The calculation of mass attenuation coefficients of well-known thermoluminescent dosimetric compounds at wide energy range

Elif Ebru Ermis

Citation: AIP Conference Proceedings **1815**, 060008 (2017); doi: 10.1063/1.4976404
View online: https://doi.org/10.1063/1.4976404
View Table of Contents: http://aip.scitation.org/toc/apc/1815/1
Published by the American Institute of Physics

Articles you may be interested in

The Calculation of X-Ray Mass Absorption Coefficients
Journal of Applied Physics **20**, 1141 (1949); 10.1063/1.1698286

Preface: Proceedings of the Turkish Physical Society 32nd International Physics Congress
AIP Conference Proceedings **1815**, 010001 (2017); 10.1063/1.4976343

Enhancement of energy spectra through constant fraction timing method
AIP Conference Proceedings **1815**, 060009 (2017); 10.1063/1.4976405

The Calculation of Mass Attenuation Coefficients of Well-Known Thermoluminescent Dosimetric Compounds at Wide Energy Range

Elif Ebru Ermis[1, a)]

[1]*Ege University, Faculty of Science, Physics Department, 35100, Bornova, Izmir, TURKEY*

[a)]Corresponding author: elermis@hotmail.com

Abstract. The photon mass attenuation coefficients of LiF, $BaSO_4$, $CaCO_3$ and $CaSO_4$ thermoluminescent dosimetric compounds at 100; 300; 500; 600; 800; 1,000; 1,500; 2,000; 3,000 and 5,000 keV gamma-ray energies were calculated. For this purpose, FLUKA Monte Carlo (MC) program which is one of the well-known MC codes was used in this study. Furthermore, obtained results were analyzed by means of ROOT program. National Institute of Standards and Technology (NIST) values were also used to compare the obtained theoretical values because the mass attenuation values of the used compounds could not found in the literature. Calculated mass attenuation coefficients were highly in accordance with the NIST values. As a consequence, FLUKA was successful in calculating the mass attenuation coefficients of the most used thermoluminescent compound.

INTRODUCTION

The attenuation of the photons by various absorbing materials under ideal narrow-beam conditions satisfies the relationship

$$I(x)=I_0e^{-\mu x} \quad (1)$$

where I_0 is the initial photon intensity, I(x) is the photon intensity after passing through an absorber of thickness x in narrow-beam geometry, and μ (cm^{-1}) is the linear coefficient, which accounts for all interaction processes, including scattering reactions that remove photons from the beam [1]. The linear attenuation coefficient μ is dependent on density, which in turn is dependent on the physical state of the material and photon energy. As a consequence, μ is not a suitable quantity for data compilations, and the related quantity (μ_ρ), which is independent of density, is used instead. This quantity is known as the mass attenuation coefficient, and its unit is square centimeters per gram (cm^2/g) or square meters per kilogram (m^2/kg) [2]. The relationship between linear and mass coefficient is [3]

$$\mu_\rho \left(\frac{cm^2}{g}\right) = \frac{\mu\,(cm^{-1})}{\rho\left(\frac{g}{cm^3}\right)} \quad (2)$$

Radiation measurements and investigations of radiation effects require various specifications of the radiation field at the point of interest. Radiation dosimetry deals with the method for a quantitative determination of energy deposited in a given medium by directly or indirectly ionizing radiations [4]. Also, dosimetry- as part of the total quality system- is an independent, inexpensive and reliable tool to control the irradiation process and plays an important role in the transfer of these processes from the laboratory to the industrial stage [5].

Thermoluminescent dosimeters (TLDs) which are one of the dosimeter types are essentially a piece of a thermoluminescent material, exposed to the radiation being measured. After irradiation stops, the TLD is heated under controlled conditions, and the light intensity is measured as a function of temperature [3]. The TLDs most

Turkish Physical Society 32nd International Physics Congress (TPS32)
AIP Conf. Proc. 1815, 060008-1–060008-4; doi: 10.1063/1.4976404
Published by AIP Publishing. 978-0-7354-1483-9/$30.00

commonly used in medical applications are LiF:Mg with Ti, and LiF:Mg with Cu and P because of their tissue equivalence [4, 6, 7]. Tissue equivalence describes the property of materials to interact with radiation in the same way as human tissues [6]. Other TLDs are $CaSO_4$:Dy and Al_2O_3:C because of their high sensivity [4, 8].

Monte Carlo (MC) method can simulate the interaction of radiation with matter. In MC method, some input data (details of geometry of radiation source, target and medium, type of radiation, energy and direction of radiation flight, etc.) are demonstrated [9].

One of the well-known MC codes which is based on FORTRAN language is FLUKA MC method. It can be simulated particle transport and interactions with matter, covering and extended range of applications spanning from proton and electron accelerator shielding to target design, dosimetry, detector design, etc. [10, 11].

ROOT is an object-oriented framework. It is possible for solving the data analysis challenges of high-energy physics using ROOT. It works by depending on C++. It is also used for advanced data analysis of MC simulations [12]. This program was used for calculation of the mass attenuation coefficients in this work.

As a result of the literature research, no study has been found about calculation of the mass attenuation coefficients of the most used thermoluminescent dosimetric compounds using FLUKA MC program. Therefore, in this study, the mass attenuation coefficients of different well-known dosimetric compounds at a wide energy range were calculated by FLUKA MC program as an alternative way. This situation motivated the author to supply the literature in this respect. The calculated attenuation values for LiF, $BaSO_4$, $CaSO_4$ and $CaCO_3$ were also compared to National Institute of Standards and Technology (NIST) values in order to check the validity of the obtained results. As a result of the comparison, it can be seen that FLUKA was an alternative method to calculate mass attenuation coefficients of the materials.

METHODS

The calculations of photon mass attenuation coefficients of different thermoluminescent compounds were carried out using FLUKA (ver. 2011.2c) program which was installed on an Ubuntu (ver. 13.10) operating system. LiF, $BaSO_4$, $CaCO_3$ and $CaSO_4$ dosimetric materials were used in this work because they are tissue equivalent and high sensitive dosimetric materials and are often used medical processes. Their elemental concentrations (% weight) and densities are presented in Table 1 since these quantities were used by FLUKA in calculation of the mass attenuation coefficients. Furthermore, their mass attenuation coefficients were calculated at 100; 300; 500; 600; 800; 1,000; 1,500; 2,000; 3,000 and 5,000 keV photon energies.

Firstly, dimensions of the materials were formed as 1 x 1 x 1 cm^3 in FLUKA MC program. Secondly, 2.10^4 mono-energetic photons with the energies of 100; 300; 500; 600; 800; 1,000; 1,500; 2,000; 3,000 and 5,000 keV were sent to each target material surface, separately. Then, FORTRAN programming language was used to determine transmitted photon numbers through the materials. Their mass attenuation coefficients were calculated by dividing the obtained linear attenuation coefficients by the compound densities (Eq. 2). The program was operated in ten cycles run for each absorber and energy value.

The output files of FLUKA were analyzed using ROOT program (ver. 5.34.18) which was also used to calculate mass attenuation coefficients of the materials. In ROOT program, the averages of the results were calculated and the uncertainties were determined by calculating their standard deviations.

NIST values were utilized to compare and check the validity of the obtained attenuation coefficients from FLUKA MC program.

TABLE 1. Elemental concentrations (% weight) and densities of the thermoluminescent compounds used by FLUKA MC program.

	Materials			
Elemental concentration (% weight)	**LiF (ρ=2.64 g/cm^3)**	**$BaSO_4$ (ρ=4.50 g/cm^3)**	**$CaCO_3$ (ρ=2.80 g/cm^3)**	**$CaSO_4$ (ρ=2.96 g/cm^3)**
Oxygen (O)	-	27.4212	47.9554	47.0095
Sulfur (S)	-	13.7368	-	23.5497
Barium (Ba)	-	58.842	-	-
Calcium (Ca)	-	-	40.0443	29.4408
Carbon (C)	-	-	12.0003	-
Lithium (Li)	26.7585	-	-	-
Fluorine (F)	73.2415	-	-	-

RESULTS

The calculated mass attenuation coefficients (μ_ρ) with their standard deviations, and NIST values of the used thermoluminescent compounds for 100; 300; 500; 600; 800; 1,000; 1,500; 2,000; 3,000 and 5,000 keV photon energies are listed in Table 2. The calculations were also carried out using XCOM program (ver. 3.1) as well. Obtained values from XCOM were not presented in this table because XCOM uses NIST database in its calculation process. Therefore only NIST values were given in Table 2. It is important to emphasize that FLUKA and NIST database is different from each other. A brief comparison can be seen in Table 2.

TABLE 2. Calculated mass attenuation coefficients (cm^2/g) of the target materials for various photon energies.

	LiF		$BaSO_4$		$CaSO_4$		$CaCO_3$	
Photon energy (keV)	**FLUKA**	**NIST**	**FLUKA**	**NIST**	**FLUKA**	**NIST**	**FLUKA**	**NIST**
100	0.14415 ±0.00078	0.14410	1.36898 ±0.01299	1.36200	0.19566 ±0.00074	0.19620	0.19489 ±0.00068	0.19550
300	0.09936 ±0.00047	0.09899	0.15487 ±0.00050	0.15560	0.10849 ±0.00040	0.10880	0.10924 ±0.00045	0.10880
500	0.08064 ±0.00040	0.08076	0.09365 ±0.00038	0.09439	0.08745 ±0.00031	0.08778	0.08709 ±0.00027	0.08770
600	0.07486 ±0.00050	0.07467	0.08286 ±0.00030	0.08275	0.08087 ±0.00039	0.08101	0.08135 ±0.00040	0.08100
800	0.06558 ±0.00025	0.06557	0.06839 ±0.00028	0.06887	0.07089 ±0.00043	0.07100	0.07133 ±0.00042	0.07099
1,000	0.05954 ±0.00039	0.05894	0.06011 ±0.00016	0.06037	0.06374 ±0.00031	0.06377	0.06320 ±0.00042	0.06377
1,500	0.04762 ±0.00042	0.04798	0.04846 ±0.00020	0.04837	0.05219 ±0.00019	0.05194	0.05241 ±0.00036	0.05193
2,000	0.04115 ±0.00028	0.04122	0.04263 ±0.00023	0.04240	0.04487 ±0.00028	0.04488	0.04491 ±0.00030	0.04483
3,000	0.03331 ±0.00029	0.03321	0.03691 ±0.00019	0.03669	0.03653 ±0.00028	0.03679	0.03646 ±0.00024	0.03666
5,000	0.02547 ±0.00019	0.02554	0.03283 ±0.00013	0.03304	0.02946 ±0.00021	0.02954	0.02901 ±0.00010	0.02926

Calculated mass attenuation coefficients and NIST values versus the photon energies of each thermoluminescent material are shown in Fig. 1.

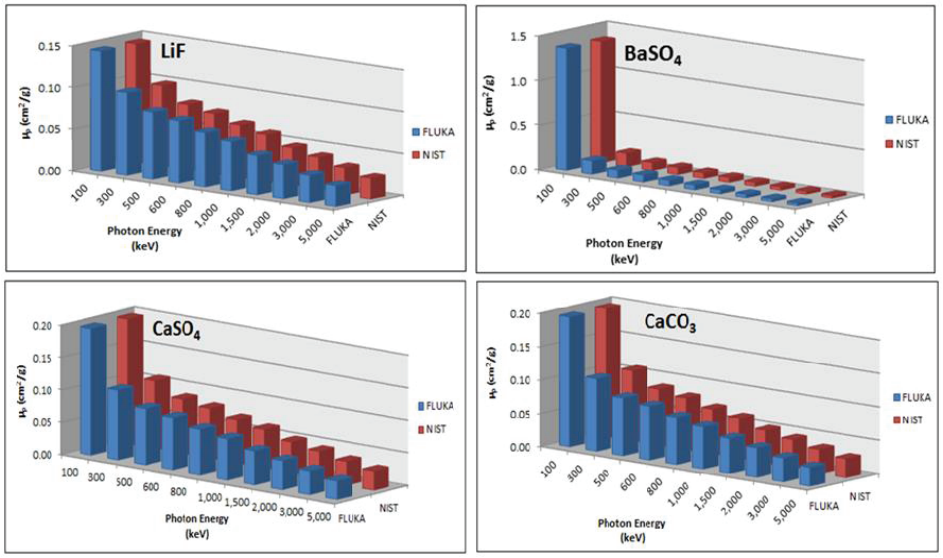


FIGURE 1. Photon mass attenuation coefficients vs. photon energies for LiF, $BaSO_4$, $CaSO_4$ and $CaCO_3$ materials respectively.

CONCLUSION AND DISCUSSION

The photon mass attenuation coefficients of different well-known thermoluminescent dosimetric compounds were calculated using FLUKA MC program at a wide energy range in this work. Obtained theoretical results were also compared to NIST values. The results for each material were given in Table 2. The calculated mass attenuation coefficients by means of FLUKA MC program were highly in compatible with the NIST values (Table 2) even if FLUKA and NIST were used different database.

As it can be seen in Fig. 1, a sharp decline has normally been observed starting from second photon energy value for $BaSO_4$ due to its higher density than the others (Table 1).

Gowda et al. [13] determined experimentally the mass attenuation coefficients of LiF, $BaSO_4$, $CaSO_4$, $CaCO_3$ TLD compounds at 279.2, 320.07, 514.0, 661.6, 1115.5, 1173.2 and 1332.5 keV photon energies using a spectrometer consisted of a high purity germanium detector. In the presented study, the mass attenuation coefficients of the most used TLD compounds were calculated through well-known FLUKA MC program different from that work. Gowda et al. determined the mass attenuation coefficients at 200-1,500 keV energy range, but these values were calculated here at 100-5,000 keV energy range. When the obtained results were compared to ones by Gowda et al., it was found that they were highly in compatible with each other in close energy range. It can be deduced from this result that FLUKA MC method can readily be used to calculate accurately the mass attenuation coefficients of TLD compounds.

Consequently, the theoretical attenuation coefficients of the most used TLD compounds in different medical applications [6, 14, 15] using well-known FLUKA program were quiet in accordance with the NIST values. It can be concluded from this result that FLUKA can be used as an alternative way to calculate the photon mass attenuation coefficients of thermoluminescent dosimetric compounds.

ACKNOWLEDGEMENTS

The Author thanks to Dr. E. Pilicer for his help in the calculation procedure and to Dr. C.Celiktas for his precious contribution to the study. This work was supported by Scientific Research Project of Ege University under Project No. 2014 FEN 026.

REFERENCES

1. J.E. Martin, *Physics for Radiation Protection* (Wiley-VCH Verlag Gmbh&Co. KGaA, Weinheim, 2006).
2. D.R. Dance, S. Christofides, A.D.A. Maidment, I.D. McLean and K.H. Ng, *Diagnostic Radiology Physics: A Handbook for Teachers and Students* (International Atomic Energy Agency, Austria, 2014).
3. N. Tsoulfanidis, *Measurements and Detection Radiation* (Taylor&Francis, USA, 1995).
4. E.B. Podgorsak, *Radiation Oncology Physics: A Handbook for Teachers and Students* (International Atomic Energy Agency, Austria, 2005).
5. International Atomic Energy Agency (IAEA) Radiation Technology Series No 4, *Guidelines for the Development, Validation and Routine Control of Industrial Radiation Processes* (International Atomic Energy Agency, Austria, 2013).
6. T. Kron, Radiat. Prot. Dosim. **85**, 333-340 (1999).
7. J.A. Nieto, ‘‘Thermoluminescence dosimetry (TLD) and its application in medical physics,’’ in *Medical Physics: Eighth Mexican Symposium on Medical Physics-2004,* AIP Conference Proceedings 724, edited by M.Vargas-Luna *et al.* (Guanajuato, Gto., Mexico, 2004), pp. 20-26.
8. M. Stabin, Phys. Med. Biol. **51**, R187-R202 (2006).
9. J. J. P. De Lima, *Nuclear Medicine Physics* (Taylor&Francis, USA, 2011).
10. A. Ferrari, P.R. Sala, A. Fasso and J. Ranft, *Fluka: A multi-particle transport code* (INFN/TC-05/11, SLAC-R-773 2005).
11. G. Battistoni, F. Cerutti, A. Fasso, A. Ferrari, S. Muraro, J. Ranft, S. Roesler and P.R. Sala, ‘‘The FLUKA Code: description and benchmarking,’’ in *Hadronic Shower Simulation Workshop-2006,* AIP Conference Proceedings 896, edited by M. Albrow and R. Raja (Batavia, Illinois, USA, 2006), pp. 31-49.
12. ROOT: An Object-Oriented Data Analysis Framework, *Users Guide 5.26* (2009).
13. S. Gowda, S. Krishnaveni, T. Yashoda, T.K. Umesh, R.Gowda, Pramana-J Phys. 63, 529-541 (2004).
14. L.A. DeWerd, Q. Liang, J.L. Reed, W.S. Culberson, Radiat. Meas. **71**, 276-281 (2014).
15. M. Baptista, P. Teles, G. Cardoso, P. Vaz, Radiat. Phys. Chem. **104**, 163-169 (2014).