Journal of Alloys and Compounds 752 (2018) 61–67

Contents lists available at ScienceDirect

Journal of Alloys and Compounds

journal homepage: http://www.elsevier.com/locate/jalcom

# Gamma ray buildup factors of lithium borate glasses doped with minerals

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A R T I C L E I N F O

*Article history:*
Received 14 December 2017
Received in revised form
6 April 2018
Accepted 8 April 2018
Available online 11 April 2018

*Keywords:*
Lithium borate glass types
Gamma ray
Buildup factor
Shielding

A B S T R A C T

Five parameters (G-P) fitting method was used to calculate the gamma ray energy absorption and exposure buildup factor values of barite-doped, limonite-doped, serpentine-doped and undoped lithium borate glass types for incident photon energy, between 0.015 MeV and 15 MeV, and penetration depths, 40 mean free path. It was observed that the buildup factor values vary with not only different incident gamma energy values, but also chemical composition of glass samples. According to our results, the barite and limonite doped glasses (B1, B2 and L2) have the lowest values of energy absorption and exposure buildup factors. Among the selected sample of glasses, the barite and limonite-doped glasses possessed superior gamma-ray shielding effectiveness due to their higher equivalent atomic number values and the lower energy absorption and exposure buildup factor values. In other words, the presence of highly equivalent atomic number minerals improves the gamma ray shielding characteristics of the lithium borate glasses. Moreover, EABF and EBF values were compared and discussed.


## 1. Introduction

Radiation shielding glasses could be considered to be used when transparent protection against ionizing radiation is essential. Radiation shielding glasses used at X-ray rooms, operating theatres, radiation therapy rooms, dental clinics, laboratories, nuclear power plants etc have gotten researcher attention [1–3]. Among the radiation shielding glasses, borate glasses have been investigated extensively due to industry demands [4–6]. Comparing with other glasses such as metal-oxide or ordinary glasses, the borate glasses have the lowest melting point and the highest bond strength and thermal stability [7,8]. Lithium borate glass is utilized in state-of-the-art technologies as vacuum ultraviolet (VUV) optics, semiconductor lithography, phosphors, lasers, solar energy converters etc … [9].

Barite ($BaSO_4$) is a natural form of barium sulfate and is widely found in nature. Although barite contains a heavy metal (barium), it is not toxic material and not dangerous for environmental. Moreover, it is a widely recognized material within industrial, medical (X-ray shielding) and manufacturing (as a pigment in paints and as a weighted filler for paper, cloth and rubber) areas due to high density value of barite. In addition, Barite is also used to make high-density concrete to block x-ray emissions in hospitals, power plants, and laboratories [10].

Limonite ($2Fe_2O_3 \cdot 3H_2O$) is found in the form of reddish-brown hydrated iron oxide, deposits of which are found mainly in low-lying areas. Serpentine ($3MgO \cdot 2SiO_2 \cdot 2H_2O$) is one of the basic ores for asbestos and consists mainly of hydrated magnesium silicate. Finally, considering limonite and serpentine ores featuring high hydrogen and iron, they could potentially be used in shielding concrete (principally neutron and gamma) for nuclear power plants [10].

During gamma rays interact with matter through Compton scattering, the incident photon energy reduces and its direction also changes which give rise to scattered secondary photons which can be estimated by the buildup factor. The gamma ray buildup factor is a multiplicative factor used to obtain the corrected response to the uncollided photons by including the contribution of scattered photons. It can be defined as the ratio of the total detector response to uncollided photons. There are two types of buildup factor; namely the energy absorption buildup factor (EABF) and the exposure buildup factor (EBF). EABF is the buildup factor in which the quantity of interest is the absorbed or deposited energy in the interested material and the detector response function is that of

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https://doi.org/10.1016/j.jallcom.2018.04.106
0925-8388/

absorption for under investigated material. EBF is the quantity of interest is the exposure and the detector response function is that of absorption in air [11]. There are many studies devoted to obtain buildup factors of different areas like radiation shielding [12–15], radiation dosimetry [16,17]. However, in the literature, there are relatively a few studies for gamma-ray attenuation properties of glasses [18–24].

This study intends to investigate gamma-ray shielding properties of barite-, limonite- and serpentine-doped and undoped lithium borate glass. The data for buildup factors up to 40 mfp (mean free path), the average distance traveled by a photon before interacting with material, for glass samples were generated by G-P fitting formula. The main emphasis was focused on the dependence on EABF and EBF of the incident photon energy, penetration depth and equivalent atomic number of glass samples. According to our results, doped lithium borate glasses are good candidate to be used for radiation shielding purpose.

## 2. Preparation of glass types

The melt-quenching technique was employed to create the following set of the glass types, namely undoped (C – Control glass), barite-doped (B1,B2), limonite-doped (L1,L2) and serpentine-doped (S1,S2) lithium borate glass types. Initially, the mixtures, which corresponds to the desired rate (Table 1), were melted within a platinum crucible in an electrical furnace at the 970 °C temperature at least 18 min to obtain homogenous melt. After, the melted samples were put into the disc-shaped platinum plate and then left to quenching progress at room temperature. By the way, the XRF method was implemented to measure the chemical content of barite, limonite, and serpentine (see outcomes in Table 2) at the beginning. In the final process, the materials' densities were measured by Archimede's principle (Table 1).

## 3. Calculation of build-up factors

The G-P fitting parameters were calculated a similar interpolation procedure adopted as in the case of the equivalent atomic number. The G-P fitting parameters for elements were obtained from the ANSI/ANS-6.4.3 standard reference database which provides the G-P fitting parameters from beryllium to iron in the energy region of 0.015–15 MeV up to 40 mfp. Then, these fitting parameters were used to calculate the energy absorption and exposure buildup factors from the G-P fitting formulas [25]:

$$B(E,x) = 1 + \frac{b-1}{b+1}(K^x - 1) \quad \text{for } K \neq 1 \tag{8}$$

$$B(E,x) = 1 + (b-1)x \quad \text{for } K = 1 \tag{9}$$

where,

**Table 2**
The chemical content of the ores.

| Compound | Barite (%) | Limonite (%) | Serpentine (%) |
|---|---|---|---|
| $SiO_2$ | 2.06 | 0.001 | 37.6 |
| CaO | 0.84 | 5.73 | 4.82 |
| MgO | 0.51 | 2.08 | 38.40 |
| $Al_2O_3$ | 0.36 | 1.90 | 3.42 |
| $Fe_2O_3$ | 0.05 | 70.94 | 5.10 |
| NaCl | 0.10 | | |
| $CaCO_3$ | 1.98 | | |
| $K_2O$ | 0.03 | 0.77 | |
| MnO | 0.09 | 0.08 | |
| $BaSO_4$ | 93.1 | | |
| SrO | 0.88 | 0.005 | |
| FeO | | | 2.04 |
| $Na_2O$ | | 2.94 | 1.17 |
| CuO | | 0.03 | |
| BaO | | | |
| $P_2O_5$ | | 0.34 | |
| $TiO_2$ | | 0.30 | |
| $Cr_2O_3$ | | | |
| $SO_3$ | | | |
| $H_2O$ | | 13.7 | 10.26 |

**Table 3**
Equivalent atomic numbers of the glasses for the energy range 0.015–15 MeV.

| Energy (MeV) | Equivalent atomic number | | | | | | |
|---|---|---|---|---|---|---|---|
| | C | B1 | B2 | L1 | L2 | S1 | S2 |
| 0.015 | 7.259 | 12.514 | 15.239 | 11.846 | 14.207 | 8.871 | 9.967 |
| 0.02 | 7.267 | 12.941 | 15.771 | 12.130 | 14.555 | 8.961 | 10.101 |
| 0.03 | 7.271 | 13.445 | 16.344 | 12.482 | 14.943 | 9.093 | 10.276 |
| 0.04 | 7.272 | 22.293 | 27.842 | 12.705 | 15.194 | 9.176 | 10.384 |
| 0.05 | 7.273 | 23.014 | 28.672 | 12.866 | 15.369 | 9.232 | 10.459 |
| 0.06 | 7.275 | 23.548 | 29.253 | 12.995 | 15.505 | 9.276 | 10.517 |
| 0.08 | 7.278 | 24.335 | 30.101 | 13.161 | 15.691 | 9.340 | 10.603 |
| 0.1 | 7.282 | 24.878 | 30.680 | 13.273 | 15.820 | 9.386 | 10.664 |
| 0.15 | 7.286 | 25.733 | 31.585 | 13.448 | 16.017 | 9.460 | 10.765 |
| 0.2 | 7.287 | 26.254 | 32.113 | 13.558 | 16.123 | 9.508 | 10.827 |
| 0.3 | 7.291 | 26.873 | 32.599 | 13.684 | 16.242 | 9.564 | 10.903 |
| 0.4 | 7.292 | 27.229 | 32.853 | 13.756 | 16.308 | 9.592 | 10.941 |
| 0.5 | 7.293 | 27.449 | 33.007 | 13.798 | 16.348 | 9.611 | 10.965 |
| 0.6 | 7.294 | 27.595 | 33.106 | 13.823 | 16.373 | 9.624 | 10.982 |
| 0.8 | 7.294 | 27.739 | 33.208 | 13.844 | 16.392 | 9.634 | 10.994 |
| 1 | 7.294 | 27.774 | 33.229 | 13.845 | 16.393 | 9.633 | 10.995 |
| 1.5 | 6.855 | 21.800 | 29.393 | 9.716 | 12.232 | 7.779 | 8.697 |
| 2 | 6.836 | 14.446 | 21.286 | 8.881 | 10.859 | 7.625 | 8.410 |
| 3 | 6.833 | 11.997 | 17.165 | 8.687 | 10.522 | 7.591 | 8.345 |
| 4 | 6.830 | 11.452 | 16.159 | 8.636 | 10.431 | 7.582 | 8.327 |
| 5 | 6.829 | 11.221 | 15.722 | 8.612 | 10.387 | 7.577 | 8.318 |
| 6 | 6.827 | 11.078 | 15.441 | 8.600 | 10.365 | 7.574 | 8.314 |
| 8 | 6.825 | 10.925 | 15.154 | 8.585 | 10.337 | 7.572 | 8.309 |
| 10 | 6.823 | 10.855 | 15.019 | 8.576 | 10.320 | 7.570 | 8.306 |
| 15 | 6.820 | 10.807 | 14.929 | 8.567 | 10.304 | 7.565 | 8.303 |

**Table 1**
Compositions and some properties of the glasses.

| Sample code | Content (wt%) | | | | | Density (g/cm$^3$) | Transparency |
|---|---|---|---|---|---|---|---|
| | Barite | Limonite | Serpentine | $LiBO_2$ | $Li_2B_4O_7$ | | |
| C | – | – | – | 49 | 51 | 2.22 | Transparent |
| B1 | 17 | – | – | 41 | 42 | 2.57 | Transparent |
| B2 | 34 | – | – | 32 | 34 | 2.69 | Transparent |
| L1 | – | 17 | – | 41 | 42 | 2.43 | Opaque black glass |
| L2 | – | 34 | – | 32 | 34 | 2.51 | Opaque black glass |
| S1 | – | – | 17 | 41 | 42 | 2.28 | Opaque yellow glass |
| S2 | – | – | 34 | 32 | 34 | 2.39 | Opaque yellow glass |