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Technical Note

Study of photon interactions and shielding properties of silicate glasses containing Bi_2O_3, BaO and PbO in the energy region of 1 keV to 100 GeV

N. Chanthima [a], J. Kaewkhao [b,c,*], P. Limsuwan [a,c]

[a] Department of Physics, Faculty of Science, King Mongkut's University of Technology Thonburi, Bangkok 10140, Thailand
[b] Center of Excellence in Glass Technology and Materials Science (CEGM), Faculty of Science and Technology, Nakhon Pathom Rajabhat University, Nakorn Pathom 73000, Thailand
[c] Thailand Center of Excellence in Physics, Commission of Higher Education, Ministry of Education, 328 Si Ayutthaya Rd., Bangkok 10400, Thailand

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ABSTRACT

The mass attenuation coefficient (μ/ρ), effective atomic number (Z_{eff}), effective electron density ($N_{e,eff}$) and half-value layer (HVL) of xR_mO_n:$(1-x)SiO_2$ glass system (where R_mO_n are Bi_2O_3, PbO and BaO, with $0.3 \leqslant x \leqslant 0.7$ is fraction by weight) have been calculated by theoretical approach using WinXCom program in the energy region from 1 keV to 100 GeV. Also, the HVL of these glass samples has been compared with some standard shielding concretes. The variations of μ/ρ, Z_{eff}, $N_{e,eff}$ and HVL with energy are shown graphically only for total photon interaction. It has been observed that the value of these parameters has been changed with energy and composition of the silicate glasses. The better shielding properties of glass samples were obtained compared with some standard shielding concretes. These results indicated that glasses in the present study can be used as radiation shielding materials.

1. Introduction

In dealing with a compound or a mixture of molecules, such as air, water, tissue and bone, it is sometimes convenient to describe the mixture by an effective atomic number (Z_{eff}) (Johns and Cunningham, 1983). The parameter μ/ρ and Z_{eff} is a basic quantity for determining the penetration of gamma-ray photons in matter. The Z_{eff} and the effective electron density ($N_{e,eff}$) is also a convenient parameter that in some cases, viz. designing radiation shielding, computing absorbed dose, energy absorption and build-up factor, represent radiation interaction with matter (Kaewkhao et al., 2008).

The advantage of glass is the ease to fabrication, good homogeneity and excellent transparency, and its radiation shielding properties can be improved by the addition of oxide in the glass formula. Glass materials have been considered a good substitute to concrete (Singh et al., 2005). Silica (SiO_2) is one of the chief constituents of the earth's crust. Silica is a naturally occurring compound that can be found in many forms such as sand, quartz, opal, rock and sea floor sediments. It is also a vital element for the life of animals and plants. The silicate glasses are the most commonly available commercial glasses owning to ease of fabrication and excellent transparency to visible light (Singh et al., 2008a).

Several approaches (Kaewkhao and Limsuwan, 2010; Kirdsiri et al., 2009, 2011; Manohara et al., 2009; Singh et al., 2002, 2005, 2003, 2004, 2006, 2008a,b) have been studied; glass samples could be use as a radiation shielding material. They are studies on borate and phosphate glass compared with some standard concrete. El Batal (2007) has reported detailed UV–visible, infrared and Raman spectroscopic of bismuth silicate glass before and after gamma irradiation. The UV-near-visible spectra could be assumed that the raw materials have trace iron impurities and Bi^{3+} ions possible sharing. The thermal properties and density are correlated with high polarizability of the Bi^{3+} cations. Singh et al. (2008a) have shown the presence of half-value layer, HVL, in lead silicate glass at 662, 1173 and 1332 keV with some standard concrete. Recently, Kurudirek et al. (2010) calculated effective atomic number and mean free path of lead borate glass, barium phosphate glass and barium–fly ash borate glass by employing an experiment of Kirdsiri et al. (2009), Kaewkhao et al. (2010) and Singh et al. (2008b), respectively, in the energy region of 1 keV to 100 GeV. El Batal (2007) and Singh et al. (2008a) are almost no such reported for Z_{eff}, and $N_{e,eff}$ and Kurudirek et al. (2010) no reported in silicate glass. These points helped us to carry out the present work. This paper is different from previous literature because we are reporting shielding properties in wide energy region of silicate glass. Nowadays, over 95% of widow and glass in commercial is silicate based glass. So, these data are very important.

* Corresponding author at: Center of Excellence in Glass Technology and Materials Science (CEGM), Faculty of Science and Technology, Nakhon Pathom Rajabhat University, Nakorn Pathom 73000, Thailand. Tel./fax: +6634 261 065.
E-mail address: mink110@hotmail.com (J. Kaewkhao).

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Low toxicity makes bismuth (Bi) a potential substitute for lead (Pb) in many applications. In some countries, bismuth–tin alloy is already used instead of Pb for shot. 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.

The main objective of this work is to (a) investigate μ/ρ, Z_{eff} and $N_{e,eff}$ for photon interactions of xR_mO_n:$(1-x)SiO_2$ glass system (where R_mO_n are Bi_2O_3, PbO and BaO, with $0.3 \leqslant x \leqslant 0.7$ is fraction by weight) in the energy region of 1 keV to 100 GeV, (b) compare the radiation shielding properties between the glass in which its composition has been modified and seven types of concrete (Bashter, 1997). The BaO contained in glass are candidate materials for the development of radiation shielding glass. From our previous experimental results (Kirdsiri et al., 2011), we can deduce values of glass samples for half-value layer (HVL).

2. Calculation method

The basic relation for calculating the effective atomic number, Z_{eff}, for all types of materials, compounds as well as mixtures can be written in terms of the fraction abundance as (Manohara et al., 2009):

Table 1
Chemical composition of glasses studied in the present work. Sample no. = sample number, $\langle Z \rangle$ = mean atomic number, $\langle N_e \rangle$ = mean electron density. Z_{eff} and $N_{e,eff}$ are the effective atomic numbers and effective electron density for photon interaction, respectively. Maximum and minimum values are given for the energy range considered (1 keV to 1 GeV).

Sample no.	Chemical composition (weight fraction)				$\langle Z \rangle$	Z_{eff}		$\langle N_e \rangle \times 10^{23}$	$N_{e,eff} \times 10^{23}$	
	BaO	PbO	Bi_2O_3	SiO_2		Min	Max		Min	Max
1	0.3	–	–	0.7	12.22	12.40	47.08	2.86	2.90	11.01
2	0.4	–	–	0.6	13.26	13.53	49.71	2.81	2.87	10.53
3	0.5	–	–	0.5	14.56	14.92	51.49	2.76	2.83	9.76
4	0.6	–	–	0.4	16.19	16.67	52.77	2.71	2.79	8.83
5	0.7	–	–	0.3	18.33	18.93	53.47	2.66	2.75	7.80
6	–	0.3	–	0.7	12.50	13.17	58.72	2.83	2.98	13.31
7	–	0.4	–	0.6	13.74	14.72	64.89	2.77	2.97	13.10
8	–	0.5	–	0.5	15.33	16.68	69.45	2.72	2.96	12.31
9	–	0.6	–	0.4	17.42	19.23	72.95	2.66	2.93	11.13
10	–	0.7	–	0.3	20.33	22.71	75.72	2.60	2.91	9.69
11	–	–	0.3	0.7	12.36	13.03	59.10	2.84	2.99	13.58
12	–	–	0.4	0.6	13.51	14.48	65.35	2.79	2.99	13.47
13	–	–	0.5	0.5	14.95	16.29	69.97	2.73	2.97	12.78
14	–	–	0.6	0.4	16.83	18.60	73.53	2.68	2.96	11.69
15	–	–	0.7	0.3	19.35	21.67	76.35	2.62	2.93	10.34

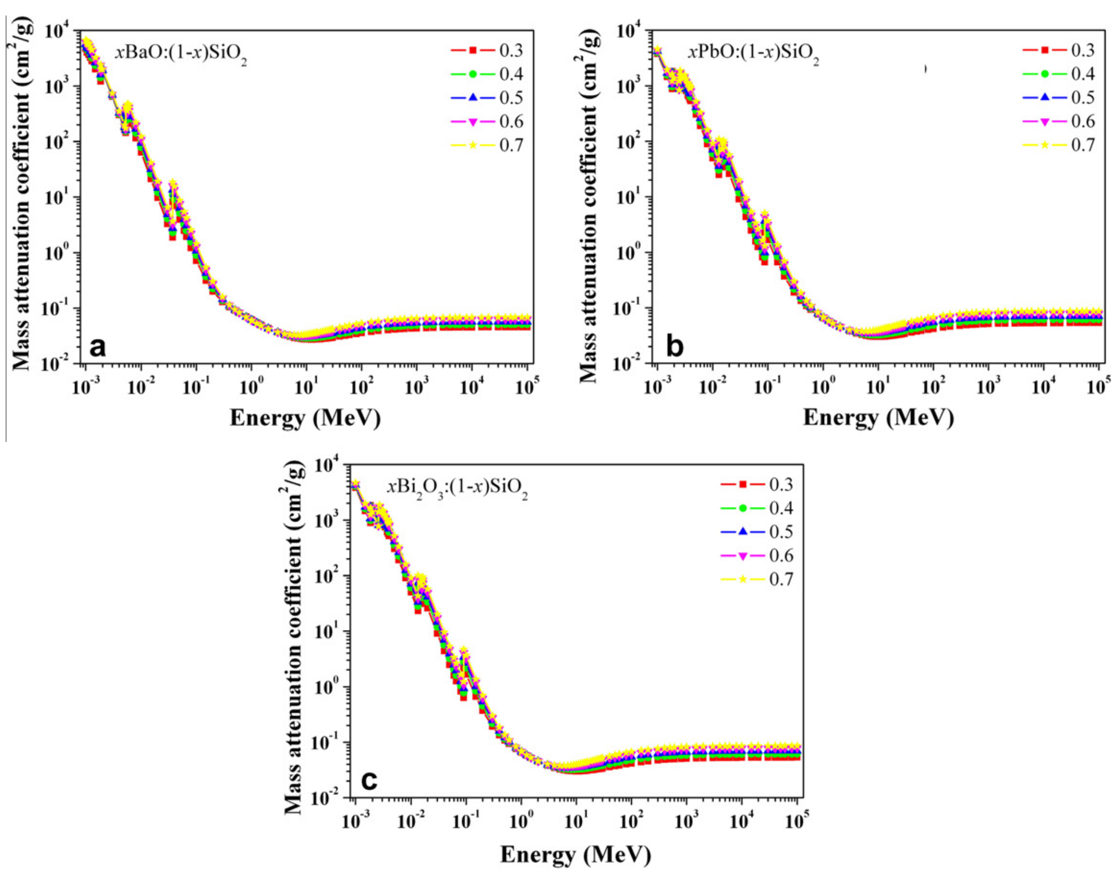

Fig. 1. The variation of mass attenuation coefficient of silicate glasses with photon energy for total interaction (with coherent). (a) $xBaO$:$(1-x)SiO_2$. (b) $xPbO$:$(1-x)SiO_2$. (c) xBi_2O_3:$(1-x)SiO_2$.