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Research Article

Beton-PbO-WO_3 Bileşiği için İyonlaştırıcı Radyasyon Etkileşim Parametrelerinden Kütle Durdurma Gücü ve Durdurma Mesafesinin 0.015-20 MeV Enerji Aralığında Hesaplanması

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Öz

Bu çalışmada, nükleer santraller, endüstri, tıp ve tarım uygulamaları gibi çeşitli alanlarda iyonize edici radyasyon zırhlamasında kullanılan, PbO ve WO_3 içerikli beton bileşiklerinin gamma radyasyon koruyucu etkisi araştırılmıştır. Nükleer yapı analizleri için malzemelerin gamma radyasyon koruyuculuğu tespit edilirken, kütle zayıflatma katsayısı (μ/ρ) değeri hesaplanır. Bu çalışmada, 0.015-10 MeV geniş foton enerji bölgesi için WinXCom yazılımı kullanılarak elde edilen kütle zayıflatma katsayıları, ortalama serbest yol (MFP), yarı değer tabakası (HVL), onuncu değer tabakası (TVL), ve tesir kesiti ∑R değerlerinin hesaplamaları için kullanılmıştır. Bununla beraber, beton-PbO-WO_3 bileşiğinin kütle durdurma gücü (MSP) ve durdurma mesafe (PR) değerleri, SRIM kodu kullanılarak H^1 ve He^{+2} parçacıkları için hesaplanmıştır. SRIM kodu gelen radyasyonun etkileşimine bakarak malzemeyi geçip gitme oranın bir fonksiyonu olarak hesaplama yapan bir yazılım programıdır. MSP hesaplamalarının temelinde, Coulomb etkileşimi yoluyla hedef elektronların iyonlaştırması ve uyarılmalarından dolayı hedef atomların yavaşlaması vardır. Bu çalışmada sunulan sonuçlara bakıldığında, kullanılan 9 farklı bileşik içinde %100 PbO numunesinin gama radyasyonuna karşı en iyi zırhlama yeteneğine sahip malzeme olduğu gösterilmiştir. Ayrıca, %100 PbO içeren malzemenin soğurulan radyasyon miktarındaki azalmaya bakılarak zırhlama malzemesi olarak kullanılmasının uygunluğu yapılan diğer çalışmaları da destekler nitelikte olduğu gösterilmiştir. Ayrıca MSP değerinin yüksek enerji bölgesinde, malzemelerin kimyasal içeriklerine bağlı olarak etkileşimin proton ve alfa parçacıkları için de neredeyse sabit olarak değiştiği görülmüştür. PR değerleri ise, parçacığın durmak için girdiği alandan absorbe olduğu nokta arasındaki mesafenin bir fonksiyonu olarak değiştiği görülmüştür.

Anahtar Kelimeler: Beton-PbO-WO_3, SRIM, MSP, PR.

Ionizing Radiation Interaction Parameters Calculation of Mass Stopping Power and Projected Range for the Concrete-PbO-WO_3 compound in the energy range 0.015-10 MeV

Abstract

In this study, gamma radiation protective effect of PbO and WO3 containing concrete compounds used in ionizing radiation shielding in various fields such as nuclear power plants, industry, medicine and agriculture applications was investigated. For nuclear structure analysis, while determining the gamma radiation protection of materials, the mass attenuation coefficient (μ/ρ) value is calculated. In this study, the mass attenuation coefficient (μ/ρ) obtained by using WinXCom software for 0.015-10 MeV wide photon energy zone; mean free path (MFP), half value layer (HVL), tenth value layer (TVL) and removal cross-section ∑R were used for calculations. However, the mass stopping power (MSP) and stopping distance (PR) values of the concrete-PbO-WO_3 compound were calculated

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for H^1 and He^{+2} particles using the SRIM code. SRIM code is a software program that calculates the interaction of incoming radiation as a function of the ratio of the incoming particle passing through the matter. The basis of MSP calculations is the slowing of target atoms due to ionization and excitation of target electrons through Coulomb interaction. Looking at the results presented in this study, it has been shown that 100% PbO sample is the best shielding material against gamma radiation in 9 different compounds used. Moreover, it has been observed that the suitability of using the material containing 100% PbO as an armoring material by looking at the reduction in the amount of absorbed radiation has also been supported by other studies. It was also observed that the interaction of MSP value in the high energy region varies almost constantly for proton and alpha particles depending on the chemical contents of the materials. PR values, on the other hand, have been observed to change as a function of the distance between the particle absorbed from the area it enters to stop.

Keywords: Concrete-PbO-WO_3, SRIM, MSP, PR.

1. Introduction

By the increasing use of ionizing radiation (gamma and x-rays) in nuclear power plants, industry, medicine and agriculture, the examination of the mass attenuation coefficients (μ / ρ) of various materials has become increasingly important (Hubbell 1982, Akkurt et al. 2010). Ionizing radiation sources have a wide range of applications in nanotechnology, biotechnology, semiconductor technology, medical applications, photochemistry, biology and geology (Jalali and Mohammadi 2008; McCuen 2012). The main purpose of radiation protection is to protect the employees by ensuring that they receive the lowest radiation dose possible to radiation workers and to ensure the use of protective materials that do not exceed the maximum radiation dose limits that can be taken in environmental applications. Therefore, the higher the density and the atomic number of the material which will be used for radiation shielding, it will be the higher the probability of radiation protection (Sharaf and Hamideen 2013). Depending on today's technological developments, there is an increase in the rates of usage of gamma and X-rays in these areas (Eke et al. 2017). The destructive and biological effects of ionizing radiation are known well (Jalali and Mohammadi 2008).

The use of new generation materials for radiation protection and the development of new radiation shielding materials have become a great need because of that the harmful effects of ionizing radiation (Jagetia 2007; Karabul et al. 2015; Çağlar et al. 2019). When performing radiation shielding calculations, simple photon-matter interaction mechanisms such as compton scattering, photoelectric effect, and dual formation must be well defined (Sayyed and Lakshminarayana 2018). In radiation shielding studies, mass attenuation coefficients (μ/ρ) are examined as a measure of the interaction of a photon with the substance (Kumar 2017;Abbasova et al. 2019)

It has been examined in various studies that PbO and WO_3 doped materials have high radiation shielding properties, and in these studies, it has been observed that PbO and WO_3 doped materials also have a potential application area (Tekin et al. 2017; Dong et al. 2017). In addition, PbO and WO_3 doped materials have been shown to have intelligent applications due to their unique chemical and physical properties. These PbO and WO_3 doped materials are stated to have the following properties. Significant differences were observed in density and mass attenuation coefficient when replacing the lead (PbO) component with WO_3. Lead is known as the subject of most studies due to its good radiation shielding material. For this study, materials with different radiation transport were produced using different ratios of lead composition (Tekin et al. 2017). Today, it is thought that matters for example concrete and Pb are used for radiation protection in nuclear power plants and both are a better alternative to concrete materials which can be recommended for required radiation protection (Akyildirim 2019). Since PbO and WO_3 doped materials absorb high energy radiation and are transparent to visible light, they are an alternative matrix compared to conventional matters (Mesbahi and Ghiasi 2018; Akkurt et al. 2010).

In this study, gamma radiation shielding properties of different ratios of PbO and WO_3 are added to concrete for photon and neutron interactions of X- and gamma rays at high energies. As a result of the researches conducted in this article, it can be concluded that this research shows that the PbO and WO_3s added to the concrete and helps to realize the effect on the radiation shield properties. The main purpose of this study is to examine the radiation shielding parameters for %100 Concrete, %75 Concrete+%25 PbO, %50 Concrete+%50 PbO, %25 Concrete+%75 PbO, %100 PbO, %75 Concrete+%25 WO_3, %50 Concrete+%50 WO_3, %25Concrete+%75 WO_3, %100 WO_3 by using μ/ρ, HVL, TVL, MFP, ∑R, MSP and PR values.

2. Material and Method

2.1. WinXCoM Calculation

In the study conducted by Hubbell and Seltzer, the mass attenuation coefficient values which are theoretically calculated (Hubbell 1982). An alternative method suitable for manual calculations shows the need for the attenuation data required to calculate by the computer. Taking this into consideration, Berger and Hubbell (Trubey, D. K. Berger 2008) developed a computer program called XCOM to calculate the attenuation coefficients and cross-sections for any element, mixture or compound in the 1 keV-100 GeV energy region. Since then a number of updates have been made to this program, and a web version is now available. Recently, widely used abd well known program (Gerward et al.; Trubey, D. K. Berger 2008). Windows infrastructure and Windows version are called WinXCom (Hubbell 1982).

In this study, the tables in the above-mentioned research were used for calculations. Concrete samples have been identified considering material properties such as elementary mass fractions and densities. Firstly, an ordinary concrete sample is modeled, considering the basic mass fraction and density properties (Dong et al. 2017).The next study was used to compare the results with the standard WinXCoM data (Trubey, D. K. Berger 2008). To verify the modeled geometry, the obtained results were compared with the standard WinXCoM data for the pure concrete sample. The mass attenuation coefficients calculated by MCNPX were found to be in good agreement with the WinXCoM results. Definitions of concrete samples, basic mass fractions and densities of materials are given in Table 1 (Tekin et al. 2017).

Table 1. Density and chemical properties of the concrete-PbO-WO$_3$ compound

Element	**%100 Concrete**	**%75Concr+ %25PbO**	**%50Concr+ %50PbO**	**%25Concr+ %75PbO**	**%100 PbO**	**%75 Concr+ %25 WO$_3$**	**%50 Concr+ %50 WO$_3$**	**%25 Concr+ %75 WO$_3$**	**%100 WO$_3$**
Density (ρ,g/cm^3)	2,26	4,0775	5,895	7,7125	9,53	3,2702	4,71	5,935	7,16
O	0,492	0,38692	0,28184	0,17676	0,07168	0,42076	0,34951	0,27827	0,20702
Na	0,005	0,00375	0,0025	0,00125	0	0,00375	0,0025	0,00125	0
Mg	0,003	0,00225	0,0015	0,00075	0	0,00225	0,0015	0,00075	0
Al	0,037	0,02775	0,0185	0,00925	0	0,02775	0,0185	0,00925	0
Si	0,37	0,2775	0,185	0,0925	0	0,2775	0,185	0,0925	0
Ca	0,082	0,0615	0,041	0,0205	0	0,0615	0,041	0,0205	0
Fe	0,011	0,00825	0,0055	0,00275	0	0,00825	0,0055	0,00275	0
Pb	0	0,23208	0,46416	0,69624	0,92832	0	0	0	0
W	0	0	0	0	0	0,19824	0,39649	0,59473	0,79298

2.2. Calculation Method of Shielding Parameters

Calculation of the MAC (μ/ρ) value is very important parameter to express the X-rays and gamma radiation retention of the material of radiation passing through a material. MAC (μ/ρ) value computed according to the Beer-Lambert law (Gerward et al. 2001; Yilmaz et al. 2011).

$$I = I_0 e^{-\mu x} = I_0 e^{-\mu_m t} \qquad (1)$$

$$\mu_m = \left(\frac{\mu}{\rho}\right) = \frac{ln(I_0/I)}{\rho t} \qquad (2)$$

where I and I_0 indicates the attenuated and incident photons and x is showed the mass thickness of the material (great important for shielding calculation). Also, μ (cm^{-1}) and μ_m (cm^{2}g^{-1}) represent, and t (gcm^{-2}) respectively. However, the density of the material is shown with ρ (gcm^{-3}).

$$\mu_m = \left(\frac{\mu}{\rho}\right) = \sum_i w_i (\mu/\rho)_i \qquad (3)$$

In the compound or a mixture, wi is given with this expression $w_i = n_i A_i / \sum_i n_i A_i$. In the equation, Ai is the atomic weight of the ith element, and ni is the number of atoms of ith constituent element. WinXCoM programme has been used for calculation of the MAC (μ/ρ) value (Gerward et al. 2001; Yilmaz et al. 2011). This value is created a major interest in the establishment of different nuclear models for X-ray and gamma photons (Singh et al. 2015).

HVL value is expressing the interaction of a material with gamma photon. It shows the halved thickness value in which the amount of radiation coming into the material (Kumar 2017). The HVL value proves how effective it is in gamma ray shielding. HVL (cm) values can be calculated following equation:

$$HVL = (\ln 2 / \mu) \qquad (4)$$

On the other hand, the TVL value refers to the thickness of the substance in which the intensity of the incoming radiation decreases by one tenth. TVL (cm) values can be calculated following equation:

$$TVL = (\ln 10 / \mu) \qquad (5)$$

MFP values represents the distance traveled by a moving photon between collisions in a material. The MFP value, is used quite often when examining radiation interaction, the other parameters. MFP (cm) values can be calculated following equation (Kamislioglu, Altunsoy Guclu, and Tekin 2020):

$$MFP = (1 / \mu) \qquad (6)$$

Fast neutron removal cross-section ΣR (cm^{-1}) is an indication of the possibility of interaction of neutrons and target material atoms. As the cross-section probability increases, the number of particles in the beam decreases accordingly as the number of interactions per unit time increases (El-Khayatt 2010). Beer-Lambert equation is utilized to compute the passage of fast neutrons (ΣR) in various thickness. ΣR (cm^{-1}) values can be calculated following equation for composition or homogeneous compound (El-Khayatt 2010):

$$\sum R = \sum W_i \left(\sum R/\rho\right)_i \tag{7}$$

where wi (g/cm^3) is the weight percentages and ΣR/ρ (cm^2/g) is the mass removal cross-section of the ith element.

The SRIM (Stopping and Range of Ions in Matter) code is the software package that calculates the stopping and range of ions, and it was developed by Ziegler and Biersack (Ziegler, Ziegler, and Biersack 2010). SRIM is a Monte Carlo simulation method and is known as a very powerful and very famous program in the relationship of radiation effects. SRIM tables for stopping power are a very friendly program that calculates the transport energy of the particle over a wide energy range. In fact, the SRIM code gives the amount of damage per unit with the help of neutron radiation damage. The effect of radiation on a particular substance, varies with amount of exposure absorption dose and energy. This radiation effect depends on the intensity of the energy, so we express it with the stopping power the energy lost while the charged particles pass through a material (Ziegler 2004).

Typical energies of beta particles released from radioactive sources are in the range of 1-10 MeV. As the energy decreases, the wavelength increases. As the atomic number increases, the coefficient of mass reduction at the specific wavelength increases with increasing Z because the stopping power increases (Ziegler et al. 2010). MSP (MeVcm^2 / g) value computed according to the Bethe-Bloch equality is given by the following equation:

$$-\frac{dE}{dx} = \frac{4\pi k_0^2 Z^2 e^4 n}{mc^2 \beta^2}\left[\ln \frac{2mc^2\beta^2}{I\left(1-\beta^2\right)} - \beta^2\right] \tag{8}$$

in this equation, we can say that the expression of the MSP depends on the mass (m), charge (e) and velocity (β) of the ion, the atomic number (Z) and density of the material (ρ) (Ziegler et al. 2010).

Understanding the losing energy of charged particles is very important in medical, medical and radiation applications. The energy loss rate of a charged particle is given by MSP and is obtained by dividing the linear stopping power by the density of the material. MSP (-dE / dx) is a function that expresses the reduction of the kinetic energy of the ionizing particle passing through a material. MSP (MeVcm^2 / g) value can be calculated using the SRIM code (Tekin, Altunsoy, et al. 2019). Thus, how effective the protective material can be explained.

The PR value of a charged particle is determined by its travel before resting. Also, the PR refer to the range is defined in g (cm^{-2}). The PR rates calculates are used to understand how charged particles are carried (Kuzmin 2006; Tekin, Issa, et al. 2019). PR value is computed following equality for proton and alpha (Tekin, Altunsoy, et al. 2019).

$$R(\beta) = \left(M/Z^2\right) R_p(\beta) \tag{9}$$

In this study, MSP and PR values for both H^1 and He^{+2} particles have been calculated using SRIM software program for %100 concrete, %75 concrete+%25 PbO, %50 concrete+%50 PbO, %25 concrete+%75 PbO, %100 PbO, %75 concrete+%25 WO$_3$, %50 concrete+%50 WO$_3$, %25 concrete+%75 WO$_3$, %100 WO$_3$ for between 0.010 and 10 MeV energies. As a result of studies, MSP and PR are indicating as a highly important parameter for identicate radiation shielding.

3. Results and Discussion

In this study, some nuclear radiation shielding parameters which are mass attenuation coefficient (MAC) μ/ρ values, HVL, TVL, MFP and ΣR values were calculated by using WinXCom software for the photon energy range 0.01 MeV to 20 MeV. The MAC (μ/ρ) values are presented Fig. 1. As seen in Fig.1., all (MAC) μ/ρ values which obtained in the energy range of 0.1 MeV to 20 MeV decrease with to the increase of photon energy. The reason for this can be commented as (MAC) μ/ρ values vary depending on photoelectric absorption, Compton scattering and pair production for a material. Actually, it is seen that the (MAC) μ/ρ values of the elements in the component changes according to the photon energy and atomic numbers (Jaeger, 1965; Chilton et al., 1984). Thus, the width of the region where an interaction predominate varies with the material type. At low energies where the photoelectric effect is dominat, the formation of photoelectiric effect varies in proportional to $Z^{4,5}$ and $1/E^3$ (Hubbell 1982; Akyildirim 2018). The (MAC) μ/ρ values is changed slightly due to Compton scattering becomes dominant interaction mechanism for the energy region from 100 keV to 10 MeV. The reason of this, it is caused by the interaction cross section changing with Z and 1/E (Trubey, D. K. Berger 2008). Especially in the region of 0.05-6 MeV, the mass attenuation coefficients of all concretes are very close to each other. Therefore, sharp decreases are observed in the (MAC) μ/ρ values of material in this investigation (Fig. 1.). From the Fig. 1. indicates that of the (MAC) μ/ρ values highest and lowest are %100 PbO and %100 concrete in this energy region, respectively.

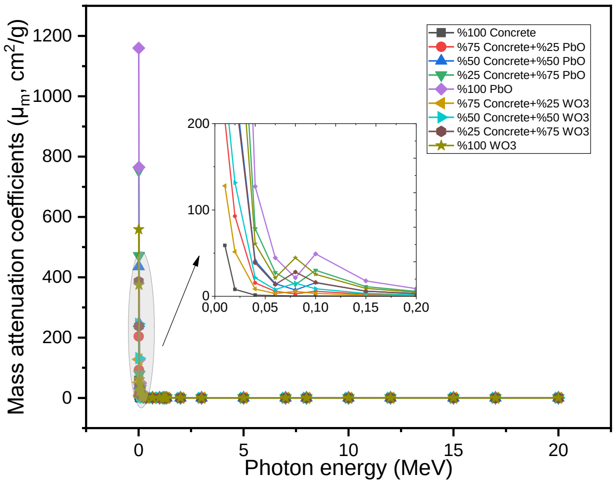

Figure 1. The MAC (μ/ρ) change graph of concrete-PbO-WO_3 compound according to the given photon energy

HVL and TVL values are the radiation shielding parameters that reduce the intensity of the radiation beam to half and tenth of its original value in a material, respectively, and they are frequently used with MFP value in radiation shielding calculations. In Fig. 2. it is given the graph of change of HVL values between 0.01 MeV and 20 MeV according to photon energy. In Fig. 3. it is given the graph of change of TVL values between 0.01 MeV and 20 MeV according to photon energy. Also, in Fig. 4. it is given a graph of change of MFP values between 0.01 MeV and 20 MeV according to photon energy. Looking at Fig. 2, Fig. 3. And Fig. 4. respectively; the HVL, TVL, and MFP values have been increased, at the same time the photon energy is increased. The HVL, TVL, and MFP values start to increase energy by taking the highest values around 5 MeV. This fact indicates that different interactions exist in different energy regions, for the HVL, TVL, and MFP values. In this study, the HVL, TVL and MFP values have been calculated for some material (%100 Concrete, %75 Concrete+%25 PbO, %50 Concrete+%50 PbO, %25 Concrete+%75 PbO, %100 PbO, %75 Concrete+%25 WO_3, %50 Concrete+%50 WO_3, %25Concrete+%75 WO_3, %100 WO_3). The value of lead and lead alloys was found to be lower than the concrete and the concrete alloys because it has a high density and atomic number. When we look at the results, it is clear that 0 PbO has the best radiation shielding properties compared to other materials. For the given energy region, %100 PbO concrete seems to be the best %100 Concrete least effective material.

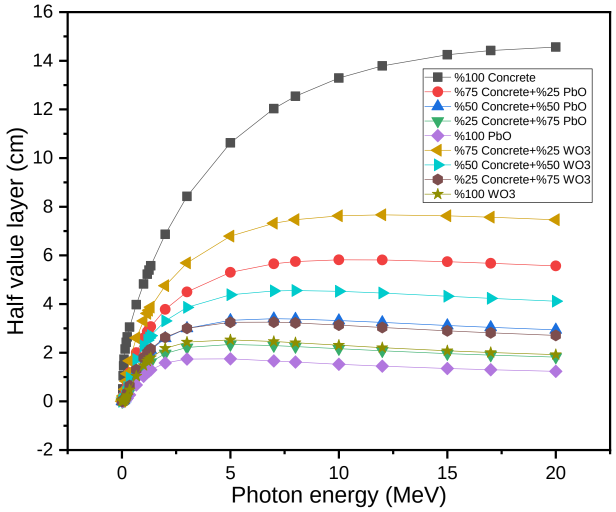

Figure 2. The HVL change graph of concrete-PbO-WO_3 compound according to the given photon energy

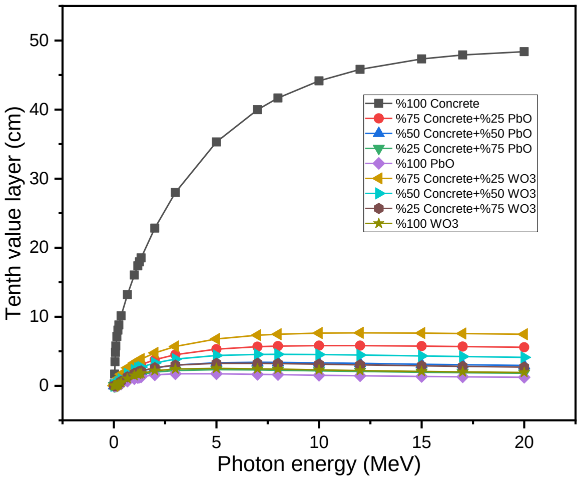

Figure 3. The TVL change graph of concrete-PbO-WO_3 compound according to the given photon energy

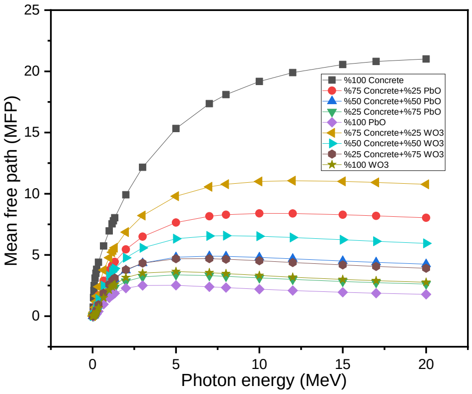

Figure 4. The MFP change graph of concrete-PbO-WO_3 compound according to the given photon energy

The neutron effective removal cross-section ∑R refers to the possibility of the neutron particle passing through the substance without interacting. In this study, the radiation shielding properties of selected materials against fast neutrons are compared in Fig. 5. As it can be seen from the Fig. 5, %100 PbO has the highest ∑R value and the %50 Concrete+%50 WO_3 has the lowest ∑R value. All the computed ∑R values for samples are given in Tablo 2. In addition, it was seen that the ∑R values were changing depending on the physical and chemical components of the materials in Fig. 5.

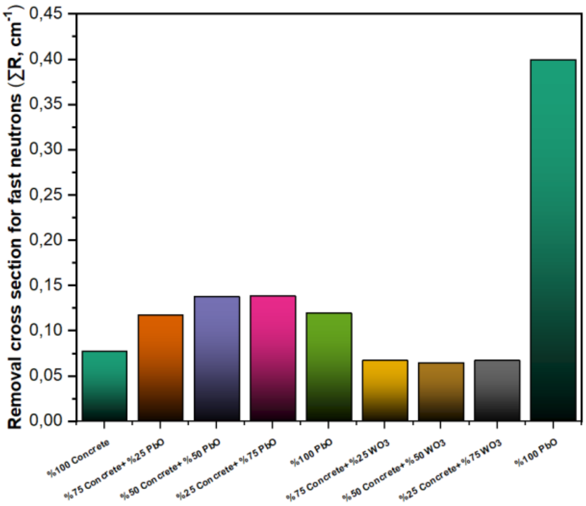

Figure 5. The $\sum_R$ values of the concrete-PbO-WO_3 compound

Table 2. The ∑R table of concrete-PbO-WO_3 compound

Element	%100 Concrete ($\rho = 2.26$ g/cm^3)			%75Concr+ %25PbO ($\rho = 4.0775$ g/cm^3)			%50Concr+ %50PbO ($\rho = 5.895$ g/cm^3)		
	Fraction by weight (%)	**Partial Density (g/cm^3)**	**$\sum_R$ (cm^{-1})**	**Fraction by weight (%)**	**Partial Density (g/cm^3)**	**$\sum_R$ (cm^{-1})**	**Fraction by weight (%)**	**Partial Density (g/cm^3)**	**$\sum_R$ (cm^{-1})**
O	0,492000	1,11192	0,04503276	0,3869	1,5777	0,0639	0,2818	1,6614	0,0673
Na	0,005000	0,0113	0,00038533	0,0038	0,0153	0,0005	0,0025	0,0147	0,0005
Mg	0,003000	0,00678	0,00022577	0,0023	0,0092	0,0003	0,0015	0,0088	0,0003
Al	0,037000	0,08362	0,00245006	0,0278	0,1132	0,0033	0,0185	0,1091	0,0032
Si	0,370000	0,8362	0,0238317	0,2775	1,1315	0,0322	0,1850	1,0906	0,0311
Ca	0,082000	0,18532	0,00450327	0,0615	0,2508	0,0061	0,0410	0,2417	0,0059
Fe	0,011000	0,02486	0,00053200	0,0083	0,0336	0,0007	0,0055	0,0324	0,0007
Pb	0	0	0	0,2321	0,9463	0,0098	0,4642	2,7362	0,0285
W	0	0	0	0	0	0	0,2818	1,6614	0,0673
TOTAL			**0,076960**			**0,116940**			**0,137386**

Element	%25Concr+ %75PbO ($\rho = 7.7125$ g/cm^3)			%100PbO ($\rho = 9.53$ g/cm^3)			%75Concr+ %25WO_3 ($\rho = 3.2702$ g/cm^3)		
	Fraction by weight (%)	**Partial Density (g/cm^3)**	**$\sum_R$ (cm^{-1})**	**Fraction by weight (%)**	**Partial Density (g/cm^3)**	**$\sum_R$ (cm^{-1})**	**Fraction by weight (%)**	**Partial Density (g/cm^3)**	**$\sum_R$ (cm^{-1})**
O	0,1768	1,3633	0,0552	0,0717	0,6831	0,0277	0,4208	1,3760	0,0075
Na	0,0013	0,0096	0,0003	0,0000	0,0000	0,0000	0,0038	0,0123	0,0075
Mg	0,0008	0,0058	0,0002	0,0000	0,0000	0,0000	0,0023	0,0074	0,0075
Al	0,0093	0,0713	0,0021	0,0000	0,0000	0,0000	0,0278	0,0907	0,0075
Si	0,0925	0,7134	0,0203	0,0000	0,0000	0,0000	0,2775	0,9075	0,0075
Ca	0,0205	0,1581	0,0038	0,0000	0,0000	0,0000	0,0615	0,2011	0,0075
Fe	0,0028	0,0212	0,0005	0,0000	0,0000	0,0000	0,0083	0,0270	0,0075
Pb	0,6962	5,3698	0,0558	0,9283	8,8469	0,0920	0,0000	0,0000	0,0075
W	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000	0,1982	0,6483	0,0075
TOTAL			**0,138297**			**0,119673**			**0,0671039**

Element	%50Concr+ %50 WO_3 ($\rho = 4.71$ g/cm^3)			%25Concr+ %75 WO_3 ($\rho = 5.935$ g/cm^3)			%100WO_3 ($\rho = 7.16$ g/cm^3)		
	Fraction by weight (%)	**Partial Density (g/cm^3)**	**$\sum_R$ (cm^{-1})**	**Fraction by weight (%)**	**Partial Density (g/cm^3)**	**$\sum_R$ (cm^{-1})**	**Fraction by weight (%)**	**Partial Density (g/cm^3)**	**$\sum_R$ (cm^{-1})**
O	0,0717	0,3376	0,0216	0,4208	2,4972	0,0075	0,0717	0,5132	0,0283
Na	0,0000	0,0000	0,0000	0,0038	0,0223	0,0075	0,0000	0,0000	0,0000
Mg	0,0000	0,0000	0,0000	0,0023	0,0134	0,0075	0,0000	0,0000	0,0000
Al	0,0000	0,0000	0,0000	0,0278	0,1647	0,0075	0,0000	0,0000	0,0000
Si	0,0000	0,0000	0,0000	0,2775	1,6470	0,0075	0,0000	0,0000	0,0000
Ca	0,0000	0,0000	0,0000	0,0615	0,3650	0,0075	0,0000	0,0000	0,0000
Fe	0,0000	0,0000	0,0000	0,0083	0,0490	0,0075	0,0000	0,0000	0,0000
Pb	0,9283	4,3724	0,0430	0,0000	0,0000	0,0075	0,9283	6,6468	0,3712
W	0,0000	0,0000	0,0000	0,1982	1,1766	0,0075	0,0000	0,0000	0,0000
TOTAL			**0,0646031**			**0,0671039**			**0,3995281**

As a result, the MSP and PR values were obtained by using the SRIM software for the concrete-PbO-WO_3 compound. In the Fig. 6 and Fig. 7. it shows that the changes in MSP values between the energies of 0.01-20 MeV. The MSP values vary as a function of kinetic energy which becomes a maximum of around 0.1 MeV and begins to decrease sharply after 0.1 MeV as shown in Fig. 6. and Fig. 7., respectively. All of these changes were calculated in it is shown in the Fig. 6 and Fig. 7. for proton (H^1) and alpha (He^{+2}) in the energy range 0.1-20 MeV, respectively. Furthermore, Fig. 6. and Fig. 7. illustrates that the %100 PbO has the minimum MSP values for the proton (H^1) and alpha (He^{+2}). Another one of the most important parameters is PR expression, it is affected by the change of kinetic energy for proton (H^1) and alpha (He^{+2}). Fig. 8. and Fig. 9. indicated that the %100 PbO sample has the lowest PR values for proton (H^1) and alpha (He^{+2}) particles. As a result of these studies, it has been shown that the material PbO can be used %100 as the best radiation shielding among the selected materials since it receives the lowest values along with PR measurements for the HVL, TVL, and MFP.

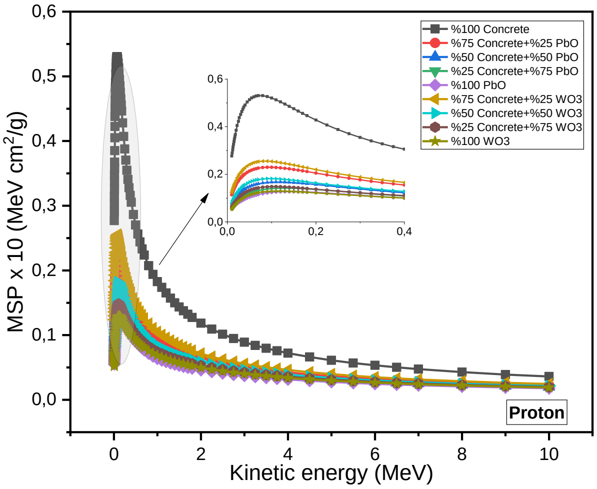

Figure 6. Collision mass stopping powers of concrete-PbO-WO_3 compound for proton particles (H^1)

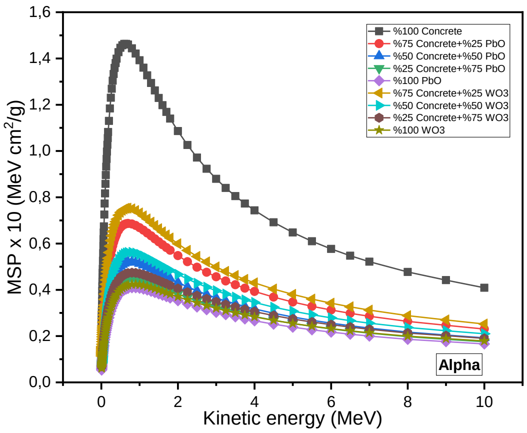

Figure 7. Collision mass stopping powers of concrete-PbO-WO_3 compound for alpha particles (He^{+2})

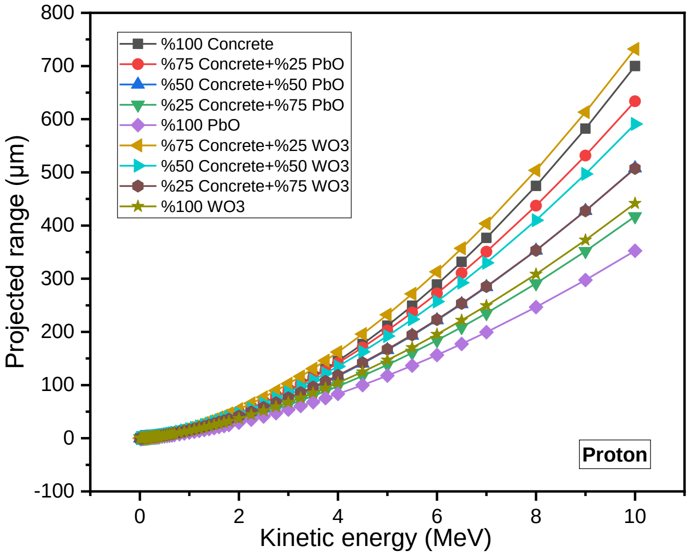

Figure 8. The PR as a function of E_k of concrete-PbO-WO$_3$ compound for proton particles (H^1)

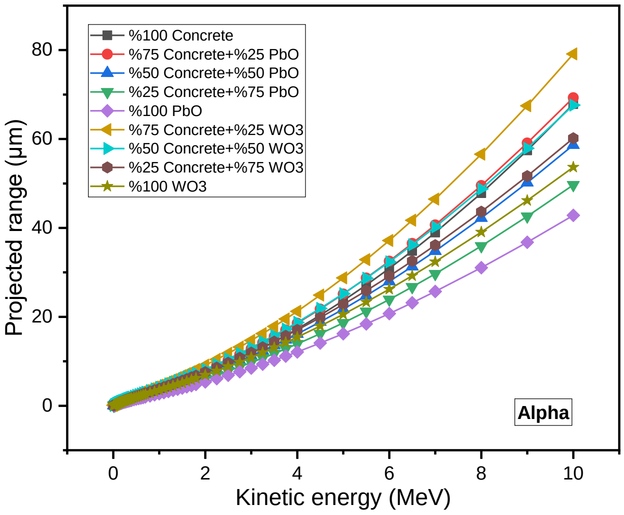

Figure 9. The PR as a function of E_k of concrete-PbO-WO$_3$ compound for alpha particles (He^{+2})

4. Conclusions and Recommendations

In this investigation, μ/ρ, HVL, TVL, MFP, ∑R, MSP, and the PR values were calculated for gamma and neutron rays. %100 Concrete, %75 Concrete+%25 PbO, %50 Concrete+%50 PbO, %25 Concrete+%75 PbO, %100 PbO, %75 Concrete+%25 WO$_3$, %50 Concrete+%50 WO$_3$, %25Concrete+%75 WO$_3$, %100 WO$_3$ materials have been used for this study. MAC, HVL, and TVL values vary depending on each other. These values have shown the best performance for %100 Concrete in 0.01-20 MeV energy region. According to the results obtained from this study, it can be stated that PbO and WO$_3$-concrete systems are promising gamma-ray protective materials. Among these materials, The %100 PbO can be deduced that the material with the least radiation shielding feature. The %100 Concrete is better as radiation shielding properties in terms of including both H^1 ion and higher density. The investigation showed the impact of the PbO and WO$_3$ matters on the radiation shielding of concrete. In addition, the results state clearly that the additive ratio PbO and the WO$_3$ change the results of μ/ρ, HVL, TVL, MFP, ∑R, MSP, and PR values. When the concrete ratios are compared, it can be seen that materials with high mas attenuation coefficient and low HVL values give better results in radiation protection studies. Therefore, it has been observed that it is inevitable to use %100 Concrete as a strong shielding material.

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