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NUMERICAL CALCULATION OF MASS STOPPING POWER AND RANGE FOR AN INCIDENT PROTON IN BREAST TISSUES FOR THE ENERGIES OF (1- 100 MEV)

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ABSTRACT

In this work the stopping power and energy range for proton was found by using numerical method and other two simulation techniques. The values of stopping power have been calculated in the range of energies between 1 MeV to 100 MeV in breast tissue. The total stopping power was calculated numerically using an equation which is derived by Eko Sulistya. The criterion for the total stopping power that obtained when summing the electronic and radioactive stopping power is obtained from PSTRA and SRIM 2013 simulation programmes. The range can be determined numerically by continuous slowing down approximation (CSDA). The result of these three methods agree with the PSTAR (NIST) data and SRIM 2013 within different percentage less than 3 %. The quantitative comparison done with other results showed that it has an overall good agreement within different percentage less than 10 %. The data will be useful for applications in radiobiology and researchers. The main stopping power mechanism is the slowing down due to interactions with target atoms through excitations and ionization of target electrons via Coulomb interaction.

The precise determination of the proton energy in radiotherapy planning can be achieved if the stopping power of protons is specified for body tissue .The equation of Bethe-Bloch is meanly used to understand how to calculate the stopping power of proton, but not for radiative energy loss.

Keywords*: mass stopping power; range; SRIM 2013; PSTAR; CSDA.*

I. INTRODUCTION

The stopping power and range can be obtained for any ions in a matter. The stopping power was developed since 1983 by James. F. Ziegler et al **[1]**. The stopping power refers to the property of the material energy loss per unit's path length and numerically can be expressed as $\frac{-dE}{dx}$ and its unit is (MeVcm^2/g).

Theoretically the stopping power of protons and heavier ions was reviewed by J. F. Ziegler **[2]**. In 1913, Niels Bohr's early work was evaluated the traditional stopping power of the fast heavy charged particle. He found a clearly formula for the stopping power for the heavy charged particles and determined the energy loss of a heavy charged particle in a collision with an electron over all possible distances and energies **[2]**. The charged particle undergoes various interactions with the orbital electrons and the nuclei of the atoms. The atoms or molecules were ionized when the fast charged particles pass through a matter and lose its energy gradually.

In 1946, Robert Wilson published the biophysical rationalization for proton therapy that is the key to engineering techniques of proton beam **[3]**. After that, the physics of proton's therapy has been modified and markedly advanced. Today, numerical equations and simulation techniques are available to predict the property of proton therapy. Proton

has different dosimetric property than photon used in normal radiation therapy. After a short region, traditional radiation has shown an exponentially lessening energy precipitation with increasing deepness in tissue. In disparity, protons display an increasing energy deposition with penetration distance leading to the extreme (the "Bragg peak") nearby the end of the range of the proton beam **[4]**. The rationales for proton therapy are superior spatial dose apportionment in the patient. The preference of protons over photons is that providing a highly conformal and uniform dose to a tumor **[5]**. The object of this work is to investigate the stopping power and range of proton in breast tissues at energy between 1 MeV and 100 MeV. The stopping power was studied by considering the velocity of the charged particles and effective of mean irritation energies of the target material. The method using in this work doesn't depend on the Bethe- Bloch formula, it only depends on constants values and energy. The density and elements installation of breast tissues were taken from ICRU **[6]**.

The range of the particle in the goal materialistic can be calculated by using continuous slowing down approximation (CSDA) **[4]**. One must consider two different energy loss mechanisms when studying the stopping power and the range of electrons, positrons and proton **[3]**. The first loss mechanism is due to collision with the target's electrons (known the collisional stopping power) and the other due to the liberation of radiation in the Coulomb field of the target's nuclei (known bremsstrahlung or radiative stopping power). In this method, the total stopping power is achieved by adding collisional and radiative stopping power of the target. When calculating the collisional stopping power, each screening effects are considered within introducing an efficient charge of both incident particle and target. Also the effect of average ionization energy of the target is considered. All these values are affecting to collisional stopping power especially less than 10 keV and Bragg's rule is employed for molecular targets **[7].**

II. MATERIALS AND METHOD

The adipose tissue and glandular tissue are similar in components and different in the percentage ratios and density. The elements composition of adipose is shown in table 1 below.

Table 1: Phantom Characterization (Data provided by ICRU report 49)

Breast Type	Elements composition of breast tissue by weight fraction						Density
	H	C	N	O	Cl	Ca	(g. cm^{-3})
100% Adipose	0.098	0.714	0.020	0.164	0.002	0.001	0.92

In this work one simulate breast tissue by assuming it consisting of 100% adipose. The basic mechanism of a movable charged particle slowing down is Coulomb interaction between the particles and electrons of the matter. This is applied for all charged particles. The equation of the stopping power for heavy ions in a homogeneous medium was obtained by Bethe- Bloch formula [**8],** using quantum mechanics. Bethe- Bloch derived a useful equation expression for the stopping power of the heavy charged particles.

$$-\frac{dE}{dx} = \frac{4\pi k_0^2 Z^2 e^4 n}{mc^2\beta^2}\left[\ln\frac{2mc^2\beta^2}{I(1-\beta^2)} - \beta^2\right] \qquad (1)$$

Where $k_0 = 8.99 \times 10^9\ Nm^2C^{-1}$ (Coulomb constant), z = atomic number of the heavy particle, e = magnitude of the electron charge, n = number of electrons per unit volume in the medium, m = electron rest mass, I = mean excitation energy of the medium, c = speed of light in vacuum, $\beta = v/c$ speed of the particle relative to light speed.

Equation (1) is not useful for low-energy ions, i.e. when the ion velocity is very smaller than the speed of the electron orbit **[9].** Fermi and Teller proposed equation for energies less than 25 keV for stopping power. For energies greater than 100 keV, Bohr proposed an equation based on the Thomas-Fermi model**[7]**.

H. Singh et al. **[10**], suggest an empirical equation to obtain the mass stopping power for protons at energies in the range of 0.5 Mev up to 200 MeV in substances such as water, bone, muscle and soft tissue of human body. The equation supposed by Singh is given by:

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$$\text{mass stopping power} = y_0 + A_1 e^{-\frac{x}{t_1}} \qquad (2)$$

where y_0 , A_1 and t_1 are constants determined from the exponential fitting of experimental data, and $x = \langle \frac{Z}{A} \rangle E^{0.05}$, depends on atomic number (Z), atomic weight (A) and energy (E).

Both Singh and Mukherjee et al **[11],** proposal's equation did not give the value of stopping power of protons for energies less than 0.5 MeV.

Eko Sulistya **[9]** established a numerical equation for mass stopping power of protons in some types of human body substance such as water, muscle, breast tissue, and bone, given by:

$$\frac{dE}{dx} = \frac{a+c\ ln\ E+e\ (\ln E)^2+g\ (\ln E)^3}{1+b\ \ln E+d\ (\ln E)^2+f\ (\ln E)^3+h\ (\ln E)^4} \qquad (3)$$

where E is the proton energy while a, b, c, d, e, f, g and h are the fitting parameters. These values depend on the type of material. These parameters of equation (3) are found by fitting the data by using SRIM 2013 program **[9]**. Many researchers reported various mass stopping power data but they do not completely agreed in the case of low proton energies. In this work one choose equation (3) and calculate the mass stopping power in breast tissue and the results will be compared with the PASTA data and SRIM 2013 program data.

Table 2: The fitting parameters values for breast tissue for (H ion) Eko Sulistya [9]

Parameter							
a	*b*	*c*	*d*	*e*	*f*	*g*	*h*
272.416	-0.688	-365.781	-0.001	184.766	0.127	-24.067	0.050

Range calculations

The distance between the initial point and final (absorption) point of incident particles in the medium is called the range (R). The range of heavy particles is almost a straight line **[12, 13].** In this method, one assumes that the incident particles lose their energy continuously where energy loss fluctuations are neglected. The CSDA range for an incident particle with initial kinetic energy E_0 is calculated by:

$$R = \int_{E_f}^{E_0} \frac{dE'}{S_{Tot}(E')} \qquad (6)$$

where $S_{Tot}(E') = S_{col}(E') + S_{rad}(E')$ is the total stopping power at energy E' , and E_f is the final energy at which the particles are assumed to be stopped by the medium **[12]**.

III. RESULT AND DISCUSSION

The electronic stopping power for heavy charged particles has been calculated numerically. Protons lose their energy due to the collisions with the atomic electrons of the stopping materials. The stopping power was also obtained by using two simulation techniques. From figure 1, it is observed that for an electronic stopping power there is a significant reduction in the energy range of 1 MeV to 40 MeV. Then it decreases gradually until it reaches 100 MeV. The physical aspects of the energy loss process of low energy protons in biological samples are of great interest for medical applications. The phenomenon of lowering electronic stopping power is related to the fact that the velocity of protons is much less than the velocity of light. The collisional stopping power has higher value when the incident particle has lower energy.

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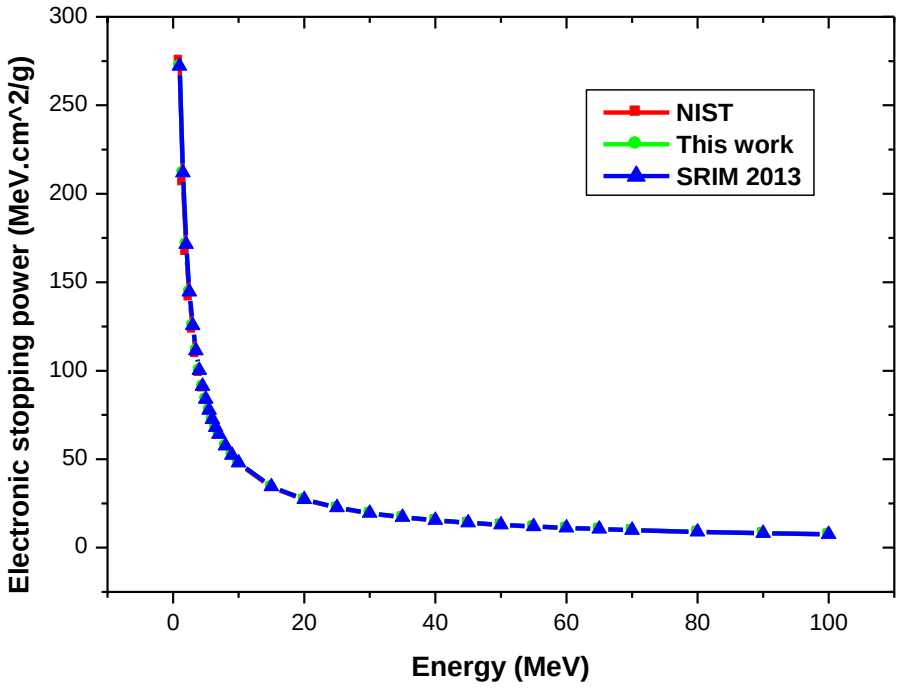

Figure.1 The electronic stopping power for a proton in breast tissue: comparison of three results obtained by NIST SRIM 2013 simulation methods, and the numerical work.

Protons interact with the nucleus of the atom via non-elastic collision in which nucleus is non-radioactive energy transformation**.** This means a reaction in which a proton has been absorbed by the nucleus and a neutron has been ejected. At lower energies a dominant mechanism is collisional stopping power, while the radiative stopping power has become important at the higher energy above 10 MeV.

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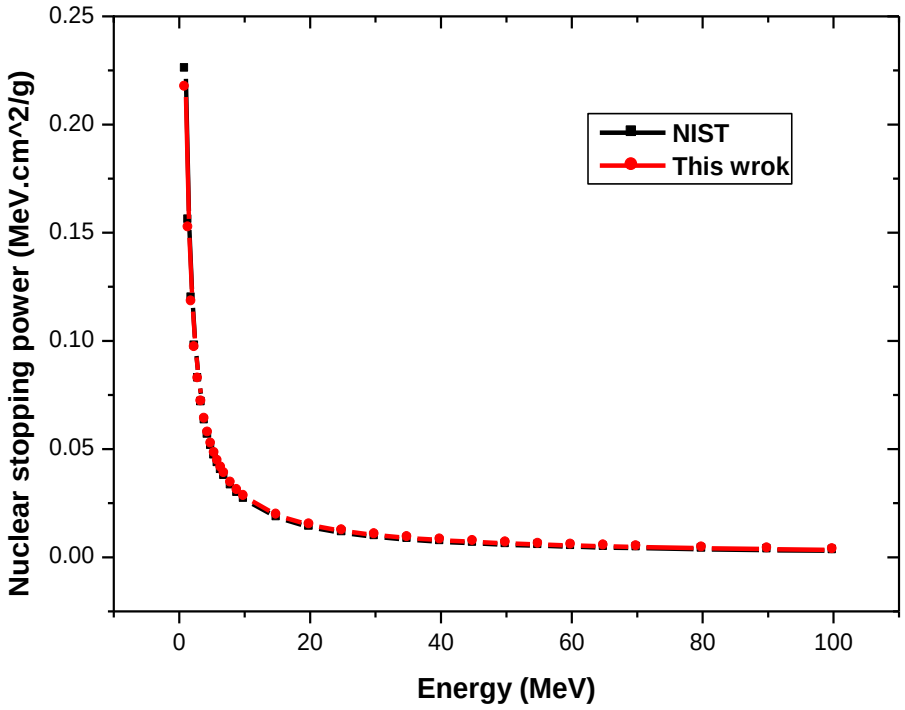

Figure .2 The nuclear stopping power of proton in breast tissue found by using numerical work compared with the NIST simulation result.

The total stopping power of proton in the breast tissue was obtained by adding the electronic (collisional) and radiative (nuclear) stopping power for incident energy between 1 MeV to 100 MeV. This energy range is quite broad for medical applications especially for breast. Furthermore, it is potentially used in other applications.

From figure 3, the numerical results agreed with the PSTAR (NIST) data and SRIM 2013 within difference percentage less than 3 %. The numerical results of this work were compared with the results of similar work by others. It is found that it has a good agreement with them **[11, 14, 15],** within difference percentage less than 10 %. These slight differences may be due to the change of elemental compositions of body tissue. These significant elemental changes results from the change of environment of different individuals even for that of the same age. Also, there are some differences due to dissimilarity methods and experimental techniques used by researchers. However, radiation interaction contains errors by virtue of additional elements. Even the elemental a composition of body tissues suffer from errors.

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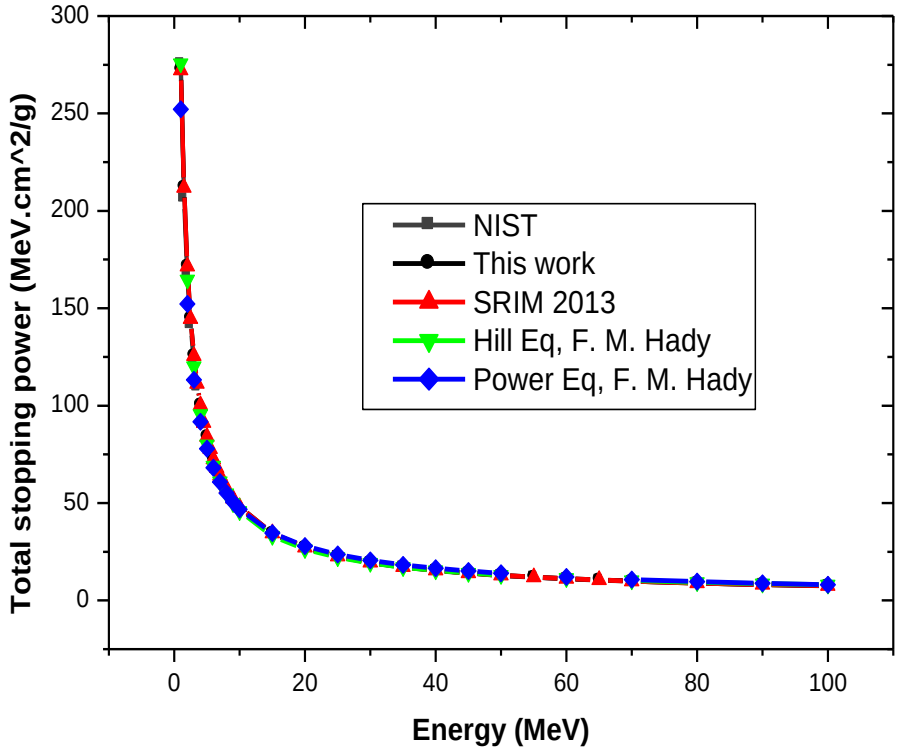

Figure .3 The total mass stopping power of proton in breast tissue the numerical work ompared with PSTARS (NIST) data base, SRIM 2013 program, Hill equation and Power equation data calculated by F.M. Hady

An empirical formula of continuous slowing down approximation ranges (CSDA) is simulated for protons in breast tissue. The (CSDA) range formula depends on several parameters such as total energy, density, atomic number and human body parts. The result is found to be in quite agreement with the values given by the PSTAR and SRIM 2013 program as shown in figure 4.

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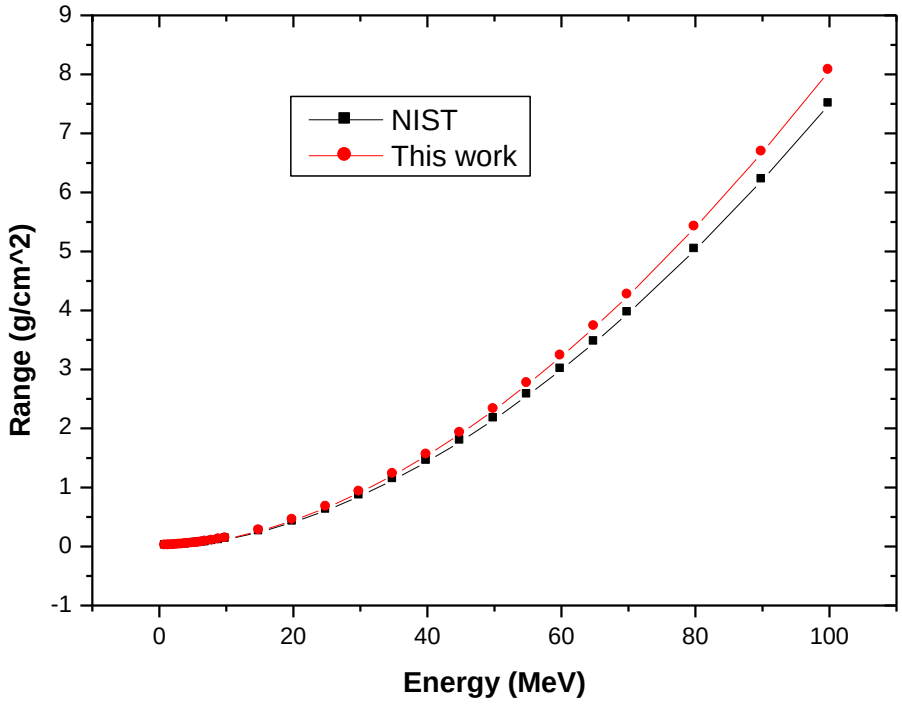

Figure .4 Continuous slowing down approximation ranges (CSDA) of proton kin breast tissue found numerically compared with NIST simulation results

IV. CONCLUSION

In this paper, the stopping power and CSDA have been determined successfully for the proton in breast tissue by using numerical methods based on Eko Sulistya equation. The total mass stopping power of materials is expressed in non-linear form. The result is in a good agreement with the previous work for all energy range values from 1 MeV up to 100 MeV. Numerical equation proposed by E. Sulistya is useful for calculation of mass stopping power but not easy to be implemented in programming.

REFERENCES

1. *Ziegler, J.F., M.D. Ziegler, and J.P. Biersack, SRIM: the stopping and range of ions in matter. 2008: Cadence Design Systems.*
2. *Ziegler, J.F., Stopping of energetic light ions in elemental matter. Journal of applied physics, 1999.* ***85****(3): p. 1249-1272.*
3. *Newhauser, W.D. and R. Zhang, The physics of proton therapy. Physics in Medicine & Biology, 2015.* ***60****(8): p. R155.*
4. *Olsen, D.R., et al., Proton therapy–a systematic review of clinical effectiveness. Radiotherapy and oncology, 2007.* ***83****(2): p. 123-132.*

5. *Azimi, P. and A. Movafeghi, Proton Therapy in Neurosurgery: A Historical Review and Future Perspective Based on Currently Available New Generation Systems. International Clinical Neuroscience Journal, 2016.* ***3****(2): p. 59-80.*
6. *ICRU, I., Tissue substitutes in radiation dosimetry and measurement. International Commission on Radiation Units and Measurements, 1989.*
7. *Gümüş, H., New stopping power formula for intermediate energy electrons. Applied Radiation and Isotopes, 2008.* ***66****(12): p. 1886-1890.*
8. *B. M. Saied, S.M.H., Stopping power and range for proton interaction with Ovary and Testis tissues. International Journal of Advanced Research in Science, Engineering and Technology 2017.* ***4****(8): p. 4353-4362.*
9. *Sulistya, E. and A.H. Kusminarto, Numerical equation for the mass stopping power of protons in human body subtances. quantum, 2014.* ***6****(2): p. 2-4.*
10. *Singh, H., S. Rathi, and A. Verma, Stopping powers of protons in biological human body substances. Universal Journal of Medical Science, 2013.* ***1****(2): p. 17-22.*
11. *Mukherjee, B., Mass stopping powers of protons up to 200 MeV in some biologically important materials. Nuclear Instruments and Methods in Physics Research, 1983.* ***211****(1): p. 235-237.*
12. *Tufan, M.Ç., T. Namdar, and H. Gümüş, Stopping power and CSDA range calculations for incident electrons and positrons in breast and brain tissues. Radiation and environmental biophysics, 2013.* ***52****(2): p. 245-253.*
13. *Seltzer, S.M. and M.J. Berger, Bremsstrahlung energy spectra from electrons with kinetic energy 1 keV–10 GeV incident on screened nuclei and orbital electrons of neutral atoms with Z= 1–100. Atomic Data and Nuclear Data Tables, 1986.* ***35****(3): p. 345-418.*
14. *Usta, M. and M.Ç. Tufan, Stopping power and range calculations in human tissues by using the Hartree-Fock-Roothaan wave functions. Radiation Physics and Chemistry, 2017.* ***140****: p. 43-50*
15. *M. F. Hady, M.H.T., K. M. Jassim, Investigations into the Proton Stopping Power of Human Body. Journal of Chemical, Biological and Physical Sciences, (JCBPS), 2015.* ***5****(4): p. 4345-4354.*