Comparison of some human tissues and some commonly used thermoluminescent dosimeters for photon energy absorption

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Abstract: Mass energy absorption coefficients and effective atomic numbers for photon energy absorption, Z_{PEAeff} have been calculated in the energy range from 1 keV to 20 MeV for human tissues, Adipose Tissue, Blood Whole, Bone Cortical, Brain Grey/White Matter, Breast Tissue, Eye Lens, Lung Tissue, Muscle Skeletal, Ovary, Testis, Soft Tissue. Mass energy absorption coefficients and effective atomic numbers for photon energy absorption have also been calculated for commonly used thermoluminescent dosimeters,TLD, in the energy range from 1 keV to 20 MeV. The energy dependence of the mass energy absorption of human tissues and TL dosimeters are shown graphically. The tissue equivalency of TLDs is investigated. The effects of the elemental composition on effective atomic numbers for photon energy absorption and the tissue equivalency of TLDs are discussed.

Keywords: Effective Atomic Number, Human Tsissue, Thermoluminescent Dosimeters, Photon Energy Absorption

1. Introduction

The mass attenuation coefficient, μ/ρ, is a measure of the probability per unit path length for interactions between the incident photon and the matter. The mass energy absorption coefficient related with the energy-deposition, μ_{en}/ρ is a measure of the average fractional amount of incident photon energy transferred to the kinetic energy of charged particles as a result of the interactions of less bremsstrahlung and other escaping secondary photons. This imparted, charged particles kinetic energy, is in turn, a more or less valid approximation of the amount of the photon energy made available for the production of chemical, biological and other effects associated with exposure to ionising radiation. The values of μ/ρ, μ_{en}/ρ for medical and health physics are known to be essential quantities in calculating of the penetration and absorbed dose of energetic photons in biological and other materials [1-3].

The commonly used effective atomic number, labeled as Z_{eff}, is determined by using mass attenuation coefficients, μ/ρ, which is a convenient parameter for representing photon interaction. Some studies to determine the Z_{eff} values of composite materials various alloys [4,5], solutions and amino acids [6], some biological materials [7, 8], soils and boron ores [9,10], some dosimetric interest [11] have been reported in the literature. A more useful effective atomic number, labeled as Z_{PEAeff} in this work, is determined by using mass energy absorption coefficients, μ_{en}/ρ, which is a convenient parameter in dosimetry as discussed above. Some studies to determine the Z_{PEAeff} values of composite materials such as thermoluminescent (TL) dosimetric compounds [12], dosimetric intereset [13] and some biological molecules [14] have also been reported in the literature.

In this study, the direct method is used for determination of effective atomic numbers of human tissues and TL dosimeters. Elemental content of human tissues studied Adipose tissue, Blood-Whole, Cortical Bone, Brain-Grey/White Matter, Breast Tissue, Eye Lens, Lung Tissue, Muscle-Skeletal, Ovary, Testis, Tissue Soft and Tissue Soft-Four Component are taken from the ICRU Report 44 [15].

Since one of the most significant properties of the TL dosimetry materials is the tissue equivalence in the field of

medical and radiation physics, determination of effective atomic number of human tissues and dosimeters is crucial. In an earlier study, effective atomic numbers of some pure thermoluminescent dosimetric compounds have been calculated with the interpolation method [11]. However, it is well known that a pure material does not exhibit TL properties. Dopants are important components of TL dosimeters as they affect the concentration of the trapping centers in the TL dosimeters and also the energy deposition. The trapping centers are responsible for storing the energy after irradiation [16]. There are no reports regarding the Z_{PEAeff} of the doped TL dosimeter in the literature. Because of this reason, Z_{PEAeff} of some commonly used pure and doped TL dosimeters LiF, TLD-100 (LiF:Mg,Ti) [17], TLD-700 (LiF:Mg,Cu,P-0.18, 0.0024, 2.3 wt %) [16], CaF_2, TLD-400 (CaF_2:Mn-2.5, 3, 4.3 % mol) [18], $BaSO_4$, $BaSO_4$:Eu,Dy (2, 2 mol %) [19], $BaSO_4$:Sm (0.5, 1 mol %), $BaSO_4$:Eu (0.5, 1 mol %), $BaSO_4$:Dy (0.5, 1 mol %) and $BaSO_4$: Tm (0.5, 1 mol %) [20], $CaSO_4$, $CaSO_4$:Dy (0.05 mol %) [21], $CaSO_4$:Tm (0.1 mol %) [22] are calculated by using the direct method in this study.

The energy dependence of μ_{en}/ρ and Z_{PEAeff} of some human tissues and TL dosimeters mentioned above is shown graphically. Z_{PEAeff} values determined are compared each other in the energy range from 1keV to 20 MeV , since photons of energy 5-1500 keV are very important in the radiation biology, especially in diagnostics and therapy [23]. The Z_{PEAeff} values of the human tissues are compared with that of the TL dosimeters for determination of tissue equivalency of TL dosimeters.

2. Calculating of the Effective Atomic Number

The effective atomic number for photon energy absorption, Z_{PEAeff}, can be determined from the mass energy absorption coefficient, μ_{en}/ρ , which has been calculated for composite materials by the additivity law [3]

$$\mu_{en}/\rho = \sum_i w_i (\mu_{en}/\rho)_i, \qquad (1)$$

where w_i and $(\mu_{en}/\rho)_i$ are the weight fraction and the mass energy absorption coefficients of the ith constituent element, respectively. The $(\mu_{en}/\rho)_i$ values of the ith constituent element have been taken from the compilation of Hubbel and Seltzer, [2].

The total molecular energy absorption cross section, $\sigma_{m,en}$, were then determined from the μ_{en}/ρ values with the following relation

$$\sigma_{m,en} = \frac{M}{N_A} \left(\frac{\mu_{en}}{\rho} \right), \qquad (2)$$

where $M = \sum_i n_i A_i$ is the molecular weight of the studied material, N_A is the Avogadro number, n_i is the total number of atoms in the molecule, and A_i is the atomic weight of the ith constituent element.

The effective atomic energy absorption cross section, $\sigma_{a,en}$,

can be determined by using the equation:

$$\sigma_{a,en} = \frac{\mu_{en}/\rho}{N_A \sum_i w_i/A_i} = \frac{1}{N_A} \sum_i f_i A_i \left(\frac{\mu_{en}}{\rho} \right)_i = \frac{\sigma_{m,en}}{\sum_i n_i}, \qquad (3)$$

where $f_i = n_i/\sum_j n_j$ is the fractional abundance of the ith element. The n_i and $\sum_j n_j$ are the number of the atoms of the ith constituent element and the total number of the atoms in the studied material, respectively.

Effective electronic energy absorption cross section, $\sigma_{e,en}$, can be calculated by:

$$\sigma_{e,en} = \frac{1}{N_A} \sum_i \frac{f_i A_i}{Z_i} \left(\frac{\mu_{en}}{\rho} \right)_i = \frac{\sigma_{a,en}}{Z_{PEAeff}}, \qquad (4)$$

where Z_i is the atomic number of the ith constituent element.

And, the effective atomic number for photon energy absorption, Z_{PEAeff}, can be given as:

$$Z_{PEAeff} = \frac{\sigma_{a,en}}{\sigma_{e,en}}. \qquad (5)$$

3. Results and Discussion

The energy dependence of mass energy absorption coefficients, μ_{en}/ρ, are shown in Fig. 1 and 2 for the human tissues and some commonly used TL dosimeters. Three energy range photoelectric absorption, Compton scattering and pair production are clearly seen from the diagrams. While the photoelectric absorption is the dominant process at low energy region, Compton scattering and pair production are the dominant process at medium energies and high energies, respectively [1].
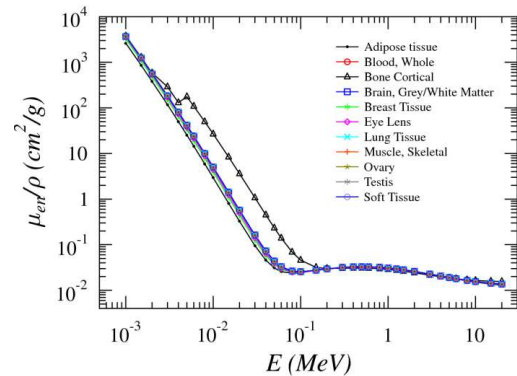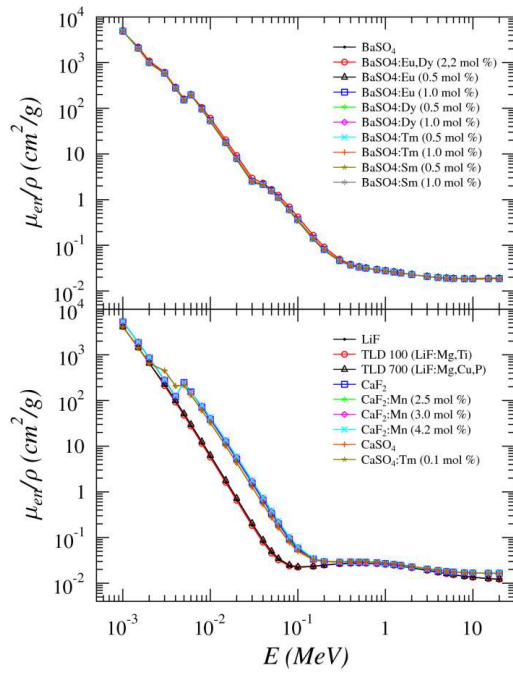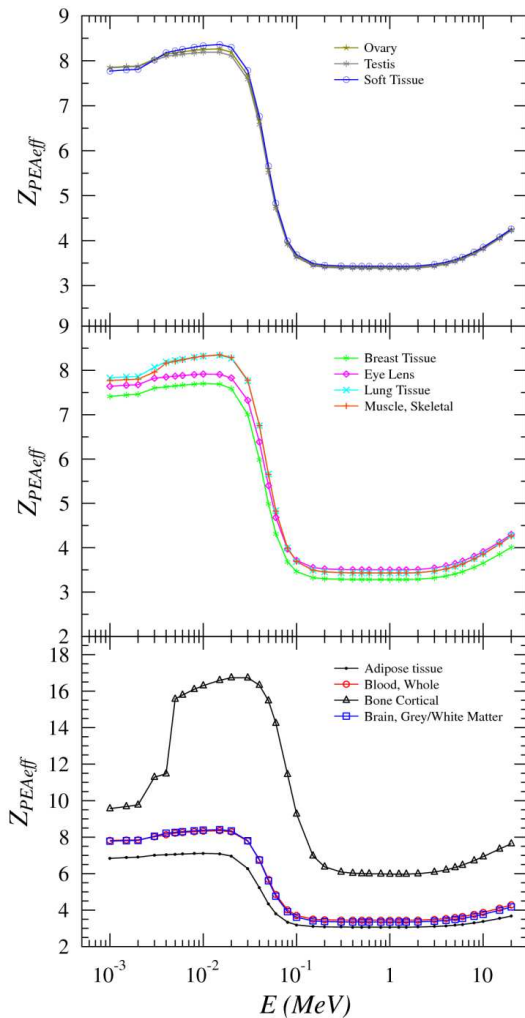

Fig. 1. *The energy dependence of the mass energy absorption coefficient, μ_{en}/ρ, of human tissues.*
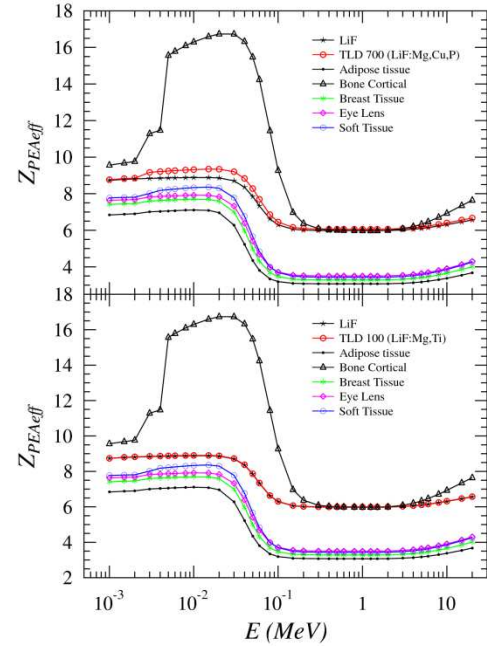
For the determination of tissue equivalence of TL dosimeters, the values of Z_{PEAeff} of the TL dosimeters are also determined and compared in the energy range from 1 keV to 20 MeV with that of the tissues studied in this work. The explanation of the variation of Z_{PEAeff} with photon energy for TL dosimeters is the same with the case for the human tissues mentioned above. It can be seen from Figs. 3-8 that the variation of Z_{PEAeff} with energy is similar for the TL dosimeters and soft tissues except for $BaSO_4$ doped with the Sm, Eu, Dy and Tm having high atomic numbers because of the abrupt changes near the absorption edges.
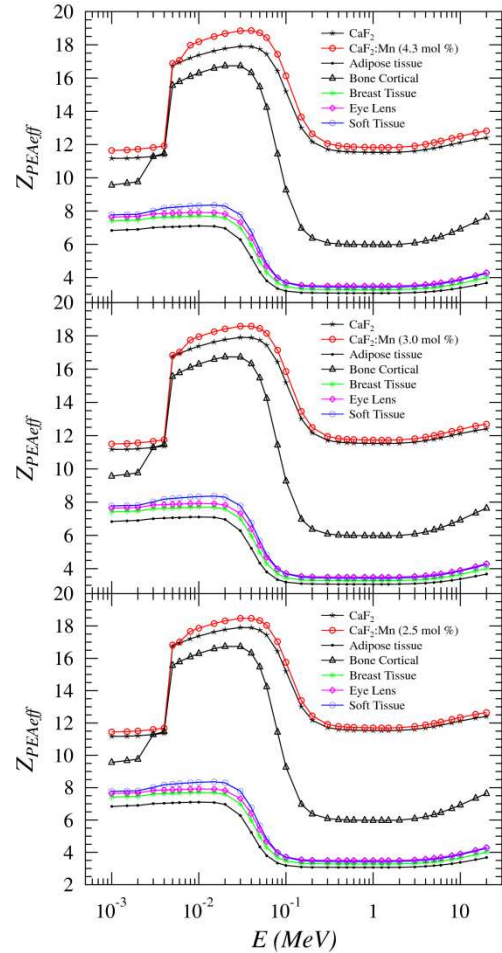
Fig. 2. *The energy dependence of the mass energy absorption coefficient, μ_{en}/ρ, of some commonly used thermoluminescent dosimeters.*
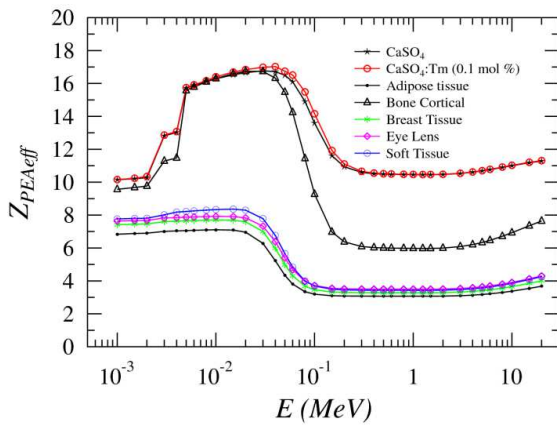

Fig. 4. *The comparison of Z_{PEAeff} values of LiF, TLD-100 and TLD-700 with Z_{PEAeff} values of Adipose Tissue, Cortical Bone, Breast Tissue, Eye lens and Soft Tissue.*

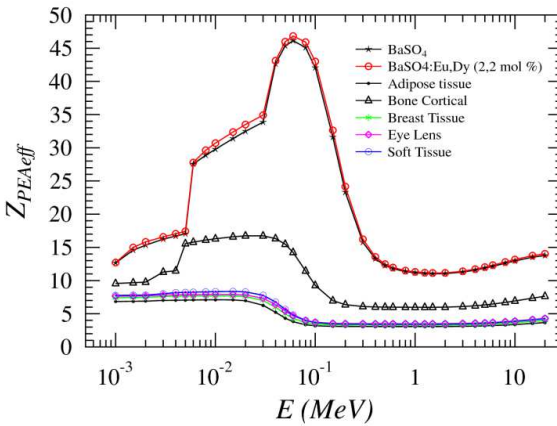**Fig. 3.** *The energy dependence of Z_{PEAeff} of human tissues.*

Fig. 5. *The comparison of Z_{PEAeff} values of CaF_2 and CaF_2:Mn (2.5, 3.0 and 4.3 % mol) with Z_{PEAeff} values of Adipose Tissue, Cortical Bone, Breast Tissue, Eye lens and Soft Tissue.*

The maximum values of Z_{PEAeff} are 8.903 for TLD 100 and 9.346 for TLD 700 at energy 15 keV, 18.473 for CaF$_2$:Mn (2.5 % mol), 18.580 for CaF$_2$:Mn (3 % mol) and 18.852 for CaF$_2$:Mn (4.3 % mol) at energy 40 keV, 17.026 for CaSO$_4$:Tm (0.1 mol %) at energy 40 keV, 48.780 for BaSO$_4$:Eu,Dy (2, 2 mol %) at energy 60 keV, 46.466 and 46.798 for BaSO$_4$:Sm (0.5 and 1 mol %) at energy 60 keV, 46.482 and 46.828 for BaSO$_4$:Eu (0.5 and 1 mol %) at energy 60 keV, 46.501 and 46.869 BaSO$_4$:Dy (0.5 and 1 mol %) at energy 60 keV, 46.508 and 46.884 fo BaSO$_4$:Tm (0.5 and 1 mol %) at energy 60 keV, respectively. It can be seen in Fig. 4 that the values of Z_{PEAeff} for LiF, TLD 100 and TLD 700 are approximately same with that of the Cortical Bone in the energy range from 200 keV to 5MeV. Therefore, LiF, TLD 100 and TLD 700 can be used as tissue equivalent materials for Cortical Bone in that energy range.
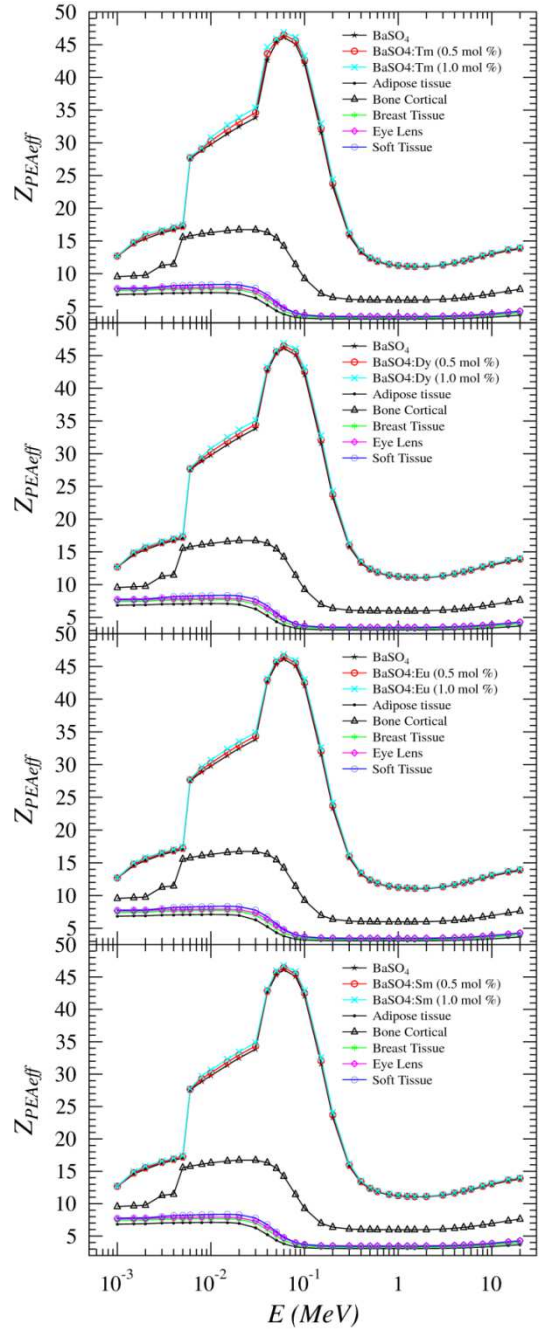

Fig. 6. *The comparison of Z_{PEAeff} values of CaSO$_4$ and CaSO$_4$:Tm (0.1 % mol) with Z_{PEAeff} values of Adipose Tissue, Cortical Bone, Breast Tissue, Eye lens and Soft Tissue.*

Fig. 7. *The comparison of Z_{PEAeff} values of BaSO$_4$ and BaSO$_4$:Eu,Dy (2, 2 mol %) with Z_{PEAeff} values of Adipose Tissue, Cortical Bone, Breast Tissue, Eye lens and Soft Tissue.*

While the CaF$_2$ and CaF$_2$:Mn (2.5 % mol) can be used as equivalent material for Cortical Bone in the energy range from 3 keV to 4 keV, CaSO$_4$ and CaSO$_4$:Tm (0.1 mol %) can be used as equivalent material for Cortical Bone in the energy range from 5 keV to 40 keV as can be seen in Fig.5 and Fig.6, respectively.

Because of their elemental compositions, pure and doped BaSO$_4$ dosimeters cannot be used as tissue equivalent materials for the studied human tissues in energy range 1keV-20 MeV as seen in Fig.7 and Fig.8.

Fig. 8. *The comparison of Z_{PEAeff} values of BaSO$_4$, BaSO$_4$:Sm (0.5 and 1 mol %), BaSO$_4$:Eu (0.5 and 1 mol %) , BaSO$_4$:Dy (0.5 and 1 mol %) and BaSO$_4$:Tm (0.5 and 1 mol %) with Z_{PEAeff} values of Adipose Tissue, Cortical Bone, Breast Tissue, Eye lens and Soft Tissue.*

4. Conclusions

Knowledge of the tissue equivalence of TL dosimeters is very important in terms of energy absorption. In this study, the effective atomic number for the mass energy absorption, Z_{PEAeff} and the mass energy absorption coefficients, μ_{en}/ρ,

for human tissues and some commonly used TL dosimeters are calculated for the examination of tissue equivalence of dosimeters. Because of the high concentration of Ca, Z_{PEAeff} value of Cortical Bone is larger than that of the other human tissues in the all energy region. LiF, TLD 100 and TLD 700 are determined in the energy range from 200 keV to 5MeV; CaF_2 and CaF_2:Mn (2.5 % mol) are determined in the energy range from 3 keV to 4 keV; and $CaSO_4$ and $CaSO_4$:Tm (0.1 mol %) are determined in the energy range from 5 keV to 40 keV as tissue equivalent materials for Cortical Bone.

Acknowledgment

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