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Neutron Shielding Properties Of Concrete With Boron And Boron Containing Mineral

[*1] Salim Orak , [2]Derya Yilmaz Baysoy

[1] Istanbul Commerce University, Faculty of Arts and Science, Turkey
[2] Halic University, Department of Electronics Technology, Istanbul, 34394, Turkey

*Corresponding author: Address: Istanbul Commerce University, Faculty of Arts and Science, Halic University, Istanbul, 34394, TURKEY. E-mail address: salimorak@hotmail.com

Abstract

Concrete is a material which widely used as a neutron shielding and in building construction such as nuclear power stations, particle accelerators and medical hospitals. Concrete is very significant for neutron shielding, because of concrete is contain of some elements (hydrogen, iron etc.) to moderate the fast neutrons which are very penetrative. Boron increases the neutron shielding effectiveness of concretes, since the boron isotope ^{10}B has a high capture cross-section for thermal neutrons (over 3800 barns). Boron can be added to concrete different ways such as addition of boron to the water used in concrete or addition of boron containing natural minerals.

Neutron shielding capabilities of the sample can be described by total neutron macroscopic cross-section (Σ_t). It is the sum of the cross-sections for all the neutron-interaction processes such as the elastic and inelastic scattering reactions and neutron capture reactions ((n,α),(n,γ)).

In this study, the effect of addition boron and colemanite on the total macroscopic cross section of Portland concrete was investigated. Colemanite is one of the most important boron minerals and Turkey has the largest colemanite reserves in the world. Its compact formula is $Ca_2B_6O_{11} \cdot 5(H_2O)$. Also, colemanite can be used for shielding fast and thermal neutrons, since it includes both of hydrate and boron.

In experiments, ^{241}Am-Be neutron source with 74 GBq activity were used in. Average neutron energy of this source is approximately 4.5 MeV. BF_3 detector with diameter 2.54 cm and length of 28 cm was used for counting neutrons. Also, Monte Carlo simulations were done for comparison of macroscopic cross section experimental results. Besides total macroscopic cross sections, absorbed doses and deposited energies by low energy neutron interactions were calculated using MCNP4C2 Monte Carlo code. The results have been compared with the standard shielding material of paraffin. Also, half-value layer (HVL) and tenth-value layer (TVL) were calculated and compared.

Keywords: *Neutron Shielding, MCNP Monte Carlo Code, Total Macroscopic Cross Section, HVL, TVL*

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1.Introduction

Concrete is the most generally used shield material as it is low-cost and adjustable for any construction design (Singh et al., 2008; Ne ville, 1989). A lot of studies about neutron shielding by using concrete have been done until now (Jaeger et al., 1975,; Kaplan, 1989; Ibrahim and Rashed, 1998, Akkurt et al., 2005; Kharita et al., 2008). Some of researchers have tried to increase of shielding effectiveness of concrete by adding boron compounds such as boric acid, borax etc. (Yarar et al., 1994, Kharita et al., 2011). One of the most important boron minerals is colemanite and its compact formula is $Ca_2B_6O_{11}$•$5(H_2O)$. Also, colemanite can be used for shielding fast and thermal neutrons, since it is include both of hydrate and boron.

In this study, we have aimed to measure experimental and simulate total neutron macroscopic cross sections for boron and colemanite loaded Portland concrete. Additionally, absorbed doses and deposited energy values have been determined by Monte Carlo simulations.

2. Experiments and Monte Carlo Simulations

Neutron absorption experiments were done for 20% boron and colemanite mineral loaded Portland concrete. For this purpose, ten samples have been prepared at 2.3 cm thickness for each additive. Experiments have been performed by ^{241}Am-Be neutron source with 74 GBq activity. Average and maximum neutron energies of this source are 4.5 and 12 MeV, respectively. Transmitted neutron particles have been measured by BF_3 detector with diameter 2.54 cm and length of 28 cm. Experimental set up used in present study is shown in Figure 1.

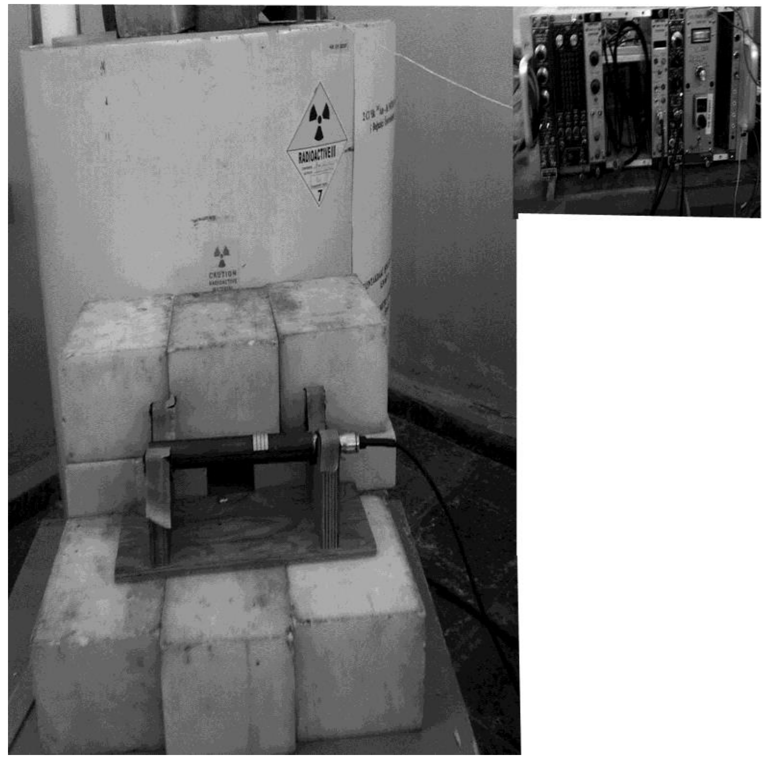

Figure 1. Experimental set up

MCNP of version 4C2 code, a well known Monte Carlo neutron-particle transport code, was used to simulate the system (Briesmeister, 2000). The neutron macroscopic cross section has been simulated from MCNP code for neutron particles having 4.5 MeV average neutron energy. The number of neutrons crossing front and back sides of the sample was determined using a surface current tally. Absorbed dose and deposited neutron energies by neutron interactions have been simulated by using power law built in function $p(x) = c|x|^a$ for the ^{241}Am-Be neutron source. Chemical compositions and elemental mass ratios of samples which are used in simulations compared to typical Portland concrete (PC) have been listed in Table 1.

Table 1. Chemical compositions and elemental mass ratios of samples

	Portland concrete (2.35 g/cm^3)	20% boron loaded PC (1.59 g/cm^3)	20% colemanite loaded PC (1.56 g/cm^3)
Hydrogen	0.0056	0.0045	0.0094
Oxygen	0.4996	0.3997	0.5242
Sodium	0.0171	0.0137	0.0137
Magnesium	0.0024	0.0019	0.0019
Aluminum	0.0458	0.0366	0.0366
Silicon	0.3150	0.2520	0.2520
Potassium	0.0191	0.0153	0.0153
Calcium	0.0831	0.0665	0.1055
Iron	0.0123	0.0098	0.0098
Boron-10	-	0.0398	0.0062
Boron-11	-	0.1602	0.0253

3. Results and Conclusion

The macroscopic cross-section Σ is important factor to determine neutron shielding property of samples. Σ_{tot} is the probability per unit path length that any type of interaction may occur. It is conventional to express this probability in terms of the cross-section σ_n per nucleus for each type of interaction. When multiplied by the number of nuclei *N* per unit volume, the cross-section σ_n is converted into the macroscopic cross-section Σ_{tot}, where

$$\Sigma_{tot} = N \sigma_n \text{ and } \Sigma_{tot} = \Sigma_{scatter} + \Sigma_{capture} \ldots \quad [1]$$

Total macroscopic cross section values were calculated from Beer-Lambert Law:

$$I(x) = I_o e^{-\Sigma x} \quad [2]$$

where I_o is some known value of beam intensity, at a material thickness of x = 0 (T. Korkut et al., 2010).

The measured and simulated values of total macroscopic cross sections of samples are shown in Table 2. As it can be seen in this table, borated concrete is better neutron shielding material than colemanite loaded concrete. Also transmission values as a function of the sample thickness were shown in figure 2 and 3. As can be seen from these figures, transmission values were decreased exponentially with increasing the sample thickness. Also experimental and simulation half value layer and tenth value layer (TVL) values of paraffin wax, boron loaded and colemanite loaded Portland concrete for 4.5 MeV neutrons were shown in Table 3 and 4

Table 2. Total macroscopic cross sections

	Experiment	Simulation
Sample	Σ_t (cm^{-1})	Σ_t (cm^{-1})
PC+20% Boron	0.128	0.127
PC+20% Colemanite	0.119	0.121

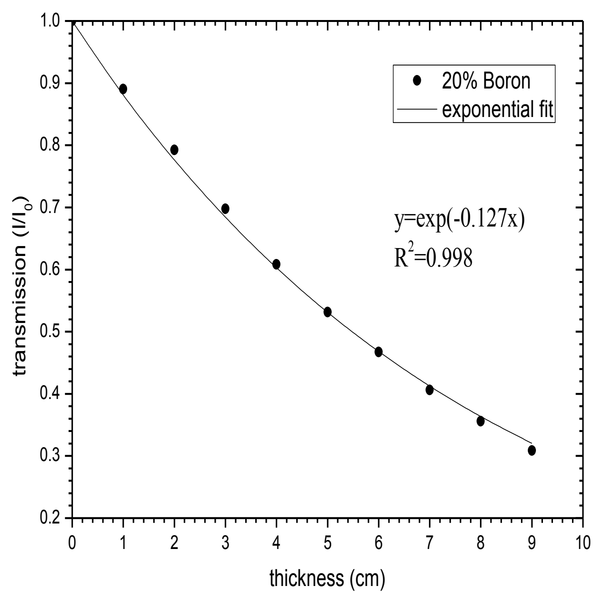

Figure 2. Transmission values as a function of borated Portland concrete sample thickness

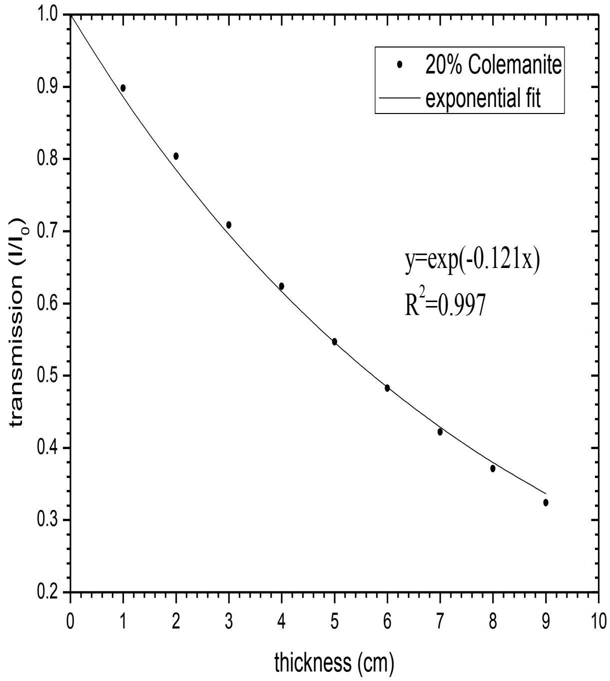

Figure 3. Transmission values as a function of colemanite loaded Portland concrete sample thickness

Table 3. HVL values of samples

Sample	Half value layer (cm)	
	Experiment	Simulation
Parafin wax	3.96*	3.97
PC+20% Boron	5.41	5.47
PC+20% Colemanite	5.82	5.72

*From Desdin and Ceballos(2000)

Table 4. TVL values of samples

Sample	Tenth value layer (cm)	
	Experiment	Simulation
PC+20%boron	17.99	18.20
PC+20%colemanite	19.35	19.03

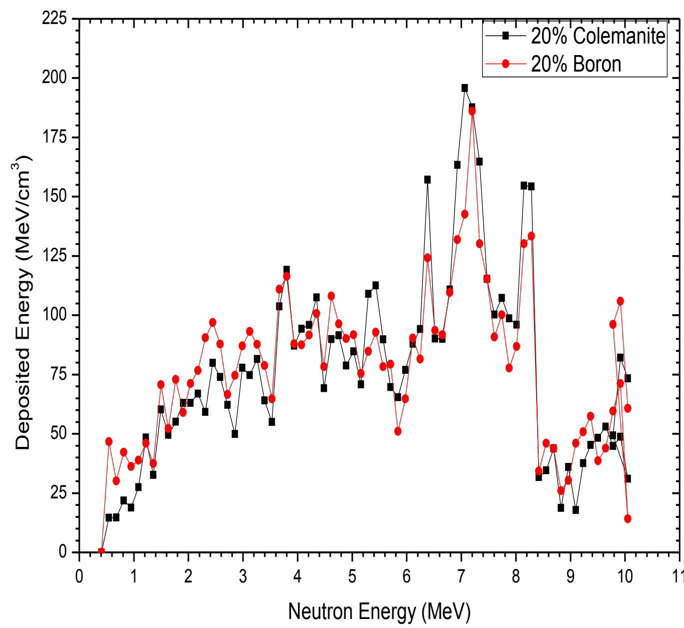

Figure 4. Deposited energy variations as a function of neutron energy

Table 5. Absorbed dose values

Sample	Absorbed Dose (μGy/h)
PC+20% colemanite	$2.31x10^3$
PC+20% boron	$2.43x10^3$

Total absorbed dose rate for samples was calculated via MCNP code. According to simulation results, 20% boron loaded Portland concrete has higher total absorption dose rate than 20% colemanite loaded concrete. Deposited energy values per unit volume as a function of neutron energy were shown in Figure 4. The simulation results confirm that borated Portland concrete sample has higher attenuation effects for lower neutron energy from 3.5 MeV. Maximum deposited energy appears 7-8 MeV energy neutron region.

When it is compared the experimental and simulation results for boron and colemanite added concrete, it is clear that addition of boron increases the effectiveness of neutron shielding than the others. Although HVL value of borated concretes are not as good as value of paraffin wax, these materials can be used for building walls of nuclear power stations, medical hospitals or as a moderator nuclear investigation centers and particle accelerators.

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