

RESEARCH PAPER

Photon Interaction Parameters of Different Tissues of Human Organs

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ABSTRACT

For proper planning in the radiography of different parts of human organs, knowledge of the photon interaction parameters in different tissues of human organs are essential. Studied the x-ray and gamma photon interaction parameters such as linear attenuation coefficient, half value layer, tenth value layer, mean free path and effective electron density of tissues of human organs like, adipose tissue, blood, brain, breast, cell nucleus, eye lens, GI tract, heart, kidney, liver, lung, lymph, muscle, ovary, pancreas, cartilage, red marrow, spongiosa, yellow marrow, skin, spleen, testis, thyroid, skeleton cortical bone, skeleton cranium, skeleton femur, skeleton humerus, skeleton mandible, skeleton ribs, skeleton sacrum, skeleton spongiosa, skeleton vertebral column and skeleton vertebral column. The present work is useful in the planning of radiography for different organs. This work also gives useful information for radiotherapy and dosimetry.

Keywords: Mass attenuation coefficient; Electron density; Tissue

1. INTRODUCTION

The study of mass attenuation coefficient in different tissues of human organs plays important role in the radiotherapy and medical diognosis. Böke¹ computed linear attenuation coefficients of tissues for liver, kidney, muscle, fat for a x-ray energies. Tomal², *et al.* measured linear attenuation coefficients for normal and neoplastic breast tissues using x-ray beams at the energy range of 8 keV – 30 keV. Ekinci and Astam³ measured mass attenuation coefficients of biological materials by energy dispersive x-ray fluorescence spectrometry. Akar⁴, *et al.* measured linear and mass attenuation coefficients for bone, muscle, fat and water at 140 keV, 364 keV, and 662 keV energies using the medical spectrometer. Bahri and Spyrou⁵ determined linear attenuation coefficients and water content of normal and pathological breast tissue using a high purity germanium detector (HPGe) at energy 59.5 keV. Singh⁶, *et al.* computed the mass energy-absorption coefficients for nuclear track detectors using GEANT4 Monte Carlo code. Adem⁷ calculated mass energy absorption coefficients for polymer gel dosimeter, five gel dosimeter, soft tissue and water in the energy range from 1 keV to 20 MeV. Chen⁸, *et al.* measured the linear attenuation coefficients of breast tissues by synchrotron radiation in the energy range from 15 keV - 26.5 keV. Siemens, Siremobil⁹, determined the linear x-ray attenuation coefficients of pathological brain tissues and this study is useful to enhance the tissue contrast in computed tomography. Ermis¹⁰, *et al.* studied the mass attenuation coefficients of different parts of the human body by various theoretical methods such as

FLUKA, GEANT4 Monte carlo methods at different energies (60 keV - 2000 keV). Manjunatha and Rudraswamy¹¹ studied the thickness and penetration depth dependence of specific absorbed fraction of energy in bone for wide energy range (0.015 MeV - 15 MeV). Manjunatha¹² studied the photon interaction parameters such as mass attenuation coefficient (μ/ρ), effective atomic number, and effective electron density (Ne) in lung tissue substitutes. Manjunatha and Rudraswamy¹³ computed the photon interaction parameters such as effective atomic numbers and electron densities in bone. Manjunatha and Rudraswamy¹⁴ computed computerised tomography number and the effective atomic number in the different regions of teeth.

It is difficult to measure the basic photon interaction parameters in tissues of human organs because many chemical and biological reactions takes place simultaneously. Thus there is a need to estimate these parameters theoretically. Hence in the present work we have studied the basic photon interaction parameters such as linear attenuation coefficient, half value layer, tenth value layer, mean free path and effective electron density of almost all tissues of human organs (Adipose tissue, blood, brain, breast, cell nucleus, eye lens, GI tract, heart, kidney, liver, lung, lymph, muscle, ovary, pancreas, cartilage, red marrow, spongiosa, yellow marrow, skin, spleen, testis, thyroid, skeleton cortical bone, skeleton cranium, skeleton femur, skeleton humerus, skeleton mandible, skeleton ribs (2nd, 6th), skeleton ribs (10th), skeleton sacrum, skeleton spongiosa, skeleton vertebral column (C4), skeleton vertebral column (D6, L3) in the energy region 1 keV-20 MeV.

2. PRESENT WORK

2.1 Effect of X-ray and Gamma Photon Interaction Parameters on Tissues

In the present work, the mass attenuation coefficients of tissues $(\mu/\rho)_t$ are generated using their composition¹⁵ and WinXCom¹⁶. The total linear attenuation coefficient (μ) can be evaluated by multiplying density of tissue to mass attenuation coefficients.

$$\mu = \left(\frac{\mu}{\rho}\right)_t \times \rho \tag{1}$$

The linear attenuation coefficients of tissues is used to estimate the distance travelled by the photon in the medium. The interaction parameter such as half value layer (HVL) is the distance travelled by the photon in tissue medium to reduce its intensity to 50 per cent and it is estimated from their linear attenuation coefficients.

$$HVL = \frac{\ln 2}{\mu} = \frac{0.693}{\mu} \tag{2}$$

The distance travelled by the photon in a tissue medium to lose its 90 per cent of its intensity is termed as tenth value layer (TVL). It is estimated from their linear attenuation coefficient,

$$TVL = \frac{\ln 10}{\mu} = \frac{2.303}{\mu} \tag{3}$$

The average distance between two successive interactions of photons in a tissue medium is termed as the relaxation length (λ) . It is also called the photon mean free path which is determined by the equation:

$$\lambda = \frac{\int_0^{\infty} x \exp(-\mu x) dx}{\int_0^{\infty} \exp(-\mu x) dx} = \frac{1}{\mu} \tag{4}$$

The basic photon interaction parameters in a tissue medium such as linear attenuation coefficient, half value layer, tenth value layer and mean free path are evaluated using equations

2.2 Effective Electron Density

When a photon interacts in a tissue medium, electron density of the medium changes and it is termed as effective electron density. The effective electron density is estimated by calculating molecular, atomic and electronic cross section. The total molecular cross section $[\sigma_m]$ is computed from the following equation using the values of mass attenuation coefficient of tissues $[(\mu/\rho)_t]$

$$\sigma_m = \left(\frac{1}{N}\right) \left(\frac{\mu}{\rho}\right)_t \sum_i n_i A_i \tag{5}$$

where n_i is the number of atoms of i^{th} element in a given molecule, $(\mu/\rho)_t$ the mass attenuation coefficient of tissue, N , the Avogadro's number and A_i , the atomic weight of element i . The atomic cross section (σ_a) is estimated using the equation

$$\sigma_a = \frac{\sigma_m}{\sum_i n_i} \tag{6}$$

The effective electronic cross section (σ_e) is computed from mass attenuation coefficient $(\mu/\rho)_t$ of i^{th} element in the

given molecule

$$\sigma_e = \left(\frac{1}{N}\right) \sum_i \left\{ \left(\frac{f_i A_i}{Z_i}\right) \left(\frac{\mu}{\rho}\right)_i \right\} \tag{7}$$

where, f_i is the fractional abundance (a mass fraction of the i^{th} element in the molecule) and Z_i is the atomic number of the i^{th} element in a molecule. The effective electron density is estimated from the atomic and electronic cross sections;

$$N_e = \frac{N}{\sum_i n_i A_i} \frac{\sigma_a}{\sigma_e} \sum_i n_i \tag{8}$$

This equation is simplified by substituting the atomic and electronic cross sections from Eqns. (6) and (7). The simplified version of effective electron density is

$$N_e = \frac{N \left(\frac{\mu}{\rho}\right)_t}{\sum_i \left\{ \left(\frac{f_i A_i}{Z_i}\right) \left(\frac{\mu}{\rho}\right)_i \right\}} \tag{9}$$

In the present work, effective electron density is computed from the Eqn. (9).

3. RESULTS AND DISCUSSIONS

We have studied the photon interaction parameters such as free mean path, HVL, TVL and electron density (N_e) in the different tissues of human organs. These parameters are graphically represented. The variation of free mean path (λ) with the energy in the different tissues of human organs is shown in Figs. 1-4. This free mean path increases with increase in the photon energy. The penetration depth of tissue in which the intensity is reduced to half is indicated as HVL. Figures 1-4 also shows the variation of HVL as a function of photon energy. The penetration depth of tissue in which the intensity is reduced to 10 per cent is indicated as TVL. The variation of TVL with photon energy is also shown in Figs. 1-4.

When photon interacts in a tissue, it collides with atoms and molecules so that the electron density changes with the energy of the incident photon. The variation of effective electron density (N_e) with photon energy is as shown in Figs. 5-8. This variation is because of dominance of different photon interactions. There are three energy ranges, where photoelectric absorption, Compton scattering and pair production, respectively, are the dominating interaction process. N_e decreases from 1keV to 100 keV because of photoelectric absorption. Above 100 keV and up to 2 MeV, N_e remains constant because of mixed contribution of photoelectric absorption and Compton scattering. After 2 MeV, N_e increases up to 200 MeV because of incoherent scattering and pair production. There after N_e remains constant with energy, this may be due to the dominance of pair production in high energy region.

Figures 9 and 10 describes the penetration of x-ray photons in different tissues of human organs at 100 keV. The x-rays of energy 80 keV-100 keV (hard x-rays) are used in the medical diagnosis, hence we have selected these energies. Figures 9 and 10 graphically demonstrated the distance travelled by the

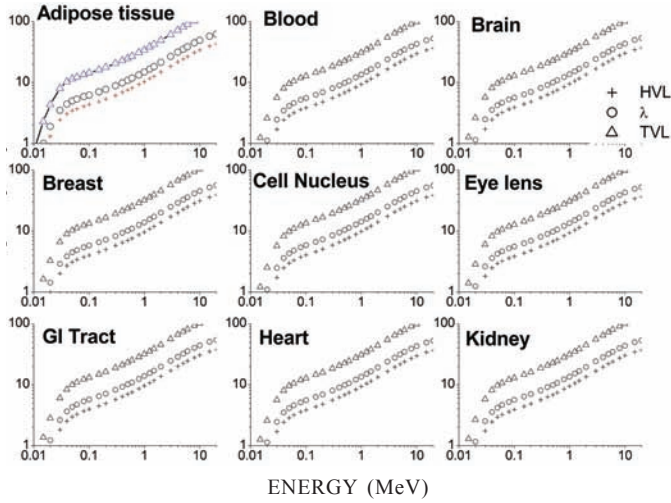


Figure 1. Variation of HVL, TVL and free mean path with photon energy for adipose tissue, blood, brain, breast, cell nucleus, eye lens, GI tract, heart and kidney.

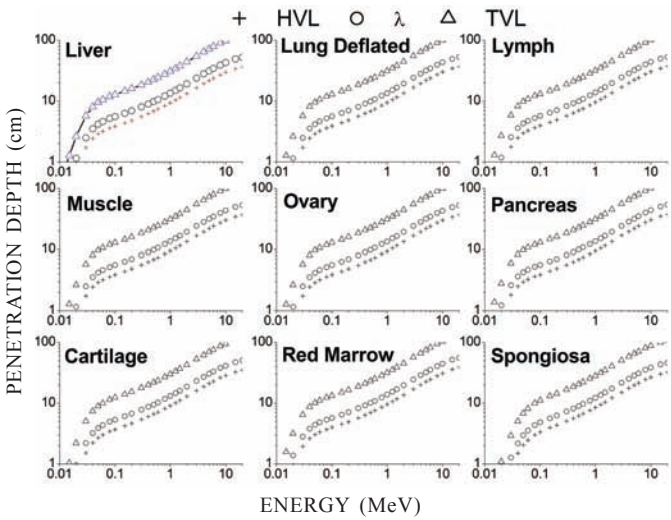


Figure 2. Variation of HVL, TVL and free mean path with photon energy for, liver, lung , lymph, muscle, ovary, pancreas, cartilage, red marrow and spongiosa.

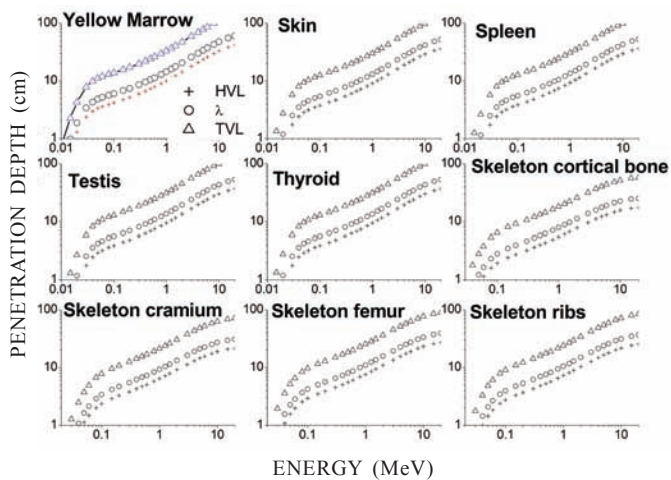


Figure 3. Variation of HVL, TVL and free mean path with photon energy for yellow marrow, skin, spleen, testis, thyroid, skeleton cortical bone, skeleton cranium, skeleton femur, and skeleton ribs (2nd, 6th).

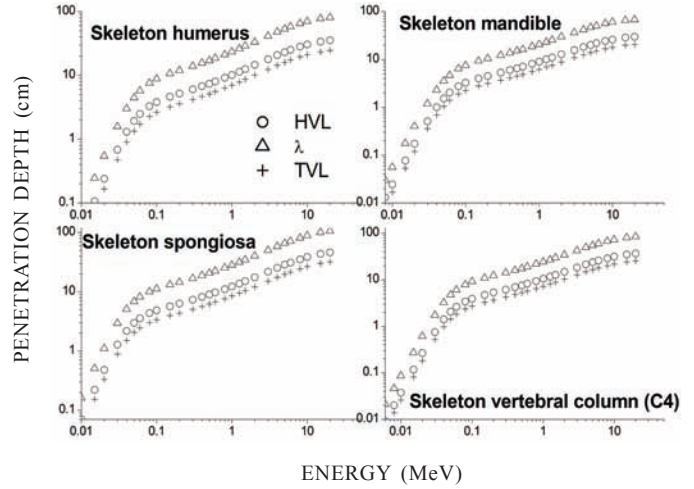


Figure 4. Variation of HVL, TVL and free mean path with photon energy for skeleton humerus, skeleton mandible, skeleton spongiosa and skeleton vertebral column (C4).

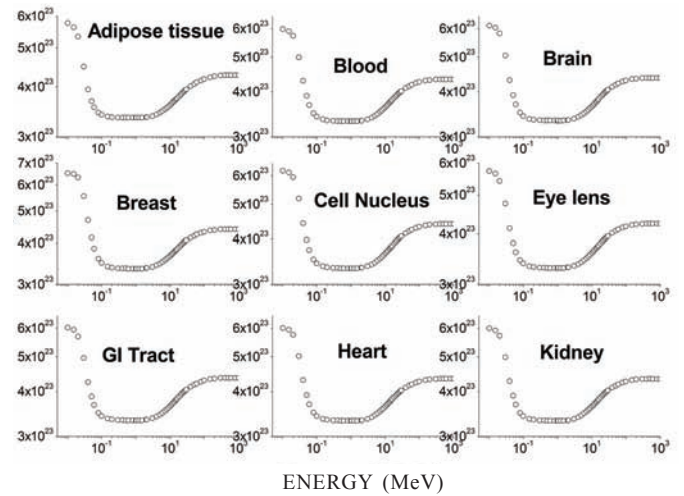


Figure 5. Variation of effective electron density (N_e) with photon energy for adipose tissue, blood, brain, breast, cell nucleus, eye lens, GI tract, heart and kidney.

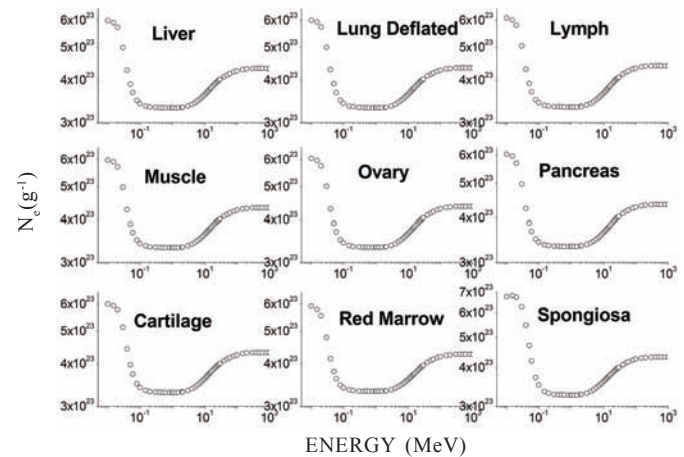


Figure 6. Variation of effective electron density with photon energy for, liver, lung, lymph, muscle, ovary, pancreas, cartilage, red marrow and spongiosa.

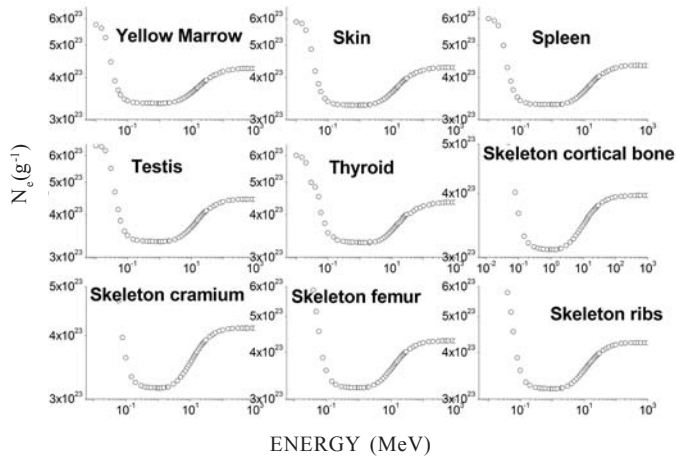


Figure 7. Variation of effective electron density with photon energy for yellow marrow, skin, spleen, testis, thyroid, skeleton cortical bone, skeleton cranium, skeleton femur, and skeleton ribs (2nd, 6th).

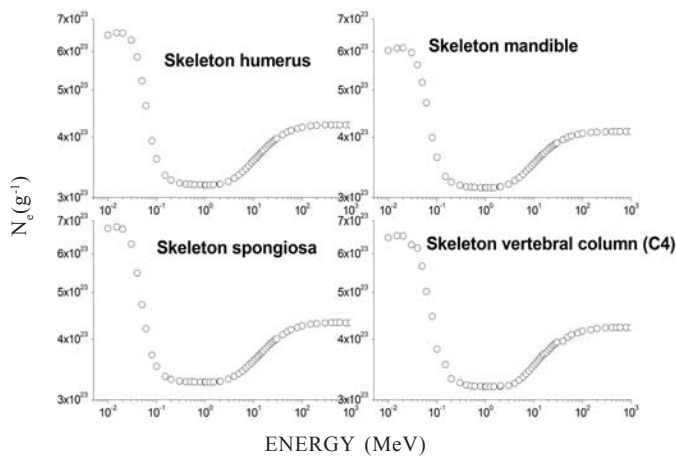


Figure 8. Variation of effective electron density with photon energy for skeleton humerus, skeleton mandible, skeleton spongiosa and skeleton vertebral column (C4).

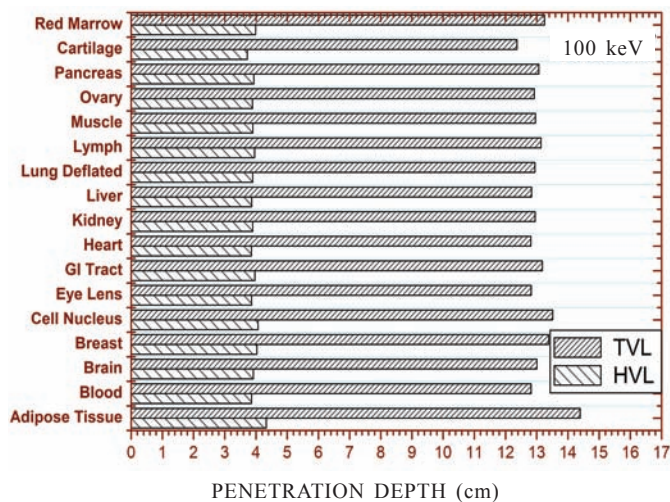


Figure 9. Penetration of photons in different tissues of human organs at 100 keV.

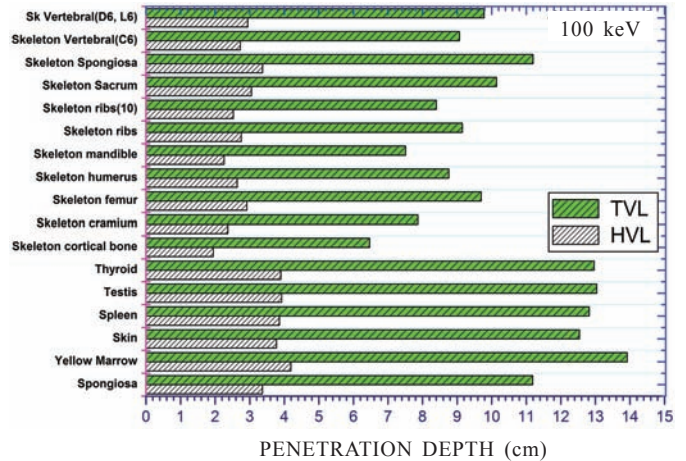


Figure 10. Penetration of photons in different tissues of human organs at 100 keV.

x-ray photon in different tissue medium to reduce its intensity to 50 per cent (HVL) and 10 per cent (TVL). For instance, when x-ray photon of energy 100 keV enters a cortical bone, it loses 50 per cent of its intensity at penetration depth ≈ 1.94 cm. When the same x-ray enters heart/kidney, penetration depth required to reduce 50 per cent of its intensity is ≈ 3.9 cm. The formation of radiographic image depends on the attenuation by the tissue. When patient was taking lungs radiograph, x-rays begins to be attenuated by skin, then x-rays will be further attenuated by the muscle, finally x-rays attenuated in the lungs. Thus for proper planning in the radiograph of different parts of human organs, knowledge of the photon interaction parameters in different tissues of human organs are essential. The present work is useful in the planning of radiography for different organs. This work also gives useful information for radiotherapy and dosimetry.

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