Gamma Ray Attenuation Properties Biomedical Important Organic Compounds

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Abstract. Gamma ray attenuation parameters such as mass attenuation coefficient ($\mu_m$), total atomic cross section ($\sigma_t$), effective atomic number ($Z_{eff}$), Effective electron density ($N_{eff}$), for Acetylsalicylic acid ($C_9H_8O_4$), Acetic acid ($C_2H_4O_2$), Acetergamine ($C_4H_7N_5$), Usnic Acid ($C_{18}H_{16}O_7$), Erucic Acid ($C_{22}H_{42}O_2$), Formic Acid ($CH_2O_2$) in the diagnostic energy range (0.122-1.330 MeV) were determined experimentally and theoretically. Theoretical values were obtained from XCOM code. In experiment, NaI(Tl) scintillation detector housed in a narrow beam geometry set up was utilized to measure the attenuation of gamma rays. All samples were irradiated to gamma rays using point radioactive sources $^{57}$Co, $^{133}$Ba, $^{22}$Na, $^{137}$Cs, $^{54}$Mn, and $^{60}$Co. From the obtained results of $\mu_m$, $\sigma_t$, $Z_{eff}$ and $N_{eff}$, it is found that these gamma ray attenuation parameters of selected samples are affected by change in the energy of incoming photons. A fairly good agreement was observed between measured and XCOM data. The attenuation parameters were decreased with increase in energy of photons owing to the dominant photon interaction in the energy range 0.122 to 1.33 MeV except $Z_{eff}$ and $N_{eff}$. The $Z_{eff}$ values of the organic compounds were observed between ~3 to ~4, agreed well with average atomic number.

1. Introduction
With the advances of technology, uses of X- and gamma rays have been increased enormously. Radioactive materials have been used in medical, pharmaceutical, agriculture, manufacturer, research, electricity production, and detector\textsuperscript{1-6}. Thus, the huge use of radioactive materials has notorious effects on the living cells\textsuperscript{2}. Gamma rays emitted by the radioactive materials can cause cell mutation, radiation sickness and cancer. The efficient use of nuclear radiation for various beneficial applications by avoiding hazardous effect on living system, it is essential to study radiation interaction with organic compounds like, amino acids, fatty acids, carbohydrates, etc. Living cells are composed of these C, H, N, O based organic compounds, responsible for various physiological functions. Investigation of gamma ray interaction with C, H, N, O based compounds has attracted great attention since couple of decades due to its valuable in radiation therapy, radiation protection, radiation physics and chemistry\textsuperscript{1,2}.
Recently, many authors reported gamma ray interaction properties experimentally and theoretically and noted that the attenuation parameters provide valuable information in radiotherapy, radiation biology, pharmaceutical and many technological applications\textsuperscript{1-6}. Radiation shielding feature in nonlinear optics, low atomic number and polymer materials and many chemical compounds have been studied and noted that these materials are valuable in radiation dosimetry applications\textsuperscript{7-11}. Gamma ray shielding properties of rocks and concretes studied comprehensively in terms of $\mu m\beta t, \beta e, Z_{\text{eff}}, N_{\text{eff}}$, exposure build-up factor (EBF) and energy absorption build-up factor (EABF) in order to used nuclear radiation\textsuperscript{3-4,12}. Recently, the glasses containing heavy metal oxides(such as Bi2O3, WO3, TeO2, PbO, MoO, BaO) have been investigated experimentally and theoretically using the XCOM, MCNPX, Phy-X/PD, Geant4 and WinXCOM simulation codes in order to provide better shielding against X- and gamma ray, neutron and charge particles\textsuperscript{12-20}.

In the present investigation, gamma ray attenuation properties of some organic compounds have been explored in order to understand the radioprotection applications. The gamma ray point sources of were used for irradiation in narrow beam geometry setup. The behaviour of $\mu m\beta t, \beta e$, $Z_{\text{eff}}$ and $N_{\text{eff}}$ against the incident photon energy studied in detailed.

2. Experimental method

The organic compounds were in powder from then transferred in to pallets with different thickness. The density and thickness of pallets were measured with great precision. The narrow beam geometry setup were then arranged as per the requirement as shown in Fig.1.

![Fig. 1 The schematic view of the experimental set up.](image)

The gamma ray point sources $^{57}$Co,$^{133}$Ba,$^{22}$Na,$^{137}$Cs, $^{54}$Mn, and $^{60}$Co were procured from BARC used for irradiation the samples. The distance between radiation source to sample, detector to sample and radiation source to detector were kept constant throughout the measurement. Initially, the intensity ($I_0$) of incoming photon without sample was measured then attenuated intensity ($I$) measured by keeping each sample one by one between radiation source and detector (Fig.1). The proper precautions were taken to minimize the background counts by providing proper shielding. The measured intensities ($I$ and $I_0$) were then used to determined attenuation parameters through the following equation\textsuperscript{1};

$$I = I_0 \exp(-\mu t)$$  \hspace{1cm} (1)

Where, $\mu$ represents the linear attenuation coefficient and $t$ is the thickness of pellet. Then mixture rule applied for compound or mixture of element\textsuperscript{2}.

$$\mu_m = \frac{\mu}{\rho} = \sum w_i \left( \frac{\mu_i}{\rho_i} \right)$$  \hspace{1cm} (2)

Where, $\mu m$ represents the probability of interaction between X-ray, gamma photon and matter of mass per unit area is called as the mass attenuation coefficient.
3. Results and Discussion

Table 1 illustrates the selected organic compounds along with molar mass and average atomic number. It is seen that the average atomic number of organic compounds such as Acetylsalicylic acid, Acetic acid, Acetoguanamine and Usnic Acid is observed in the range of ~4 except Erucic Acid (~3). From Table 1, it is observed that Acetoguanamine has the slightly different chemical composition among the selected materials.

Table 1 Selected organic compounds along with its chemical compositions and molar mass.

| Samples             | Chemical formula | Molar mass (g/mol) | Mean atomic number (\(\bar{z}\)) |
|---------------------|------------------|-------------------|----------------------------------|
| 1. Acetylsalicylic acid | C\(_9\)H\(_8\)O\(_4\) | 180.158           | 4.476                            |
| 2. Acetic acid      | C\(_2\)H\(_4\)O\(_2\) | 60.050            | 4.000                            |
| 3. Acetoguanamine   | C\(_4\)H\(_7\)N\(_5\) | 125.140           | 4.125                            |
| 4. Usnic Acid       | C\(_{18}\)H\(_{16}\)O\(_7\) | 344.315           | 4.390                            |
| 5. Erucic Acid      | C\(_{22}\)H\(_{42}\)O\(_2\) | 338.570           | 2.879                            |

Then obtained results of \(\mu m\) were used to determined \(\bar{\rho_t}, \bar{\rho_e}Z_{\text{eff}}\) and Neff for all the selected organic compounds, detailed description of these parameters along with formulae given in our previous work 1-3.

3.2. Mass attenuation coefficients (\(\mu m\))

From the measured results of attenuated (I) and un-attenuated (I0) intensity, the \(\mu m\) values of all the selected organic compounds were determined by applying mixture rule through the Eq. (2). The experimentally determined results of \(\mu m\) along with the XCOM data are presented in Table 2.

Table 2 Mass attenuation Coefficients (\(\mu m\)) of some organic materials.

| Energy | 122keV | 356keV | 511keV | 662keV | 840keV | 1170keV | 1275keV | 1330keV |
|--------|--------|--------|--------|--------|--------|---------|---------|---------|
| S N o  | Th     | Ex     | Th     | Ex     | Th     | Ex      | Th      | Ex      |
| 1 Acetyl salicylic Acid | 0.1  | 0.1 | 0.1 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 2 Acetic Acid | 0.1 | 0.1 | 0.1 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 3 Acetoguanamine | 0.1 | 0.1 | 0.1 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 4 Usnic Acid | 0.1 | 0.1 | 0.1 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 5 Erucic Acid | 0.1 | 0.1 | 0.1 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| 6 Formic acid | 0.1 | 0.1 | 0.1 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
It is seen that the experimental and theoretical results of $\mu m$ are in good agreement. Experimental error in the measured data was within 5%. The error in the measured results was due to mainly the deviation in the sample thickness and impurity in the samples. Experimentally determined results of $\mu m$ are plotted in the Fig.2.

![Graph showing $\mu m$ vs energy of gamma rays](image)

**Fig.2.** Typical plots of $\mu m$ Vs.energy of gamma rays.

It is depicted that the $\mu m$ of the organic compounds decrease with gamma ray energy of photons. It is also seen from Fig.2 that the $\mu m$ values of all the samples decrease sharply between 122 to 1170 keV. This attributed to the prevalence of Compton scattering photon interaction process in these energies. Above 1170 keV, the values of $\mu m$ are gradually deceased with energy of incident photon owing to the pair production photon interaction process becomes gradually dominant for these energies. The $\mu m$ values of Erucic Acid are found highest than the other selected samples at all energies where $\mu m$ values of Acetylsalicylic acid, Acetic acid, Acetoguanamine and Usnic Acid observed in the almost similar except at energy above 1170 keV.

Thus it is suggested that the Usnic Acid has the better gamma ray attenuation capacity at all energies among the selected organic compounds whereas Acetylsalicylic acid and Acetic acid have the worst gamma ray attenuation capacity at high energies (above 1170 keV). Results of $\mu ms$ as affected by the chemical constituent of the selected organic compounds as Usnic Acid(content of C, H and N) possesses the slightly different $\mu m$ values (higher) and other selected organic compounds (content C, H and O) possess almost similar low $\mu m$.

### 3.3. Total and electronic cross section ($\sigma_{tot}$ and $\sigma_e$)

From the experimentally and theoretically obtained results of $\mu m$, $\sigma_{tot}$ and $\sigma_e$ were determined as shown in the Figs. 3 and 4. It is seen that the $\sigma_{tot}$ and $\sigma_e$ varies with incident gamma ray energy photon and decline with the energy. It is seen that $\sigma_{tot}$ and $\sigma_e$ values decrease speedy initially then gradually decrease with energy. The behavior of $\sigma_{tot}$ and $\sigma_e$ observed almost similar to $\mu m$ data in the entire energies, this could be explain very well by Compton and pair production interaction processes dominated in the respective energies. It is seen that the total and electronic cross sections of Usnic Acid and Erucic Acid have lowest and highest at all the energies, respectively, this could be explain
similar to mass attenuation coefficient. The experimental and theoretical (XCOM) results of $\sigma_{\text{tot}}$ and $\sigma_e$.

Fig. 3 The typical plots of $\sigma_{\text{tot}}$ Vs. energy of gamma rays.

Fig. 4. The typical plots of $\sigma_e$ Vs. energy of gamma rays.

3.4. **Effective atomic number and electron density (Zeff and Neff)**

Measured results of effective atomic numbers (Zeff) for the organic compounds are displayed in Fig.5. It is seen that the Zeff of the all selected organic compounds vary marginally with the incident energy of gamma ray photons and almost independent with the energy. This may be due to the scattering cross section of Compton scattering is proportional to the atomic number ($z$) and incident energy of photon (E-1). The variations in values of Zeff are hardly noticeable with the increase in the gamma ray energy.
and the Z_{eff} observed in the following order; (Usnic Acid)Z_{eff}< (Acetic acid)Z_{eff}<(Acetoguanamine)Z_{eff}< (Acetylsalicylic acid)Z_{eff}< (Erucic Acid)Z_{eff}.

![Graph showing the typical plots of Z_{eff} Vs. energy of gamma rays.](image)

**Fig. 5.** The typical plots of Z_{eff} Vs. energy of gamma rays.

**Table 3** Effective electron density (N_{eff}) of some organic materials.

| Sample Name | 122keV | 356keV | 511keV | 662keV | 840keV | 1170keV | 1275keV | 1330keV |
|-------------|--------|--------|--------|--------|--------|---------|---------|---------|
| Acetylsalicylic Acid | 3.1 | 3.1 | 3.1 | 3.1 | 3.1 | 3.1 | 3.1 | 3.1 |
| Acetic Acid | 41 | 48 | 41 | 48 | 41 | 48 | 41 | 48 |
| Acetoguanamine | 3.2 | 3.2 | 3.2 | 3.2 | 3.2 | 3.2 | 3.2 | 3.2 |
| Usnic Acid | 09 | 09 | 09 | 09 | 09 | 09 | 09 | 09 |
| Erucic Acid | 3.1 | 3.1 | 3.1 | 3.1 | 3.1 | 3.1 | 3.1 | 3.1 |
| Formic Acid | 3.1 | 3.1 | 3.1 | 3.1 | 3.1 | 3.1 | 3.1 | 3.1 |
| 4 Usnic Acid | 48 | 48 | 48 | 48 | 48 | 48 | 48 | 48 |
| 5 Erucic Acid | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 | 3.3 |
| 6 Formic Acid | 3.1 | 3.1 | 3.1 | 3.1 | 3.1 | 3.1 | 3.1 | 3.1 |
It is also observed from Fig.5 that the Z_{\text{eff}} of Acetylsalicylic acid, Acetic acid, Acetoguanamine, Usnic Acid and Erucic Acid are observed 4.4, 4, 4.1, 4.3 and 3, respectively which is in the good accord with the average atomic numbers as given in Table 1. The effective atomic numbers (N_{\text{eff}}) determined experimentally and theoretically are given in the Table 3. It is seen that the Neff values are vary marginally with the incident energy of gamma ray. This independent nature of Neff with energy could be explained similar way as of Z_{\text{eff}}. The values of Neff are observed in the range of (~3.1 to 3.4)*10^{23} for the selected energies.

4. Conclusions

The μm, β_{\text{tot}}, β_{\text{e}}, Z_{\text{eff}} and N_{\text{eff}} of the Usnic Acid, Acetic acid, Acetoguanamine, Acetylsalicylic acid, Erucic Acid were measured and compared with XCOM data base. Error in the experimental and theoretical results was observed within 5%. These attenuation parameters were observed to affect by the chemical composition and environment in an experiment. The results of μm, β_{\text{tot}} and β_{\text{e}} were observed affected by Compton and pair production photon interaction processes in the respective energies, and these parameters were decreased with the intensity of gamma ray. The results with Z_{\text{eff}} and N_{\text{eff}} were observed independent of energy. Finally, it is conclude that the Erucic Acid has the better gamma ray shielding capacity among the selected compounds. The investigation on gamma ray interaction with organic compounds in the medical diagnostic energy range could be useful in radiation protection and radiation medicine biology applications.

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