercial iron, commercial copper and commercial lead. From this figure it is seen that the total collision density(F) decreases with increasing the γ-rays energies. It is also found that the total collision density(F) decreases with decreasing the atomic number for alloy samples.

Conclusion

In this study the density of commercial aluminum, iron, copper and commercial lead were measured and found to 2.756, 8.255, 8.6 and 11.098 gm /cm^3, respectively. The values of measured total linear attenuation coefficient for γ-rays energies (0.511, 0.662, 1.17, 1.274, and 1.33) in MeV were higher for commercial lead than in case of commercial Iron, commercial copper and commercial aluminum alloys while commercial copper was higher from aluminum and iron. The values of measured half value thickness $X_{1/2}$ in cm for commercial lead, commercial copper and commercial Iron alloys are lower than in case of commercial Aluminum. The values of measured $X_{1/2}$ increase with increasing the γ-rays energies in MeV for all samples under investigations. The values of both measured and calculated total γ-rays mass attenuation coefficient are higher for commercial lead than in case of commercial copper, commercial iron and commercial aluminum alloys. Experimentally, it was found that the total linear attenuation coefficient commercial lead alloy is higher than commercial copper, Iron and aluminum alloys, while commercial copper is higher than commercial iron and aluminum alloys. It is also found that the total cross section (σ_t) increases with increasing the atomic number. However, for commercial lead it is high compared with commercial aluminum, commercial iron and commercial copper at all different energies. The mean free path (λ) increases with increasing the γ-rays energies. In addition the mean free path (λ) increases with decreasing the atomic number for commercial alloy (AL, Fe, Pb, Cu). The total collision density (F) decreases with increasing the γ-rays energies and addition the total collision density (F) decrease with decreasing the atomic number for commercial alloy (AL, Fe, Pb, Cu) . The effective atomic number and electron density for commercial alloy (AL, Fe, Pb, Cu), of materials and for all photon energies greater than 500 KeV on some nuclear properties. The commercial lead alloy has the optimum nuclear properties in comparison with the commercial iron, commercial copper and commercial aluminum. While commercial Copper has better nuclear properties than commercial iron and commercial aluminum.

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