Multiple Scattering Effects of Gamma Rays in Some Titanium Compounds

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ABSTRACT
Absorption buildup factors for some titanium compounds like Titanium dioxide (TiO_2), Titanium Carbide (TiC), Titanium Nitride (TiN) and Titanium Silicate ($TiSi_2$) has been calculated using the G.P. fitting technique upto penetration depth of 40 mean free path (mfp). The variation of energy absorption buildup factor with incident photon energy for the selected compounds of titanium has been studied. It has been investigated that the value of energy absorption build up factor is higher in the intermediate energy region as compared to the lower and higher energy regions for all selected compounds of titanium.

Keywords
Titanium compounds, multiple scattering, buildup factor.

1. INTRODUCTION
Titanium is the ninth most occurring element in the nature. Due to its hardness, brightness and strongness, it is widely used in aerospace, sports and medicine fields. Titanium compounds are also found useful in various fields. They found applications in paint, coloring food and cosmetics, crayons, UV protection fields, lubricants, wear resistant tools and many more. Due to many applications of compounds of titanium an attempt has been made to check its possibility in radiation shielding. Radiation physicists face a main problem of leakage of radiation due to the Compton multiple scattering events. This multiple scattering is the main reason for violation of the Lambert-Beer law i.e. $I = I_0e^{\mu x}$. In order to maintain this law, a correction factor B called the buildup factor is used. Buildup factor measures the degree upto which the Lambert-Beer law is violated. Then the intensity equation after modification becomes $I = BI_0e^{\mu x}$ where B is the buildup factor. Remember buildup factor is always equals to or greater than unity.

There are two types of buildup factors – one is energy absorption buildup factor and the other is exposure buildup factor. In the former, the quantity of concern is absorbed or deposited energy in the material and detector response function is that of the absorption in the material whereas in the latter, the quantity of concern is the exposure of energy and detector response function is that of absorption in air.

There are several different methods such as G.P. fitting method given by Harima et al. [1], invariant embedding method given by Shimizu and Hirayama [2] and Shimizu et al [3] are available for computing buildup factors. American National Standards ANSI/ANS 6.4.3 [4] used G.P. fitting method and provided energy buildup factor data for 23 elements in which one was compound and two were mixtures viz. water, air with suitable interval up to the penetration depth of 40 mean free paths. M.J. Berger and J. Hubbell [5] provided for the first time the database of mass attenuation coefficient as well as cross-sections for about 100 elements in the form of software package named as XCom, which is also capable of generating mass attenuation coefficients for compounds and mixtures. Y. Harima [6] had given a review and latest status of buildup factor applications for the materials like water, elements Fe, Pb, Be, B, C, N, O, F, Na, Mg, Al, Si, S, P, Ar, K, Ca, Cu, Sn, Mo, La, Gd, W, U and concrete in the energy range from 0.01 to 0.3 MeV and 0.5 to 10 MeV with penetration depth from 1 to 40 mfp, using various codes ADJ-MOM, PALLAS and ASFIT. H. Hirayama & K. Shin [7] had used EGS4 Monte Carlo code to study multilayer gamma ray exposure buildup factors up to 40 mfp for water, iron and lead at energies 0.1, 0.3, 0.6, 1.0, 3.0, 6.0 and 10 MeV.G. S. Sidhu et al. [8] had calculated absorption buildup factor for some biological samples viz. Cholesterol, chlorophyll, muscle, tissue, hemoglobin, cell and bone in the energy range of 0.015 to 15.0 MeV with penetration depth upto 40 mfp, using G.P. fitting method. Shimizu et al.[9] compared the buildup factor values obtained by three different approaches (G.P. fitting, invariant embedding and Monte Carlo method) and only small discrepancies were observed for low-Z elements up to 100 mean free path. K. Trots et al.[10] proposed vector regression model for the estimation of gamma ray buildup factors for multi–layer shields for Al, Fe, Pb, water and concrete in the energy range of 5 to 10 MeV with penetration depth more than 10 mfp. P.S. Singh et al. [11] measured variation of energy absorption build up factors with incident photon energy and penetration depth for some commonly used solvents. T. singh et al [12] worked on Chemical composition dependence of exposure buildup factors for some polymers

After reviewing the above literature, it has been observed that with the ever increasing use of gamma ray photons in medicine and bio-physics, there is a dire need of proper investigations concerning gamma rays multiple scattering effects on some Titanium compounds.

2. COMPUTATIONAL WORK
The computations of energy absorption buildup factor have been divided into three parts, which are given following:-

2.1 Computations Of Equivalent Atomic Numbers (Z_{eq})
Equivalent atomic number is a quantity similar to atomic number of elements. It is the number given to compound/mixture by giving proper weightage to the Compton multiple scattering processes. However, the equivalent Z mostly possesses the real values and it is an energy dependent parameter. As buildup factor is a direct consequence of multiple scattering, hence equivalent atomic

number (Z_{eq}) is used for the calculation of buildup factors. For the calculation of (Z_{eq}), the values of Compton partial attenuation coefficient μ_{comp} and the total attenuation coefficients μ_{total} were obtained in cm^2/g fistly for the selected compounds of titanium in the energy value from 0.015 to 15.0 MeV, using WinXCom computer program (Gerward et al., 2001) The values of Z_{eq} for the titanium compounds will be calculated by the following formula:

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

Where Z_1 and Z_2 are the atomic numbers of elements corresponding to the ratios of μ_{comp} and μ_{total}, R_1 and R_2 respectively.R (μ_{Comp}/μ_{total}) is the ratio for the selected titanium compounds at a particular energy value, which lies between ratios R_1 and R_2 such that $R_1 < R < R_2$.

2.2 Computations of G.P. fitting parameters

American National Standard (1991) has provided the energy absorption G.P. fitting parameters of 23 elements, one compound (H_2O) and two mixtures (air and concrete) in the energy range of 0.015–15.0 MeV and up to a penetration depth of 40 mfp. The calculated values of Z_{eq} for the selected titanium compounds were used to interpolate G.P. fitting parameters (b, c, a, X_k and d) for the energy absorption buildup factor, in the energy range (0.015–15.0 MeV) and penetration depth (1–40 mfp). The formula (Sidhu et al., 2000) used for the purpose of interpolation of the G.P. fitting parameters is as follows:

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

where Z_1 and Z_2 are the atomic numbers of elements between which the equivalent atomic number Z_{eq} of the selected titanium compounds lies. P_1 and P_2 are the values of G.P. fitting parameters corresponding to Z_1 and Z_2 respectively at a given energy.

2.3 Computations of buildup factors

The computed G.P. fitting parameters (b, c, a, Xk and d) were then used to calculate the energy absorption buildup factors for the selected compounds of titanium at some standard incident photon energies in the range of 0.015–15.0 MeV and upto a penetration depth of 40 mfp, with the help of G.P. fitting formula, as given by following equations (Harima et al.,)

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

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

where

$$K(E,x) = cx^a + d\frac{\tanh\left(\frac{x}{X_k} - 2\right) - \tanh(-2)}{1 - \tanh(-2)} \quad \text{for } X \leq 40 \text{ mfp}$$

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3. RESULTS AND DISCUSSION

The energy absorption buildup factor for the selected compounds of titanium has been shown in Figs. 3.1 to 3.4. From these figures it is found that energy absorption buildup factor for all the selected compounds of titanium in the energy region of 0.015–15.0 MeV up to the penetration depth of 40 mean free path is always greater than one. This is due to build up of photons from scattering due to larger penetration depth of the titanium compounds. The dependence of energy absorption buildup factor on incident photon energy and penetration depth has been discussed as following:-

Figs. 3.1 – 3.4 show the variation of energy absorption buildup factor with incident photon energy for all the selected compounds of titanium at 1, 5, 10, 20, 30 and 40 mean free path respectively. It has been found that in spite of different equivalent atomic numbers (Z_{eq}) of the selected titanium compounds shows almost similar pattern with the increase in incident photon energy. Initially, energy absorption buildup factor increases with the increase in incident photon energy for all of the selected compounds of titanium.

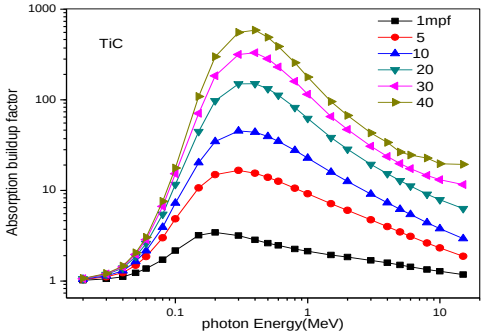

Fig. 3.1: Variation of energy absorption buildup factor with incident photon energy in case of titanium carbide.

The dominance of absorption processes in the lower and higher energy regions (photo -electric absorption in the lower and pair-production/triple production in the higher photon energy region) is the reason for this variation of energy absorption buildup factor with incident photon energy. In the initial state i.e. in the lower photon energy region, photo-electric absorption is the dominant photon interaction process; so energy absorption buildup factor shows minimum values for these compounds of titanium.

With the increase in the incident photon energy, the Compton scattering process overtakes photo-electric absorption process. It results in the multiple Compton scattering events, which results in increasing the absorption buildup factors. Since scattering process decreases the energy of incident photon, so multiple scattering events results in the maximum value of the energy absorption buildup factors for these titanium compounds. Further increase in incident photon energy, almost identical values of energy absorption buildup factors for titanium compounds has been observed.

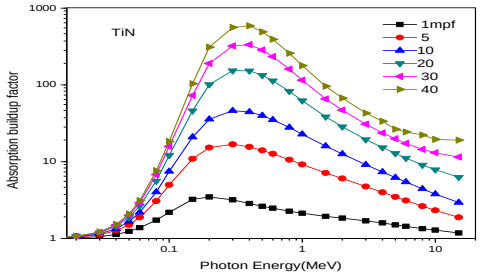

Fig. 3.2: Variation of energy absorption buildup factor with incident photon energy in case of titanium nitride

In the energy region from 3.0 to 15.0 MeV, one more absorption process, i.e. pair/triplet production starts dominating which not only decrease the absorption buildup factor values but also exhibit a significant variation to a small extent due to the chemical composition of the selected titanium compounds. It may be due to the fact that dependence of the cross-section for this absorption process on the equivalent atomic number (Z_{eq}) is not so much significant as for the photo-electric absorption process.

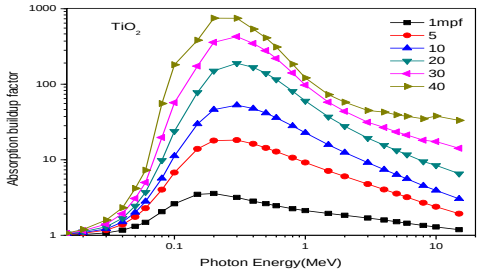

Fig. 3.3: Variation of energy absorption buildup factor with incident photon energy in case of titanium dioxide.

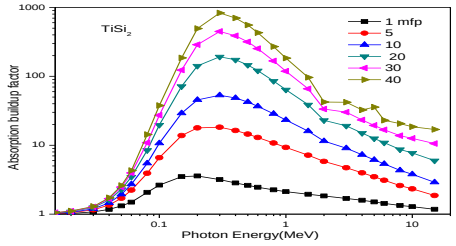

Fig. 3.4: Variation of energy absorption buildup factor with incident photon energy in case of titanium silicate

4. CONCLUSION

From the above studies, it can be concluded that the degree of violation of the Lambert–Beer law i.e. value of energy absorption buildup factor is less in the energy regions where absorption processes are dominant over the scattering process and when the penetration depth of the material is least. It is also found that for the higher equivalent atomic number (Z_{eq}) of the interacting material, the value of energy absorption buildup factor is least.

Among the selected titanium compounds, TiC has higher values for equivalent atomic number and lower value for energy absorption build factor as compared to the other selected titanium compounds.

The energy absorption buildup factor depends strongly on the nature of the material in the lower energy region, becomes almost independent in the intermediate energy region and shows a little dependence in the higher energy region.

The calculated values of G.P. fitting parameters and energy absorption buildup factors for selected compounds of titanium may be found useful in the future study of variety of shielding configurations.

5. ACKNOWLEDGMENTS

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