Calculations of Stopping Power, and Range of Ions Radiation (Alpha Particles) Interaction with Different Materials and Human Body Parts

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Abstract Radiation is naturally present in our environment and artificially in hospitals, both types of radiation interact with human body. In this work we studied interaction of Ions radiations and alpha particles with matter; we calculated the stopping power (in MeV cm2/g) and Range from the theory of Bethe-Bloch formula as giving in the reference. This has been done for different target materials in biological human body substances such as water, bone, muscle and tissue and at different energies of the ions. All these calculations were done using different programs; SRIM, STAR and Matlab, the results will be shown for Range Vs energy, and stopping power vs energy. Fitting model was employed using Matlab for water. Total stopping power was obtained by summing the electronic collisional and radioactive stopping power of the target materials, and then employing the continuous slowing down approximation (CSDA) to calculate the path length (Range). The total stopping power is proportional to Z^2, Z/A, and I, increases rapidly at low energies, reaches a maximum and decreases gradually with increasing energy.

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1. Introduction

The Stopping power and energy dissipation of charged particles through matter has been a subject of great interest for 100 years [1,2,3] because of its wide areas of application, such as ion implantation, fundamental particle physics, nuclear physics, radiation damage, radiology [2,3]. Heavy charged particles traversing matter lose energy primarily through the ionization and excitation of atoms [4]. The stopping power is defined as the mean energy loss per unit path length–*dE*/*dx*. It depends on the charge and velocity of the projectile and, of course, the target material [5,6]. Early investigations of the energy loss of charged particles traversing matter arrive at a general stopping power formula [6].

If an ion beam penetrates through matter it loses energy due to collisions with electrons (electronic stopping) and target nuclei (nuclear stopping) [7]. The total stopping power is then just the sum of the stopping powers due to electronic and nuclear interactions [8,9]. At low energies the total energy loss is usually described in terms of electronic stopping power [10]. The nuclear component of the stopping power can also be ignored [7]. The possible phenomena contributing to the electronic stopping in the velocity region well below the light velocity are [9]:

1. Momentum Exchange in a Collision between the Ion and a Free Electron in the Target Material.
2. Ionization of the Ion.

3. The Ion Captures An Electron.
4. Excitation of the Ion.
5. Excitation of a Target Atom
6. Ionization of a Target Atom.
7. Collective Effects Such As the Polarization or the Plasmon Excitation

In this work the interactions of ion radiation with matter will be studied, this will include the heavy charged particles like alpha particles and ions, also we will show the effects of theses interactions with human body, skin, and bone, skeletal and different parts of the body.

Energy loss and dose are correlated with each other and help to formulate the interaction of internal and external radiation with matter to predict the affectivity of the radiation treatment and the possible damage to adjacent body tissue. Radiation treatment is based on different kind of radiation and depends on the different kind of interaction between the radiation and matter (body tissue) [9], the energy loss and dose which human body might exposed during medical treatments or accidents or from natural radioactivity, this will help us in the dose limit and to be more protected, in Gaza we use different kind of radiation in universities, hospitals, knowing the energy loss, dose will help us to protect ourselves and our environment.

The stopping power, energy loss, range, straggling and equivalent dose rate of ions in air, tissue and polymers are very important in many research and application fields, such as radiation dosimetry, radiation biology (such as cell lethality, cytogenesis changes, mutagenesis and DNA

recombination), radiation chemistry, radiotherapy and nuclear physics [11,12]. Different methods have been reported for measuring the stopping power of charged particles such as direct energy loss measurement through films, backscattering from thick substrate covered with deposited absorbing layers, gamma resonance shift measurements, self-supporting method and an indirect verification of the stopping power based on alpha energy losses in air [2-7].

Many experimental and theoretical studies about energy loss, stopping power, range, straggling of ions such as (H, He, Li, C, O) and equivalent dose have been carried in many different human body parts.

The main objectives is to calculate the energy loss per distance which is the stopping power and ranges results from the above external and internal radiation interactions with matter, this will leads the evaluations of energy loss and doses which are very important for radiation treatment and the possible   damage to adjacent body tissue.

It is well known that the ionization value in tissues is proportional to cells damage. Therefore, the main aim of this study is to evaluate helium ions energy deposition in target organ and in the various entrance layers (skin, water, adipose tissue, muscle skeletal, and bone). We use the energy that varies between 10 Kev and 10 MeV, and calculate the stopping power from the Bethe-Bloch formula as giving in the theory of [13], for these calculations we will use the SRIM 2008 code [11,12], and Pstar, Astar, Estar codes [16].

We expect to get results for stopping power vs energy, and Range vs energy for the previous matters and body parts listed above, these study are very important for knowing,

The data for stopping power and range will be fitted to a suitable module.

2. Stopping Power

Stopping power of a medium can be defined as the average unit of energy loss suffered by the charge particles per unit path length in the medium under consideration. [14,15,16,17].

Stopping power consists of two components: collisions and radiative. The first is the most important for α-particles, resulting from the collision interaction between the incident particles and atomic electrons. Mass collision stopping power is widely used to reduce the dependence on the medium density (ρ) [16]. The total stopping power can be obtained from SRIM-2003 program [15], which calculates the stopping power and range of ions (10eV-2GeV/amu) in matter using a quantum mechanical treatment of ion-atom collision (the manual of SRIM refers to the moving atom as an "ion", and all target atoms as "atom"). A full description of the calculation was given by Ziegler and Biersack [15]. Stopping power of a medium can be defined as the average unit of energy loss suffered by the charge particles per unit path length in the medium under consideration. [16]

The energy loss in matter has been calculated by many physicists, but the basic, classic derivation was due to

Bloch who improved a calculation by Bethe; hence the Bethe-Bloch Formula.

The rate of energy loss is given by (– dE/dx); dE/dx being a loss of energy, is a negative quantity. The calculation of dE /dx is done in such a way as to determine the energy deposited in the medium (positive) – hence the explicit negative sign for the loss of energy of the particle.

The derivation of the formula is quite long, but we can guess that there are various forms of the formula, which are essentially the same – it just depends on the way particular authors have wanted to parametrise the quantities appearing in the formula. You will not be expected to remember the exact expression. You should also note that "x", distance, is not always expressed in metres, but often in units of mass per metre^2, square meter,. This latter parameter comes from multiplying the length parameter by the density of the material. This is a more convenient and useful unit of material thickness as far as experimentalists are concerned. The full expression for the Bethe-Bloch formula can be written as:

$$-\frac{dE}{dx} = \left(\frac{e^2}{4\pi\varepsilon_0}\right)^2 \frac{4\pi N_A Z_\rho}{mc^2\beta^2 A}\left[\ln\left(\frac{2mc^2\beta^2}{I}\right) - \ln\left(1-\beta^2\right) - \beta^2\right]. \quad (1)$$

The quantity -dE/dx is known as the STOPPING POWER and is denoted as S.

The range is simply defined as the distance a particle moves in a medium before all its energy is lost. This can be determined from the stopping power provided we know the the form of S from zero energy up to the initial energy of the particles in the incident beam.

3. Calculations of Stopping Power and Range for Ions

The stopping power and range have been calculated for α-particles (helium ion) and protons (H ions) in different targets like, water, carbon, air, calcium, magnesium, and phosphor.

SRIM is a computer code, which uses the stoppage and range ions in matter and contains the transport of ions in matter (TRIM) code [11]. SRIM 2008 is a set of programs that calculates the stoppage and range of ions with energy from 10 eV to 2 GeV. In SRIM, the user specifies the ion type, its energy and direction to evaluate target damage, sputtering, ionization, and phonon production. In particular, it calculates the displacement concentration and its distribution [11]. In this research, SIRM2008 code has been used for SRIM tables of stopping power, linear energy transfer (LET) and projected range (R) versus particle energy are very useful for the computation of particle transport in a wide range of simulation applications which do not directly involve a specific ion transport code. Although a special independent executable program (SRIM Module.exe) can be used as a subroutine for Windows applications, we used the following function for fitting for modeling the linear energy transfer given by SRIM tables in the defined energy range [17]:

$$LET = 10^{A(E)} \qquad (2)$$

$$A(E) = \sum_i^8 a_i \, x \sin(b_i) \, \log_{10}\big((E) + C_i\big) \qquad (3)$$

Where a_i, b_i and c_i correspond to a set of 8 x 3 = 24 real coefficients characteristics of a given ion for a given target material. Similarly, for the projected range versus energy in the same energy domain, we adopt the following modeling:

$$R(E) = 10^{B(E)} \qquad (4)$$

$$B(E) = p_{10} + \sum_i^9 p_i \, x \, [\log 10(E) 10i \qquad (5)$$

Where coefficients p_i corresponds to a set of 10 real coefficients for each given ion.

The ASTAR program calculates stopping power and range tables for helium ions in various materials. Select a material and enter the desired energies or use the default energies. Energies are specified in MeV, and must be in the range from 0.001 MeV to 1000 MeV [13].

Also the effect of radiation on different human parts like skin, bone, muscle, skeletal, adipose tissue, and water, where studied using these codes by calculating the stopping power and range on these different target, also dose can be easily calculating from stopping power.

a) Stopping Power

The average **linear rate of energy loss** of a heavy charged particle in a medium (MeV cm^{-1}) is of fundamental importance in radiation physics, dosimetry and radiation biology.

This quantity, designated $-dE/dx$, is called the **stopping power** of the medium for the particle.

It is also referred to as the **linear energy transfer** (LET) of the particle, usually expressed as keV µm^{-1} in water.

Stopping power and **LET** are closely associated with the dose and with the **biological effectiveness** of different kinds of radiation [14].

b) Mass Stopping Power

The **mass stopping power** of a material is obtained by dividing the stopping power by the density ρ.

Common units for mass stopping power, -dE/ρdx, are MeV cm^2 g^{-1}.

The mass stopping power is a useful quantity because it expresses the rate of energy loss of the charged particle per g cm^{-2} of the medium traversed.

In a gas, for example, - dE/dx depends on pressure, but –dE/ρdx does not, because dividing by the density exactly compensates for the pressure.

Mass stopping power does not differ greatly for materials with similar atomic composition.

Mass stopping powers for water can be scaled by density and used for tissue, plastics, hydrocarbons, and other materials that consist primarily of light elements [13].

c) Range

The **range** of a charged particle is the distance it travels before coming to rest. The range is **NOT** equal to the energy divided by the stopping power. Like mass stopping power, the range in g cm^{-2} applies to all materials of similar atomic composition.

A useful relationship:

For two heavy charged particles **at the same initial speed** β, the ratio of their ranges is simply

$$R_1 / R_2 = M_1 (Z_1)^2 / M_2 (Z_2^2) \qquad (6)$$

where:

R_1 and R_2 are the ranges, M_1 and M_2 are the rest masses and Z_1 and Z_2 are the charge.

If particle number 2 is a proton ($M_2 = 1$ and $Z_2 = 1$), then the range R of the other particle is given by:

$$R(\beta) = (M / Z^2) R_p(\beta) \qquad (7)$$

Where $R_p(\beta)$ is the proton range.

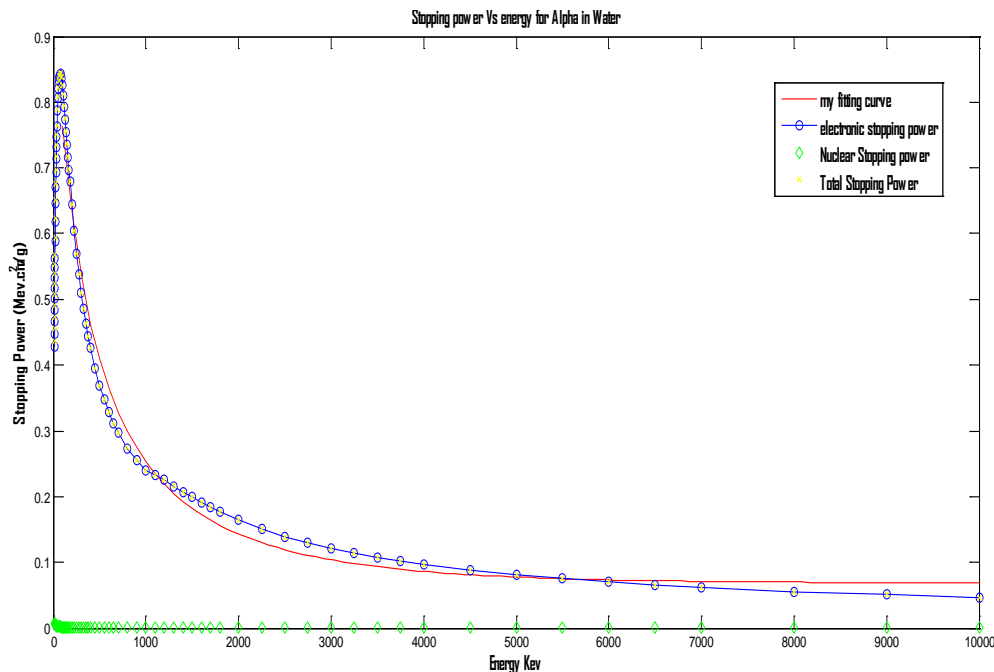Figure 1 to Figure 11, shows the stopping power and Range vs energy of alpha particles:

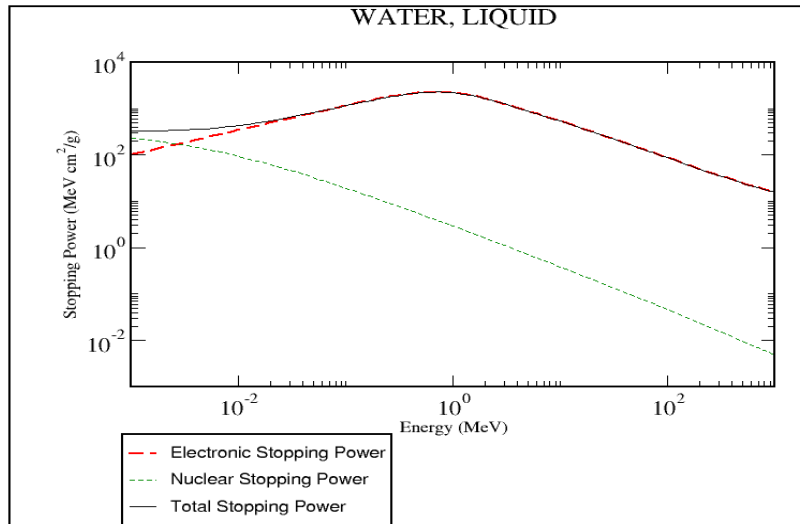**Figure 1.** Stopping power of alpha particle in Water (by Srim with my fitting)

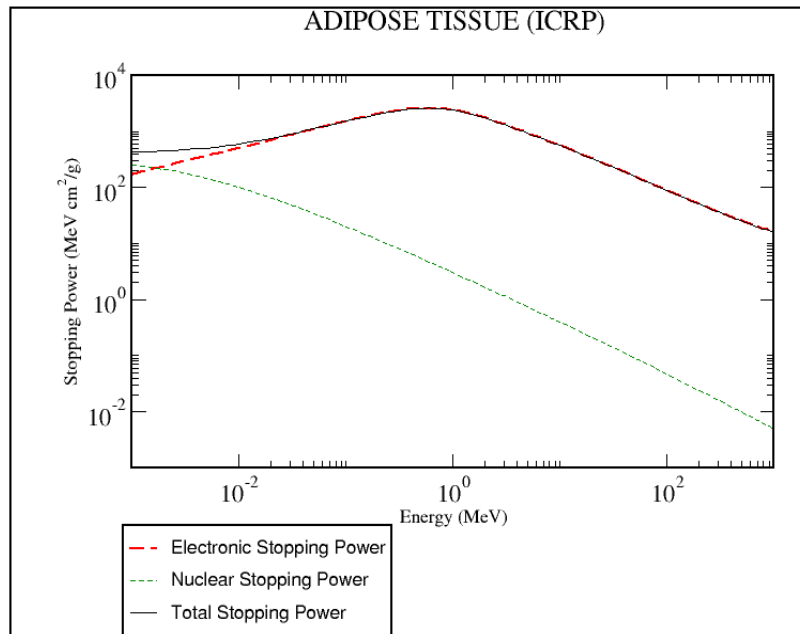**Figure 2.** Stopping power of (By A star) Water Helium in

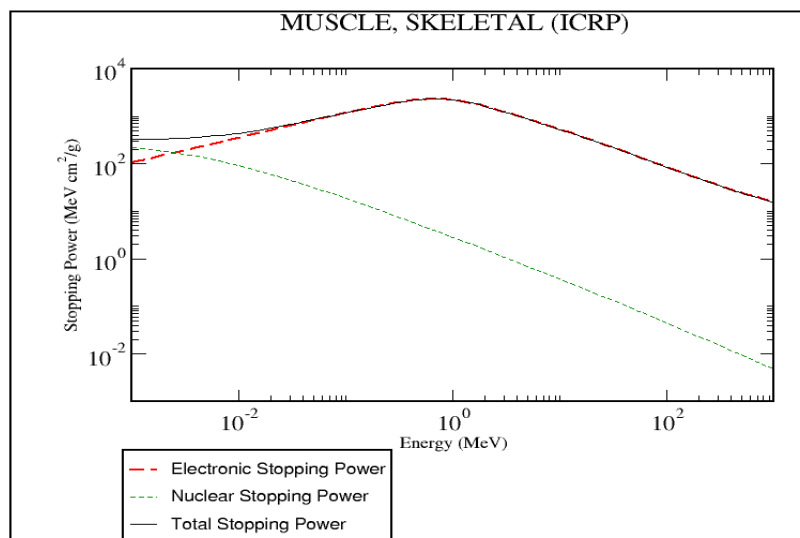**Figure 3.** Stopping power of Helium in Adipose tissue

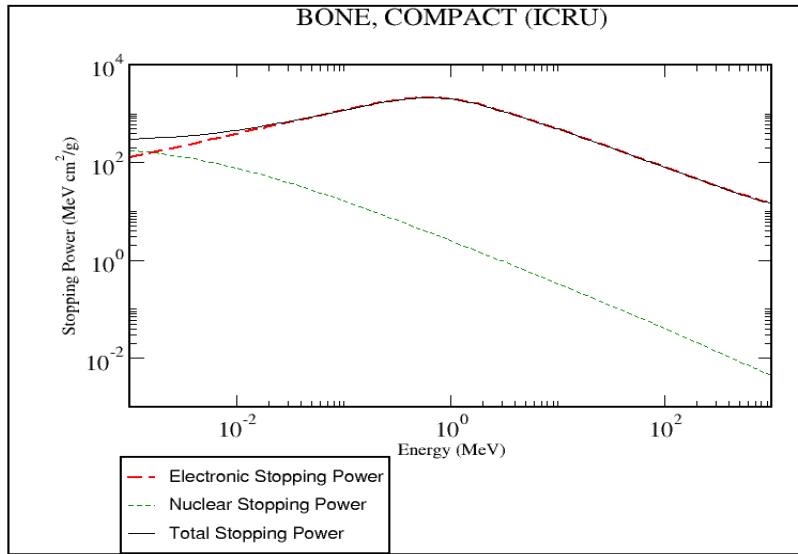**Figure 4.** Stopping power of Helium in Muscle

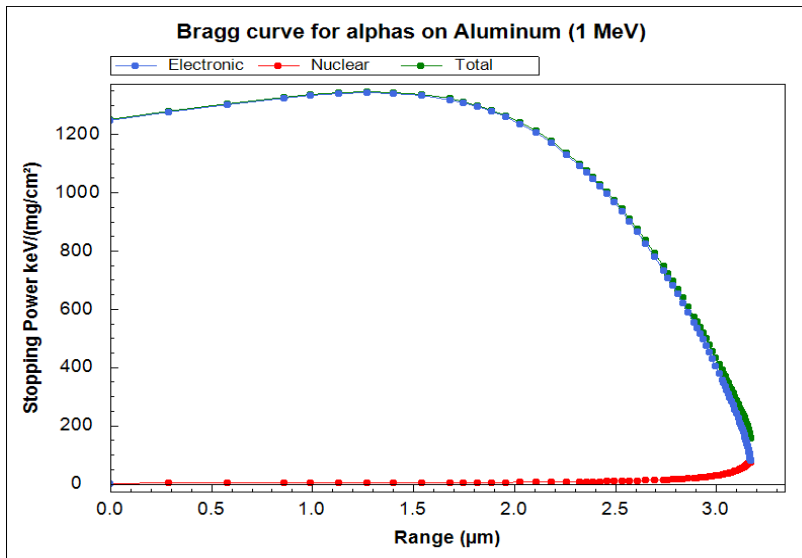**Figure 5.** Stopping power of Helium in Bone

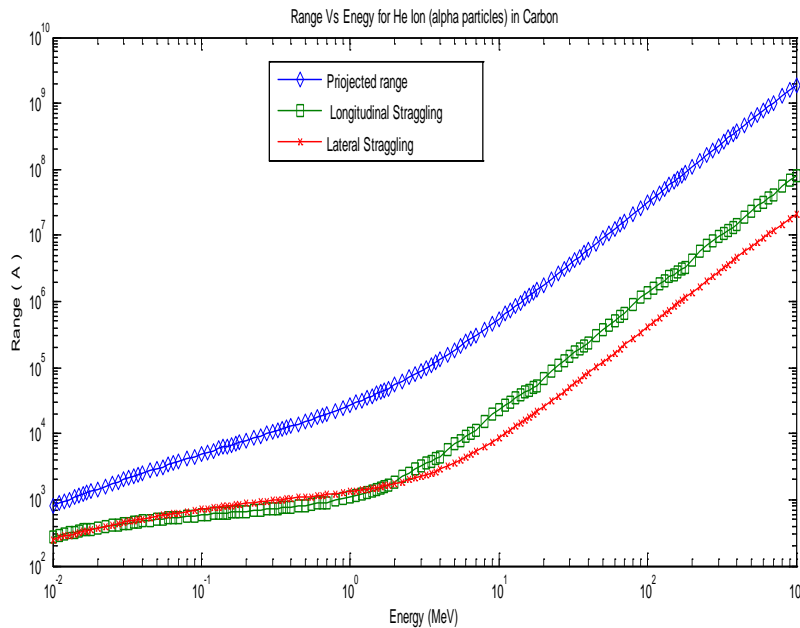**Figure 6.** Stopping power of alphaes On Aliminum

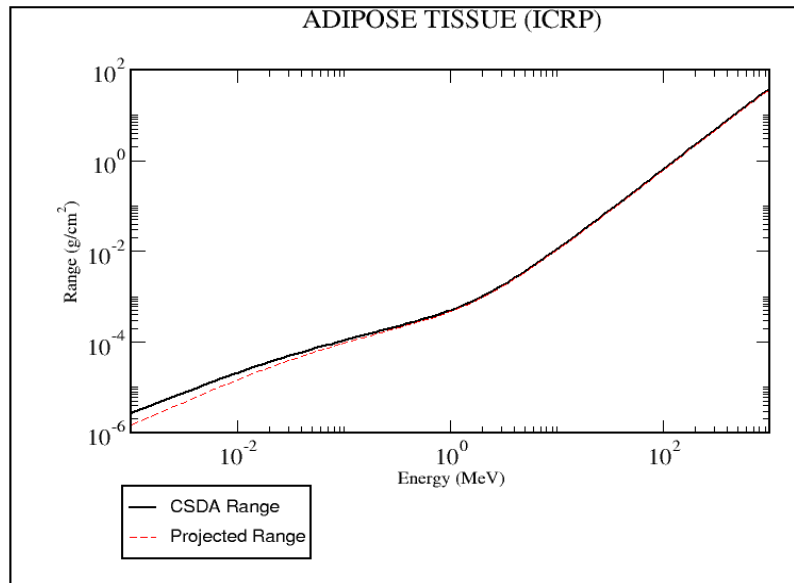**Figure 7.** Stopping power of Alpha pericles in carbon from MATLA

Figure 8. Range of He in Adiapose Tissue
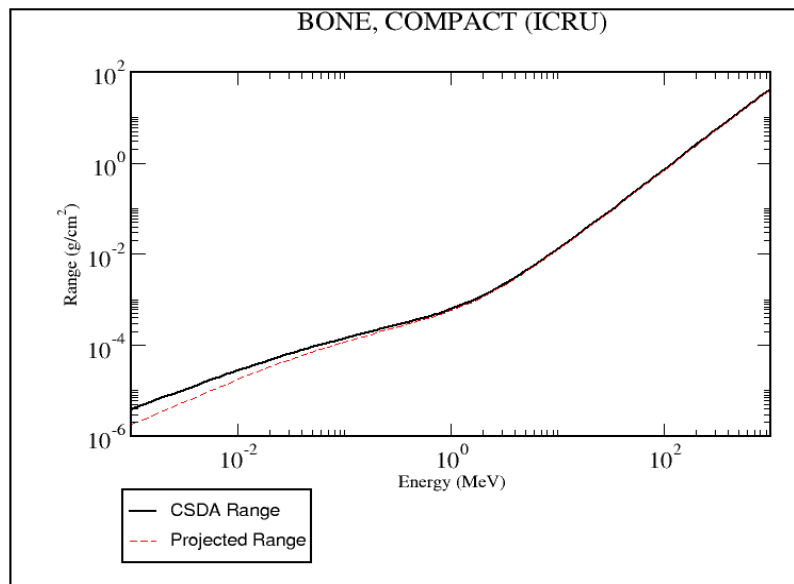

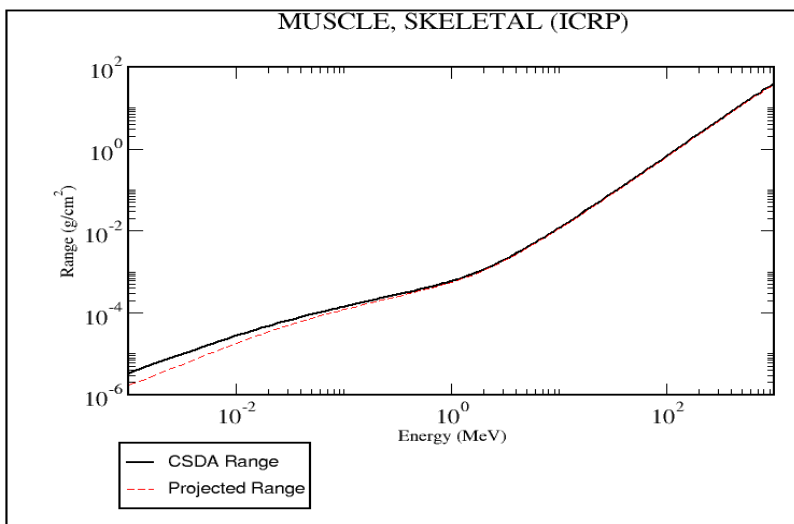**Figure 9.** Range of He in bone

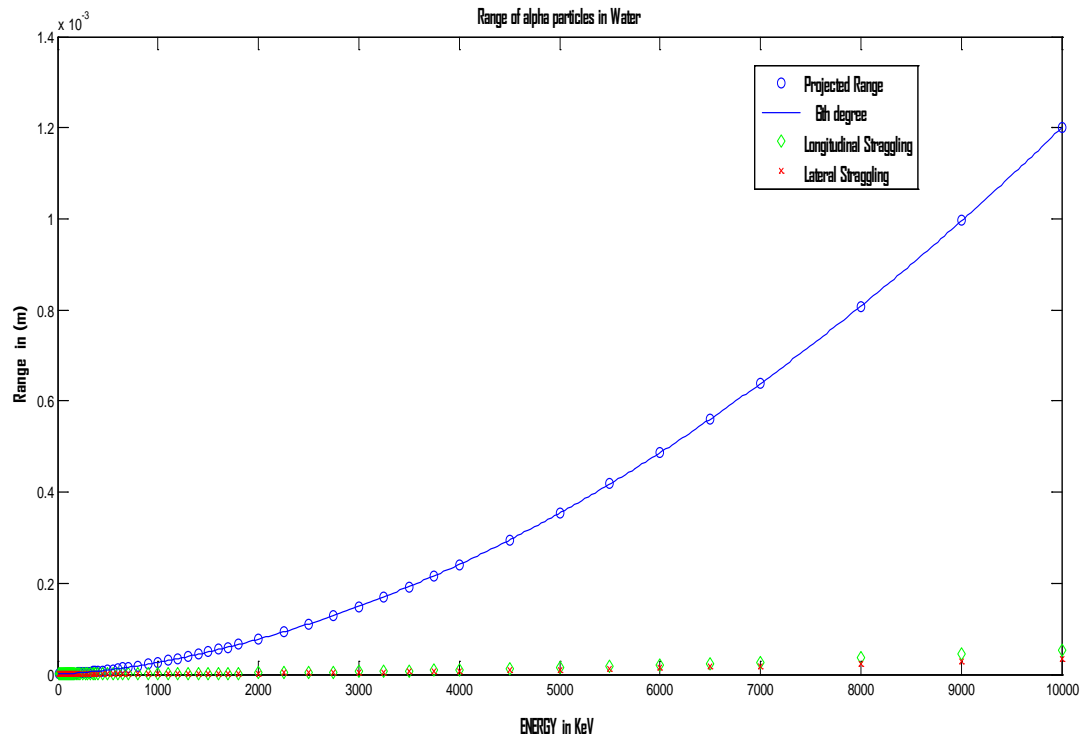
Figure 10. Range of He in muscle

Figure 11. Range of alpha in water by srim (my fitting)

4. Conclusion

The main aim of this study is to evaluate helium ions energy deposition in target organ and in various entrance layers (skin, water, depose tissue, muscle skeletal, bone). We used the energy that varies between 10KeV and 10MeV, and calculated the stopping power, for each energy beam using the SRIM2008 code which is the program used for the calculation, from the results we conclude that:

1) The total stopping power is proportional to Z^2, Z/A and I.

2) $(dE/\rho dX)_{total}$ increases rapidly at low energies reaches a maximum and decreases gradually with increasing energy.

3) The stopping power allows us to calculate the range of the heavy particles in the absorber material.

4) Because of the specific energy dependence of the energy loss (or stopping power curve) incoming high energy particles experience only little energy loss *dE/dx,* but the energy loss maximizes when particles have slowed down to energies which correspond with the peak of the energy loss curve.

For high initial energies the coefficients are large which translates into a maximum of energy loss at smaller depths which decreases gradually with the decrease of the absorption coefficient towards lower energies. Body tissue is typically low Z material and the range can be approximated.

My fitting curves for stopping power and range of alpha particles in water were very good agree with present data of SRIM code.

References

[1]   J. F. Ziegler at el, (2010), SRIM – The stopping and range of ions in matter (2010), Nuclear Instruments and Methods in Physics Research B, 268, page 1818-1823.

[2]   Berger, M. J, ESTAR, PSTAR, ASTAR, A PC package for calculating stopping powers and ranges of electrons, protons and helium ions, Version 2, International Atomic Energy Agency, nuclear data services, documentation series of the IAEA nuclear data section, (1993).

[3]   National Research Council, Committee on the Biological Effects of Ionizing Radiation, Health Effects of Exposure to Low Levels of Ionizing Radiation, BEIR V, National Academy Press, Washington, D.C.,1990.

[4]   Fred A. Mettler, Jr., M.D. and Arthur C. Upton, M.D. Medical Effects of Ionizing Radiation, Grune & Stratton, Inc., Orlando, Florida, 1995.

[5]   Ahmed, S. N., physics and Engineering of Radiation Detection, Queen's University, Kingston, Ontario, (2007)118-120.

[6]   Y.H. Song, and Y.N. Wang, "Effect of ion-nucleus sizes on the electric stopping power for heavy ions in solids", Nucl. Instr. and Meth. in Phys. Res. B 135, 124-127, (1998).

[7]   W. Brandt, and M. Kitagawa, "Effective stopping-power charges of swift ions in condensed matter", Phys. Rev. B25 (9), 5631-5637, (1982).

[8]   L.E. Porter, "Further observations of projectile-z dependence in target parameters of modified Bethe–Bloch theory", Int. J. Quantum Chem. 95 (4-5), 504-511, (2003).

[9]   P.M. Echenique, R.M. Nieminen, J.C. Ashley, and R. Ritchie, "Nonlinear stopping power of an electron gas for slow ions", Phys. Rev. A33 (2), 897-904, (1986).

[10] J. F. Ziegler, Nucl. Instr. Meth. B 219-220, 1027 (2004).

[11] J. F. Ziegler, "SRIM – the stopping and range of ions in matter", http://www.srim.org (2009).

[12] A. Jablonski, C. J. Powell, and S. Tanuma, *Surf. Interface Anal.* 37, 861 (2005).

[13] A. Jablonski, Prog. *Surf. Sci.* 79, 3 (2005).

[14] A. Jablonski, F. Salvat, and C. J. Powell, *J. Phys. Chem. Ref. Data* 33, 409 (2004).

[15] F. Salvat, A. Jablonski, and C. J. Powell, *Comput. Phys. Commun.* 165, 157 (2005).

[16] http://physics.nist.gov/cgi-bin/Star/ap_table.

[17] Hunt, J. G., Dantas B. M., Azeredo, A. M. G. F. *Visual Monte Carlo in-vivo in the CONRAD and IAEA Whole Body Counter Intercomparisons*. In. Workshop on Uncertainty Assessment in Computational Dosimetry, Bologna, 2007.