PROCEEDINGS OF SCIENCE

Investigating Thermal Neutron Radiation Shielding Features of Gd_2O_3-doped Material (Quartz, Al, W): A Monte Carlo Simulation (MCNP6)

Mirac Kamislioglu[a]*, Ayse Bat[b]

[a]Bandırma Onyedi Eylül University,

10200, Balıkesir, Turkey

[b]Eciyes University,

38030, Kayseri, Turkey

E-mail: mkamislioglu@bandirma.edu.tr

In this study, thermal and fast neutron total macroscopic cross sections in quartz and other elements (like Al, W) doped with Gd_2O_3 are calculated by using the (MCNP6) Monte Carlo Simulation Code. Furthermore, the macroscopic effective removal cross-section of fast neutrons was calculated theoretically for the selected materials and doped materials. The results obtained from the calculations showed that total macroscopic cross-section values are higher in Gd_2O_3-added materials. In addition, it has been observed that the selected materials have the highest fast neutron total cross section with the contribution of Gd_2O_3. The results of this study provide a good understanding of the shielding properties of Quartz, and some elements like Al and W doped with Gd_2O_3 against thermal and fast neutrons.

Keywords: Radiation Shielding, Gadolinium, Neutron Interaction, MCNP6, Removal Cross-Section.

41st International Conference on High Energy physics - ICHEP2022
6-13 July 2022
Bologna, Italy

© Copyright owned by the author(s) under the terms of the Creative Commons Attribution-NonCommercial-NoDerivatives 4.0 International License (CC BY-NC-ND 4.0).

PoS(ICHEP2022)1192

1. Introduction

Neutrons are uncharged particles and have different interaction mechanisms with material atoms according to their energies. The determination of these interactions is very important for measuring and shielding neutron radiation [1]. In recent years, the use of neutrons in medicine, elemental analysis, and nuclear power plants has been increasing. Neutrons do not give a direct signal in a detector, as they are uncharged particles like photons. The measurement of a neutron can be made not from the direct signal from the neutron, but from the signal given by a charged particle formed as a result of a neutron-induced reaction. In this respect, the study of neutrons is very important [1].

2. Neutrons Interactions

Thermal neutrons (0.025 eV) can enter the target nucleus and cause a nuclear reaction since neutrons have no charge and thus are not affected by the Coulomb barrier. However, depending on the cross-section, some nuclear reactions require fast neutrons (energy <10 MeV) (Figure 1).

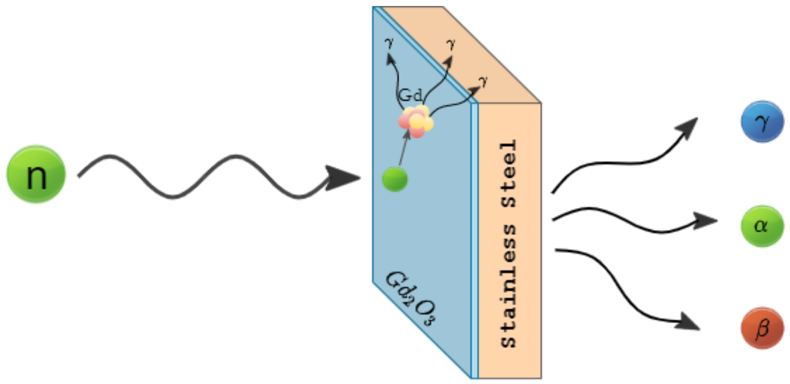

Figure 1. A diagram showing the mechanism by which neutrons interact with the material

Since neutrons are uncharged particles, they can easily enter the nucleus and initiate a nuclear reaction. Neutrons can penetrate the target up to thermal energies. For charged particles to penetrate the nucleus, they must cross the Coulomb barrier. At reactors, neutrons are slowed in a moderator (usually water), and slowed neutrons initiate new fissions. Nuclear reactions with thermal neutrons are attractive for many reasons. The reaction efficiencies are high due to large cross-sections and high thermal neutron fluxes. These reactions are indeed sufficient to be used as a source of charged secondary particles. Thermal neutrons are in thermal equilibrium with the molecules/atoms of the surrounding environment. The energy distribution of this neutron group can be represented by the Maxwellian distribution. Thermal neutrons have an energy of about 0.025 eV at a temperature of 20°C [2].

3. Monte Carlo Simulations (MCNP6)

MCNP is a general-purpose Monte Carlo N-Particle code that can be used for neutron, photon, or electron transport. Monte Carlo Simulation is an alternative way of defining and

PoS(ICHEP2022)1192

solving problems when experimental conditions are limited, risky, and difficult. This code deals with the random three-dimensional configuration of materials in geometric cells bounded by first- and second-order surfaces [3]. In this study, we used the MCNP6 program to calculate the total macroscopic cross-section of materials frequently used in neutron shieldings such as Al, W, and Quartz.

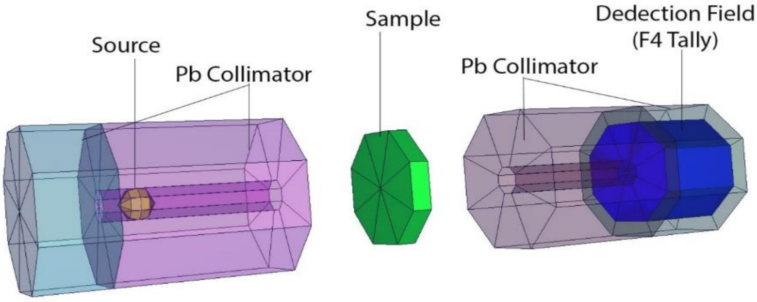

Figure 2. Simulation geometry set up with MCNP6

MCNP database uses libraries of continuous energy nuclear and atomic data. The MCNP6 simulation geometry is shown in Figure 2. The density values for W, Al, and Quartz components are 2.7 g/cm^3, 19.25 g/cm^{3,} and 2.648 g/cm^3, respectively. The total simulation setup is designed by considering the Beer-Lambert law [3]. The fast neutron total macroscopic cross-section in Al, with and without Gd_2O_3 doping, is shown as a function of the neutron energy in Figure 3 (a-b).

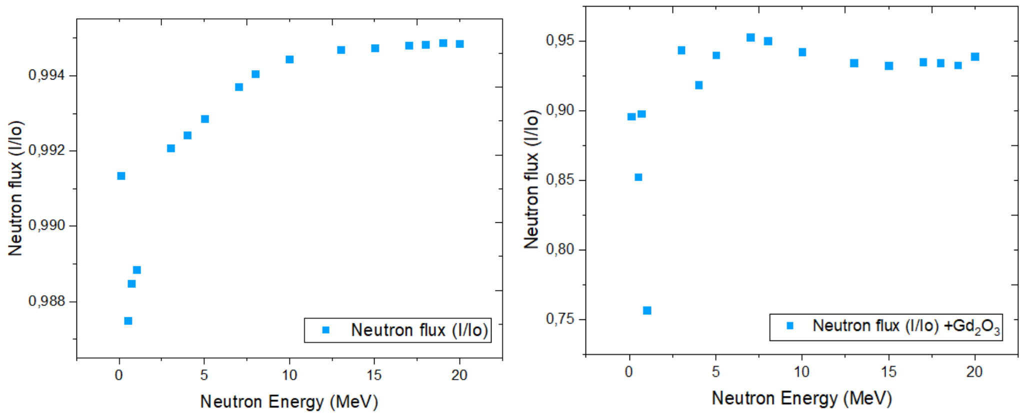

Figure 3 (a) Thermal neutron total macroscopic cross-sections of Al **(b)** Al-Gd_2O_3 doped.

4. Removal of Cross-Section

The neutron effective removal cross-section ΣR represents the probability that a neutron undergoes a first collision, which removes it from the group of the penetrating uncollided neutrons. The ΣR is approximately constant for neutron energies between 2 and 12 MeV and may be calculated by using the following formula. The neutron effective reduction cross-section for the compounds can be obtained from the values of (cm^{-1}) or ΣR / ρ (cm^{2}g^{-1}) for each component:

$$\Sigma_R = \Sigma_i \rho_i (\Sigma R/\rho)_i$$

where ρ_i and ΣR / ρ_i are, respectively, the partial density (g cm^{-3}), and the mass removal cross-section of the ith constituent (cm^2 .g^{-1}), compound or simple element [4].

PoS(ICHEP2022)1192

The removal cross-section values for fast neutrons of selected materials such as Al, W, and Quartz and Al-Gd_2O_3, W-Gd_2O_3, and Quartz-Gd_2O_3 doped are given in Figure 4 (a), (b). The results obtained showed that the removal cross-section value was higher for Al-Gd_2O_3 and W-Gd_2O_3 materials.

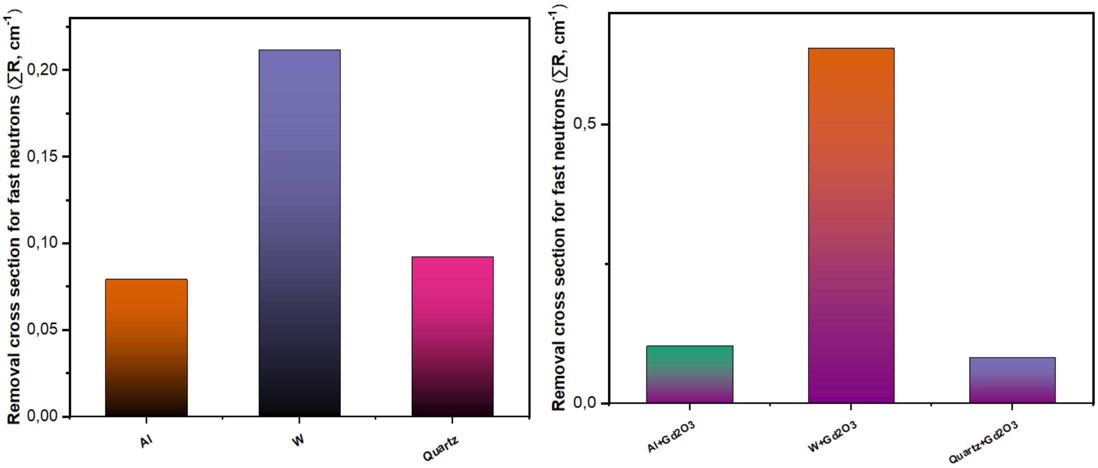

Figure 4. (a) The removal cross-section values for fast neutrons of Al, W, and Quartz **(b)** The removal cross-section values for fast neutrons of Al-Gd_2O_3, W-Gd_2O_3, and Quartz-Gd_2O_3 doped

5. Conclusion

This study investigated the variation of thermal neutron total macroscopic removal cross-sections for Al, W, and Quartz with the doping of Gd_2O_3 in different thicknesses. Since the element with the highest density is W, it has also been observed that it has the highest total macroscopic cross-section of thermal neutrons. The physical properties of the materials to be used in nuclear technology should be examined by considering both thermal and fast neutron total macroscopic sections.

Acknowledgment: We would like to thank Asst. Prof. Emrah Tiras for providing us with the research environment.

References

[1] W. Ramadan, K. Sakr, M. Sayed, et al., Investigation of acrylic/boric acid composite gel for neutron attenuation, Nuclear Engineering and Technology, S1738-5733(19)30931-3.

[2] A. Ittipongse and R. Fungklin, “Neutron activation for analysing elements in the material,” in Key Engineering Materials, 675–676, 700–703, 2016, DOI: 10.4028/www.scientific.net/KEM.675-676.700.

[3] M. Kamislioglu, Research on the effects of bismuth borate glass system on nuclear radiation shielding parameters. Results Phys. 22, 103844 (2021).

[4] M. F. Kaplan, Concrete radiation shielding nuclear physics, concrete properties, design, and construction. Longman Scientific & Technical, 1989.

PoS(ICHEP2022)1192