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Monte Carlo Calculation of Mass Attenuation Coefficients of Some Biological Compounds

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Abstract: This study aims to compute total mass attenuation coefficients of thirteen biological samples found in human body using the well-established Monte Carlo method. The simulations utilize a point photon source which emits mono-energetic photons directed as a parallel beam toward the cylindrical absorber behind which was placed a small disc-shaped vacuum detector. All the components in the problem geometry were surrounded by a vacuum sphere to avoid any interactions in materials other than the sample. In this manner, the simulation setup ensures that no scattered photons contribute to the flux in the detector. The simulations were carried out at thirty-six different photon energies between 10 keV-20 MeV. The results of this study indicate very good agreement with theoretical data and measurement values available in literature and indicate that Monte Carlo technique may be used as an alternative for calculations of mass attenuation coefficients.

Key words: Photons, Mass attenuation coefficient, Biological materials, Monte Carlo simulations

Bazı Biyolojik Bileşiklerin Kütlesel Zayıflatma Katsayılarının Monte Carlo Yöntemi ile Hesaplanması

Özet: Bu çalışma insan vücudunda bulunan 13 biyolojik numunenin toplam kütlesel zayıflatma katsayılarını Monte Carlo yöntemi ile hesaplamayı amaçlamaktadır. Simülasyonlarda, noktasal bir foton kaynağı, tek enerjili fotonları paralel bir demet şeklinde silindirik bir soğurucuya yönlendirmiş ve soğurucunun arkasına disk şeklinde küçük bir vakum dedektör yerleştirilmiştir. Problem geometrisindeki tüm bileşenler numune dışındaki materyallerle etkileşimi önlemek için bir vakum küresi ile çevrelenmiştir. Bu şekilde, simülasyon düzeneği dedektör akısına saçılan fotonların katkı yapmamasını sağlamıştır. Simülasyonlar, 10 keV-20 MeV enerji aralığında 36 farklı foton enerjisinde gerçekleştirilmiştir. Çalışmanın sonuçları literatürde var olan ölçüm değerleri ve teorik veriler ile çok iyi uyum göstermektedir ve Monte Carlo tekniğinin kütlesel zayıflatma katsayılarının hesaplanması için bir alternatif olarak kullanılabileceğini ortaya çıkarmıştır.

Anahtar kelimeler: Fotonlar, Kütlesel zayıflama katsayısı, Biyolojik materyaller, Monte Carlo simülasyonları

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1. Introduction

Photons emitted from radioactive sources or produced by radiation devices are widely used in medical and industrial applications due to being a penetrating type of ionizing radiation. When traversing material media, they lead to certain radiation effects as a result of energy transfer. If the interaction takes place in a biological material, the process of energy deposition may induce some harmful effects, the severity of which is related to the absorbed dose as well as the composition of the material itself.

One usually treats the interaction of photons of ionizing energy with matter using a parameter known as the attenuation coefficient [1]. This quantity, when defined as linear attenuation coefficient (denoted as μ and expressed in units of cm^{-1}), provides an understanding for the probability for a photon to undergo scatter or absorption interactions per unit distance of an absorbing material. Thus, total linear attenuation coefficient includes the effects of photoelectric absorption, Compton scattering and pair production mechanisms as well as some minor reactions depending on the elemental composition and density of the material along with the energy of the photons themselves. Alternatively, to eliminate any dependence on density or physical state of the material, sometimes mass attenuation coefficient (μ/ρ, in units of cm^2/g) is preferred to identify the attenuation capability (absorption plus scattering) of a material against all photons of a specific energy. μ/ρ is also considered to be useful in determining a first estimate of a thickness of a material to shield a known type and energy of ionizing photon beam [2]. Consequently, μ/ρ, being made up of different interaction cross sections, provides valuable information for estimating what kind of interaction a photon may go through in a material medium which in turn can be used to determine the amount of energy to be deposited to the absorber.

There are many studies in literature that report mass attenuation coefficients for various materials in a wide range of photon energies. A comprehensive review of the available studies can be found in [3]. In addition, there is an online database that provides tabular data for many elements, compounds or mixtures [4]. Because of the difficulties in gamma sources and measurement setups, measurement data are limited to a small set of gamma energies and a restricted number of materials [5-8]. In addition, there is a scarce amount of data for organic materials that are biologically significant, such as carbohydrates, amino acids, fatty acids and proteins, because they undertake specific physiological functions in human body or other living organisms [9-17]. These materials usually contain hydrogen, carbon, nitrogen and oxygen to a great extent and are considered to be important in estimating radiation damage especially in medical applications of ionizing radiation. Since the deposition of energy by ionizing photons in biological materials is a direct result of absorption or scatter processes, their mass attenuation coefficients can help characterize the radiation effects which in turn will provide a crude estimate of absorbed dose on which harmful tissue reactions and stochastic effects of radiation are based.

The purpose of this study is to compute total mass attenuation coefficients of some biological samples found in human body. The calculations employ Monte Carlo simulations for a wide range of photon energies encountered in practical situations and compare the investigated μ/ρ values with XCOM results and some measurements.

2. Material and Method

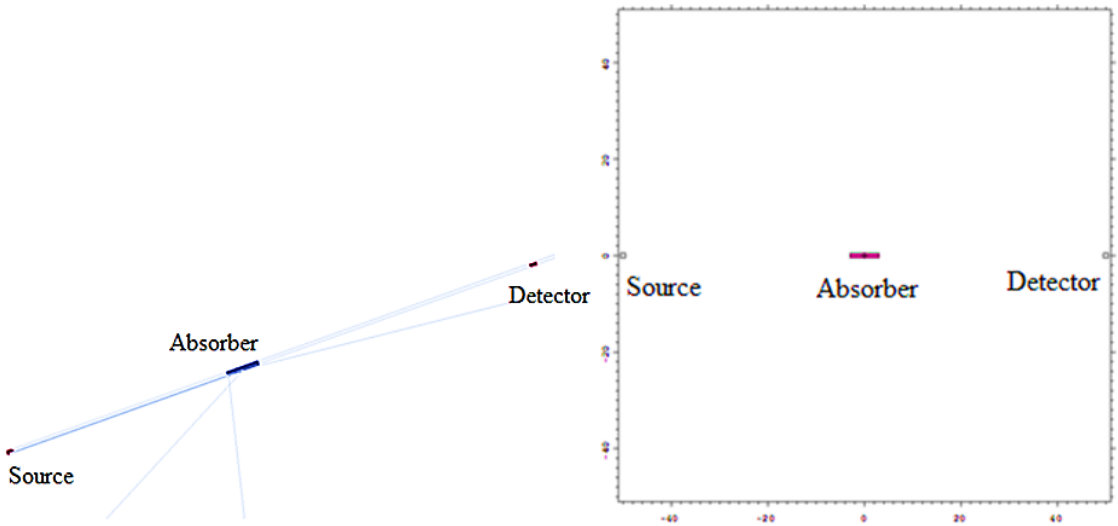
Monte Carlo method is a statistical method widely used in many different fields of science and engineering. The technique utilizes certain probability distributions and pseudo-random numbers to estimate an average of a physical quantity that is difficult to determine either analytically or numerically. It is very applicable to radiation transport problems that are encountered in applications of ionizing radiation because photon interactions with matter may be described on the basis of microscopic cross-sections which themselves are described as probabilistic quantities that depend on beam parameters and elemental compositions. In photon transport analyses, a Monte Carlo code can be used to compute such dosimetric quantities as flux, energy deposition, dose, etc. based on these interaction cross sections [18].

In this study, two Monte Carlo software packages were employed for modeling the geometry of the source, the absorber and the detector as well as estimating the interaction and detection of photons. MCNP6 is a general-purpose radiation transport package developed in Los Alamos National Laboratory [19] which is, with its MCNPX version, capable of transporting many different types of source particles in three-dimensional geometries and can handle various types of detectors for recording particle contributions. GAMOS, on the other hand, is a variant of the famous Monte Carlo package Geant4 developed by CERN [20] and is widely used by medical physicists to model radiation sources in clinical settings [21]. Both MCNP and GAMOS include various physics packages to treat different types of particles in a wide energy range as well as scoring packages to derive desired particle properties.

In this study, the simulations include a point photon source placed in a cylinder (r=0.5 cm; h=1cm) which emits mono-energetic photons directed in a parallel manner toward a cylindrical sample (r=0.5 cm; h=1 mean free path) 50 cm away from the source. The detector was modeled as a small vacuum disc (r=0.5 cm, h=1 cm) located 100 cm away from the source. All the components of the problem geometry were surrounded by a vacuum sphere (r=100 cm) to avoid interactions in materials other than the sample.

The whole simulation setup, as seen in Figure 1, is in compliance with the narrow-beam geometry requirement that is employed in attenuation coefficient measurements and thus ensures no contribution from any scattered photons. A broad-beam geometry will, on the other hand, allow all the photons to go through multiple scattering events and may still have a chance to reach the detector. In this case, however, the detector will overestimate the intensity of non-interacting photons [1].

In this paper, different organic compounds encountered in biological systems were investigated for photon transmission. Table 1 provides chemical formula and molecular mass of each sample which can be grouped as amino acids (L-serine, L-Lysine, L-Tryptophan), protein (Glycoprotein), enzymes (Aminocaproic acid, Lactose, Subtilisin, Thrombin) and fatty acids (Arachidic, Behenic, Heneicosylic, Margaric and Nonadecylic acids) [15]. As can be seen in Table 1, all the samples basically contain a varying proportion of the elements H, C, N, O, S or Cl and the percent fraction of an individual element in a sample was calculated for Monte Carlo simulations based on the corresponding molecular formula and atomic weights.



(a) GAMOS/Paraview (b) MCNP6

Figure 1. Plots of the model geometry taken from the Monte Carlo codes used in the study

Table 1 Some properties of the biological samples investigated in this study

Sample	Chemical formula	Molecular weight (g/mol)
Aminocaproic Acid	$C_6H_{13}NO_2$	131.17
Arachidic Acid	$C_{20}H_{40}O_2$	312.53
Behenic Acid	$C_{22}H_{44}O_2$	340.58
Glycoprotein	$C_{28}H_{47}N_5O_{18}$	741.69
Heneicosylic Acid	$C_{21}H_{42}O_2$	326.56
Lactose	$C_{12}H_{22}O_{11}$	342.30
L-Lysine	$C_6H_{14}N_2O_2$	146.19
L-Serine	$C_3H_7NO_3$	105.09
L-Tryptophan	$C_{11}H_{12}N_2O_2$	204.23
Margaric Acid	$C_{17}H_{34}O_2$	270.45
Nonadecylic Acid	$C_{19}H_{38}O_2$	298.50
Subtilisin	$C_{26}H_{32}N_3O_6Cl$	518.00
Thrombin	$C_{12}H_{10}ClN_3S$	263.75

For each sample, various photon energies in the range 10 keV-20 MeV were investigated, each representing a different simulation. All the Monte Carlo runs were carried out with 10^7 particle tracks which yielded less than 0.1% statistical errors both in MCNP and GAMOS simulations.

In estimating photon intensity, cell flux feature of each code was utilized which returns an average of the total flux ($1/(cm^2)$) recorded by the detector with ($I(x)$; x is the absorber thickness in cm) and without (I_0) each absorber in place. Beer-Lambert equation was then utilized to obtain mass attenuation coefficient (μ/ρ; in units of cm^2/g) for each sample and photon energy considered.

$$\frac{\mu}{\rho} = \left(-\frac{1}{x\rho}\right)\frac{I(x)}{I_0} \tag{1}$$

3. Results and Discussion

Monte Carlo evaluations of total mass attenuation coefficients were performed for thirteen biological samples and vacuum. The simulations were carried out at thirty-six different photon energies between 10 keV-20 MeV. For each simulation, the flux values obtained from the Monte Carlo simulations were inserted into Equation (1) to obtain μ/ρ results of both codes which are presented in Table 2.

Table 2 Total mass attenuation coefficients (cm^2/g) of the biological samples at various photon energies determined by MCNP and GAMOS simulations

Energy	Aminocaproic A.		Arachidic A.		Behenic A.		Glycoprotein	
(MeV)	MCNP	GAMOS	MCNP	GAMOS	MCNP	GAMOS	MCNP	GAMOS
0.01	3.205	3.192	2.481	2.471	2.449	2.439	3.773	3.759
0.015	1.06	1.062	0.8562	0.8598	0.847	0.8505	1.218	1.221
0.02	0.5566	0.5598	0.4759	0.478	0.4722	0.4742	0.6181	0.6214
0.03	0.3011	0.3021	0.2814	0.2824	0.2805	0.2815	0.3144	0.3159
0.04	0.2359	0.2353	0.2305	0.2298	0.2302	0.2295	0.2381	0.2378
0.05	0.2092	0.2088	0.2087	0.2082	0.2086	0.2083	0.2076	0.207
0.06	0.1945	0.1947	0.196	0.1959	0.196	0.1961	0.1912	0.1916
0.08	0.1775	0.1773	0.1805	0.1802	0.1806	0.1803	0.1731	0.1728
0.1	0.1665	0.1659	0.17	0.1693	0.1701	0.1695	0.1619	0.1613
0.122	0.1572	0.1566	0.1608	0.1603	0.1609	0.1604	0.1526	0.152
0.15	0.1478	0.147	0.1513	0.1507	0.1515	0.1507	0.1433	0.1425
0.2	0.1349	0.1343	0.1383	0.1378	0.1384	0.1379	0.1307	0.1304
0.3	0.1169	0.1166	0.1199	0.1195	0.12	0.1196	0.1132	0.1127
0.356	0.1096	0.1093	0.1124	0.1122	0.1125	0.1122	0.1061	0.1057
0.4	0.1047	0.1044	0.1074	0.1071	0.1075	0.1072	0.1014	0.1011
0.5	0.09557	0.09535	0.09803	0.0979	0.09813	0.09784	0.09251	0.09222
0.511	0.09468	0.09443	0.09712	0.09703	0.09722	0.09714	0.09165	0.09148
0.6	0.08835	0.08809	0.09062	0.09042	0.09072	0.09052	0.08552	0.08536
0.662	0.08458	0.08419	0.08677	0.08654	0.08686	0.0866	0.08187	0.08166
0.8	0.07761	0.07745	0.07961	0.07945	0.0797	0.07945	0.07512	0.07482
1	0.06976	0.0697	0.07156	0.07143	0.07164	0.07153	0.06752	0.06748
1.17	0.06446	0.064	0.06613	0.06565	0.0662	0.06574	0.06239	0.06205
1.25	0.06236	0.06194	0.06397	0.06363	0.06404	0.06375	0.06036	0.05986
1.275	0.06173	0.06127	0.06332	0.06299	0.06339	0.06295	0.05975	0.05936
1.33	0.06038	0.06015	0.06194	0.06166	0.062	0.06164	0.05844	0.05819
1.5	0.05671	0.0564	0.05817	0.05789	0.05823	0.05801	0.0549	0.05471
2	0.04865	0.04859	0.04988	0.04982	0.04993	0.0498	0.04712	0.04708
3	0.03893	0.03878	0.03984	0.0397	0.03988	0.03976	0.03778	0.03763
4	0.03326	0.03322	0.03396	0.03384	0.03399	0.0339	0.03235	0.03232
5	0.02951	0.02947	0.03005	0.02997	0.03007	0.03003	0.02877	0.0287
6	0.02684	0.02681	0.02726	0.02721	0.02728	0.02721	0.02623	0.02618
8	0.02337	0.02328	0.02357	0.02355	0.02359	0.02357	0.02291	0.02287
10	0.02119	0.02113	0.02122	0.02127	0.02124	0.02125	0.02091	0.02088
12	0.01971	0.01966	0.01974	0.0197	0.01974	0.01966	0.01953	0.01949
15	0.01825	0.01816	0.01816	0.01806	0.01816	0.01809	0.01818	0.01812
20	0.01685	0.01678	0.01663	0.01652	0.01662	0.01652	0.01691	0.01683

Table 2 (continued)

Energy	Heneicosylic A.		Lactose		L-Lysine		L-Serine		L-Tryptophan	
(MeV)	MCNP	GAMOS	MCNP	GAMOS	MCNP	GAMOS	MCNP	GAMOS	MCNP	GAMOS
0.01	2.465	2.454	4.079	4.061	3.249	3.236	4.069	4.052	3.02	3.007
0.015	0.8514	0.8549	1.307	1.309	1.072	1.075	1.304	1.306	1.001	1.004
0.02	0.474	0.4761	0.6546	0.6586	0.5611	0.5641	0.6536	0.6573	0.528	0.5309
0.03	0.2809	0.282	0.3251	0.3265	0.302	0.3033	0.325	0.3265	0.2879	0.2889
0.04	0.2303	0.2297	0.2426	0.2426	0.236	0.2353	0.2428	0.2427	0.2265	0.2263
0.05	0.2087	0.2083	0.21	0.2094	0.209	0.2085	0.2103	0.2097	0.2013	0.2009
0.06	0.196	0.196	0.1927	0.1929	0.1941	0.1944	0.193	0.1933	0.1872	0.1873
0.08	0.1806	0.1801	0.1738	0.1736	0.1771	0.1768	0.1742	0.1739	0.171	0.1707
0.1	0.17	0.1694	0.1623	0.1618	0.1661	0.1655	0.1626	0.1621	0.1604	0.1598
0.122	0.1608	0.1603	0.1529	0.1523	0.1568	0.1562	0.1532	0.1526	0.1515	0.1509
0.15	0.1514	0.1507	0.1435	0.1428	0.1474	0.1467	0.1438	0.143	0.1424	0.1417
0.2	0.1384	0.1379	0.1309	0.1305	0.1345	0.1341	0.1312	0.1308	0.13	0.1295
0.3	0.12	0.1196	0.1134	0.1129	0.1166	0.1162	0.1136	0.1132	0.1127	0.1123
0.356	0.1124	0.112	0.1062	0.1059	0.1092	0.109	0.1064	0.1061	0.1056	0.1052
0.4	0.1075	0.1072	0.1015	0.1012	0.1044	0.1039	0.1017	0.1014	0.1009	0.1006
0.5	0.09808	0.09794	0.09261	0.09234	0.09528	0.09488	0.0928	0.09253	0.09208	0.09178
0.511	0.09717	0.09703	0.09175	0.09155	0.0944	0.09418	0.09194	0.09172	0.09122	0.09109
0.6	0.09067	0.09039	0.0856	0.08544	0.08808	0.08798	0.08579	0.08558	0.08512	0.08502
0.662	0.08682	0.08657	0.08196	0.08181	0.08433	0.08398	0.08213	0.08179	0.08149	0.08129
0.8	0.07966	0.07939	0.07519	0.07504	0.07737	0.07699	0.07535	0.07509	0.07477	0.07459
1	0.0716	0.07152	0.06758	0.06748	0.06955	0.06958	0.06773	0.0677	0.06721	0.06728
1.17	0.06617	0.06569	0.06245	0.06206	0.06427	0.06392	0.06259	0.06216	0.06211	0.06175
1.25	0.06401	0.06349	0.06042	0.06001	0.06217	0.0618	0.06055	0.06016	0.06008	0.05974
1.275	0.06336	0.06314	0.05981	0.05935	0.06154	0.06107	0.05994	0.05951	0.05947	0.05904
1.33	0.06197	0.06166	0.0585	0.05825	0.0602	0.05998	0.05862	0.05841	0.05817	0.05783
1.5	0.0582	0.05789	0.05495	0.05473	0.05654	0.05628	0.05507	0.05484	0.05464	0.05439
2	0.04991	0.04976	0.04718	0.04707	0.04851	0.04846	0.04728	0.04718	0.04689	0.04673
3	0.03986	0.03977	0.03784	0.03775	0.03883	0.03872	0.03792	0.03781	0.03755	0.03747
4	0.03398	0.03392	0.03238	0.03234	0.03318	0.03309	0.03248	0.0324	0.03211	0.03204
5	0.03006	0.02997	0.02884	0.02879	0.02944	0.02939	0.0289	0.02885	0.02851	0.02846
6	0.02727	0.02724	0.02631	0.02628	0.02678	0.02675	0.02637	0.02633	0.02596	0.02594
8	0.02358	0.02355	0.02301	0.02297	0.02329	0.02329	0.02306	0.02302	0.02265	0.02257
10	0.02132	0.02129	0.02102	0.02101	0.02117	0.02116	0.02106	0.021	0.02058	0.02052
12	0.01974	0.01969	0.01965	0.01962	0.0197	0.01966	0.01969	0.01964	0.01917	0.01914
15	0.01816	0.01805	0.01832	0.01823	0.01825	0.01816	0.01835	0.01827	0.01779	0.01773
20	0.01663	0.01653	0.01707	0.01702	0.01686	0.0168	0.0171	0.01705	0.01647	0.01639

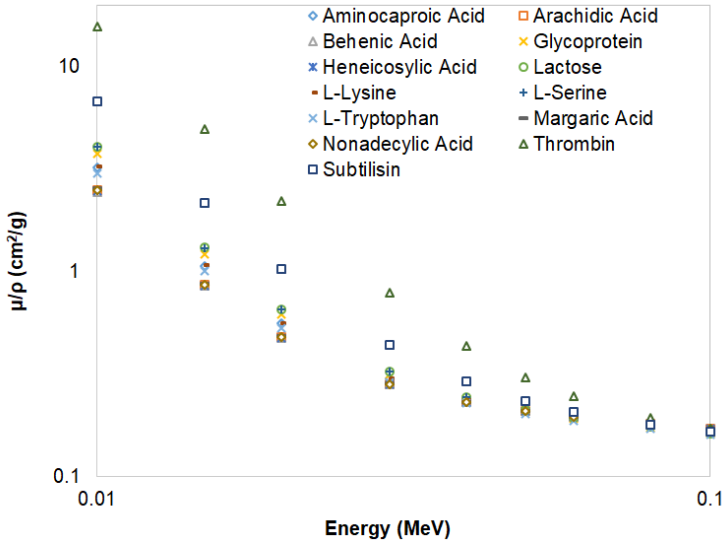
Table 2 (continued)

Energy	Margaric A.		Nonadecylic A.		Subtilisin		Thrombin	
(MeV)	MCNP	GAMOS	MCNP	GAMOS	MCNP	GAMOS	MCNP	GAMOS
0.01	2.543	2.532	2.5	2.489	6.786	6.777	15.71	15.67
0.015	0.8736	0.8769	0.8615	0.8647	2.17	2.169	4.931	4.925
0.02	0.4828	0.4851	0.478	0.4802	1.029	1.035	2.208	2.222
0.03	0.2831	0.2843	0.2819	0.283	0.4372	0.4389	0.7846	0.7898
0.04	0.231	0.2305	0.2306	0.23	0.2894	0.2887	0.433	0.4313
0.05	0.2088	0.2084	0.2087	0.2082	0.2334	0.2328	0.3047	0.3036
0.06	0.1959	0.1958	0.1959	0.1959	0.2058	0.2059	0.2453	0.2457
0.08	0.1803	0.1799	0.1805	0.1801	0.1789	0.1786	0.1934	0.1933
0.1	0.1697	0.169	0.1699	0.1692	0.1645	0.1644	0.1703	0.1702
0.122	0.1605	0.16	0.1607	0.1602	0.1538	0.1534	0.1555	0.1554
0.15	0.151	0.1503	0.1512	0.1505	0.1437	0.1428	0.1432	0.1427
0.2	0.138	0.1376	0.1382	0.1377	0.1306	0.13	0.1288	0.1282
0.3	0.1197	0.1191	0.1198	0.1194	0.1129	0.1124	0.1105	0.11
0.356	0.1121	0.1119	0.1123	0.1121	0.1057	0.1053	0.1034	0.1032
0.4	0.1072	0.1068	0.1073	0.1069	0.101	0.1007	0.09871	0.09852
0.5	0.09784	0.0976	0.09797	0.09783	0.09216	0.09191	0.08999	0.08985
0.511	0.09693	0.09686	0.09706	0.09696	0.0913	0.09108	0.08914	0.08897
0.6	0.09044	0.09036	0.09057	0.09028	0.08518	0.08501	0.08312	0.08292
0.662	0.0866	0.08639	0.08672	0.08644	0.08155	0.08127	0.07956	0.07933
0.8	0.07945	0.07907	0.07956	0.07927	0.07481	0.0745	0.07298	0.07285
1	0.07142	0.07143	0.07152	0.07146	0.06724	0.06718	0.06557	0.06555
1.17	0.066	0.06564	0.06609	0.06555	0.06213	0.06185	0.06059	0.06005
1.25	0.06385	0.06332	0.06394	0.06357	0.06011	0.05969	0.05862	0.05826
1.275	0.0632	0.06279	0.06328	0.06279	0.0595	0.0591	0.05802	0.05776
1.33	0.06181	0.06152	0.0619	0.0616	0.0582	0.05802	0.05676	0.05645
1.5	0.05805	0.05766	0.05813	0.05788	0.05467	0.05444	0.05333	0.05306
2	0.04978	0.04963	0.04985	0.04977	0.04694	0.04691	0.04587	0.04573
3	0.03977	0.03959	0.03982	0.03965	0.03767	0.03757	0.03701	0.0369
4	0.03391	0.0338	0.03394	0.03389	0.03229	0.03219	0.03194	0.03185
5	0.03001	0.02995	0.03004	0.02997	0.02875	0.02868	0.02863	0.02857
6	0.02727	0.02723	0.02725	0.02721	0.02624	0.02619	0.02631	0.02631
8	0.0236	0.02354	0.02361	0.02353	0.02302	0.02294	0.02343	0.02337
10	0.02131	0.0213	0.02131	0.02128	0.02102	0.02099	0.02167	0.0216
12	0.01974	0.01969	0.01974	0.01967	0.01967	0.0196	0.02052	0.02043
15	0.01817	0.01811	0.01816	0.01809	0.01836	0.01832	0.01943	0.01927
20	0.01665	0.01657	0.01664	0.0165	0.01714	0.01709	0.0185	0.01819

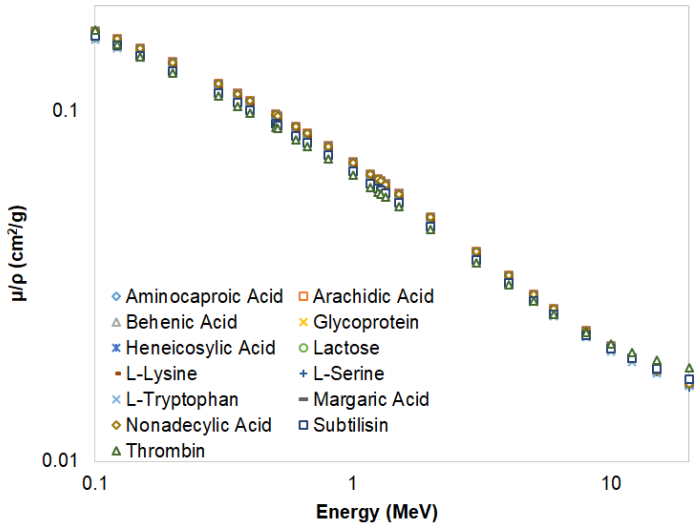
As expected, μ/ρ values of all the materials first exhibit a sharp decrease as a function of energy up to about 50 keV as displayed in Figures 2(a) and (b) for MCNP results. This is mainly due to photoelectric absorption being the dominant mode of interaction for elements of low atomic number in this energy interval. After this initial sudden decrease, μ/ρ values observe a gradual decline for all the samples at each energy. This latter behavior, on the other hand, can be attributed to the Compton scattering being more significant at intermediate and higher energies.

As shown in Figures 2(a) and (b), a couple of enzymes (namely, subtilisin and thrombin) display higher μ/ρ values especially at lower photon energies. This may be attributed as the direct result of the chloride and sulphur contents of these samples where these elements offer relatively higher photoelectric absorption for low energy photons due to their relatively higher atomic numbers (Z) compared to the other

elements in these compounds. This effect is also true for the samples which do not contain C or S. In that case, the oxygen amount of a sample becomes predominant and the μ/ρ values then correlate with the oxygen ratio of the samples. For example, lactose having the highest O percentage (51%) among the samples studied has the highest μ/ρ values while behenic acid with the lowest oxygen content (9%) shows the lowest μ/ρ values for low energy photons. In contrast, at further photon energies, this dependence on the relative high Z content of the elements disappears for all the compounds and the graph displays similar μ/ρ values almost without regard to their elemental compositions.



(a) 0.010-0.1 MeV

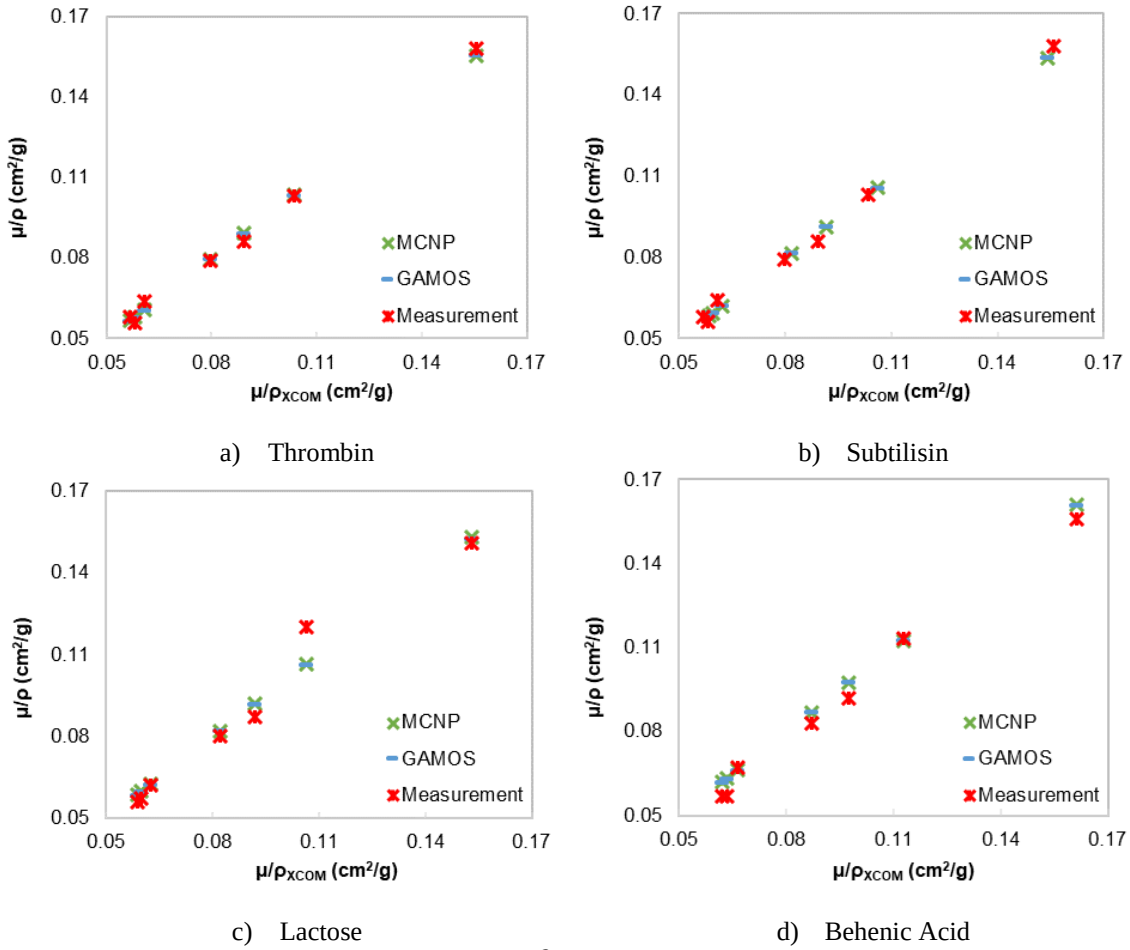


(b) 0.10-20 MeV

Figure 2. Mass attenuation coefficients (cm^2/g) of the biological samples as a function of photon energy computed with MCNP6

The majority of the MCNP and GAMOS results investigated in this study were observed to agree with each other within <0.5% which is a proof that the simulation parameters used in both codes were rather similar. When the results of each code were compared with those of XCOM [4] from the literature data, MCNP was seen to produce results agreeing within <0.5% of XCOM while the percentage difference of GAMOS results were only slightly higher. The corresponding R^2 values of the correlations were

exactly one in both comparisons which indicate a very satisfactory agreement between simulation results and tabular data. The results of this study were also checked against the measurement data reported by Gaikwad [15]. Figure 3 compares results of MCNP, GAMOS and the measurement study with data from XCOM tables for four of the samples that depict some discrepancy as mentioned above. The measurement data that are available at energies greater than 122 keV show some deviations from the other three data sets but follows a similar overall trend with XCOM data (R^2>0.9697).



a) Thrombin b) Subtilisin

c) Lactose d) Behenic Acid

Figure 3. Total mass attenuation coefficients (cm^2/g) of some of the biological samples obtained from MCNP, GAMOS and a measurement study [15] compared with XCOM database [4]

4. Conclusion

This study proposes a Monte Carlo approach to determine mass attenuation coefficients for some biological compounds found in human body. This approach could be an alternative when measurements are difficult to carry out either due to some gamma energies being available or difficulties in physically producing samples. One can produce attenuation coefficient data at any photon energies and for any material thickness. The results obtained from the Monte Carlo simulations show very good agreement with theoretical data as well as measurement values and indicate that Monte Carlo technique can be used as an alternative for calculations of interaction parameters for materials of interest.

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