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Original Article

Gamma Ray Shielding Study of Barium–Bismuth–Borosilicate Glasses as Transparent Shielding Materials using MCNP-4C Code, XCOM Program, and Available Experimental Data

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A B S T R A C T

In this work, linear and mass attenuation coefficients, effective atomic number and electron density, mean free paths, and half value layer and 10^{th} value layer values of barium–bismuth–borosilicate glasses were obtained for 662 keV, 1,173 keV, and 1,332 keV gamma ray energies using MCNP-4C code and XCOM program. Then obtained data were compared with available experimental data. The MCNP-4C code and XCOM program results were in good agreement with the experimental data. Barium–bismuth–borosilicate glasses have good gamma ray shielding properties from the shielding point of view.

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1. Introduction

Today's application of radiation sources and radioactive materials in various fields, such as nuclear power plants, nuclear medicine, as well as industry and agriculture, has made it essential to study different parameters related to shielding against harmful and dangerous radiations [1–5].

Concretes are the most common radiation shielding materials, because they are inexpensive and easily adapted to any types of construction, so they are commonly used against ionizing radiations [6–8]. However, concrete has many disadvantages and can be damaged by many processes, such as the expansion of aggregates, freezing of trapped water, fire or radiant heat, bacterial corrosion, leaching, physical and chemical damage, and considerable variability in its composition and water content [9]. In addition, concrete is opaque to visible light, and with the increasing use of gamma rays in the industry of medicine and agriculture, it is important to develop transparent radiation shielding materials. Glass materials are a good option for this purpose because they are 100% recyclable, can be transparent to visible light, and their properties can be modified and changed by adding other compounds [10,11].

Various types of glasses have been introduced to different nuclear applications. In the present work, barium–bismuth–borosilicate glass has been considered. Borosilicate glass is a type of glass with silica and boron oxide constituents [12]. These glasses are well known for their very low thermal expansion coefficients, resistance to
Q4 thermal shock, and ability for transmission to visible light. Bismuth contributes to the stabilization of glass structure and improves chemical durability [11]. Moreover, bismuth and barium, due to their high atomic numbers, promote gamma ray shielding properties of the glass. The linear and mass attenuation coefficients, effective atomic number and electron density, means free paths, and half value layer (HVL) and 10th value layer (TVL) values of barium–bismuth–borosilicate glasses were calculated for ^{60}Co (1,173 keV and 1,332 keV) and ^{137}Cs (662 keV) gamma rays on the basis of the elemental composition of glass samples
Q5 using MCNP-4C code and XCOM program. The MCNP code is a general-purpose Monte Carlo radiation transport code for modeling the interaction of radiation with matter [13].

In addition, the theoretical values for mass attenuation coefficients of different elements, compounds, and mixtures have been provided by Hubbell et al. [14] and Gerward et al.
Q6 [15] and given in the form of XCOM program at energies from 1 keV to 100 GeV. Therefore, XCOM program was used for the determination of shielding characteristics and for comparison with MCNP results too. Also, in order to verify and validate simulated and calculated values, the obtained results were compared with available experimental data [16].

2. Materials and methods

2.1. Geometry of glass samples

Cylindrical geometries were employed for the modeling of glass samples. Eight sections of subcylinders, 15 cm in diameter and 2 cm in thickness, were considered for every type of sample and set on the z axis in tandem.

2.2. Source specification

Attenuation coefficients of the glass samples were measured in a narrow beam transmission geometry using sources as a planar, collimated beam and monoenergetic energies with uniform distribution of radioactive material Q7
upon them, which emit gamma rays perpendicular to the front face of the shields (in the direction of z axis). A disc source with 2 cm diameter, which was parallel to the x/y plane and the origin of which was on the z axis, was defined in an MCNP data card with ERG, PAR, POS, and DIR com- Q8
mands for energy, type of particle, position, and direction, respectively.

2.3. Material specification of glass samples

The elemental composition of glass samples depends mainly on the mix proportions and chemical composition of the materials used. According to the experimental condition [16], the barium–bismuth–borosilicate glass samples were considered as $50BaO–xBi_2O_3–(50–x)$ borosilicate glass, where x is expressed in terms of mol% (x is 0, 5, 10, 15, and 20). The chemical composition and densities of glass samples and borosilicate glass are shown in Tables 1 and 2, respectively. Also, the percentages by weight of each element in the glass samples used in the material card of MCNP are presented in Table 3.

2.4. Detector geometry and tally definition

A small cylinder, 2 cm in diameter and 2 cm in length, was considered as the detector volume and set inside a detector collimator 33 cm away from the source. The collimator is

Table 1 – Chemical composition and densities of glass samples.

Glass samples	Density (g/cm^3)	Composition (mol%)		
		BaO	Bi_2O_3	Borosilicate glass
S1	3.45	50	0	50
S2	3.67	50	5	45
S3	3.81	50	10	40
S4	3.97	50	15	35
S5	4.21	50	20	30

Table 2 – Chemical composition (by weight) of borosilicate glass.

Compound	%
B_2O_3	20.20
Na_2O	8.21
Al_2O_3	17.35
SiO_2	48.51
K_2O	5.73

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