International Journal of Advance Research in Science and Engineering
Volume No.07, Special Issue No.08, March 2018
www.ijarse.com
IJARSE
ISSN: 2319-8354

EXPOSURE BUILDUP FACTOR STUDIES FOR SOME Pb-Zn BINARY ALLOYS

Taranjot Kaur[1], Jeewan Sharma[2], Tejbir Singh[1]

[1]*Physics Department, Sri Guru Granth Sahib World University, Fatehgarh Sahib, 140 407, Punjab, India*
[2]*Nanotechnology Department, Sri Guru Granth Sahib World University, Fatehgarh Sahib, Punjab, India*

ABSTRACT

The present study aims to investigate the radiation protection efficiency of xPb(100-x)Zn(where x = 20, 40, 60, 80) binary alloys in terms of effective atomic number (Z_{eff}) and gamma ray exposure buildup factor (EBF). Z_{eff} has been calculated using atomic to electronic cross section ratio method and EBF has been calculated using five parametric geometric progression fitting formula for the selected binary alloys in 0.015 MeV – 15.0 MeV energy range. The EBF values for the selected binary alloys shows significant variations with photon energy, chemical composition and penetration depth. The minimum values of EBF has been observed for Pb80Zn20 alloy sample; which indicates better radiation protection efficiency of this alloy.

Keywords: Exposure buildup factor, Pb-Zn binary alloy, Radiation protection efficiency

I. INTRODUCTION

The key factor which plays major role in the designing of a protective shielding system is prevention from highly penetrating rays (x-rays and gamma rays). To have better attenuation from these rays, material should have high atomic number (Z) and density (ρ). With theseproperties, Lead (Pb) enjoys the advantage of being dense (11.34 g/cm^3) and have high atomic number (Z=82). It has unique properties like high ductility, malleability, low melting point, corrosion resistance and softness etc., which made its widespread use in various fields such as in ceramics, automobiles, paints, storage batteries and shielding etc [1]. Owing to toxic nature and heavy weight of lead element, its use in such fields is of prime concern[2]. In order to reduce the toxicity of lead, it should be sheathed in/replaced by concrete [3] or can be alloyed [4-5] with other elements. This makes its advantageous use with reduced quantity in many areas like shielding blocks, industrial use and in radiotherapy etc. When Pb-cement ratio is increased in concrete, its strength has been decreased [6]. It has been observed that alloys have superior, improved and enhanced qualities in comparison to constituent elements [7]. Mostly, alloying results in increase in ductility, hardness, tensile strength, elastic modulus, creep resistance etc. [8-9]. Due to these qualities offered by alloys, many researchers have found its potential use in protection from harmful radiations. El- Khatib et al. [10] has explored the shielding effectiveness of brass, bronze, Pb-Sb, Steel, Al-Si alloys. Murty et al. [11] determined mass attenuation coefficient

(μ_m), Z_{eff} and electron density (N_e) for W/Cu alloys. Singh et al. [12] explored the efficiency of vanadium and nickel alloys by determining its μ_m , Z_{eff} and N_e. Sharma et al. [13] explored shielding effectiveness of binary alloys such as Zn-Sn, Sn-Pb and Zn-Pb. Kaur et al. [14] reported the scope of Pb-Zn alloys in gamma rays shield designing.

The gamma ray buildup factor is most useful parameter for calculating the distribution of flux within the material. EBF is defined as the ratio of correct value of photon flux after its transmission through target material to the uncollided photon beam flux measured at particular point. American National Standards ANSI/ANS 6.4.3 [15] has utilized the geometric progression (G-P) method and provided buildup factor data for 23 elements, one compound and two mixtures i.e. (air and water) and for concrete in the energy range 0.015 – 15.0 MeV and up to penetration depth of 40 mean free paths (mfp). In extension to our previous work [14], this study aims to investigate the radiation protection efficiency of Pb-Zn binary alloys in terms of EBF.

II. COMPUTATIONAL WORK

2.1 Effective atomic number (Z_{eff})

The effective atomic number is a parameter similar to atomic number of elements. However, it is energy dependent parameter and is assigned to compounds/mixtures for the visualization of photon interaction of photons within irradiating material. Z_{eff} values for the selected alloys werecomputed using atomic (σ_a) to electronic (σ_e) cross sectionsratio method [14].

$$Z_{eff} = \frac{\sigma_a}{\sigma_e} \tag{1}$$

2.2 G-P fitting exposure parameters (b, c, a, X_k and d)

The Z_{eff} values of the selected alloys as listed in Table 1 were used in logarithmic interpolation methodto obtain G-P fitting exposure parametersfor the selected alloys as follows [7]:

$$C = \frac{C_1(\log Z_2 - \log Z_{eff}) + C_2(\log Z_{eff} - \log Z_1)}{\log Z_2 - \log Z_1} \tag{2}$$

where C_1 and C_2 are the values of the G-P fitting parameters corresponding to the atomic numbers of Z_1 and Z_2, respectively at specific energy. Z_1 and Z_2 are the elemental atomic numbers, within which Z_{eff} of selected alloys lies. G-P fitting exposure parameters of seven elements ($_{29}$Cu, $_{42}$Mo, $_{50}$Sn, $_{57}$La, $_{64}$Gd, $_{72}$W, $_{82}$Pb) from ANS 6.4.3 were used for present computations.

2.3 Exposure buildup factor (EBF)

The exposure buildup factor for the selected alloys using G-P fitting parameters in the 0.015 MeV – 15.0 MeV energy region and upto penetration depth of 40 mfp has been done using the following formula [7]:

$$B(E,x) = 1 + \frac{b-1}{K-1}(K^x - 1) \quad for\ K \neq 1\ (3)$$

$$B(E,x) = 1 + (b-1)x \quad for\ K = 1\ (4)$$

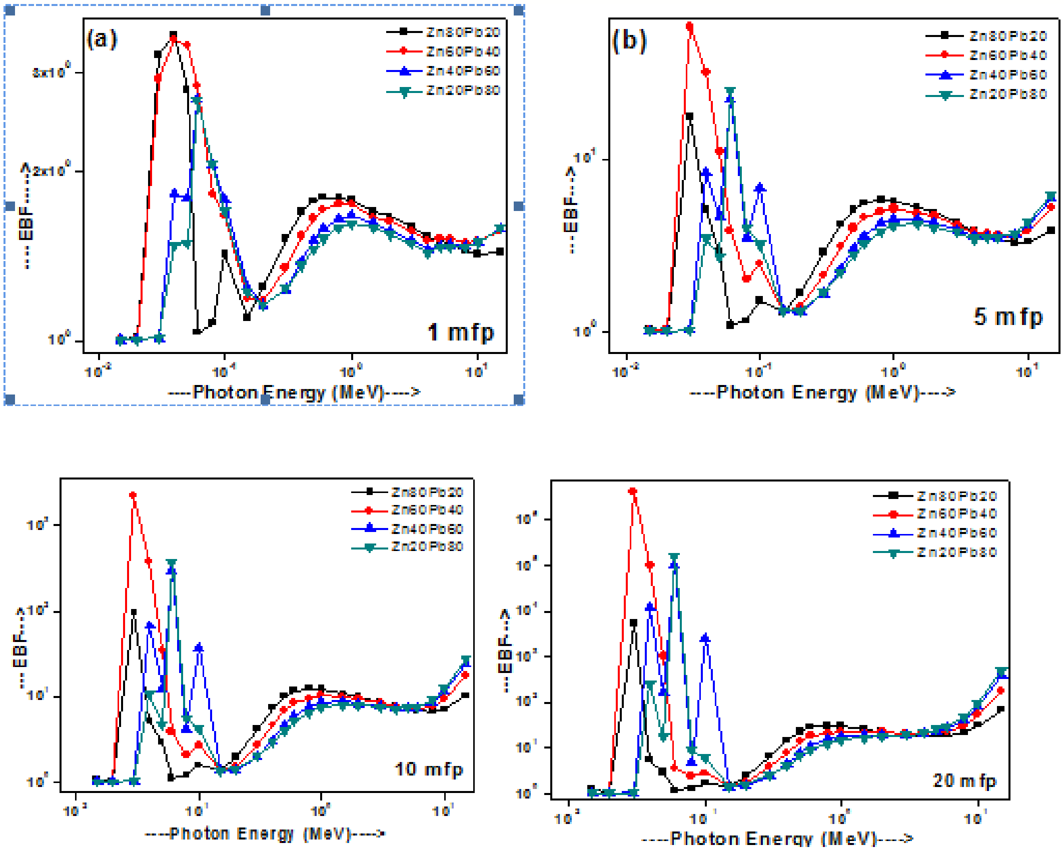
where, $K(E,x) = cx^a + d\,\frac{\tan h(x/X_K - 2) - \tan h(-2)}{1 - \tan h(-2)} \quad for\ x \leq$ 40 mfp (5)

Table 1. Effective atomic numbers (Z_{eff}) of the Pb-Zn binary alloys for energy region 0.015 MeV – 15.0 MeV.

Energy (MeV)	Pb-Zn Binary alloy in different composition			
	Pb80Zn20	Pb60Zn40	Pb40Zn60	Pb20Zn80
0.015	64.75	52.35	43.06	35.81
0.02	70.18	59.14	48.80	39.11
0.03	70.88	60.14	49.76	39.72
0.04	71.39	60.89	50.49	40.20
0.05	71.74	61.41	51.01	40.54
0.06	71.95	61.73	51.33	40.76
0.08	72.06	61.90	51.51	40.88
0.10	78.98	74.71	68.01	56.26
0.15	78.15	72.92	65.21	52.90
0.20	76.80	70.16	61.24	48.77
0.30	73.57	64.31	54.06	42.70
0.40	70.61	59.74	49.38	39.47
0.50	68.30	56.60	46.52	37.73
0.60	66.59	54.48	44.74	36.72
0.80	64.39	51.96	42.76	35.65
1.00	63.11	50.59	41.74	35.13
1.50	61.88	49.35	40.85	34.68
2.00	61.96	49.43	40.91	34.71
3.00	62.80	50.27	41.51	35.01
4.00	63.63	51.14	42.15	35.33
5.00	64.32	51.88	42.70	35.62
6.00	64.87	52.49	43.17	35.86
8.00	65.66	53.38	43.86	36.24
10.0	66.22	54.03	44.37	36.52
15.0	67.08	55.07	45.22	36.99

III. RESULTS AND DISCUSSION

The variation of EBF with photon energy for the selected alloys at penetration depths of 1, 5, 10, 20, 30, 40 mfp has been illustrated in Fig. 1(a-f). It can be observed from these figures that EBF values for all alloy samples are small (nearly unity at 1 mfp) at lower photon energy and then gradually increases with increase in photon energy until attains maximum values of EBF in the intermediate energy region, afterwards it decreases with further increase in photon energy. This behavior can be explained on the basis of dominance of photon interaction processes in the different energy regions. In the lower and higher energy regions, there is complete absorption of photon due to photo electric effect and pair production process respectively, which are responsible for low values of EBF in both regions. In the intermediate energy region due to dominance of Compton scattering process, number of multiple scattered photons increases, which causes large values for EBF in that region.



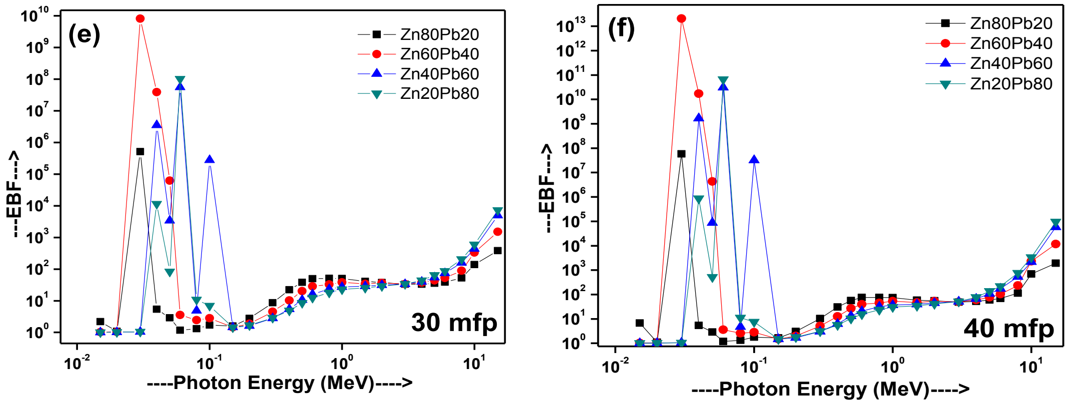


Figure 1. Variation of exposure buildup factor with incident photon energy at (a) 1mfp (b) 5 mfp (c) 10 mfp, (d) 20 mfp (e) 30 mfp and (f) 40 mfp respectively.

It has been observed that magnitude of EBF is directlyproportional topenetration depth of the alloys. With the increase in penetration depth; scattered volume increases which results in increase of scattered photon multiplication factor and finally increase in EBF values. For penetration depth of 1mfp, the magnitude of EBF values for the selected alloys lies between 1-5, while for higher penetration depths such as 5, 10, 20, 30 and 40 mfp, EBF values is in between 1-60, 1-10^{3}, 1-10^{6}, 1-10^{10}, 1-10^{13} respectively. The maxima value of EBF lies at nearly 30 keV, particularly for Pb40Zn60 alloy (Z_{eff} = 49.76); which can be related with K-absorption edge of Sn (Z = 50) at 29.20 keV. Among the selected alloys, Pb80Zn20 offers higher values for Z_{eff} and lower values of EBF. The results of present study and earlier findings for Pb-Sn alloys [7] are in good agreement.

Below 4 MeV, EBF values are inversely proportional to Z_{eff} of the selected alloys; which seems to be obvious. It can be explained on the basis that photon absorption processes (photoelectric effect and pair production) depends strongly on atomic number as compared to scattering processes (Compton and Rayleigh scattering). However above 4 MeV photon energy and above 5 mfp penetration depth, inverse trend in EBF values for all the selected alloys have been observed. This attributes to the formation of electron-positron pair as a result of pair production process, which during its escape from interacting material losses its kinetic energy in collisions/scatterings in large dimensions and come to rest. At rest, electron-positron annihilate to produce two gamma photons of 0.511 MeV in opposite direction. Therefore, in this manner, phenomenon of conversion of higher energy photons into lower energy photons (double in number) occurs. It is known that, the pair production cross section depends on square of atomic number (i.e. Z^2). Hence, the pair production probability (creation of e^- e^+ pair) and later for annihilation process (conversion into two gamma photons) increases with the increase in Z.

IV. CONCLUSION

Z_{eff} values for all the selected alloys lies in between 30 and 82 (atomic number of constituent elements: Zn and Pb). Further, Z_{eff} values varies with the photon energy as well as with the composition of constituent elements. The weight fraction of constituent elements plays a major role in Z_{eff} value. At a particular photon energy, significant difference in Z_{eff} values can be observed with the difference of 20 % weight fraction of constituent elements.

The EBF values for Pb-Zn alloys exhibitstrong dependency on photon energy as well as penetration depth. Its dependence with photon energy isweakat lower and higher energy regions due to dominance of photon absorption process in these regions.WhereasEBF has strong dependence on photon energy in intermediate energy region. On the other hand, it increases with the increase in penetration depth for all the selected alloys. It can be concluded that Pb80Zn20 alloy due to its higher Z_{eff} and lower EBF values;has better radiation protection efficiency among all the selected alloys.

V. ACKNOWLEDGEMENT

One of the authors Dr. Tejbir Singh is thankful to SERB, New Delhi (SR/FTP/PS-081/2012) for financial help to carry out these investigations.

REFERENCES

[1] G. Flora, D. Gupta and A. Tiwari, Toxicity of lead: A review with recent updates,*Interdisciplinary Toxicology, 2*, 2012, 47–58.

[2] A.B. El Basaty, A.M. Deghady and E.A. Eid, Influence of small addition of antimony (Sb) on thermal behavior, microstructural and tensile properties of Sn-9.0Zn-0.5Al Pb-free solder alloy,*Material Science and Engineering A,701*,2017, 245–253.

[3] M. Alwaeli, Investigation of gamma radiation shielding and compressive strength properties of concrete containing scale and granulated lead-zinc slag wastes,*Journal of Cleaner Production, 166,* 2017, 157-162.

[4] M. Kamal, B.M. Moharram, H. Farag, A. El-Bediwi andH.F. Abosheiasha, Structure, attenuation coefficients and physical properties of Bi–Pb–Sn fusible alloys,*Radiation Effects and Defects in Solids,161*, 2006, 137–142.

[5] T. Kaur, J. Sharma and T. Singh, Thickness optimization of Sn–Pb alloys for experimentally measuring mass attenuation coefficients,*Nuclear Energy and Technology,3,*2017, 1–5.

[6] O.D. Rezaei and S. Azimkhani, Investigation of gamma-ray shielding properties of concrete containing different percentages of lead, *Applied Radiation and Isotopes, 70,* 2012, 2282–2286.

[7] S. Kaur, A. Kaur, P. S. Singh and T. Singh, Scope of Pb-Sn binary alloys as gamma rays shielding material,*Progress in Nuclear Energy, 93,*2016, 277-286.

[8] T.Ahmed and H.M. Flower, The phase transformations in alloys based on titanium aluminides Ti_3Al-V and TiAl-V,*Material Science and Engineering, 152,*1992, 31-36.

[9] V.N. Moiseev, N.V. Sysoeva and I.G. Polyakova, Effect of additional carbon and boron alloying on the structure and mechanical properties of alloy VT22,*Material Science and Heat Treatment*, *40*,1998, 3-4.

[10] A.H. El-Kateb, R.A.M. Rizk and A.M. Abdul-Kader, Determination of atomic cross-sections and effective atomic numbers for some alloys, *Annals of Nuclear Energy, 27,* 2000, 1333-1343.

[11] V.R.K. Murty, D.P. Winkoun andK.R.S. Devan, Effective atomic number for W/Cu alloy using transmission experiments, *Applied Radiation and Isotopes, 53,* 2000, 945-948.

[12] T. Singh, P. Kaur and P.S. Singh, Parameters of dosimetric interest of some vanadium and nickel compounds, *Asian Journal of Chemistry, 18,* 2006, 3325-3328.

[13] R. Sharma, J. K. Sharma and T. Singh, Effective atomic numbers for some alloys at 662 keV using gamma rays back scattering technique,*Physical Science International Journal*, *11*, 2016,1-6.

[14] T. Kaur, J. Sharma and T. Singh, Feasibility of Pb-Zn binary alloys as gamma rays shielding materials,*International Journal of Pure and Applied Physics*, *13*,2017, 222-225.

[15] ANS/ANSI 6.4.3., Gamma ray attenuation coefficient and buildup factors for engineering materials, American Nuclear Society, La GrangePark, IL, USA. 1991.