Advances in Mechanics
Volume 11, Issue 2, 2023
Page 43-55

THE SHIELDING BEHAVIOR OF SEVERAL HYDROGENOUS MATERIALS FOR FAST NEUTRONS

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Abstract

The interactions of neutrons with matter differ in comparison with photons so that they do not show regular changes with the atomic number(Z) or their kinetic energy (E_k). Therefore, they are of great interest in many fields like nuclear energy, health physics and materials science, where the process of shielding and removing fast neutrons takes place by continuous deceleration inside the protective shield until it reaches the thermal equilibrium state .

In the current study, the coefficients of the interaction of fast neutrons such as the macroscopic cross-sectional area Σ_R to remove the fast neutrons, the mean free path (λ) and the half- value thickness layer ($x_{1/2}$) for a number of polymeric, and composite materials were calculated using two empirical equations that written in Excell2012, for choosing the most suitable protective shields from for the fast neutrons. In the present study , the most suitable material in terms of its having to a shielding property for fast neutrons of removal cross section is aluminum oxide (the percentage of hydrogen by weight is equal to *0.02839*), whose values were *0.115* cm^{-1} and *0.105* cm^{-1} According to the equations of James and Zoller, and in the second place is the concrete mecnetite material (with a hydrogen weight ratio: *0.00716997*) and the lowest value for the removal cross section of fast neutrons is the resin 25WD, which has a value (Σ_R) of *0.06377129* cm^{-1} and *0.05942722* cm^{-1} .According to the equations of James and Zoller. As far as the best material in terms of the lowest value of the mean free path and the Half value layer are concerned, it was aluminum oxide relative to the compounds studied in the current study. All the current results are reasonable agreement with the previous studies, except for the element hydrogen.

Keywords: fast neutron - free path - half layer thickness - polyethylene - concrete.

1- Introduction

An important way to control the risk of external radiation is by means of shielding methods . In general, this is the preferred technique because it leads to safe working conditions, while the procedure of depending upon increasing the separation distance from the radioactive source or decreasing the time of exposure to ionizing radiation may include continuous managerial control over workers in Radiation Field. The amount of shielding required depends on a number of factors such as the type of emitted radiation, the intensity radioactivity of the source, and the acceptable dose rate outside the shielding material [1]. Neutron shielding is a very complex issue ,this is due to the wide range of neutron energies that it possesses. This means that any protective equipment must take into account the huge amount of different energy-dependent interactions.

In the theoretical and practical studies conducted by a group of researchers [2-8], where they examined the neutron shielding capabilities of different materials enforced by strengthening materials. In the current study, theoretical calculations were made for a group of superimposed materials using the equations of James and Zoller through the use of Excel 2012, where we do the calculations on the neutron shielding coefficients such as the mean free path, the half value layer and the fast neutron removal cross section and compared these results with that calculated by the previous researchers to show the accuracy of the obtained results.

1- Theoretical calculations

2-1 -Neutron removal cross sections Σ_R

The removal cross-sectional for neutron is defined as the probability of the first collision, due to which neutrons are removed from the non-interacting beam of fast neutrons, and the reaction mechanism for fast neutrons is elastic scattering [9]. Neutron has a complex resonance structure that changes with its energies. The neutron attenuation factors are further complicated by the amount of hydrogen material incorporated into the shields of the fast neutrons by taking advantage of the slowing down property they are possess; therefore, the value of $\Sigma_R$is empirically calculated for each shield material as a coefficient of removal [10]. From the current study, several empirical equations have been applied for the purpose of calculating the mass removal cross section. Among the equations used for compounds and mixtures is the James Wood equation [11]

$$\frac{\Sigma_R}{\rho}\left(\frac{cm^2}{g}\right)=\frac{0.206}{A^{0.333}Z^{0.294}} \qquad (1)$$

As for the Z Zoller equation [12 - 13], it is defined as:

$$\frac{\Sigma_R}{\rho}\left(\frac{cm^2}{g}\right)=\frac{0.19}{Z^{0.743}}\ldots forZ \leq 8 \qquad (2)$$

$$\frac{\Sigma_R}{\rho}\left(\frac{\mathrm{cm}^2}{\mathrm{g}}\right)=\frac{0.125}{\mathrm{Z}^{0.565}}\ldots \mathrm{for} \quad \ldots.\mathrm{Z}>8 \qquad (3)$$

As these equations are determined by A, Z, ρ, the density of the material and the atomic and mass number of each of the elements contributing to the formation of the composed material, with respect to the calculation of Σ_R, it can be calculated for a mixture of a number of elements according to the following equation [11]

$$\Sigma_R=\sum_i W_i(\frac{\Sigma_R}{\rho})_i \qquad (4)$$

Where W_i , ρ , $\frac{\Sigma_R}{\rho}$ is the partial density in units of (*g/cm*$^{-3}$), the density and the mass neutron removal cross-sectional of the element (*i*), mentioning again that the partial density of the compound element (*i*) this can be calculated as follows:

$$W_i=(\rho)_{sam}w_i \qquad (5)$$

Where W_i is the weight ratio of element (i) and $(\rho)_{sam}$ is the density of the sample under study and the mass cross-sectional area of the compound containing (n) elements is defined by equation [11]:

$$(\frac{\Sigma_R}{\rho})_C = \sum_{i=1}^{n} w_i (\frac{\Sigma_R}{\rho})_j \qquad (6)$$

Where W_i and $(\frac{\Sigma_R}{\rho})_j$ are the mass ratio and the neutron removal cross-sectional area of element (j) which is measured in (cm^2/g).

2-2- Mean Free path (λ)

The concept of "mean free path " represents the average distance traveled by a neutron between two successive collisions in the matter. We take into consideration what will lead us to the concept of the mean free path. Suppose a fast neutron incident on a target matter. The probability that the atom in the substance being bombarded is proportional to the path Δx in the substance and equal to $\sum \Delta x$. Thus, the probability that the neutron traverses the path Δx without collision is $1-\sum \Delta x$. So the probability of traveling the distance $n.\Delta x = x$ without collision is defined as follows [14]:

$$(1-\sum \Delta x)^n = (1-\sum \Delta x)^{\frac{x}{\Delta x}} = (1-\sum \Delta x)^{\Sigma x / \Sigma \Delta x} \qquad (7)$$

As $\Delta x \to 0$ approaches with x remaining constant and ($n \to \infty$), this probability becomes:

$$lim_{\Delta x \to 0}(1-\sum \Delta x)^{\Sigma x / \Sigma \Delta x} = e^{-\Sigma x} \qquad (8)$$

Thus the fraction $e^{-\Sigma x}$ of the incident neutrons travels the distance x without any collision, or in other words, $e^{-\Sigma x}$ is the probability of a neutron crossing the distance x free from any collision. The probability that the neutron will collide with an atom in the differential distance dx after passing the distance x is $\sum dx\, e^{-\Sigma x}$, so the probability that it will collide after any random path length is equal to:[14]

$$\int_0^{\infty} e^{-\Sigma x} \sum dx = 1 \qquad (9)$$

However, we don't want to know that the collision definitely occurs with an infinite interval, but even so, we don't want to know that the collision definitely occurs with an infinite interval, but rather what is the average time period after which the neutron collides. To find this average path, we find the product of multiplying all paths by their frequency of occurrence, their sum, and dividing by the total number. The mean free path along the collision line is defined as:

$$\lambda(cm) = \frac{1}{\Sigma_R} \qquad (10)$$

The concept of the free path is very useful when making quick shielding calculations. For example, if the length of the free path of neutrons is equal to one centimeter in an element, this means that the neutron travels a distance of 1 cm inside the material until it interacts by scattering.

2-3 -Half Value Layer $x_{1/2}$

The value of a half- layer ($x_{1/2}$) is basically defined as the required thickness of a sample of material that can be made to reduce the uncollided radiation to half of its original value. The value of ($x_{1/2}$) is an important property that determines whether a material sample acts adequately as a shielding material [15] .

$$x_{\frac{1}{2}}(cm) = \frac{0.693}{\Sigma} \qquad (11)$$

The concept of the value (HVL) is very useful when making rapid and approximate shielding calculations. For example, the value of a layer of thickness equal to unity of a material indicates that it reduces the radiation intensity to half of its original value, and two layers of half thickness reduce the intensity to a quarter of its original value and so on .

All the equations from (1) to (11) do not included any effect on the electrons present in each element for which the shielding properties are calculated, and this is in fact the result of the neutron being an uncharged particle and the electron being charged With a negative charge, the two particles do not interact with each other electromagnetically, as well as the large amount of the neutron mass compared to the mass of the electron, which is approximately 1840 times, which means that there is no significance interaction between them, even if that happens.

3- Results and discussion

Tables (1, 2 and 3) and figures (1, 2 and 3) represent the values of neutron removal cross-sectional area $\left(\frac{\Sigma_R}{\rho}\right)$ for aluminum oxide compounds, standard WD 250 resin and 5% boron-reinforced polyethylene obtained using the James equations J and Zoller's equation Z, which are represented by equations from (1) to (6) respectively, and compared with the values of the neutron removal section area [16]. We note from the figures that the values of Σ_R depend largely on the molecular structure and density of the composed material. In addition, it is noted that there is a good agreement for all components Aluminum oxide, resin and polyethylene enforced with boron, exception of hydrogen, whose values are not close to the James and Zoller values equations. It should be noted that the effect of light elements (with a low mass number) on the total values $\Sigma_R(cm^{-1})$ for the composite materials (despite its low density compared to other elements) most affecting than heavy elements, especially the element hydrogen, where the mass of the hydrogen nucleus is approximately one atomic unit and is approximately equivalent to the neutrons mass. Therefore, when a neutron collides with the hydrogen nucleus, an elastic collision results in the elastic neutron scattering from the light elements. A large part of the kinetic energy of a neutron, as an average in a single scattering process. Specifically, for scattering from hydrogen, the average energy loss is half of the initial neutron energy, thus, the scattering of fast neutrons by hydrogen essentially acts as an effect absorption or removal reaction because the neutron, is removed from the energy region of the fast neutrons by a single scattering event [16]. Therefore, this becomes clear by substituting in the mass number of hydrogen A = 1 and using $\theta > \frac{\pi}{2}$ in the equation [20] :

$$\frac{E}{E_0} = [\frac{cos\theta+(cos^2\theta+A^2-1)^{\frac{1}{2}}}{(A+1)}]^2 \qquad (12)$$

The scattering energy is always equal to zero, the neutron scatters with the hydrogen nucleus (proton) at angles from $\theta = 0$ to $\theta = \frac{\pi}{2}$ and from observing the tables mentioned, we note that the decrease in the percentage of hydrogen will lead to a decrease in the value of Σ_R and vice versa and results in the difference in the cross-sectional area values to remove Neutrons due to the difference in the approved data base, which was used when formulating the different empirical equations for the hydrogen Σ_R, and what results in a specific value for the optional arbitrary constant, in addition to the special bases to which both the mass (A) and atomic (Z) numbers of each element of a substance were exponential to the target material in the two equations used. With regard to polyethylene doped with boron by 5%, as shown in Table (3). We note that the boron that is added operates to increase the total density, and this is due to the large absorption cross-sectional value of the boron element, which is equal to (760 barn), this in turn works to absorb Gamma ray photons generated from the interactions of the neutron with hydrogen [9].

Table (1) Comparison of the calculated and measured values [16] of the fast neutron removal section of aluminum oxide ($\rho = 2.698$ g/cm^3).

Element	Partial Density ρ (g cm^{-3})	Σ_R/ρ(cm^{2}g^{-1}) J	Σ_R/ρ(cm^{2}g^{-1}) Z	Σ_R/ρ (cm^2 g^{-1}) Ref.[16]	Σ_R (cm^{-1}) J	Σ_R (cm^{-1}) Z	Σ_R (cm^{-1}) Ref.[16]
H	7.66E-02	0.206	0.19	0.598	1.58E-02	1.46E-02	4.58E-02
O	1.23E+00	0.044359377	0.04052824	0.0405	5.44E-02	4.97E-02	4.97E-02
Al	1.37E+00	0.03230328	0.029344858	0.0293	4.42E-02	4.01E-02	4.01E-02
Sc	1.53E-07	0.023662679	0.022379795	0.0224	3.63E-09	3.43E-09	3.43E-09
Cr	8.51E-06	0.021681234	0.020753467	0.0208	1.84E-07	1.77E-07	1.77E-07
Fe	2.65E-02	0.020660257	0.019835816	0.0241	5.47E-04	5.25E-04	5.67E-04
Co	2.53E-06	0.020079933	0.019417329	0.0194	5.08E-08	4.91E-08	4.91E-08
Zn	2.51E-04	0.018849035	0.018295172	0.0183	4.73E-06	4.59E-06	4.59E-06
La	5.96E-05	0.012114395	0.012730361	0.0127	7.22E-07	7.59E-07	7.57E-07
Ce	1.32E-06	0.012023845	0.012605881	0.0126	1.59E-08	1.67E-08	1.67E-08
Hf	5.09E-07	0.010415292	0.011156222	0.0112	5.30E-09	5.68E-09	5.70E-09
Au	1.39E-07	0.009798121	0.010586459	0.0106	1.36E-09	1.47E-09	1.47E-09
Th	2.70E-06	0.008929434	0.009834743	0.0098	2.41E-08	2.65E-08	2.64E-08
Total Σ_R (cm^{-1})					1.15E-01	1.05E-01	1.36E-01

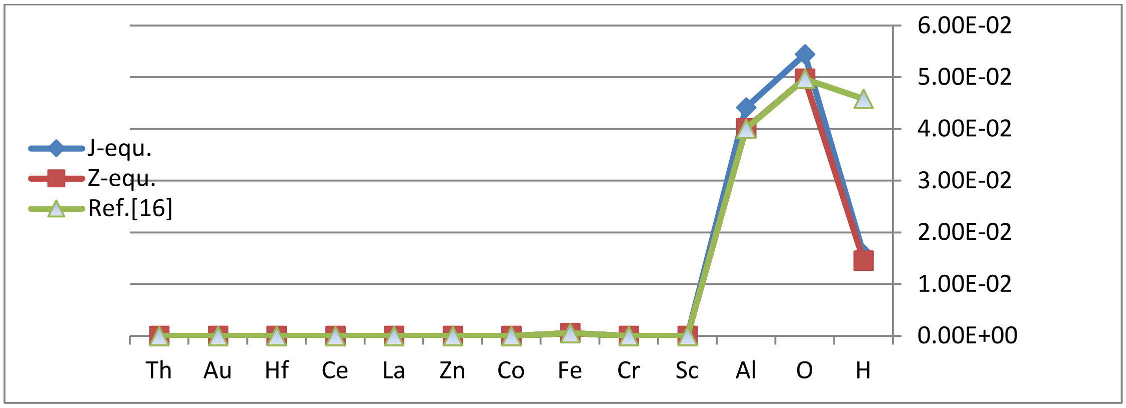

Figure (1) Comparison of the values calculated using the James J Wood and Zoller Z equations and measured [16] for the fast neutron removal section of aluminum oxide (ρ = 2.698 g / cm^3).

Table (2) Comparison of the calculated and measured values [16] of the fast neutron removal section of resin 250 WD (ρ = 1.4 g/cm^3).

Element	Partial Density ρ (g cm^{-3})	Σ_R/ρ (cm^2 g^{-1}) J	Σ_R/ρ (cm^2 g^{-1}) Z	Σ_R/ρ (cm^2 g^{-1}) Ref.[16]	Σ_R (cm^{-1}) J	Σ_R (cm^{-1}) Z	Σ_R (cm^{-1}) Ref.[16]
H	0.01014	0.206	0.19	0.0598	0.00208884	0.0019266	0.06064
B	0.01767	0.057708415	0.057467048	0.0575	0.001019708	0.00101544	0.00102
C	0.64384	0.053132918	0.050186536	0.0502	0.034209098	0.0323121	0.03232
N	0.02920	0.048235382	0.044755432	0.0448	0.001408473	0.00130686	0.00131
O	0.46360	0.044359377	0.04052824	0.0405	0.020565007	0.01878889	0.01878
Na	0.00044	0.035792208	0.032249512	0.0341	1.57486E-05	1.419E-05	0.00001
Mg	0.00077	0.034396759	0.03070242	0.0333	2.64855E-05	2.3641E-05	0.00003
Al	0.11607	0.03230328	0.029344858	0.0293	0.003749442	0.00340606	0.0034
Si	0.00190	0.031226231	0.028141528	0.0252	5.93298E-05	5.3469E-05	0.00005
Cl	0.00146	0.027379524	0.025217752	0.0295	3.99741E-05	3.6818E-05	0.00004
Ca	0.02336	0.024965738	0.023005309	0.0243	0.0005832	0.0005374	0.00057
Fe	0.00029	0.020660257	0.019835816	0.0241	5.99147E-06	5.7524E-06	0.00001
Total Σ_R (cm^{-1})					0.063771297	0.05942722	0.11818

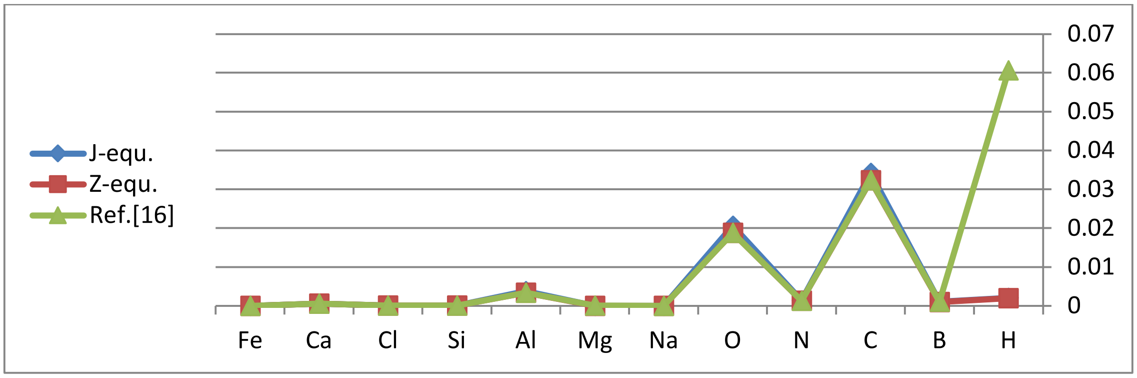

Figure (2) Comparison of the values calculated using the James Wood J and Zoller Z equations and measured [16] for the fast neutron removal section of resin 250 WD ($\rho = 1.4$ g / cm^3).

Table (3) Comparison of calculated and measured values [17] Fast neutron removal section for polyethylene supported by 5% boron (ρ 0.95 g/cm^3)

Element	Partial Density ρ (g cm^{-3})	Σ_R/ρ (cm^2 g^{-1}) J	Σ_R/ρ (cm^2 g^{-1}) Z	Σ_R/ρ (cm^2 g^{-1}) Ref.[17]	Σ_R (cm^{-1}) J	Σ_R (cm^{-1}) Z	Σ_R (cm^{-1}) Ref.[17]
H	0.110200	0.206000	0.190000	0.598000	0.022701	0.020938	0.065900
B	0.047500	0.057708	0.057467	0.057500	0.002741	0.002730	0.002731
C	0.581400	0.053133	0.050187	0.050200	0.030891	0.029178	0.029186
O	0.210900	0.044359	0.040528	0.040500	0.009355	0.008547	0.008541
Total Σ_R (cm^{-1})					0.065689	0.061394	0.106359

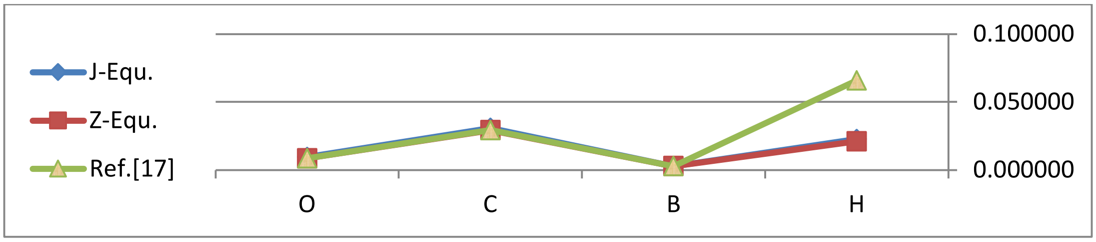

Figure (3) Comparison of the values calculated by the James Wood J and Zoller Z equations with the measured [17] fast neutron removal section of polyethylene supported by 5% boron ($\rho = 0.95$ g / cm^3.

As far as concrete calculations, tables (4 and 5) and figures (4 and 5) represent the neutron removal cross-sectional area values ($\frac{\Sigma_R}{\rho}$) for barite concrete and ordinary concrete. The values of Σ_R for barite concrete are greater than that of ordinary cement, with error equals [20]:

$$Error = \left|\frac{standard - cal.}{cal}\right| \times 100\% \qquad (13)$$

For Brytes concrete the error ratios were 1.759% and 7.23% respectively and this can be explained as a result of the increase in mass density ($\rho_{Barytes} = 3.491 g/cm^3$, $\rho_{ord} = 2.37 g/cm^3$), due to the addition of the fraction weight of some elements of barite concrete such as Potassium, Carbon and Calcium, and in comparison with ordinary cement, all this elements render the separation distances between atoms that make up the cement and barite materials closer and thus increase the property of attenuation through the increasing number of frequented interactions represented by elastic collisions and inelastic collisions of fast neutrons per unit time and per unit distance within the barite concrete , until it reaches a state of thermal equilibrium compared to ordinary cement.

Table (4) Comparison of the calculated cross-sectional area values for the removal of fast neutrons resulting from the application of the James Wood J and Zoller Z equations with those measured [18] in barite concrete.

Element	Partial Density ρ (g cm^{-3})	Σ_R/ρ (cm^2 g^{-1}) J	Σ_R/ρ (cm^2 g^{-1}) Z	Σ_R/ρ (cm^2 g^{-1}) Ref.[18]	Σ_R (cm^{-1}) J	Σ_R (cm^{-1}) Z	Σ_R (cm^{-1}) Ref.[18]
Fe	0.30700	0.020660257	0.019835816	0.02	0.006342699	0.0060896	0.00614
H	0.01500	0.206	0.19	0.602	0.00309	0.00285	0.00903
O	1.09000	0.044359377	0.04052824	0.041	0.048351721	0.04417578	0.04469
Mg	0.01300	0.034396759	0.03070242	0.032	0.000447158	0.00039913	0.000416
Ca	0.15900	0.024965738	0.023005309	0.024	0.003969552	0.00365784	0.003816
Ba	1.47000	0.012236571	0.012858307	0.0124	0.01798776	0.01890171	0.018228
Na	0.00500	0.035792208	0.032249512	0.033	0.000178961	0.00016125	0.000165
Si	0.06100	0.031226231	0.028141528	0.0295	0.0019048	0.00171663	0.0017995
Al	0.02000	0.03230328	0.029344858	0.0301	0.000646066	0.0005869	0.000602
Mn	0.00300	0.021025773	0.020280278	0.0202	6.30773E-05	6.0841E-05	0.0000606
S	0.34800	0.028717014	0.026096497	0.0275	0.009993521	0.00908158	0.00957
Total Σ_R (cm^{-1})					0.092975315	0.08768126	0.0945171

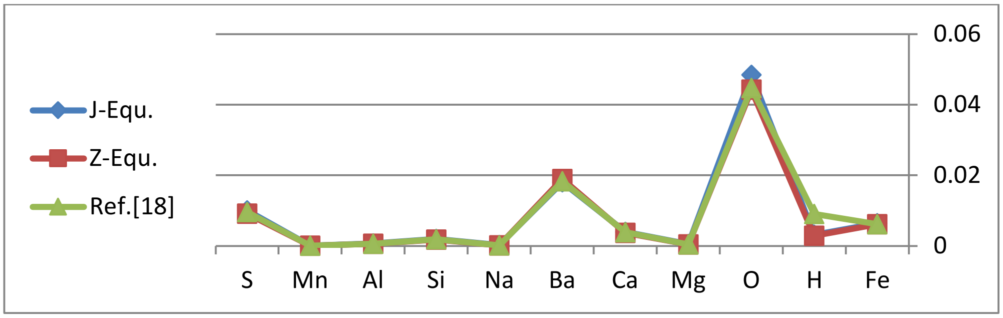

Figure (4) Comparison of the values calculated by the James Wood and Zoller equations with the measured [18] fast neutron removal section of barite concrete.

Table (5) Comparison of the values calculated by the James Wood J and Zoller Z equations with the measured [18] for the fast neutron removal section of ordinary concrete.

Element	Partial Density ρ (g cm^{-3})	Σ_R/ρ (cm^2 g^{-1}) J	Σ_R/ρ (cm^2 g^{-1}) Z	Σ_R/ρ (cm^2 g^{-1}) Ref.[18]	Σ_R (cm^{-1}) J	Σ_R (cm^{-1}) Z	Σ_R (cm^{-1}) Ref.[18]
O	1.10300	0.044359377	0.04052824	0.041	0.048928393	0.04470265	0.045223
Si	0.28150	0.031226231	0.028141528	0.0295	0.008790184	0.00792184	0.00830425
Al	0.03300	0.03230328	0.029344858	0.0301	0.001066008	0.00096838	0.0009933
Fe	0.01830	0.020660257	0.019835816	0.02	0.000378083	0.000363	0.000366
Ca	0.77120	0.024965738	0.023005309	0.024	0.019253577	0.01774169	0.0185088
C	0.07610	0.053132918	0.050186536	0.05	0.004043415	0.0038192	0.003805
Na	0.01160	0.035792208	0.032249512	0.033	0.00041519	0.00037409	0.0003828
K	0.00790	0.025559879	0.023681774	0.0245	0.000201923	0.00018709	0.00019355
H	0.02500	0.206	0.19	0.602	0.00515	0.00475	0.01505
Mg	0.04260	0.034396759	0.03070242	0.032	0.001465302	0.00130792	0.0013632
Total Σ_R (cm^{-1})					0.089692074	0.08213586	0.0941899

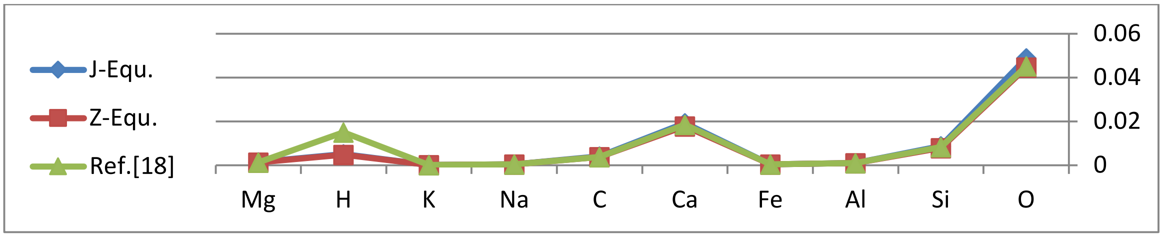

Figure (5) Comparison of the values calculated by the James Wood J and Zoller Z equations with the measured [18] for the fast neutron removal section of ordinary concrete.

As for the values of the free path rate (Table 6), we find that the greatest value of the attenuation distance for fast neutrons by using the James Wood and Zoller equations was for the polyethylene compound reinforced with boron at a rate of 5%, which amounts to (*15.22324* cm^{-1} and *16.2888236* cm^{-1}). Then resin 250WD, which according to the results of applying the James and Zoller equations, they were as follows :(*15.681035* cm^{-1} over *16.827305* cm^{-1}). These results indicate that the fast neutrons travel the greatest distance within it. In other words, the fast neutrons that entered into it is subjected to the least number of elastic and inelastic collisions per unit distance within the depth of the material until it is removed from the neutron beam. We note that the lowest value of the attenuation distance of thermal neutrons is for the aluminum oxide , which amounted to (*8.695652* cm^{-1} and *9.5238095* cm^{-1}) These results indicate that the penetration depth of fast neutrons in the aluminum oxide is the shortest, which means that the neutrons incident on this substance are exposed to a large number Of the collisions per unit distance within the material, as a result of which the neutron loses a large part of its kinetic energy E_k compared to other composed materials. The variation between the values of the mean free path between the maximum value and the minimum value material is due to the increase in the proportions of light elements of aluminum oxide. Which has a density of $\rho = 2.698\ g/cm^3$ compared to the density of polyethylene reinforced by 5% $\rho = 1.7\ g/cm^3$, which causes andecrement in the separation distances between the atoms and molecules of these compounds, and thus results in a decrease in the distance traveled by thermal neutrons within the material.

Table (6) Comparison of the values calculated by the James Wood J and Zoller Z equations with the measured values of a number of previous studies of the free path rate of fast neutrons in several Hydrogenous composite materials.

Composite material	λ (cm) J-equation present study	λ (cm) Z-equation present study	λ (cm) calculated By
Alumium oxide	8.695652	9.5238095	7.352941 Ref.[16]
Resins WD250	15.681035	16.827305	8.46166 Ref.[16]
Boronated poly ethylene 5%	15.22324	16.2888236	9.4021192 Ref.[17]
Brytes concrete	10.755543	11.4049454	10.580096 Ref.[18]
Ordinary concrete	11.149257	12.17495014	10.61685 Ref.[18]

The highest value of the half-thick layer required (Table 7) to attenuate the fast neutrons to half their original value is the resin material, which reached (*10.86926* cm^{-1}) and (*11.663799* cm^{-1}) according to the results of the James Wood and Zoller equations respectively, it was found that 5% boron-reinforced polyethylene is the second largest HVL required to attenuate thermal neutrons, and its values was (*10.5511952* cm^{-1} and (*11.290* cm^{-1}) according to the results of the James Wood and Zoller equations, which it reflects the condition of descriptive agreement between the values of the attenuation distance (λ) and the value of the half-value layer , which are inversely proportional to the removal cross-sectional of the fast neutrons. It is noted from Table (7) that the lowest value is for the half- value layer needed to attenuate the fast neutron beam was that of Aluminum oxide (*6.026086 cm*$^{-1}$ and *6.6014 cm*$^{-1}$), and in the second order was barite concrete, where its values were (*10.755543 cm*$^{-1}$ and *10.580096 cm*$^{-1}$) respectively. According to the results of the James Wood and Zoller equations, it is noted from the tables mentioned that the values of ($x_{1/2}$) decrease as the density of the composed material increases, and the reason is due to the increase in the vicinity of the interfacial distances between atoms and molecules, which works to further hinder the progress of neutrons into the depth of the material In other words, the number of collisions per unit time increases per unit distance within the shielding material.

Table (7) Comparison of the calculated and measured values for the values of the thickness of the half layer x $_{1/2}$ (cm^{-1}) fast neutrons for a number of hydrogen substances

Composite	x$_{1/2}$ (cm^{-1}) J-present study	x$_{1/2}$ (cm^{-1}) Z-present study	x$_{1/2}$ (cm^{-1}) calculated By
Alumium oxide	6.026086	6.6014	Ref.[16] 5.09667
Resins WD250	10.86926	11.663799	Ref.[16] 5.8651817
Boronated poly ethylene 5%	10.5511952	11.290	Ref.[17] 6.517052
Brytes concrete	7.4551743	7.905305	Ref.[18] 7.3335637
Ordinary concrete	7.728076	8.439032	Ref.[18] 7.3590

4 - Conclusions

In the this study, we found that the most suitable material according to having a shielding property for fast neutrons as a removal cross-sectional is aluminum oxide (the percentage of hydrogen by weight is equal to *0.02839*), whose values were (*0.115 cm*$^{-1}$ and *0.105 cm*$^{-1}$),according to James equations and Zoller. Secondly, was Barite concrete while the minimum value for the shielding of fast neutrons was Resin 25WD, which had Σ_R values of *0.06377129* and *0.05942722 cm*$^{-1}$ according to the James and Zoller equations, as well as the largest percentage, a weighty contribution to the composition of the composed material are the elements aluminum, oxygen and hydrogen. The current study also showed that the most suitable shielding element that works best to remove fast neutrons when interacting is hydrogen, which is characterized by two basic characteristics, namely low atomic number, and a relatively high mass density.

3) The values of $\Sigma_R(cm^{-1})$ are a function of the chemical composition and the density of the sample, and there is no effect on the density of electrons within a single substance.

4) The selection of any material as a protective shield from thermal neutrons depends mainly on the values of the macroscopic cross-sectional $\Sigma_R(cm^{-1})$, which in turn is based on the values of

the fraction by weight of the elements included in its composition.
5) The greatest value of the cross-sectional for removing fast neutrons $\Sigma_R(cm^{-1})$ for any composite material is an indication that it contains the largest percentage by weight of light elements such as hydrogen, carbon, oxygen and the rest of the elements with a small atomic number, and that the smallest value of the cross-sectional area. The accidental removal of fast neutrons $\Sigma_R(cm^{-1})$ for any composite material is an indication that it contains the lowest percentage by weight of the light elements.

5 – References

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