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Energy Stopping Power of Electrons in the Energy Range (0.01- 1000 MeV) In Some Human Body Tissues and Water

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Abstract

Electron accelerator is considered as an important tool in cancer radio-therapy and it providing unique choice in treatment of superficial tumor. In this paper, the mass stopping power of electrons has been calculated in biomedical human substances such as bones, soft-tissues and water with energy range of (10 keV- 1000 MeV) using two methods. The first method is done by calculating the energy loss of electrons in the tissue as one compound. The second method is by calculating the collision energy loss of electrons for each element of the compositions of bone, soft-tissue and water, and then calculates the collision energy loss of the tissue, where the tissue was considered to be made up of thin layers of pure elements (H, C, N, O, Na, Mg, P, S, Cl, K, Ca, Fe and Zn). The present results of the mass stopping power (dE/ρdX) for bone, tissue (soft) and water were compared for the two methods with the standard published results (ESTAR PROGRAM). The results are found in excellent agreement with the standard published data, where the error doesn't exceeds 0.3% when the first method was used. But it was found that the error is high when the second method is used. Therefore, we recommended using the first method and treating the tissue as one compound instead of it is composed of thin layers of pure elements.

Keywords: stopping power, human body tissues, electron therapy, bone, biomedical human substances.

حساب الفقدان لطاقة الالكترونات في بعض الانسجة البشرية ضمن مدى طاقة الالكترونات (0.01 – 1000 مليون الكترون فولت)

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الخلاصة :

يعتبر معجل الالكترونات احد الوسائل المهمة في العلاج الاشعاعي للأورام السرطانية وقد تكون هي الوسيلة الوحيدة في معالجة بعض حالات الاورام السرطانية مثل معالجة الاورام السرطانية تحت السطحية والجلدية. تم في هذا البحث حساب قدرة الايقاف للالكترونات خلال مرورها في الانسجة الرخوة والعظام وبعض مكونات الجسم البشري(الماء) في مدى الطاقة من (10 keV) الى (1000 MeV) باستخدام طريقتين , الاولى هي حساب الفقدان في طاقة الالكترونات خلال مرورها في النسيج واعتبار النسيج كمركب واحد. والطريقة الثانية حساب الفقدان في طاقة الالكترونات خلال مرورها في النسيج واعتبار النسيج مكونا من عدة طبقات كل طبقة تمثل عنصرا من العناصر الكيميائية المكونة له (Zn,Fe,Ca,K,Cl,S,P,Mg,Na,H).وقد تبين بان النتائج الحالية متطابقة بشكل كبير مع اهم النتائج العالمية المنشورة ولا تتعدى نسبة الخطأ 0.3% كأقصى حد عند استخدام الطريقة الاولى ويمكن اعتمادها كنتائج قياسية لحساب الجرعات المكافئة للالكترونات عند مرورها في تلك الانسجة.وفي حالة استخدام الطريقة الثانية وجد ان نسبة الخطأ عالية على النتائج,وبناء عليه توصي الدراسة الحالية بعدم اعتماد الطريقة الثانية في حساب الفقدان في طاقة الالكترونات خلال مرورها في الانسجة .

1. Introduction

When charged particles pass through matter they interact with atomic electrons by several ways. The charge particles may interact with atoms through inelastic collision and resulting in excitation and ionization of atoms, this is known as collision loss. The charged particles may suffer another type of interaction which is known as elastic collision in which it doesn't loss any energy. In addition, the particle can interact with atoms through bremsstrahlung production and it known as radiative loss. The current knowledge, both experiment and theoretical, is far from being complete, and is often inadequate for the determination of stopping power values of a variety of materials and for a wide range of particle energies. [1].

Information about interaction of radiation with matter especially with the tissue of human body and water is very important from the point of dosimetry and radiation protection, radiotherapy and calibration of computed tomography scanners.

Since the human body contains mostly water, the knowledge of depth dose profile of charged particles in this stopping medium is also of great importance for an accurate treatment planning.

Electron linear accelerator becomes one of the effective equipment in cancer radiotherapy and treatment of many tumors [2, 3], so that the radiation dose should be accurate to obtain therapeutic success, when a significant under dose can cause failure to control the disease and overdose increases the risk of damage to normal tissues. Therefore the knowledge of mean free path and continuous slowing down approximation range (CSDA) for biological materials are also important, so that many authors made several studies on biological compounds [4-9].

Tissues and water equivalent materials (TEMs) can be used in quality assurance in radiotherapy[10], dosimetry measurements, CT-Scanner calibration[11], such materiel was consider to be equivalent to a tissue has the same radiation characteristics as the real human tissues ,accordingly many (TEMs) have been studied and developed [12-22].

Phantoms are physical or virtual representations of the human body to be used for the determination of absorbed dose to radiosensitive organs and tissues. In radiation protection a widely used physical model is the ALDERSON-RANDO phantom (Alderson [23], Fisher and Snyder [24,25] introduced this type of phantom for an adult male which also contains ovaries and a uterus .the phantom has been further developed by Snyder et al [26,27]. Since then it is known as "MIRD-5 phantom" (*M*edical *I*nternal *R*adiation *D*ose Committee (MIRD) Pamphlet No.5).and many other phantoms for children of various age [28], and a pregnant female adult phantom Stabin et al [29].

The International Commission on Radiological Protection (ICRP) has created a task group on dose calculations, which, among other objectives, should replace the currently used mathematical MIRD phantoms by voxel phantoms [30].

2-Mass Stopping Power of the Electrons

The electron loses their energy by ionization and excitation of 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 [31]:

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

Where,

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

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

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

$$F^-(\tau) = 1 - \beta^2 + \frac{1}{(\tau+1)^2}\left[\frac{\tau^2}{8} - (2\tau+1)Ln2\right] \quad \text{is used for electrons} \ldots.(2)$$

and

$$F^+(\tau) = 2Ln2 - \frac{\beta^2}{12}\left[23 + \frac{14}{(\tau+2)} + \frac{10}{(\tau+2)^2} + \frac{4}{(\tau+2)^3}\right] \quad \text{for positrons} \ldots(3)$$

where

$\frac{C}{Z}$ is for shell correction accounting for non-participation of K-shell electrons at low energies and;

δ is for the polarization or density effect correction in condensed media [31,32,33]

$$\delta(X) = \begin{cases} 4.6052X + C & X > X_1 \\ 4.6052X + a(X1 - X)^m + C & X_0 < X < X_1 \\ 0 \quad \text{for non - conducting materials} & X < X_o \\ \delta(X_o)10^{2(x-xo)} \quad \text{for conducting materials} & X < Xo. \end{cases}$$

The parameters X_o, Xi, *a*, ***m,*** and C Parameters for elements and many compounds and mixtures were published [34, 35].

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

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

Where,

$\hbar\omega_o$: is the Plasma energy $= \sqrt{4\pi N_e r_e^3}\, m_oc^2/\alpha = 28.816\sqrt{\rho\langle Z/A\rangle} \quad eV$

N_e : is the electron density (electron /cm^3)of the medium.

α : is the Fine structure constant = 1/137

ρ : is the density of the medium (g/cm^3)

2.1 Stopping Power In Compound

The mass stopping power can be well approximated for a mixture of elements or chemical compounds through the assumption of Bragg's additive Rule [36, 37].

It states "that atoms contribute nearly independently to the stopping power, and hence their effects are additive "in terms of the weight fractions w_i of elements of atomic number Z_i Present in a compound or mixture. The mass stopping power $\left(\frac{dE}{\rho dX}\right)_{mix}$ can be written according to Bragg's additive Rule as:

$$\left(\frac{dE}{\rho dX}\right)_{mix} = \sum_i w_i \left(\frac{dE}{\rho dX}\right)_{Z_i} \quad \ldots\ldots\ldots\ldots..(4)$$

Where, w_i is the fraction by weight of the ith element.

The rule can also be applied for mass collision and radiative stopping power as well, and the mean excitation energy for compound or mixture can also be calculated using the same rule by the following relation [38];

$$\ln I = \frac{\sum_j w_j (Z_j/A_j)\, lnI_j}{\sum_j w_j (Z_j/A_j)}$$

Where: Z_j is the atomic weight of the jth element in the compound
A_j is the atomic mass of the jth element in the compound
I_j is the excitation energy of the jth element in the compound

3. Calculation of Energy Loss of Electrons

Following the ESTAR program [39] which is a PC package used for calculating stopping power and ranges of electrons in any element and the results of about (180) compounds and mixture were published. In the present study we use two methods to calculate the energy loss of electrons in the energy range of electrons from 10 keV up to 1000 MeV for tissues and water. The first one is by calculating the energy loss of electrons in the tissue as one compound using equation (1).The results are compared with published results and given in Table(1).

The second method is by calculating the collision energy loss of electrons for each element of the compositions of bone, soft-tissue and water using Eq. (1), where the tissue was considered to be made up of thin layers of pure elements. The composition of tissue (soft), bone (compact) and water (liquid) are given in Table (2).Accordingly we calculate the stopping power in H, C, N, O, Na, Mg, P, S, Cl, K, Ca, Fe and Zn, which are the elemental compositions of the tissues and water using Eq.(1). The excitation energy and the density effect parameters used in this study were taken from NIST program .[39].The results are compared with the standard and presented in Table (3) and Table (4), and then using Eq. (4) to calculate the collision energy loss in the tissues and water.

The present results of the mass stopping power (dE/ρdX) for bone, tissue (soft) and water which are calculated by this method are compared with other published results and presented in Table (5).

3.1 calculation of Z_{eff}, A_{eff} and $(Z/A)_{eff}$

In the calculation of stopping power of electrons in the tissues, the values of Z_{eff}, A_{eff} and $(Z/A)_{eff}$ have been used and can be calculated using the following formulas [40]:

$$Z_{eff} = \frac{\sum (w_i Z_i^2/A_i)}{\sum (w_i Z_i/A_i)} \;\ldots\ldots\ldots.\; (5)$$

$$A_{eff} = \frac{Z_{eff}}{(Z/A)_{eff}} \;\ldots\ldots\ldots\ldots\ldots.(6)$$

Where $(Z/A)_{eff}$ is given by:

$$(Z/A)_{eff} = \sum (w_i Z_i/A_i) \;\ldots\ldots\ldots\ldots(7)$$

4. Discussion and Conclusion

The results of the present work of stopping power are in excellent agreement with the standard results published by reference [39], where the error on the present study doesn't exceeds 0.3% as a maximum when the tissues and water was considered as one compound as shown in Table (1). The present study provides good information about the stopping power of electrons in some human substances when the electron accelerator is used in tumors and cancer therapy. The present study also provided excellent and accurate results about the stopping power of electron in 14 elements as showing in Table (3) and Table (4).

It can be noticed that from Table (5), when the second method is used to calculate the collision energy loss of electrons in bone, soft-tissue and water in which the tissue was considered to be composed of a thin layer of pure elements of the tissue′s composition, the error on the results is high and reached to about 25% in some cases, so we recommended to use the first method and treating the tissue as one compound instead of composed of thin layers of pure elements.

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Table (1): Comparison of the mass collision stopping power of electrons with the standard results in Bone, Tissue (soft) and Water, where all tissues was considered to be as one compound

/dEρ(g/^{2}cm.MeV)dX									
ENERGY (MeV)	**BONE**			**(soft)TISSUE**			**WATER**		
	ESTA](std)R [39	present study	%ERROR	ESTAR [39](std)	present study	ERROR %	)ESTAR [39](std	present study	%ERROR
0.010	20.680	20.671	0.043	22.570	22.511	0.264	22.560	22.509	0.224
0.020	12.130	12.134	0.032-	13.170	13.137	0.249	13.170	13.148	0.170
0.040	7.191	7.192	0.008-	7.767	7.751	0.202	7.777	7.763	0.186
0.060	5.370	5.371	0.016-	5.787	5.776	0.185	5.797	5.787	0.181
0.080	4.412	4.413	0.032-	4.749	4.740	0.191	4.757	4.749	0.162
0.100	3.820	3.821	0.031-	4.107	4.100	0.176	4.115	4.108	0.158
0.200	2.599	2.600	0.037-	2.786	2.782	0.155	2.793	2.789	0.153
0.400	1.996	1.997	0.026-	2.142	2.139	0.158	2.148	2.145	0.147
0.600	1.815	1.816	0.033-	1.955	1.952	0.146	1.963	1.961	0.117
0.800	1.740	1.741	0.053-	1.876	1.873	0.146	1.886	1.883	0.147
1.000	1.705	1.706	0.071-	1.839	1.836	0.164	1.849	1.847	0.124
2.000	1.684	1.685	0.088-	1.812	1.810	0.123	1.824	1.821	0.141
4.000	1.735	1.736	0.077-	1.859	1.857	0.116	1.870	1.868	0.102
6.000	1.778	1.779	0.063-	1.901	1.898	0.144	1.911	1.909	0.102
8.000	1.810	1.811	0.074-	1.932	1.930	0.102	1.943	1.941	0.122
10.000	1.835	1.836	0.074-	1.958	1.955	0.139	1.968	1.966	0.112
20.000	1.909	1.911	0.084-	2.035	2.032	0.139	2.046	2.044	0.118
40.000	1.976	1.977	0.054-	2.105	2.102	0.131	2.118	2.116	0.117
60.000	2.012	2.013	0.069-	2.142	2.140	0.100	2.156	2.154	0.093
80.000	2.037	2.038	0.068-	2.168	2.166	0.110	2.182	2.180	0.083
100.000	2.056	2.058	0.077-	2.188	2.185	0.127	2.202	2.200	0.090
200.000	2.114	2.116	0.084-	2.247	2.245	0.091	2.263	2.260	0.118
400.000	2.171	2.173	0.091-	2.306	2.304	0.087	2.322	2.320	0.091
600.000	2.204	2.206	0.102-	2.341	2.339	0.098	2.357	2.354	0.117
800.000	2.228	2.230	0.096-	2.365	2.363	0.099	2.381	2.379	0.075
1000.000	2.246	2.248	0.090-	2.384	2.382	0.082	2.400	2.398	0.088

Table (2): Composition of Tissues (Soft) ICRP [41] **, Bone** (Compact) ICRU**[36]** and **Water** (Liquid) **[39]**

[41] :(ICRP)SOFT ,composition of TISSUE **00+E1.00000 =(3cm/g)Density** **72.300000 =(eV)Mean Excitation potential**					**(ICRU)COMPACT ,Composition of BONE** **[36]** **00+E1.85000= (3cm/g)Density** **= (eV)Mean Excitation potential**				**:[39] LIQUID ,Composition of WATER** **00+E1.00000= (3cm/g)Density** **75.0000= (eV)Mean Excitation potential**			
.No	**Element**	**Densityρ (3cm/gm)**	**Fraction by weight**	**Mean ionization potentia (eV)I)l**	**mentEle**	**Densityρ (3cm/gm)**	**Fraction by weight**	**Mean ionization potential (eV)I)**	**Element**	**Densityρ (3cm/gm)**	**Fraction by weight**	**Mean ionization potential (eV)I)**
1	H	3-10×0.0899	0.104472	19.2	H	10×0.0899 3-	0.063984	19.2	H	3-10×0.0899	0.111894	19.2
2	C	2.26	0.232190	81	C	2.26	0.278000	81	O	3-10×1.429	0.888106	95
3	N	3-10×1.25	0.024880	82	N	3-10×1.25	0.027000	82				
4	O	3-10×1.429	0.630238	95	O	3-10×1.429	0.410016	95				
5	Na	0.97	0.001130	149	Mg	1.74	0.002000	156				
6	Mg	1.74	0.000130	156	P	1.82	0.070000	173				
7	P	1.82	0.001330	173	S	2.07	0.002000	180				
8	S	2.07	0.001990	180	Ca	1.55	0.147000	191				
9	Cl	3.21	0.001340	174								
10	K	1.78	0.001990	190								
11	Ca	1.55	0.000230	191								
12	Fe	7.87	0.000050	286								
13	Zn	7.13	0.000030	330								

Table (3): Values of mass collision stopping power (MeV.cm^2/g) for electrons in pure elements of the tissues composition

Elements	**H**		**C**		**N**		**O**		**Na**		**Mg**		**P**	
Energy (MeV)	*/dEρdX*		*/dEρdX*		*/dEρdX*		*/dEρdX*		*/dEρdX*		*/dEρdX*		*/dEρdX*	
	.dst	.calc	.std	.calc	.std	.calc	.std	.calc	.std	.calc	.std	.calc	.std	.calc
0.010	51.24	51.22	19.99	19.93	19.95	19.90	19.37	19.33	16.79	16.77	17.15	17.12	16.41	16.39
0.020	29.16	29.15	11.69	11.66	11.68	11.65	11.38	11.35	9.99	9.98	10.22	10.20	9.81	9.80
0.040	16.87	16.86	6.91	6.89	6.90	6.89	6.75	6.73	5.98	5.97	6.12	6.11	5.89	5.89
0.060	12.45	12.44	5.15	5.14	5.15	5.14	5.04	5.03	4.49	4.48	4.60	4.59	4.43	4.42
0.080	10.15	10.14	4.23	4.22	4.23	4.22	4.14	4.13	3.70	3.70	3.79	3.78	3.65	3.65
0.100	8.74	8.73	3.65	3.65	3.66	3.65	3.59	3.58	3.21	3.21	3.29	3.28	3.17	3.17
0.200	5.85	5.85	2.47	2.47	2.49	2.48	2.44	2.44	2.20	2.19	2.25	2.25	2.17	2.17
0.400	4.45	4.44	1.89	1.88	1.91	1.91	1.88	1.88	1.70	1.70	1.74	1.74	1.68	1.68
0.600	4.04	4.04	1.71	1.71	1.75	1.75	1.73	1.72	1.56	1.56	1.60	1.59	1.54	1.54
0.800	3.88	3.88	1.64	1.64	1.69	1.69	1.67	1.67	1.51	1.51	1.54	1.54	1.48	1.48
1.000	3.82	3.81	1.61	1.61	1.67	1.67	1.65	1.64	1.49	1.49	1.52	1.52	1.46	1.46
2.000	3.82	3.82	1.59	1.59	1.69	1.69	1.67	1.67	1.51	1.51	1.53	1.53	1.47	1.47
4.000	4.02	4.02	1.64	1.64	1.80	1.80	1.78	1.78	1.58	1.58	1.60	1.60	1.54	1.54
6.000	4.18	4.17	1.68	1.68	1.88	1.88	1.86	1.86	1.63	1.63	1.65	1.65	1.59	1.59
8.000	4.30	4.29	1.71	1.71	1.94	1.94	1.92	1.92	1.66	1.66	1.68	1.68	1.63	1.62
9.000	4.35	4.34	1.72	1.72	1.97	1.96	1.94	1.94	1.67	1.67	1.69	1.69	1.64	1.64
10.000	4.39	4.39	1.74	1.73	1.99	1.99	1.97	1.96	1.68	1.68	1.70	1.70	1.65	1.65
20.000	4.70	4.70	1.80	1.80	2.14	2.14	2.12	2.12	1.76	1.75	1.77	1.77	1.72	1.72
40.000	5.01	5.01	1.87	1.86	2.29	2.29	2.27	2.27	1.82	1.82	1.84	1.84	1.79	1.79
60.000	5.14	5.14	1.90	1.90	2.36	2.35	2.34	2.34	1.86	1.86	1.88	1.88	1.83	1.82
80.000	5.21	5.21	1.92	1.92	2.40	2.39	2.38	2.38	1.89	1.89	1.90	1.90	1.85	1.85
100.000	5.26	5.26	1.94	1.94	2.42	2.42	2.41	2.41	1.91	1.91	1.92	1.92	1.87	1.87
200.000	5.38	5.38	1.99	1.99	2.51	2.51	2.49	2.49	1.96	1.96	1.98	1.98	1.92	1.92
400.000	5.49	5.49	2.05	2.04	2.59	2.59	2.57	2.57	2.01	2.01	2.03	2.03	1.98	1.98
600.000	5.55	5.55	2.08	2.07	2.63	2.63	2.62	2.61	2.04	2.04	2.06	2.06	2.01	2.01
800.000	5.60	5.60	2.10	2.10	2.66	2.66	2.65	2.64	2.07	2.06	2.09	2.08	2.03	2.03
1000.000	5.63	5.63	2.12	2.11	2.68	2.68	2.67	2.67	2.08	2.08	2.10	2.10	2.05	2.04

Table (4): Values of mass collision stopping power (MeV.cm^2/g) for electrons in pure elements of the tissues composition

Elements	**P**		**S**		**Cl**		**K**		**Ca**		**Fe**		**Zn**	
Energy (MeV)	*/dEρdX*		*/dEρdX*		*/dEρdX*		*/dEρdX*		*/dEρdX*		*/dEρdX*		*/dEρdX*	
	.Std	.cal	.Std	.cal	.Std	.cal	.Std	.cal	.Std	.cal	.Std	.cal	.Std	.cal
0.010	16.41	16.389	16.75	16.73	16.23	16.21	16.10	16.08	16.51	16.50	13.88	13.87	13.15	13.14
0.020	9.81	9.798	10.03	10.01	9.70	9.69	9.66	9.65	9.91	9.89	8.46	8.45	8.06	8.06
0.040	5.894	5.887	6.029	6.02	5.83	5.83	5.82	5.81	5.97	5.96	5.15	5.14	4.93	4.93
0.060	4.429	4.425	4.533	4.53	4.39	4.38	4.38	4.37	4.49	4.49	3.89	3.89	3.74	3.74
0.080	3.654	3.650	3.741	3.74	3.62	3.62	3.61	3.61	3.71	3.70	3.22	3.22	3.10	3.10
0.100	3.172	3.169	3.248	3.24	3.14	3.14	3.14	3.14	3.22	3.22	2.80	2.80	2.70	2.70
0.200	2.171	2.169	2.224	2.22	2.16	2.15	2.16	2.15	2.21	2.21	1.93	1.93	1.87	1.87
0.400	1.677	1.676	1.719	1.72	1.68	1.67	1.67	1.67	1.71	1.71	1.50	1.50	1.45	1.45
0.600	1.537	1.535	1.574	1.57	1.54	1.54	1.54	1.54	1.58	1.57	1.37	1.37	1.33	1.33
0.800	1.483	1.481	1.519	1.52	1.49	1.49	1.49	1.49	1.52	1.52	1.33	1.33	1.29	1.29
1.000	1.461	1.460	1.496	1.49	1.48	1.48	1.47	1.47	1.50	1.50	1.31	1.31	1.27	1.27
2.000	1.47	1.469	1.505	1.50	1.51	1.51	1.49	1.49	1.51	1.51	1.32	1.32	1.28	1.28
4.000	1.541	1.540	1.579	1.58	1.61	1.61	1.56	1.56	1.59	1.58	1.38	1.38	1.35	1.34
6.000	1.591	1.590	1.633	1.63	1.69	1.69	1.62	1.61	1.64	1.64	1.42	1.42	1.39	1.39
8.000	1.625	1.624	1.67	1.67	1.75	1.75	1.66	1.65	1.68	1.67	1.46	1.46	1.42	1.42
10.000	1.651	1.649	1.698	1.70	1.80	1.80	1.69	1.69	1.71	1.70	1.48	1.48	1.45	1.45
20.000	1.723	1.722	1.776	1.77	1.95	1.94	1.78	1.78	1.79	1.79	1.56	1.56	1.53	1.53
40.000	1.789	1.788	1.846	1.84	2.08	2.08	1.85	1.85	1.86	1.86	1.63	1.63	1.60	1.60
60.000	1.826	1.825	1.884	1.88	2.14	2.15	1.89	1.89	1.90	1.90	1.66	1.66	1.64	1.64
80.000	1.851	1.850	1.91	1.91	2.19	2.20	1.92	1.92	1.93	1.93	1.69	1.69	1.67	1.66
100.000	1.869	1.868	1.93	1.93	2.23	2.23	1.94	1.94	1.95	1.95	1.71	1.70	1.68	1.68
200.000	1.924	1.923	1.987	1.99	2.33	2.34	2.00	2.00	2.01	2.00	1.76	1.76	1.74	1.74
400.000	1.977	1.976	2.042	2.04	2.41	2.42	2.05	2.05	2.06	2.06	1.81	1.81	1.79	1.79
600.000	2.008	2.006	2.073	2.07	2.45	2.46	2.08	2.08	2.09	2.09	1.84	1.84	1.82	1.82
800.000	2.029	2.028	2.096	2.09	2.47	2.49	2.11	2.10	2.12	2.11	1.86	1.86	1.84	1.84
1000.000	2.046	2.044	2.113	2.11	2.50	2.51	2.12	2.12	2.13	2.13	1.88	1.88	1.86	1.86

Table (5): Comparison of the mass stopping power of electrons in bone, tissue (soft) and water, where the tissue was considered to be made up of thin layers of pure elements with the standard resu

/dEρ(g/^{2}cm.MeV)dX									
ENERGY (MeV)	**BONE**			**(soft)TISSUE**			**WATER**		
	)ESTAR [39](std	present study	%ERROR	ESTAR 39](std) [	resentp study	ERROR %	ESTA](std)R [39	present study	ERROR %
0.010	20.680	20.943	1.273-	22.570	22.790	0.974-	22.560	22.895	1.485-
0.020	12.130	12.273	1.181-	13.170	13.280	0.837-	13.170	13.346	1.336-
0.040	7.191	7.264	1.016-	7.767	7.826	0.760-	7.777	7.867	1.161-
0.060	5.370	5.421	0.945-	5.787	5.828	0.709-	5.797	5.860	1.088-
0.080	4.412	4.452	0.901-	4.749	4.780	0.654-	4.757	4.807	1.058-
0.100	3.820	3.852	0.849-	4.107	4.133	0.630-	4.115	4.157	1.026-
0.200	2.599	2.616	0.642-	2.786	2.800	0.495-	2.793	2.819	0.932-
0.400	1.996	2.009	0.636-	2.142	2.147	0.244-	2.148	2.166	0.848-
0.600	1.815	1.835	1.124-	1.955	1.961	0.332-	1.963	1.982	0.991-
0.800	1.740	1.768	1.621-	1.876	1.890	0.740-	1.886	1.913	1.443-
1.000	1.705	1.741	2.086-	1.839	1.861	1.188-	1.849	1.887	2.033-
2.000	1.684	1.749	3.851-	1.812	1.874	3.400-	1.824	1.910	4.701-
4.000	1.735	1.838	5.915-	1.859	1.976	6.289-	1.870	2.026	8.353-
6.000	1.778	1.906	7.190-	1.901	2.055	8.088-	1.911	2.115	10.660-
8.000	1.810	1.957	8.133-	1.932	2.115	9.455-	1.943	2.182	12.306-
10.000	1.835	1.998	8.865-	1.958	2.162	10.439-	1.968	2.236	13.618-
20.000	1.909	2.123	11.197-	2.035	2.313	13.671-	2.046	2.408	17.712-
40.000	1.976	2.240	13.384-	2.105	2.458	16.787-	2.118	2.576	21.630-
60.000	2.012	2.296	14.104-	2.142	2.524	17.833-	2.156	2.650	22.930-
80.000	2.037	2.330	14.397-	2.168	2.564	18.249-	2.182	2.695	23.492-
100.000	2.056	2.355	14.559-	2.188	2.592	18.466-	2.202	2.726	23.797-
200.000	2.114	2.428	14.858-	2.247	2.673	18.975-	2.263	2.815	24.390-
400.000	2.171	2.497	15.006-	2.306	2.750	19.236-	2.322	2.898	24.785-
600.000	2.204	2.535	15.039-	2.341	2.792	19.274-	2.357	2.943	24.875-
800.000	2.228	2.562	14.989-	2.365	2.821	19.288-	2.381	2.974	24.915-
1000.000	2.246	2.582	14.972-	2.384	2.843	19.257-	2.400	2.997	24.884-