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CALCULATION OF CONTINUOS SLOWING DOWN APPROXIMATION (CSDA) RANGE OF ELECTRONS INTERACTION WITH PARTS OF HUMAN BODY

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Abstract: This study uses an empirical method to determine the Continuous slowing down approximation ranges (CSDA) of electrons in human body parts, such as blood and the eye lens, in the energy range of 30-1000 keV. Continuous slowing down approximation ranges (CSDA) are crucial for applications including chemical investigations of a solid's surface regions, electron beam lithography, and radiation biology. The formula for the (CSDA) range is dependent on factors such as the overall energy, the density, and the effective atomic number of the various body sections. It is discovered that the CSDA range calculations for electrons in the 30-1000 keV energy range agree correctly with the numbers provided by the ESTAR [1] program. Additionally, a graphic representation of the CSDA range vs. energy values has been provided.

***Index Terms*: CSDA range, Effective atomic, density, total energy and ESTAR Program.**

I. INTRODUCTION

In many research and application fields, including radiation dosimetry, radiation biology (including cell lethality, cytogenesis changes, mutagenesis, and DNA recombination), radiation chemistry, radiotherapy, and nuclear physics, knowledge of the stopping power, energy loss, range, straggling, and equivalent dose rate of ions in air, tissue, and polymers is crucial (2).

In several domains, including the production of semiconductor devices through impurity atom implantation and the structure analysis of solid-first wall interactions and plasma-first wall interactions in nuclear fusion reactors, the stopping power, or average energy loss per unit path length, is crucial. The electron range is defined as a measurement of the electrons' straight-line penetration distance in a solid by T. E. Everhart et al. [3].

When electrons in a solid collide with other electrons in the material, electrons with energy in the kilo-electron volt range are scattered inelastically. The literature contains effective contributions that are based on investigations of the CSDA range and stopping power of electrons in various absorber types. Complete tables with CSDA ranges for numerous samples ranging from 10 keV to 10^3 MeV were published by Berger and Seltzer [4]. A basic formula for the electron stopping power in various absorbers is frequently required for numerous applications in radiation dosimetry, surface layer characterization, and nuclear spectroscopy. For low energy electrons less than 10 keV in liquid water, D. Emfietzoglou et al. [5] investigated the computation of inelastic mean-free-paths and collision stopping-powers and extended the MC code [6,7] to the transport of electrons in liquid water over a wide range of impact energies down to about a few electron volts.

Saeed S. Kamoon et al [8] calculated the mass stopping power of electrons in biomedical human substances such as bones, soft-tissues and water with energy range of (10 keV- 1000 MeV).

Sugiyama's model was extended to low and high energy areas by Hasan gumus et al. [9] in order to compute the stopping powers for non-relativistic heavy ions in a range of target materials. Systematic estimates of the stopping power and inelastic mean free pathways for electrons at energies ranging from 20 eV to 20 keV in a set of 10 significant scintillators were conducted by S. Zhenyu Tan et al. [10]. The dielectric model, along with the optical energy loss functions (OELFs) and Born-Ochkur exchange correction, serves as the foundation for the computations. A relation for continuous slowing down approximation (CSDA) ranges for electrons of materials like bones, muscles, fat, and water in terms of energy from 30 keV to 1000 keV was reported by Hemlata Singh et al. [11].

The International Commission on radiation Units and Measurements (ICRU) Report 37 [12] tabulates stopping powers and ranges for electrons generated by the ESTAR Program [1] for 72 materials at a standard grid of 81 kinetic energies between 10 keV and 10^6 keV. Similar tables can be computed using ESTAR for any other element, compound, or mixture. Compute stopping powers at all kinetic energy levels between 1 keV and 10 GeV as well.

In the current work, we present a method to obtain the CSDA ranges for electrons in some human body parts (blood and the lens of the eye) at energy range (30-1000 keV). Much experimental and theoretical research has been conducted regarding energy loss, stopping power, range, straggling of ions such as (H, He, Li, C, O), and equivalent dose in many different human body parts. The results acquired using this method are found to be in proper agreement when compared to the CSDA range values obtained by the ESTAR program.

II. THEORY AND COMPUTATIONAL METHOD

Grimes et al. [13] calculate approximate analytical solution of the Bethe equation for charged particles in the radiotherapeutic energy range

$$-dE/dx = 4\pi nZ^2/m_ec^2\beta^2(e^2/4\pi\epsilon_o)^2(\ln(2m_ec^2\beta^2/I(1-\beta^2))-\beta^2) \text{ --------(1)}$$

Utilizing the Bethe-Bloch formula theory, Almutairi et al. [14] computed the electronic mass stopping power and the range of protons in several biological human body sections (water, muscle, skeletal and bony, cortical) in the energy range of protons 0.04 to 200 MeV. Good agreements were discovered between the electronic mass stopping powers and ranges and the PSTAR data, particularly for energies between 1 and 200 MeV for the stopping power and 4 and 200 MeV for the range.

$$-dE/\rho dx = 5.08 \times 10^{-31}\, z^2n/\beta^2\rho[F(\beta) - \ln I]$$

where β is v/c where v is the proton velocity and c is light velocity, I is the mean excitation energy and F(β) is given by $F(\beta) = \ln 1.02 \times 10^6\, \beta^2/(1-\beta^2) - \beta^2$

For some materials, such as aluminum, silicon, copper, and liquid water, Hasan Gumus et al. [15] introduced a new algorithm for the stopping power calculation in the case of incoming positrons for low and intermediate energy positrons below 10 keV. They also modified the formula for stopping power originally proposed by Rohrlich and Carlson [16]. An empirical formula for the CSDA range was published by Gupta et al. [17]. Using the empirical relation for the total stopping power of electrons, an empirical equation was constructed for the CSDA range of monoenergetic electrons in the energy region 0.2- to 10-MeV.For the CSDA range, the equivalent empirical equation is

$$R(T_0) = mc^2/SZ + 1.3230[(Y^{az+b-1}/az + b - 1) + 1/Y]^{Y}{}_{1.1957} \text{ ----------(2)}$$

This formula is valid only for stopping materials of atomic numbers from 1 to 92 but it is not valid in low energy region.

Hasan Gumus et al. [18] modified Rohrlich – Carlson Model for CSDA range, stopping power and mean penetration depth energy relationships in some hydrocarbons and biologic materials such as: C_2H_6 (ethane), C_4H_{10} (butane), C_6H_{14}(hexane), C_8H_{18} (octane), $C_5H_5N_5$ (adenine) and $C_5H_5N_5O$ (guanine) for10 eV to100 MeV.

Hasan Gumus [19] calculated stopping power and range of electrons for some human body tissues. The modified collision SP formula for incoming electrons can be written as

$$-dE/\rho dx = (4\pi e^4 z^2 N_o/mv^2 A)\, Z_2 \{\ln (E/I) - F(\tau)/2\}$$

Where $F(\tau) = 1 - \beta^2 + [(\tau^2/8) - (2\tau+1)\ln 2]/ (1 + \tau)2$

A straightforward empirical connection, R = A + B X, where A and B are constants, was proposed by Hemlata Singh et al. [11] et al. for the CSDA ranges of electrons in the energy regions 30 to 1000 keV for materials such bones, muscles, fat, and water. The value of is dependent upon energy (E), effective atomic number (Z), and density (D). They demonstrated a maximum 16.38% error with those standard values when they compared the computed values for the CSDA range of electrons with the values provided by Berger and Seltzer [4]. A straightforward empirical relation for CSDA ranges for electrons with energies between 25 and 200 keV has been published by Tan et al. [20]. It goes as follows:

$$R_o = 1.90 \times 10^{-6} (A/Z)^{2.5} E^{1.6} \text{ gm/cm}^2$$

Above relation is based on the CSDA Range data of Berger and Seltzer [21]. Where A, Z and E denotes atomic weight, atomic number and energy respectively. However, this relationship holds true for errors that are between 2% to 5% for 70 <Z<92 and within 10% for 30<Z<70. The relation's drawback is that it only applies to a relatively narrow range of energies and offers no guidance for atoms with lower atomic numbers. In this study, we provide an empirical formula to determine the electron's CSDA range

$$R = 333 \times 10^{-8} X - 488 \times 10^{-14} X^2 - 48 \times 10^{-5} \text{----------(3)}$$

Where $X = (Z/A)^{-1.75} E^{1.6}$ which depends upon Effective atomic number (Z), Mass number (A) and Energy (E).

III. Result and Discussion

Equation (3) is used to get the electrons' CSDA range values. Table 1 displays these assessed values as well as the CSDA range values for human body components such blood and lenses that were acquired using the ESTAR program for energies ranging from 30 keV to 1000 keV. We can see from the table that both numbers are rather close to one another. The maximum percentage error between the CSDA range values in blood and eye lenses that we calculated and the CSDA range values of the ESTAR software is 3.77 and 3.03, respectively. Our empirical relation's evaluation of the CSDA range values closely matches the ESTAR program's stated data.

Figures 1-2 demonstrate that the CSDA range increases steadily with electron energy and that the values of the ESTAR program's CSDA range and our computed values accord well. Also, Figure 3 illustrates how the percentage error varies with electron energy

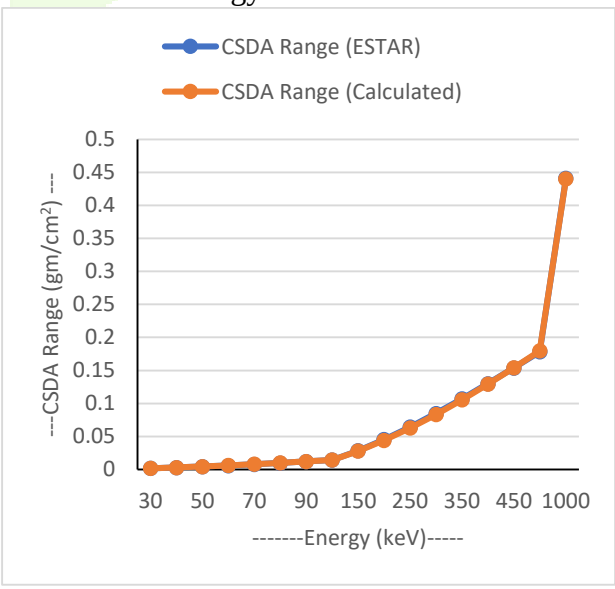

Fig. 1: Variation of CSDA Range (gm/cm^2) with electron energy (keV) for Blood

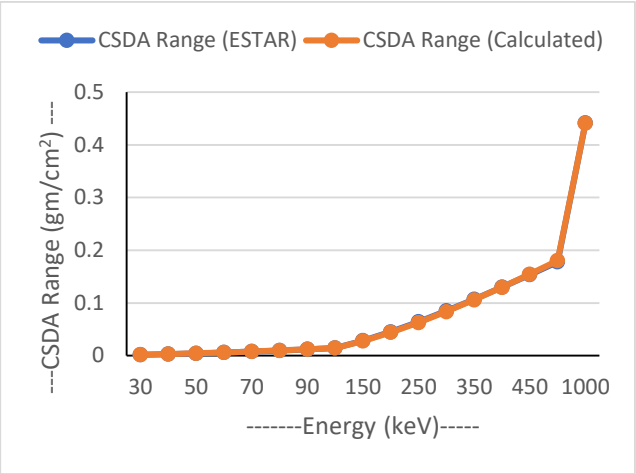

Fig. 2: Variation of CSDA Range with electron energy (keV) for Eye Lens

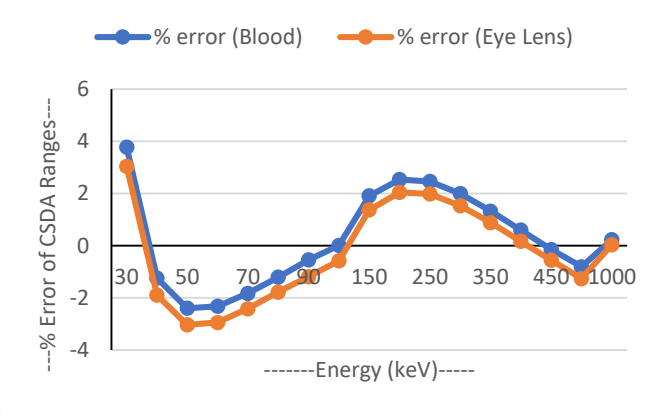

Fig. 3: Variation of % error of CSDA Range with electron energy (keV)

Table-1
Values of CSDA ranges for electrons of Blood and Eye lens

Energy (KeV)	ESTAR Values of Blood	Our Calculated Value of Blood	% error (Blood)	ESTAR Values of Eye lens	Our Calculated Value of Eye lens	% error (Eye lens)
30	0.001774	0.001707	3.771367	0.001769	0.001715	3.036588
40	0.002947	0.002984	-1.24118	0.002941	0.002997	-1.88831
50	0.004362	0.004466	-2.39515	0.004353	0.004485	-3.03169
60	0.005998	0.006137	-2.31822	0.005986	0.006162	-2.9363
70	0.007838	0.007981	-1.82479	0.007824	0.008013	-2.41066
80	0.009868	0.009987	-1.20585	0.009851	0.010026	-1.77676
90	0.01208	0.012145	-0.54185	0.01205	0.012192	-1.18253
100	0.01445	0.014448	0.011671	0.01442	0.014504	-0.58165
150	0.02845	0.027906	1.911122	0.0284	0.028011	1.368742
200	0.04531	0.044162	2.533298	0.04525	0.044326	2.041999
250	0.06434	0.062757	2.460175	0.06426	0.062987	1.980938
300	0.08503	0.083331	1.998034	0.08493	0.083633	1.527696
350	0.107	0.105578	1.328878	0.1069	0.105955	0.884101
400	0.13	0.129226	0.595766	0.1299	0.12968	0.169416
450	0.1538	0.154022	-0.1446	0.1537	0.154555	-0.55646
500	0.1783	0.179733	-0.80368	0.1781	0.180344	-1.25981
1000	0.4413	0.44027	0.233295	0.4415	0.44133	0.038616

IV. CONCLUSION

It is clear from the current study that the CSDA ranges of materials may be stated in terms of the material's mass number, atomic number, and electron incident energy. Notable features of the suggested empirical relation include its simplicity, broad applicability, and values that better align with data from the literature.

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