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Radiological properties of plastics and TLD materials its application in radiation dosimetry

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Abstract. In the current study, we evaluated the tissue equivalency of nine different commonly used thermoluminescence compounds and six plastic materials over the photon energy range of 15 KeV to 20 MeV. Our result confirmed that the ratio of number of electrons per gram, electron density of the entire TLD compounds and plastic materials to ICRU-44 soft tissue was lesser than unity, except in the case of polypropylene plastics. The effective atomic number ratio of all the plastic materials was also <1 excluding Poly-vinyl-chloride, and for TLD lithium borate material, it was <1 others which showed the deviation with respect to photon energy. Mass attenuation coefficient (μ/ρ), mass absorption coefficient (μ_{en}/ρ) was calculated and the results are discussed in this paper.

1. Introduction

Tissue equivalent materials have enormous applications in a wide range of fields such as space research, phantom, radiology, nuclear engineering, health physics, radiation physics and radiation dosimetry etc [1-5]. In radiotherapy, tissue substitute materials are employed to extract the dose, similar to the human tissue organs. It is made up of low Z material such as (H,C,N,O etc) [6,16]. Radiation absorption properties of the particular material are similar to human tissue. This material is called tissue substitute or tissue equivalent material. International commission on radiation units and measurement (ICRU-44) has published various tissue substitute materials [7]. Knowledge of gamma ray interaction is important for the calculation of absorbed dose to predict the biological effect of the radiation. Photo electric effect, Compton effect and Pair production are the three major processes for photon attenuation in the energy range of 15KeV to 15MeV. Hence, mass attenuation coefficient and mass energy absorption coefficient depend on those processes. Photoelectric effect depends on the third power of atomic number of the material and it is predominant in the energy range of 20 to 100KeV [8]. KeV energy is mostly used in radiobiological study, therapy and diagnosis. On the other hand, MeV energy range plays an important role in cancer radiotherapy and imaging. Equivalent atomic number is one of the important parameters to know the photon scattering result that buildup of photons it deposited energy at some particular depth its leads to skin sparing effect. Polymethyl metha acrylate (PMMA) which is the most commonly used tissue substitute material due to ease of handling [9]. In medical physics, the most fundamental application of radiation and radioisotopes is radiation dosimetry [10, 11]. Dosimetry may involve in-patient (in-vivo), phantom (in-vitro), environmental monitoring in hospitals. Occupational exposure measurement with a personal detector helps monitor the dose levels. A good TL material can have properties such as tissue equivalency, low fading, good precision and accuracy, high sensitivity, better stability under the environmental condition such as temperature and humidity etc [12]. Thermoluminescence dosimeter plays a vital role in radiation detector particularly in radiotherapy. Only a few TL materials have the tissue equivalent properties among them lithium borate is the most attractive.

$Li_2B_4O_7$:Mn phosphor is the first TL based dosimetry but it has poor sensitivity. Depending on the application, it should be varied for therapy or diagnosis [13]. Many of the methods such as interpolating method, direct method, Auto Zeff, XMuDat computer program are available for calculating the effective atomic number. Researchers have studied the effective atomic number of different biological tissues, soils, amino acids, fatty acids etc [14, 15]. Ferreira *et al* studied the tissue equivalence of ten different materials. Among them, modelling clay and nylon are more tissue equivalent materials and they suggested that the total mass attenuation coefficient is a valuable parameter to prescribe the tissue equivalency of the material [16]. In this present analysis, we studied the tissue equivalent properties of nine various thermoluminescence and plastic materials.

2. Materials and Methods

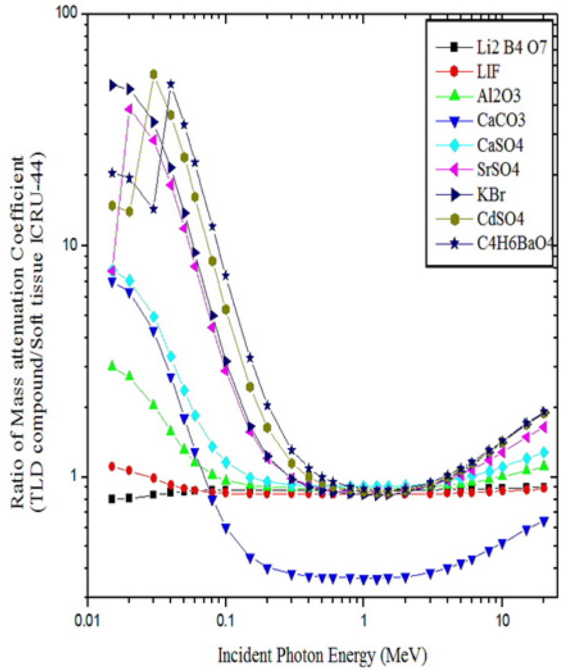
We selected nine different thermoluminescence compounds namely Lithium borate, Lithium fluoride, Aluminium Oxide, Calcium carbonate, Calcium sulfate, Strontium sulfate, Potassium bromide, Cadmium sulfate (anhydrous salt), Barium acetate and the following six plastic materials - Polyethylene terephthalate, Poly-vinyl-chloride, PMMA, Polypropylene, Nylon, and Bakelite. Mass absorption and Mass attenuation coefficient of the element was generated using NIST Win XCom and mixture rule was used to calculate the coefficients of materials [17]. Effective atomic number, electron density and number of electrons per gram were calculated according to the literature [18]. Results were compared with ICRU-44 soft tissue (four compartments).

3. Result and discussion

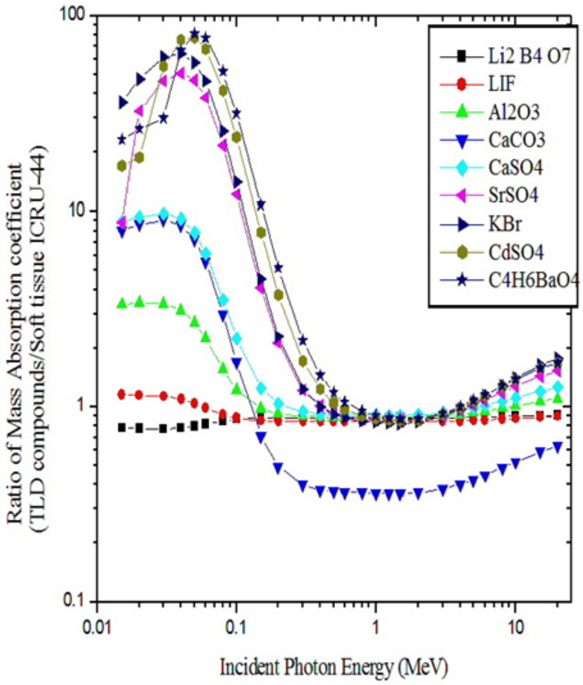
Ratio of effective atomic number of all the plastics is almost unity excluding poly-vinyl-chloride. Which has the Z_{eff} of 13.86 due to high atomic number element such as chlorine (Z=17) presence of 0.567% & inclusion of K-edge absorption [19]. Ratio of effective atomic number of TL compounds to soft tissue is varied according to the materials. For Lithium borate, Lithium fluoride, Calcium sulfate, Calcium carbonate and Aluminium oxide less than 2.5 and others have the ratio of within 5.

Table 1. Electron density (ρ_e), Number of electrons per gram (n_e) and Effective atomic number (Zeff) of TL compounds and plastics

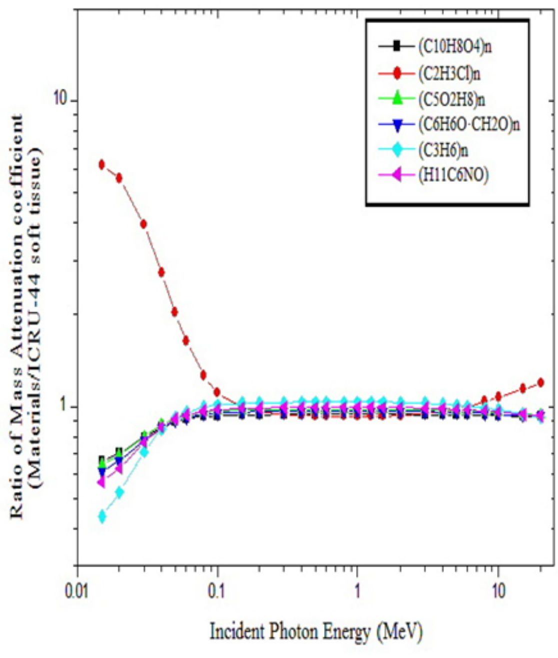
S.No	**Materials name**	**ρ_e $\times 10^{23}$ e/cm^3**	**n_e $\times 10^{23}$ e/g**	**Zeff**
1	Lithium borate	1.21618	2.91883	7.248515
2	Lithium fluoride	1.05484	2.78478	8.197445
3	Aluminium Oxide	0.747376	2.95214	11.14045
4	Calcium carbonate	1.10929	3.00729	15.07936
5	calcium sulfate	1.26565	2.9363	16.69195
6	Strontium sulfate	0.711768	2.8186	29.18566
7	Potassium bromide	0.996992	2.73176	31.09977
8	Cadmium sulphate	0.590988	2.77232	38.13204
9	Barium acetate	1.27007	2.78146	43.49785
10	Polyethylene terephthalate	3.13273	2.27009	6.637982
11	Poly-vinyl-chloride	3.08252	2.51634	13.86187
12	PMMA	3.247	2.75177	6.467169
13	Bakelite	3.17485	2.44219	6.404653
14	Polypropylene	3.37635	3.56908	5.474942
15	Nylon	3.25937	2.8098	6.144411
16	ICRU-44 Soft tissue	3.30937	3.30937	7.26272



(i.a)



(i.b)



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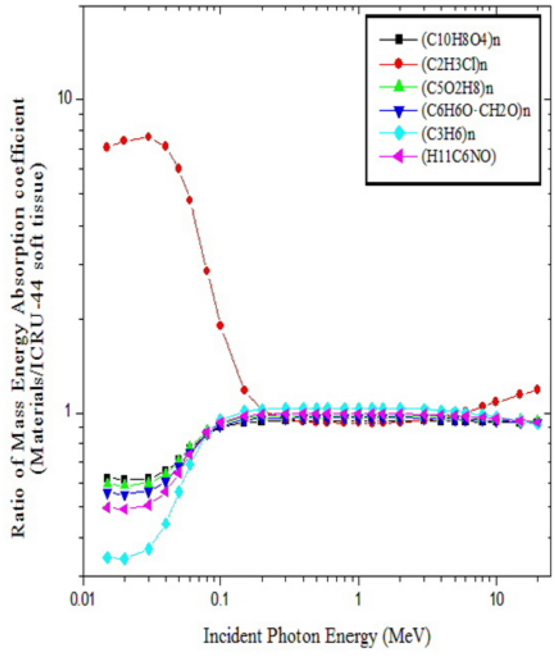

(i.b)

Figure 1. Ratio of Photon mass attenuation coefficient and mass energy absorption coefficient of selected materials are shown figure i a), b) is for TL compounds and figure ii a) & b) for plastics.

Ratio of mass absorption and mass attenuation coefficient of lithium borate thermoluminescence compound to ICRU-44 soft tissue is almost unity in the entire energy range of 0.015MeV to 20MeV. For other TL compounds shows the deviation in lower and higher energy range due to photoelectric and pair production process respectively, it depends on the chemical composition [16, 19]. These results can be shown in the figure i).a & b. In medium energy range all the TL compound consider as tissue equivalent approximately 0.105MeV to 4MeV. In this energy range most probable interaction is Compton and pair production it depends on the number of electrons per gram and square of the atomic number respectively. Lithium borate and lithium acetate not contain the higher atomic number material such as S, Cl, Ba, Br, Sr hence interaction probabilities is all most close to soft tissue. Photoelectric effect is strongly depends on the cube of atomic number, these materials (lithium borate & lithium acetate) exhibits almost close to the effective atomic number of the ICRU-44 tissue. Ratio of electron density, number of electrons per gram of thermoluminescence, plastics materials to ICRU-44 tissue is unity except cadmium sulfate plastics. This can be shown in the table 1. Ratio of mass attenuation, mass absorption coefficient of Polyethylene terephthalate, PMMA, Bakelite and Nylon plastics to soft tissue are unity in the energy range of 0.15MeV to 20 MeV except polyvinyl chloride & Polypropylene. These can be shown in the figure ii a) & b). In case of polyethylene we observed the deviation in the medium energy ranging from 0.1MeV to 6 MeV it may due to compton scattering (i,e) contain high number of electrons per gram (3.56908×10^{23} e/g). B.F Wall *et al* studied the different preparation methods for lithium borate compound and analysed use of medical dosimetry. He found that according to the doping material it changes the properties (i,e) doping with Cu, Ag least attractive compare to Cu and Mn doping. It is incapable for below 500 µGy dose measurement. Li2B4O7:Cu offers more advantages below 500 µGy compare to conventional manganese doping one but suffer from the fading over an hour. His result suggests that degree of light induced fading does not affect the much more in medical dosimetry [20]. Light tight sachets may used to control the fading.

4. Conclusion

Tissue equivalency of various thermoluminacence compound and plastics was verified in terms of their radiological properties. Among them, lithium borate TL material is considered as an ICRU-44 tissue equivalent material over the entire energy range of 15KeV to 20MeV. The presence of high atomic number element destroys the properties of tissue equivalency in lower energies due to the absorption edges. Depending on the application, those tissue equivalent materials were used to construct phantom. This should be varied depending on the clinical application such as diagnosis or therapy.

5. Reference

[1] Hill B *et al* 2005 *Med. Phys*. **32** 1589-97
[2] Davies J B *et al* 2008 *Radiat. Phys. Chem*. **77** 690-96
[3] Hill R *et al* 2010 *Med. Phys*. **37** 4355-63
[4] Hill R *et al* 2014 *Phys. Med. Biol*. **59** R183-231
[5] Hill R *et al* 2009 *Med. Phys*. **36** 3971-81
[6] Kienboch R *et al* 1906 *Arch. Roentgen Ray* **11** 17
[7] ICRU 1989 Report No.44 Bethesda MD
[8] Mann K S *et al* 2012 *Appl. Radiat. Isot.***70** 681-691
[9] Manohara *et al* 2011 *J. Appl. Clin. Med. Phys.* **12** 4
[10] Juan Azorín Nieto *et al* 2004 *AIP. Con. Proc.* **724** 20
[11] Furetta C *et al* 2001 *Nucl. Instr. and Meth A*. **456** 411-417
[12] Singh V P *et al* 2014 *J. Nucl. Chem.* 7
[13] Gill H *et al* 1998 *Radiat. Phys. Chem.* **51** 671-672
[14] Baldock C *et al* 2010 *Phys. Med. Biol*. **55** R1-63
[15] Baldock C *et al* 1998 *Phys. Med. Biol*. **43** 695-702
[16] Ferreira C *et al* 2010 *J. Phys.: Conf. Ser.* **249** 012029
[17] Hubbell J H *et al* 1996 *NIST Standard Reference Database* 26
[18] Sellakumar P *et al* 2007 *Radiat. Phys. Chem.* **76** 1108-15
[19] Singh V P *et al* 2014 *Radiat. Prot.* **49** 115-21
[20] Wall B F *et a1* 1982 *Phys. Med. Biol.* **27** 1023-34