# Study of exposure and energy absorption buildup factor for some building materials available in Iraq

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**Abstract:**

Exposure buildup factor (EBF) and energy absorption buildup factor (EABF) for some building materials (cement, clay brick, thermiston, gypsum and ordinary concrete) available in Iraq at the photon energy range 0.015-15.0 MeV up to penetration depth 40 mfp has been calculated using five parameter geometric progression (G.P) fitting formula. The variation of EBF and EABF with incident photon energy, penetration depth and equivalent atomic number ($Z_{eq}$) for the selected building materials has been studied. Variation in value of EABF was due to dominance of different interaction processes in different energy regions and the chemical composition of studied materials. Also, the half value layer of chosen building materials has been computed as a function of incident photon energy. It was observed that concrete has well gamma ray shielding materials than other selected building materials.

**Keywords: Gamma ray buildup factor; energy absorption, exposure, GP method, building materials.**

# دراسة عامل تراكم التعرض وعامل تراكم امتصاص الطاقة في بعض مواد البناء المتوفرة في العراق

**الخلاصة:**

تم حساب عامل تراكم التعرض وعامل تراكم امتصاص الطاقة في بعض المواد الانشائية (اسمنت، طابوق، ثرمستون، جبس وخرسانة عادية) المتوفرة في العراق للفوتونات في مدى الطاقة 0,015 - 15 مليون الكترون فولت لعمق اختراق يصل الى 40 متوسط مسار حرباستخدام طريقة المتوالية الهندسية ذات البارمترات الخمسة. تم دراسة اعتماد عامل التراكم على كل من طاقة الفوتون الساقط ، عمق الأختراق و العدد الذري المكافئ للمادة الانشائية. لوحظ ان قيمة عامل التراكم تتغيرحسب التفاعل المهيمن في مناطق الطاقة والتركيب الكيميائي للمادة الانشائية. كذلك تم حساب سمك النصف للمواد الانشائية كدالة لطاقة الفوتون الساقط وقد لوحظ بان الخرسانة هي افضل المواد الانشائية وقاية من الاشعاع.

**الكلمات المفتاحية : عامل التراكم ، امتصاص الطاقة ، طريقة Gp ، مواد البناء ، اشعة كاما**

## I. INTRODUCTION

Buildup factors are the shielding materials and geometry dependent parameters which correct the simple attenuation calculations so that they include the contribution of the radiation field produced by the collided part of beam. As far as application of buildup factors in practical shielding problems is concerned, these have been incorporated into a number of point kernel methods of dose calculations in the case of a variety of radiation sources. Exposure buildup factor (EPF) and energy absorption buildup factor (EABF) are the main two types of buildup factors. Buildup factor in which the energy response function is that of absorption in air and the quantity of interest is exposure is called as exposure buildup factor and the buildup factor in which energy response function is that of absorption in the material and the quantity of interest is the absorbed or deposited energy in the shielding medium is known as energy absorption buildup factor (Chilton et al., 1984 and Sidhu et al., 2000). To calculate buildup factor there are different methods like geometric progression (G.P) fitting parameters (Harima et al., 1986), invariant embedding method (Shimizu, 2002) and Monte Carlo code (Sardari et al. 2009). American National Standards ANSI/ANS 6.4.3-1991 used G.P fitting method and provided buildup factor data for 23 elements, one compound and two mixtures viz. water, air and concrete at 25 standard energies in the energy range 0.015-15 MeV with suitable interval up to the penetration depth 40 mean free path. The G.P fitting formula is known to

be accurate within a few percent errors. Harima (1993) has made an extensive historical review and an assessment for the status of buildup factor calculations and applications. Singh et al. (2008) have investigated the variation of energy absorption buildup factors with incident photon energy and penetration depth for some commonly used solvents. Singh et al. (2010) have studied the buildup of gamma ray photons in fly ash concretes. Manohara et al.(2011) studied the variation of exposure buildup factors for heavy metal oxide glass with photon energy and penetration depth. Vipan et al.(2012) have investigated on some low z alkali materials as gamma ray shields. Sandeep and Gurdeep (2012) have a comprehensive study on energy absorption and exposure buildup factors for some soils and ceramic materials. Sardari and Kurudirek (2013) have studied the energy absorption and exposure buildup factors in some solutions of alkali metal chlorides. Vishal and Singh (2013) have studied the exposure buildup factor in some soils. In the present work an attempt has been made to compute exposure buildup factor (EBF), energy absorption buildup factor (EABF) values for some essential Iraqi building materials in the energy region 0.015-15.0 MeV up to penetration depths of 40 mfp using G.P fitting method. Such data will be of prime importance for those who are working with scattering of photons and related phenomena like radiation shield designing.

## 2. MATERIALS AND METHODS

### 2.1. Selected Materials

The materials studied here represent walls and roofs, walls were represented by clay bricks and thermiston blocks covered with a thin layer of cement or gypsum. Roofs were represented by concrete or clay bricks covered with a thin layer of gypsum. Concrete sample was prepared in a mixture of gravel, sand, cement and water that are in common use in Iraq (e.g. ordinary concrete: 55% gravel, 27% sand and 18% cement). The samples were collected from five factories in Karbala Governorate that are commonly used in Iraq. The density of each sample was calculated from their whole dimensions and masses, the chemical compositions of the investigated samples are given in Table 1.

Table1. Density and elemental composition for selected building materials.

| Samples | Density ($g/cm^3$) | Chemical composition (fraction by weight) |
|---|---|---|
| Cement | 1.659±0.060 | O: 0.344606, Mg:0.010614 , Al:0.019635 , Si:0.096197, S:0.008851 , Ca:0.458684, Fe: 0.033013 . |
| Clay brick | 1.304±0.045 | O:0.43231, Mg:0.02593, Al:0.07009, Si:0.21262, S:0.00869, Ca:0.21444, Fe:0.03592 |
| Thermiston (White) | 0.522±0.030 | O:0.43493, Mg:0.00433, Al:0.03063 Si:0.24880 , S:0.00789, Ca:0.25958, Fe:0.01385 |
| Gypsum | 0.915±0.034 | O:0.46540, Mg:0.00692, Al:0.01338, Si:0.16665, S:0.11386, Ca:0.22866, Fe:0.00513 |
| Ordinary concrete | 2.320±0.095 | H:0.00280, O:0.43778, C:0.00986, Al:0.01723, Si:0.23835 S:0.00377, Ca:0.27519, Fe:0.01503 |

## 2.2 Computational Work

Buildup factors are computed using G.P fitting parameters and the equivalent atomic number $Z_{eq}$ of selected building materials. Computations are illustrated step by step as follows:

### A. Computations of equivalent atomic number

The equivalent atomic number $Z_{eq}$ is a parameter assigned to a compound or mixture by giving a proper weight to Compton scattering, since the buildup factor is a consequence of multiple scattering for which the main contribution is due to Compton scattering. Values of the Compton partial mass attenuation coefficient $(\mu/\rho)_{Comp,}$ and the total mass attenuation coefficient $(\mu/\rho)_{total}$ have been obtained for the elements and for the selected tissues by using the XCOM computer program ( Berger and Hubbell, 1999). The $Z_{eq}$ for a given sample is then calculated by matching the ratio, $(\mu/\rho)_{Comp}$ $/(\mu/\rho)_{total}$ of that sample at a given energy with the corresponding ratio of a pure element at the same energy. If this ratio lies between the two ratios for known elements, then the value of $Z_{eq}$ is interpolated using the following formula (Harima, 1983):

$$Z_{eq}=\frac{Z_1(\log R_2-\log R)+Z_2(\log R-\log R_1)}{\log R_2-\log R_1} \quad (1)$$

Where $Z_1$ and $Z_2$ are the atomic numbers of two elements, $R_1$ and $R_2$ are the ratio $(\mu/\rho)_{Comp}$ $/(\mu/\rho)_{total}$ for the respective elements, and $R$ is the corresponding ratio for a given material at a particular energy. The computed $Z_{eq}$ for selected building samples is given in table2.

### B. Computations of G.P fitting parameters

The computed values of $Z_{eq}$ for the chosen samples of building materials were used to interpolate G. P fitting function parameters for the buildup factors in chosen energy range ( 0.015 - 15.0MeV) and penetration depth ( 1- 40 mfp) . The formula used for the purpose of interpolation of the G.P. fitting parameters is given as (Harima et al., 1986 and Sidhu et al., 2000 ):

$$P=\frac{P_1(\log Z_2-\log Z_{eq})+P_2(\log Z_{eq}-\log Z_1)}{\log Z_1-\log Z_2} \quad (2)$$

where $P_1$ and $P_2$ are the values of G.P fitting parameters corresponding to atomic number $Z_1$ and $Z_2$ respectively at a given energy and $Z_{eq}$ is the equivalent atomic number of chosen sample at same energy.

Table 2. Equivalent atomic number ($Z_{ea}$ ) of selected building materials.

| Energy (MeV) | Equivalent atomic number ($Z_{ea}$ ) Gypsum | Thermiston | Brick | Concrete | Cement |
|---|---|---|---|---|---|
| 0.015 | 14.347 | 14.660 | 14.658 | 14.717 | 16.620 |
| 0.02 | 14.497 | 14.776 | 14.792 | 14.870 | 16.796 |
| 0.03 | 14.640 | 14.932 | 14.970 | 15.032 | 17.200 |
| 0.04 | 14.732 | 15.032 | 15.643 | 15.574 | 17.056 |
| 0.05 | 14.795 | 15.100 | 15.163 | 15.208 | 17.115 |
| 0.06 | 14.822 | 15.153 | 15.222 | 15.261 | 17.154 |
| 0.08 | 14.852 | 15.230 | 15.306 | 15.333 | 17.211 |
| 0.1 | 14.965 | 15.273 | 15.341 | 15.375 | 17.235 |
| 0.15 | 15.068 | 15.528 | 15.685 | 15.715 | 17.397 |
| 0.2 | 15.089 | 15.000 | 15.512 | 15.486 | 17.293 |
| 0.3 | 14.857 | 15.600 | 15.640 | 15.240 | 17.372 |
| 0.4 | 15.077 | 15.333 | 15.538 | 15.615 | 17.511 |
| 0.5 | 15.250 | 15.375 | 15.450 | 15.625 | 17.300 |
| 0.6 | 15.133 | 14.999 | 15.667 | 15.667 | 17.285 |
| 0.8 | 15.250 | 15.500 | 15.000 | 15.000 | 16.971 |
| 1 | 14.500 | 15.000 | 15.000 | 15.500 | 17.333 |
| 1.5 | 14.000 | 14.000 | 14.286 | 14.286 | 16.041 |
| 2 | 13.083 | 13.250 | 13.333 | 13.417 | 15.500 |
| 3 | 12.872 | 13.143 | 13.048 | 13.166 | 15.097 |
| 4 | 12.813 | 13.072 | 12.926 | 13.116 | 15.085 |
| 5 | 12.843 | 13.194 | 12.990 | 13.361 | 15.097 |
| 6 | 12.832 | 13.045 | 12.958 | 13.078 | 15.038 |
| 8 | 12.814 | 13.067 | 12.968 | 13.080 | 15.051 |
| 10 | 12.813 | 13.055 | 12.947 | 13.074 | 15.033 |
| 15 | 12.794 | 13.046 | 12.913 | 13.046 | 15.007 |

### C. Computation of buildup factor

The G.P fitting parameters were then used to generate EBF and EABF for the chosen samples at energy range of 0.015 to 15.0 MeV using the following G.P fitting formula (Harima et al., 1986):

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

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

$$K(E,x) = cx^a + d\frac{\tanh(x/X_k-2)-\tanh(-2)}{1-\tanh(-2)} \qquad x \leq 40 mfp \qquad (5)$$

Where E is the incident photon energy, x is the penetration depth in unit of mean free path , a, b, c, d and $X_k$ are the G.P fitting parameters. $K$ is the photon dose multiplication and change in the shape of the spectrum with increasing penetration depth in mean free path ( mfp), the mean free path is defined as the average distance that photons of a given energy travel before two successive interactions in a given medium occur.

## 2.3 Calculation uncertainty

In order to check the reliability of present method, EABF values for water are compared with EABF values given by ANSI/ANS-6.4.3 data base for a few randomly selected energies 2, 5, 10, and 15 MeV and penetration depth (1- 40) mfp. From fig. 1 it can be analyzed that our calculated EABF values of water by the present method are in excellent agreement with standard data. This gives confidence in our results for the building materials.

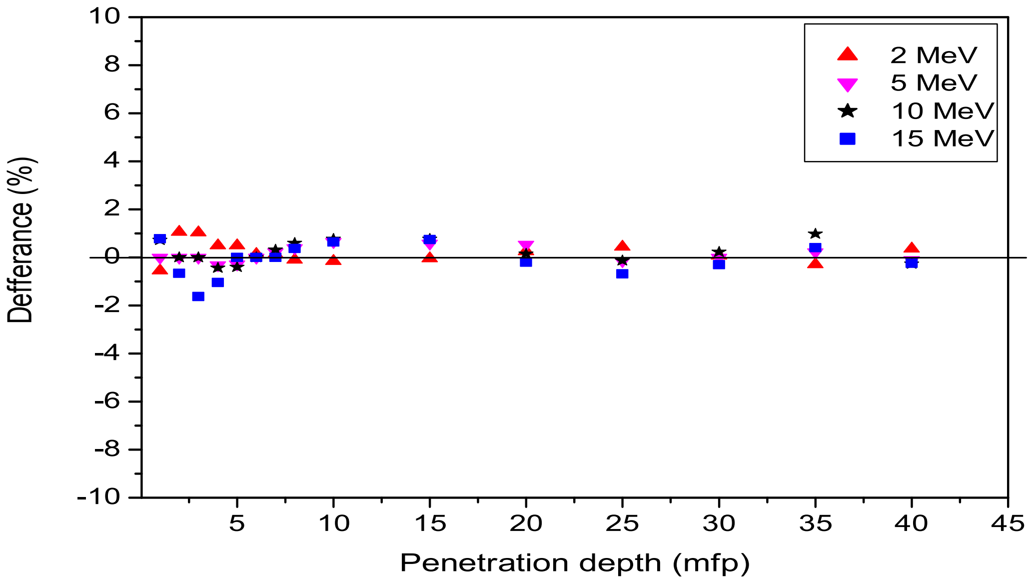


Fig. 1 Difference (%) between ANSI / ANS6.4.3 data and present work with respect to the calculated values of energy absorption factor for water at incident photon energies 2,5,10and 15 MeV up to penetration depth 40mfp.

### 2.4 Calculation of half value layer and tenth value layer

The thickness of the material that reduces the photon beam intensity to half of its original value ($I_0$), i.e. (½) $I_0$, is called the half value layer (HVL) and is given by:

$$HVL = \frac{\ln 2}{\mu} = \frac{0.693}{\mu} \quad (6)$$

Where μ is the linear attenuation coefficient of the material at a given photon energy. Similarly, the tenth value layer (TVL) is defined as the thickness of the layer that reduces the photon beam intensity to one tenth of its original value ($I_0$), i.e. (1/10)$I_0$.

$$TVL = \frac{\ln 10}{\mu} = \frac{2.303}{\mu} \quad (7)$$

## 3. RESULTS AND DISCUSSIONS

The generated EBF and EABF values for building materials have been shown in graphical form at fixed penetration depth (Figs. 2) as well as at fixed energy values (Figs. 3).

### 3.1 Effect of incident photon energy on EBF and EABF

Figs. 2 (a-h) show the energy dependence of EBF and EABF at some selected penetration depths of 1, 5, 20 and 40 mfp for building materials listed in Table 1. Initially, the EBF and EABF values increase with the increasing photon energy up to a maximum energy at intermediate energies, and then further start decreasing with increase in energy of gamma ray. Here the low value of EPF and EABF around 0.015 MeV are due to predominance of photoelectric effect, which results in fast removal of low energy photons, thereby not allowing these photons to buildup. At intermediate energies, Compton scattering is the main photon interaction process, the buildup factor reaches large values for a given penetration depth. This is due to the fact that, Compton scattering is known to give rise to extensive multiple scattering of photons, which only helps in the degradation of photon energy and fails to remove a photon completely. Because of this, the multiple scattering of photons exist for a longer time in the interacting material, which leads to a higher value of buildup factor. This also explains the high value of buildup factors within the energy range 0.1-0.8 MeV, which results in a broad peak around a particular value of incident photon energy 0.3MeV. Furthermore it is also observed that for energies greater than 2 MeV, the dominance of pair production phenomenon over Compton effect increases, so values of buildup factor decreases. The variation of EBF and EABF with incident photon energy seems to be independent of chemical composition of chosen building materials beyond 2 MeV. It can also be seen; at photon energy 15MeV, the EPF and EABF values are low due to predominance of pair- production.

### 3.2 Effect of penetration depth on EBF and EABF

The calculated of EBF and EABF values have been plotted as a function of penetration depth for all selected building samples. These are shown in figs.3 (a-h) for some selected photon energies 0.03, 0.15, 1.5 and 15 MeV. It is can be seen that, in general, there is continuous increase in EPF and EABF with increase in penetration depth. At photon energy 0.03 MeV, EPF and EABF values are low because of dominance of photoelectric effect, but at photon energy 0.15 MeV, the buildup factor values are much higher due to dominance of Compton effect. It can also be seen; at any given energy, the buildup factor can take very high values at the largest penetration depth (40 mfp).

### 3.3 Dependence of EBF and EABF on equivalent atomic number

Figs. 2 (a-h) also show the variations of EBF and EABF values with chemical composition (i.e. equivalent atomic number) for the selected materials. It can be observed that all samples have different EBF and EABF values at photon energy range of 0.1-0.8 MeV. For example, cement has the highest $Z_{eq}$ values leading to low value of buildup factor than other materials. So the values of buildup factor vary inversely with the values of $Z_{eq}$. Figs. 2(a-h) also show the EBF and EABF are independent of the chemical composition at incident photon energy larger than 1MeV.

### 3.4 Comparison between EABF and EBF

Figs. 4 (a-c) show the relative differences (%) between EBF and EABF, the maximum differences exist in intermediate energy region where Compton scattering is the main photon interaction process, thus leading to large difference between EBF and EABF values. Also there are significant variations between EABF and EBF where the larger buildup factors occur. In general, EABF have higher values than EBF due to the fact that the selected building materials under investigation have higher $Z_{eq}$ values than that of air. In these figures, the positive values of differences (%) refer to the higher values of EABF when compared with EBF.

### 3.5 Variation of half value layer (HVL) and tenth value layer (TVL) with incident photon energy

Figs.5 (a and b) show the variation of HVL and TVL with incident photon energy for selected building materials. It is established that the material which has low value of HVL has high absorption for gamma rays than other samples. Using HVL and TVL for the selected samples, concrete have minimum values of HVL and TVL of the selected materials in the specified energy range. Hence concrete has very good shielding ability than other selected materials.

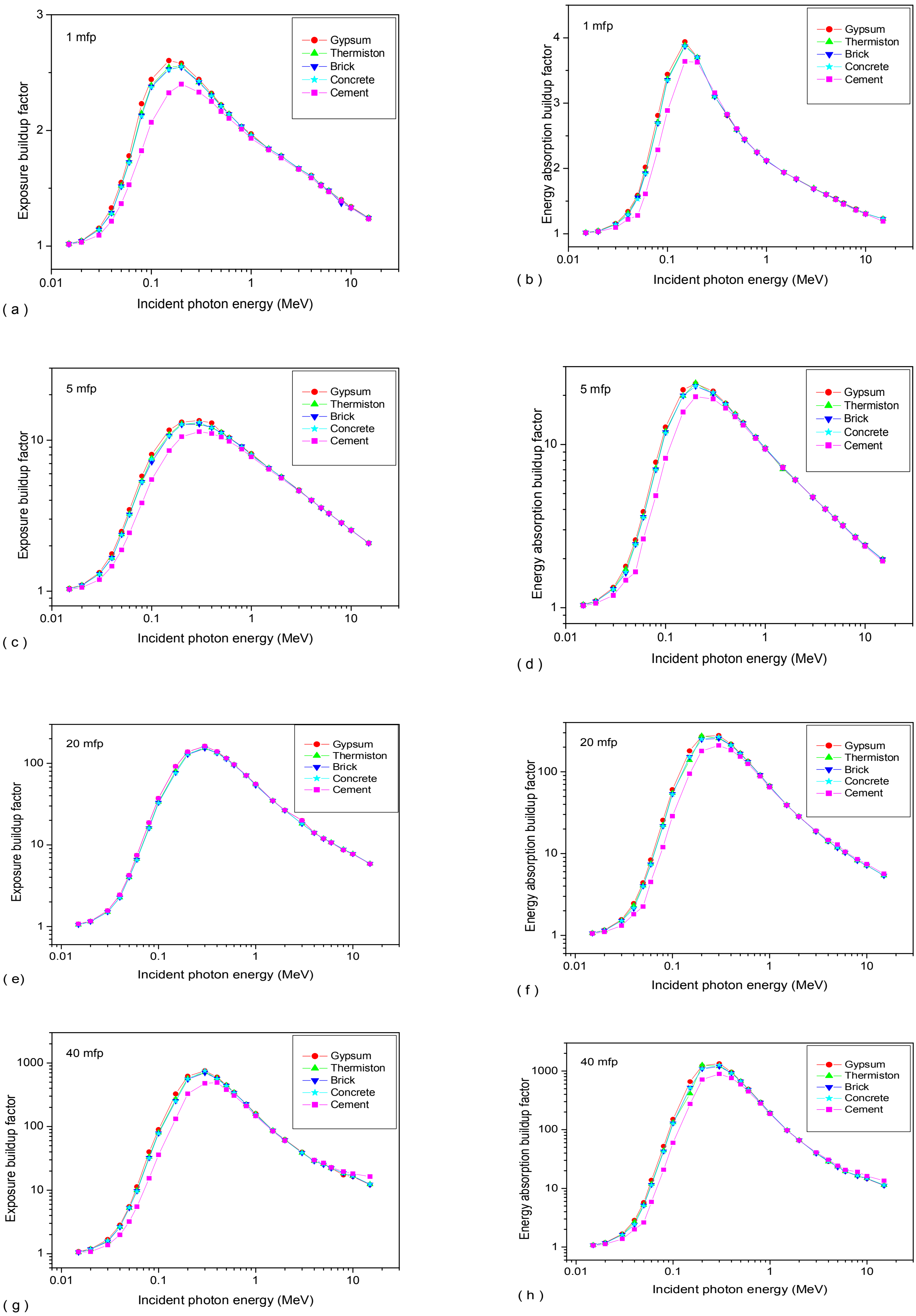


Figure 2. The EBF and EABF values for all chosen minerals in the energy region 0.015- 15.0 MeV; (a)-(b) at 1mfp, (c)-(d) at 5mfp, (e)-(f) at 20mfp and (g)-(h) at 40mfp.

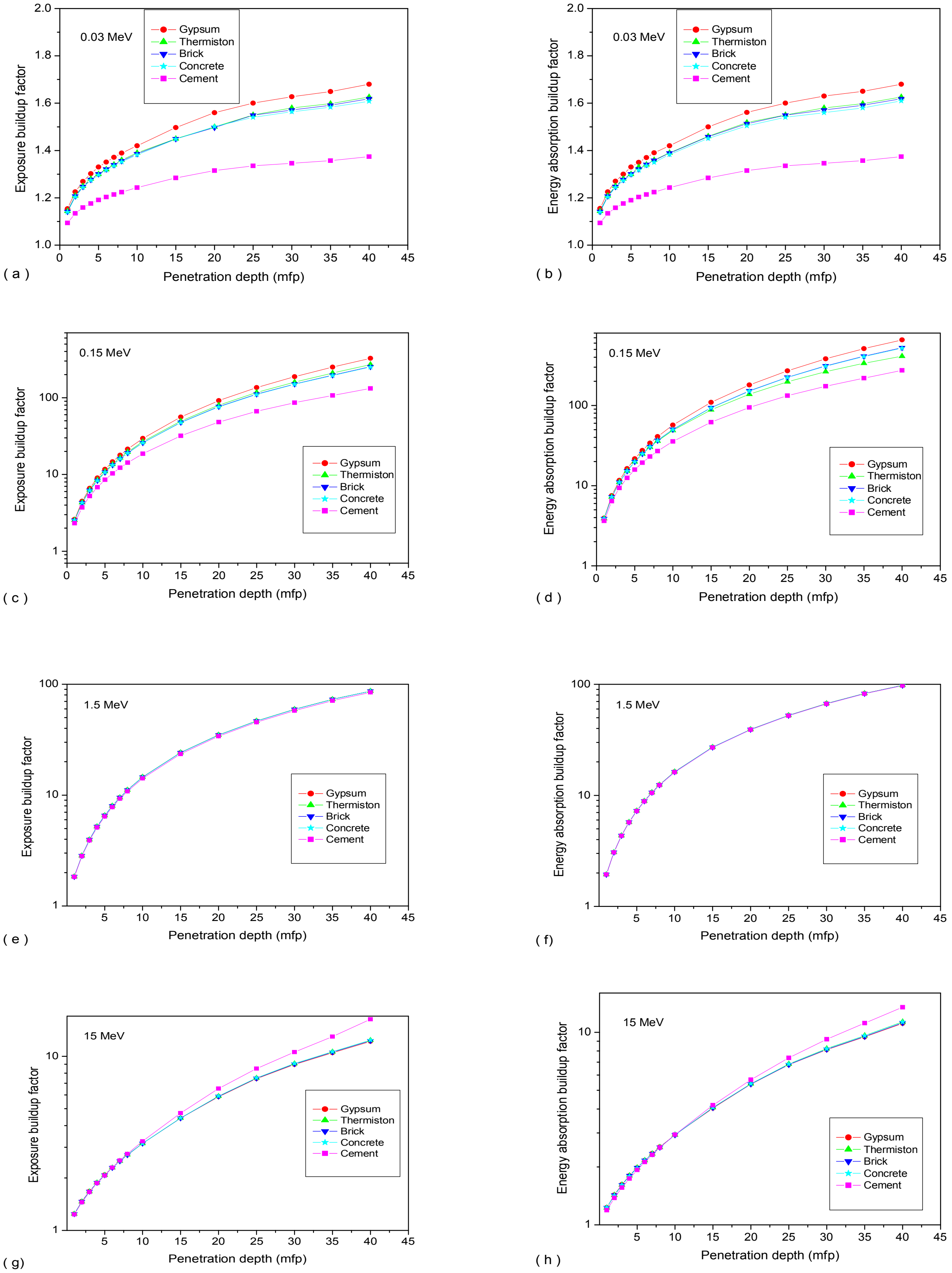


Figure 3. The EBF and EABF values for all chosen minerals up to penetration depth of 40 mfp; (a)-(b) at 0.03MeV, (c)-(d) at 0.15 MeV, (e)-(f) at 1.5 MeV and (g)-(h) at 15MeV.

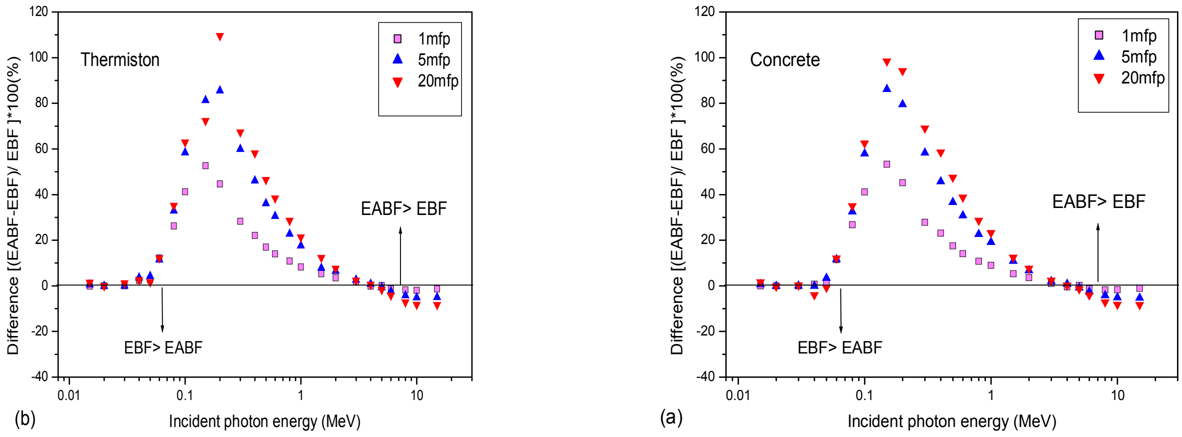


Figure 4. The variation of percentage (%) difference between EBF and EABF at incident photon energy range 0.015-15MeV: (a) for concrete and (b) for therimston.

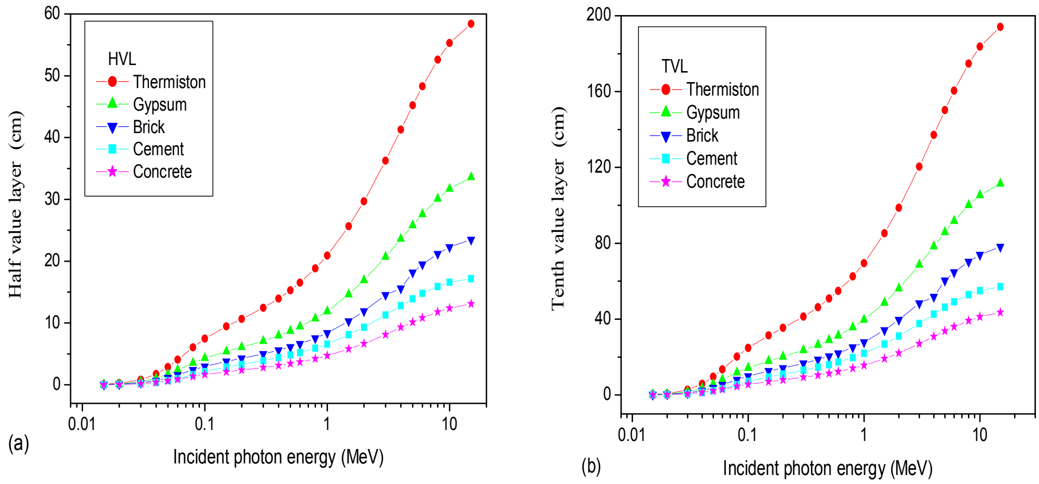


Fig. 5. Variation of the half value layer(HVL) and tenth value layer(TVL) with incident photon energy range 0.015- 15MeV for allseleted samples.

# 4. Conclusions

The generated EBF and EABF have been studied as a function of photon energy and penetration depth for the selected building materials available in Iraq. The dependence of buildup factor has been briefly discussed and following conclusions were drawn from the investigation:

- Compton scattering process increases the values of EBF and EABF while the absorption processes such as photoelectric absorption and pair production lower the values of energy absorption buildup factor.
- EBF and EABF values increases with the increasing photon energy and reaches a maximum value at photon

energy 0.3 MeV approximately, where Compton scattering predominates. then start decreasing further with the increasing energy.

- The variation of EABF and EBF with incident photon energy seem to be independent of chemical composition of chosen building materials beyond 2 MeV.
- A good shielding material should have high value of $Z_{eq}$ and low value of EABF.
- There is continuous increase in EBF and EABF with increase in penetration depth for all building materials.
- The low value of THV, low cost and easily available the concrete has well as gamma ray shielding materials than other selected samples.

## References

American National Standard Institute (1991) *Gamma-ray attenuation coefficients and* buildup factors for engineering materials. Report ANSI/ANS-6.4.3-1991.La Grange Park, Illinois: American Nuclear Society.

Berger, M.J. and Hubbell, J.H., 1987/1999. XCOM: Photon Cross-Sections Database, Web Version 1.2, National Institute of Standards and Technology, Gaithersburg, MD20899, USA. http://physics.nist.gov /xcom (Originally published as NBSIR 87-3597 ”XCOM: Photon Cross Sections on a Personal Computer”)

Chilton A.B., Shultis J.K. and Faw R.E. (1984) Principle of Radiation Shielding.Prentice-Hall, Englewood cliffs, New Jersey.

Harima Y. (1983) An approximation of gamma ray buildup factors by modified geometrical progression. Nucl. Sci. Eng. 83, p.299-309.

Harima Y., Sakamoto Y, Tanaka S.and Kawai M.( 1986) Validity of geometric-progression formula in approximating gamma-raybuildup factors.Nucl Sci Eng.;94(1)p.24–35.

Manohara S.R, Hanagodimath S.M. an Gerward L., Mittal K.C.(2011) Exposure buildup factors of heavy metal oxide glass. A radiation Shield Journal of the Korean Physical Society, 59, No. 2, p. 2039-2042.

Sandeep Gupta and Gurdeep Singh (2012) A Comprehensive study on energy absorption and exposure buildup factors for some soils and ceramic Materials, IOSR Journal of Applied Physics,Volume 2, Issue 3,P.24-30.

Sardari,D. and Kurudirek M.(2013) Studies on energy absorption and exposure buildup factors in some solutions of alkali metal chlorides. International Journal of Physical Sciences, Vol. 8(12), p. 481-491.

Sardari D., Abbaspour A., Baradaran S., and Babapour, F.(2009) Estimation of gamma and X-ray photons buildup factor in soft tissue with Monte Carlo method. Appl.Radiat. Isot. 67, p.1438 – 1440.

Shimizu A. (2002) Calculations of gamma-ray buildup factors up to depths of 100 mfp by the method of invariant embedding, (I) analysis of accuracy and comparison with other data. J. Nucl. Sci. Technol. 39, p.477-486.

Sidhu G. S., Singh P. S.and Mudahar G. S. (2000), A study of energy and effective atomic number dependence of the exposure build-up factors in biological samples. J. Radiol. Prot. 20, p. 53-68.

Singh SP, Singh T. and Kaur, P., (2008) Variation of energy absorption buildup factors with incident photon energy and penetration depth for some commonly used solvents. Ann. Nucl.Energy35,p.1093-1097.

Vipan Kumar, Kulwinder Singh Mann, Manohara S. R.and Gurdeep Singh Sidhu, (2012) Investigation on some low Z alkali materials as gamma ray shields. International Journal of Latest Research in Science and Technology, Vol.1,Issue 4 ,p.324-333.

Vishal Pathak, Gurdeep Singh Sidhu (2013) Exposure buildup factor studies in some soils. International Journal of Scientific and Research Publications, Vol.3, Issue 3,p.1-8.