December 2009 Volume 5 Issue 4

Trade Science Inc.

Materials Science

An Indian Journal

Full Paper

MSAIJ, 5(4), 2009 [400-404]

Partial interaction and radiation shielding properties of bismuth barium borate glass system

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Received: 15th September, 2009 ; Accepted: 25th September, 2009

ABSTRACT

The mass attenuation coefficients, partial interaction and shielding properties of xBi_2O_3: (60-x) BaO:$40B_2O_3$ where $10 \leq x \leq 50$ glass system have been investigated on the basis of the mixture rule. The results are in good agreement with the theoretical values, calculated by WinXCom. Mass attenuation coefficients and shielding properties were increased with increasing of Bi_2O_3 conentration, due to increasing of photoelectric absorption in glass samples, However the Compton scattering are also main interaction in total interaction. Their shielding properties are also better than ordinary shielding materials. These results are indicating the possibility of lead free glasses in radiation shielding materials.

KEYWORDS

Mass attenuation coefficients;
Half value layer;
Radiation shielding;
Glass.

INTRODUCTION

With increasing use of gamma-ray active isotopes in industry, medicine and agriculture, it has now become necessary to study shielding properties in various materials of technological and biological importance. There is always a need to develop material which can be used under harsh conditions of nuclear radiation exposure and can act as shielding materials[1]. For nuclear radiation shielding, a large quantity of shielding material is required, therefore, study of propagation flux of radiation flux in shielding materials is an essential requirement for shield design.

Major mass of nuclear radiation shielding consist of layers of different concretes with different compositions and densities, but considerable variations in water content in concretes add uncertainly in calculation of attenuation coefficient and related shielding parameters[2]. Moreover they are also opaque to visible light. Materials to be used for shield design should have homogeneity of density and composition. Glasses are promising materials in this regard. Several glasses have been developed for nuclear engineering applications because they accomplish the double task of allowing visibility while absorbing radiations like gamma-rays and neutron, thus protection observer[2,3].

A good shielding glass should have high value of interaction cross-section and at the same time, mechanical and optical properties must be studied. Nowadays, bismuth and barium are playing on important role in radiation glass shielding replace lead due to environmental hazardous of lead and protectionism in world economy. Good reviews on radiation shielding glass development have been published recently by several authors[1-7].

In this work, we have measured total mass attenuation coefficients and calculated the partial interaction of candidate materials to develop lead free radiation shielding glass (bismuth and barium). TBi_2O_3-BaO-B_2O_3 glasses system at 662keV were investigated and compared shielding parameters (HVL) with some standard shielding materials for useful radiation shielding glass and materials design.

THEORY

In this section we summarize theoretical relations used in the present work. The total probability for interaction μ, called the total linear (μ) attenuation coefficient, is equal to the sum of the partial probabilities[8].

$$\mu = \tau + \sigma + \kappa \qquad (1)$$

Where τ, σ and κ is the probability for photoelectric absorption, Compton scattering and pair production respectively, and can be derived from the following formula[8].

$$\tau(cm^{-1}) = aN(Z^n / E_\gamma^m)[1 - f(Z)] \qquad (2)$$

$$\sigma(cm^{-1}) = NZf(E_\gamma) \qquad (3)$$

$$\kappa(cm^{-1}) = NZ^2 f(E_\lambda, Z) \qquad (4)$$

In which a is a constant coefficient, independent of Z and $E\gamma$. Parameters m and n are constants with values between 3 and 5 depending on gamma energy. N is atomic density and Z is atomic number. Although the coherent scattering can appear but it is negligible at high energy. Theoretical values of the mass attenuation coefficients (μm) of mixture or compound have been calculated by WinXCom, based on the mixture rule[9]. Thus:

$$\frac{\mu}{\rho} = \mu_m = \sum_i^n w_i (\mu_m)_i \qquad (5)$$

where $(\mu m)_i$ is the mass attenuation coefficient for the individual element in each component, and w_i is the fractional weight of the element in the each component. This mixture is valid when the effects of molecular binding, chemical and crystalline environment are negligible. Theoretical values for the mass attenuation coefficient can be found in the tabulation by Hubbell and Seltzer. A lot of manual work can be saved by using suitable software. Berger and Hubbell developed XCOM for calculating mass attenuation coefficients or photon interaction cross-sections for any element, compound or mixture at energy from 1keV to 100GeV. Recently, XCOM was transformed to the Windows platform by Gerward et al.[10], called WinXCom.

WinXCom can generate cross-section or attenuation coefficients of element, mixture and compound on a standard energy grid, spaced approximately logarithmically, or on a grid specified by the user, or for a mix of both grids. The program provides total cross-sections and attenuation coefficients as well as partial cross-section for incoherent and coherent scattering, photoelectric absorption and pair production. For Compound, the quantities calculated are partial and total mass attenuation coefficients. Total attenuation coefficients without the contribution from coherent scattering are also given, since they are often used in gamma-rays transport calculation[11].

EXPERIMENTAL

Sample preparation and characterization

The glass samples were prepared by using high purity Bi_2O_3, $BaCO_3$ and H_3BO_3 in the composition range of (w%) xBi_2O_3:(60-x)BaO:40B_2O_3 where 10≤x≤50. Each batch weighs about 50g was melt in porcelain crucibles by placing them in an electrical furnace for an hour, at 1100°C till a bubble free liquid was formed. These melts were quenched at room temperature in air by pouring between the melt on a stainless steel plate and pressing with another stainless steel plate. The quenched glasses were annealed at 500°C for 3hour to reduce thermal stress, and cooled down to room temperature. All glass samples were cut and polished in proper shape for further studies. At the room temperature, densities (ρ) of all glass samples were measured by Archimedes's method using xylene as an immersion liquid. The density is calculated according to the formula;

$$\rho = \frac{w_A}{w_A - w_B} \times \rho_{xylene} \ g/cm^3 \qquad (7)$$

where w_A the weight of the sample in air, is the weight of the sample in xylene, and density of xylene is 0.863g/cm^3.

Transmission experiment and data processing method

The block diagram of good geometry set up is shown in Figure 1. The source and absorber system were mounted on composite of adjustable stands. With the help of a screw arrangement the platform having material was also made capable of movement in the transverse direction to the incident beam for proper alignment (In this experiment fix at 13cm). The sample detector solid angle was <0.5×10-4 sr. The Cs^{137} radioactive source of 15m Ci strength were obtain from office of atomic for peace (OAP), Thailand. The incident and transmitted gamma-rays intensities were determined for a fixed preset time in each experiment by recording the corresponding counts, using the 2″×2″ NaI(Tl) detector (BICRON model 2M2/2) having an energy resolution of 10.2% at 662keV, with CANNERRA PMT base model 802-5. The statistical uncertainly was kept below 0.3% by choosing the maximum counting time (fixed present time at 3,000 second) so that 105-106 counts were recorded in the full energy peak[2]. The dead time in this experiment was 0.73%-1.37%. The pulse shaping time is 0.5μs. The optimum sample thickness was selected in this experiment, suggest from published literature[12-14]. The statistical error analysis in this experiment calculated from standard error (ratio of standard deviation to mean) of 3 part (i)ray-sum measurement, (ii)density measurement and (iii)thickness measurement. Finally, the total standard error has been determined from combine errors for the ray-sum measurement, density measurement and thickness measurement in quadrature[12,13]. The measurements were repeated three times to improve the statistical error. The spectra were recorded using by a CANBERRA (Accuspec NaI plus) PC-based multichannel analyzer card. The validation of gamma-rays transmission measurement was checked by measure lead (Pb) slab in cover range of ray-sum in this research (ray-sum in this research about 0.5).The linear attenuation coefficients (μ) for Pb can determined from slope of graph plot of ray-sum with thickness. The deviations from linearity of graph here will indicate problems due to scatter and beam hardening respectively. From the result, the system is linearity in this experimental region (R2=0.9976), and slope=1.17cm^{-1} which is in good agreement with its theoretical value of 1.24 cm^{-1}, calculated from WinXCom program.

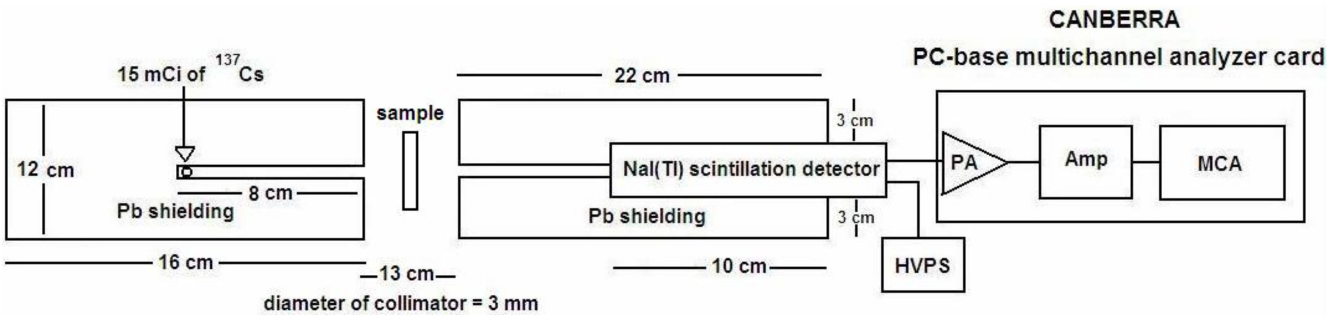

Figure 1 : Experimental setup of transmission method

RESULTS AND DISCUSSION

The chemical composition, density and mass-thickness of glass samples are given in TABLE 1. It is seen that the density of glass samples increases with higher Bi_2O_3 content, due to higher molecular weight of Bi_2O_3 compared to that of BaO, therefore it is expected result.

TABLE 2 lists the experimental and theoretical values of total mass attenuation coefficients of xBi_2O_3:(60-x)BaO:40B_2O_3 glass system, where 10≤x≤50. In general, the experimental values agree with the theoretical values which are calculated from WinXCom within experimental error 0.00%-1.34%, show that the mass attenuation coefficients increase with Bi_2O_3 content, due

TABLE 1 : Chemical composition, densities and mass thickness of glass samples

Composition (% w)			Density(g/cm^3)	Mass Thickness (g/cm^2)
xBi_2O_3	(60-x)BaO	$40B_2O_3$		
10	50	40	4.48	7.44
20	40	40	4.95	7.62
30	30	40	5.14	7.56
40	20	40	5.49	7.69
50	10	40	5.58	7.70

TABLE 2 : Total mass attenuation coefficients (cm^2/g) of Bi_2O_3-BaO-B_2O_3 glass system

% of Bi_2O_3	$(\mu_m)_{th}$($\times10^{-2}$ cm^2/g)	$(\mu_m)_{ex}$($\times10^{-2}$ cm^2/g)	%RD*
10	7.99	7.98±1.07	0.13
20	8.30	8.30±1.40	0.00
30	8.61	8.57±0.68	0.47
40	8.93	8.81±0.65	1.34
50	9.24	9.32±0.50	0.87

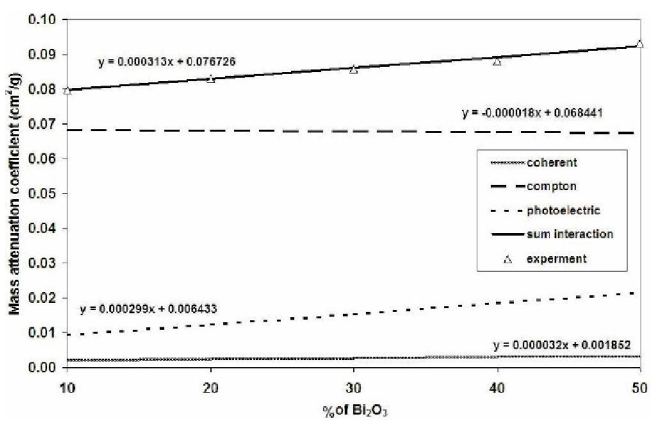

Figure 2 : Mass attenuation coefficients with partial interactions of glass samples as a function Bi_2O_3 content

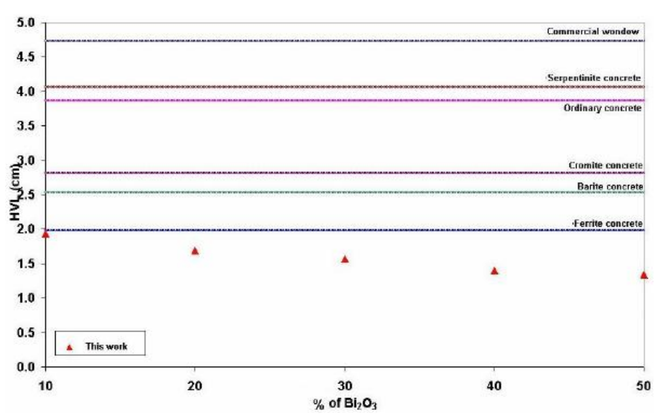

Figure 3 : The half value layer of xBi_2O_3:(60-x)BaO:$40B_2O_3$ glass system (this work) compare with some standard radiation shielding materials

to increasing of photoelectric absorption interaction of all glass samples as show in Figure 2. Similarly result is good agreement in case of Bi_2O_3-B_2O_3 were published by K.Singh et al.[3]. The Compton scattering interactions are also comparable for the whole range of glasses studied, and the decreasing rate is very tiny with increasing of Bi_2O_3 concentration. The pair production interaction does not occur due to the energy less than 1.02MeV. The coherent scattering interactions were observed, but have very little effect at this energy. However, Compton scattering gives dominant contribution to the total mass attenuation coefficients for studied all glass samples.

In addition, Figure 3 shows the half value layer (HVL) of xBi_2O_3: (60-x) BaO:$40B_2O_3$ glass system in this research compare with some standard radiation shielding materials taken from literature[1,15]. It has been observed that HVL of xBi_2O_3:(60-x) BaO:$40B_2O_3$ glasses system were decrease with increasing of Bi_2O_3 concentration, reflecting the better shielding properties, and better than some standard radiation shielding materials, The results imply very useful of Bi and Ba component in radiation glass shielding. Beside all mentioned usefulness of new material, the development of lead-free radiation protecting glass will leave non-toxically impact to our environment.

CONCLUSIONS

In conclusion, the mass attenuation coefficients, partial interaction and half value layer of xBi_2O_3 :(60-x)BaO:$40B_2O_3$ glass system have been investigated on the basis of the mixture rule. The results are good agreement with the theoretical values, calculated by WinXCom. All shielding parameters are increase with Bi_2O_3 content. This may be due to the dominance of incoherent (Compton) scattering in this energy (662keV). Their shielding properties are also better standard shielding materials. Moreover, it has been also observed that the very useful of Bi and Ba component in shielding glass matrix. These results are indicating the possibility of lead free glasses in radiation shielding materials.

ACKNOWLEDGEMENTS

The authors would like to thank to National Research Council of Thailand (NRCT) for funding this research and thanks to Professor L.Gerward of Department of Physics, Technical University of Denmark for providing the WinXCom program.

REFERENCES

[1] N.Singh, K.J.Singh, K.Singh, H.Singh; Radiat.Meas., **41**, 84 **(2006)**.

[2] N.Singh, K.J.Singh, K.Singh, H.Singh; Nucl.Instr.and Meth.B, **225**, 305 **(2004)**.

[3] K.Singh, H.Singh, V.Sharma, R.Nathuram, A.Khanna, R.Kumar, S.S.Bhatti, H.S.Sahota; Nucl.Instr.and Meth.B, **194**, 1 **(2002)**.

[4] K.Singh, H.Singh, G.Sharma, L.Gerward, A.Khanna, R.Kumar, R.Nathuram, H.S.Sahota; Radiat.Phys.Chem., **72**, 225 **(2005)**.

[5] K.J.Singh, N.Singh, R.S.Kaundal, K.Singh; Nucl.Instr.and Meth.B, **266**, 944 **(2008)**.

[6] S.Singh, A.Kumar, D.Singh, K.S.Thind, G.S.Mudaha; Nucl.Instr.and Meth.B, **266**, 140 **(2008)**.

[7] H.Singh, K.Singh, L.Gerward, K.Singh, H.S.Sahota, R.Nathuram; Nucl.Instr.and Meth.B, **207**, 257 **(2003)**.

[8] M.Jalali, A.Mohammadi; J.Envi.Rad., **77**, 523 **(2008)**.

[9] D.F.Jackson, D.J.Hawkes; Phys.Rep., **70**, 169 **(1981)**.

[10] L.Gerward, N.Guilbert, K.B.Jensen, H.Levring; Rad.Phys.Chem., **60**, 23 **(2001)**.

[11] L.Gerward, N.Guilbert, K.B.Jensen, H.Levring; Rad.Phys.Chem., **71**, 653 **(2004)**.

[12] D.C.Creagh, J.H.Hubbell; Acta Cryst.A, **43**, 102 **(1987)**.

[13] D.C.Creagh, J.H.Hubbell; Acta Cryst.A, **46**, 402 **(1990)**.

[14] B.Nordfors; Ark.Fys., **18**, 37 **(1960)**.

[15] J.Kaewkhao; Ph.D. Thesis, King mongkut's University of Technology Thonburi, Thailand 64 **(2008)**.