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Total Stopping Power Calculation of Electrons in Blood, Lung, and Soft Tissue in Energy Range (0.01-1000) Mev

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Abstract: *In this research is to calculate the total stopping power (stot) of electrons which are two parts: Radiative stopping power (srad) and collisional stopping power (scoll) as well as stopping time for the human body's tissues (blood, lung, and soft tissue) using the relative equation of Bethe- Bloch in a range Electron Energies (0.01-1000) MeV, the current results are compared with E-star program values, and it was found that our results match well with the E-star program values and their correlation coefficient (0.9).*

Keywords: Bethe-Bloch, stopping power, radiative, collision, E-star program

Introduction

The study of the interaction of ionizing radiation (x-rays, electrons, positrons, protons and heavy ions) with living tissues is of utmost importance in the treatment of cancer because the amount of energy transferred by ionizing radiation to cancer cells will determine the outcome of the treatment. Ion radiotherapy has become popular because it can provide a high dose of radiation to the target while avoiding nearby healthy tissues and organs [1]. Stopping power is the rate of energy loss per unit distance in the material and is divided into two parts: electronic and nuclear stopping energy [2]. Turning off energy is the most important parameter of the energy loss process for active ions that pass through the substance. The loss of energy from heavy ions is complicated by the effect of charge exchange that leads to fluctuations in the charge state [3]. The electronic discontinuation is caused by the interaction of ions with the electrons linked to the target [4]. The lost energy of ions that penetrates the material can be caused by a number of processes Excitation and impact of target atoms, electron capture, ionization or excitation of the projectile [5]. Evaluations of the stopping force of β are studied in two different ways: the first is to consider the electron and lucitron interactions with the target electrons, which are called the colliding stopping force, while the second is considered to be the fact that the radioactive charged particles are radioactive, which is called the radiation stopping force (braking radiation) or loss [6].

1. Total stopping power of the electrons

The electron loses its energy by ionizing and exciting orbital electrons in the middle. Block stopping power (dE / ρ dX) can be defined as the rate of energy loss per unit path of an electron or positron length by excitation and ionization which was known as "collision energy loss". The mass of collective collision arrest of electrons and positrons are given by [7].

$$S_{coll} = (dE/\rho dx)coll = K\left[Ln\left\{\frac{\tau^2(\tau+2)}{2\left(\frac{I}{m_0c^2}\right)^2}\right\} + F^{\pm}(\tau) - \delta(\beta\gamma) - \frac{2C}{Z}\right] \quad \ldots\ldots \ldots..(1)$$

Where:

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

$$K = \frac{2Cm_0c^2}{\beta^2} = \frac{0.1535Z}{A\beta^2}$$

$$\beta = \frac{v}{c}$$

$$\tau = \frac{E}{m_0c^2}$$

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τ is the kinetic energy of the electrons in unites of $m_0 c^2$

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

And

$F^+(\tau) = 2\ln 2 - \frac{\beta^2}{12}\left[23 + \frac{14}{(\tau+2)} + \frac{10}{(\tau+2)^2} + \frac{4}{(\tau+2)^3}\right]$ *for positrons…………….(3)*

Where

$\frac{C}{Z}$ *is 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*[8]

$$\delta = 0 \qquad X < X_0$$

$$\delta = (4.606 \times X) + [a(X_i - X)^m] \qquad X_0 < X < X_i \quad \ldots\ldots\ldots(4)$$

$$\delta = (4.606 \times X) + C \qquad X > X_i$$

where

$$X = \log\left(\log\frac{\beta}{\sqrt{1-\beta^2}}\right) \quad \ldots\ldots\ldots\ldots(5)$$

The parameters X_0 *,* X_i *,* a, m *and C parameters for elements and many compounds and mixtures were published. Bethe and Heitler have obtained an approximate relationship between the Scoll collision and the* $Srad$ *in the relationship:[9]*

$$S_{tot} = S_{coll} + S_{rad} \quad \ldots\ldots\ldots(6)$$

$$S_{rad} = S_{coll}\left(\frac{EZ}{800}\right) \quad \ldots\ldots\ldots(7)$$

$$S_{tot} = S_{coll}\left(1 + \frac{EZ}{800}\right) \quad \ldots\ldots\ldots(8)$$

For vehicles, the added Bragg base has been found to work well. The rule states that the mass stopping strength of a substance that contains several elements is equal to the weighted sum of the mass stopping force of the constituent atoms [10].

$$\left(\frac{-dE}{\rho dX}\right)_{com} = \sum_i w_i \left(\frac{-dE}{\rho dX}\right)_i \quad \ldots\ldots\ldots(9)$$

Where:

$$\omega_i = \frac{n_i A_i}{A_{com}}$$

ω_i: the ratio of the weight of the elements in the compound

n_i : number of atoms of the j^{th} kind of atoms in a compound or mixture atomic mass of medium :A_i

ρ: *the density of the medium*

$(-dE/\rho dx)_{com}$: *mass stopping power of compound*

$(-dE/\rho dx)_i$: *mass stopping power for the elements in the compound*

Bragg rule is [11]:

$$(-dE)/\rho dx)_i = \frac{\omega_1}{\rho_1}(-dE)/dx)_1 + \frac{\omega_2}{\rho_2}(-dE)/dx)_2 + \cdots \quad \text{.........} (10)$$

Stopping time

The Stopping time is the time interval required to stop the charging particle in an absorbed medium. This time the stopping power can be expressed using the differentiation chain [12].

$$\frac{dE}{dt} = \left(\frac{dE}{\rho dx}\right)\left(\frac{\rho dx}{dt}\right) = \frac{1}{\rho}\left(\frac{dE}{dx}\right)(\rho v) = \rho v\left(\frac{dE}{\rho dx}\right) \quad \text{............} \quad (11)$$

Where, v = dx / dt is the particle speed. A rough estimate of the time it takes for a heavy charged particle to stop in the material can be made, if one assumes that the deceleration rate is constant. For E kinetic particles, this time around [13].

$$t = \frac{E}{dE/_{dt}} = \frac{E}{\rho v\left(\frac{dE}{\rho dx}\right)} \quad \text{..................} (12)$$

Where, t in unit (sec)

2. Results and Discussion

The results of the total stopping power are shown in Figs 1, 2 and 3, respectively. These results are obtained by applying equations 1, 2,7 , and 8 using MATLAB 2015 for blood tissue, lung, and delicate tissue in the energy range (0.01 - 1000) MeV. Figures demonstrate good agreement with the E-star program, and the correlation coefficient (0.9). When the electron enters a medium, it will lose its kinetic energy and change its direction continuously as well, thus the electron will suffer from many deviations at large angles along its path after it approaches the nuclear field of the target atom. The collision interaction between the incident electrons and the orbital electrons is due to the interaction of the electric fields of both electrons. As the fallen electron approaches orbital electrons, no actual connection occurs between them, but its reaction is similar to that of similar magnetic electrodes, and the SRad value is proportional to the energy of the falling electron. This situation can be explained as slow electrons (low energy electrons) spend most of their time interacting with orbital electrons This indicates that these electrons have a high probability of interacting with atomic electrons, while the fast electrons have a low probability of interacting with atomic electrons and pass over the columbic field without being influenced by the electrons, thus this induces the electrons to open up more channels of radiative energy loss. By comparing the results of SColl and SRad, we found that the SColl dominates the SRad due to the low energy range therefore Stot value is largely influenced by SColl. In Figures (1,2 and 3), at energies greater than 1 MeV we observe a divergence between the present results and Estar results. This could be due to Bethe-Bloch relativistic formula used in the calculations of this work used the correction to density to minimize the errors. Figure (4) shows the stopping time of the studied tissue, as the stopping time increases with the increase of the energy of the falling electron, but decreases by increasing the density of the studied tissue.

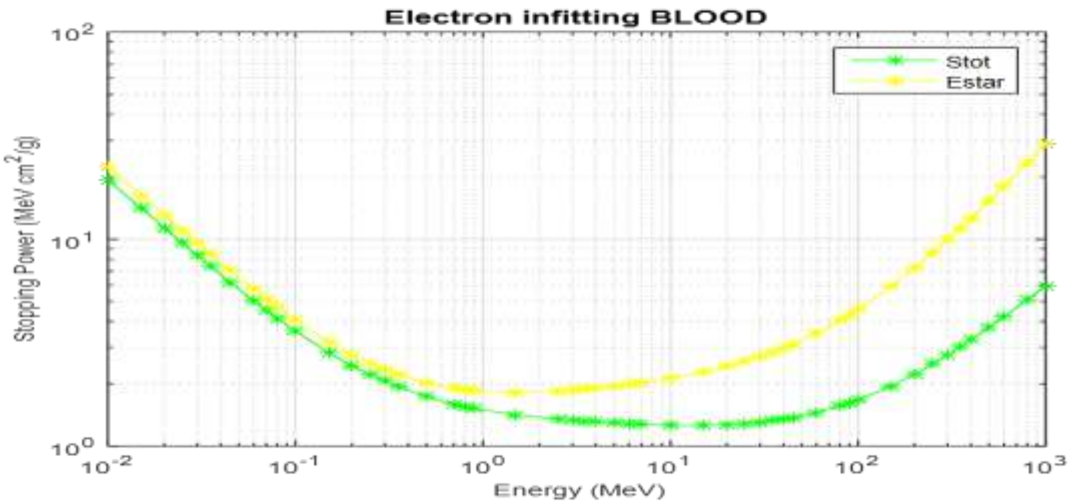

Fig. (1) Comparison of the present work and E-star results for total stopping power of electrons in the Blood.

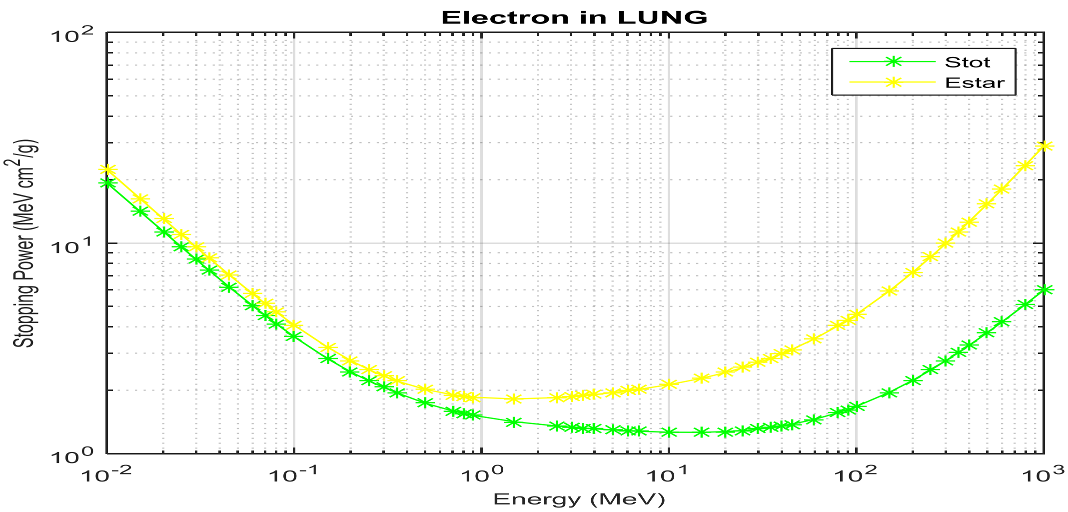

Fig. (2) Comparison of the present work and E-star results for total stopping power of electrons in the Lung.

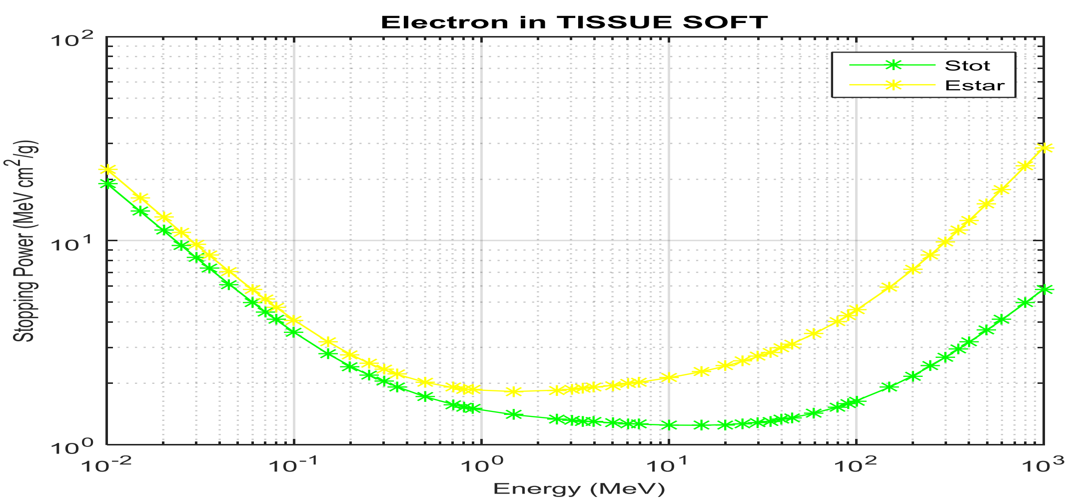

Fig. (3) Comparison of the present work and E-star results for total stopping power of electrons in the Tissue soft.

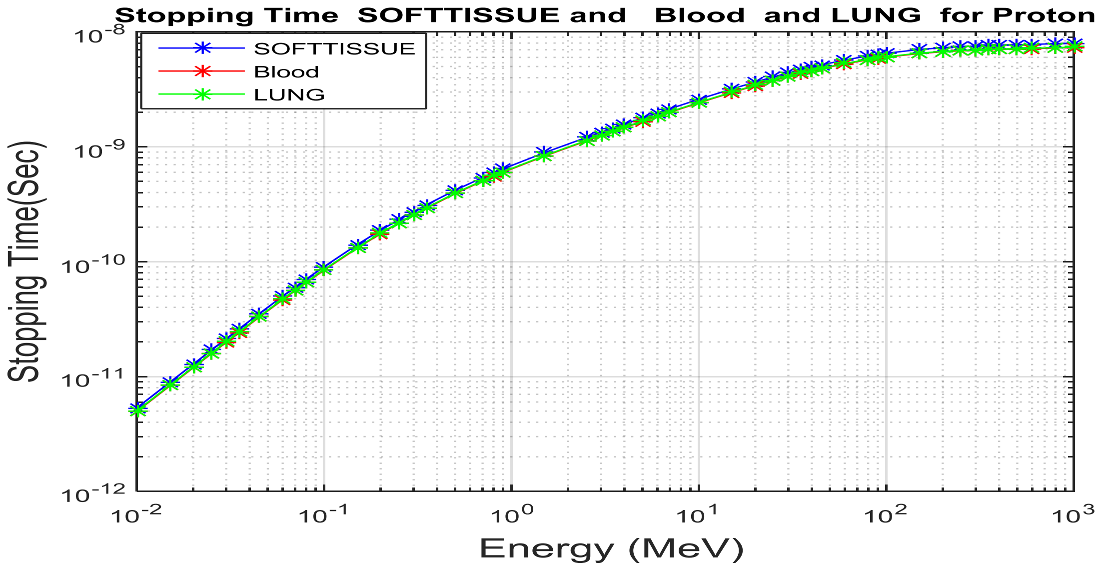

Fig. (4) Calculated stopping time of electrons in the tissues (Blood ,Lung and Soft Tissue)

4. Conclusion

Through the results of this research, we can conclude the following: Calculations indicate that Stot decreases with increasing energy of the falling particle at energies (0.01-10) MeV because the collision stopping power is the effect, then the total stopping force increases by increasing the energy of the dominant electrons because Radiation stop energy is effective, and this energy depends on the speed of the particles that determine the type of interactions with the target and depends on the speed of the particles that determine the type of interactions with the target. The value of Stot depends on the energy of the transverse particle, but its dependence is weak on the atomic number of the target. It was concluded that the Bethe- Bloch equation is good for calculating the stopping power of electrons in the studied tissues, and we have also noticed that the stopping time increases with increasing energy of the falling electron but decreases with increasing density of studied tissues.

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