International Journal of Science and Research (IJSR)
ISSN (Online): 2319-7064
Index Copernicus Value (2015): 78.96 | Impact Factor (2015): 6.391

Study of Some Shielding Parameters of Gamma Rays and Fast Neutrons for Various Shielding Materials

Ahmed Fadhil Mkhaiber[1], Salwah Kareem Dawood[2]

Department of Physics – College of Education (Ibn Al-Haitham) – University of Baghdad, Iraq

Abstract: ***In this paper, some of the shielding parameters for gamma rays like linear attenuation coefficient , effective atomic number, half value layer , and removal cross section of fast neutrons were calculated for polymer composite consisted of polystyrene as basic material (PS) and various reinforced materials (B,B_2O_3,clay) with different reinforced concentration (5,15,25,35,45)% . X-Com program was used to calculate the values of gamma attenuation coefficient at various energies (0.5,1,3,5,7) Mev .Results have been shown that with increasing of reinforced materials concentrations, the linear attenuation coefficient , removal cross section, and effective atomic number increase while half value layer decrease , and when the energy increase , linear attenuation coefficient decrease while half value layer and effective atomic number increase.***

Keywords: Shielding, removal cross section, attenuation

1. Introduction

Nuclear energy has many applications in different fields such as medicine, industry, agriculture, etc. Although these great benefits, the radiation has a grave risk to humans health [1]. So it is important to protect against it by designing a shield between the radiation source and the surrounding environment. Generally, the radiations that must be considered are neutron and gamma where each of them has adifferent way of interaction with the matter , for that it's important to study the attenuation of these rays in the materials to choose the most effective shield depending on radiation type and its energy [1,2]. In this study, various materials (B, B_2O_3, Clay) with different concentrations (5, 15, 25, 35, 45)% have been added to polystyrene to study shield designs that can be used to reduce radiation danger . A study has been made about the effect of the concentration and energy on some attenuation parameters.

2. Theory

2.1 Linear Attenuation coefficient (μ)

It's known as the probability of removing a photon from the incident beam for each path unit. Where it has the unit of inverse length dimension cm^{-1} [3]. Linear attenuation coefficient value depends on many variables like photon energy and shield density [4]. It also has a high dependency on an atomic number of matter [5]. .The Linear attenuation coefficient is related to mass attenuation coefficient by the following relationship [6]:

$$\mu_m=\mu/\rho \quad (cm^2/g)$$

Where μ_m is mass attenuation coefficient .This parameter is one of the most important factors for describing the penetration of gamma rays through materials [7].

2.2 Effective atomic number (Z_{eff})

Atomic number of the composite material can't be presented by a single number as in pure elements [8]. This number of the composite material is known as the effective atomic number and it varies with energy [9]. It is a suitable parameter for evaluating gamma rays interaction for compound or mixture [10]. Is given by the following formula [11]:-

$$Z_m = \delta_a/\delta_{el}$$

Where δ_a,δ_{el} represent atomic cross section and electron cross-section respectively. Z_m represents the effective atomic number of basic material (PS).

Z_{eff} of composite material is given by [12]

$$Z_{eff} = \sum_{i=1}^{2} w_i Z_i$$

W_i, Z_i represent fraction weight and an atomic numberof shield materials respectively.

2.3 Half Thickness (X½)

Is a simple measure for shield material effectiveness [13], to protect from photons or neutrons , where is defined as medium thickness where the half value of the incident energy has been attenuated [14,15]. it is given by [16]

$$X_{½} = 0.693/\mu$$

2.4 The removal cross sections of fast neutrons (Σ_R)

It's known as the probability of neutron interaction through the path that is a cross with a group of nuclei [17] .The removal cross section for compound or mixtureis given by the general formula [18]

$$\Sigma_R = \sum_i \rho_i \,(\Sigma_R/\rho)_i$$

Where $\rho_i$is partial density.

Σ_R/ρ is mass removal cross section, Which can be calculated for any compound or mixture by the following experimental equation [19]

$$\Sigma_R/\rho = 0.206\, A^{-1/3} Z^{-0.294} \quad (cm^2/g)$$

Where A:is the atomic weight

Z : atomic number

3. Result and Discussion

3.1 Gamma-ray attenuation coefficients

The total linear attenuation coefficient (μ) was plotted as function of reinforcement materials concentrations as shown in the figures (1-3), and from these figures, we can find that the (μ) increase gradually with the increase of concentrations for all mixtures, this can be attributed, when the reinforcement materials concentration increase, the shield density will increase also, and this lead to increasing in gamma-ray attenuation. It can be said that polystyrene alone has a low μ value, however, by increasing reinforcement materials concentrations, the characteristics of matter start to improve and subsequently attenuation coefficient values increase.

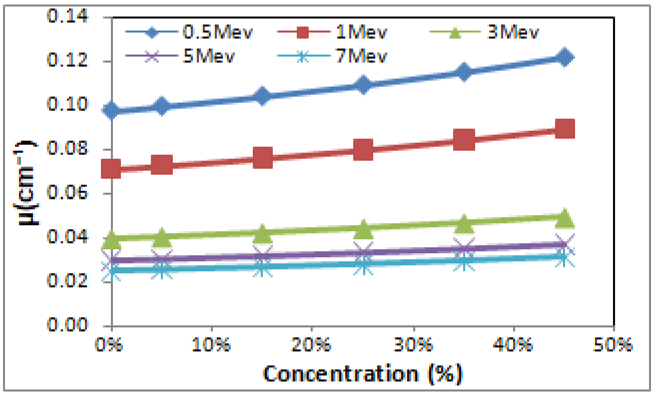

Figure 1: Linear attenuation coefficients as a function of concentration (%) for PS+B composites

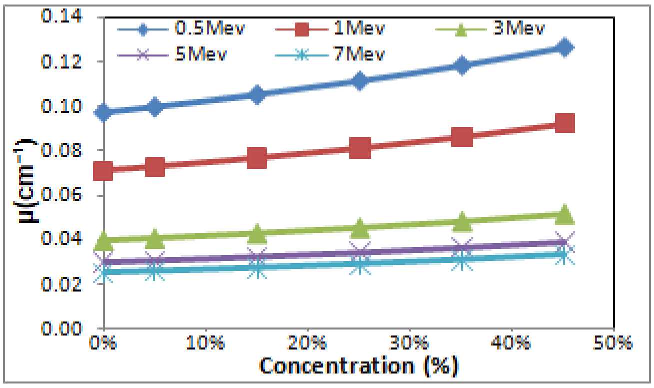

Figure 2: linear attenuation coefficients as a function of concentration (%) for PS+B_2O_3 composites

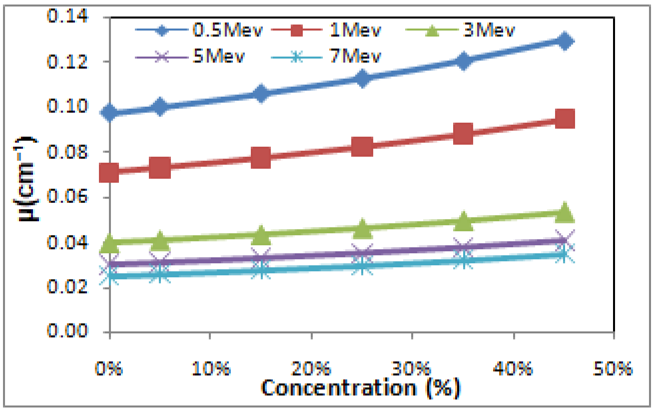

Figure 3: Linear attenuation coefficients as a function of concentration (%) for PS+$Al_2Si_2O_9H_4$ composites

The figures (4-6) illustrate the relationship between μ and energy. It can be observed when the energy increase, the values of (μ) is decreased because of the different mechanism of gamma ray interaction with the matter. In low energy region ,(μ)is decreased rapidly with energy increase for all materials and this because the dominance of photoelectric effect, which has a high cross-section where it proportionate with (Z^5) and that explain why μ values are high in this region of energy. In medium energy region, Compton effect is dominant and μ value decreases with energy increase and that's because of the cross-section of Compton effect is proportionate linearly with (Z). In the high-energy region , it has been noted a slight difference in(μ) with increasing of energy. This is consistent with the study [20].

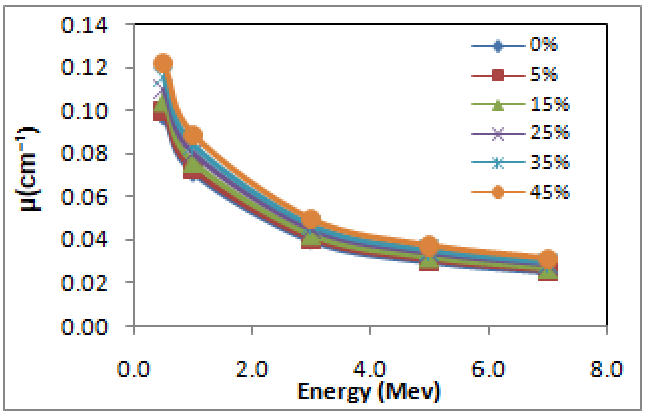

Figure 4: Linear attenuation coefficients as a function of energy at different concentration for PS+B composites

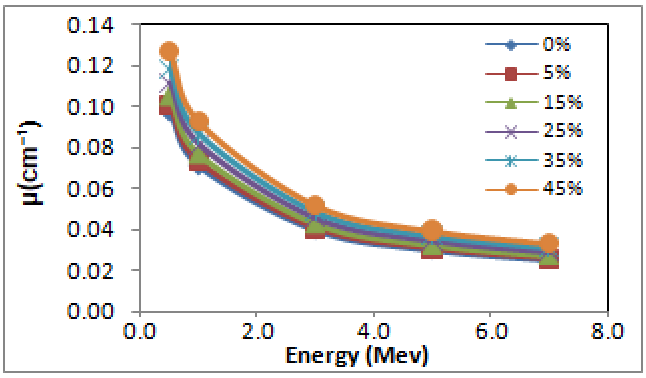

Figure 5: Linear attenuation coefficients as a function of energy at different concentration for PS+B_2O_3 composite

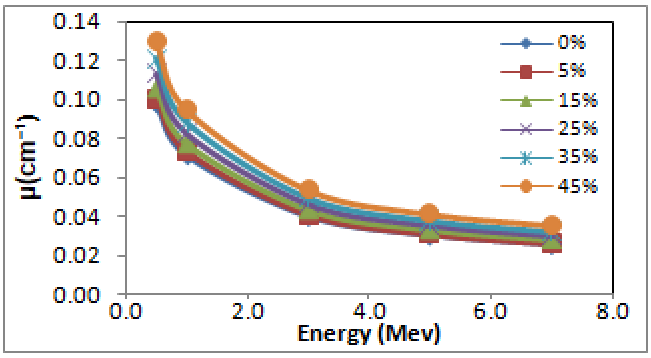

Figure 6: Linear attenuation coefficients as a function of energy at different concentration for PS+$Al_2Si_2O_9H_4$ composites

3.2 Effective atomic number (Z_{eff})

In figures (7-9) illustrate the relationship between Z_{eff} and the concentration, we can note that the Z_{eff} increase with the increasing of reinforcement materials concentrations and this can be explained by the fact that attenuation increases with increased concentration, and subsequently atomic number increase so by increasing reinforcement materials concentrations, we can obtain high atomic number materials that make it suitable to be used as shields against gamma-ray. This is consistent with the study [21].

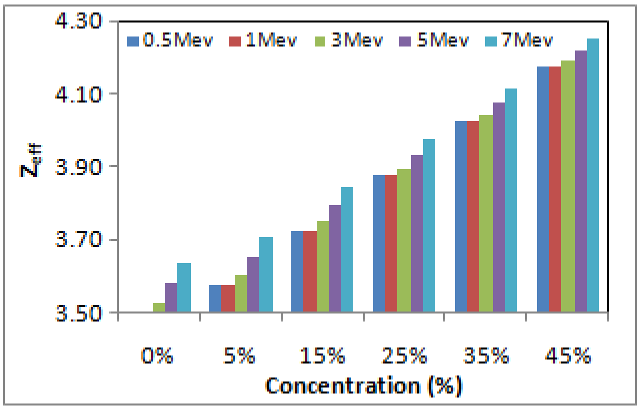

Figure 7: Effective atomic number as a function of concentration (%) at different energy for PS+B composites

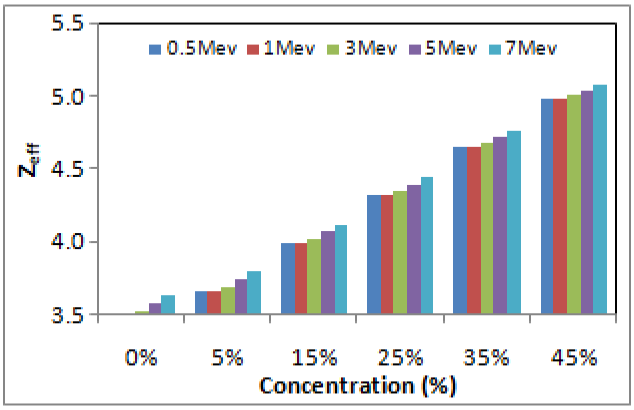

Figure 8: Effective atomic number as a function of concentration (%)at different energy for PS+B_2O_3 composites

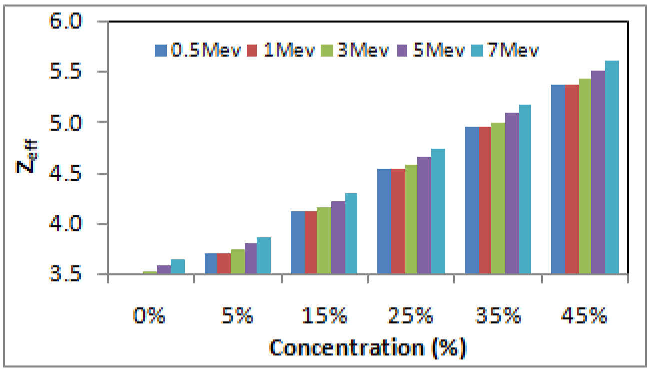

Figure 9: Effective atomic number as a function of concentration (%) at different energy for PS+$Al_2Si_2O_9H_4$composites

Figures (10-12) shows how the Z_{eff} changes with the energy. The minimum value for Z_{eff} exists in the medium energy range, where Compton is the main interaction process and that's attributed to its cross section that depends on (Z). Then, Z_{eff} increases with energy increase where pair product becomes the main process due to its dependence on Z^2, and it proportionates directly with energy.

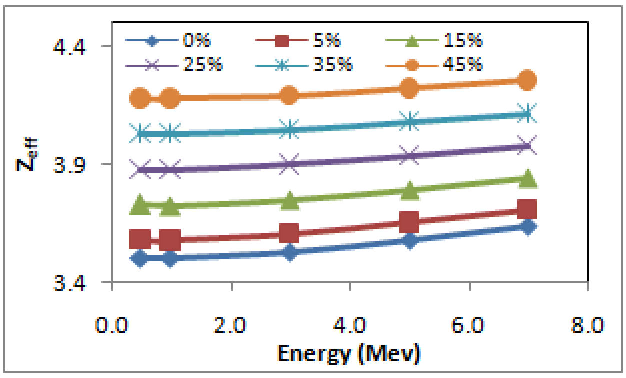

Figure 10: Effective atomic number as a function of energy at different concentration for PS+B composite

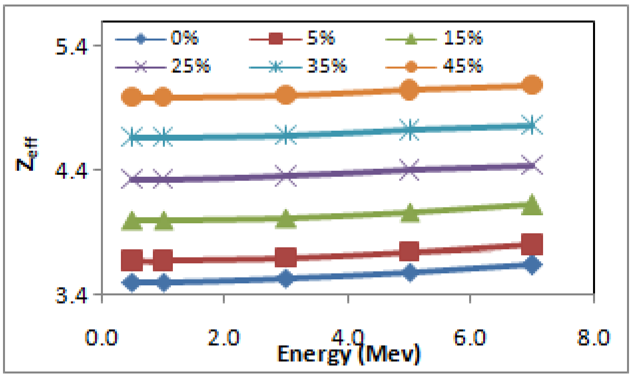

Figure 11: Effective atomic number as a function of energy at different concentration for PS+B_2O_3 composites

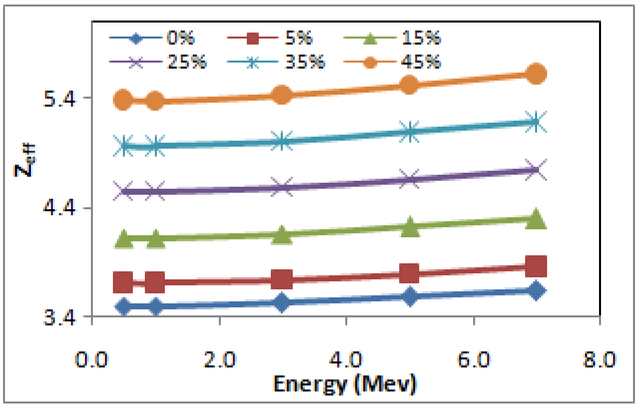

Figure 12: Effective atomic number as a function of energy at different concentration for PS+$Al_2Si_2O_9H_4$ composites

3.3 In figures (13-15) we can see that the **half value layer ($X_{½}$)** values decrease with the increase of reinforcement concentrations ,this indicates to improvement in attenuation properties for all composite.

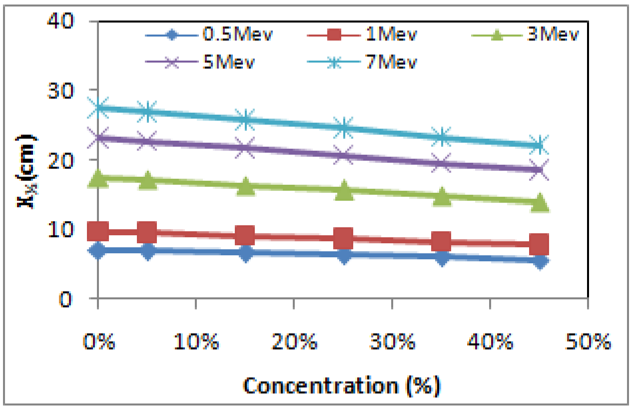

Figure 13: Half value layer as a function of concentration (%) at different energy for PS+B composites

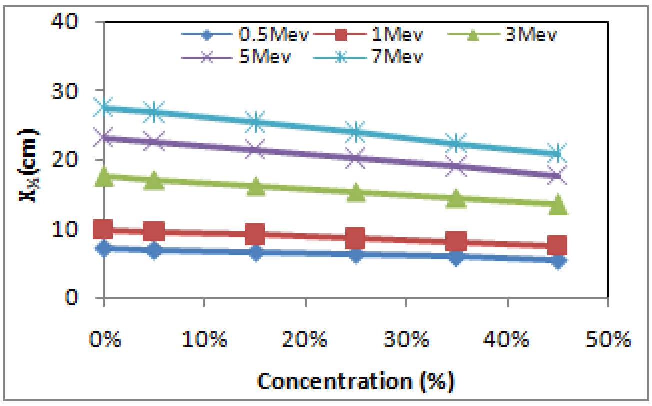

Figure 14: Half value layer as a function of concentration (%) at different energy for PS+B_2O_3 composites

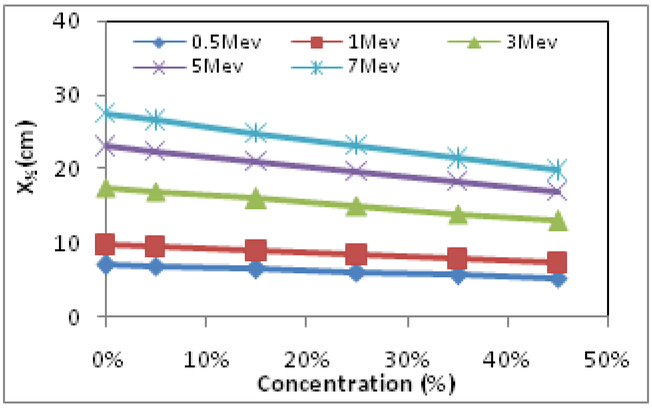

Figure 15: Half value layer as a function of concentration (%) at different energy for PS+$Al_2Si_2O_9H_4$ composites

The relationship between $X_{½}$ and energy is shown in figures (16-18) where we can note that there is an increase in $X_{½}$value with the increase in energy. This can be explained that in the range of high energies we need a high thickness of half value layer.

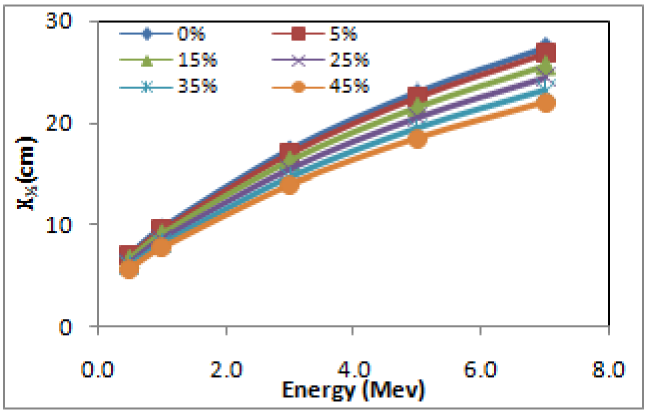

Figure 16: Half value layer as a function of energy at different concentration for PS+B composites

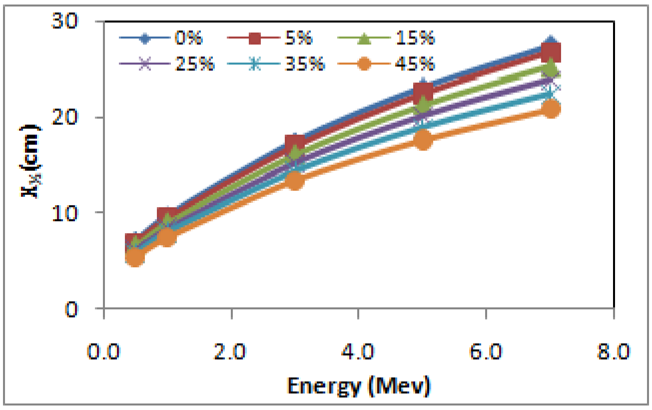

Figure 17: Half value layer as a function of energy at different concentration for PS+B_2O_3 composites

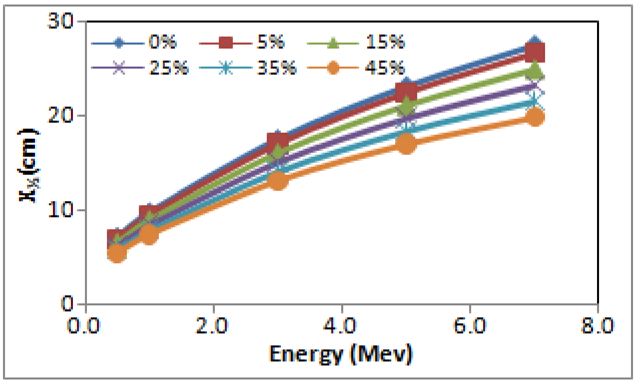

Figure 18: Half value layer as a function of energy at different concentration for PS+$Al_2Si_2O_9H_4$ composite

3.4Removal cross sections of fast neutrons (Σ_R)

In figure (19) we can see that the Σ_R values increase with the concentration increase because of hydrogen content which is considered the most important parameter that affects neutrons attenuation , we have found that maximum value for Σ_R is in the mixture(PS+B). The reason for this is the presence of boron which has a good absorption for neutrons because of its high cross-section and high weight percentage compared to(PS+B_2O_3) (PS+$Al_2Si_2O_9H_4$) .

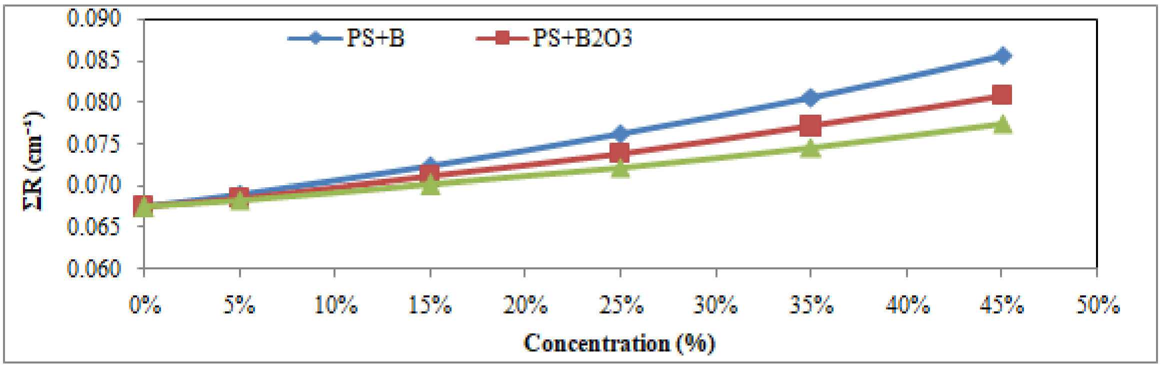

Figure 19: Fast Neutrons Effective Removal Cross-Section as a function of concentration for all composite

3.5 Half value layer($X_{1/2}$) for fast neutron:

Figure (20) shows that the values of $X_{1/2}$ decrease with the increase of concentration. were found that the mixture (PS+B) has the lowest value of half value layer.

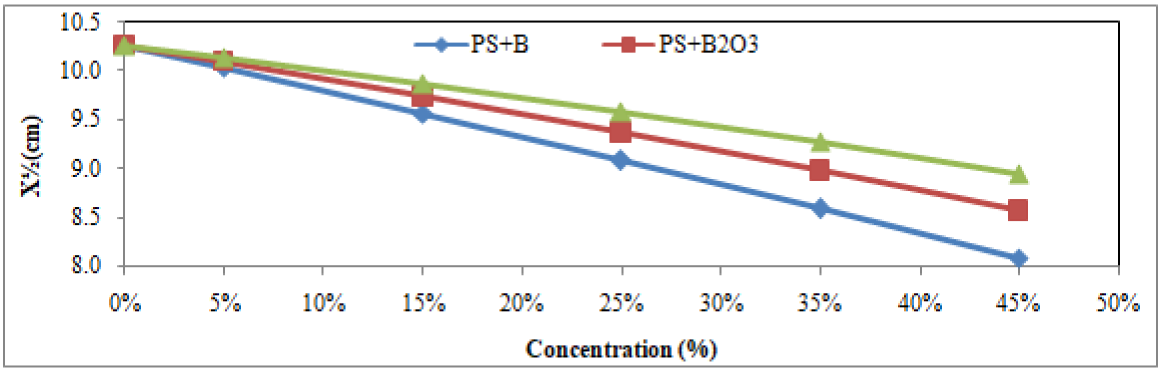

Figure 20: Half value layer as a function of concentration for all composite

4. Conclusion

Based on the results which obtained in this study, the shielding parameter effect by the change of concentration and energy and the mixture (PS+B) can be used to shield against neutrons, and the mixture ($PS+Al_2Si_2O_9H_4$) is best against gamma rays.

Table 1: Linear attenuation coefficient values at different energies and at different concentration of reinforcement materials concentrations

Group	Concentration	0.5Mev	1Mev	3Mev	5Mev	7Mev
PS	0%	0.097	0.071	0.039	0.030	0.025
PS+B	5%	0.099	0.072	0.040	0.030	0.025
	15%	0.104	0.076	0.042	0.032	0.026
	25%	0.109	0.079	0.044	0.033	0.028
	35%	0.115	0.084	0.046	0.035	0.029
	45%	0.121	0.088	0.049	0.037	0.031
$PS+B_2O_3$	5%	0.099	0.072	0.040	0.030	0.025
	15%	0.105	0.076	0.042	0.032	0.027
	25%	0.111	0.081	0.045	0.034	0.029
	35%	0.118	0.086	0.048	0.036	0.031
	45%	0.126	0.092	0.051	0.039	0.033
PS+ $Al_2Si_2O_9H_4$	5%	0.100	0.073	0.040	0.030	0.026
	15%	0.106	0.077	0.043	0.032	0.027
	25%	0.113	0.082	0.046	0.035	0.029
	35%	0.120	0.088	0.049	0.037	0.032
	45%	0.129	0.094	0.053	0.041	0.035

Table 2: Effective atomic number value at different energies and at different concentrations of reinforcement materials

groups	concentration	0.5Mev	1Mev	3Mev	5Mev	7Mev
PS	0%	3.501	3.500	3.527	3.579	3.637
PS+B	5%	3.576	3.575	3.601	3.650	3.705
	15%	3.726	3.725	3.748	3.792	3.842
	25%	3.876	3.875	3.895	3.934	3.978
	35%	4.025	4.025	4.043	4.076	4.114
	45%	4.175	4.175	4.190	4.218	4.250
$PS+B_2O_3$	5%	3.666	3.665	3.691	3.742	3.798
	15%	3.996	3.995	4.020	4.066	4.118
	25%	4.326	4.325	4.348	4.391	4.439
	35%	4.655	4.655	4.676	4.716	4.760
	45%	4.985	4.985	5.004	5.040	5.081
PS+ $Al_2Si_2O_9H_4$	5%	3.709	3.707	3.737	3.794	3.856
	15%	4.124	4.122	4.157	4.223	4.295
	25%	4.540	4.537	4.577	4.652	4.733
	35%	4.955	4.952	4.997	5.081	5.171
	45%	5.371	5.367	5.417	5.510	5.609

Table 3: Half value layer at different energies and at different concentration of reinforcement materials

groups	concentration	0.5Mev	1Mev	3Mev	5Mev	7Mev
PS	0%	7.104	9.731	17.429	23.056	27.421
PS+B	5%	6.956	9.528	17.066	22.580	26.858
	15%	6.652	9.112	16.323	21.598	25.696
	25%	6.340	8.683	15.558	20.595	24.511
	35%	6.018	8.242	14.771	19.554	23.277
	45%	5.686	7.788	13.959	18.482	22.006
$PS+B_2O_3$	5%	6.931	9.494	17.002	22.477	26.707
	15%	6.580	9.013	16.127	21.289	25.265
	25%	6.221	8.521	15.237	20.091	23.807

	35%	5.856	8.022	14.332	18.868	22.331
	45%	5.484	7.512	13.414	17.635	20.839
$PS+Al_2Si_2O_9H_4$	5%	6.912	9.469	16.947	22.380	26.566
	15%	6.525	8.939	15.969	21.010	24.841

	25%	6.132	8.403	14.980	19.639	23.137
	35%	5.734	7.860	13.985	18.271	21.433
	45%	5.332	7.309	12.981	16.895	19.749

Table 4: Calculations of Fast Neutrons Effective Removal Cross-Section for Pure Polystyrene (**ρ=1.04g/cm^{-3}**)

groups	Concentration	element	Σ_R/ρ (cm^{2}g^{-1})	Fraction by Weight	Partial Density (g/cm^3)	Σ_R (cm^{-1})
PS	0%	C	0.053	0.922	0.959	0.050
		H	0.205	0.077	0.080	0.016
Total Σ_R						0.067
		B	0.058			
		O	0.044			
		Al	0.032			
		Si	0.031			

Table 5: Calculations of Fast Neutrons Effective Removal Cross-Section for Polystyrene + Boron Composite

PS+B															
concentration	5%			15%			25%			35%			45%		
element	C	H	B	C	H	B	C	H	B	C	H	B	C	H	B
Fraction by Weight	0.876	0.074	0.050	0.784	0.066	0.150	0.692	0.058	0.250	0.600	0.050	0.350	0.507	0.043	0.450
Partial Density (g/cm^3)	0.938	0.079	0.053	0.890	0.075	0.170	0.836	0.070	0.302	0.774	0.065	0.452	0.774	0.065	0.452
Σ_R (cm^{-1})	0.050	0.016	0.003	0.047	0.015	0.010	0.044	0.014	0.018	0.041	0.013	0.026	0.037	0.012	0.036
Total Σ_R	0.069			0.072			0.076			0.081			0.086		

Table 6: Calculations of Fast Neutrons Effective Removal Cross-Section for Polystyrene + Boron trioxide Composite

$PS+B_2O_3$																				
concentration	5%				15%				25%				35%				45%			
element	C	H	B	O	C	H	B	O	C	H	B	O	C	H	B	O	C	H	B	O
Fraction by Weight	0.876	0.074	0.016	0.034	0.784	0.066	0.047	0.103	0.692	0.058	0.078	0.172	0.600	0.050	0.109	0.241	0.507	0.043	0.140	0.310
Partial Density (g/cm^3)	0.939	0.079	0.017	0.037	0.893	0.075	0.053	0.118	0.841	0.071	0.094	0.209	0.782	0.066	0.142	0.314	0.713	0.060	0.196	0.436
Σ_R (cm^{-1})	0.050	0.016	0.001	0.002	0.047	0.015	0.003	0.005	0.045	0.015	0.005	0.009	0.042	0.013	0.008	0.014	0.038	0.012	0.011	0.019
Total Σ_R	0.069				0.071				0.074				0.077				0.081			

Table (7) : Calculations of Fast Neutrons Effective Removal Cross-Section for Polystyrene + Clay ($Al_2Si_2O_9H_4$) Composite.

$PS+Al_2Si_2O_9H_4$																									
concentration	5%					15%					25%					35%					45%				
element	C	H	O	Al	Si	C	H	O	Al	Si	C	H	O	Al	Si	C	H	O	Al	Si	C	H	O	Al	Si
Fraction by Weight	0.876	0.074	0.028	0.01	0.011	0.784	0.068	0.084	0.031	0.033	0.692	0.062	0.139	0.052	0.054	0.6	0.056	0.195	0.073	0.076	0.507	0.05	0.251	0.094	0.098
Partial Density (g/cm^3)	0.94	0.08	0.03	0.011	0.012	0.896	0.078	0.096	0.036	0.037	0.847	0.076	0.171	0.064	0.067	0.789	0.073	0.257	0.096	0.1	0.723	0.071	0.358	0.134	0.139
Σ_R (cm^{-1})	0.05	0.016	0.001	0	0	0.048	0.016	0.004	0.001	0.001	0.045	0.016	0.008	0.002	0.002	0.042	0.015	0.011	0.003	0.003	0.038	0.015	0.016	0.004	0.004
Total Σ_R	0.068					0.07					0.072					0.075					0.077				

Table 8: Half value layer for Fast Neutron at different Concentration of reinforcement material

Concentration	*PS+B*	*$PS+B_2O_3$*	*$PS+Al_2Si_2O_9H_4$*
0%	10.265	10.265	10.265
5%	10.033	10.095	10.140
15%	9.561	9.743	9.876
25%	9.079	9.372	9.590
35%	8.587	8.981	9.281
45%	8.084	8.567	8.946

References

[1] Y. Elmahroug, B. Tellili & C. Souga. (2013).” Calculation of gamma and neutron shielding parameters for some materials polyethylene-based”, Int.JPR , 3(1):33-40.

[2] Y. Elmahroug , B. Tellili , C. Souga , K. Manai.(2015).” ParShield: A computer program for calculating attenuation parameters of the gamma rays and the fast neutrons “, Annals of Nuclear Energy,76:94-99.

[3] Glenn F.Knoll. (2000)."Radiation Detection and Measurement",3rd , John Wiley & Sons , Inc , New Jersey ,USA .

[4] Woods J (1982). “Computational methods in reactor shielding”. Pergamon, New York.

[5] Vishwanath P Singh, N M Badiger& Nil Kucuk. (2014).”Gamma-ray and neutron shielding properties of some soil samples”, Indian J.of pure & Applied Physics,52:579-587.

[6] Chandra, Ramesh (2004). “ Nuclear Medicine Physics: The Basics, 6th Edition “, Lippincott Williams & Wilkins.
[7] Abdel-Rahma, M,A and Et al. (2000).” effect of sample thickness on the measured mass attenuation coefficients of some compounds and elements for 59.54,661.6 and 1332.5 keV gamma-rays “, Nucl Instrum Methods Phys Res,447,432.
[8] Hine, G.J., (1952).” The effective atomic numbers of materials for various gamma interactions”, Phys. Rev.,85: 725–737.
[9] Manohara, S.R., Hanagodimath, S.M., Thind, K.S., Gerward, L.(2008). “On the effective atomic number and electron density: a comprehensive set of formulas for all types of materials and energies above 1 keV”, Nucl. Instrum. Method Phys. Res. B, 266: 3906–3912.
[10] M. J. Berger, J. H. Hubbell, S. M. Seltzer et al.(2010). “XCOM: photon cross sections database” ,NIST Standard Reference Database (XGAM) NBSIR, 87-3597.
[11] Guru Prasad S et al. (1998). ”Effective atomic numbers for photo absorption in alloys in the energy region of absorption edges”, Rad Phys Chem, 53:449–453.
[12] Nicholas Tsoulfanidis. (1995). “measurement and detection of radiation”, Second Edition , University of Missouri-Rolla.
[13] Jacob Shapiro (2002).”Radiation protection”, fourth edition, USA.
[14] J.Kenneth Shultis& Richard E.Faw (2002). ”Fundamentals of Nuclear”,New York. Basel.
[15] Raymond L.Murray (2000).“Nuclear Energy”, fifth edition , USA.
[16] Kieran Maher & other Wikibooks (2006).“Basic physics of Nuclear Medicine”.
[17] Blizard, E.P., Abbott, L.S., (1962). “Reactor Handbook”, vol. III, Part B, Shielding. John Wiley & Sons, Inc.
[18] Kaplan, M.F., (1989).” Concrete Radiation Shielding”, John Wiley & Sons, New York, USA.
[19] James E.Martin (2006).“Physics for Radiation Protection”, second edition, Federal Republic of Germany.
[20] Korkut,T. (2011) . ”A new radiation shielding material”, Annals of nuclear energy.38 : 56-59.
[21] Ahmed Fadhil Mkhaiber and Abdulraheem Dheyaa Ibrahim (2015).“The Effect of the Concentration Chang of Reinforcing Materials on the Values of Some Theoretical Attenuation Parameters“, Advances in Physics Theories and Applications , Vol.46 ,ISSN 2225-0638.