Calculation of Stopping Power and Range of Nitrogen Ions with the Skin Tissue in the Energies of (1-1000) MeV

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Abstract

The use of heavy ions in the treatment of cancer tumors allows for accurate radiation of the tumor with minimal collateral damage that may affect the healthy tissue surrounding the infected tissue. For this purpose, the stopping power and the range to which these particles achieved of Nitrogen (N) in the skin tissue were calculated by programs SRIM (The Stopping and Range of Ions in Matter),(SRIM Dictionary) [1],(CaSP)(Convolution approximation for Swift Particles)[2]which are famous programs to calculate stopping power of material and Bethe formula , in the energy range (1 - 1000) MeV .Then the semi - empirical formulas to calculate the stopping power and range of Nitrogen ions in the skin tissue were founded from fitting for average the values which calculated by using these programs using (MATLAB2016) program,the maximum value of energy for Nitrogen ions can lose along its path in skin tissue is founded and the range correspond to this value, the maximum range for Nitrogen ions can be reached in the skin tissue is founded too .The importance of the research is to know the data of thes particles and their use in treatment without causing a bad effect on the patient.

Keywords: Stopping power, Range, Nitrogen ions, skin tissue.

Introduction

Of the important quantities that must be known when studying the particles therapy field or interaction of heavy particles with matter is the stopping power and range.The stopping power is the ability of the medium to stop the particles which penetrate it,the mass stopping power of a material is obtained by dividing the stopping power by the density (ρ). Unit for mass stopping power) is $\text{Mev.}\,\text{cm}^2\text{g}^{-1}$[3,4], the range of the particle is the average distance travelled before the particle loses all its original kinetic energy [5],which computed by numerical integration of the stopping power.These quantities are studied to determine the energy needed for the particle to penetrate a specific dimension in the tissue,the energy range (1-1000)MeV has been chosen because in low energies heavy ions cannot penetrate the materials as the light particles.

The interaction of charged particles with materials enters a number of medical fields and nuclear interactions; generally, the interaction of heavy charged particles such as Nitrogen (N) is different from that of other particles such as protons and alpha particles, which makes it more positive in the treatment of cancer diseases because of the ionic density in the latter orbit, making the damage in the RNA molecule in one cell more effective and this increases the biological efficiency of the dose factor (1.5-3) compared with the use of protons [6].

The aim of this work is to study appropriate database can be chosen by selecting the appropriate energy of Nitrogen ions to irradiate the infected skin tissue and prevent the passage of these particles into adjacent non-infected tissues, which may cause adverse medical effects on the patient, tables (1) & (2) show some properties of both Nitrogen ion and skin tissue respectively [18,19].

Table (1): Properties of Nitrogenion

Name of element	Sym bol	Number of protons	Number of neutrons	Number of electrons	Atomic weight (amu)	Electrons configuration	Valenc y	Atomic density atoms/cm^3 x10^{22}
Nitrogen	N	7	7	7	14.0067 4	[He]2s^{2}2p^3	3	4.4111

Table (2): Properties of skin tissue

Human Tissue	Density g/cm^3	C	Cl	H	K	N	Na	O	P	S
Skin	1.09	0.204	0.003	0.100	0.001	0.042	0.002	0.645	0.001	0.002

Thus, the range and stopping power of the skin tissue for Nitrogen ions will be studied using several programs which are CaSP, SRIM and SRIM Dictionary and Bethe formula, also we calculate the range of this particle.Previous research in this area has been carried out on this ion and carbon such as shown in references [7,8].In the present work we compared some famous and available theoretical (Casp 5.2)[13] and semi-empirical (SRIM 2008)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 [14 & 15], procedures of stopping power calculation has been checked using statistical analysis of deficits between computed and experimental data of (skin tissue) for (Nitrogen) ions in energy range of (1-1000) MeV.

The range formulas were obtained by directly integrating the reciprocal of stopping power for (Nitrogen) ions and the values of the range for the (skin tissue) are calculated and compared with (SRIM).

Theory

Stopping power

The Bethe -Bloch formula is used to calculate the stopping power of heavy charged particles derived using relative quantitative
e mechanics given by the relationship [9,10]:

$$-\frac{dE}{dx}=\frac{4\pi n z^2 K_0{}^2 e^4}{m_0 v^2}[\ln\frac{2m_0 v^2}{I}-\ln(1-\frac{v^2}{c^2})-\frac{v^2}{c^2}] \quad \text{--------(1)}$$

Where
(dE/dx): stopping power
Z: charge of the incident particle
n: number of electrons per unit volume.
m_0: rest mass of electron.
V: velocity of incident particle.
e: electron charge.
K_0: 1/4 ЛЄ $_0$
I: mean excitation or the ionization energy of the medium.
This equation shows dependence of (dE/dx) on the velocity of interact particle but ($\ln\frac{2m_0v^2}{I}$) almost does not give any little change in (v) .Many researchers have reported different tables and relationships for stopping power.
For mixture or compound the stopping power can be calculated from the following relation [11]:

$$\frac{dE}{dx}=\sum_i w_i(\frac{dE}{dx})_i \text{ --------(2)}$$

Where W_i:Wight fraction of I the element, (dE/dx):stopping power

Range of Nitrogen ions

Because the stopping power depends on the energy of particle, thenit is possible to calculate the path of the particle which corresponds to the lower particle energy from the initial valueE_0 to some smaller valueE_1 . Based on the definition of the stopping power, that path is equal to the integral [12]

$$R=\int_0^R dx=\int_{T_0}^{0}\frac{-dE}{-\frac{dE}{dx}}=\int_{T_1}^{T_0}\frac{dE}{\frac{dE}{dx}}=\int_{T_1}^{T_0}\frac{dE}{\frac{dE}{dx}}+R_1(T_1) \text{ --------(3)}$$

Where dx: path length variable of integration.
(dE/dx): stopping power.
T_0: the initial kinetic energy of the charge particles.
T_1: some limit of energy below the calculation cannot be performed.

Results and discussion

In the present work the calculations of the mass stopping power and range of Nitrogen ions in the elements of skin tissue (C=20.4%,Cl=0.3%,H=10%, K=0.1%,N=4.2%,Na=0.2%,O=64.5% ,P= 0.1%andS=0.2%) [14] in energy range (1-1000)MeV have been done using the (SRIM 2008), (Casp 5.2) and (SRIM Dictionary for compound) programs. The results tabulated in table (3) and plotted in figures (1, 2, 3) show these measurements.

1-Using MATLAB 2016 we obtained the following semi-empirical formula for mass stopping power for Nitrogen ions by calculation of the weighted average for mass stopping power.

$$S.P.in(P.W.) = \frac{P_1E^5 + P_2E^4 + P_3E^3 + P_4E^2 + P_5E + P_6}{E^3 + q_1E^2 + q_2E + q_3}$$

We get the equation constants which are as follows:

p1 = 0.001452 , p2 = -2.065 , p3 = 902.8 , p4 = 2.727e+05 , p5 = -2.761e+05

p6 = -3.569e+04 , q1 = 14.56 , q2 = 23.18, q3 = -45.88

R-square: 0.9994

Table (3): Mass stopping power for Nitrogen ions interacts with the skin tissue by using (four methods)

Energy of ion (MeV)	Mass stopping power (MeV.cm^2/gm) for (Nitrogen) in skintissue					
	SRIM	SRIM Dic.	CaSP	Bethe formula	Present work	
					average	S.P.(P.W)
1	5829.87577	5902.3	4762.852348	---	5498.342706	5348.636351
1.5	7286.08458	7353.66	5263.076574	---	6634.273718	6664.196082
2	8412.20801	8474.3	5763.300801	---	7549.93627	7645.374797
2.5	9242.73505	9300.42	6263.525027	---	8268.893359	8361.436688
3	9828.62625	9882.93	6763.749253	---	8825.101834	8885.628442
3.5	10226.68953	10279.86	7263.973479	---	9256.841003	9267.338962
4	10491.20518	10546.72	7764.197705	---	9600.707628	9541.483557
4.5	10659.3842	10714.22	8264.421932	---	9879.342044	9733.364575
5	10758.30473	10812.17	8764.646158	---	10111.70696	9861.675633
5.5	10809.02347	10860.46	8699.568096	---	10123.01719	9940.45256
6	10821.24134	10869.01	8634.490034	---	10108.24712	9980.380449
6.5	10803.55049	10857.77	8569.411972	---	10076.91082	9989.691218
7	10764.06504	10816.68	8504.33391	---	10028.35965	9974.793011
8	10633.36169	10684.89	8374.177786	---	9897.476491	9891.456953
9	10455.50658	10513.47	8244.021662	---	9737.666082	9759.445934
10	10248.92908	10302.31	8113.865538	---	9555.034872	9597.41597
15	9094.253699	9141.683	7415.186299	---	8550.374333	8647.400909
20	8050.268767	8090.766	6716.50706	---	7619.180609	7753.203714
25	7193.924093	7228.57	6359.174551	---	6927.222881	7000.109233
30	6591.041032	6619.748	6001.842042	---	6404.210358	6376.125145
35	6092.542085	6115.147	5644.509532	---	5950.732872	5856.608617
40	5598.546414	5618.688	5287.177023	6044.437236	5637.212168	5419.554539
50	4847.408699	4862.029	4572.512005	5082.038759	4840.997116	4727.660204
60	4298.816412	4309.577	4181.189729	4403.941426	4298.381142	4205.537945
70	3876.092723	3883.248	3789.867453	3898.023094	3861.807817	3797.328098
80	3538.274317	3542.996	3398.545177	3504.791009	3496.151626	3468.849045
90	3259.265825	3261.797	3134.411563	3189.590786	3211.266294	3198.223214
100	3023.705049	3025.636	2870.277949	2930.798647	2962.604411	2970.866049
150	2221.785886	2221.138	2099.142198	2111.347112	2163.353299	2214.256719
200	1744.551875	1744.8786	1664.935326	1670.393015	1706.189704	1774.286927
250	1428.197874	1429.7185	1433.411251	1392.221288	1420.887228	1477.109751
300	1210.48499	1213.6094	1201.887176	1199.653292	1206.408714	1258.509254
350	1060.196372	1062.53	1077.254282	1057.922051	1064.475676	1089.288779
400	957.8560555	959.7696	952.6213887	948.963801	954.8027113	954.2707945
450	876.6943946	877.922	874.2780738	862.4258826	872.8300878	844.7863435
500	804.1515824	805.3835	795.9347588	791.9324599	799.3505753	755.5246614
550	744.0099594	745.0517	741.8201841	733.3342081	741.0540129	683.0508682
600	693.1722391	694.1249	687.7056094	683.8101478	689.7032241	625.045018
650	649.6404998	650.502	648.0007671	641.3730382	647.3790763	579.8837272
700	611.8549986	612.6823	608.2959249	604.5811076	609.3535828	546.3970222
800	549.7222417	550.4499	547.2791275	543.9010829	547.838088	511.2011931
900	500.576204	501.2245	499.1535146	495.8667158	499.2052336	514.7370867
1000	460.7448034	461.3039	459.8376999	456.8551042	459.6853769	554.1427266

2-The following semi-empirical equation were obtained from same program for range of Nitrogen ions in skin tissue:

$$Range\ (P.W.) = aE^{b+c}$$

We get the equation constants which are as follows:
a = 4.617e-06 ,b = 1.794 , c = 0.002386
R-square: 1

3-We note that the maximum value of mass stopping powers found in Hydrogen element, because Hydrogen was gas molecules in the traversing path of the heavy ions and hence the more probability of interaction and more energy loosed, this conclusion is identical to what is stated in the reference [15].

4- From table(3)we found that the maximum value of energy the Nitrogen ions can lose along its path in skin tissue are (9989.691218MeV.cm^2/g) which correspond to the energy (6.5 MeV) . Figure (4), illustrates this.

5-We note that the range corresponds to energy which can lose along its path of Nitrogen ions in skin tissue is (0.002518656cm) in energy (6.5 MeV). Figure (5), illustrates this.

6-From figures (4) note that the theoretical values are consistent with the present work values of the mass stopping power values for Nitrogen ions in skin tissue indicating the validity of the present results.

7-From figures (5) note that the theoretical values correspond to the present work values of the range for Nitrogen ions in skin tissue, this indicates the validity of the present results.

8- Figure (6) shows the of the Bruuge peak the range to which the Nitrogen ions loses most of its energy in skin tissue.

9- Nitrogen ions can penetrate skin tissue a distance (1.115039336 cm) in the energy (1000MeV).

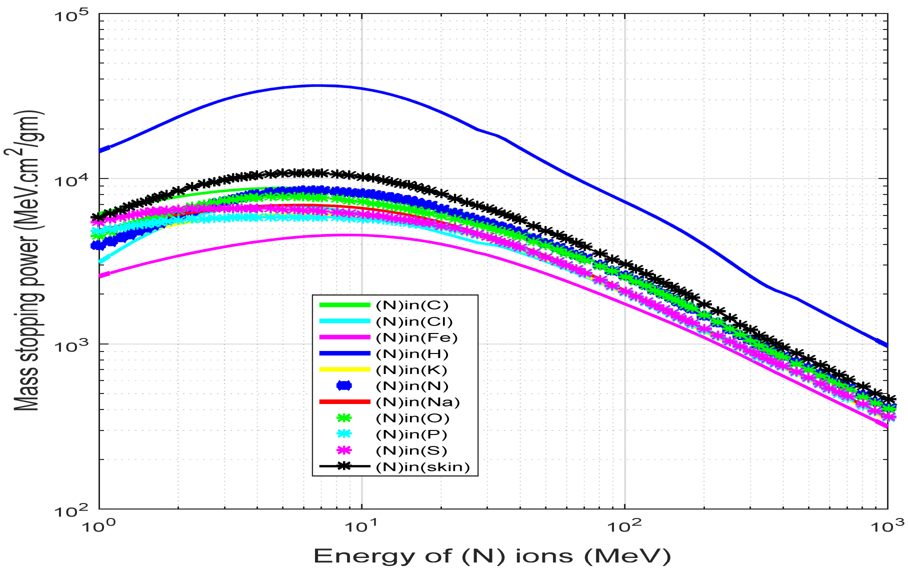

Figure (1): Mass stopping power for nitrogen in elements presented in skin using SRIM program

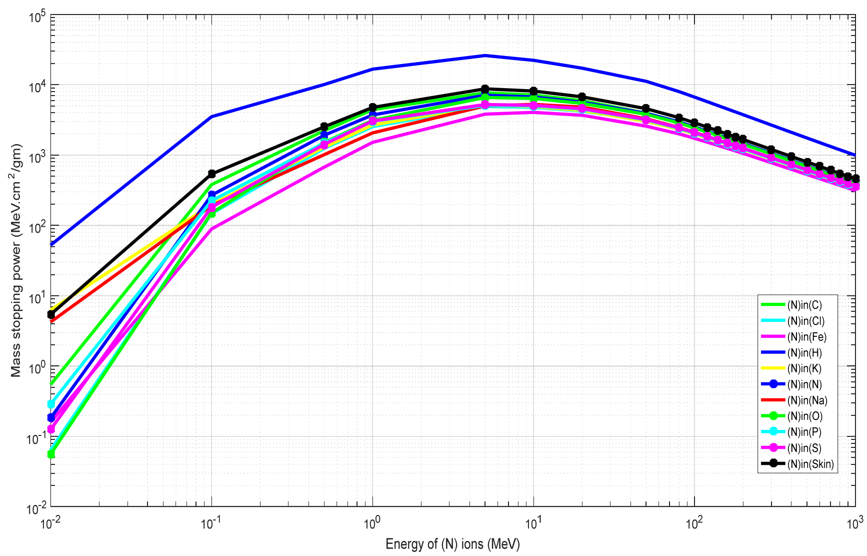

Figure (2): Mass stopping power for nitrogen in elements presented in skin using CaSP program

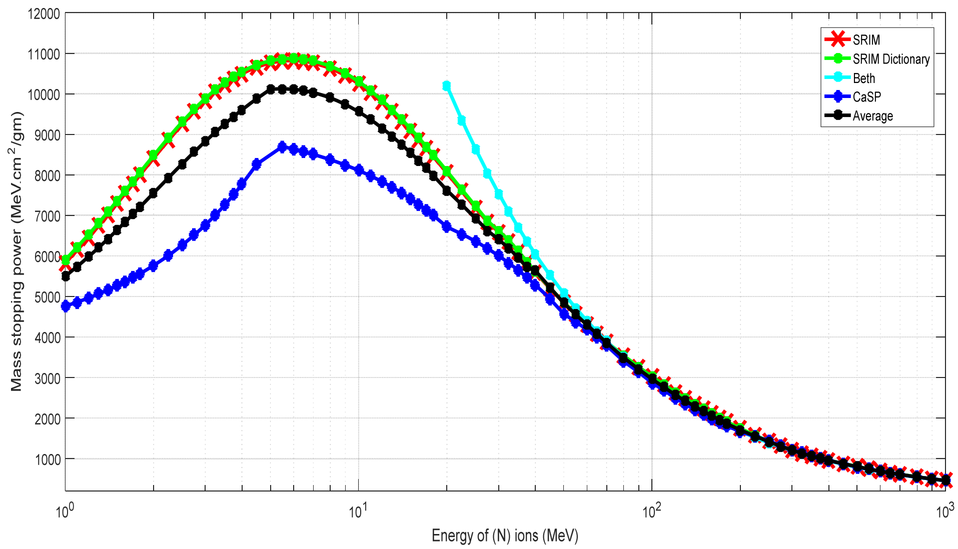

Figure (3): Mass stopping power for N with skin tissue using SRIM ,SRIM Dictionary, CaSP programs, Bethe formulae and average for these values

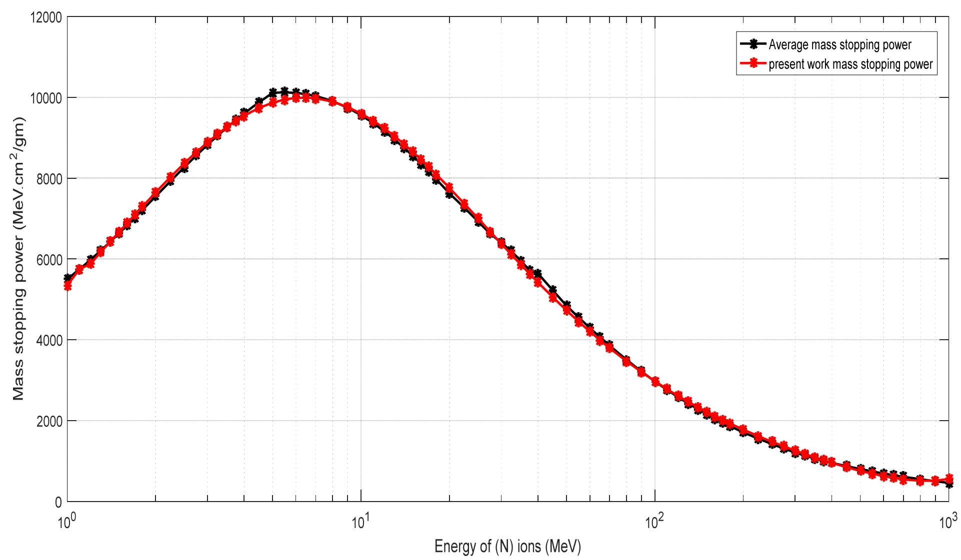

Figure (4): Comparison mass stopping power for N with skin tissue calculated by P.W and average of four methods

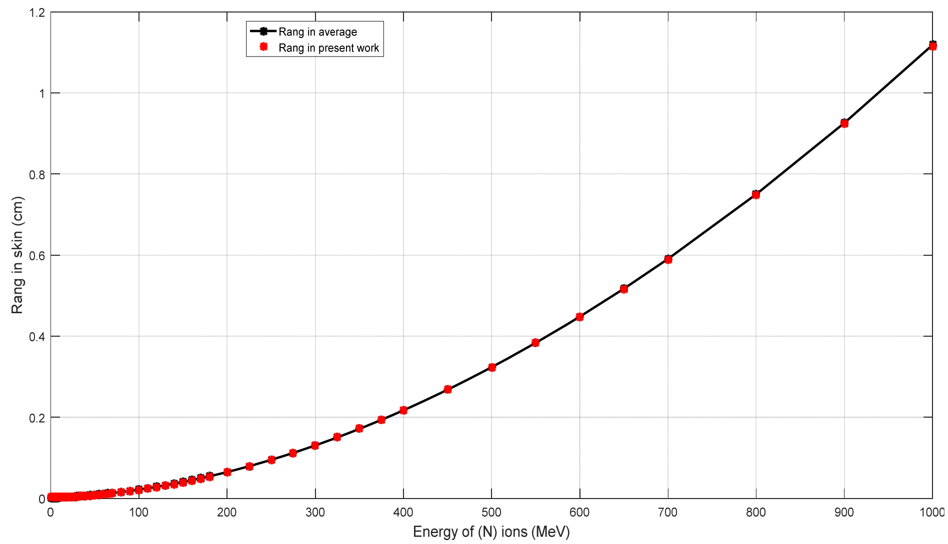

Figure (5): Comparison Range for N with skin tissue calculated by semi-empirical P.W and range calculated theoretically.

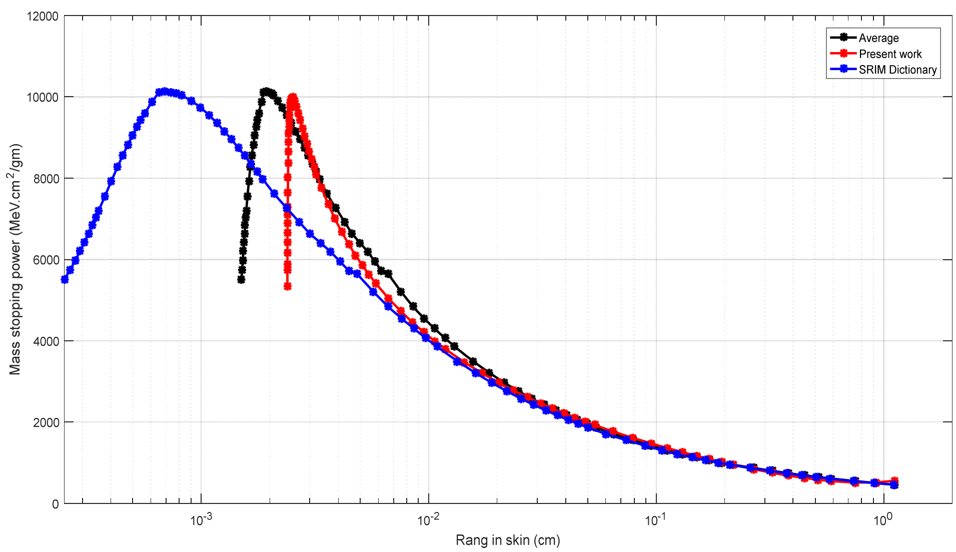

Figure (6): The Braggcurve(P.W.) for N in skin tissue

Conclusions

The menders can be provided with a database of Nitrogen ions to enable them to deal with these ions to treat tumors in the skin tissue,we conclude that the atoms most responsible for loss of energy in the skin tissue are Hydrogen atoms,the maximum value of energy the Nitrogen ions can lose along its path in skin tissue are (9989.691218MeV.cm^2/g) which correspond to the energy (6.5MeV) ,the Range correspond to energy which can lose along its path of Nitrogen ion in skin tissue is (0.002518656cm) in energy (6.5 MeV).Nitrogen ions can penetrate skin tissue a distance (1.115039336 cm) in the energy (1000MeV),which allows the processor to take into account this energy and the corresponding range of the reach of this particle when used in treatment.

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