Australian Journal of Basic and Applied Sciences, 11(11) August 2017, Pages: 21-29

AUSTRALIAN JOURNAL OF BASIC AND APPLIED SCIENCES

ISSN:1991-8178 EISSN: 2309-8414
Journal home page: www.ajbasweb.com

Calculating the X-ray attenuation coefficients of gelatin as human tissue substitute

[1]Fadhil Fuliful, [2]Abdalsattar Hashim, [3]Rajaa Madlool

[1]*Physics department, College of Science,Kerbala,Universityof Kerbala, Iraq.*
[2]*Physics department, College of Science,Krbala,University of kerbala, Iraq.*
[3]*Physics department, College of Science,Kerbala, University of Kerbala, Iraq.*

Address For Correspondence:
Fadhil, University of Kerbala, Physics department, College of Science, Kerbala, Iraq,
E-mail: Fadhil.Khaddam@yahoo.com.

ARTICLE INFO

Article history:
Received 18 June 2017
Accepted 28 July 2017
Available online 20 August 2017

Keywords:
mass attenuation coefficients, test object, elemental analysis, XCOM program.

ABSTRACT

In order to study the development of x-ray imaging use in medical for human, tested materials are one of the most important ways for determined the effects of x-ray dose on human tissue. The total mass attenuation and linear attenuation coefficients are a promised way for evaluating the usage in dosimeter of these materials .In this paper, we prepare gelatin sample and using Elemental Analyzer(Euro-EA) to determine elemental compositions (mass fraction of each element) of gelatin which used in this work, gelatin have many application in medical and industries also it used as a test objects to evaluate the effects of ionized radiations (x-ray) on human.XCOM program employed to calculate the values of mass attenuation coefficients of gelatin for different photon energies (1-120) keV of x-ray. The results show that the values of mass attenuation coefficients are high at low photon energies but it decreases slowly as the energy of x-ray increase (40-120)keV at the same fraction by weight. Matching of the mass attenuation coefficients values of gelatin with mass attenuation coefficients of simulated tissue showed acceptable match at low photon energies

INTRODUCTION

There are many applications of gelatin, employed in coating cell culture plates, blocking reagent in Western blotting, immunohistochemistry and used as a component of culture media for species differentiation in bacteriology. Additionally, gelatin used as a biocompatible polymer and also it used as a delivery vehicle for the release of bioactive molecules and in the generation of scaffolds for tissue engineering applications (Young *et al*., 2005). Industrial applications include using gelatin as a stabilizer, thickener, texturizer in foods, manufacture of rubber substitutes, adhesives, cements, lithographic, printing inks, plastic compounds, artificial silk, photographic plates, films, matches and light filters for mercury lamps. In the pharmaceutical industry, gelatin used as a suspending agent, encapsulating agent, and tablet binder; as well as it used in veterinary applications as a plasma expander and hemostatic sponge (Huang *et al*., 2005). It is important to estimate the amount of radiation delivered to composite substances by the ionizing radiation such as x-ray, in order to know the effect of x-ray doses received by patient, several materials used to simulate the human tissue and organs for long time (Egbe *et al*., 2007). Experimental and theoretical studying investigated mass attenuation coefficients of x-rays for elemental foils using NaI (Tl) detector system and compared it's results with employed XCOM program (Kaginelli *et al*., 2009). Determine the doses received by the patient exposure to ionizing radiation, using different type of materials as soft tissue-simulating are necessary to verify the best material to simulate the human cerebral tissue (Ferreira *et al*., 2010). Seven tissue-equivalent materials (Nylon,Polyacetate, Polymethylmethacrylate (PMMA), water, muscle-equivalent, bone-equivalent and adipose-equivalent) were tested, through their attenuation (linear attenuation coefficient) and scattering (scattering profile) properties, an

To Cite This Article: Fadhil Fuliful, Abdalsattar Hashim, Rajaa Madlool., Calculating the X-ray attenuation coefficients of gelatin as human tissue substitute. ***Aust. J. Basic & Appl. Sci.,*** *11(11): 21-29, 2017*

energy dispersive X-ray system (EDXS) employed to analyze these properties simultaneously(Wender *et al*., 2013).The angular distribution of photons scattered (scattering signature) have been measured using Five tissue equivalent materials ,by mammography and conventional adiology, also four samples used in bone densitometry at the photon energy 17.44 keV employing a X-ray tube equipped with a graphite monochromatic, a goniometer system and a NaI detector(Poletti *et al*., 2004). The mass attenuation coefficients (μ/ρ)were determined of fabricated Rhizophoraspp, particleboard for photons energies (15.77–25.27) keV, the work carried out by studying the attenuation of X-ray fluorescent photons from zirconium, molybdenum, palladium, silver, indium and tin targets, the theoretical values were calculated for average breast tissues in young-age, middle-age and old-age groups using photon cross section database (XCOM), the comparison between measured mass attenuation coefficients and the calculated XCOM values to be very close to in breasts of old-age group (Shakhreet *et al*., 2013).The effects of different doses and dose rates of X-ray and gamma ray on human lymphocytes were investigated, after separating mononuclear cells with Lymphocytes from human peripheral blood, they were exposure with different X-ray doses (KHARMAN *et al*., 2010). A study was performed to estimate the efficiency of different mixtures of barite concrete which used as a shielding in diagnostic X-ray rooms., CdTe detector model XR-1OOT used to measure the mass attenuation coefficients and SSD light indicator of machine measured the distance between the source and the exposed surface of all samples which it was 350 cm, the comparison between measured mass attenuation coefficients (μ/ρ) and the results of the XCOM program were achieved (Almeida *et al*., 2015). A different methods used to evaluate the effective atomic numbers of some low-*Z* materials, It was determined that polyethylene (PE), polystyrene (PS), Perspex (PX), and nylon 6-6 (PA-6) were equivalent to adipose and muscle, plaster of Paris (POP) was equivalent to cortical bone, TH/L2 was equivalent to thyroid tissue, polypropylene (PP) was equivalent to yellow bone marrow and adipose tissues, polycarbonate (PC) was equivalent to spongiosa (Vishwanath *et al*., 2014). The mass attenuation coefficients (μ_m) for some natural minerals collected from different places of Turkey were measured at various low photon energies (15.8 to 26.2) keV (Ibrahim *et al* 2011). The mass attenuation coefficients μ/ρ of some thermosluminescent dosimetric materials have been investigated using Geant4 simulation toolkit, the Geant4 toolkit simulation results of μ/ρ are compared with experimental data wherever possible ,comparisons are also investigate with predictions from the XCOM program in the energy range 1 keV to 100 GeV, a reasonable agreement among Geant4 toolkit simulation, XCOM program and experimental data are obtained (Vishwanath *et al*., 2014). The mass attenuation coefficient (μ_m), the mass energy absorption coefficient (μ_m/ρ) , and kerma relative to air were determined for some alloys at photon energies(17.44 -51.70) keV by using an HP-Ge detector with a resolution of 182eV at 5.9 Kev (Demet *et al*., 2015).

The aim of this study is preparing gelatin sample in order to analysis it to its components (fraction by weight)., it is possible to use gelatin as test objects for determined the effects of x-ray radiation on human. Elemental analyzer (Euro-EA) employed to analysis gelatin into its components (N=5.706,C=25.552 ,H=6.281,S=0.352 O=62.105) which used as input data for the program. Mass attenuation coefficients are evaluated by using XCOM program for photon energy range (1-120) keV. Gelatin used as a powder manufactured from bovine skin stored in room temperature and the concentration for use is 100-200 μg /cm^2, Bio-Reagent, suitable for cell culture .Mass attenuation coefficients of Gelatin compare with the simulated values of biological tissue showed acceptable at low photon energies.

2. Theoretical part:

X-rays and gamma rays radiations product by man- made used in different applications such as analysis of food products screening of baggage's , medical imaging tests, cancer treatment, and airport security scanners. When the electromagnetic radiation passes through matter, it suffer attenuation and reduction in intensity, this reduction obtained by two process scattering and absorption (attenuation).The scattering of x-ray photon at attenuator material atoms causes a part of the x-ray radiation to change its direction. This phenomenon reduces the intensity in the original direction. The scattering happens either elastic or inelastic. In absorption the entire energy of the x-ray quanta transferred to the atoms or molecules of the irradiated material as excitation or ionizing energy and causes damage the cells also effects on DNA.

3. Theoretical calculation of absorption:

Then ionized radiation passes through any matter, its intensity progressively reduces as a consequence of a complex series of interactions between radiation and atoms of the attenuating medium such as x and Gama rays. The photons of x-ray are either absorbed or scattered out of the beam, there are three mechanisms exist.

3.1. Photoelectric absorption:

There is poor data on the molecular photoelectric cross-section (ρ_{ph}) for a test objects, then could be calculated according to the formula (Hubbell, 2006).

$$\sigma_{ph} = \rho N_A \sum_I \frac{w_i}{A_i} \sigma_i \quad (1)$$

Where N_A is Avogadro's number, ρ is the density of the material, and A_i, w_i, σ_i are the atomic mass, the fraction by weight, and the atomic cross section of the i_{th} component of the medium, respectively.

3.2. Incoherent (Compton) scattering:

The total incoherent scattering cross section per atom for inelastic scattering can be written as

$$\sigma_{inc} = \int_{\theta=0}^{\theta=\pi} d\sigma_{KN}(\theta) S(x,z) \quad (2)$$

$S(x,z)$ is incoherent scattering function taken from the tables of (Hubbell, 2006).

3.3. Coherent (Rayleigh) scattering:

The coherent (Rayleigh) scattering cross section can be derived by integrating the differential cross section over all possible scatter angles per atom given as (King *et al*., 2011)

$$\sigma_{coh} = \int_{\theta=0}^{\theta=\pi} d\sigma^T(\theta)[F(x,z)]^2 \quad (3)$$

Where $d\sigma^T$ is the classical or Thomson (1906) cross section for a single free electron, the atomic form factor $F(x,z)$ is a function of the variable x, which x equal to $sin^{-1}(\theta/2)/\lambda$.

The x-ray photons are suffer two process absorbed and scattered out of the beam. If the single-pack photonic energy incidents on material, photons and matters interaction happen immediately, as a result of interactions, if we assume, that the properties of the incident radiation remain unchanged in spite of attenuation, an increase in the thickness x by the amount dx will cause a decrease in the incident I by the amount dI. The relative reduction in intensity is proportional to the absolute increase in thickness $-dI = I\mu\, dx$ (4)

The proportionality factor μ is referred to as the linear coefficient attenuation. As the intensity $I = 1$ for $x = 0$. Integration of equation (4) given as

$$I = I_0\, exp^{-\mu x} \quad (5)$$

Eq. (5) becomes

$$\mu = -\frac{1}{x}\, ln\frac{I}{I_0} \quad (6)$$

This relationship is known as *Lambert's law* of attenuation. It also illustrates that the attenuation depends on the attenuating material and the wavelength of the x-rays. If the path length of photons a cross the attenuator measured in unit (cm), then the Linear Attenuation Coefficient μ_L calculated in (cm^{-1}).

$$\mu_L = -\frac{1}{x} ln\frac{I}{I_0} \quad (7)$$

If the path length of photons a cross the attenuator measured in mass per unit area (g /cm^2), then the Mass Attenuation Coefficient μ_M evaluated in cm^2 /g

$$\mu_M = \frac{\mu_L}{\rho} = \left(-\frac{1}{\rho x}\right) \ln\left(\frac{I}{I_0}\right) \quad (8)$$

ρ blindness and middle density

Theoretical values of mass attenuation coefficients are obtained by (Hubbell, 2006).

$$\mu/\rho = \sigma_{tot}/uA \quad (9)$$

Where $u = 1.660\ 540\ 2 \times 10^{-24}$ g is the atomic mass unit, A is the relative atomic mass of the sample, The total cross section can be written as the sum over contributions from the principal photon interactions

$$\sigma_{tot} = \sigma_{ph} + \sigma_{inc} + \sigma_{co} \quad (10)$$

Gelatin used in many applications .Before calculating the total mass attenuation coefficient, it is necessary to obtain the elemental compositions (mass fraction of each element). For obtaining the mass fraction of the Hydrogen (H), Carbon (C), Nitrogen (N) and Sulphur (S) which gelatin contained, it used Elemental Analyzer

(Euro EA) which is explained in Figure 1. The mass fraction remaining was considered as Oxygen (O). Gelatin is basically composed of these elements (H, C, O, N, S) (Young *et al*., 2005)-(Kaginelli *et al*., 2009). The total mass attenuation coefficient can be obtained through the total cross section for photons Eqns. (9, 10) .To calculate the total mass attenuation coefficient, the software XCOM was utilized (Berger and Hubbell, 1987)-(Hubbell and Seltzer, 1995). The mass fraction of each element inserted as input data and XCOM used to calculate the total mass attenuation coefficient.

Fig. 1: Elemental Analyzer (Euro EA)

RESULTS AND DISCUSSION

Table 1 shows the elemental compositions obtained for gelatin. The results for each element used as input data on the XCOM software. Thus, the total mass attenuation coefficient for each element was calculated in the energy range of photons (1 to 120) keV. Elemental Analyzer used to determine the gelatin components ((H, C, O, N, and S)

Table 1: Elemental composition for gelatin

Element	Element%
Nitrogen	5.706
Carbon	25.552
Hydrogen	6.281
Sulphur	0.352
Oxygen	62.109

The chemical formula of gelatin which used in this research illustrated in Figure2.it is clear that the components are (N, H , C, S, O).and it is evident that the Elemental Analysis is agree with chemical formula

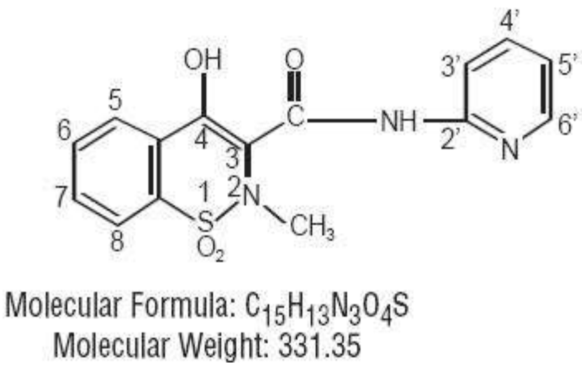


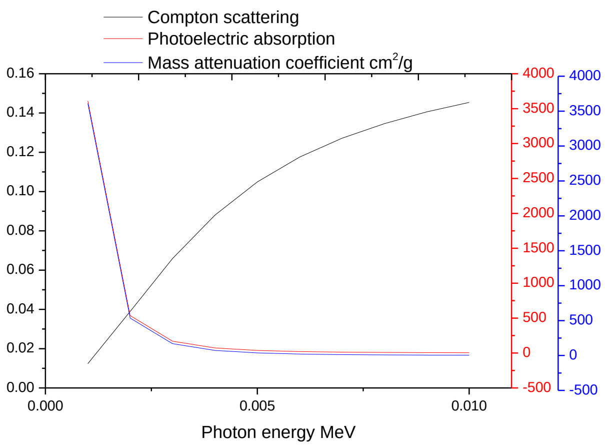
Fig. 2: Chemical formula of gelatin

All the Figures (2-14) show the mass attenuation coefficients of gelatin against x-ray photon at different energies. As expected the values decreases if the photon energy increased. Figure 3 shows these sharply decreasing in mass attenuation coefficients of gelatin for photon energy at the range (1-10) keV, it's clear that mass attenuation coefficient without coherent and photoelectric absorption have high values but Compton scattering has very low values .This behavior of parameters continue until we used the photon energy in the range 30 to 40 keV(see figure 6) . Attenuation by Compton scattering began to increase slightly at photon energy (40-120)keV but mass attenuation coefficients decrease strongly due to decreasing in photoelectric absorption at the same energy range . At high photon energies, values of mass attenuation coefficients close to Compton scattering in the range of photon energies (60-120)keV because photoelectric absorption approach to zero.

Table 2 show the comparison between mass attenuation coefficient of gelatin and biological sample (bone and muscle) at different photon energies, it is evident that there is agreement between mass attenuation coefficients of gelatin and biological tissue (muscle) at x-ray photon energies (Akar *et al*., 2006) . Therefor gelatin can be used as tissue substitutes in image quality studies

Table 2: comparison between mass attenuation coefficients of test object (gelatin)and biological samples (bone and muscle)

E MeV	Bone (Akar) $\mu_m\, cm^2 g^{-1}$	Muscle (Akar) $\mu_m\, cm^2 g^{-1}$	Test object (gelatin) $\mu_m\, cm^2 g^{-1}$
1.00E-3	3.781E+03	3.719E+03	3.612E+03
3.00E-3	2.958E+02	1.812E+02	1.701E+02
5.00E-3	1.917E+02	4.206E+01	3.717E+01
8.00E-3	5.323E+01	1.037E+1	8.893E+00
1.00E-2	2.851E+1	5.356E+0	4.509E+00
3.00E-2	1.331E+0	3.783E-01	3.032E-01
5.00E-2	4.242E-01	2.262E-01	1.964E-01
8.00E-2	2.229E-01	1.823E-01	1.674E-01
1.00E-1	1.855E-01	1.693E-01	1.579E-01



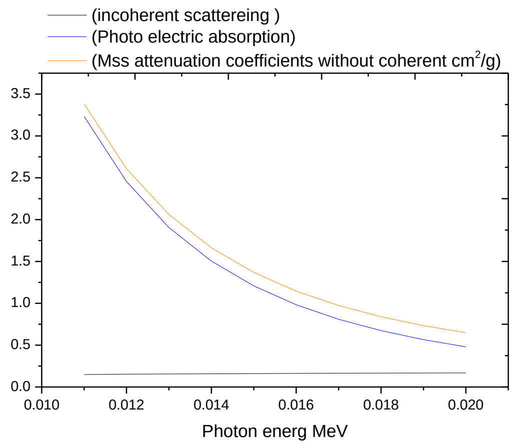


Fig. 3: Mass attenuation coefficient μ_M of gelatin for x- ray photon of energies (1-10)keV
Fig. 4: Mass attenuation coefficient μ_M of gelatin for x- ray photon of energies (10-20)keV

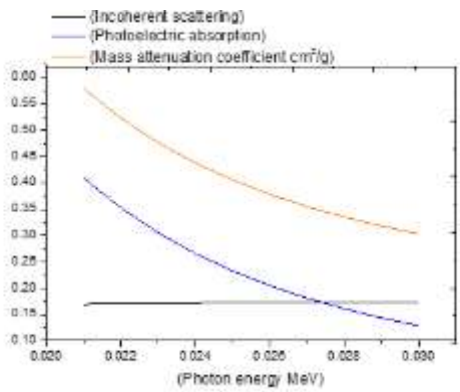


Fig. 5: Mass attenuation coefficient μ_M of gelatin for x- ray photon of energies (20-30)keV

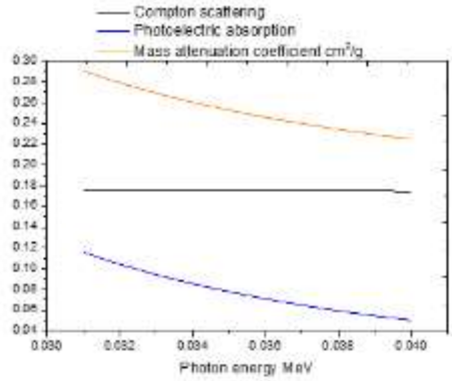


Fig. 6: Mass attenuation coefficient μ_M of gelatin for x- ray photon of energies (30-40)keV

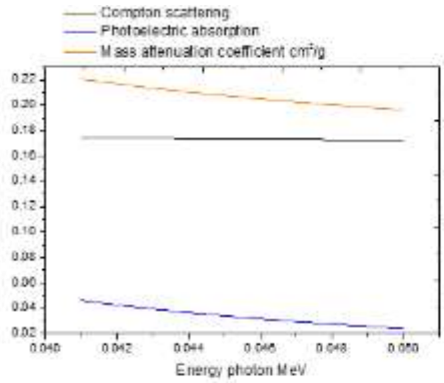


Fig. 7: Mass attenuation coefficient μ_M of gelatin for x- ray photon of energies (40-50)keV

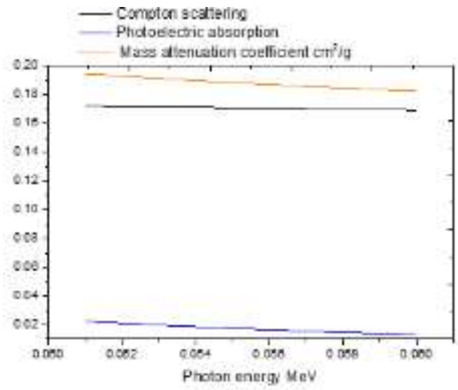


Fig. 8: Mass attenuation coefficient μ_M of gelatin for x- ray photon of energies (50-60)keV

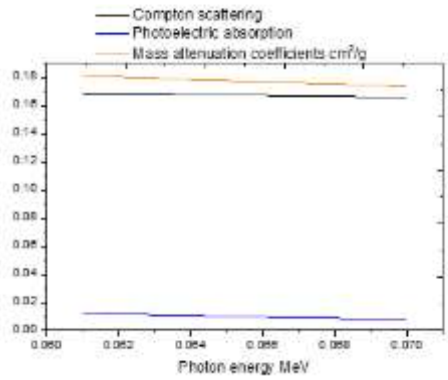


Fig. 9: Mass attenuation coefficient μ_M of gelatin for x- ray photon of energies (60-70)keV

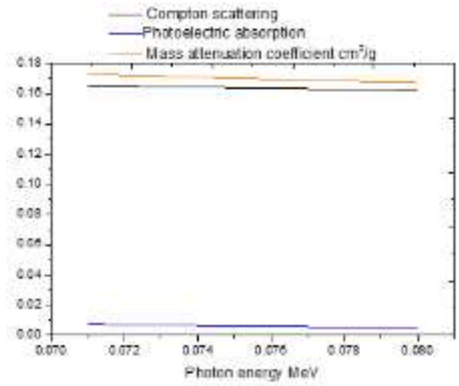


Fig. 10: Mass attenuation coefficient μ_M of gelatin for x- ray photon of energies (70-80)keV

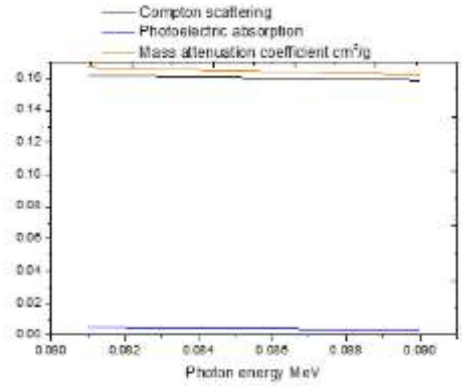


Fig. 11: Mass attenuation coefficient μ_M of gelatin for x- ray photon of energies (80-90)keV

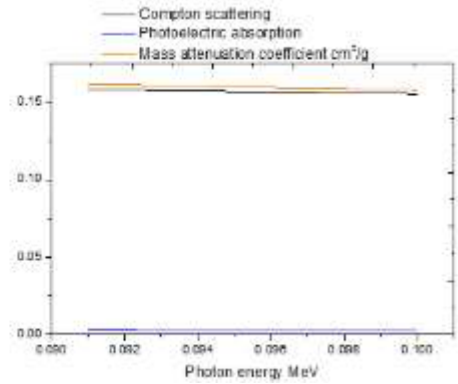


Fig. 12: Mass attenuation coefficient μ_M of gelatin for x- ray photon of energies (90-100)keV

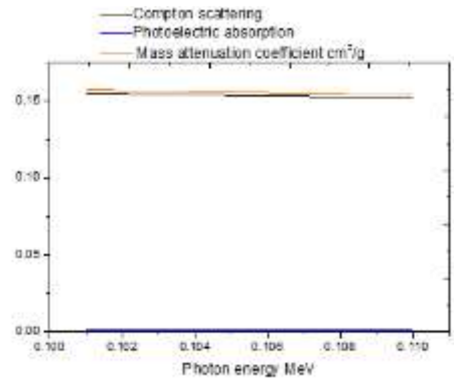


Fig. 13: Mass attenuation coefficient μ_M of gelatin for x- ray photon of energies (100-110)keV

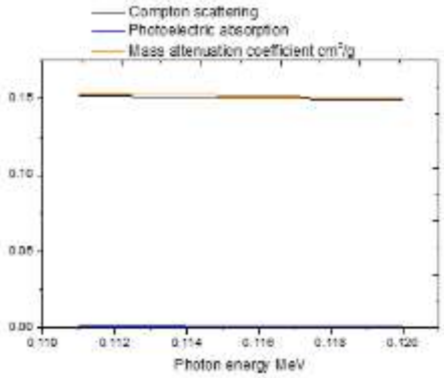


Fig. 14: Mass attenuation coefficient μ_M of gelatin for x- ray photon of energies (110-120)keV

Conclusion:

Mass attenuation coefficients are a reasonable way for determine the effects of ionized rays on material, because of difficulties in measuring the x-ray that absorb by human tissue through medical process,therefor test objects are best way for studying the effects of x-ray on human. Mass attenuation coefficients of gelatin which used as a test object decreases as the photon energies of x-ray increased because attenuation due to photoelectric absorption approaches zero and Compton scattering grows gradually. Gelatin with friction by weight (N=5.706, C=25.552, H=6.281, S=0.352and O=62.105) can be used as tissue substitutes in image quality studies.

REFERENCES

Almeida, Junior, Airton, T., Nogueira M.S, Santos, M.A.P., L.L. Campos and F.G.S. Araujo, 2015. MASS ATTENUATION COEFFICIENTS OF X-RAYS IN DIFFERENT BARITE CONCRETE USED IN RADIATION PROTECTION AS SHIELDING AGAINST IONIZING RADIATION,X Congreso Regional Latinoamericano IRPA de Protección Seguridad Radiológica.

Akar, A., H. Baltas, U.C- evik, F. Korkmaz and N.T. Okumusoglu, 2006. Measurement of attenuation coefficients for bone, muscle, fat and water at 140, 364 and 662 keV g-ray energies, Journal of Quantitative Spectroscopy & Radiative Transfer, 102: 203-211.

Berger, M.J and J.H. Hubbell, 1987. 99 XCOM: Photon Cross Sections Database, Web Version 1.2, available at http://physics.nist.gov/xcom. National Institute of Standards and Technology, Gaithersburg, MD 20899, USA. Originally published as NBSIR 87-3597 "XCOM: Photon Cross Sections on a Personal Computer".

Demet, YILMAZ., Yusuf S AH_IN and Lutfu DEMIR, 2015. Studies on mass attenuation coefficient, mass energy absorption coefficient, and kerma for Fe alloys at photon energies of 17.44 to 51.70 keV, Turkish Journal of Physics, 39: 81-90.

Egbe, N.O., A.F. Nneoyi-Egbe, S.O. Inyang and W.E. Azogor, 2007. An Evaluation of Some Common Laboratory Materials by X-ray Attenuation, for use as Human Tissue Substitutes. Journal of Association of Radiographers of Nigeria, 21: 39-49.

Ferreira, C.C., R.E. Ximenes and C.A.B. Garcia, J.W. Vieira and A.F. Maia, 2010. Total mass attenuation coefficient evaluation of ten materials commonly used to simulate human tissue, Journal of Physics: Conference Series, 249: 012029.

Hubbell, J.H and S.M. Seltzer, 1995. Tables of x-ray mass attenuation coefficients and mass energy absorption coefficients 1 keV to 20 MeV for elements Z = 1 to 92 and 48 additional substances of dosimetric interest, *National Institute of Standards and Technology*.

Huang, Y, *et al*. 2005. in vitro characterization of chitosan-gelatin scaffolds for tissue engineering. Biomaterials, 26: 7616-7627.

Hubbell, J.H., 2006. Review and history of photon cross section calculations Phys. Med. Biol., 51: 245-262.

Ibrahim Han, Hasan Kolayli and Mehmet Sahin, 2011. determination of mass attenuation coefficients for natural minerals from different places of Turkey, International Journal of the Physical Sciences, 6(20): 4798-4801.

Kaginelli, S.B., T. Rajeshwari1, Sharanabasappa, B.R. Kerur and Anil S. Kumar, 2009. Effective atomic numbers and electron density of dosimetric material, 34(3): 176-179.

KHARMAN, AKRAM FARAJ, M.M. ELIAS and SARAH BAATOUT, 2010. EFFECTS OF X AND GAMMA RAYS ON HUMAN LYMPHOCYTES, ROMANIAN J. BIOPHYS., 20(4): 355-367.

King, B.W., K.A. Landheer and P.C. Johns, 2011. X-ray coherent scattering form factors of tissues water and plastics using energy dispersion. Phys.Med.Biol., 56: 4377-4397.

Poletti, M.E., O.D. Gonc_alvesa and I. Mazzaro, 2004. Measurements of X-ray scatter signatures for some tissue-equivalent materials, Nuclear Instruments and Methods in Physics Research B 213: 595-598.

Shakhreet, B.Z., S. Bauk and A. Shukri, 2013. Mass attenuation coefficients of fabricated Rhizophora spp. particleboard for the 15.77 – 25.27 keV range, Am. J. Sci. Ind. Res., 4(1): 89-94.

Young, S. *et al*. 2005. Gelatin as a delivery vehicle for the controlled release of bioactive molecules. J. Control Release, 109: 256-274.

Vishwanath, P. Singh, N.M. Badiger and Nil Kucuk, 2014. determination of Effective Atomic Numbers Using Different Methods for Some Low-Z Materials, Journal of Nuclear Chemistry, Article ID 725629, 7.

Vishwanath, P., Singh M.E. Medhat and N.M. Badiger, 2014. Photon attenuation coefficients of thermoluminescent dosimetric materials by Geant4 toolkit, XCOM program and experimental data: A comparison study, Annals of Nuclear Energy, 68: 96-100.

Wender Geraldelli, Alessandra Tomal, and Martin E Poletti, 2013. Characterization of Tissue-Equivalent Materials through Measurements of the Linear Attenuation Coefficient and Scattering Profiles Obtained With Polyenergetic Beams, IEEE TRANSACTIONS ON NUCLEAR SCIENCE, 60: 2.