Black Sea Journal of Engineering and Science
Open Access Journal
e-ISSN: 2619-8991

BSPublishers

Araştırma Makalesi (Research Article)
Volume 1 - Issue 2: 35-40 / April 2018
(Cilt 1 - Sayı 2: 35-40 / Nisan 2018)

PREDICTING STOPPING POWER AND RANGE VALUE FOR HIGH ENERGY ELECTRONS IN THE MUSCLE AND SKIN TISSUES

Zeynep YÜKSEL[1*], M. Çağatay TUFAN[1]

[1] *OndokuzMayıs University, Faculty of Arts and Sciences, Physics Department, 55139 Samsun, Türkiye*

***Submission:** March 09, 2018; **Published:** April 01, 2018*
*(**Gönderi:** 09 Mart 2018**; Yayınlanma:** 01 Nisan 2018)*

Abstract: High-energy electron beams are used for especially for radiotherapy of localized superficial tumors. Knowing as accurately as the stopping power and range values is important in electron beam therapy. Electrons beams are preferred in surface treatments due to their characteristic feature. In this work, we have calculated stopping power and range values for incident electrons ranging from 0.1 to 900 MeV range on muscle and skin by using Thomas-Fermi electron density. The obtained data is important in terms of creating a database for such studies.

Keywords: Supported liquid membranes, Seperation, Immobilization, Stability, Transport

***Corresponding author:** OndokuzMayıs University, Faculty of Arts and Sciences, Physics Department, 55139 Samsun, Türkiye
Email: zeynep.boz@omu.edu.tr (Z. YÜKSEL)

1. Introduction

In the interaction of charged particles with matter, information about the stopping power and range values plays an important role. Stopping power is defined as the energy lost per unit path length of the incident particle in matter, and the range of incident particle is the average path length traveled by a charged particle in matter. These two quantities are required for areas such as structure and surface analysis, Monte Carlo simulation study for both nuclear and space applications, quantitative calculations of delivered doses to the tissues in radiation therapy, sensitive dosimeters to verify the therapy systems, etc. (Cleland 2009; Bagalà et al., 2013; Venanzio et al., 2013; Gallo et al., 2017; Ravichandran et al., 2016). There are many studies to calculate stopping power and range for electrons in various matters at different energy ranges. These studies have been considered oscillator strength evaluation, or evaluating the complex dielectric response function, or depending on atomic electron densities (Akar, 2005; Bragg and Klemann, 1905; Bethe, 1930; Bloch, 1933; Jablonski et al., 2006; Thomas, 1927; Yarlagadda, 1978).

High-energy electrons have been used in radiotherapy and imaging since the 1950s (Hongstrom and Almond 2006). In radiotherapy, electron beams are used as an additional therapy in the treatment of tumors up to 5 cm in depth from the surface and by photon beams. The use of electron beams in radiotherapy allows the protection of healthy tissues extending behind the volume to be irradiated by providing high surface desire (Khan, 2003).

When we look at the radiation types used in the treatment of radiation therapy, it is seen that electrons are frequently used for surface treatments. It is important to determine the effect of these electrons especially on the skin and the muscle. The aim of this paper is to obtain stopping power and range values for incident electrons energy ranging from 0.1 to 900 MeV in muscle and skin.

2. Materials and Methods

There are two different mechanism for the calculation of the stopping power: called electronic and radiative. Total stopping power is given as follows:

$$S_{tot}(E)=S_{ccll}(E)+S_{rad}(E) \quad (1)$$

The collisional stopping power for the electrons has been calculated by using the formula of the Rohrlich and Carlson (1954) modified by Sugiyama (1985). In this formulation consider the effective charge and mean excitation energy of the target, and effective charge of the incident particles. According to this, the collisional stopping power for electrons is given as;

$$S_{coll}(E)=-\frac{1}{p}\frac{dE}{dx}=\frac{4\pi e^4 z^{*2}}{m_e v^2}\frac{N_0}{A}Z_2^*\left\{\ln\left(\frac{E}{I_2^*}\right)+F^-(\tau)/2\right\} \quad (2)$$

where

$$F^-(\tau)=1-\beta^2+\left[(\tau^2/8)-(2\tau+1)\ln 2\right]/(1+\tau)^2 \quad (3)$$

$\beta=v/c$; m_e, E, N_0, A, z*, Z_2*, I_2*, τ and *p* are the electron mass, the kinetic energy of the incident particles, Avogadro's number, the atomic weight of the target, the effective charge of the incident particles, the effective charge of the target, the effective mean excitation energy of the target, the kinetic energy of the incident particles in units of electron rest mass mc^2 and is the density of the target, respectively.

In order to determine the effective charge and mean excitation energy of the target, Z_2* and I_2* the Bohr's stripping criterion (Bohr 1940; 1941) is applied. Then, the collisional stopping power was calculated with following the procedures described by Gümüş, Tufan and coworkers (Gümüş 2008; Tufan and Gümüş, 2011; Tufan et al., 2013). The effective charge of incident electrons z* is given by Sugiyama (Sugiyama 1981) as

$$z^*=1-(-2200\beta^{1.78}) \quad (4)$$

The radiative stopping power is known Bremsstrahlung which is a phenomenon in which charged particles lose their energy and radiate when they enter the media. We used Tsai's (Tsai 1974) analytical approach because radiative energy loss calculations are difficult due to Bremsstrahlung. Radiative stopping power is given as (Amsler et al., 2008):

$$S_{rad}(E)\approx E/X_0 \quad (5)$$

where X_0, which is called the radiation length of electron in matter, is given by (Tsai 1974)

$$\frac{1}{X_0}=4\alpha r_e^2\frac{N_0}{A}\left\{Z^2\left[L_{rad}-f(Z)\right]+ZL'_{rad}\right\} \quad (6)$$

where α=1/137.03599911, r_e=2.817940325 *fm*, *E* and *A* are the fine structure constant, the classical electron radius, the kinetic energy of incident particle and the atomic mass of the target, respectively; L_{rad} and L'_{rad} are given in Table 1, and

$$f(Z)=a^2\begin{bmatrix}(1+a^2)^{-1}+0.20206-0.0369a^2+\\ 0.0083a^4-0.002a^6\end{bmatrix} \quad (7)$$

with =αZ.

Table 1. Tsai's definition for L_{rad} and L'_{rad}

Element	Z	L_{rad}	L'_{rad}
H	1	5.31	6.144
He	2	4.79	5.621
Li	3	4.74	5.805
Be	4	4.71	5.924
Others	>4	ln(184.25$Z^{-1/3}$)	ln(1194$Z^{-2/3}$)

In this work, we have followed the procedure described in Refs. (Tufan 2013; 2011) for both calculation of collisional and radiative stopping power.

Range is average path length traveled by a charged particle and calculated with **C**ontinuous **S**lowing **D**own**A**pproximation (CSDA). According to the CSDA, range of an incident particle with initial kinetic energy E_0 is calculated by

$$R=\int_{E_f}^{E_0}\frac{dE'}{S_{tot}(E')} \quad (8)$$

where $S_{tot}(E')=S_{coll}(E')+S_{rad}(E')$ is the total stopping power at energy *E'* and E_f is the final energy at which particles were assumed to be stopped by the medium.

3. Results and Discussions

In this work, we calculated the stopping power and range values for incident electrons in muscle and skin. Material composition of these tissues are taken from the ICRU Report 44 (ICRU 1989) and shown in Table 2.

The results obtained for collisional, radiative and stopping power and CSDA range are given in Table 3, 4 for incident electron energies ranging from 0.10 to 900 MeV. As seen from the Tables, there is no difference between our results for skin and musclesince our calculation based on the Tietz (1956) definition of charge densities, and the material compositions of skin and muscle are almost same. The actual differences are found as 0.03% for collisional, 0.0001% for radiative, 0.007% for total stopping power and 0.04% for CSDA Range. For ESTAR's results these discrepancies are 0.18%, 3.4%, 1.02% and 0.7% for collisional, radiative and total stopping powers, and range, respectively.

Table 2. Material composition of muscle and skin

Element	Fraction by weight	
	Skin	Muscle
H	0.100588	0.100637
C	0.228250	0.107830
N	0.046420	0.027680
O	0.619002	0.754773
Na	0.000070	0.000750
Mg	0.000060	0.000190
P	0.000330	0.001800
S	0.001590	0.002410
CI	0.002670	0.000790
K	0.000850	0.003020
Ca	0.000150	0.000030
Fe	0.000010	0.000040
Zn	0.000010	0.000050

Table 3. Stopping power and CSDA range results for electrons in muscle tissue

Energy (MeV)	Collisional Stopping Power ($MeVcm^2/g$)	Radiative Stopping Power ($MeVcm^2/g$)	Total Stopping Power ($MeVcm^2/g$)	CSDA-Range (g/cm^2)
0.1000	0.36937×10^{1}	0.25642×10^{-2}	0.36963×10^{1}	0.16141×10^{-1}
0.2000	0.24974×10^{1}	0.51284×10^{-2}	0.25026×10^{1}	0.50403×10^{-1}
0.4000	0.19072×10^{1}	0.10257×10^{-1}	0.19174×10^{1}	0.14444×10^{0}
0.6000	0.17359×10^{1}	0.15385×10^{-1}	0.17513×10^{1}	0.25445×10^{0}
0.8000	0.16674×10^{1}	0.20513×10^{-1}	0.16879×10^{1}	0.37102×10^{0}
1.0000	0.16375×10^{1}	0.25642×10^{-1}	0.16631×10^{1}	0.49058×10^{0}
2.0000	0.16329×10^{1}	0.51284×10^{-1}	0.16842×10^{1}	0.10914×10^{1}
4.0000	0.17028×10^{1}	0.10257×10^{0}	0.18054×10^{1}	0.22379×10^{1}
6.0000	0.17586×10^{1}	0.15385×10^{0}	0.19124×10^{1}	0.33134×10^{1}
8.0000	0.18011×10^{1}	0.20513×10^{0}	0.20063×10^{1}	0.43339×10^{1}
10.000	0.18351×10^{1}	0.25642×10^{0}	0.20915×10^{1}	0.53099×10^{1}
20.000	0.19430×10^{1}	0.51284×10^{0}	0.24558×10^{1}	0.97058×10^{2}
40.000	0.20518×10^{1}	0.10257×10^{1}	0.30775×10^{1}	0.16949×10^{2}
60.000	0.21154×10^{1}	0.15385×10^{1}	0.36540×10^{1}	0.22902×10^{2}
80.000	0.21606×10^{1}	0.20513×10^{1}	0.42119×10^{1}	0.27994×10^{2}
100.00	0.21955×10^{1}	0.25642×10^{1}	0.47597×10^{1}	0.32458×10^{2}
200.00	0.23040×10^{1}	0.51284×10^{1}	0.74324×10^{1}	0.49115×10^{2}
400.00	0.24124×10^{1}	0.10257×10^{2}	0.12669×10^{2}	0.69470×10^{2}
600.00	0.24557×10^{1}	0.15385×10^{2}	0.17861×10^{2}	0.82699×10^{2}
800.00	0.25207×10^{1}	0.20513×10^{2}	0.23034×10^{2}	0.92532×10^{2}
900.00	0.25391×10^{1}	0.23078×10^{2}	0.25617×10^{2}	0.96647×10^{2}

Table 4. Stopping power and CSDA range results for electrons in skin tissue

Energy (MeV)	Collisional Stopping Power (MeVcm²/g)	Radiative Stopping Power (MeVcm²/g)	Total Stopping Power (MeVcm²/g)	CSDA-Range (g/cm²)
0.1000	0.36936 x10^{1}	0.25642 x10^{-2}	0.36963 x10^{1}	0.16141 x10^{-1}
0.2000	0.24974 x10^{1}	0.51284 x10^{-2}	0.25026 x10^{1}	0.50403 x10^{-1}
0.4000	0.19072 x10^{1}	0.10257 x10^{-1}	0.19174 x10^{1}	0.14444 x10^{0}
0.6000	0.17359 x10^{1}	0.15385 x10^{-1}	0.17553 x10^{1}	0.25445 x10^{0}
0.8000	0.16674 x10^{1}	0.20513 x10^{-1}	0.16879 x10^{1}	0.37102 x10^{0}
1.0000	0.16375 x10^{1}	0.25642 x10^{-1}	0.16631 x10^{1}	0.49058 x10^{0}
2.0000	0.16329 x10^{1}	0.51284 x10^{-1}	0.16842 x10^{1}	0.10914 x10^{1}
4.0000	0.17028 x10^{1}	0.10257 x10^{0}	0.18054 x10^{1}	0.22379 x10^{1}
6.0000	0.17586 x10^{1}	0.15385 x10^{0}	0.19124 x10^{1}	0.33134 x10^{1}
8.0000	0.18011 x10^{1}	0.20513 x10^{0}	0.20063 x10^{1}	0.43339 x10^{1}
10.000	0.18351 x10^{1}	0.25642 x10^{0}	0.20915 x10^{1}	0.53099 x10^{1}
20.000	0.19430 x10^{1}	0.51284 x10^{0}	0.24558 x10^{1}	0.97058 x10^{1}
40.000	0.20518 x10^{1}	0.10257 x10^{1}	0.30775 x10^{1}	0.16949 x10^{2}
60.000	0.21154 x10^{1}	0.15385 x10^{1}	0.36540 x10^{1}	0.22902 x10^{2}
80.000	0.21606 x10^{1}	0.20513 x10^{1}	0.42119 x10^{1}	0.27994 x10^{2}
100.00	0.21955 x10^{1}	0.25642 x10^{1}	0.47597 x10^{1}	0.32458 x10^{2}
200.00	0.23040 x10^{1}	0.51284 x10^{1}	0.74324 x10^{1}	0.49115 x10^{2}
400.00	0.24124 x10^{1}	0.10257 x10^{2}	0.12669 x10^{1}	0.69470 x10^{2}
600.00	0.24757 x10^{1}	0.15385 x10^{2}	0.17861 x10^{1}	0.82699 x10^{2}
800.00	0.25207 x10^{1}	0.20513 x10^{2}	0.23034 x10^{1}	0.92532 x10^{2}
900.00	0.25391 x10^{1}	0.23078 x10^{2}	0.25617 x10^{1}	0.69947 x10^{2}

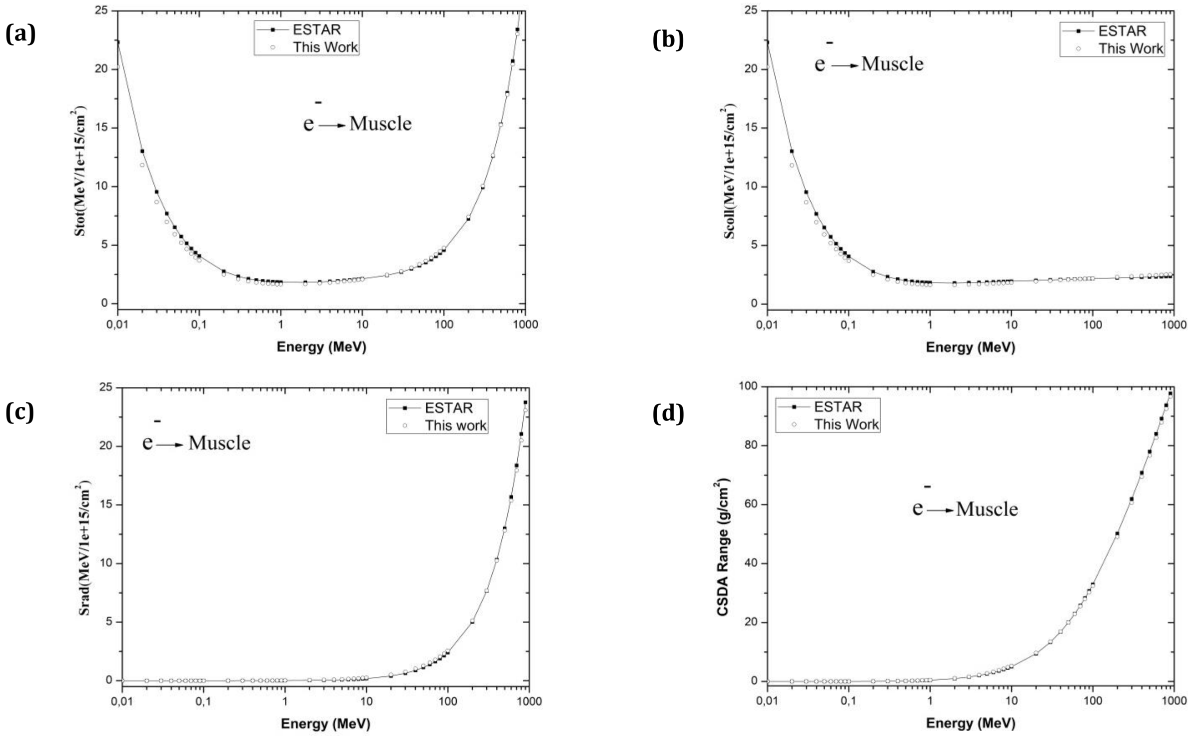

Figure 1. (a) Total stopping power, **(b)** collisional stopping power, **(c)** radiative stopping and **(d)** The CSDA range of incident electrons in muscle, skeletal tissue

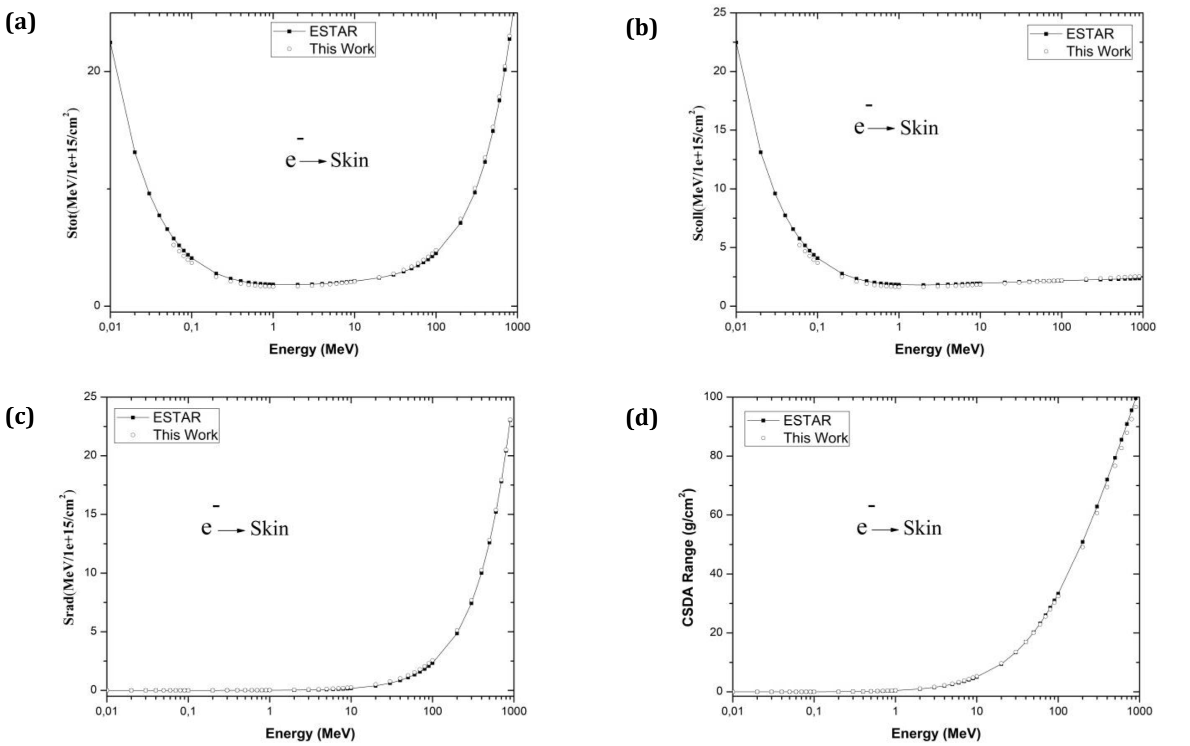

Figure 2. (a) Total stopping power, **(b)** collisional stopping power, **(c)** radiative stopping and **(d)** The CSDA range of incident electrons in skin tissue.

The results obtained for collisional, radiative and stopping power and CSDA range are given in Table 3, 4 for incident electron energies ranging from 0.10 to 900 MeV. As seen from the Tables, there is no difference between our results for skin and musclesince our calculation based on the Tietz (1956) definition of charge densities, and the material compositions of skin and muscle are almost same. The actual differences are found as 0.03% for collisional, 0.0001% for radiative, 0.007% for total stopping power and 0.04% for CSDA Range. For ESTAR’s results these discrepancies are 0.18%, 3.4%, 1.02% and 0.7% for collisional, radiative and total stopping powers, and Range, respectively.

Moreover, as seen from the figures obtained results are accordance with the ESTAR (2003) database, and the agreements are less than 7% for collisional and total stopping power and range data at the energy range 0.10 to 900 MeV while it is almost 10% for radiative stopping power at the energy above 10 MeV. Since the radiative stopping power proportional with the incident particle’s energy, it is important above 10 MeV and becomes dominant mechanism above 100 MeV.

4. Conclusion

In radiotherapy, electron beams are widely used for the medical treatments to skin and muscle layer. Since then, it is important to know stopping power and range values to account for the effect of the electron beams in skin and muscle. In this work, stopping power and CSDA range values have been calculated for electrons in skin and muscle at the incident energy ranging from 0.10 to 900 MeV. In fact, this energy range is very high for medical treatments. Since this energy range covers many applications, i.e. radiotherapy, high energy physics, material analysis, one can easily use presented values in their field. This study has been based on the ourprevious work, and as mentioned above it is the application of previous work.

References

Akar A, Gümüş H. 2005. Electron stopping power in biological compounds for low and intermediate energies with generalized oscillator strength (GOS) model. Radiat Phys Chem, 73: 196-203.

Amsler C, Doser M, Antonelli M. et al.,. (Particle Data Group). 2008. Review of particle physics (in Experimental Methods and Colliders). PhysLett B, 667:1–1340.

Bagal`a P, Venanzio CD, Falco MD, Guerra AS, Marinelli M, Milani E, Pimpinella M, Pompili F, Prestopino G, Santoni R, Tonnetti A, Verona C, Verona-Rinati G. 2013. Radiotherapy electron beams collimated by small tubular applicators: characterization by silicon and diamond diodes. Phys Med Biol, 58: 8121–8133.

Bragg WH, Kleeman R. 1905. On the alpha particles of radium and their loss of range in passing through various atoms and molecules. Philos Mag, 10: 318–340.

Bethe HA. 1930. Zur Thorie des Durchgags Cehneller Karpuskularstrahlendurch Materie. Ann Physik Ann Phys (Leipzig), 5: 325-400.

Bloch F. 1933. Zur Bremsungrasch Bewecter Teikhen Beim Durchangangdurch Materie. Ann Phys (Leipz.), 16: 285.

Bohr N. 1940. Scattering and stopping of fission fragments. Phys Rev, 58: 654–655.

Bohr N. 1941. Velocity–range relation for fission fragments. Phys Rev, 59:270–275.

Cleland MR. 2009. Industrial applications of electron accelerators, pp.383-416. Published version from, CERN cds.cern.ch/record/1005393/files/p383.pdf.

ESTAR 2003. Stopping power and range tables for electron. Data available from /http://physics.nist.gov/PhysRefData/Star/Text/ESTAR.html.

Gallo S, Iacoviello G, Bartolotta A, Dondi D, Panzeca S, Marrale M. 2017. ESR dosimeter material properties of phenols compound exposed to radiotherapeutic electron beams. Nucl. Instrum. Methods B, 407:110–117.

Gümüş H. 2008. New stopping power formula for intermediate energy electrons. Appl Rad Isot, 66: 1886-1890.

Hogstrom KR, Almond PR. 2006. Review of electron beam therapy physics. Phys Med Biol, 51: 455–489.

ICRU 1989. Tissue substitutes in radiation dosimetry and measurement ICRU Report 44. International Commission on Radiation Units and Measurements, Bethesda.

Jablonski A, Tanuma S, Powell CJ. 2006. New universal expression for the electron stopping power for energies between 200 eV and 30 keV. J Surf Interface Anal, 38: 76-83.

Khan FM. 2003. The Physics of Radiation Therapy, The 3rd Editon, Minnesota: Williams & Wilkins.

Ravichandran R, Binukumar JP, Amri I, Davis CA. 2016. Diamond detector in absorbed dose measurements in high-energy linear accelerator photon and electron beams. J Appl Clinical Med Phys, 17(2): 291-303.

Rohrlich F, Carlson BC. 1954. Positron-electron differences in energy loss and multiple scattering. Phys Rev, 93: 38-44.

Sugiyama H. 1981. Electronic stopping power formula for intermediate energies. Radiat Eff, 56: 205-209.

Sugiyama H. 1985. Stopping power formula for intermediate energy electrons. Phys Med Biol, 30: 331-335.

Thomas LH. 1927. The calculation of atomic fields. Cambridge Philos Soc, 23: 542-548.

Tufan MÇ, Gümüş H. 2011. A Study on the calculation of stopping power and CSDA Range for incident positrons. J Nucl Mater, 412: 308-314.

Tufan MÇ, Namdar T, Gümüş H. 2013. Stopping power and CSDA range calculations for incident electrons and positrons in breast and brain tissues. Radiat Environ Biophys, 52: 245–253.

Tsai YS. 1974. Pair production and bremsstrahlung of charged leptons. Rev Mod Phys, 46: 815–851.

Venanzio CD, Marinelli M, Milani E, Prestopino G, Verona C, Verona-Rinati G. 2013. Characterization of a synthetic single crystal diamond Schottky diode for radiotherapy electron beam dosimetry. Med Phys, 40(2):021712.

Yarlagadda BS, Robinson JE, Brandt W. 1978. Effective-charge theory and the electronic stopping power of solids. Phys Rev B, 17: 3473-3483.