

## Calculation of the total mass stopping power for electrons in some human body tissues in the energy range 0.01-1000 MeV

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### Abstract

The mass collision energy loss ( $dE/\rho dX$ ), the mass radiative energy loss ( $S_{rad}/\rho$ ) and the total mass stopping power of electrons in the energy range of 0.01 MeV up to 1000 MeV has been calculated for Lung, Urea and Skin. The results of the present work for the mass collision stopping power of electrons in Lung, Urea and Skin are in excellent agreement with the standard results given by ESTAR program, where the maximum percentage error between the present calculated values and that of ESTAR program in Lung tissue, Urea and Skin tissue is 0.27%, 0.3% and 0.8% respectively. The mass radiative energy loss of electrons in the same energy range is also calculated using a modified equation, and the results are found to be in very good agreement with the standard published values. The employed modified equation used to calculate the mass radiative energy loss of electrons is valid in the energy range of electrons from 0.01 MeV up to 1000 MeV and gives accurate results. As the results of total stopping power calculation are concerned, they are found in excellent agreement with the published results, where the error is less than 1%.

### Key words

Mass stopping power, radiative energy loss, total energy, human body tissues.

### Article info.

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## حساب قدرة الايقاف الكلية للالكترونات لبعض أجزاء الجسم البشري في مدى الطاقة من 0.01 الى 1000 مليون الكترون فولت

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### الخلاصة

حسبت قدرة الايقاف التصادمية وقدرة الايقاف الاشعاعية وكذلك قدرة الايقاف الكلية للالكترونات ضمن مدى الطاقة (من 0.01 الى 1000 مليون الكترون فولت) عند مرورها في بعض مكونات الجسم البشري مثل نسيج الرئة واليوريا ونسيج الجلد وقد اظهرت نتائج فيما يخص قدرة الايقاف التصادمية تطابقا ممتازا عند مقارنتها مع النتائج القياسية العالمية المنشورة. حيث تبين ان نسبة الخطأ المئوي في نتائج حساب قدرة الايقاف التصادمية في كل من النسيج الرئوي واليوريا ونسيج الجلد هي 0.27% و 0.3% و 0.8% على التوالي. كما حسبت ايضا قدرة الايقاف الاشعاعية ضمن نفس مدى الطاقة المذكورة انفا وباستخدام معادلة تم تحويلها بإضافة دالة تعتمد على طاقة الالكترون الى المعادلة الاصلية. وقد بينت النتائج بعد مقارنتها بأحدث النتائج العالمية القياسية المنشورة بأنها متطابقة معها بدرجة ممتازة. كما تبين ان المعادلة الجديدة يمكن استخدامها ضمن مدى طاقة الالكترونات (من 0.01 الى 1000 مليون الكترون فولت) وبدرجة عالية من الدقة. اما بالنسبة لحساب قدرة الايقاف الكلية فقد اظهرت النتائج بانها على درجة عالية من الدقة ايضا وان نسبة الخطأ اقل من 1%.

## Introduction

The stopping power and the range of electrons in a media are characteristics of the stopping media. The knowledge of such physical quantities, since such quantities are very important in the electron radiotherapy and in the calculation of radiation dose. When the energy of the electrons is more than the ionization energy of the molecule, the electrons shall interact with biological cells by ionization and excitation with atomic electrons. During the passage of electrons through the human tissues, electron can emit electromagnetic radiation which is known as bremsstrahlung. The energy loss due to ionization and excitation is known as collisional energy loss. The calculation of electron's range and the energy loss in biomedical materials was the subject of many researches [1-5]. The calculation of energy loss due to emission of bremsstrahlung is more complicated than the calculation of energy loss due to ionization and excitation, and there is no exact formula used in such calculations, but there are only an approximate equations [6-8], that will be given for the calculation of radiative loss for electrons only, since the energy loss by bremsstrahlung radiation is important, which is less importance for heavy charged particles. Adwan N. H. Al-Ajili et al., [9] had been used an approximate equation to calculate the energy loss due to emission of bremsstrahlung in the energy range 0.1-10 MeV, The result obtained by the approximate equations didn't give appropriate results, and it was found that a high error to calculate the results

when it compared with the standard values due to Berger and Seltzer [1] and had been showed an error up to 18.5 % at 10 MeV with that standard values. The Error could be reached more higher at energies near 1000 MeV. The limitation of the relation is that it is not valid for such calculation and does not give any idea for high energy region.

Aman Allah et al. [10], had been used the same approximate formula as reference [9]. It can be recognized from their graphs that, the error is high in the energy range 0.1-10MeV, where the effect of the energy loss by emission of bremsstrahlung had no importance effect, since the energy loss by this process was considerable above 10 MeV.

The present study is undertaken to calculate the mass collisional energy loss with minimum possible error and to modify the approximate formula to calculate the energy loss by bremsstrahlung in intermediate and high energy region.

## Theory

### Mass collisional of electrons stopping powers

Electron loses its energy by ionization and excitation by the orbital electrons in the medium. Mass stopping Power ( $dE/\rho dX$ ) can be defined as the rate of energy loss per unit path length of an electron or positron by excitation and ionization which was known as "collisional energy loss". The mass collision stopping powers for electrons and positrons are given by [8]:

$$\left(\frac{dE}{\rho dX}\right)_c = K \left[ \text{Ln} \left\{ \frac{\tau^2(\tau + 2)}{2 \left(\frac{I}{m_0 c^2}\right)^2} \right\} + F^{\mp}(\tau) - \delta(\beta\gamma) - \frac{2C}{Z} \right] \quad (1)$$

where,

$$K = \frac{2Cm_0c^2}{\beta^2} = \frac{0.1535 Z}{A\beta^2} \quad (\text{Mev.cm}^2.\text{g}^{-1}) \quad I \text{ and } m_0c^2 \text{ in eV}$$

$$\tau = \frac{T}{m_0c^2} \quad T \text{ is the kinetic energy of the electrons in unites of } m_0c^2$$

$$F^-(\tau) = 1 - \beta^2 + \frac{1}{(\tau + 1)^2} \left[ \frac{\tau^2}{8} - (2\tau + 1)\text{Ln}2 \right] \quad \text{is used for electrons} \quad (2)$$

and

$$F^+(\tau) = 2\text{Ln}2 - \frac{\beta^2}{12} \left[ 23 + \frac{14}{(\tau + 2)} + \frac{10}{(\tau + 2)^2} + \frac{4}{(\tau + 2)^3} \right] \quad \text{for positrons} \quad (3)$$

$\frac{C}{Z}$  is for shell correction accounting for non-participation of K-shell electrons at low energies and can be calculated by the formula [8];

$$C = \pi \left( \frac{N_A Z}{A} \right) \left( \frac{e^2}{m_0c^2} \right)^2$$

$\delta$  is for the polarization or density effect correction in condensed media [11]

$$\delta(X) = \begin{cases} 4.6052X + C & X > X_1 \\ 4.6052X + a(X_1 - X)^m + C & X_0 < X < X_1 \\ 0 & \text{for non - conducting materials } X < X_0 \\ \delta(X_0) 10^{2(x-x_0)} & \text{for conducting materials } X < X_0. \end{cases}$$

The parameters  $X_0$ ,  $X_1$ ,  $a$ ,  $m$ , and  $C$  Parameters for elements and many compounds and mixtures were published [34, 35].

In this equation,  $X = \log_{10} (\tau(\tau + 2))^{\frac{1}{2}}$   
 $\tau$  is the electron kinetic energy in units of rest mass, and

$$C = -2\text{ln} \left( \frac{I}{\hbar\omega_0} \right) - 1$$

where,

$$\hbar\omega_0: \text{ is the plasma energy } = \sqrt{4\pi N_e r_e^3 m_0c^2 / \alpha} = 28.816 \sqrt{\rho \langle Z/A \rangle} \text{ eV}$$

$N_e$ : is the electron density (electron /cm<sup>3</sup>) of the medium.

$\alpha$  : is the Fine structure constant = 1/137

$\rho$ : is the density of the medium (g/cm<sup>3</sup>)

### The mass radiative stopping power

Electrons and positrons passing through matter undergo acceleration (deceleration) in the interaction with the strong electric field of the nucleus and the atomic electrons. This leads to emission of x-ray and gamma radiation, the process which is known as *Bremsstrahlung*. The total power radiated, in non relativistic limits, is given by Larmor formula [12]:

$$P = \frac{2}{3} \frac{e^2 a^2}{4\pi\epsilon_0 c^3} \quad (4) \quad \text{in SI unite}$$

relativistic generalization is given by the Liénard–Wiechert potentials [13]

$$P = \frac{2}{3} \frac{e^2 a^2}{c^3} \quad (5) \quad \text{in cgs unite}$$

where  $a$ : is the acceleration.

$e$ : is the electron charge, and  $c$  is the speed of light.

The power radiated by a single electron can be expressed in terms of the classical electron radius and electron mass as:

$$P = \frac{2}{3c} m_e r_e a^2 \quad (6)$$

where  $r_e = \frac{e^2}{m_0c^2}$

The acceleration of electron under the effect of electric field is given by:

$$a = \frac{e^2 Z}{M (4\pi\epsilon_0)R^2} \quad (7)$$

which means,  $a \propto (Z/M)$ .

The energy flux density (S) of the radiation field can be found by computing its Poynting vector:

$$S = \frac{e^2 a^2}{(4\pi c)R^2} = \frac{e^2 \left( \frac{e^2 Z}{M (4\pi\epsilon_0)R^2} \right)^2}{(4\pi c)R^2} \quad (8a)$$

$$= \frac{e^6}{c\epsilon_0^2 (4\pi)^3 R^6} \left( \frac{Z}{M} \right)^2 \quad (8b)$$

It can be seen from equation 8b that the intensity of radiation produced is proportional to  $(Z/M)^2$ . So it be noticed that a relatively unimportant energy loss mechanism for electrons below about 10 MeV in low-Z materials and it is completely negligible for heavy charged particles.

In a similar way to that for collision losses a radiative stopping power  $(dE/dX)_{rad}$  (or sometimes it is written

as  $S_{rad}$ ), and also a mass radiation stopping power  $(S_{rad}/\rho)$  can be define. The mass radiative stopping power is the rate of energy loss by electrons or positrons that results in the production of bremsstrahlung. The Bethe–Heitler theory leads to the following formula for the mass radiative stopping power [14]:

$$\left( \frac{S}{\rho} \right)_{Rad} = \alpha N_a r_e^2 \times \frac{Z^2}{A} \times (E + m_0 C^2) B \quad (9)$$

where B is a slowly varying function of Z and E, varying between 5.33 and 15 for energies in the range from less than 0.5 MeV to 100 MeV.

Reference [6]: give the following formula for the mass radiative stopping power at high energies (complete screening:  $\tau \gg 1/\alpha Z^{1/3}$ ):

$$\left( \frac{S}{\rho} \right)_{Rad} = \frac{4\alpha N_a r_e^2}{\beta^2} \times \frac{Z(Z+1)}{A} \times (\tau + 1) m_0 C^2 \times \ln \left( \frac{183}{Z^{1/3}} + \frac{1}{18} \right) \quad (10)$$

where  $\alpha$  is the fine structure constant =  $1/137$

$N_a$ : is Avogadro number

$r_e$ : is the classical electron radius  $(e^2/4\pi\epsilon_0 m_e c^2) = 2.8179 \times 10^{-15}$  m.

$\beta = v/c$

Z is the atomic number of absorber

$\tau$  is the kinetic energy of the electron in unite of  $m_0 c^2$ .

$m_0 c^2$ : is the electron mass  $\times c^2$ .

Leo [7] gives another approximate equations to calculate the energy loss by Bremsstrahlung at low and high energy region.

$$\left( \frac{S}{\rho} \right)_{Rad} = 4\alpha N_a r_e^2 \times \frac{Z^2}{A} \times \ln \left( \frac{2E}{m_0 c^2} - \frac{1}{3} - f(Z) \right) \quad (11)$$

while at high energies, for complete screening, as:

$$\left( \frac{S}{\rho} \right)_{Rad} = 4\alpha N_a r_e^2 \times Z^2 \frac{E}{A} \left( \ln \frac{183}{Z^{1/3}} + \frac{1}{18} - f(z) \right) \quad (12)$$

In the present work the calculation of the radiative stopping power is done

by employing Eq. (10), with parameter H, then equation (10) becomes;

$$\left(\frac{S}{\rho}\right)_{Rad} = \frac{4\alpha N_a r_e^2}{\beta^2} \times \frac{Z(Z+1)}{A} \times (\tau + 1)m_0 C^2 \times \text{Ln} \left( \frac{183}{Z^{\frac{1}{3}}} + \frac{1}{18} \right) \mathbf{H} \dots (13a)$$

The initial values of **H** parameter were obtained by dividing the standard values of ref. (15) by the values obtained by Eq. (10), and then fitted to equation of the form:

$$\mathbf{H} = \left( a + \frac{bE^c}{d^c + E^c} \right)$$

So that; Eq. (13a) becomes:

$$\left(\frac{S}{\rho}\right)_{Rad} = \frac{4\alpha N_a r_e^2}{\beta^2} \times \frac{Z(Z+1)}{A} \times (\tau + 1)m_0 C^2 \times \text{Ln} \left( \frac{183}{Z^{\frac{1}{3}}} + \frac{1}{18} \right) \left( a + \frac{bE^c}{d^c + E^c} \right) \quad (13b)$$

where  
E is the energy of the electron.

The fitting parameters a, b, c and d are given in following table:

Fitting Parameters	LUNG	UREA	SKIN
a	-0.0118	-0.0119	-0.0120
b	1.037	1.043	1.051
c	0.63	0.63	0.63
d	4.41	4.52	4.47

The total stopping power for light charged particles is equal to the sum of

both collisional and bremsstrahlung stopping powers [1, 8].

$$\left(\frac{dE}{\rho dX}\right)_{Tot} = \left(\frac{dE}{\rho dX}\right)_{coll} + \left(\frac{dE}{\rho dX}\right)_{rad} \quad (14)$$

**Calculations**

The mass collision energy loss of electrons in the energy range of electrons from 0.01 MeV up to 1000 MeV has been calculated for Lung, Urea and Skin using Eq. (1), and the correction for k- shell accounting for non-participation of K-shell electrons at low energies and the polarization or density effect correction ( $\frac{C}{Z}$ ) in condensed media ( $\delta$ -parameter) have been considered. The results are presented in Table 1.

The mass radiative energy loss of electrons in the same energy range is calculated by using of Eq. (13b), and the results are compared with most new published results and are given in Table 2. The total mass stopping power is obtained as the sum of both collisional and bremsstrahlung stopping powers as illustrated in Eq. (14), where the results are compared with the standard published results and are presented in Table 3.

**Table 1: Comparison of the present results of the collision mass stopping power for electrons in Lung, Urea and Skin with the standard published data in the energy range (0.01-1000 MeV).**

Collision Mass Stopping power (dE/pdX) for Electrons (MeV cm <sup>2</sup> /g)									
Energy in (MeV)	LUNG			UREA			SKIN		
	ESTAR [15]	Present work	Error%	ESTAR [15]	Present work	Error%	ESTAR [15]	Present work	Error%
0.010	22.320	22.262	0.262	21.790	21.725	0.296	22.470	22.291	0.799
0.020	13.040	13.005	0.270	12.710	12.681	0.225	13.110	13.011	0.755
0.040	7.696	7.679	0.220	7.500	7.484	0.220	7.734	7.678	0.726
0.060	5.737	5.725	0.217	5.589	5.577	0.213	5.763	5.722	0.713
0.080	4.708	4.699	0.199	4.586	4.577	0.203	4.729	4.695	0.709
0.100	4.073	4.065	0.203	3.967	3.959	0.208	4.090	4.061	0.697
0.200	2.764	2.759	0.172	2.691	2.686	0.177	2.775	2.756	0.688
0.400	2.126	2.122	0.174	2.068	2.065	0.167	2.133	2.119	0.658
0.600	1.942	1.939	0.179	1.879	1.876	0.144	1.945	1.932	0.677
0.800	1.864	1.861	0.162	1.800	1.798	0.134	1.865	1.853	0.653
1.000	1.827	1.824	0.140	1.763	1.760	0.160	1.827	1.815	0.635
2.000	1.802	1.799	0.156	1.735	1.733	0.124	1.800	1.789	0.638
4.000	1.849	1.846	0.158	1.781	1.779	0.134	1.847	1.835	0.660
6.000	1.890	1.887	0.150	1.822	1.819	0.146	1.888	1.876	0.644
8.000	1.921	1.919	0.111	1.853	1.851	0.134	1.920	1.907	0.658
10.000	1.947	1.944	0.156	1.877	1.875	0.106	1.945	1.932	0.656
20.000	2.024	2.021	0.145	1.951	1.948	0.138	2.021	2.008	0.635
40.000	2.094	2.092	0.114	2.016	2.014	0.107	2.090	2.077	0.618
60.000	2.132	2.129	0.119	2.052	2.049	0.131	2.127	2.114	0.601
80.000	2.158	2.155	0.128	2.076	2.074	0.106	2.153	2.140	0.619
100.000	2.177	2.175	0.098	2.095	2.093	0.119	2.173	2.159	0.643
200.000	2.237	2.235	0.111	2.153	2.150	0.139	2.232	2.218	0.616
400.000	2.296	2.293	0.110	2.210	2.207	0.155	2.291	2.277	0.620
600.000	2.330	2.328	0.104	2.243	2.240	0.142	2.325	2.311	0.593
800.000	2.355	2.352	0.115	2.266	2.264	0.098	2.349	2.335	0.598
1000.000	2.374	2.371	0.135	2.285	2.282	0.144	2.368	2.354	0.582

**Table 2: Comparison of the present results of the radiative mass stopping power for electrons in Lung, Urea and Skin with the standard published data in the energy range (0.01-1000 MeV).**

Radiative Mass Stopping power ( $S_{rad}$ ) for Electrons ( $\text{MeV cm}^2/\text{g}$ )									
Energy in (MeV)	LUNG			UREA			SKIN		
	ESTAR [15]	Present work	Error%	ESTAR [15]	Present work	Error%	ESTAR [15]	Present work	Error%
0.0100	0.0038	0.0037	4.1275	0.0036	0.0033	6.6472	0.0037	0.0035	5.8610
0.0200	0.0039	0.0042	-6.2438	0.0036	0.0038	-5.4288	0.0037	0.0039	-5.6278
0.0400	0.0040	0.0041	-3.8528	0.0036	0.0038	-3.7337	0.0038	0.0039	-3.7137
0.0600	0.0040	0.0041	-1.0146	0.0037	0.0037	-1.0422	0.0038	0.0039	-0.9981
0.0800	0.0041	0.0041	0.8131	0.0038	0.0037	0.7414	0.0039	0.0039	0.7995
0.1000	0.0042	0.0041	1.9442	0.0039	0.0038	1.8400	0.0040	0.0039	1.8932
0.2000	0.0047	0.0046	2.9161	0.0044	0.0043	2.8064	0.0045	0.0044	2.8321
0.4000	0.0063	0.0062	0.7155	0.0058	0.0058	0.6458	0.0060	0.0060	0.6605
0.6000	0.0082	0.0082	-0.3780	0.0076	0.0076	-0.3993	0.0078	0.0079	-0.4117
0.8000	0.0103	0.0104	-0.8264	0.0096	0.0097	-0.8022	0.0099	0.0100	-0.8344
1.0000	0.0127	0.0128	-0.8948	0.0118	0.0119	-0.8929	0.0122	0.0123	-0.9509
2.0000	0.0265	0.0266	-0.3630	0.0247	0.0248	-0.3101	0.0255	0.0256	-0.3207
4.0000	0.0599	0.0598	0.0754	0.0560	0.0559	0.0977	0.0577	0.0577	0.0788
6.0000	0.0974	0.0973	0.0771	0.0911	0.0911	0.0747	0.0939	0.0939	0.0667
8.0000	0.1374	0.1374	0.0302	0.1287	0.1286	0.0448	0.1326	0.1326	0.0277
10.0000	0.1793	0.1792	0.0684	0.1680	0.1679	0.0588	0.1731	0.1730	0.0708
20.0000	0.4038	0.4032	0.1375	0.3789	0.3785	0.1172	0.3901	0.3896	0.1195
40.0000	0.8851	0.8845	0.0715	0.8315	0.8311	0.0442	0.8556	0.8552	0.0463
60.0000	1.3840	1.3841	-0.0089	1.3010	1.3014	-0.0322	1.3380	1.3388	-0.0566
80.0000	1.8920	1.8930	-0.0530	1.7790	1.7805	-0.0856	1.8300	1.8313	-0.0715
100.0000	2.4060	2.4076	-0.0660	2.2630	2.2651	-0.0919	2.3270	2.3294	-0.1043
200.0000	5.0200	5.0237	-0.0746	4.7250	4.7292	-0.0889	4.8580	4.8622	-0.0864
400.0000	10.3400	10.3416	-0.0158	9.7380	9.7392	-0.0128	10.0100	10.0112	-0.0122
600.0000	15.7100	15.7035	0.0415	14.8000	14.7913	0.0587	15.2100	15.2031	0.0453
800.0000	21.0900	21.0865	0.0164	19.8700	19.8637	0.0319	20.4300	20.4157	0.0700
1000.0000	26.4900	26.4826	0.0281	24.9600	24.9484	0.0466	25.6500	25.6409	0.0354

**Table 3: Comparison of the present results of the total mass stopping power for electrons in Lung, Urea and Skin with the standard published data in the energy range (0.01-1000 MeV).**

Total Mass Stopping Power for Electrons ( MeV cm <sup>2</sup> /gm)									
Energy in (MeV)	LUNG			UREA			SKIN		
	Present work	ESTAR [15]	Error%	Present work	ESTAR [15]	Error%	Present work	ESTAR [15]	Error%
0.010	22.265	22.330	0.290	21.729	21.790	0.281	22.294	22.470	0.783
0.020	13.009	13.040	0.239	12.685	12.720	0.273	13.015	13.110	0.725
0.040	7.683	7.700	0.219	7.487	7.504	0.223	7.682	7.738	0.727
0.060	5.729	5.741	0.216	5.581	5.593	0.217	5.726	5.767	0.715
0.080	4.703	4.712	0.198	4.580	4.590	0.208	4.699	4.733	0.710
0.100	4.069	4.077	0.200	3.963	3.970	0.188	4.065	4.094	0.699
0.200	2.764	2.769	0.186	2.691	2.696	0.204	2.760	2.779	0.672
0.400	2.129	2.132	0.163	2.070	2.074	0.177	2.125	2.139	0.657
0.600	1.947	1.950	0.168	1.884	1.887	0.164	1.940	1.953	0.681
0.800	1.871	1.874	0.140	1.807	1.810	0.152	1.863	1.875	0.651
1.000	1.837	1.840	0.152	1.772	1.775	0.165	1.828	1.840	0.670
2.000	1.826	1.828	0.124	1.758	1.760	0.135	1.814	1.826	0.653
4.000	1.906	1.908	0.111	1.835	1.837	0.134	1.892	1.904	0.605
6.000	1.984	1.987	0.128	1.910	1.913	0.136	1.970	1.982	0.620
8.000	2.056	2.059	0.135	1.979	1.982	0.144	2.040	2.052	0.588
10.000	2.123	2.126	0.135	2.043	2.045	0.102	2.105	2.118	0.603
20.000	2.424	2.427	0.111	2.327	2.330	0.139	2.398	2.411	0.547
40.000	2.976	2.979	0.098	2.845	2.848	0.106	2.932	2.946	0.466
60.000	3.514	3.516	0.069	3.351	3.353	0.068	3.453	3.466	0.376
80.000	4.048	4.050	0.043	3.854	3.855	0.017	3.971	3.983	0.302
100.000	4.582	4.583	0.012	4.358	4.358	0.010	4.488	4.500	0.257
200.000	7.258	7.257	-0.017	6.879	6.878	-0.017	7.080	7.090	0.135
400.000	12.635	12.640	0.039	11.946	11.950	0.035	12.288	12.300	0.097
600.000	18.031	18.040	0.050	17.031	17.040	0.052	17.514	17.530	0.089
800.000	23.439	23.450	0.048	22.127	22.140	0.057	22.751	22.770	0.085
1000.000	28.853	28.860	0.023	27.230	27.250	0.073	27.995	28.020	0.089



## Results and discussion

The results of the present work for mass collision stopping power of electrons in Lung, Urea and Skin were in excellent agreement with the standard results of reference [15]. The maximum percentage error between the present work values and that of ESTAR program in Lung tissue, Urea and Skin tissue is 0.27%, 0.3% and 0.8% respectively.

The mass radiative energy loss of electrons in the same energy range is calculated using Eq.(13b). The Maximum percentage error between the present work values and that of ESTAR program in Lung tissue, Urea and Skin tissue is 6.2%, 6.6%, and 5.86% respectively, this error appear at low energy region and it was not important and could be neglected in that energy region. It can be noticed that the results are agreement with the energy range of electrons (0.06-1000 MeV), where the error was very low and less than 1%.

## Conclusions

It can be concluded that, the employed equation used in the calculation of the mass radiative energy loss of electrons is valid in the energy range of electrons from 0.06 MeV up to 1000 MeV gives accurate results. When the total stopping power was concerned, one can found that the results are in good agreement with the published results, where the error is less than 1%.

## References

- [1] M. J. Berger, S. M. Seltzer, Tables of energy losses and ranges of electron and positron, NASA SP-3012, 1982.
- [2] Anshu Saxena, S.K. Rathi, A.S. Verma, Elixir Bio. Phys., 37 (2011) 3860-3863.
- [3] Sandeep Gupta, International Journal of Engineering Technology, Management and Applied Sciences (IJETMAS), 3, Special Issue, (2015) 152-161.
- [4] Singh Hemlata<sup>1</sup>, Rathi S.K., Verma A.S., Res. J. Chem. Sci., 3, 3 (2013) 4-8.
- [5] Priyanka Agrawal, S. K. Rathi, A. S. Verma, Elixir Chem. Phys., 37 (2011) 3856-3859.
- [6] P. Mayles, A. Nahum, J.C. Rosenwald, Hand book of radiotherapy physics: theory and practice, 2007, p 46
- [7] W.R. Leo, "Techniques for Nuclear and Particle Physics Experiments", Springer-Verlag, 2<sup>nd</sup> rev. ed. 1994, XVIII, 382 p. 12.
- [8] F. H. Attix, Introduction to radiological physics and radiation dosimetry, Wiley & Son, New York, (1986).
- [9] Adwan N. H. Al-Ajili, Sabah M. Aman Allah, Rafa A. Abad, Ahmad M. O. Al-Bayti, Tikrit Journal of Pure Science, 21, 1 (2016) 82-86.
- [10] Sabah Mahmoud Aman Allah, Enas Mohamad Salaman, Rafea Abduala Abad, Journal of Babylon University, Pure and Applied Sciences, 22, 7 (2014) 1973-1982.
- [11] R. M. Sternheimer, S. M. Seltzer, M. J. Berger, Phys. Rev., B 26 (1982) 6067.
- [12] Jackson, John D. (1998). Classical Electrodynamics (3rd ed.). Wiley. ISBN 0-471-30932-X. (Section 14.2ff).
- [13] D.J. Griffiths, Introduction to Electrodynamics. Prentice Hall, ISBN 0-13-805326-X., 1999.
- [14] Radiation Oncology Physics: A Handbook for Teachers And Students, E.B. Podgorsak Technical Editor, International Atomic Energy Agency, Vienna, 2005, chapter 2, p52.
- [15] ESTAR. Stopping power and range tables for electron. Data available. NIST (national institute of standards and technology) <http://physics.nist.gov/PhysRefData/Star/Text/ESTAR.html>.