Tikrit Journal of Pure Science Vol. 29 (3) 2024

TJPS

https://doi.org/10.25130/tjps.v29i3.1593

IASJ
المجلات الاكاديمية العراقية

Tikrit Journal of Pure Science
ISSN: 1813 – 1662 (Print) --- E-ISSN: 2415 – 1726 (Online)

Journal Homepage: http://tjps.tu.edu.iq/index.php/j

Theoretical Study to Calculate the Radiation Stopping Power for Electrons in Human Tissues

Musaab Imad Mohammed Noman

General Directorate of Education of Salah Uddin, Salah Uddin, Iraq

ARTICLE INFO.

Article history:

-Received: 12 / 12 / 2023
-Received in revised form: 27/ 12 / 2023
-Accepted: 3 / 1 / 2024
-Final Proofreading: 7 / 2 / 2024
-Available online: 25 / 6 / 2024

Keywords: Radiation Stopping Power، Human Tissues، Berger-Seltzer، Approximate Function، Data Fitting.

Corresponding Author:
Name: Musaab Imad Mohammed Noman
E-mail: : musaab.imad@gmail.com
Tel:

ABSTRACT

In this research, the radiation stopping power of electrons in some human tissues (adipose tissues, blood, bone compact, bone cortical, brain, eye lens, lung, skin, and testicles) was studied within the energy range from (10 MeV) to (1000 MeV). The study of the energy loss of charged particles through matter is of great importance in medical physics in general and radiotherapy in particular in order to determine the radiation dose in the case of medical tests or treatment and the effect of this dose in the cells adjacent to the target cells and possible damage to the tissues adjacent to the affected tissues. Calculations have been performed using the modified Berger-Seltzer equation (where a new formula was found to calculate the approximate function as a function of the energy of the incident electron using the data matching method and using the Curve Expert program). The radiation stopping power of each of the components of the tissue was found separately, and then the stopping power of the tissue was found using the Bragg rule for compounds. All calculations were performed using the MATLAB program. Comparing the results obtained with the value of the universal code E-Star, it was found that they matched well and that the error rate was less than (1 %).

دراسة نظرية لحساب قدرة الإيقاف الاشعاعية للإلكترونات في النسيج البشري

مصعب عماد محمد نعمان

المديرية العامة لتربية صلاح الدين، تكريت ، العراق

الملخص

في هذا البحث تم دراسة قدرة الإيقاف الاشعاعية للإلكترونات في بعض الانسجة البشرية (الانسجة الدهنية والدم والعظم المضغوط وقشرة العظم والدماغ وعدسة العين والرئة والجلد والخصيتين) ضمن مدى الطاقة (من 10 الى 1000 ميكا الكترون فولط). ان دراسة فقدان الجسيمات المشحونة لطاقتها خلال المادة له أهمية كبيرة في الفيزياء الطبية بشكل عام والعلاج الاشعاعي بشكل خاص وذلك لتحديد الجرعة الاشعاعية في حالة الفحص الطبي أو العلاج وتأثير هذه الجرعة في الخلايا المجاورة للخلايا المستهدفة والاضرار المحتملة على الأنسجة المجاورة للأنسجة المصابة. تم اجراء الحسابات باستعمال معادلة بيرغر–سيلتزر المعدلة (حيث تم إيجاد صيغة جديدة لحساب الدالة التقريبية كدالة لطاقة الالكترون الساقط باستعمال طريقة موائمة البيانات Data Fitting وباستخدام برنامج Curve Expert). تم ايجاد قدرة الايقاف الاشعاعية لكل عنصر من العناصر المكونة

https://doi.org/10.25130/tjps.v29i3.1593

للنسيج على حده ومن ثم ايجاد قدرة الايقاف للنسيج باستخدام قاعدة براك للمركبات. تم اجراء جميع الحسابات باستعمال برنامج الـ MATLAB. وبمقارنة النتائج المتحصلة مع قيمة الكود العالمي E-Star وجد بانها متطابقة بشكل جيد وان نسبة الخطأ كانت اقل من (1 %).

1. Introduction

The stopping power is the rate of losses energy of a charged particle within a material, the lost amount of incident particle energy increases as the particle penetrates further into the target material. The stopping power depends on the specific ionization coefficient and the average energy required to form an electron – ion pair. Since the specific ionization coefficient depends on the energy of the particle and its type, and the average energy required to form the pair depends on the type of target material, so the stopping power will depend on the type of incident particle, its energy and the type of the target material [1,2]. When the energy of the incident electrons is small ($E < 0.5$ MeV), these electrons will lose their energy by exciting the orbital electrons of the atoms of the target material or ionizing these atoms, and since the mass of the electron is small, its speed will be large, which means that the electron's existence time near a certain atom of the target material will be extremely small, which leads to a decrease in the coefficient of qualitative ionization. According to the laws of conservation of energy and momentum, when an incident electron interferes with the orbital electrons of the target material, a large amount of energy will be transferred from the incident electron to the orbital electron of the target material, up to half the energy of the incident electron. Therefore, the probability of the transference a large amount of energy will be great, also the collision between the incident electron and the electrons and the nucleus of the target material may lead to a deviation in the path of the incident electron, so the path of the electron inside the material will be broken line. Therefore, when the energy of the incident electron increases, the energy loss will occur by means of inelastic collisions (excitation and ionization of the atoms of the target material) in addition to the release of electromagnetic radiation known as stopping radiation, which plays the main role in the loss of energy of the incident electrons at high energies [1-4]. This study aims to calculate the radiation stopping power using a new formula to calculate the approximate function used in the Berger-seltzer equation in order to obtain the lowest possible error ratio.

1.1 Radiation Stopping Power

The rate of energy lost per distance unit from the electron's path is represented by the release of electromagnetic radiation as a result of nuclear stopping, and when an electric charge is exposed to acceleration or deceleration, it radiates energy in the form of electromagnetic waves, and so when a charged particle passes by the nucleus in the atom, it releases electromagnetic radiation as a result of the acceleration exposed to the particle [5,6]. The amount of energy lost by a charged particle in the form of radiation is inversely proportional to the square of its mass, so alpha particles and the proton that have a certain energy will produce one in a million of the rays produced by an electron that has the same energy, and because of the high dependence of the energy lost by radiation on speed, decelerating rays are ignored for all charged particles within the usual energy limits, except electrons, because when an electron passes close to the nucleus, the high gravitational force to which it is exposed causes it to deviate from its original path and causes orbital acceleration, thus, the electron releases its energy in the form of electromagnetic radiation at a rate proportional to the acceleration square, and the direction of the radiation is often forward in the direction of the electron's path [7,8]. As for the energies of the emitted photons rays, they range from the lowest possible value to the highest value that they can get, which is equal to the kinetic energy of the electron. According to the laws of electromagnetism, when a charged particle is accelerated, this particle emits electromagnetic rays whose intensity is proportional to the acceleration square, and when an electron passes near a nucleus that its charge is q, its path deviates, and this deviation represents the acceleration, and this acceleration results in electromagnetic rays known as stopping radiation and leads the electron to lose part of its energy. The radiation processes are clearly obvious in the elastic scattering of charged particles in the nuclear coulomb field [9].

2. Methods of Calculations

2.1. Radiation Stopping Power in Elements

The scientist Berger-Seltzer proposed a precise experimental equation to calculate the radiation stopping power resulting from the double effect of electron-electron and electron-nucleus deceleration, which is given by the following equation [10]:

$$S_{Rad} = -\frac{1}{\rho}\left(\frac{dE}{dx}\right)_{Rad} = \varphi\frac{Z^2}{A}\,[\,E + m_e c^2\,]\,\Phi_{Rad}^{Total} \quad \ldots(1)$$

where ($\varphi = \alpha r_e^2 N_A = 3.49 \times 10^{-4}\ \frac{cm^2}{g}$), ($\alpha$ is the exact composition constant $= \frac{1}{137}$), (r_e is the classical electron radius $= \frac{e^2}{m_e c^2} = 2.818 \times 10^{-15}$ m), (N_A = Avogadro number $= 6.022 \times 10^{23}\ \frac{atoms}{mole}$), Z is the atomic number of the target substance, A represents the mass number of the target substance, E represents energy of the incident electron in MeV, (m_e is the rest mass of electron $= 9.11 \times 10^{-31}$ kg), (C represents the speed of light in a vacuum $= 3 \times 10^{8}$

https://doi.org/10.25130/tjps.v29i3.1593

$\frac{m}{s}$), ($m_e c^2$ = rest energy of an electron = 0.511 MeV), and Φ_{Rad}^{Total} represents the approximate function which depends on the energy of the incident electron and the atomic number of the target substance.

2.2. The Approximate Function

The scientist Berger-Seltzer proposed an equation for calculating the approximate function as a function of the energy of the incident electron E and the atomic number of the target substance Z given by the following relation [10]:

$$\Phi_{Rad}^{Total} = d_1(Z)\frac{1+[\sum_{i=1}^{4} f_i(Z)(\ln E)^i]}{1+[\sum_{i=1}^{4} h_i(Z)(\ln E)^i]} \quad \ldots(2)$$

The nine coefficients $d_1(Z)$ and $f_i(Z)$ and $h_i(Z)$ where i=1 to 4, are given in Table (1) for the constituent elements of human tissues. The coefficients were determined with a non-linear, least-squares fitting procedure (CURFIT) given by BEVINGTON [9].

Table 1: The values of the coefficients of the elements involved in the structure of Human tissues according to the Berger – Seltzer formula [10].

Elements	d1	f1	f2	f3	f4	h1	h2	h3	h4
Hydrogen	9.8520	0.4138	0.1970	0.0276	0.002	-0.0088	0.0689	0.0012	0.0007
Carbon	6.6697	0.2213	0.1462	0.006	-0.0008	-0.0765	0.0576	0.0004	-0.0002
Nitrogen	6.5870	0.2272	0.1493	0.0068	-0.0009	-0.0637	0.0570	0.0009	-0.0002
Oxygen	6.5293	0.2581	0.1603	0.0111	-0.0005	-0.0281	0.0579	0.0023	-0.0001
Sodium	6.4357	0.3042	0.1860	0.0181	-0.0001	0.0286	0.0667	0.0041	0.0002
Magnesium	6.4243	0.3386	0.1963	0.0232	0.0005	0.0669	0.0679	0.0058	0.0003
Silicon	6.4158	0.3751	0.2079	0.0291	0.0011	0.1118	0.0705	0.0077	0.0006
Phosphorus	6.4150	0.3799	0.2111	0.0297	0.0011	0.1192	0.0724	0.0077	0.0006
Sulfur	6.4185	0.3891	0.2147	0.0314	0.0013	0.1318	0.0738	0.0083	0.0007
Chlorine	6.4232	0.3924	0.2171	0.0319	0.0013	0.1382	0.0755	0.00833	0.0007
Potassium	6.4390	0.3988	0.2213	0.0331	0.0014	0.1508	0.0785	0.0086	0.0008
Calcium	6.4495	0.4011	0.2229	0.0337	0.0019	0.1562	0.0799	0.0087	0.0008
The Iron	6.5278	0.4021	0.2279	0.0366	0.0018	0.1759	0.0870	0.001	0.001
Zinc	6.5917	0.3966	0.2283	0.0378	0.0019	0.1824	0.0913	0.0106	0.0011

2.3 New Formula to Calculate the Approximate Function

In this research, using the data fitting method, a new formula was found to calculate the approximation function. A Curve Expert program was used in finding this new formula. This program simulates the practical results and creates mathematical formulas to calculate these results. The best formula was chosen that achieves the lowest error rate when comparing the obtained results with the results obtained from Berger-Seltzer formula. The formula is as follows:

$$\Phi_{Rad}^{Total} = \frac{a}{1 + (\frac{E}{b})^c} \quad \ldots.(3)$$

This formula depends on the energy of the incident electron only and on three coefficients (a), (b), and (c) shown in Table (2).

Table 2: The values of the coefficients included in the calculation of the new formula of the approximate function.

Elements	a	b	c	Elements	a	b	C
Hydrogen	45.69667	8.35780	-0.59994	**Phosphorus**	18.78248	3.41013	-0.59637
Carbon	22.44984	4.62979	-0.60808	**Sulfur**	18.61664	3.34446	-0.59803
Nitrogen	21.67315	4.41040	-0.60810	**Chlorine**	18.46952	3.28642	-0.59255
Oxygen	20.99692	4.18067	-0.60903	**Potassium**	18.23024	3.19053	-0.58727
Sodium	19.60054	3.65756	-0.60723	**Calcium**	18.14460	3.15555	-0.58326
Magnesium	19.34757	3.58675	-0.60459	**The Iron**	17.45012	2.81156	-0.57700
Silicon	18.94964	3.46626	-0.59941	**Zinc**	17.01260	2.58362	-0.57070

2.4. Radiation Stopping Power in Compounds

When calculating the radiation stopping power of a compound, it is treated as consisting of thin layers of pure elements included in the composition of that compound, and the energy of chemical bonds between its constituent elements is ignored [11]. Therefore, the radiation stopping power of the compound is equal to the sum of the stopping power of each element separately, taking into account the percentage of participation of each element in the compound and according to the Bragg rule, that is, the radiation stopping power in the compound is written as follows [12]:

$$\left(\frac{dE}{dx}\right)_{comp} = \left(\frac{N_1}{N_O}\right)_1 \left(\frac{dE}{dx}\right)_1 + \left(\frac{N_2}{N_O}\right)_2 \left(\frac{dE}{dx}\right)_2 \quad \ldots(4)$$

Or in the following form:

$$\left(\frac{dE}{dx}\right)_{comp} = \sum_i w_i \left(\frac{dE}{dx}\right)_i \quad \ldots(5)$$

Since $\left(\frac{dE}{dx}\right)_{comp}$ is the stopping power of the compound $\left(\frac{dE}{dx}\right)_1$, $\left(\frac{dE}{dx}\right)_2$ which is the stopping power of the first and the second substance forming this compound, and N_0 is the total number of atoms of the compound per cm^3 and N_1 and N_2 the number of atoms of the first and second substance per cm^3 and w_i is the weight percentage of each element in

https://doi.org/10.25130/tjps.v29i3.1593

the compound, was is calculated by the law of weight percentage ratios of elements included in chemical compounds, which equals the molar mass of the element multiply the atoms number of the element division on the molar mass of the compound [13]. Human tissues consist of the following elements: hydrogen, carbon, nitrogen, oxygen, sodium, magnesium, silicon, phosphorus, sulfur, chlorine, potassium, calcium, iron and zinc, each element has a specific weight percentage in each tissue, which is shown in Table (3).

Table 3: Weight percentages of elements included in the composition of human tissues [14].

Elements	Adipose Tissue	Blood	Dense Bone	Thin Bone	Brain	Eye Lens	Lung	Skin	Testicles
Hydrogen	11.948	10.187	6.398	4.723	11.067	9.927	10.128	10.059	10.417
Carbon	63.724	10.002	27.8	14.433	12.542	19.371	10.231	22.825	9.227
Nitrogen	0.797	2.964	2.7	4.199	1.328	5.327	2.865	4.642	1.994
Oxygen	23.233	75.941	41.002	44.61	73.772	65.375	75.707	61.9	77.388
Sodium	0.05	0.185	0	0	0.184	0	0.184	0.007	0.226
Magnesium	0.002	0.004	0.2	0.22	0.015	0	0.073	0.006	0.011
Silicon	0	0.003	0	0	0	0	0	0	0
Phosphorus	0.016	0.035	7	10.497	0.354	0	0.08	0.033	0.125
Sulfur	0.073	0.185	0.2	0.315	0.177	0	0.225	0.159	0.146
Chlorine	0.119	0.278	0	0	0.236	0	0.266	0.267	0.244
Potassium	0.032	0.163	0	0	0.31	0	0.194	0.085	0.208
Calcium	0.002	0.006	14.7	20.993	0.009	0	0.009	0.015	0.01
The Iron	0.002	0.046	0	0	0.005	0	0.037	0.001	0.002
Zinc	0.002	0.001	0	0.01	0.001	0	0.001	0.001	0.002

3. Results and discussion

A new formula was used to calculate the approximate function, and although the method of finding the new formula is the same as the method of finding the formula used in the Berger-Seltzer equation, which is data fitting, the new formula is characterized by simplicity and its dependence on the energy of the incident electron only, while the Berger-Seltzer formula depends on the energy of the incident electron and the atomic number of the target material. When comparing the values obtained from the two formulas, it is found out that the error rate is less than (0.7 %) as shown in Table (4). This may indicate that the approximate function depends on the energy of the incident electron only, or that the effect of the atomic number is small.

Table 4: The error rate of the approximate function of the new formula compared to the formula used by Berger-Seltzer.

Element	10 MeV	50 MeV	100 MeV	300 MeV	500 MeV	700 MeV	900 MeV	1000 MeV
Hydrogen	0.69%	0.03%	0.32%	0.24%	0.03%	0.14%	0.27%	0.33%
Carbon	0.07%	0.16%	0.02%	0.07%	0.05%	0.04%	0.03%	0.03%
Nitrogen	0.10%	0.17%	0.04%	0.05%	0.05%	0.05%	0.05%	0.05%
Oxygen	0.13%	0.18%	0.07%	0.03%	0.05%	0.07%	0.08%	0.09%
Sodium	0.09%	0.16%	0.07%	0.02%	0.04%	0.07%	0.10%	0.11%
Magnesium	0.12%	0.17%	0.09%	0.01%	0.05%	0.08%	0.11%	0.13%
Silicon	0.16%	0.19%	0.11%	0.00%	0.05%	0.09%	0.13%	0.14%
Phosphorus	0.16%	0.19%	0.12%	0.00%	0.05%	0.10%	0.14%	0.15%
Sulfur	0.29%	0.05%	0.01%	0.09%	0.13%	0.17%	0.20%	0.22%
Chlorine	0.18%	0.19%	0.13%	0.01%	0.05%	0.10%	0.15%	0.17%
Potassium	0.18%	0.20%	0.14%	0.01%	0.05%	0.11%	0.16%	0.18%
Calcium	0.14%	0.25%	0.18%	0.05%	0.03%	0.08%	0.13%	0.16%
The Iron	0.23%	0.23%	0.17%	0.02%	0.06%	0.13%	0.19%	0.21%
Zinc	0.19%	0.32%	0.25%	0.06%	0.04%	0.12%	0.18%	0.21%

The radiation stopping power of electrons in human tissues (adipose tissues, blood, bone compact, bone cortical, brain, eye lens, lung, skin, and testicles) was calculated in the energy range from (10 MeV) to (1000 MeV). This was done by calculating the radiation stopping power of the elements composing these tissues (hydrogen, carbon, nitrogen, oxygen, sodium, magnesium, silicon, phosphorus, sulfur, chlorine, potassium, calcium, iron and zinc) by using Berger-Seltzer equation, and then the Bragg rule for compounds was applied to calculate the radiation stopping power of tissues, where the radiation stopping power of these elements was collected after multiplying them by their percentage of participation in each tissue to find the radiation stopping power for each tissue separately.

From Tables (5) and (6), we notice that the values of the radiation stopping power increase with the increase in the energy of the incident electrons, and this indicates their ability to penetrate the coulombic

https://doi.org/10.25130/tjps.v29i3.1593

potential barrier, and it is submitted to the strong nuclear interaction. When the incident electrons approach the nucleus, a change occurs in the speed of the electron, and since speed is a directional quantity that includes departure and direction, any change in its direction due to its deviation from the nucleus will be accompanied by a change in speed. When the electron passes near the coulombic field of the nucleus of the target atom, the latter will be exposed to a formidable attractive force that results in it drifting sharply from its original path. This change in direction represents acceleration, and this behaviour of the electron is completely consistent with Maxwell's theory, which states that the loss of electromagnetic radiation of a charged particle is at a rate proportional to the square of the acceleration, as the production of slow down radiation increases with the increase in the energy of the incident electron [15]. By comparing the values of the lost radiation energy of the elements, we find that the radiation stopping power of the electrons increases with the increase in the atomic number of the elements. The explanation for this is that by increasing the atomic number, the coulombic effect increases and the amount of acceleration acquired increases.

Tables (5) and (6) show the calculated results for the radiation stopping power when using the new formula for the approximate function.

Table 5: The radiation stopping power of the elements (Hydrogen, Carbon, Nitrogen, Oxygen, Sodium, Magnesium, and Silicon) using the modified Berger – Seltzer equation.

Electron Energy (MeV)	Hydrogen (MeV cm^2 g^{-1})	Carbon (MeV cm^2 g^{-1})	Nitrogen (MeV cm^2 g^{-1})	Oxygen (MeV cm^2 g^{-1})	Sodium (MeV cm^2 g^{-1})	Magnesium (MeV cm^2 g^{-1})	Silicon (MeV cm^2 g^{-1})
10.0	0.088	0.152	0.173	0.194	0.245	0.274	0.317
20.0	0.204	0.342	0.388	0.434	0.545	0.606	0.702
30.0	0.330	0.543	0.616	0.688	0.859	0.956	1.105
40.0	0.461	0.750	0.850	0.948	1.182	1.315	1.520
50.0	0.596	0.961	1.088	1.213	1.511	1.680	1.940
60.0	0.733	1.174	1.330	1.482	1.842	2.049	2.365
70.0	0.872	1.390	1.573	1.753	2.177	2.420	2.794
80.0	1.013	1.607	1.819	2.025	2.514	2.794	3.226
90.0	1.155	1.826	2.066	2.299	2.852	3.170	3.659
100.0	1.298	2.045	2.314	2.575	3.192	3.548	4.095
200.0	2.763	4.277	4.832	5.370	6.637	7.376	8.509
300.0	4.260	6.542	7.387	8.204	10.126	11.252	12.979
400.0	5.773	8.823	9.959	11.057	13.636	15.152	17.476
500.0	7.296	11.113	12.542	13.921	17.160	19.066	21.991
600.0	8.826	13.411	15.133	16.793	20.693	22.991	26.517
700.0	10.361	15.713	17.729	19.671	24.232	26.923	31.052
800.0	11.900	18.020	20.329	22.554	27.777	30.862	35.594
900.0	13.442	20.330	22.933	25.440	31.326	34.804	40.142
1000.0	14.987	22.642	25.540	28.329	34.878	38.751	44.694

Table 6: The radiation stopping power of the elements (Phosphorus, Sulfur, Chlorine, Potassium, Calcium, Iron, and Zinc) using the modified Berger – Seltzer equation.

Electron Energy (MeV)	Phosphorus (MeV cm^2 g^{-1})	Sulfur (MeV cm^2 g^{-1})	Chlorine (MeV cm^2 g^{-1})	Potassium (MeV cm^2 g^{-1})	Calcium (MeV cm^2 g^{-1})	The Iron (MeV cm^2 g^{-1})	Zinc (MeV cm^2 g^{-1})
10.0	0.328	0.359	0.364	0.409	0.440	0.523	0.588
20.0	0.725	0.792	0.803	0.899	0.967	1.144	1.279
30.0	1.141	1.247	1.263	1.414	1.520	1.793	2.001
40.0	1.568	1.714	1.735	1.941	2.087	2.457	2.738
50.0	2.002	2.187	2.214	2.476	2.662	3.130	3.486
60.0	2.441	2.666	2.698	3.017	3.244	3.811	4.242
70.0	2.883	3.148	3.186	3.563	3.830	4.496	5.003
80.0	3.328	3.633	3.677	4.111	4.420	5.186	5.768
90.0	3.775	4.121	4.171	4.663	5.012	5.879	6.537
100.0	4.224	4.611	4.666	5.217	5.608	6.575	7.309
200.0	8.777	9.575	9.690	10.830	11.642	13.623	15.127
300.0	13.387	14.601	14.777	16.514	17.753	20.758	23.038
400.0	18.026	19.658	19.895	22.233	23.903	27.937	30.996
500.0	22.683	24.733	25.033	27.974	30.076	35.142	38.984
600.0	27.351	29.822	30.184	33.731	36.267	42.365	46.992
700.0	32.029	34.920	35.345	39.499	42.469	49.603	55.015
800.0	36.714	40.025	40.515	45.276	48.682	56.852	63.051
900.0	41.405	45.137	45.690	51.059	54.902	64.110	71.096
1000.0	46.100	50.254	50.871	56.849	61.129	71.374	79.149

The radiation stopping power of electrons in human tissue was compared with the values of the international code E-Star, and the largest percentage of error was about (0.36 %) for adipose tissue, (0.43

https://doi.org/10.25130/tjps.v29i3.1593

%) for blood, and (0.36 %) for compact bone, as shown in Table (7). (0.37 %) for bone cortex, (0.41 %) for brain, and (0.43 %) for eye lens, as shown in Table (8). (0.42 %) for lung, (0.39 %) for skin, and (0.41 %) for testicles, as shown in Table (9). The reason for the difference between the results calculated in this research and the E-STAR code values is the difference in the method used to calculate radiation stopping power. Radiative stopping powers are evaluated in E-STAR with a combination of theoretical bremsstrahlung cross sections described by Seltzer and Berger (1985), and analytical formulas (using a high-energy approximation derived by Bethe et al) are used above (50 MeV), and accurate numerical results of Pratt et al. (1977) below (2 MeV) [16]. While in this research, a semi-experimental equation was used, and no approximation or correction was calculated. Despite this, the error rate is small and less than (0.5 %).

Tables (7), (8) and (9) show the comparison of the calculated radiation stopping power when using Berger-Seltzer equation after compensate new formula to calculate the approximate function with the values of the universal code E-Star.

Table 7: The radiation stopping power of the studied tissues (Adipose tissue, Blood and Bone compact) and their comparison with the values of the universal code E-Star [16].

Electron Energy (MeV)	Adipose Tissue (MeV cm^2 g^{-1})			Blood (MeV cm^2 g^{-1})			Bone Compact (MeV cm^2 g^{-1})		
	This Work	E-Star	Error rate %	This Work	E-Star	Error rate %	This Work	E-Star	Error rate %
10.0	0.155	0.154	-0.36	0.180	0.179	-0.43	0.221	0.220	-0.36
20.0	0.348	0.349	0.07	0.403	0.403	0.05	0.492	0.493	0.08
30.0	0.553	0.554	0.17	0.639	0.641	0.20	0.778	0.780	0.21
40.0	0.765	0.766	0.16	0.883	0.884	0.20	1.072	1.074	0.16
50.0	0.980	0.982	0.13	1.130	1.132	0.17	1.371	1.374	0.20
60.0	1.198	1.200	0.13	1.381	1.383	0.17	1.674	1.676	0.12
70.0	1.419	1.420	0.09	1.634	1.636	0.15	1.979	1.982	0.14
80.0	1.641	1.642	0.08	1.888	1.890	0.09	2.287	2.289	0.10
90.0	1.864	1.865	0.05	2.144	2.146	0.07	2.596	2.598	0.09
100.0	2.089	2.089	0.02	2.402	2.404	0.09	2.906	2.909	0.10
200.0	4.370	4.368	-0.03	5.016	5.016	0.00	6.058	6.059	0.02
300.0	6.685	6.682	-0.04	7.667	7.665	-0.03	9.253	9.251	-0.02
400.0	9.017	9.012	-0.05	10.337	10.330	-0.07	12.469	12.460	-0.08
500.0	11.359	11.350	-0.08	13.018	13.010	-0.06	15.699	15.690	-0.06
600.0	13.709	13.700	-0.06	15.707	15.690	-0.11	18.938	18.920	-0.10
700.0	16.063	16.050	-0.08	18.402	18.380	-0.12	22.184	22.160	-0.11
800.0	18.422	18.410	-0.07	21.101	21.070	-0.15	25.435	25.400	-0.14
900.0	20.785	20.770	-0.07	23.804	23.770	-0.14	28.690	28.640	-0.18
1000.0	23.150	23.130	-0.08	26.510	26.470	-0.15	31.949	31.890	-0.19

Table 8: The radiation stopping power of the studied tissues (Bone cortical, Brain and Eye lens) and their comparison with the values of the universal code E-Star [16].

Electron Energy (MeV)	Bone Cortical (MeV cm^2 g^{-1})			Brain (MeV cm^2 g^{-1})			Eye Lens (MeV cm^2 g^{-1})		
	This Work	E-Star	Error rate %	This Work	E-Star	Error rate %	This Work	E-Star	Error rate %
10.0	0.249	0.248	-0.37	0.179	0.178	-0.41	0.174	0.174	-0.43
20.0	0.552	0.553	0.09	0.401	0.401	0.07	0.391	0.391	0.06
30.0	0.872	0.874	0.21	0.636	0.637	0.19	0.620	0.621	0.20
40.0	1.200	1.202	0.17	0.877	0.879	0.19	0.856	0.858	0.19
50.0	1.534	1.537	0.21	1.123	1.125	0.15	1.096	1.098	0.14
60.0	1.871	1.875	0.19	1.373	1.375	0.18	1.340	1.342	0.16
70.0	2.212	2.215	0.13	1.624	1.626	0.12	1.585	1.587	0.10
80.0	2.555	2.558	0.12	1.877	1.879	0.09	1.833	1.835	0.12
90.0	2.900	2.903	0.11	2.132	2.134	0.09	2.082	2.083	0.07
100.0	3.246	3.249	0.09	2.388	2.390	0.08	2.332	2.333	0.06
200.0	6.760	6.762	0.04	4.988	4.987	-0.01	4.871	4.870	-0.02
300.0	10.320	10.320	0.00	7.625	7.622	-0.04	7.447	7.444	-0.04
400.0	13.905	13.900	-0.04	10.280	10.270	-0.10	10.041	10.040	-0.01
500.0	17.504	17.490	-0.08	12.947	12.940	-0.05	12.646	12.640	-0.05
600.0	21.113	21.090	-0.11	15.621	15.610	-0.07	15.258	15.240	-0.12
700.0	24.729	24.700	-0.12	18.301	18.280	-0.11	17.877	17.860	-0.09

https://doi.org/10.25130/tjps.v29i3.1593

800.0	28.351	28.310	-0.15	20.986	20.960	-0.12	20.499	20.470	-0.14
900.0	31.978	31.920	-0.18	23.674	23.640	-0.14	23.125	23.090	-0.15
1000.0	35.609	35.530	-0.22	26.365	26.320	-0.17	25.755	25.720	-0.13

Table 9: The radiation stopping power of the studied tissues (Lung, Skin and Testicles) and their comparison with the values of the universal code E-Star [16].

Electron Energy (MeV)	Lung (MeV cm^2 g^{-1})			Skin (MeV cm^2 g^{-1})			Testicles (MeV cm^2 g^{-1})		
	This Work	E-Star	Error rate %	This Work	E-Star	Error rate %	This Work	E-Star	Error rate %
10.0	0.180	0.179	-0.42	0.174	0.173	-0.39	0.180	0.179	-0.41
20.0	0.404	0.404	0.05	0.390	0.390	0.06	0.404	0.404	0.08
30.0	0.640	0.641	0.19	0.619	0.620	0.18	0.640	0.642	0.19
40.0	0.883	0.885	0.19	0.854	0.856	0.19	0.884	0.886	0.20
50.0	1.131	1.133	0.17	1.094	1.095	0.12	1.132	1.134	0.20
60.0	1.382	1.384	0.15	1.336	1.338	0.12	1.383	1.385	0.17
70.0	1.635	1.637	0.12	1.581	1.583	0.10	1.636	1.638	0.13
80.0	1.890	1.892	0.10	1.828	1.830	0.10	1.891	1.893	0.10
90.0	2.146	2.148	0.07	2.076	2.078	0.08	2.148	2.150	0.11
100.0	2.404	2.406	0.08	2.326	2.327	0.06	2.405	2.407	0.07
200.0	5.021	5.020	-0.01	4.859	4.858	-0.02	5.023	5.023	-0.01
300.0	7.675	7.672	-0.03	7.428	7.426	-0.03	7.679	7.676	-0.04
400.0	10.347	10.340	-0.07	10.016	10.010	-0.06	10.352	10.350	-0.02
500.0	13.030	13.020	-0.08	12.615	12.610	-0.04	13.038	13.030	-0.06
600.0	15.722	15.710	-0.07	15.221	15.210	-0.07	15.730	15.720	-0.07
700.0	18.419	18.400	-0.10	17.833	17.810	-0.13	18.429	18.410	-0.10
800.0	21.121	21.090	-0.15	20.449	20.430	-0.09	21.132	21.100	-0.15
900.0	23.826	23.790	-0.15	23.069	23.040	-0.13	23.839	23.800	-0.16
1000.0	26.534	26.490	-0.17	25.692	25.650	-0.16	26.549	26.510	-0.15

4. Conclusions

The loss of the radiation energy of electrons is a probability process that is linearly proportional to the energy of the incident electron and the atomic number of the target material, as is obvious in the Berger-Seltzer equation, as the kinetic energy of the incident electron decreases, the probability of radiation of interaction decreases because electrons spend most of their time in collision interactions with the electrons of the atoms of the target material and thus consume most of their kinetic energy, which prevents their access to the nuclear field, and a small percentage of deceleration ray is emitted, so the values of the stopping power of the target material are very little. The values of the radiation stopping power increase by increasing the kinetic energy of the incident electrons and this case can be explained by the fact that electrons with low energies (slow) spend a longer period of time in their interactions with the orbital electrons of the target material and thus have the greatest probability of interacting with the orbital electrons, while we find that electrons with high energies (fast) penetrate the coulomb field of the orbital electrons without being much affected by them. This means that they have a low probability of interacting with the orbital electrons. From comparing the values of the radiation stopping power of the elements included in the structure of human tissues, we find that the radiation stopping power increases with increasing atomic number. The explanation for this is that with increasing the atomic number, the coulomb effect increases, as the acceleration gained by electrons increases. The behaviour of the incident electrons on the target material is the same whether the material is an element or a compound.

References

[1] Dunn, W.L., & Hugtenburg, R.P. (2006). The Interaction of Radiation with Matter: Charged Particle and Electron Interactions. *CERN IEEE Short Course*.

[2] Mott, J.H.L., & Daniel, J.M. (2021). Interactions of electromagnetic radiation and subatomic particles with matter–Part 2. *Clinical Oncology*, *33*(7), 455-460.

[3] McParland, B.J. *"Nuclear Medicine Radiation Dosimetry - Advanced Theoretical Principles"*, Springer-Verlag London Limited, (2010).

[4] L'Annunziata, M.F. (Ed.). (2012). *Handbook of radioactivity analysis*. Academic press.

[5] Bichsel, H. and Schindler, H. *"The Interaction of Radiation with Matter"*, Particle Physics Reference Library, Springer, Vol.2, p.p. 5-44, (2020).

[6] Habeb, S.J., & Allah, S.M.A. (2016). Estimation of the total energy loss and continuous slowing down range (CSDA) of positrons in carbon and silver. *Tikrit Journal of Pure Science*, *21*(3), 135-143.

[7] Gibbons, J.P. (2019). Khan's The Physics of Radiation Therapy. *Wolters Kluwer Health.*

https://doi.org/10.25130/tjps.v29i3.1593

[8] Podgorsak, E.B. (2016). *Radiation Physics for Medical Physicists*. Springer.
[9] Mayles, P., Nahum, A., & Rosenwald, J.C. (2021). *Handbook of radiotherapy physics: theory and practice*. Taylor & Francis Group.
[10] Seltzer, S.M., & Berger, M.J. (1982). Procedure for calculating the radiation stopping power for electrons. *The International Journal of Applied Radiation and Isotopes*, *33*(11), 1219-1226.
[11] Groom, D.E., Mokhov, N.V., & Striganov, S.I. (2001). Muon stopping power and range tables 10 MeV–100 TeV. *Atomic Data and Nuclear Data Tables*, *78*(2), 183-356.
[12] Hadi, S.M., & Saied, B.M. (2019). Stopping power and range of proton interaction with AL_2O_3, ZrO_2 and SiO_2. In *AIP Conference Proceedings* (Vol. 2201, No. 1). AIP Publishing.
[13] Tufan, M., & Gűműş, H. (2008). Stopping Power Calculations of Compounds by Using Thomas-Fermi-Dirac-Weizsäcker Density Functional. *Acta Physica Polonica A*, *114*(4), 703-711.
[14] Detwiler, R.S., McConn, R.J., Grimes, T.F., Upton, S.A., & Engel, E.J. (2021). *Compendium of material composition data for radiation transport modeling* (No. PNNL-15870 Revision 2). Pacific Northwest National Lab. (PNNL), Richland, WA (United States).
[15] Cember, H. (2009). Introduction to Health Physics: Fourth Edition. Medical Physics, 35(12), 5959.
[16] Berger, M.J., Coursey, J.S., Zucker, M.A., & Chang, J. (2017). Stopping-power and range tables for electrons, protons, and helium ions, NIST Standard Reference Database 124. *National Institute of Standards and Technology (NIST), Physical Measurement Laboratory (PML)*.