Theoretical study of Energy loss of proton in human tissues

Dr.Maher N.Sarsam[1], Dr.Bashair Mohammed Saied and Khansaa nasir aklo[2]
(1) Alsalam University College (2) Baghdad University-college of education Ibn Al-Haitham

ABSTRACT

Charged particles lose energy by nuclear interactions through travelling in matter are very important and very useful especially in nuclear therapy. Using Bethe and Ziegler equation and Srim, Pstar Programs, we calculate, the proton stopping power in tissue by considering the tissue as composed of 9 elements; the proton stopping powers were calculated for those elements for the energy interval 1 - 10 MeV. In addition the proton stopping power for Breast and Lung tissues are evaluated too. Results are presented and compared with the latest published data .

==

Keywords: **Proton therapy, Stopping Power, Energy loss, Human tissue, Beth and Ziegler equations**

---

1. Introduction

Charged particles are often used for radiation therapy because they have a well-defined penetration in tissues, the depth being dependent on the incident energy of particles and the nature of the irradiated material . Charge particles (protons , deuterons , alpha particles) has an important effect in radiation therapy as they have the ability to deliver their energies to the target. Beams of charged particles have a unique dose distribution, exhibiting a relatively flat entrance dose region (plateau) followed by a sharp dose peak, Bragg peak, in which the particles lose the rest of their energy. The advantage of proton s is that there is no radiation beyond the range end, while for heavier ions nuclear fragmentation of the incoming ions result in the formation of lighter ions that deposit energy beyond the primary Bragg peak. [1]

The kinetic energy loss per unit distance suffered by a charged particle, is denoted as –dT/dx, it's conventionally known as stopping power [2]. The total stopping power for proton interacting with any material or chemical composition (including the human

tissues) are calculated by Bethe formula with (I) representing the mean excitation potential of the material or the chemical composition and represented by:-

$$-\frac{dE}{dx}\left(\frac{Mev}{10^{21}\ atom/cm2}\right) = 0.239114\frac{Zt}{Ep}\ ln\left[2.17 * 10^{-3}\ \frac{Ep}{Iev}\right] \quad \dots\dots\dots (1)$$

Zt = atomic number of the target.

I (eV) = (9.76 + 58.8 × $Z^{-1.19}$)Z ....(2)

The results of this formula are valid for energies > 1 MeV, where more consistent results are recorded. Good agreements with the results of SRIM and PSTAR are observed. [3]

Ziegler formula

To bridge the gap between the high- and low-energy theories, interpolation formulas of different levels of complexity were proposed by Varelas and Biersack [4] :

Where the stopping power (S) is calculated as:

$$S = \frac{S\ Low\ S\ High}{S\ Low + S\ High} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots..(3)$$

Where S Low (Low Energy Stopping) is

$$S\ Low = B1E^{1/2} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots..\dots\dots(4)$$

And S High (High Energy Stopping) is

$$S\ High = \frac{B2}{E}\ln\left(1 + \frac{\mathrm{B3}}{\mathrm{E}} + \mathrm{EB4}\right) \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots..(5)$$

Here B1, B2, And B3 are fitting constants represented in table (1). [4].

SRIM (Stopping and Range of Ions in Matter)

SRIM is a software package concerning the Stopping and Range of Ions in Matter. Since its introduction in 1985, major upgrades are made about every six years. Currently, more than 700 scientific citations are made to SRIM every year. A recent textbook ‘‘SRIM – The Stopping and Range of Ions in Matter” describes in detail the fundamental physics of the software. Since this time, corrections have been made based on new experimental data.

For SRIM-2010, the following major improvements have been made:

(1) About 2800 new experimental stopping powers were added to the database, increasing it to over 28,000 stopping values.

(2) Improved corrections were made for the stopping of ions in compounds.

(3) New heavy ion stopping calculations have led to significant improvements on SRIM stopping accuracy.

(4) A self-contained SRIM module has been included to allow SRIM stopping and range values to be controlled and read by other software applications.

(5) Individual interatomic potentials have been included for all ion/atom collisions, and these potentials are now included in the SRIM package. The SRIM code simulates the transport of heavy ions pof than 2 GeV/u in matter. The models are based on quantum mechanical treatments and, thus statistical, in the sense that the ions makes macroscopic movements during their collision thus the collision results are averaged. This procedure, common to most charged-particle transport algorithms. A full catalog of stopping power plots can be downloaded at www.SRIM.org. Over 500 plots presented the accuracy of the stopping and ranges produced by SRIM along with 27,000 experimental data points are indicated. References to the citations which reported the experimental data are included. The principle authors of the SRIM series are James F. Ziegler and Jochen P.Biersack, although others have contributed. [5]

PSTAR

A PC package is documented for calculating stopping powers and ranges of electrons, protons and helium ions in matter for energies from 1 keV up to 10 GeV, These databases can also calculate similar results at any other energy grid between these limits, Energies are specified in MeV. Stopping powers and ranges for electrons can be calculated for any element, compound or mixture. Stopping powers and ranges of protons and helium ions can be calculated for 74 materials (26 elements and 48 compounds and mixtures).

The ESTAR, PSTAR and ASTAR calculate stopping powers and ranges for electrons, protons and alpha particles (helium ions). A detailed description of the methods used in these programs can be found in ICRU Reports [6] and [7]. [8]

2. Materials and Methods

It is known that the chemical composition of human tissues are of importance in studying micro-dosimetric distributions in human irradiated with radiation. Chemical composition of human tissues depend in general on breed, diet, age, sex, health, etc., and they may vary appreciably (5-10%) among individual human beings. [9]

The chemical composition of the Breast and Lung tissues are given in Table(2). [10]

Energy loss in Compound and Mixtures

It is usual to think of a compound or mixture as made up of thin layers of the pure elements in the proportion (Bragg additivity). Let w_i its weight fraction:

$$\langle\frac{dE}{dx}\rangle = \sum_i w_i \left(\frac{dE}{dx}\right)_i \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots . (6)[11].$$

And we was calculate the stopping power for every each elements by using eq(1) and eq(3) and Srim, Pstar software and the results represented in table (3).

3. Data Reduction and Analysis

We calculate the stopping power of the Breast and Lung tissues using Bethe formula eq(1) and Ziegler and SRIM, PSTAR software for each element of their composition, results are represented in tables(3,4).

Table 1: Coefficient for Stopping of Hydrogen. [4]

ELEMENT	B1	B2	B3	B4
H [1]	1.44	242.6	1.2E4	0.1159
C [6]	2.989	1445	957.2	0.02819
N [7]	3.35	1683	1900	0.02513
O [8]	3	1920	2000	0.0223
Na [11]	2.869	2628	1854	0.01472
P [15]	3.647	3561	1560	0.01267
S [16]	3.891	3792	1219	0.01211
Cl [17]	5.714	4023	878.6	0.01178
K [19]	5.833	4482	545.7	0.01129

Table 2: Elemental composition of Breast and Lung tissues.[10]

S.N	Human Tissues	Composition(element: fraction) by weight
1-	Breast tissue	H: 0.106, C: 0.332, N:0.030, O: 0.527, Na:0.001, P:0.001, S: 0.002, Cl:0.001
2-	Lung tissue	H: 0.103, C: 0.105, N:0.031, O:0.749, Na: 0.002, P: 0.002, S: 0.003, Cl: 0.003, K:0.002

When we applied this (element: fraction) by weight in eq(7) for Breast tissue composition and with the stopping power by four deferent equation and computer program (Bethe equation, zieglar equation, Srim Program, Pstar Program we found:-

Table 3. Stopping Power in Breast Tissues in (MeV/10^21atom/cm2)

Stopping Power in Human Tissues in (MeV/10^21atom/cm2)						
Ep(MeV)	Brest Tissue					
	Stopping Power				Present Work	
	Bethe	Zieglar	Pstar	Srim	Average SP	S.P (P.W)
1	4.6899	4.9477	4.8499	4.6638	4.7878	4.7941
2	2.8918	3.0397	2.9881	3.0247	2.9861	2.9650
3	2.1411	2.2492	2.2215	2.2456	2.2143	2.2152
4	1.7193	1.8048	1.7881	1.8059	1.7795	1.7892
5	1.4459	1.5167	1.5092	1.5207	1.4981	1.5086
6	1.2528	1.3133	1.3069	1.3194	1.2981	1.3072
7	1.1086	1.1613	1.1560	1.1689	1.1487	1.1543
8	0.9964	1.0431	1.0454	1.0518	1.0342	1.0334
9	0.9063	0.9483	0.9528	0.9576	0.9412	0.9350
10	0.8323	0.8704	0.8771	0.8807	0.8651	0.8530

We calculate the stopping power for each element of the Lungt tissue using eq(7) using the four different equations (Bethe formulan, Ziegler equation, Srim Program, Pstar Program) as shown in table 4.

Table 4. Stopping Power in Lung Tissues in (MeV/10^21atom/cm2)

Stopping Power in Human Tissues in (MeV/10^21atom/cm2)						
Ep(MeV)	Lung Tissue					
	Stopping Power				Present Work	
	Bethe	Zieglar	Pstar	Srim	Average SP	S.P (P.W)
1	4.9951	5.2469	5.1684	4.8823	5.0732	5.0801
2	3.0885	3.2290	3.1871	3.2199	3.1811	3.1558
3	2.2894	2.3926	2.3695	2.3942	2.3614	2.3627
4	1.8397	1.9216	1.9100	1.9265	1.8995	1.9106
5	1.5479	1.6159	1.6131	1.6231	1.6000	1.6121
6	1.3417	1.3999	1.3979	1.4090	1.3871	1.3973
7	1.1876	1.2384	1.2366	1.2488	1.2279	1.2340
8	1.0676	1.1127	1.1191	1.1240	1.1059	1.1048
9	0.9713	1.0119	1.0203	1.0234	1.0067	0.9995
10	0.8922	0.9289	0.9397	0.9415	0.9256	0.9116

Fiq 1 represent the stopping power of proton interacting the Breast tissue ,while fig 2 represent the stopping power of proton interacting the Lung tissue.

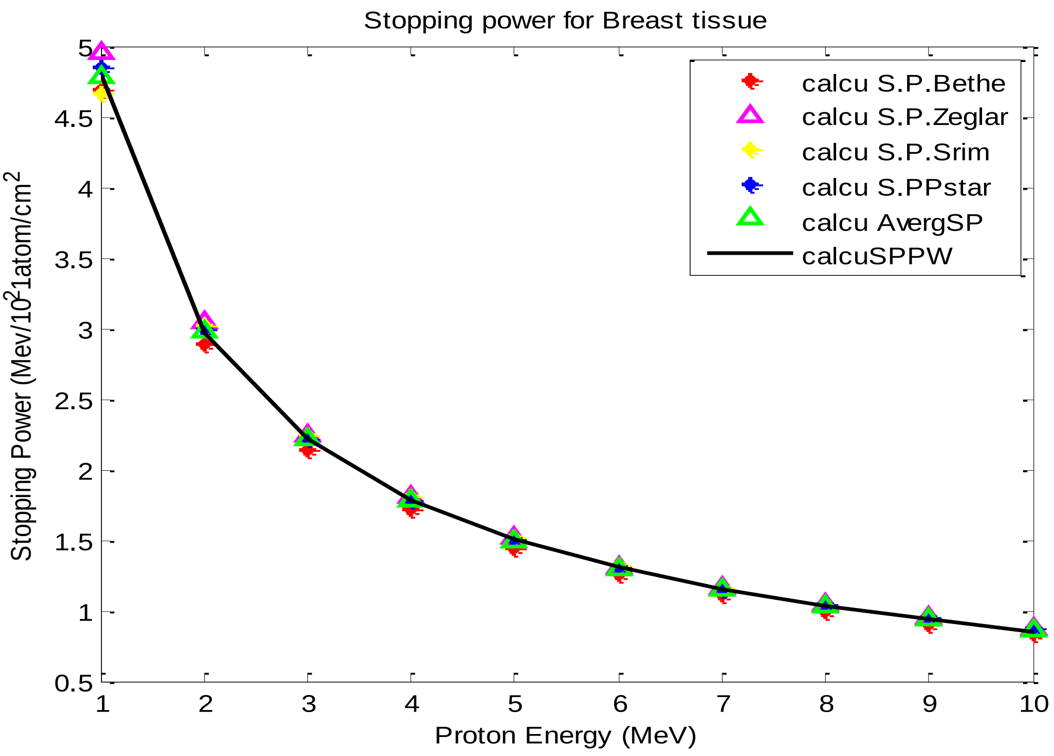

Fig 1. Stopping power for Proton in Breast tissue

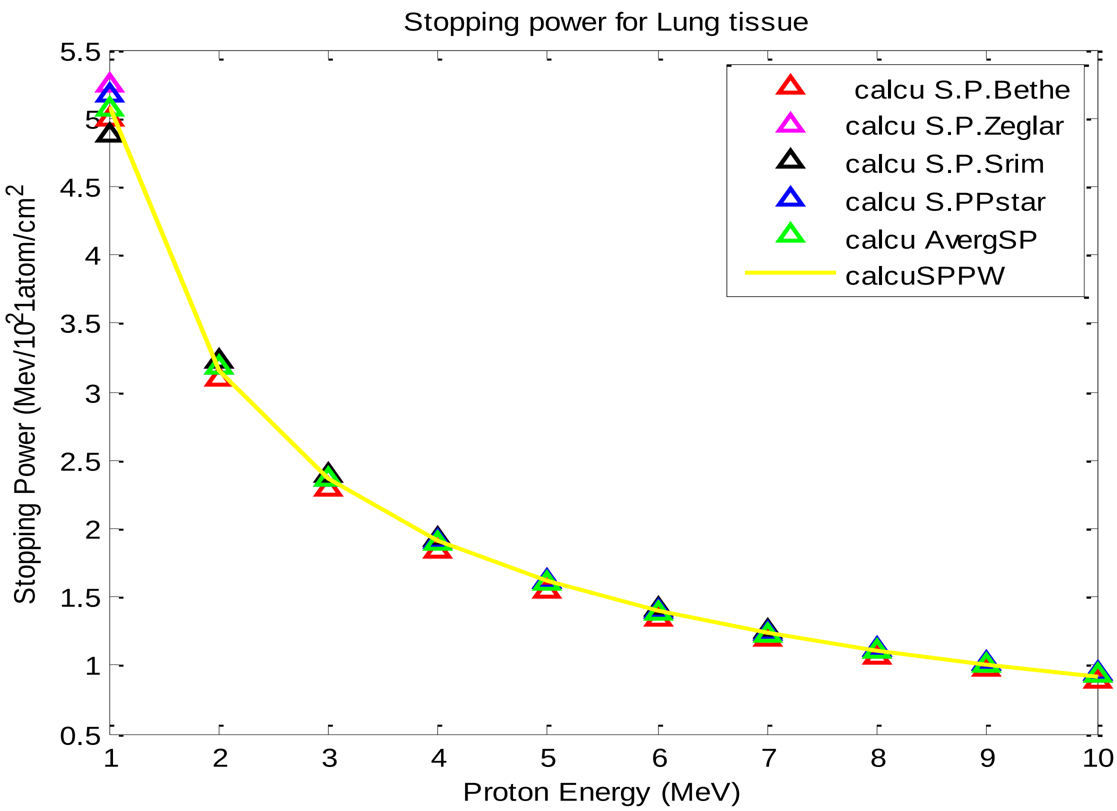

Fig 2. Stopping power for proton in Lung tissue

4. Conclusion:

Results shows clearly that the four methods gives approximately the same results. The Beth and Ziegler formulas derived from theoretical considerations, while SRIM and PSTAR are computed fitted programs. We conclude from results that we can propose two empirical equations for the stopping power for the Lung and Breast.

$F(x) = a \times x^{b} + c$ ……………………………………………………….…(7)

Where a and b and c are fitting constant and it will deferent in Beast tissue and Lung tissue,

Breast tissue: a = 5.121, b = -0.6375, c = -0.3269

Lung tissue: a = 5.453, b = -0.6279, c = -0.3729

F(x): Stopping power for Breast tissue

X: is represent energy loss of proton Ep, and the equation in Breast tissue become:

$-\left(\frac{dE}{dx}\right) Breast = 5.121 \times Ep^{-0.6375} - 0.3269$………………………..(9)

And Lung tissue become:

$\left(\frac{dE}{dx}\right) Lung = 5.453 \times Ep^{-0.6279} - 0.3729$ ……………………........(10)

Error rate in these equation are 0.9999,

And the data output from these equations are apply in table (3,4) represented by SP(P.W), and these data plotting in fig(1,2).

And we have preferred to retain the reference numbers from this Bibliography.

5. References:

[1] K. Kettern. H. H. Coenen, S.M. Qaim, (2009), Quantification of radiation dose from short – lived positron Emitters formed in human tissues under proton therapy conditions, Radiation Physics and Chemistry, 78 (2009) 380 – 385.

[2] R.D. Evan, The Atomic Nucleus (McGraw - Hill, New York, (1955), Chaps 18 – 22, W.E. Meyerhof, Element of Nuclear Physics (McGraw – Hill, New York, 1967), Charged – Particle Interaction: Stopping Power, Collisions and Ionization 22101 Applied Nuclear Physics (Fall 2004), Lecture 14.

[3] Ali Hassan Ahmed, July (2006), Empirical Formula for Calculating Neutron Yield from (α,n) and (p,n) Reactions for the Light Element Targets, A Thesis submitted to the council of the college of science university of salah Addin – ERBIL.

[4] H.H Andersen, J.F. Ziegler, 1977, HYDROGEN stopping Power and Ranges in All Elements, Volume3, Pergamon Press Inc., Maxwell House, Faiview Park, Elmsford, New York 10523, U.S.A.

[5] Mohan Singh, Lakhwant Singh, (2011), Electronic Stopping Power of Various Organic Compounds for Proton (0.05-10MeV): A Comparative study, Material Physics and Mechanics, 12, 43-57.

[6] International Commission on Radiation Unit and Measurement, ICRU Report 37, Stopping Power for Electrons and Positrons, 1984.

[7] International Commission on Radiation Unit and Measurement, ICRU Report 49, Stopping Powers and Ranges for Proton and Alpha Particles, 1993.

[8] Martin J. Berger, (Dec 1993), Estar, Pstar, and Astar:- computer programs for calculating Stopping Power and Range for Electrons, Protons and Helium Ions, Version2, International Atomic energy Agency, NUCLEAR DATA SERVICES, Documentation series of the IAEA Nuclear data Section.

[9] young S. Kim, (1974), Human Tissues: Chemical Composition and Photon Dosimetry Data, Radiation Research, 57, 38 – 45.

[10] S.R. Manohara, S.M. Hnagodimath, L.Gerward, (2011), Energy absorption buildup factors of human organs and tissues at energies and penetration depths relevant for radiotherapy and diagnostics, Journal of Applied clinical Medical Physics, Vol 12, No4, 1 – 15.

[11] Don Groom, (8 December 1993), Energy loss in matter by heavy particles, Particle data group notes, PDG-93-06

دراسة نظرية لفقدان طاقة البروتون في النسيج البشري

د.ماهر ناصر سرسم[1] ,د.بشائر محمد سعيد , خنساء ناصر عكلو[2]

(1) كلية السلام الجامعة (2) جامعة بغداد –كلية التربية/ابن الهيثم

الخلاصة

ان فقدان الجسيمات المشحونة لطاقتها من خلال التفاعلات النووية جراء اختراقها المادة تعتبر من الامور غاية في الاهمية وبشكل خاص في موضوع التشخيص والمعالجات الطبية. تم استخدام معادلات بيث وزيكلر وكذلك برنامجي سرم وبيستار في حسابات قدرة ايقاف البروتونات في النسيج البشري بافتراض تكوينه من تسعة عناصرولمجال طاقي من 1 ولغاية 10 ميف وكذلك تم حساب قدرة ايقاف البروتونات في انسجة الرئة والصدر.تم استعراض كافة النتائج ومقارنتها باحدث المنشورات العالمية .