Calculations Of Stopping Power, And Range Of Electrons Interaction With Different Material And Human Body Parts

M. O. El-Ghossain

Abstract: In this work we studied interaction electrons with matter; I calculated the stopping power (in MeV cm2/g) from the theory of Bethe-Bloch formula as giving in the reference , and the Range will be calculated. This has been done for different target materials in biological human body substances such as water, bone, muscle and tissue and different energies electrons. All these calculations were done using different programs; STAR and Matlab, the results will be shown for, stopping power vs energy and Range Vs energy. The stopping power in some biological compounds for electrons was calculated over the energy range from (10^{-2}MeV to 10^{3} MeV). Total stopping power was obtained by summing the electronic (collisional) and radiative stopping power of the target materials, and then employing the continuous slowing down approximation (CSDA) to calculate the path length (Range). The total stopping power is proportional to Z^2 , Z/A and I, increases rapidly at low energies, reaches a maximum and decreases gradually with increasing energy, the data were fitted to a suitable empirical formula as shown in the figures.

Index Terms: stopping power, range, electron, human body..

1. Introduction

Knowledge of the stopping power, energy loss, range, straggling and equivalent dose rate of ions in air, tissue and polymers are very important in many research and application fields, such as radiation dosimetry, radiation biology (such as cell lethality, cytogenesis changes, mutagenesis and DNA recombination), radiation chemistry, radiotherapy and nuclear physics [2-5]. Different methods have been reported for measuring the stopping power of charged particles such as direct energy loss measurement through films, backscattering from thick substrate covered with deposited absorbing layers, gamma resonance shift measurements, self-supporting method and an indirect verification of the stopping power based on alpha energy losses in air [2-7]. Many experimental and theoretical studies about energy loss, stopping power, range, straggling of ions such as (H, He, Li, C, O) and equivalent dose have been carried in many different human body parts, In this work the interactions of electrons with matter will be studied, which a light charge particles like, also we will show the effects of theses interactions with human body, skin, bone, skeletal and different parts of the body. The main objectives is to calculate the energy loss per distance which is the stopping power and ranges results from the above external and internal radiation interactions with matter, this will leads the evaluations of energy loss and doses which are very important for radiation treatment and the possible damage to adjacent body tissue. It is well known that the ionization value in tissues is proportional to cells damage. Therefore, the main aim of this study is to evaluate electron energy deposition in target organ and in the various entrance layers (skin ,water , adipose tissue , muscle skeletal , bone). We use the energy that varies between 10 Kev and 1000 MeV, and calculate the stopping power from the Bethe-Bloch formula as giving in the theory of [1] , for these calculations we will use the Estar and Mtlab codes [7, 8].

- *M. O. El-Ghossain*
- *The Islamic University of Gaza, Physics Department, Gaza, Gaza Strip, Palestine* ghossain@iugaza.edu.ps

We expect to get results for stopping power vs energy, and Range vs energy for the previous matters and body parts listed above, these study are very important for knowing, Energy loss and dose are correlated with each other and help to formulate the interaction of internal and external radiation with matter to predict the affectivity of the radiation treatment and the possible damage to adjacent body tissue. Radiation treatment is based on different kind of radiation and depends on the different kind of interaction between the radiation and matter (body tissue) [9], the energy loss and dose which human body might exposed during medical treatments or accidents or from natural radioactivity, this will help us in the dose limit and to be more protected, in Gaza we use different kind of radiation in universities, hospitals, knowing the energy loss, dose will help us to protect ourselves and our environment.

2. Stopping Power of Electrons:

Stopping power of a medium can be defined as the average unit of energy loss suffered by the charge particles per unit path length in the medium under consideration.[1, 2] Stopping power consists of two components: collisions and radiative. The first is the most important, resulting from the collision interaction between the incident particles and atomic electrons. Mass collision stopping power is widely used to reduce the dependence on the medium density (ρ) [2]. The total stopping power can be obtained from SRIM-2003 program [15], which calculates the stopping power and range of ions (10eV-2GeV/amu) in matter using a quantum mechanical treatment of ion-atom collision (the manual of SRIM refers to the moving atom as an "ion", and all target atoms as "atom"). A full description of the calculation was given by Ziegler and Biersack [1]. Stopping power of a medium can be defined as the average unit of energy loss suffered by the charge particles per unit path length in the medium under consideration. [2, 3] The energy loss in matter has been calculated by many physicists, but the basic, classic derivation was due to Bloch who improved a calculation by Bethe; hence the Bethe-Bloch Formula. The rate of energy loss is given by (– dE/dx); dE/dx being a loss of energy, is a negative quantity. The calculation of dE /dx is done in such a way as to determine the energy deposited in the medium (positive) – hence the explicit negative sign for the loss of energy of the particle [4]. You should also note that "x", distance, is not always expressed in metres, but often in units of mass per metre^2 , square meter,. This latter parameter comes from multiplying the length parameter by the density of the material. This is a more convenient and useful unit of material thickness as far as experimentalists are concerned. The full expression for the Bethe-Bloch formula can be written as:

$$-\frac{dE}{dx}=\left(\frac{e^2}{4\pi\varepsilon_0}\right)^2\frac{4\pi z^2 N_A Z\rho}{mc^2\beta^2 A}\left[\ln\left(\frac{2mc^2\beta^2}{I}\right)-\ln(1-\beta^2)-\beta^2\right] \qquad (1.1)$$

The quantity -dE/dx is known as the STOPPING POWER and is denoted as S. The range is simply defined as the distance a particle moves in a medium before all its energy is lost. This can be determined from the stopping power provided we know the the form of S from zero energy up to the initial energy of the particles in the incident beam The range can be determined as given below:

$$\text{Range (approx.)} \quad R=\int dx=\int_E^0\frac{dE}{dE/dx} \qquad (1.2)$$

Where the integration from 0 to maximum distance. We can use the Bethe-Bloch formulism to calculate the stopping power for electrons. To this we must add the contribution from Bremsstrahlung [1]. It is not surprising that the formula (and its derivation) for energy loss by Bremsstrahlung is complicated and messy. However, we can again say: The resultant formula is:

$$\left(\frac{dE}{dx}\right)_c=\left(\frac{e^2}{4\pi\varepsilon_0}\right)^2\left[\frac{2\pi N_0 Z\rho}{mc^2\beta^2 A}\right]\left[\begin{array}{l}\frac{T(T+mc^2)\beta^2}{2I^2mc^2}+(1-\beta^2)-(2\sqrt{1-\beta^2}\\ -1+\beta^2)\ln 2-\frac{1}{2}(1-\sqrt{1-\beta^2})^2\end{array}\right] \qquad (1.3)$$

T kinetic energy of electron, I ionization, ρ density The important dependence (putting aside the slowly varying logarithmic term) is: We see that Bremstrahlung is important at high energies. We can also see why we must consider this process of energy loss for electrons, but not for heavy charged particles. The mass of the proton is almost 2000 times greater than that of the Electron, therefore the contribution from Bremsstrahlung for heavy charged particles will be at least 2 x 10^6 less than it is for an electron. Clearly we can only carry out the integration if we have a functional form for dE/dx over the full energy range. As I have remarked before, this is problematic at low energies. The energy loss of the electron per unit length was derived by Bethe and can be written as:

$$\left(\frac{dE}{dx}\right)_r=\left(\frac{e^2}{4\pi\varepsilon_0}\right)^2\left[\frac{N_0 Z^2\rho(T+mc^2)}{137m^2c^4A}\right]\left[4\ln\frac{2(T+mc^2)}{mc^2}-\frac{4}{3}\right] \qquad (1.4)$$

Where T is the kinetic energy of the electron, the subscripts c and r stands for the energy losses due to collisions and radiations, respectively. The expression for the radiative loss is valid only for relativistic energies below 1 MeV, the radiation losses are negligible. The total energy loss is just the sum of these contributions [1]:

$$\frac{dE}{dx}=\left(\frac{dE}{dx}\right)_c+\left(\frac{dE}{dx}\right)_r \qquad (3.5)$$

The ratio of Bremsstrahlung (radiation r) losses to collisional, c, losses, for an electron, varies approximately as [1]:

$$\frac{\left(\frac{dE}{dx}\right)_r}{\left(\frac{dE}{dx}\right)_c}\cong\frac{E}{mc^2}\frac{Z}{1600} \qquad (3.6)$$

mc^2 = 0.511 MeV

The energy at which this ratio is unity is known as the CRITICAL ENERGY for the electron in the particular material.

4. Calculations of Stopping Power of electrons:

The Stopping Power calculation for electrons traversing matter is similar to that for heavy charged particles. The interaction of incident electrons with atomic electrons, leading to excitation and ionization, can be calculated from Bethe's theory, and it is called the "Collisional Stopping Power". In addition to that, electrons are accelerated in the Coulomb field of nuclei, and this leads to electromagnetic radiation, the so-called "Bremsstrahlung". The corresponding stopping power is the "Radiative Stopping Power" [7, 8, 9].

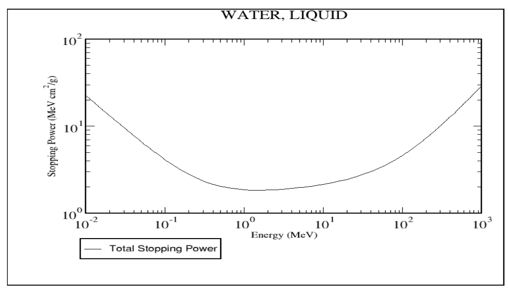

Figure 1: *Stopping power of electron in water*

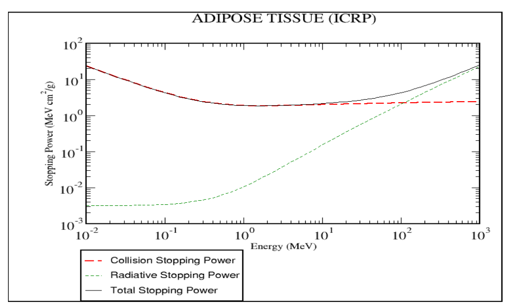

Figure 2: *Stopping power of electron in Adipose tissue*

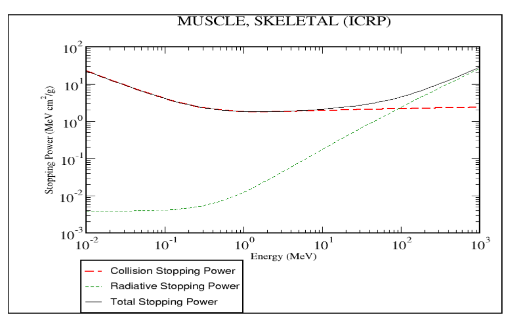

Figure 3: *Stopping power of electron in muscle*

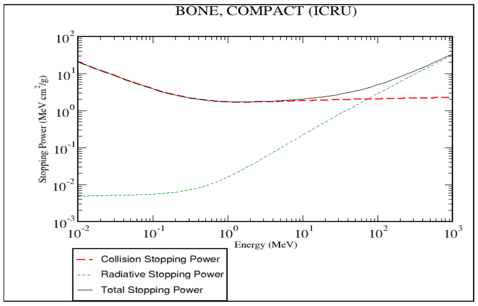

Figure 4: *Stopping power of electron in Bone*

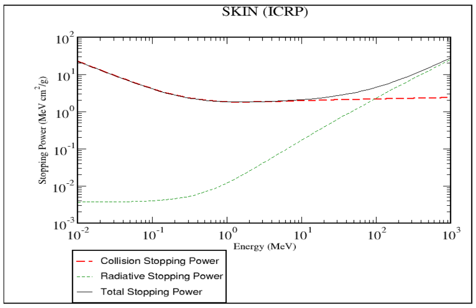

Figure 5: *Stopping power of electron Skin*

5. Calculation of the Range of electron and Fitting:

The **range** of a charged particle is the distance it travels before coming to rest. The range is **NOT** equal to the energy divided by the stopping power. Like mass stopping power, the range in g cm^{-2} applies to all materials of similar atomic composition [11, 12, 13, 14, 15, 16[.

A useful relationship:

For two heavy charged particles **at the same initial speed** β, the ratio of their ranges is simply:

$R_1(\beta)/ R_2(\beta) = M_1 z_1{}^2/M_2 z_2{}^1$,

where:

R_1 and R_2 are the ranges

M_1 and M_2 are the rest masses and

z_1 and z_2 are the charges

The figures below show the range of electrons in different materials including human body parts. Fitting equations have been tried for the range; it was found that the fifth degree and sixth degree fit very well as shown in the figures [10,11, 12,].

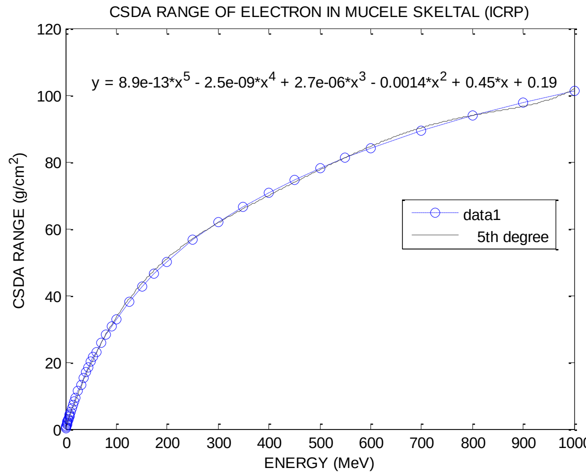

Figure 6: *Range of electron in muscle with fitting equation*

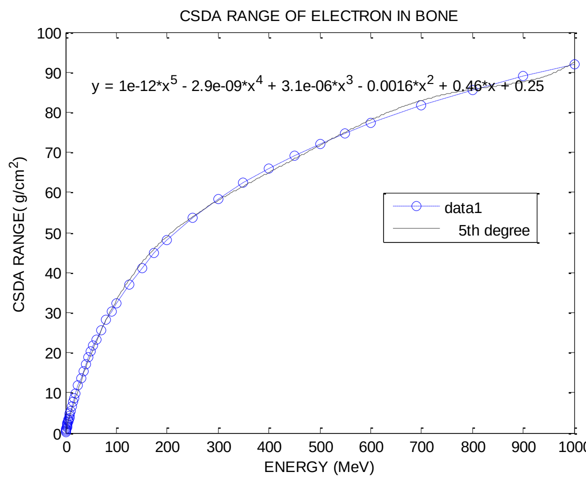

Figure 7: *Range of electron in Bone with fitting equation*

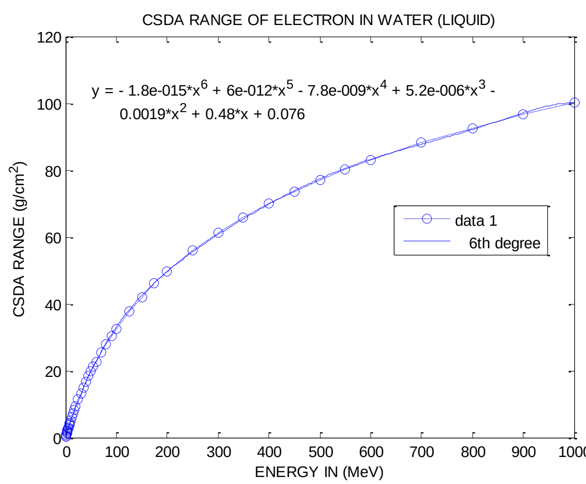

Figure 8: *Range of electron inWater with fitting Equation*

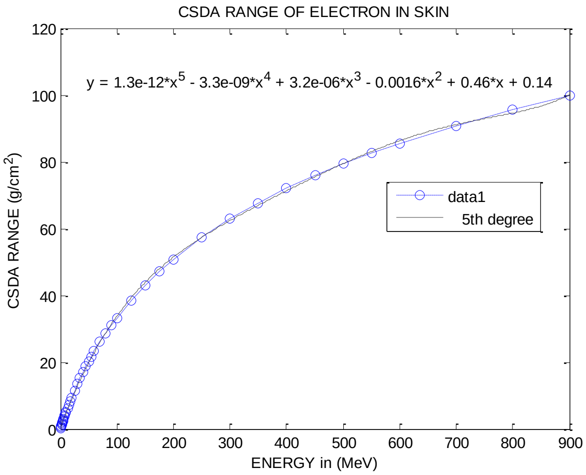

Figure 9: *Range of electron in Skin with fitting equation*

Conclusion:

It is well known that the ionization value in tissues is proportional to cells damage. Therefore, the main aim of this study is to evaluate electron energy deposition in target organ and in various entrance layers (skin, water, dipose tissue, musle, skeletal, ,bone). We used the energy that varies between 10KeV and 1000MeV , and obtained the stopping power diagram for each energy beam using the ESTAR cod.

- The total stopping power is proportional to Z^2 ,Z/A and I.
- $(dE/\rho dX)_{total}$ increases rapidly at low energies reaches amaxmimum and decreases gradually with increasing energy.
- The stopping power allows to calculate the range of the electrons particles in the absorber material.
- -Heavy particles are less scattered than electrons due to their heavy masses and the beam shows significantly better spatial resolution.
- Because of the specific energy dependence of the energy loss (or stopping power curve) incoming high energy particles experience only little energy loss *dE/dx,* but the energy loss maximizes when particles have slowed down to energies which correspond with the peak of the energy loss curve. The energy of the particles (with an initial energy E_i) at a certain depth *d* can be derived by:

$$E(d) = E - \int_0^x \frac{dE}{dx} dx$$

For high initial energies the coefficients are large which translates into a maximum of energy loss at smaller depths which decreases gradually with the decrease of the absorption coefficient towards lower energies.

Stopping power of electron in the energy range from 0.01Mev to 1000Mev for a number of elements . For low Z substances ,dE/dx is almost constant between 0.5 Mev and several Mev .The rise of the curves at high energies is due to increasing bremsstrahlung probability. Body tissue is typically low Z material and the range can be approximated. The different fitting equations have been tried for different material ranges, the fifth and sixth degree fit very well with the coefficients shown on the graphs.

References:

[1] Kenneths.Krane , Introductory Nuclear Physics ,Oregon stat University, 1987

[2] R. Macian, Biological Effects of Radiation ,Reactors Concepts Manual, USNRC Technical Training Center

[3] National Research Council, Committee on the Biological Effects of Ionizing Radiation, Health Effects of Exposure to Low Levels of Ionizing Radiation, BEIR V, National Academy Press, Washington, D.C.,1990

[4] Fred A. Mettler, Jr., M.D. and Arthur C. Upton, M.D. Medical Effects of Ionizing Radiation, Grune & Stratton, Inc., Orlando, Florida, 1995.

[5] World Health Organization (.November 2012),Ionizing radiation ,health effects and protective measures, http://www.who.int/mediacentre/factsheets/fs371/en

[6] A.Markowicz, Rene Van Grieken , Handbook of X-Ray Spectrometry, Second Edition

[7] MICHAEL F. L' ANNUNZIATA ,HANDBOOK OF RADIOACTIVITY ANALYSIS, THIRD EDITION ,2012

[8] http://physics.nist.gov/PhysRefData/Star/Text/ESTAR.html

[9] http://physics.nist.gov/cgi-bin/Star/ap_table.pl

[10] Hasan Gumus and Fevzi Koksal," Effective Stopping charges and stopping Power calculations for heavy Ions," Radiation Effects & Defects in Solids. Vol. 157, pp. 445–458, 2002.

[11] S. Tanuma, C.J. Powell and D.R. Penn, "Calculations of stopping powers of 100 eV to 30 keV electrons in 10 elemental solids," Surface and Interface Analysis. vol. 37, issue 11, pp. 978 – 988, 2005.

[12] Zhenyu Tan and Yueyuan Xia," Stopping power and mean free path for low-energy electrons in ten scintillators over energy range of 20–20,000 eV," Applied Radiation and Isotopes. Vol. 70, issue 1, pp. 296-300, 2012.

[13] Hemlata Singh, S.K Rathi and A.S.Verma," Ranges of Electrons for Human Body Substances," Research Journal of Chemical Sciences, Vol. 3, Issue 3, pp. 4-8, March 2013.

[14] Hunt, J. G., Dantas B. M., Azeredo, A. M. G. F. Visual Monte Carlo in-vivo in the CONRAD and IAEA Whole Body Counter Intercomparisons. In. Workshop on Uncertainty Assessment in Computational Dosimetry, Bologna, 2007.

[15] Hunt, J. G., da Silva, F. C., Mauricio, C. L. The validation of Voxel phantoms and Monte Carlo methods applied to external irradiations. Radiation protection and Dosimetry, Vol 108, no. 1, pp. 85-89, 2004.

[16] http://www.vmcsoftware.com/Index.html