Proton Irradiation the DNA of Human Cells

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Abstract. Proton beam therapy provides favorable physical characteristics to kill cancer cells. It is known that all living organisms contain DNA, so we will simulate the bombardment of dry DNA of human’s body cells by protons. The knowledge of stopping powers is very important especially for ion beam cancer therapy. The simulations first-principles dynamics helps the mostly employed linear description of response theory. The study denotes that DNA has suffered ionization by proton bombarding, which leads to long –lasting harm to human or cancer DNA that empowers us to diagnose the latter and treat it with radiation. Through using Bethe and Ziegler’s equations, and also the SRIM programs, we determine the stopping power of the interaction of proton with human’s DNA at approximate energy of 1 to 2.5 MeV. The human’s DNA components are made of five main elements. All mathematical processes and analysis are achieved using Matlab program. The results are introduced in tables and figures. The researchers have formulated the power equation that denotes the values of stopping power according to the range of energy under investigation.

Keywords: Bethe equation, Ziegler equation, energy loss, Human cancer DNA, Stopping Power, SRIM.

1. Introduction

The particle therapy has introduced new innovative therapy for cancer by giving developed precision and radiobiological characteristics over the common photons. Globally, there are more than 150,000 patients treated in the present time [1]. Interaction between incident protons and human biological materials is highly significant to expect the influences of radiation on the live tissues and radiation dosimetry. The use of beams with energetic ion of radiation therapy becomes an encouraging method since more doses can be placed topically on the tumor spots to decrease the destruction of the contiguous crucial body parts. Hadron-therapy use of the energy deposition at the point that the penetrating proton beams will lose whole energy, i.e. the swift decreasing for the dosage at this point that could be employed for high dose deposition inside a particular swelling size. Electrons and photons do not have this property [2]. In radiotherapy of cancer, the choosing of the range and energy of the incident protons are vital for dose control. There is an extensive development in numerous algorithms employed to determine the dose depth and allocations for ion beams. Applying of Bethe theory on the solids where energy loss of particles measurements depends on it shows us the term energy loss is important for mean excitation energy of the material[3].
Charged particles can pass through matter and ionize the atoms they come across. They will lose their energy steadily numerous tiny stages. Mostly, they employ the mass stopping power that refers to the linear stopping power divided by density to express by units like MeV/(mg/cm²). Then, it is manifested as the loss of energy for each unit of the attenuator thickness measured in g/cm² [4]. So, it can be considered that there is an independence of the stopping power with respect to the density of the material. We can consider stopping power as crucial issue in several areas of technology, particularly high-tech usage in addition to medical procedures [5]. The paper investigates the energy loss by electronic excitations of the beams of fast proton through DNA for discrete and continuum states at varied incident energy.

The rapid charged particle, which passes through a medium, loses its power mainly by electronic excitation of object particles excluding the situation at very low speeds [6]. Incident particles may lead to DNA destruction by physical and chemical interventions within a short period of time. So, the elastic energy loss will be ignored within the energy limit measured. It should be observed that in the range of low and medium energies, we need to regard the electron capture procedures and incident particle losses that provides an unceasing charge interchange of the projectile in their pathway through the solid influencing its energy loss. The loss of energy happens when protons crossing matter by succeeding collisions with the particles and atoms that they encounter. It is worth noting here that loss of energy is mainly because proton collisions by electrons in stopping material [7]. If protons encounter an extremely light nucleus, they will scatter, recoil nucleus could move to a substantial extent before the energy is entirely precipitated [8]. Since the dose of radiation precipitated by photons decrease progressively with pervasive depth, the deposited dose by protons rises gradually to almost up to three-quarters of its travel distance inside stopping material, then increased to reach extreme value before swiftly slow to zero. Bragg peak is the depth that the extreme energy is deposited by protons. The position of the peak is relational to the proton beam energy [9].

2. Bethe Equations

The particles beam that crosses a target will lose its energy. The loss of energy is because of scattered electrons and nuclei, and the stopping electronic is clearly manifested almost in all regions of energy. The loss of energy relies on energy or more accurately the beam velocity. A quantum-mechanical derivation comprises relativistic effects identified as the Bethe - Bloch equation [10]:

\[
S.P = \left( \frac{ze^2}{4\pi\varepsilon_0} \right) \frac{4\pi Z \rho N_A}{Amv^2} \left[ \ln \left( \frac{2mv^2}{I} \right) - \ln(1 - \beta^2) - \beta^2 \right]
\]

where: S.P stopping power, \( v = \beta c \) is the ion velocity, \( ze \) = ion charge, \( m \) = mass of electron, \( I \) = ionization potential, \( N_A \) = Avogadro's number, \( A, Z, \rho \) were the numbers of mass, atomic number, and density of the stopping material, respectively [10].

3. Ziegler Equations

Varelas and Biersack suggested a theoretical interpolation to treat the gap between maximum and minimum energy for various states by chief terms [11]:

\[
(S.P_{DNA})^{-1} = (S_{LOW})^{-1} + (S_{HIGH})^{-1}
\]

\( S_{LOW} \) represent the low energy stopping and equal to:

\[
S.P_{LOW} = A_1E^{1/2}
\]

\( S_{HIGH} \) represents the high energy stopping and equal to:

\[
S.P_{HIGH} = A_2 \ln \left( 1 + \frac{A_3}{E} \right)
\]

\[
EA_4
\]

\( A_1, A_2, A_3, \) and \( A_4 \) are fitting constants in able (1).
Table 1. Fitting constants for equations (3 and 4) [11].

| Elements | $A_1$ | $A_2$ | $A_3$ | $A_4$ |
|----------|-------|-------|-------|-------|
| H        | 1.44  | 242.6 | 1.2   | 0.1159|
| O        | 3     | 1920  | 2000  | 0.0223|
| N        | 3.35  | 1683  | 1900  | 0.02513|
| C        | 2.989 | 1445  | 957.2 | 0.02819|
| P        | 3.647 | 3561  | 1560  | 0.01267|

In situation of high incident energy, fitting formula equation (2) approximately corresponds to equation (1). Therefore, the formula of Varelas and Biersack has a greatly plainer and the valid approximate conduct at all energy ranges [11].

4. SRIM software
Measurements of "Stopping and Range of Ions in Matter" can be made by software like SRIM. There are many scientific references to SRIM annually. Current SRIM has new improvements depending on new empirical data. The latest version contains major improvements based on experimental data [12, 13].

5. Results and discussions
The entire stopping power of protons interacts with the DNA elements that measured employing the three methods as follows; Bethe equation, Ziegler equation and the computer program SRIM software. Considering the human DNA as composed of five elements which are hydrogen 30%, oxygen 16%, nitrogen10%, carbon40%, and Phosphorus 4%.

Figure1. DNA strands [14]

The total stopping power of proton interaction with H, O, N, C and P for energy range from 1 to 2.5MeV are measured employing the abbreviated formula of equation (1) [10].
S.P_{DNA}=0.239114\frac{Z}{E_p}\ln \left[ 2.178 \times 10^{-3}\frac{E_p}{I} \right] \tag{5}

The measures are achieved by Matlab, with reliance on the values of the ionization potential for the elements as \( I_C=1.0039\times10^{-4} \) eV, \( I_H= 6.8560\times10^{-5} \) eV, \( I_N= 1.0895\times10^{-4} \) eV, \( I_O= 1.1769\times10^{-4} \) eV, \( I_P= 1.8155\times10^{-4} \) eV.

Also we can use equations (2-4) to measure the total stopping power by Ziegler equations. And then we use the SRIM program to obtain the stopping power to the mentioned elements separately. All data are presented in figures (2-6).

**Figure 2.** Proton stopping power in hydrogen

**Figure 3.** Proton stopping power in Oxygen
Figure 4. Proton stopping power in nitrogen

Figure 5. Proton stopping power in carbon

Figure 6. Proton stopping power in phosphorus.

So, using Bragg additively, the stopping power for human DNA was calculated by equation (6) and extrapolated to extract equation (7) to use in a wide range of protons energy.

\[
S\cdot P_{\text{DNA}} = 0.3 \cdot S\cdot P_{\text{H}} + 0.16 \cdot S\cdot P_{\text{O}} + 0.1 \cdot S\cdot P_{\text{N}} + 0.4 \cdot S\cdot P_{\text{C}} + 0.04 \cdot S\cdot P_{\text{P}} \quad (6)
\]

General model Power equation:
S. P$_{DNA} = a \times (E_p)^{b+c}$  \hspace{1cm} (7)

Coefficients (with 95% confidence bounds):  
\begin{align*}
a &= 4.919 \\
b &= -0.5071 \\
c &= -1.05 \\
\end{align*}

The results are shown in figure (7) and table (2).

![DNA Stopping Power](image)

**Figure 7.** Proton stopping power in the DNA of human cells.

**Table 2.** Proton stopping power in the DNA of human cells.

| Ep MeV | DNA Stopping Power |
|-------|--------------------|
| 1.0000 | 3.8584             |
| 1.3000 | 3.2602             |
| 1.5000 | 2.9544             |
| 1.7000 | 2.7059             |
| 1.9000 | 2.5005             |
| 2.0000 | 2.4083             |
| 2.1000 | 2.3259             |
| 2.3000 | 2.1753             |
| 2.5000 | 2.0444             |

**Conclusion**

The crucial objective is the DNA for the most of biologic radiation impacts that includes the killing of living cells, cancer-making and mutation. Incident ionizing protons may prompt DNA destruction by the interaction of major and minor particles (direct) and also by the interaction of radiolysis yields with the DNA target (indirect) for a specific Short time range.

Three methods have been validated to calculate the stopping power of protons in DNA main components. After that, the algebraic process of the stopping power for specific component was taken in order to reduce the simple discrepancies in it, followed by the total stopping power of the DNA was calculated taking into consideration the percentages of participation of each element in the formation of DNA. Then the results were fitted to obtain a general equation to obtain the stopping power of the DNA in all proton energy ranges.

The Ziegler and SRIM were the true representation of Bethe equation by our six curves.

Our results for stopping protons in the DNA aim to provide an extra accurate description of the biological milieu.
Our expectations correspond with the existing empirical data and theoretical measures existed in the literature of the most of proton energy range studied here (1MeV –2.5MeV), however, there were huge variances perceived at lower energies.

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