إقــــــرار

أنا الموقع أدناه مقدم الرسالة التي تحمل العنوان:

MEDICAL EFFECTS OF RADIATION INTERACTIONS

أقر بأن ما اشتملت عليه هذه الرسالة إنما هو نتاج جهدي الخاص، باستثناء ما تمت الإشارة إليه حيثما ورد، وإن هذه الرسالة ككل أو أي جزء منها لم يقدم من قبل لنيل درجة أو لقب علمي أو بحثي لدى أي مؤسسة تعليمية أو بحثية أخرى.

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MEDICAL EFFECTS OF RADIATION INTERACTIONS

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واللجنة إذ تمنحها هذه الدرجة فإنها توصيها بتقوى الله ولزوم طاعته وأن تسخر علمها في خدمة دينها ووطنها.

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بسم الله الرحمن الرحيم

قُلْ هَلْ يَسْتَوِي الَّذِينَ يَعْلَمُونَ وَالَّذِينَ لا يَعْلَمُونَ إِنَّمَا يَتَذَكَّرُ أُولُوا الألْبَابِ

[الزمر : ٩]

إهداء

إلى حكمتي .....وعلمي

إلى أدبي ....وحلمي

إلى طريقي .... المستقيم

إلى طريق......... الهداية

إلى ينبوع الصبر والتفاؤل والأمل

إلى كل من في الوجود بعد الله ورسوله { والديّ }

إلى سندي وقوتي وملاذي بعد الله {زوجي}

إلى من آثروني على نفسهم

إلى من علموني علم الحياة

إلى من أظهروا لي ما هو أجمل من الحياة {إخوتي}

إلى من كانوا ملاذي وملجئي

إلى من تذوقت معهم أجمل اللحظات

إلى من سأفتقدهم ...... وأتمنى أن يفتقدوني {صديقاتي}

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ABSTRACT

Radiation is naturally present in our environment and exist since the birth of this planet. It comes from outer space (cosmic), the ground (terrestrial), and even from within our own bodies. It is present in the air we breathe, the food we eat, the water we drink, and in the construction materials used to build our homes.

low doses – less than 10,000 mrem (100 mSv) – spread out over long periods of time (years) don't cause an immediate problem to any body organ. The effects of low doses of radiation, if any, would occur at the cell level, and thus changes may not be observed for many years (usually 5-20 years) after exposure.

Although radiation may cause cancers at high doses and high dose rates, currently there are no data to establish unequivocally the occurrence of cancer following exposure to low doses and dose rates – below about 10,000 mrem (100 mSv).

In this work we studied interaction of different radiations types with matter; we calculated the stopping power (in MeV cm2/g) from the theory of Bethe-Bloch formula as giving in the reference [15] , also Range and doses will be calculated. This has been done for different target materials in biological human body substances such as water, bone, muscle and tissue and different energies of the ions and electrons. 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 at the last chapter.

The stopping power in some biological compounds for electrons was calculated over the energy range from (10^{-2}MeV to 10^{3} MeV). Total stopping power was obtained by summing the electronic (collisional) and radiative 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.

Finally doses also calculated using Monte Carlo simulation techniques , VMS, these photons, in the form of gamma rays or X-rays, have enough energy to cause ionization in the human body, and can therefore cause a radiation dose, some results for dose calculation will be shown for different cases using the VMS code.

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Introduction To Radiation In Environment

1.1 Background

Everything, living and non-living is made up from atoms. Inside each atom is a central part called a **nucleus.** The nucleus contains **protons** which have a positive charge and **neutrons** which have no charge. The number of protons is the same for all atoms of a particular **element** e.g. Iron atoms have 26 protons. Round the nucleus are **electrons** these have a negative charge. The number of protons in an atom is equal to the number of electrons so that an atom is electrically **neutral.**

The nucleus carries a positive electrical charge while the electron is a negative electrical charge. As electrons are bound to the nucleus of the atom, so are the particles within the nucleus . “Radioactive” materials consist of unstable atoms, also called radionuclides. Their nuclear structure changes because the unstable atoms emit radiation and change to other atoms that may not be radioactive. Eventually, all radionuclides stop emitting radiation, their nuclear structure stops changing, and they become stable.

Unstable nuclei may emit a quantity of energy, or they may emit a particle , this emitted atomic energy or particle is what we call radiation [1].

Radiation is energy in the form of waves or streams of particles. There are many kinds of radiation all around us. When people hear the word radiation, they often think of atomic energy, nuclear power and radioactivity, but radiation has many other forms. Sound and visible light are familiar forms of radiation; other types include ultraviolet radiation (that produces a suntan), infrared radiation (a form of heat energy), and radio and television signals. [2]

The earth and its inhabitants are constantly exposed to radiation emitted by the sun, the stars and other cosmic sources, as well as from radioactive materials found in the crust of the earth. On earth, exposure to radiation is inevitable because of radioactive materials found in water, air and even within the human body. Radiation is invisible, but exists in the form of particles and electromagnetic waves consisting of small bundles of energy called photons.

1.2 Types of Radiation

Radiation is energy in the form of electromagnetic waves or stream of particles. There are two forms of radiation –ionizing and non-ionizing.

1.2.1 Non-ionizing radiation

Non-ionizing radiation has less energy than ionizing radiation; it does not possess enough energy to produce ions (to remove electrons from atom). Examples of non-ionizing radiation are visible light, infrared, radio waves, microwaves, and sunlight. These are defined as Extremely Low-frequency (ELF) waves and are not considered to pose a health risk [2] **.**

1.2.2 Ionizing radiation

Ionizing radiation is capable of knocking electrons out of their orbits around atoms, upsetting the electron/proton balance and giving the atom a positive charge. Electrically charged molecules and atoms are called ions. Ionizing radiation includes the radiation that comes from both natural and man-made radioactive materials [2].

There are several types of ionizing radiation:

(a)Alpha radiation (α):

Alpha radiation consists of alpha particles that are made up of two protons and two neutrons each and that carry a double positive charge. Due to their relatively large mass and charge, they have an extremely limited ability to penetrate matter. Alpha radiation can be stopped by a piece of paper or the dead outer layer of the skin. Consequently, alpha radiation from nuclear substances outside the body does not present a radiation hazard. However, when alpha-radiation-emitting nuclear substances are taken into the body (for example, by breathing them in or by ingesting them), the energy of the alpha radiation is completely absorbed into bodily tissues. For this reason, alpha radiation is only an internal hazard. An example of a nuclear substance that undergoes alpha decay is radon-222, which decays to polonium-218 [2].

(b)Beta radiation (β):

Beta radiation consists of charged particles that are ejected from an atom's nucleus and that are physically identical to electrons. Beta particles generally have a negative charge, are very small and can penetrate more deeply than alpha particles. However, most beta radiation can be stopped by small amounts of shielding, such as sheets of plastic, glass or metal. When the source of radiation is outside the body, beta radiation with sufficient energy can penetrate the body's dead outer layer of skin and deposit its energy within active skin cells. However, beta radiation is very limited in its ability to penetrate to deeper tissues and organs in the body. Beta-radiation-emitting nuclear substances can also be hazardous if taken into the body. An example of a nuclear substance that undergoes beta emission is tritium (hydrogen-3), which decays to helium-3.

(c)Neutrons:

Neutrons are neutral particles and uncharged particles. They are one the particles that make up an atomic nucleus. Because they have no charge, they are very penetrating.[3].

(d)Protons

Protons are positively particles found in every atomic nucleus .Their mass are close to that of a neutron. Protons are the chief constituent of primary cosmic rays [3].

(e)Heavy ions

Heavy ions, larger than alpha particles, are the nuclei of any atoms that have been stripped of their electrons. They move at the great speeds and have large amounts of energy. They are common in auter space ,and may also be produced by special types of accelerators[3].

(f)Electrons

Electrons are small negatively charged particles also found in all normal atoms. They are about 1800 times smaller than neutrons .Electrons are often given off when radioactive materials break down ,in which case they are called Beta rays[3].

(g) Photon radiation (gamma [γ] and X-ray)

Photon radiation is electromagnetic radiation. There are two types of photon radiation of interest for the purpose of this document: gamma (γ) and X-ray. Gamma radiation consists of photons that originate from within the nucleus, and X-ray radiation consists of photons that originate from outside the nucleus, and are typically lower in energy than gamma radiation. Photon radiation can penetrate very deeply and sometimes can only be reduced in intensity by materials that are quite dense, such as lead or steel. In general, photon radiation can travel much greater distances than alpha or beta radiation, and it can penetrate bodily tissues and organs when the radiation source is outside the body. Photon radiation can also be hazardous if photon-emitting nuclear substances are taken into the body. An example of a nuclear substance that undergoes photon emission is cobalt-60, which decays to nickel-60[2] .

1.3 Sources of radiation

1.3.1 Natural sources:

Throughout the history of life on earth, organisms continuously have been exposed to cosmic rays, radionuclides produced by cosmic ray interactions in the atmosphere, and radiation from naturally occurring substances which are ubiquitously distributed in all living and nonliving components of the environment. It is clear that contemporary life have adjusted or are doing so to all features and limitations of the environment, including the natural radiation background which are[4,5].

a) Cosmic rays :

Radiation of extraterrestrial origin, which rain continuously upon the earth, is termed "cosmic rays".

The fact that this highly penetrating radiation was impinging upon the earth from space, rather than emanating from the earth, was deduced from balloon experiments in which ionization measurements were made at various altitudes from sea level to 9,000 m. It was found that the ionizing radiation rate decreased for some 700 m and from that point increased quite rapidly with elevation. The initial decrease could be explained by a decreased intensity of terrestrial gamma rays, while the increasing component was due to cosmic rays. The likely origin of cosmic rays is the almost infinite number of stars in the Universe. Evidence for this is the increased cosmic ray intensity observed on earth following solar flares. However, it is clear that the sun is not normally a major contributor to the total cosmic flux since diurnal variations are very small. Cosmic ray intensity increases sharply with elevation until a maximum is reached at an altitude of about 20 km. From 20 km to the limit of the atmosphere (up to 50 km), the intensity decreases [4,5].

b) **Terrestrial radiation**:

Radionuclides, which appeared on the Earth at the time of formation of the Earth, are termed "primordial". Of the many radionuclides that must have been formed with the Earth, only a few have half-lives sufficiently long to explain their current existence. If the Earth was formed about $6 \cdot 10^{9}$ years ago, a primordial radionuclide would need a half-life of at least 10^{8} years to still be present in measurable quantities. Of the primordial radionuclides that are still detectable, three are of overwhelming significance. These are K-40, U-238 and Th-232. Uranium and thorium each initiate a chain of radioactive progeny, which are nearly always found in the presence of the parent nuclides . Although many of the daughter radionuclides are short-lived, they are distributed in the environment because they are continually being forming from long-lived precursors [6].

c) Radon :

The most important of all sources of natural radiation is tasteless, odorless, invisible gas about eight times heavier than air, called radon. It has two main isotopes – Radon-222, one of the radionuclides in the sequence formed by the decay of U-238, and Radon-220, produced during the decay series of Th-232.

Bedrock, soil, plants, animals, and decomposer compartments all release radon to the atmosphere. Radon is the decay product of radium and is produced in any material containing radium. Since radon is one of the inert gases, it can escape from surfaces, which are in contact with the atmosphere. The amount of radon, which emanates from a given mass of rock, depends upon the quantity of radium present and upon the amount of surface area presented by the mass. The more finely broken a given mass of rock, the more radon it can release. The concentration of radon in the air adjacent to radium-bearing material also depends upon the rate of fresh air movement into the space in question. In basements, caves, and mine shafts that have poor air circulation, the radon concentrations can build up to very significant levels. Efficient ventilation in mines is often necessary to maintain radon concentrations below those, which would be hazardous for workers[5].

1.3.2 Man – Made Sources:

Over the last few decades man has "artificially" produced several hundred radionuclides. And he has learned to use the power of the atom for a wide variety of purposes, from medicine to weapons, from the production of energy to the detection of fires, from illuminating watches to prospecting for minerals.

Individual effects from man-made sources of radiation vary greatly. Most people receive a relatively small amount of artificial radiation, but a few get many thousand times the amount they receive from natural sources. This variability is generally greater for man-made sources than for natural ones. Most man-made sources can be controlled more readily than most natural ones. Though exposure to external radiation due to fallout from past nuclear explosions, for example, is almost as inescapable and uncontrollable as that due to cosmic rays from beyond the atmosphere or to radiation from out of the earth itself [4].

a) **Medical sources**

In industrial and medical applications, typically only single radionuclide is involved, thus simplifying identification of leakage pathways from encapsulation, from radioactive tracer tests and for disposal process.

The use of radioisotopes in medicine is widespread and may potentially have significant radiological impact. These applications can be classified as (1) diagnostic uses, (2) therapy, (3) analytical procedures and (4) pacemakers and similar portable sources. The major potential environmental impact arises from the use of radioactive tracers in nuclear medicine, a field that has grown enormously in recent years. Nuclear medicine exposures can be classified as (1) exposure of the patient, (2) exposure of hospital personnel, (3) exposure during transport of radioactive pharmaceuticals, (4) exposure during manufacture and (5) exposure from radioactive waste [4,5].

b) **In Industrial sources :**

Radioisotopes are much more widely used in industry than is generally recognized and represent a significant component in the man-made radiation environment. The principal applications include industrial radiography, radiation gauging, smoke detectors and self-luminous materials. Because most of these applications entail the utilization of encapsulated sources, radiation exposures would be expected to occur mainly externally during shipment, transfer, maintenance, and disposal.

In the past decade, radiation exposures in research and industrial applications were roughly half those due to medical occupational exposure; hence, their contribution to the direct population dose is substantial [4].

c) Nuclear Explosions:

For the last 50 years, everyone has been exposed due to radiation from fall-out from nuclear weapons. Almost all is the result of atmospheric nuclear explosions carried out to test nuclear weapon. This testing reached two peaks: first between 1954 and 1958 and second, greater, in 1961 and 1962.

In 1963 the three countries (USSR, United States, United Kingdom) signed the Partial Test Ban Treaty, undertaking not to test nuclear weapon in the atmosphere, oceans and outer space. Over next two decades France and China conducted series of much smaller tests, but they stopped, too, after 1980. Underground tests are still being carried out, but they generally give rise to virtually no fall-out [5].

d) Nuclear Power :

The production of nuclear power is much the most controversial of all the man-made sources of radiation, yet it makes a very small contribution to human exposure. In normal operation, most nuclear facilities emit very little radiation to the environment. By the end of 2006 there were 437 nuclear power reactors in operation in 30 countries, worldwide. These power stations are just part of the nuclear fuel cycle. This starts with the mining and milling of uranium ore and proceeds to the making of nuclear fuel. After use in power stations the irradiated fuel is sometimes "reprocessed" to recover uranium and plutonium. Eventually the cycle will end with the disposal of nuclear wastes. At each stage in this cycle radioactive materials can be released [5].

e) **Nuclear and Radiation accidents:**

Some severe nuclear and radiation accidents are created radioactive contamination in the environment. On 26 April 1986, the most serious accident in the history of the nuclear industry occurred at Unit 4 of the **Chernobyl** nuclear power plant in the former Ukrainian Republic of the Union of Soviet Socialist Republics, near the common borders of Belarus, the Russian Federation and Ukraine. Major releases of radionuclides from the Chernobyl reactor continued for ten days following the explosion on April 26. These included radioactive gases , condensed aerosols and fuel particles. The total release of radioactive material was about 14 EBq (1EBq = 10^{18} Bq), including 1.8 EBq of ^{131}I, 0.085 EBq of ^{137}Cs, 0.01 EBq of ^{90}Sr and 0.003 EBq of plutonium isotopes. Radioactive noble gases contributed about 50% of the total activity released.

More than 200,000 square kilometers of Europe was contaminated with levels of ^{137}Cs above 37 kBq/m^2. Much of this area was within the three most affected countries, Belarus, Russia and Ukraine. The level of deposition was extremely varied and was enhanced in areas where it was raining while the contaminated air masses passed. Most of the strontium and plutonium was deposited within 100 km of the destroyed reactor due to their larger particle sizes [5].

1.3.3. Radiation Exposure from Background Radiation

Naturally occurring background radiation is the main source of exposure for most people. Levels typically range from about 1.5 to 3.5 millisievert per year but can be more than 50 mSv/yr [6].

Ionizing radiation is also generated in a range of medical, commercial and industrial activities. The most familiar and, in national terms, the largest of these sources of exposure is medical X-rays. Natural radiation contributes about 85% of the annual dose to the population and medical procedures most of the remaining 14%. Natural and artificial radiations are not different in kind or effect.

There are many sources of harmful, high energy radiation. Industrial radiographers are mainly concerned with exposure from x-ray generators and radioactive isotopes, but let's start by considering sources of radiation in general. It is important to understand that eighty percent of human exposure comes from natural sources such as outer space, rocks and soil, radon gas, and the human body. The remaining twenty percent comes from man-made radiation sources, such as those used in medical and dental diagnostic pro, One source of natural radiation is cosmic radiation. The earth and all living things on it are constantly being bombarded by radiation from space. The sun and stars emits EM radiation of all wavelengths. Charged particles from the sun and stars interact with the earth's atmosphere and magnetic field to produce a shower of radiation, typically beta and gamma radiation. The dose from cosmic radiation varies in different parts of the world due to differences in elevation and the effects of the earth's magnetic field cedures Radioactive material is also found throughout nature. It occurs naturally in soil, water, plants and animals. The major isotopes of concern for terrestrial radiation are uranium and the decay products of uranium, such as thorium, radium, and radon. Low levels of uranium, thorium, and their decay products are found everywhere. Some of these materials are ingested with food and water, while others, such as radon, are inhaled. The dose from terrestrial sources varies in different parts of the world. Locations with higher concentrations of uranium and thorium in their soil have higher dose levels. All people also have radioactive isotopes, such as potassium-40 and carbon-14, inside their bodies. The variation in dose from one person to another is not as great as the variation in dose from cosmic and terrestrial sources. There are also a number of manmade radiation sources that present some exposure to the public. Some of these sources include tobacco, television sets, smoke detectors, combustible fuels, certain building materials, nuclear fuel for energy production, nuclear weapons, medical and dental X-rays, nuclear medicine, X-ray security systems and industrial radiography. By far, the most significant source of man-made radiation exposure to the average person is from medical procedures, such as diagnostic X-rays, nuclear medicine, and radiation therapy [5,6].

1.4 Radiation law and activity:

The nature of radioactive decay is determined by the fundamental fact that the probability per unit time that a radioactive nucleus will undergo decay is equal to some positive constant, λ, called the decay constant. The value of this constant depends on the type of decay and on certain properties of the nucleus undergoing decay (the parent nucleus) as well as the nucleus which remains after the decay has taken place (the daughter nucleus). From this fundamental relation it follows that of a sample containing N radioactive nuclei at time t, the number decaying per unit time is N λ and the number dN which decay in time dt is N λ dt. Since the nuclei which decay in time dt represent a *decrease* in the number of parent nuclei present in the sample, one writes the change in N as dN = – N λ dt. Integrating this expression from t = 0 to some later time t yields the radioactive decay law:

$$N = N_0 e^{-\lambda t} \qquad (1.1)$$

where N_0 is the number of parent nuclei present at t = 0. The activity, or number of disintegrations per second, is given by

$$A = -dN/dt = \lambda N_0 e^{-\lambda t} = A_0 e^{-\lambda t} \qquad (1.2)$$

where A_0 is the initial activity. The unit of activity is the Becquerel, defined as 1 disintegration/sec. Also used is the Curie (Ci), where 1 Ci = 3.7×10^{10} Becquerels.

The decay rate of a radioactive isotope is normally characterized by its half-life, $t_{1/2}$, which is defined as the time required for one-half of a given number of nuclei to decay. Equivalently, $t_{1/2}$ is the time interval during which the activity of a radioactive sample decreases by a factor of two [7] .

$$N/N_0 = ½ = e^{-\lambda t_{1/2}} \quad \text{or} \quad t_{1/2} = \ln 2/\lambda = 0.693/\lambda$$

1.5 Objectives of This Works *:*

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

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 proton , helium and electron ions energy deposition in target organ and in the various entrance layers (skin ,water , adipose tissue , muscle skeletal , 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 [15] , for these calculations we will use the SRIM 2008 code [31] , and Pstar , Astar , Estar codes [32,33,34] .
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, energy loss and dose which 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.

Chapter (2)

Interaction Of Radiation With Matter

2 .1 Introductions:

The detection, characterization and effects of radiation are almost entirely dependent upon their interaction with matter.

Types of radiation are **direct ionizing radiation** and **indirect ionizing radiation**. The flows of charged particles, such as alpha particles, beta particles, electrons, are phenomena of direct ionizing radiation, because though coulomb interaction with matter it directly causes ionization and excitation of atoms. Indirect ionizing radiation (neutrons, γ-quantums) is radiation of particles or photons, which have no charge and during interaction with matter can transfer energy to charged particles, nuclei and atom electrons due to electromagnetic or nuclear interaction [8].

2.2 Interaction of heavy particles with matter (alpha):

Because alpha particles are comparatively heavy and have a charge, they react strongly with matter, producing large numbers of ions per unit length of their path. As a result, they are not very penetrating. For example, 5 MeV alpha particles will only travel about 3.6 cm in air and will not penetrate an ordinary piece of paper. For the other materials the average travel distance with respect to air is approximately inversely proportional to the respective densities of each material. 5 MeV alpha particles will only travel about 4 μm in mammal tissue.

Alpha particles can interact with either nuclei or orbital electrons in any absorbing medium such as air, water, tissue or metal. An alpha passing in the vicinity of nucleus may be deflected with no change in energy (Rutherford scattering), deflected with small change in energy or absorbed by nucleus, causing nuclear transformation (this process is negligible for alphas).

The most probable process involved in the absorption of alphas, however, are ionization and excitation of orbital electrons. Ionization occurs whenever the alpha particle is sufficiently close to electron to pull it out from orbit though coulomb attraction. Each time this occurs, the alpha loses kinetic energy and is thus slowed. The alpha also loses kinetic energy by exciting orbital electrons with interactions that are insufficient to cause ionization. As it becomes slowed, the alpha has tendency to cause ionization at an increasing rate. As the alpha nears to the end of its track, its rate of ionization peaks and within very short distance, it stops, collects two electrons and becomes helium atom[8,13].

Since alphas are low in penetration ability, they themselves are usually not hazardous for external exposure, unless the alpha-emitting nuclide is deposited to organism. When internally deposited, alpha particles are often more damaging than most other types of particles because comparatively large amounts of energy are deposited within a very small volume of tissue, Using relativistic quantum mechanics, Bethe derived the following expression for the stopping power of a uniform medium for a heavy charged particle is:

$$\frac{dE}{dx} = \frac{4\pi Z^2 e^2 n}{mc^2 \beta^2}\left[\ln \frac{2mc^2\beta^2}{I(I-\beta^2)} - \beta^2\right] \qquad (2.1)$$

Where:

- z = atomic number of the heavy particle,
- e = charge on an electron,
- n = electron density,
- m = rest mass of an electron,
- c = speed of light,
- β = speed of particle relative to light, and
- I = mean excitation energy of medium

2.3 Interaction of light particles with matter (beta):

Beta particles can interact with electrons as well as nuclei in the medium through which they are traveling. Beta particles passing near nucleus will be deflected by the coulomb forces and losses of the beta particles kinetic energy may or may not (Rutherford scattering) occur.

The interactions of beta particles with orbital electrons are most important. Coulomb repulsion between beta particles and electrons frequently results in ionization. In the ionization process, the beta particles lose an amount of energy equal to the kinetic energy of the electron plus the energy used to free it from the atom. A beta particle may produce 50 to 150 ion pairs per centimeter of air before its kinetic energy is completely dissipated. The characteristic X-rays are emitted, when the vacant internal electron orbits are refilled with other electrons. Beta particles also cause excitation of external orbital electrons, which in turn leads to the emission of ultraviolet photons.

The ultimate fate of a beta particle depends upon its charge. A negatively charged beta particle, after its kinetic energy has been spent, either combines with a positively charged ion, or becomes a "free electron". Positrons, however, have a different fate. In spite of the fact that they dissipate their kinetic energy just like beta particles through ionization and excitation, they cannot exist at rest in the vicinity of the electrons. When a positron has been slowed sufficiently, it will be attracted to the opposite charge of an electron. When the electron and positron collide, they are both annihilated and an amount of energy equal to the sum of the particle masses is released in the form of two photons. These photons are referred to as "annihilation radiation". Both annihilation photons carry energy of 0.512 MeV, which is equivalent to the rest mass of the electron or the positron. Because of this phenomenon, 0.512 MeV photons often provide a convenient means for measurement of positron-emitting radionuclides.

Like alpha particles, betas have a characteristic average traveling distance (range) through matter that is dependent upon their initial kinetic energy. Beta particle range may be expressed as distance traveled in a certain medium. For example, beta particle with energy about 2 MeV will travel up to 9 m in air and about 10 mm in water. The range can be calculated using the formula [8,13]

$$R(T) = \int_0^T \left(-\frac{dE}{dx} \right)^{-1} dE \tag{2.2}$$

2.4 Interaction of X- and Gamma Ray:

The interaction of photons (γ- quantums) with matter involves several distinct processes. The relative importance and efficiency of each process is strongly dependent upon the energy of the photons and upon the density and atomic number of the absorbing medium. We shall first consider the general case of photon attenuation and then discuss some of the important processes separately [8, 13].

a)Rayleigh Scattering

When a photon interacts with atom, it may or may not impart some energy to it. The photon may be deflected with no energy transfer. This process is called Rayleigh scattering and is most probable for very low-energy photons.

b)Compton Effect

The Compton effect is usually the predominant type of interaction for medium energy photons (0.3 to 3MeV). In this process the photon interacts with an atomic electron sufficiently to eject it from orbit, the photon retains a portion of its original energy and continues moving in a new direction. Thus, the Compton effect has an absorption component and scattering component. The amount of energy lost by the photon can be related to the angle at which the scattered photon travels relative to the original direction of travel.

The scattered photon will interact again, but since its energy has decreased, it becomes more probable that it will enter into a photoelectric or Rayleigh interaction. The free electron produced by the Compton process may be quite energetic and behave like a beta particle of similar energy, producing secondary ionization and excitation before coming to rest [10].

c)Photoelectric Absorption

The most probable fate of a photon having energy slightly higher than the binding energy of atomic electrons is photoelectric absorption. In this process, the photon transfers all of its energy to the electron and its own existence terminates. The electron will escape its orbit with a kinetic energy equal to the difference between the photon energy and its own binding energy. Photoelectric absorption is most important for photons below 0.1 MeV if the absorbing medium is water or biological tissue. However, in high Z (atomic mass number) materials such as lead, this process is relatively important for photons up to about 1 MeV.

Photoelectric absorption of a gamma ray must occur near an atom and leads to the photon's energy being completely converted into releasing an electron from a constituent atom of the medium. The electron released is usually from an inner shell. The photoelectron emerges with a kinetic energy:

$$(KE)_e = E_\gamma - B_e \qquad (2.3)$$

where B_e is the binding energy of the electron.

As with ionization produced by any process, secondary radiation are initiated, in this case, by the photoelectron which may have sufficient energy to produce additional ionization and excitation of orbital electrons. Also, filling of the electron vacancy left by the photoelectron results in characteristic X-rays [10].

d)Pair Production

Photons with energy greater than 1.024 MeV, under the influence of the electromagnetic field of a nucleus, may be converted into electron and positron. At least 1.024 MeV of photons energy are required for pair production, because the energy equivalent of the rest mass of the electron and positron is 0.51 MeV each. Pair production is not very probable, however, until the photon energy exceeds about 5 MeV. The available kinetic energy to be shared by the electron and the positron is the photon energy minus 1.02 MeV, or that energy needed to create the pair. The probability of pair production increases with Z of the absorber and with the photon energy.

f) Relative Importance of Photon Attenuation Processes

The various processes of photon attenuation can now be considered by examining the effects of photon energy and atomic mass number of the absorber on their relative importance .

Consider a well-collimated monoenergetic beam of photons of initial intensity I_0. Due to the three processes above the intensity will be exponentially attenuated:

$$I = I_0 \exp(-N\sigma x) = I_0 \exp(-\mu x) \qquad (2.4)$$

N is atomic density, $\sigma = \sigma_{photoelectric} + Z\sigma_{Compton} + \sigma_{pair\ production}$

i.e σ is the sum of the three possible cross sections (probability of scattering).

$X_{1/2}$ = half value thickness=.693/ μ, $\mu = N\sigma$

2.5 Interaction of Neutrons with matter

The neutrons interact with atoms due to electromagnetic and nuclear forces. The neutrons affect living matter by the process of moderation. A high-energy neutron encountering biological material is apt to collide with a proton with sufficient force to dislodge the proton from the molecule, which held it. The proton (normally called the "recoil proton") may then have sufficient energy to travel some distance in the tissue causing secondary damage through ionization and excitation of molecules along its path [8].

The interactions of all these types of radiations will be studied in order to calculate the stopping power, Range, and dose which are very important parameters for medical treatments, diagnosis, and radiation protection.

Chapter (3)

Energy loss

And

Doses

3 .1 Energy losses:

In this chapter we will discuss all the theory regarding the energy loss, which is the amount of energy absorbed by matter from radiation interactions, energy loss per unit length, stopping power, range, and dose. For this all the equations used will be discussed specially Bethe-Bloch Formula for both heavy charge particles and electrons interaction with matter, these information’s will be a good theoretical model for this study. 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], which have the following processes:

3.1.1 Light charged particles (electrons)

- Excitation and ionization of atoms in absorber material (atomic effects)
- Interaction with electrons in material (collision, scatter)
- Deacceleration by Coulomb interaction (Bremsstrahlung)

3.1.2 Heavy charged particles (Z>1)

- Excitation and ionization of atoms in absorber material (atomic effects)
- Coulomb interaction with nuclei in material (collision, scatter)

  (Long range forces)

3.1.3 Neutron

Interaction by collision with nuclei in material (short range forces), the interaction between radiation particles and absorb material determines the energy loss of the particles and therefore the range of the particles in the absorber material.

Each interaction process leads to a certain amount of energy loss, since a fraction of the kinetic energy of the incoming particle is transferred to the body material by scattering, excitation, ionization or radiation loss.

The sum over all energy loss events along the trajectory of the particle yields the total energy loss.

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[18].

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:

$$-\frac{dE}{dx} = \left(\frac{e^2}{4\pi\varepsilon_0}\right)^2 \frac{4\pi z^2 N_A Z\rho}{mc^2\beta^2 A}\left[\ln\left(\frac{2mc^2\beta^2}{I}\right) - \ln(1-\beta^2) - \beta^2\right] \qquad (3.1)$$

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.

The range can be determined as given below:

$$\text{Range (approx.)} \quad R = \int \mathrm{d}x = \int_E^0 \frac{\mathrm{d}E}{\mathrm{d}E/\mathrm{d}x} \propto E^{1+k} \qquad (3.2)$$

Where the integration from 0 to maximum energy, l+k is integer.

3.1.1 Energy Loss of Electrons

The electrons has the following characteristics:

- The electron will make fewer collisions than a heavy charged particle
- The electron can be deflected to large angles
- There is not a well-defined range
- Radiation losses are also important
- At a given energy the speed of an electron is much greater than that of a heavy charged particle – therefore the stopping power from coalitional processes is much smaller

We can use the Bethe-Bloch formulism to calculate the stopping power for electrons. To this we must add the contribution from Bremsstrahlung [15].

It is not surprising that the formula (and its derivation) for energy loss by Bremsstrahlung is complicated and messy. However, we can again say:

The resultant formula is:

$$\left(\frac{dE}{dx}\right)_c = \left(\frac{e^2}{4\pi\varepsilon_0}\right)^2 \left[\frac{2\pi N_0 Z\rho}{mc^2\beta^2 A}\right] \left[\begin{array}{l} \frac{T(T+mc^2)\beta^2}{2I^2 mc^2} + (1-\beta^2) - (2\sqrt{1-\beta^2} \\ -1+\beta^2)\ln 2 - \frac{1}{2}(1-\sqrt{1-\beta^2})^2 \end{array}\right] \quad (3.3)$$

T kinetic energy of electron, I ionization, ρ density

The important dependence (putting aside the slowly varying logarithmic term) is:

We see that Bremstrahlung is important at high energies. We can also see why we must consider this process of energy loss for electrons, but not for heavy charged particles. The mass of the proton is almost 2000 times greater than that of the electron, therefore the contribution from Bremsstrahlung for heavy charged particles will be at least 2 x 10^6 less than it is for an electron.

Clearly we can only carry out the integration if we have a functional form for dE/dx over the full energy range. As I have remarked before, this is problematic at low energies.

The energy loss of the electron per unit length was derived by Bethe and can be written as:

$$\left(\frac{dE}{dx}\right)_r = \left(\frac{e^2}{4\pi\varepsilon_0}\right)^2 \left[\frac{N_0 Z^2 \rho (T+mc^2)}{137 m^2 c^4 A}\right]\left[4\ln\frac{2(T+mc^2)}{mc^2} - \frac{4}{3}\right] \qquad (3.4)$$

Where T is the kinetic energy of the electron, the subscripts c and r stands for the energy losses due to collisions and radiations, respectively. The expression for the radiative loss is valid only for relativistic energies below 1 MeV, the radiation losses are negligible . The total energy loss is just the sum of these contributions [15]:

$$\frac{dE}{dx} = \left(\frac{dE}{dx}\right)_c + \left(\frac{dE}{dx}\right)_r \qquad (3.5)$$

The ratio of Bremstrahlung (radiation r) losses to collisional , c, losses, for an electron, varies approximately as [15]:

$$\frac{\left(\frac{dE}{dx}\right)_r}{\left(\frac{dE}{dx}\right)_c} \cong \frac{E}{mc^2}\frac{Z}{1600} \qquad (3.6)$$

mc^2 = 0.511 MeV

The energy at which this ratio is unity is known as the CRITICAL ENERGY for the electron in the particular material.

3.2 Radiation units

(i) Rad (radiation absorbed dose) :

A unit of absorbed dose of radiation. Rad is a measure of the amount of energy deposited in tissue , which is the absorption of 100 erg for each gram ,the unit rad can be used for any type of radiation , but it dose not describe the biological effects of the different radiations due to the weighing factor of radiation type Q. [11]

1 rad = 100 erg/gram

(ii) Rem (Roentgen equivalent man):

A unit of equivalent absorbed dose of radiation which takes into account the relative biological effectiveness of different forms of ionizing radiation, or the varying ways in which they transfer their energy to human tissue. The dose in rem equals the dose in rad multiplied by the quality factor (Q). For beta and gamma radiation, the quality factor is taken as one, that is, rem equals rad. For alpha radiation, the quality factor is taken as 20, that is, rems equal 20 times rads. Rem is essentially a measure of biological damage. For neutrons , Q is typically taken as 10[11].

rem = rad x Q

(iii) Gray (Gy):

When ionizing radiation penetrates the human body or an object, it deposits energy. The energy absorbed from exposure to radiation is called an absorbed dose. The absorbed dose is measured in a unit called the gray (Gy). A dose of one gray is equivalent to a unit of energy (joule) deposited in a kilogram of substance [12].
A unit of absorbed radiation dose equal to 100 rad. Gray is a measure of deposition of energy in tissue[11].

1 Gy = 100 rad= 1 joule/kg

(iv) Sievert (Sv):

A unit of equivalent absorbed dose equal to 100 rem [11]. **1 Sv = 100 rem** ,

Sv = Gy x Q

(v) Curie (Ci):

The traditional unit of radioactivity, which measure the number of decays per second, equal to the radioactivity of one gram of pure radium-226 [11].
1 Ci = 37 billion dps = 37 billion Bq

(vi) Becquerel (Bq):

The standard international unit of radioactivity equal to one disintegration per second [11]. 1 Bq = 27 pCi

(vii) Disintegrations per second (dps):

The number of subatomic particles (e.g. alpha particles) or photons (gamma rays) released from the nucleus of a given atom over one second. One dps = 60 dpm (disintegrations per minute) [11]. 1 dps = 1 Bq

3.3 Radiation Dose :

a) Exposure

The amount of electrical charge (ΔQ) produced by ionizing electromagnetic radiation per mass (~m) of air is called exposure (X);

$$X = \Delta Q / \Delta m$$

Exposure is in the units of charge per mass, i.e., coulombs per kg or C/kg. The historical unit of exposure is the roentgen (abbreviated R), which is defined as:

$$1\ R = 2.58\ X\ 10^{-4}\ C/kg\ (exactly)$$

Radiation fields are often expressed as an exposure rate (R/hr or mR/min). The output intensity of an x-ray machine is measured and expressed as an exposure (R) per unit of current times exposure duration (milliampere second or mAs) (e.g., 5 mR/mAs at 70 kVp for a source/image distance of 100 cm, and with an x-ray beam filtration equivalent to 2 mm AI) [12].

b) Absorbed dose (Imparted Energy) D :

The total amount of energy deposited in matter, called the imparted energy, is the product of the dose and the mass over which the energy is imparted. The unit of imparted energy is the joule: *(J/kg)* x kg =J

For example, assume each l-cm slice of a head computed tomography (CT) scan delivers a 30 mGy (3 rad) dose to the tissue in the slice. If the scan covers 15 cm, the dose to the irradiated volume (ignoring scatter from adjacent slices) is still 30 mGy

(3 rad); however, the imparted (absorbed) energy is approximately 15 times that of a single scan slice[12].

c) Equivalent dose

When radiation is absorbed in living matter, a biological effect may be observed. However, equal absorbed doses will not necessarily produce equal biological effects. The effect depends on the type of radiation (e.g., alpha, beta or gamma). For example, 1 Gy of alpha radiation is more harmful to a given tissue than 1 Gy of beta radiation. To obtain the equivalent dose, the absorbed dose is multiplied by a specified radiation weighting factor (w_R). **A radiation weighting factor (w_R)** is used to equate different types of radiation with different biological effectiveness.
was established by the International Commission on Radiological Protection (lCRP) in (1990). The equivalent dose is expressed in a measure called the sievert (Sv). This means that 1 Sv of alpha radiation will not have the same biological effect as 1 Sv of beta radiation. In other words, the equivalent dose provides a single unit that accounts for the degree of harm that different types of radiation would cause to the same tissue [14] .

Type of radiation	weighing factor W_R
X-rays, gamma rays, beta particles, and electrons	1
1 Protons (>2 MeV)	5
Neutron (energy dependent)	5-20
Alpha particles and other multiple-charged	20

Table 3-1. Radiation Weighting Factors (Wr) For Various Types Of Radiation

LET (**linear energy transmission**), radiations that produce dense ionization tracks cause more biologic damage per unit dose than low LET radiations and thus have higher radiation weighting factors. The product of the absorbed dose (D) and the radiation weighing factor is the equivalent dose (H)

The SI unit for equivalent dose is the sievert (Sv). Radiations used in diagnostic imaging (x-rays, gamma rays, and electrons) have a W_R of 1: thus 1 mGy = 1 mSv.

For heavy charged particles such as alpha particles, the LET is much higher and thus the biologic damage and the associated W_R is much greater (Table 3-1). For example, 10 mGy from alpha radiation may have the same biologic effectiveness as 200 mGy of x-rays.

The quantity H is replaced by an earlier but similar quantity, the *dose equivalent,* which is the product of the absorbed dose and the *quality factor (Q)*. The quality factor is analogous to W_R.

$$H = \Sigma_R \; D \; W_R$$

The traditional unit for both the dose equivalent and the equivalent dose is the rem. A sievert is equal to 100 rem, and 1 rem is equal to 10 mSv.

d) Effective dose

Different tissues and organs have different radiation sensitivities. For example, bone marrow is much more radiosensitive than muscle or nerve tissue. To obtain an indication of how exposure can affect overall health, the equivalent dose is multiplied by a tissue weighting factor (w_T) related to the risk for a particular tissue or organ. This multiplication provides the effective dose absorbed by the body. The unit used for effective dose is also the sievert.

Not all tissues are equally sensitive to the effects of ionizing radiation. Tissue weighting factors *(w_T)* were established in lCRP to assign a particular organ or tissue (T) the proportion of the detriment from stochastic effects (e.g., cancer and genetic effects) resulting from irradiation of that tissue compared to uniform whole-body irradiation. These tissue weighting factors are shown in Table 3-2. The sum of the products of the equivalent dose to each organ or tissue irradiated *(H_T)* and the corresponding factor *(w_r)* for that organ or tissue is called the effective dose *(E).* The effective dose is expressed in the same units as the equivalent dose (sievert or rem) [12].

$$E(Sv) = \Sigma \, W_T \; H_T(Sv) = \Sigma \, W_T \; \Sigma_R \; D \; W_R$$

Tissue or Organ	Tissue Weighting factor
Gonads	.20
marrow (red)	.12
Colon	.12
Lung	.12
Stomach	.12
Bladder	.05
Breast	.05
Liver	.05
Esophagus	.05
Thyroid	.05
Skin	.01
Bone surface	.01
Remainder	.05
Total	1.0

Table 3-2. Tissue Weighing Factors Assigned By The International Commission On Radiological Protection which change the effective dose by change of tissue type

Chapter 4

Medical Effects Of Radiation

4.1 Introduction

Whether the source of radiation is natural or man-made, whether it is a small dose of radiation or a large dose, there will be some medical effects [20].

Radiation causes ionizations of atom, which may affect molecules, cells tissues, organs, and the whole body [20].

Radiation may affect living things by damaging the cells that make up the living organism. Radiation effects on a cell are random. That is, the same type and amount of radiation could strike the same cell many times and have a different effect, including no effect, each time. However, in general, the more radiation that strikes a cell, the greater the chances of causing an effect. If a significant number of cells are affected, the organism may be damaged or even die [21,22].

All living things are constantly exposed to background radiation.

Most cells have the ability to repair some damage done by this level of radiation. As a result, the effects of doses similar to background levels are impossible to measure. Effects of such low levels of radiation are

Often estimated for very large groups of people rather than for individuals [21,22].

When a cell absorbs radiation, there are four possible effects on the cell.

• The cell may suffer enough damage to cause loss of proper function, and the cell will die.

• The cell may lose its ability to reproduce itself.

• The cell's genetic code (i.e., the DNA) may be damaged such that future copies of the cell are altered, which may result in cancerous growth.

• The absorption of radiation by a cell may have no adverse effects.

Cells are made up of molecules. Cell damage may be caused by interaction of radiation with these molecules. If radiation strikes a molecule crucial to the cell's function, such as DNA, damage to the cell is likely to be greater than if the radiation strikes a less crucial molecule such as water.

Cells that multiply rapidly are more likely to be affected by radiation than others. An example of rapidly dividing cells is fetal tissue. For this reason, a fetus is especially sensitive to radiation.

Another example is a cancerous tumor, which can often be destroyed by radiation treatment. Cells can often repair radiation damage, but if the cell multiplies (splits into two identical cells) before it has had time to repair the most recent radiation damage, the new cells might not be accurate copies of the original one[22].

4.2 Types of exposure

Radiation exposure may be internal or external, and can be acquired through various exposure pathways[23].

1) **Internal exposure**:

The ionizing radiation occurs when a radionuclide is inhaled, ingested or otherwise enters into the bloodstream (e.g. injection, wounds). Internal exposure stops when the radionuclide is eliminated from the body, either spontaneously (e.g. through excreta) or as a result of a treatment.

2) **External exposure**:

Which occur when airborne radioactive material from natural sources and others (dust, liquid, aerosols) is deposited on skin or clothes. This type of radioactive material can often be removed from the body by simply washing and shielding.

Exposure to ionizing radiation can also result from external irradiation (e.g. medical radiation exposure to X-rays). External irradiation stops when the radiation source is shielded or when the person moves outside the radiation field..

4.3 Medical use of ionizing radiation

The medical use of ionizing radiation is of great importance for diagnosis, therapy and research in modern health care. It includes several medical specialties, often classified according to the following four groups:

(1) Diagnostic radiology.

(2) Radiotherapy.

(3) Nuclear medicine. and

(4) Biomedical research.

4.3.1 Diagnostic radiology:

Diagnostic radiology utilizes the ability of ionizing radiation to penetrate matter. The radiation is produced in an X-ray tube and directed towards the area of interest. The radiation that penetrates the body is recorded on a photographic film or some other imaging device, e.g., image intensifier, fluorescent screen etc. The amount of radiation that penetrates an object is dependent on certain physical properties, such as the energy of the radiation and the density and thickness of the object. This means that an object that consists of soft tissue and bone tissue will produce an X-ray image on which the tissues can be identified by the differences in blackening of the film which are the result of differences in transmission. Contrast media are often used to artificially increase the contrast of the image and thus to separate soft tissue organs and blood vessels from their surroundings [27].

The objective of diagnostic radiology is to produce an image of sufficient quality to allow diagnosis. To achieve this, several modalities are available, ranging from simple static imaging (radiography) to sophisticated real time imaging using dedicated equipment (fluoroscopy).

In computed tomography (CT) the X-ray tube is rotated around the patient yielding transmission profiles in many directions. These profiles can be used to reconstruct a transverse image of the object. This gives more accurate information about the exact location of a pathological abnormality such as a tumor. Another advantage of computed tomography is its ability to detect small differences in the absorption of radiation between different tissues, resulting in images with much higher contrast than those produced by conventional X-ray imaging techniques.

Interventional radiology comprises image guided therapeutic interventions via percutaneous access. Originally, only X-ray fluoroscopy was used to guide interventional procedures. Nowadays, ultrasound, computerized tomography and magnetic resonance imaging are also used to precisely localize the lesion, to guide the interventions and to control and document the result [28].

The most common use of ionizing radiation in medicine is for diagnostic radiology. It is carried out not only in hospitals with their very specialized radiological departments, but also in general practice and in dentistry. Continuing development of more sophisticated X-ray techniques is resulting in more reliable diagnosis, earlier detection of disease and less discomfort for the patient. It is important to realize that an X-ray examination is often the only diagnostic tool available and for a large fraction of all patients the X-ray examination plays a basic role in the final diagnosis.

A radioactive solution is injected into the patient. Gamma radiation given out by the solution can be detected outside the body using a gamma camera. The solution can be traced around the body showing whether the organs that it passes through and to are functioning properly, to test and diagnose organs as below. [28].

The tracer must have the following properties :

1. it will concentrate in the organ being investigated
2. it will lose its radioactivity quickly so as not to damage the body

   - short half life

3. it will emit rays that can get through the body to be detected outside

   -gamma rays.

4.3.2 Radiotherapy

Radiotherapy is mainly the use of ionizing radiation in the treatment of cancer, even though it also may be used to treat some non-malignant diseases. The major mechanism by which radiation causes permanent damage to living tissue is the inhibition of the ability of cells to divide. In order to achieve this, a much more intense irradiation of the patient is necessary than is required for diagnostic radiology. The objective is to deliver a dose high enough to kill the tumor cells but at the same time not do irreparable harm to healthy tissues.

Cancer is a disease that, without treatment, must be regarded as 100 percent lethal. It is a common disease all over the world, although types of cancer can vary considerably in frequency between different countries and even between different areas or ethnic groups within a country. The incidence of cancer in the industrialized world is in the range of 300-400 new cases each year per 100,000 population. The incidence of cancer is very age-dependent with a significant increase at older ages due to immune change. The reported incidence can be substantially lower in countries having a lower mean age of the population.

Radiotherapy can be performed either by external beam therapy or by brachytherapy (”brachy” means near). External beam therapy is often called teletherapy (”tele” means at a distance) [29].

If radiation is given from the outside this is called external therapy. Gamma rays from a radioactive source are used. Radiotherapy works by passing radiation into the body from different directions so that it always passes through the tumor and therefore kills its cells. The healthy cells around the tumor receive a much lower dose of radiation.

In external beam therapy the radiation can be generated in X-ray tubes or in particle accelerators. Also equipment with a strong radioactive source (cobalt-60 in modern equipment) is frequently used. Less common is the use of neutron sources and accelerators for heavy ions. A special kind of therapy equipment is the so called gamma-knife which uses a focused array of hundreds intersecting beams of gamma radiation from Co-60 to treat lesions within the brain. The technique provides an alternative method of treatment for a number of conditions, for which open neurosurgery may be either not practicable or carry a high risk of complications.

Internal therapy can be done by inserting a radioactive source into the affected area or by injecting a drug containing the radioactive material which will stay in the infected part.

Brachytherapy is the use of radioactive sources (radionuclides), which are implanted directly into tumor (interstitial therapy) or into a natural body cavity (intracavitary therapy). Different radionuclides can be used as well as sources of different shapes, such as wires, seeds, needles, tubes, etc. The trend in brachytherapy is towards the use of sources giving a high dose rate (HDR) and towards permanent implants of radioactive sources. Both methods reduce the time of hospitalization of the patient[29] .

The type of radiotherapy used is basically dependent on the type and site of the tumor.

In the 1950s the introduction of artificial radionuclides such as cobalt-60 energy and cesium-137 emitting gamma rays resulted in a skin-sparing effect and a better penetration which increased the possibility of treating tumors sited deep inside the body with minimal if any damage to the skin. Since about 1980, the more common use of linear accelerators as well as the use of computers in dose-planning have been important factors in the development of modern high quality radiotherapy performed with high accuracy and precision, as have also been the introduction of computed tomography and magnetic resonance imaging (MRI) for precise localization of the tumor. Intensity-modulated radiation therapy (IMRT) is a new and advanced mode of high precision radiotherapy that utilizes computer-controlled linear accelerators to deliver precise radiation doses to a malignant tumor. The radiation dose is designed to conform to a 3D shape of the tumor by controlling the intensity of the beam. Typically, combinations of several intensity-modulated fields coming from different beam directions produce a custom tailored radiation dose that maximizes tumor dose while also protecting normal tissue.

Other factors such as improved diagnosis, better care of the patient and increasing knowledge of radiobiology have also been of great importance in the improvement of treatment [27].

4.3.3 Nuclear medicine

The application of unsealed radioactive sources in medicine is now commonly known as "nuclear medicine", defined in its broadest sense as encompassing all applications of radioactivity in the fields of biology and medicine.

Diagnostic nuclear medicine involves use of radioactive tracers to measure the global or regional function of an organ. The radioactive tracer (radiopharmaceutical) is given to the patient by an intravenous injection, orally or by inhalation depending on the organ and the function to be studied. The uptake, turnover and/or excretion of the tracer substance is then studied with a gamma- camera, or other instruments such as a rectilinear scanner or a simple stationary radiation detector. The uptake of the tracer is generally a measure of the organ function or metabolism or the organ blood flow. The most common nuclear medicine procedures include bone scintigraphy for detection of skeletal metastasis, lung scintigraphy for detection of pulmonary embolism, kidney function studies, thyroid scintigraphy for detection of thyroid nodulus and heart scintigraphy for diagnosis of ischemic heart disease.

The most common radioactive substance used in nuclear medicine is technetium-99m. There are several reasons for this: 1) it is easy to produce, 2) it gives a low radiation dose to the patient, 3) the energy of the emitted radiation is optimal for imaging with the gamma camera. It can also quite easily be used to label a large number of pharmaceuticals for the examination of many organs.

The use of positron emission tomography (PET) is increasing dramatically at present. The reason are new radiopharmaceuticals labeled with fluorine-18, especially FDG, a glucose analogue, which can be used in staging of cancer as well as in nuclear cardiology and neurology. Especially in oncology there is a new use of combined imaging instruments, hybrid imaging, which consists of a gamma camera and CT or a PET-camera and CT. These instruments combine functional imaging with a precise localization of e.g. a tumor through image fusion. Mobile units of these instruments are also available [39].

Therapy using unsealed radioactive sources includes, for instance, treatment of the thyroid (hyperthyroidism and thyroid cancer) using radioactive iodine and pain palliation of bone metastasis using radioactive bone seeking agents. Attempts are made to use unsealed radioactive sources incorporated in endovascular stents to prevent restenosis of the vessel after angioplasty. lot of development is going on in order to find new radiopharmaceuticals labeled with biologically effective radionuclide's in order to treat tumors of different kinds[27].

4.3.4 Biomedical research

The use of radioactive trace substances and ionizing radiation is common in biomedical research. The basic work is normally carried out in the laboratory and using animal models in order to study chemical, physiological and metabolic processes as well as the turnover of pharmaceuticals. Such investigations are a necessary part of the introduction of new diagnostic and therapeutic methods. In order to transform the mechanisms to humans it is generally necessary to use humans in the studies, both healthy volunteers and patients suffering from a certain illness.

Some studies include different diagnostic methods using X-rays, some studies may include radioactivity measurements of samples of body fluids after injection of a small amount of a radioactive trace substance. Also the introduction of new methods in radiotherapy should be defined as biomedical research. In all investigations involving exposure of humans, a careful estimation of the effective dose should be made. The associated risk should then be weighted against the benefit for the patient or the society [27].

4.4 Health Effects of Radiation

These are divided into two categories: **threshold effects** and **non-threshold effects.** Threshold effects appear after a certain level of radiation exposure is reached and enough cells have been damaged to make the effect apparent. Non-threshold effects can occur at lower levels of radiation exposure [21]

1) Threshold effects :

Occur when levels of radiation exposure are tens, hundreds, or thousands of times higher than background, and usually when the exposure is over a very short time, such as a few minutes. They do not occur when doses of radiation are smaller than the threshold value.

2) Non-threshold effects :

can occur at any level of radiation exposure. However, the risk of harmful health effects generally increases with the amount of radiation absorbed. The most studied non-threshold effect is cancer. Studies are somewhat complicated by the facts that most cancers are not caused by radiation, exposure to a particular dose may cause cancer in one person but not in another, and the cancer often doesn't appear until many years after the exposure. It is currently impossible to determine which cancers are caused by radiation and which are caused by other carcinogens in our environment. Susceptibility to radiation-induced cancer depends on a number of factors such as the site of exposure in the body, and the sex and age of the exposed individual. Sites in the body where cells rapidly grow and multiply, and those where radioactive materials tend to concentrate, are more prone to cancer than others. For example, the breast and thyroid gland have relatively high susceptibilities to radiation-induced cancer, while the kidney and nerve cells have lower susceptibilities [21]

.

4.4.1 Radiation Effects on Populations

Because it is impossible to predict the effect of low levels of radiation on any one person, studies of the human health effects of radiation are usually done by trying to predict how many people in a large population might be affected. The result of such studies is an estimation of how many people in a population of, say, a million may get cancer because of a specific radiation exposure. The estimated cancers due to this specific radiation exposure are in addition to cancers that would normally be expected in a population of this size [21,22].

a) The effect of radiation on living things

All living things are made of cells. Each cell has a central nucleus which carries the special code (DNA) of the living organism. It is this code that determines what the organism will be like.

Radiation can ionise the chemicals in the nucleus of the cell so that the code is changed.

If radiation damages blood cells it can cause vomiting, loss of hair and increase the likelihood of infection. High doses of radiation can destroy cells completely and cause death.

Alpha radiation produces large amounts of ionization over short distances in body tissue. If the source is outside the body the radiation will be absorbed by dead layers of skin and will do little damage. If the source is swallowed or taken in by an open wound it can be very dangerous.

Beta radiation is absorbed by about one cm of body tissue. If the source is outside the body only a small amount will enter the body. Organs such as the heart, kidneys etc. will be protected unless the radioactive material is put into the body.

Gamma rays can pass straight through the body. They can cause damage to all parts of the body whether the source is inside or outside the body.

b) Effect of radiation on non-living things Ionisation:

Everything living and non-living is made up of atoms and radiation can cause ionization of an atom which will affect the way that atom reacts with other atoms.

Photographic Fogging: Alpha, beta and gamma radiation will blacken photographic film. This means that film can be used as a detector of radiation.

Scintillations: Some substances such as zinc sulphide are **fluorescent** this means that they can absorb the energy of the radiation and change it into light energy. The pulses of light energy that are given out when a radioactive particle hits the material are called scintillations.

eg one gram of plutonium has an activity of about 2000 MBq

Sievert (Sv): The unit of **equivalent dose**

eg one chest Xray 0.1 mSv

1 mSv : the annual dose to the most exposed nuclear industry worker half the natural dose from natural radiation in Britain 100 x the dose that would be absorbed by flying to Spain by jet

4.5 Radiation Limit and Risks:

4.5.1 Radiation limit:

Current science suggests there is some risk from any exposure to radiation. However, it is very hard to tell whether a particular cancer was caused by very low doses of radiation or by something else. While experts disagree over the exact definition and effects of “low dose,” radiation protection standards are based on the premise that any radiation exposure carries some risk [16] .

4.5.2 Radiation Risks:

Radiation can damage living tissue by changing cell structure and damaging DNA. The amount of damage depends upon the type of radiation, its energy and the total amount of radiation absorbed. Also, some cells are more sensitive to radiation. Because damage is at the cellular level, the effect from small or even moderate exposure may not be noticeable. Most cellular damage is repaired. Some cells, however, may not recover as well as others and could become cancerous. Radiation also can kill cell. The most important risk from exposure to radiation is cancer. Radiation can damage health in ways other than cancer. It is less likely, but damage to genetic material in reproductive cells can cause genetic mutations, which could be passed on to future generations. Exposing a developing embryo or fetus to radiation can increase the risk of birth defects[16].

Although such levels of exposure rarely happen, a person who is exposed to a large amount of radiation all at one time could become sick or even die within hours or days. This level of exposure would be rare and can happen only in extreme situations, such as a serious nuclear accident or a nuclear attack[17].

Chapter 5

Calculations

And

Results

5.1 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 calculate the stoppage and range ions in matter and contains the transport of ions in matter (TRIM) code [30, 31]. 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 [31].

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[33].

The ESTAR program calculates stopping power, density effect parameters, range, and radiation yield tables for electrons 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 10000 MeV [34].

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[13].

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, -d*E*/dx depends on pressure, but –d*E*/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].

Figures(5.1 - 5.8)are shown for stopping power and range Vs energy for heavy particles H ions (protons), in the graph the **Collision stopping power** is the average rate of energy loss per unit path length, due to Coulomb collisions that result in the ionization and excitation of atoms. For heavy charged particles, the collision stopping power is often called electronic stopping power and **Nuclear stopping** power is the average rate of energy loss per unit path length due to the transfer of energy to recoiling atoms in elastic collisions. Important only for heavy charged particles.

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 :

$R_1/R_2 = M_1(Z_1)^2/M_2(Z_2^2)$ (5.1)

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 charges

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:

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

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

Figures (5.9 - 5.17) , shows the stopping power and Range vs energy of alpha particles in different targets, where CSDA range is a very close approximation to the average path length traveled by a charged particle as it slows down to rest, calculated in the continuous-slowing-down approximation. In this approximation, the rate of energy loss at every point along the track is assumed to be equal to the total stopping power. Energy-loss fluctuations are neglected. The CSDA range is obtained by integrating the reciprocal of the total stopping power with respect to energy, and Projected range: average value of the depth to which a charged particle will penetrate in the course of slowing down to rest. This depth is measured along the initial direction of the particle

5.2 Calculations Stopping Power and Range for electrons:

The Stopping Power calculation for electrons traversing matter is similar to that for heavy charged particles. The interaction of incident electrons with atomic electrons, leading to excitation and ionization, can be calculated from Bethe's theory, and it is called the "**Collisional Stopping Power**". In addition to that, electrons are accelerated in the Coulomb field of nuclei, and this leads to electromagnetic radiation, the so-called "Bremsstrahlung". The corresponding stopping power is the "**Radiative Stopping Power**".

Figures(5.18 - 5.26) , shows stopping power and range for electrons in different targets. The stopping power in some biological compounds for electrons was calculated over the energy range from (10^{-2}MeV to 10^{3} MeV). Total stopping power was obtained by summing the electronic (collisional) and radiative stopping power of the target materials and then employing the continuous slowing down approximation (CSDA) to calculate the path length of incident particles in the target.

5.3: Dose Calculations :

Effect of radiation depends on:

-the nature of radiation (alpha, beta or gamma)

-the type of body tissue that absorbs it (blood, bone etc.)

-the total amount of energy absorbed

The most important parameters for treatment planning and dose calculations are:

*energy loss of radiation

*stopping power of radiation (LET)

*range and scatter of radiation

*dose and isodose of radiation

These parameters need to be carefully studied for planning the radiation treatment to maximize the damage for the tumor while minimizing the potential damage to the normal body tissue. An insufficient amount of radiation dose does not kill the tumor, while too much of a dose may produce serious complications in the normal tissue, may in fact be carcinogens as follow:[9,13] .

a) Alpha and Low energy Beta emitters distributed in tissue.

A radionuclide, ingested or inhaled, and distributed in various parts of the body is called an **internal emitter**.

Many radionuclides follow specific metabolic pathways, acting as a chemical element, and localize in specific tissues.

b) **iodine** concentrates in the thyroid

radium and **strontium** are bone seekers

tritium will distribute throughout the whole body in body water

cesium tends to distribute throughout the whole body.

If an internally deposited radionuclide emits particles that have a short range, then their energies will be absorbed in the tissue that contains them.

Let:

A = the activity concentration in Bq g^{-1}, of the radionuclide in the tissue

E_{av} = the average alpha or beta particle energy, in MeV per disintegration

The rate of energy absorption per gram tissue is A*E* (MeV g^{-1} s^{-1}).

The **absorbed dose rate** is [37]:

$D = AE_{av}\ (MeV/g.s) \times 1.6x10^{13}\ g/kg$ (5.2)

$= 1.60 \times 10^{-10}\ AE_{av}\ Gy\ s^{-1}$

c) Dose for A Point Source of Gamma Rays

$D = \Psi(\mu_{en}/\rho) = (C\ E)/(4\pi r^2)\ (\mu_{en}/\rho)$ (5.3)

D= Dose rate

Ψ = energy fluence rate (MeV/cm^2 sec)

C = activity (Bq)

E = energy per decay (MeV)

μ_{en}/ρ = mass energy-absorption coefficient of air (cm^2 g^{-1})

(~ same for photons between ~60keV and 2MeV)

d) Dose for A Beam of Photons

Dose = energy absorbed/mass

$Dose = (\mu_{en}/\rho)(N)(E)(\rho x)(A)/(A\ \rho\ x) = (\mu_{en}/\rho)(N)(E)$ (5.6)

(μ_{en}/ρ) = mass energy absorption coefficient (cm^2/g)

N = photon fluence (photons/cm^2)

E = energy per photon

ρ = density

x = thickness

A = area

e) Dose Calculation from stopping power:

Stopping power is used to determine dose from charged particles by the relationship:

$D = \Phi \ dE/(\rho dx)$ in units of MeV/g (5.7)

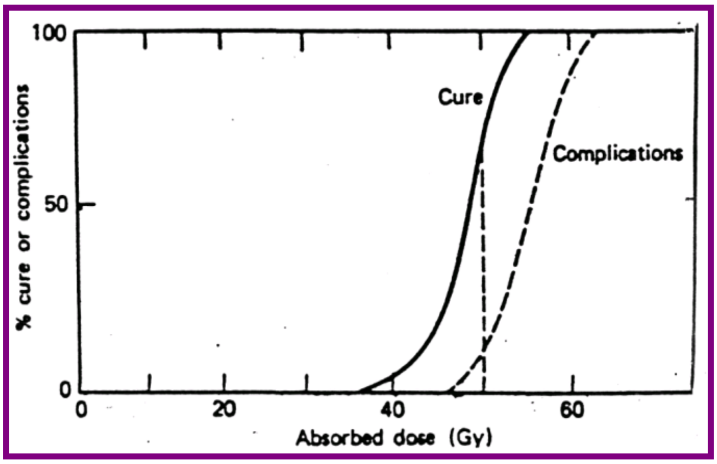
where

Φ =the particle fluence, the number of particles striking an object over a specified time interval,

To convert to units of dose ..we do the following manipulation.

$D = \Phi \ dE/(\rho dx)$ MeV/g $= \Phi \ dE/(\rho dx)$ (1.6×10^{-10}) Gy (5.8)

The energy loss of the radiation defines the " linear energy transfer“ and therefore the absorbed dose *D.* The solid line indicates the probability for destroying the tumor cells as a function of dose. The dashed line corresponds to the probability of causing cancer as a function of dose. A reduction of dose from 50 Gy to 45 Gy (5%reduction) lowers the chances of cure significantly from 65% to 15%. On the other hand an increase of dose by 5% to 60 Gy may kill all the cancer cells but increases the risk of complications from 10% to 80%.



VMC dose calculation simulates mathematically the irradiation of the human body by various

s radiation sources, including point, ground, cloud or internal sources. The Equivalent dose is calculated for relevant tissues and the Effective dose is also calculated [36, 37, 38].

VMC dose calculation is especially useful to quickly estimate the doses from radioactive sources in the case of emergencies or accidents. When a point source has been placed in a pocket, or near the body surface, VMC dose calculation can "zoom in" to the tissue region near the point source, to estimate the much larger doses to enable a prognosis of the deterministic radiation effects to this area.

VMC dose calculation has been extensively validated by comparing the results from the program with the doses measured in physical phantoms, and also by direct comparison with results generated using other Monte Carlo programs such as EGSnrc and MCNP.

Table 5.2 shows output results from VMS code for a point source from ^{22}Na which a gamma emitter of activity 5 Ci at distance x= 5 cm from a human target the doses of different part of the body is shown in the table and the total effective dose is 0.20 mSv.

Visual Monte Carlo - dose calculation Date of run: 5/2/2015

Project : na22		5 Ci of Na-22
Point source : x = 5 cm, y = 35.6 cm, z = 138 cm.		Exposure time = 1 second
10000 nuclear transformations.	Run started at 01:49:25	Report printed at 01:55:15

Organ doses D_T in mGy

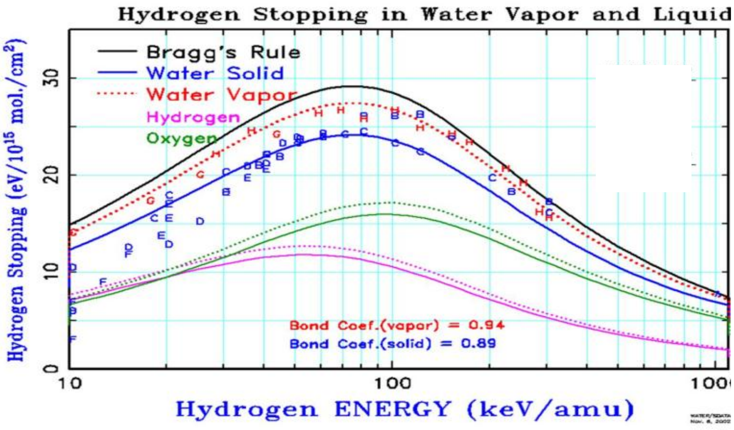
Bone marrow	0.07	Thyroid	0.46
Colon	0.10	Bone surface	0.12
Lung	0.39	Brain	0.08
Stomach	0.33	Salivary glands	0.20
Breast	0.00	Skin	0.11
Remainder	0.24	Adrenals	0.49
Gonads	0.00	Extrathor airways	0.32
Bladder	0.04	Gall bladder	0.33
Oesophagus	0.32	Heart	0.57
Liver	0.27	Kidneys	0.08

Lymphatic nodes	0.57 mSv
Effective dose	0.20 mSv

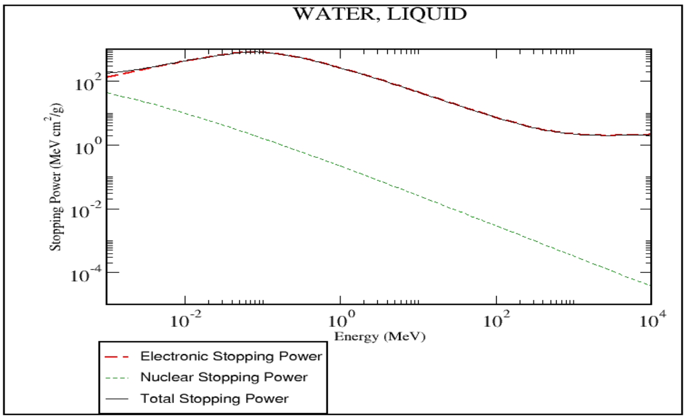
Table 5.1shows out put results from VMS for 5 Ci ^{22}Na gamma emmiter at x= 5 cm, y= 35.6 cm, z= 138 cm.

Also different sources and different runs have been done using VMS is shown in the figure 5.27 and 5.28.

1) Stopping power and range of H ions (proton):



Figure(5.1):Stopping power of Hydrogen in water by srim



Figure(5.2): stopping power of Hydrogen in water, by by pstar

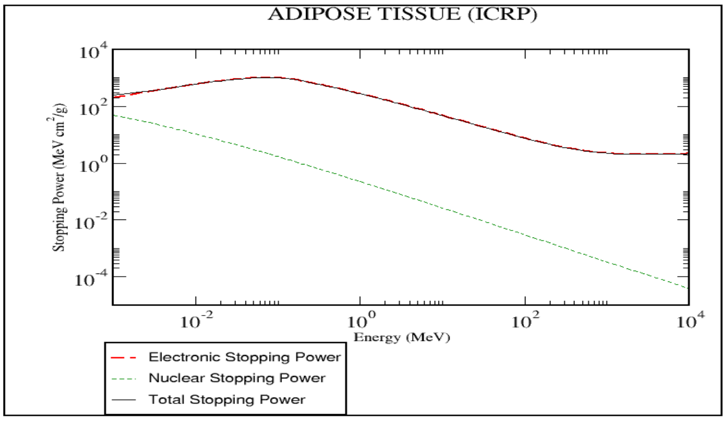


Figure (5.3): Stopping power of (H) in adipose tissue

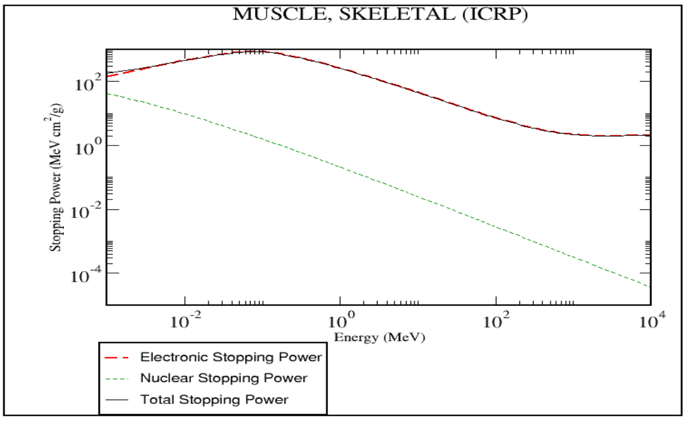


Figure (5.4): Stopping power of (H) with Muscle

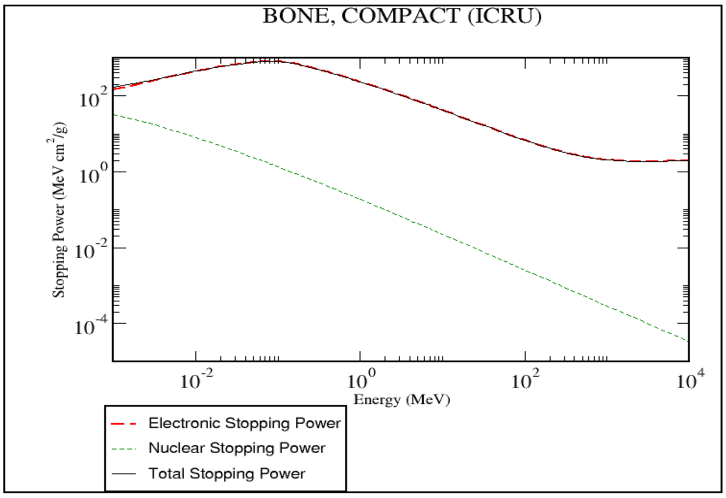
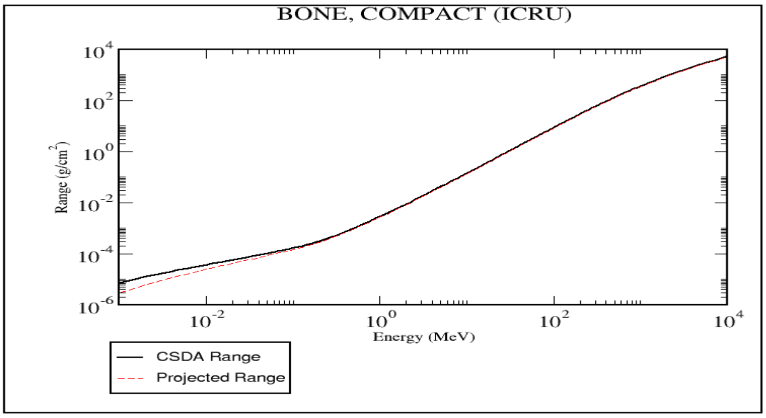
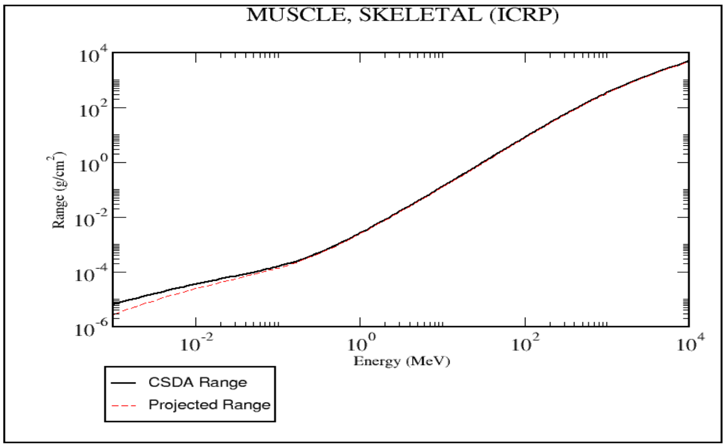


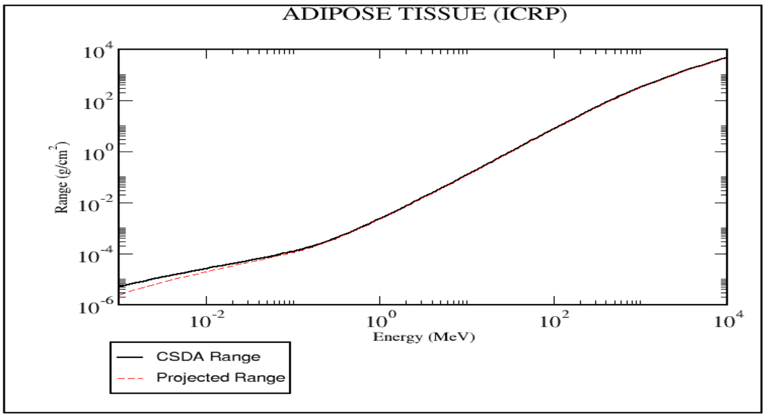
Figure (5.5) Stopping power of Hydrogen in Bone



Figure(5.6): Range of H in bone



Figure(5.7) : Range of H in muscle



Figure(5.8): Range of H in Adiapose Tissue

2) Stopping power and range of He ions (alpha):

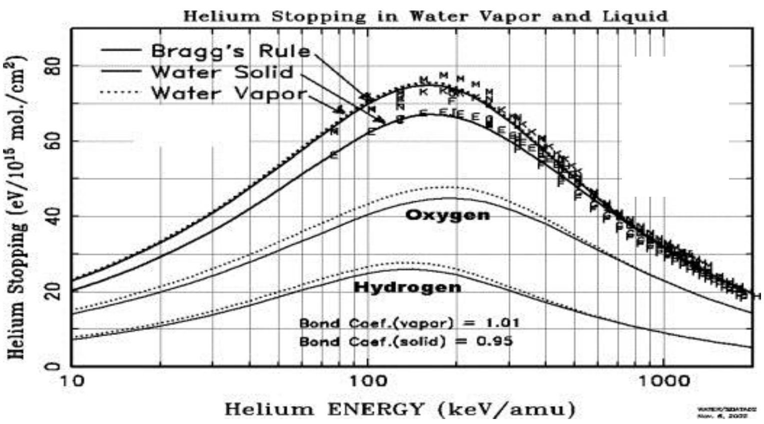


Figure (5.9) : Stopping power of Helium in Water (by srim)

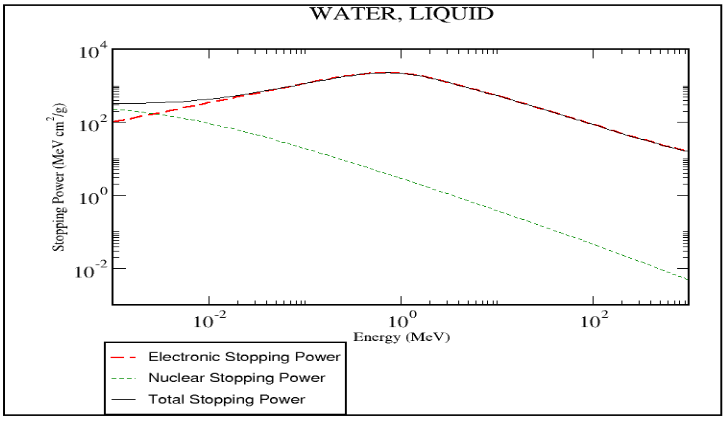


Figure (5.10) : Stopping power of Helium in Water **(by A star)**

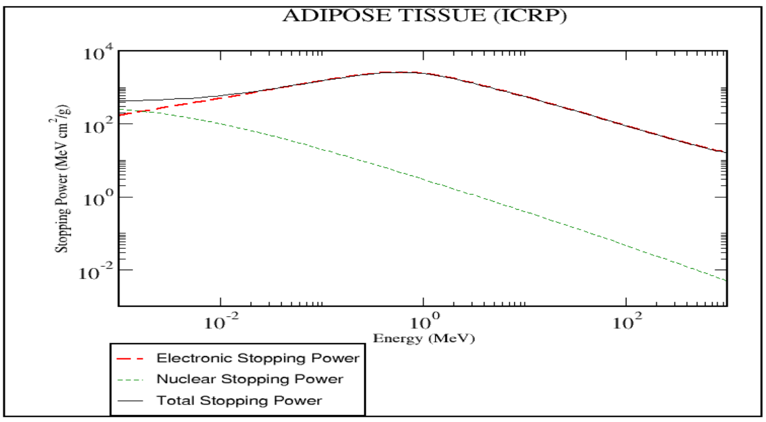


Figure (5.11) : Stopping power of Helium in Adipose tissue

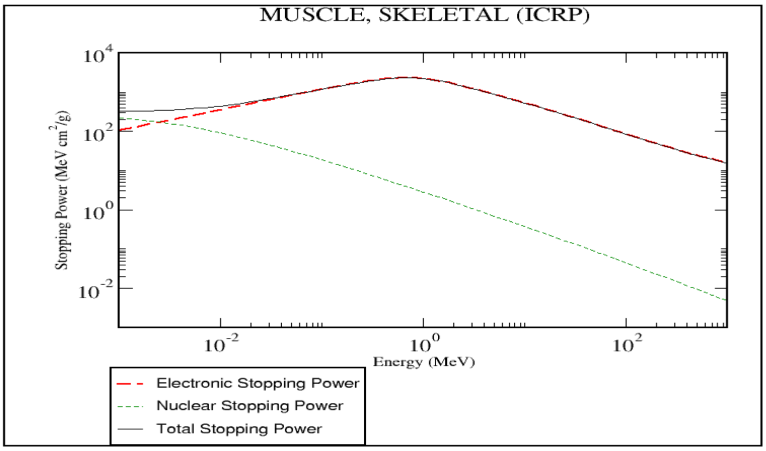


Figure (5.12): Stopping power of Helium in Muscle

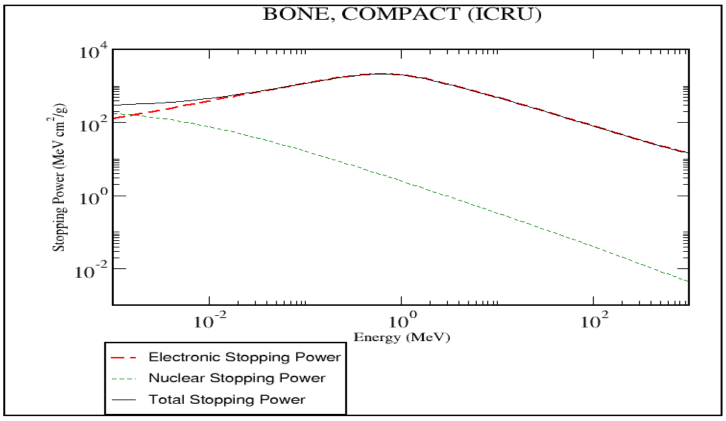


Figure (5.13): Stopping power of Helium in Bone

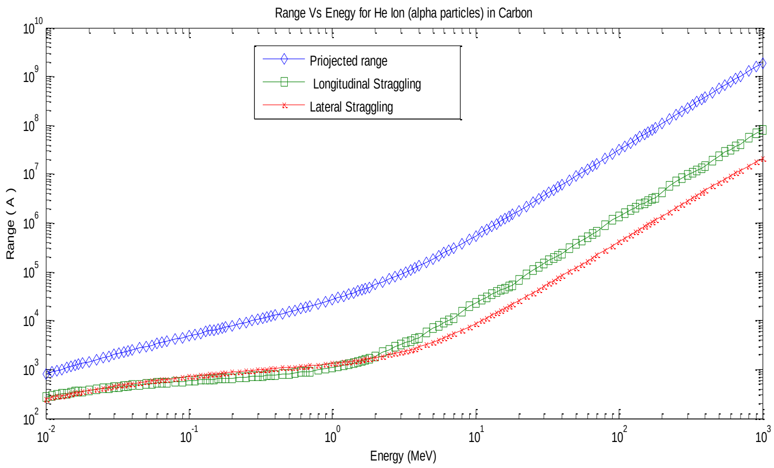


Figure (5.14) : Stopping power of Alpha pericles in carbon from MATLA

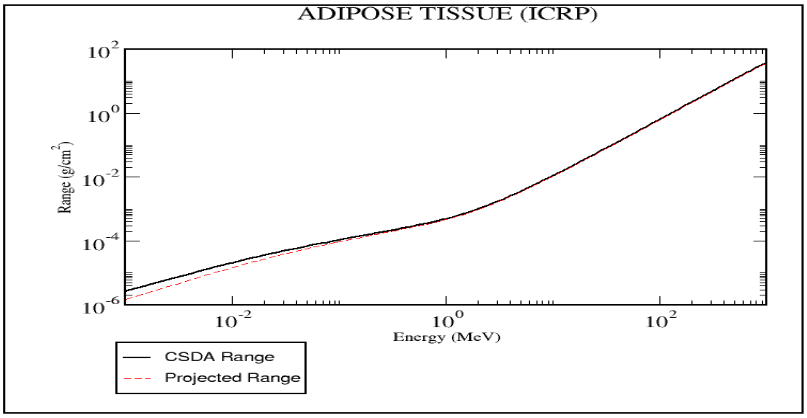
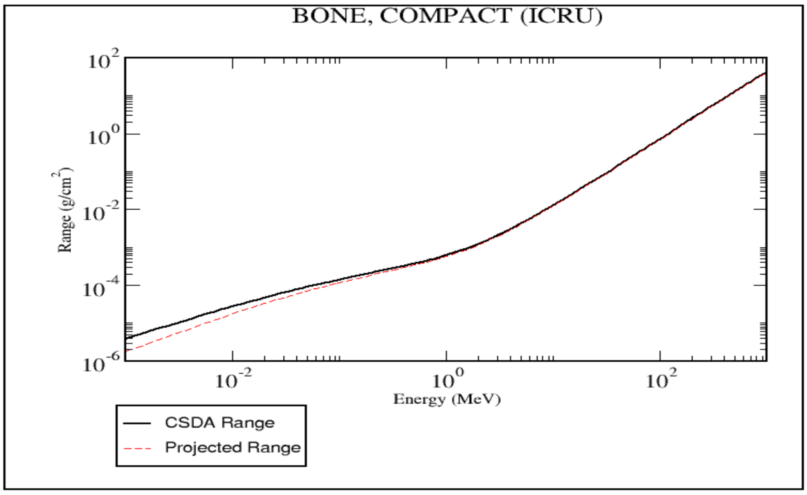
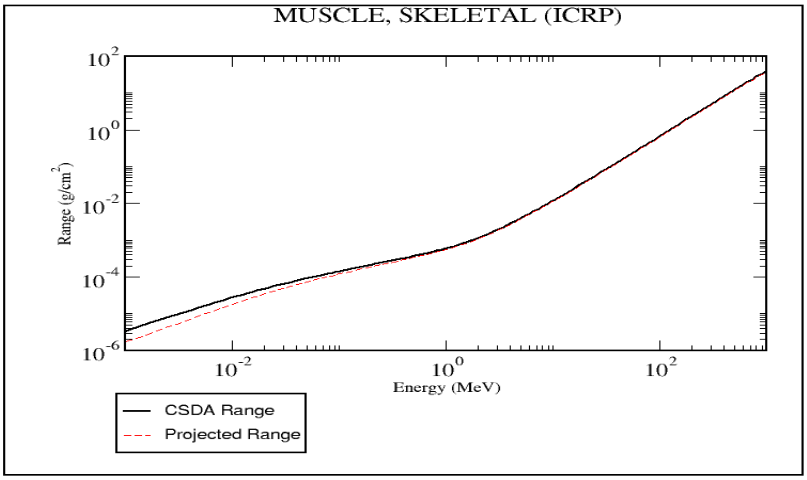


Figure (5.15):Range of He in Adiapose Tissue

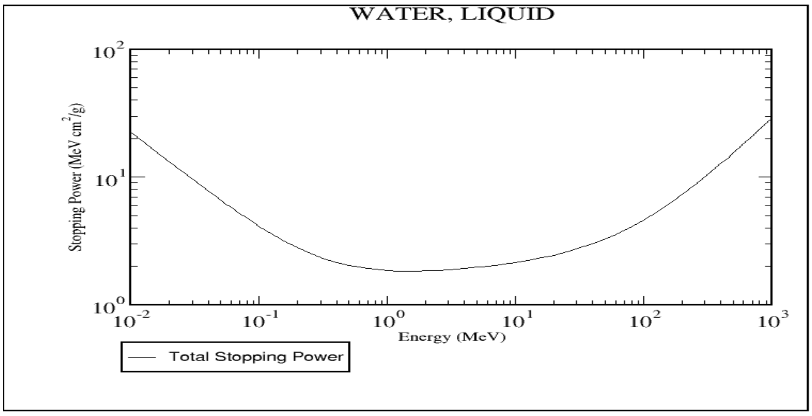


Figure(5.16): Range of He in bone

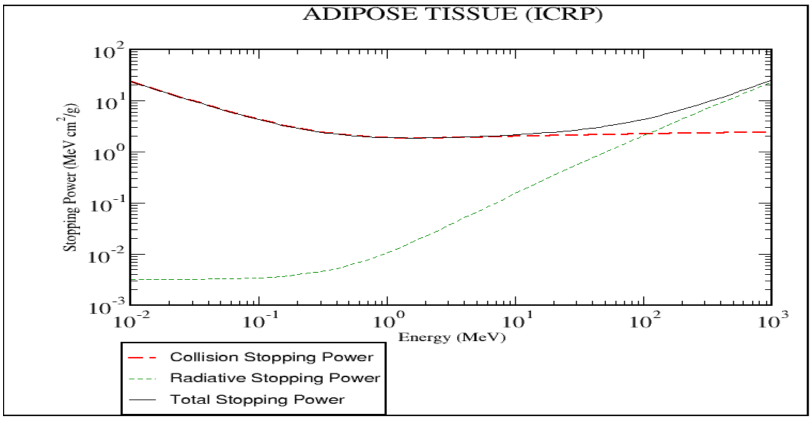


Figure(5.17) : Range of He in muscle

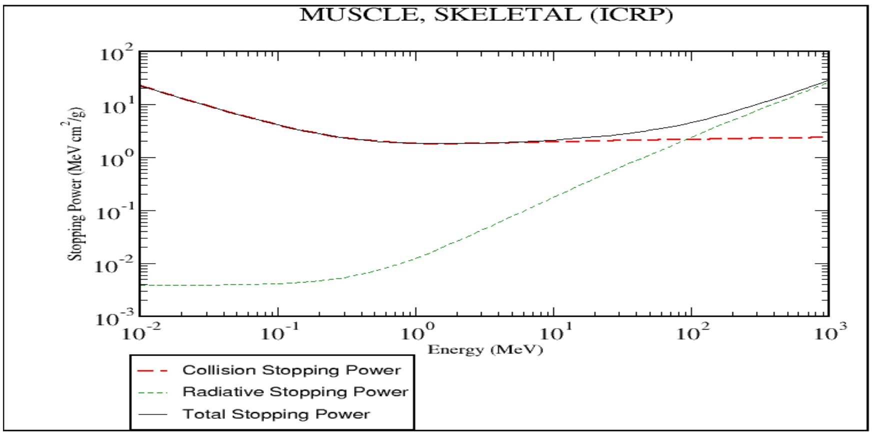
3) Stopping power and range of electrons :



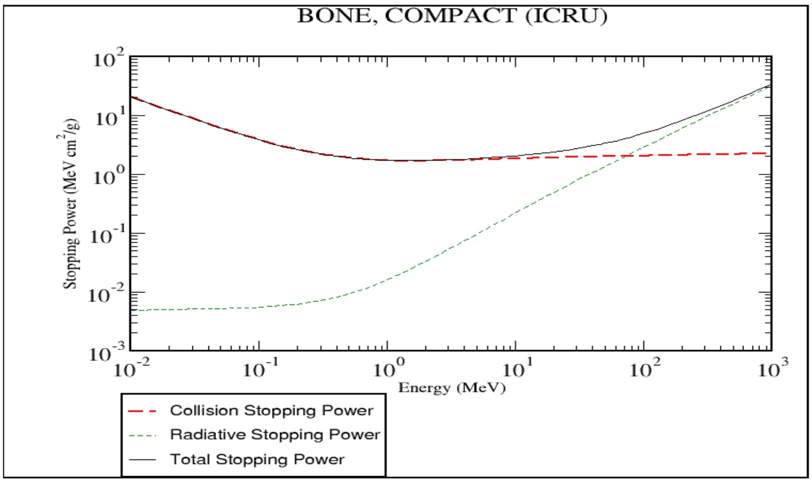
Figure(5.18) : Stopping power of electron in water



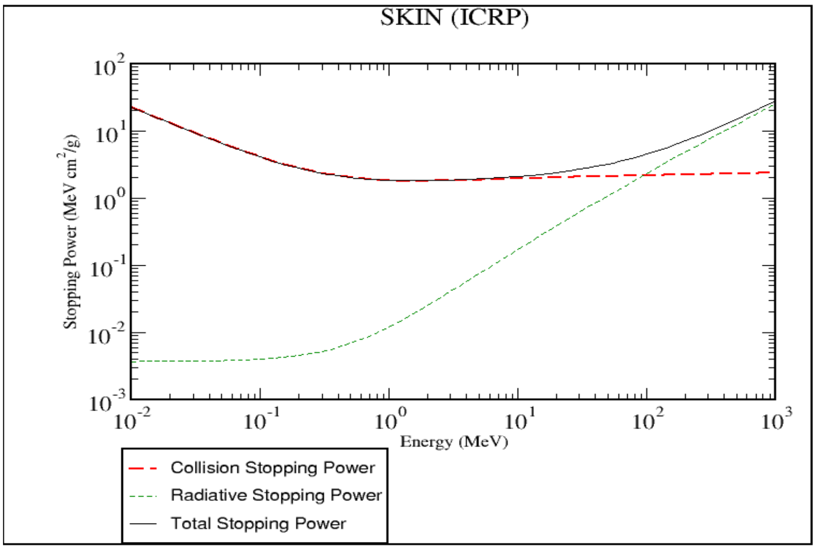
Figure(5.19) : Stopping power of electron in Adipose tissue



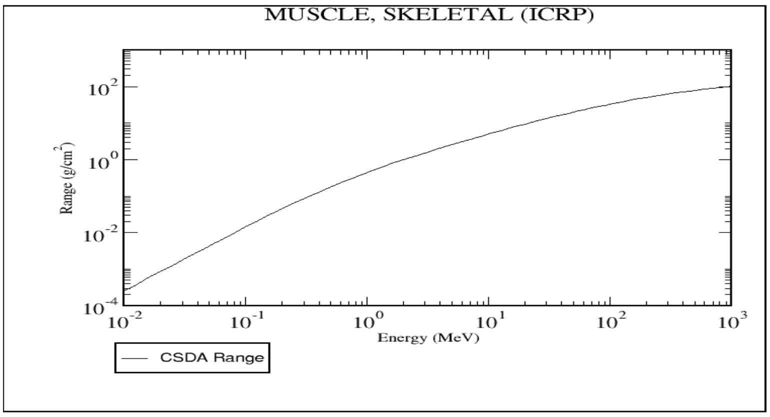
Figure(5.20) : Stopping power of electron in muscle



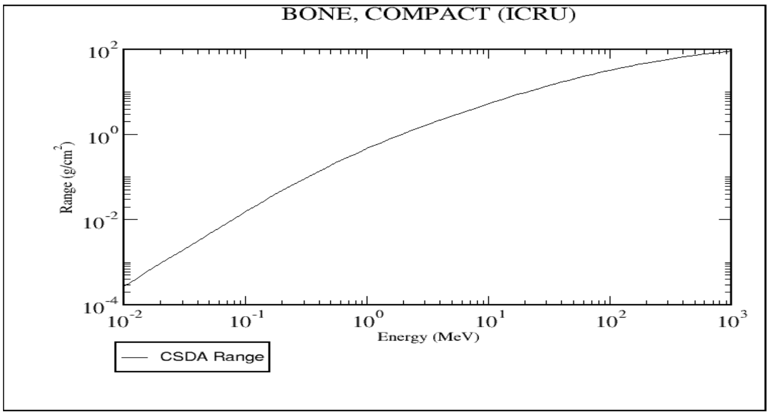
Figure(5.21) : Stopping power of electron in Bone



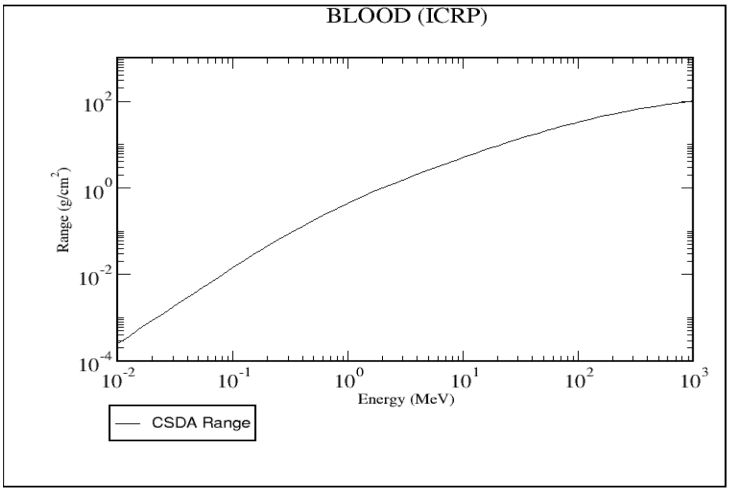
Figure(5.22) : Stopping power of electron Skin



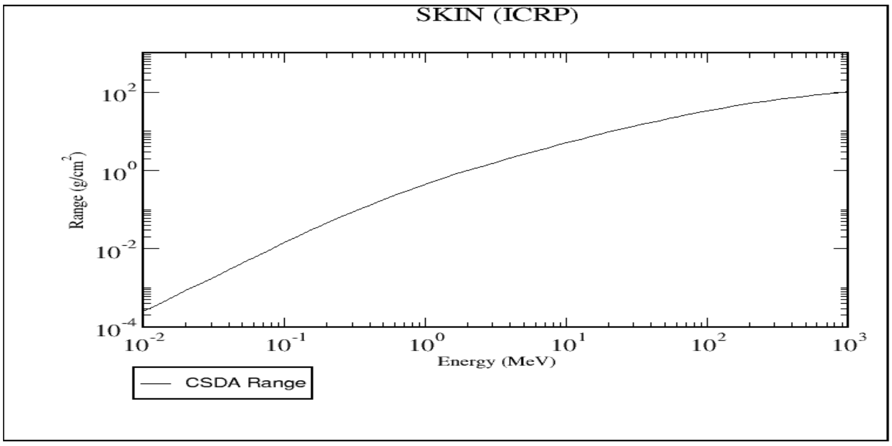
Figure(5.23) : Range of electron in muscle



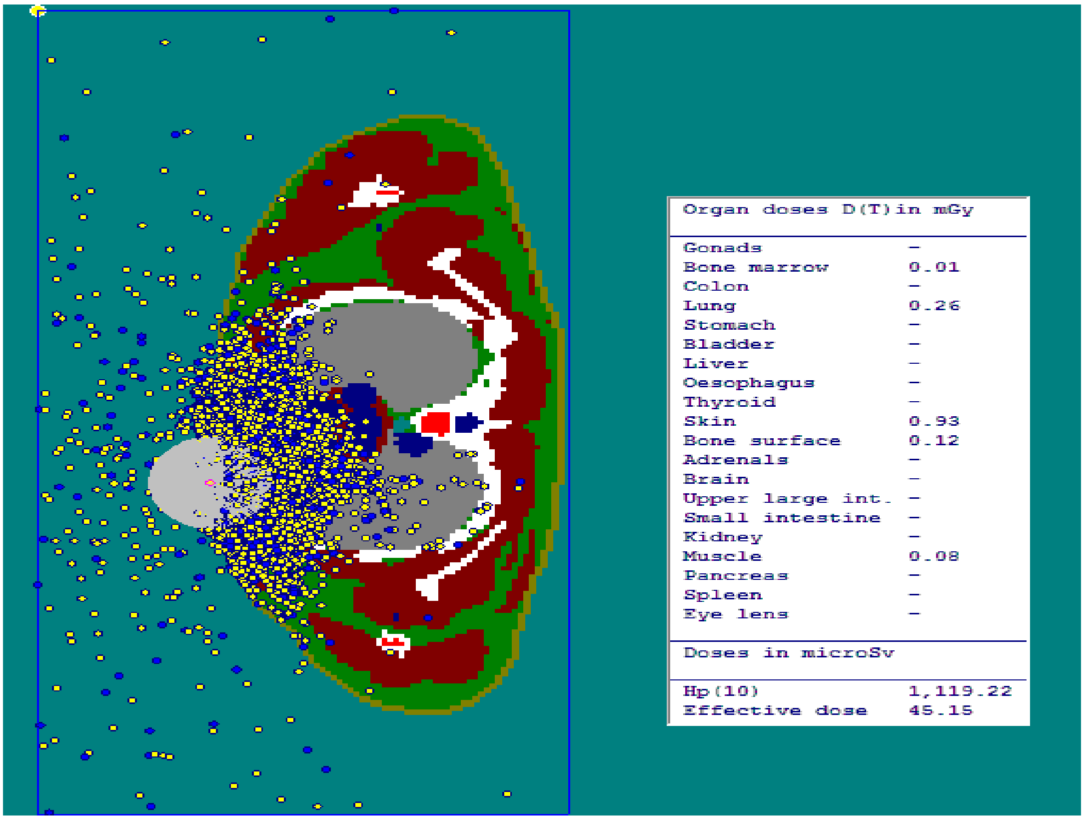
Figure(5.24) : Range of electron in Bone



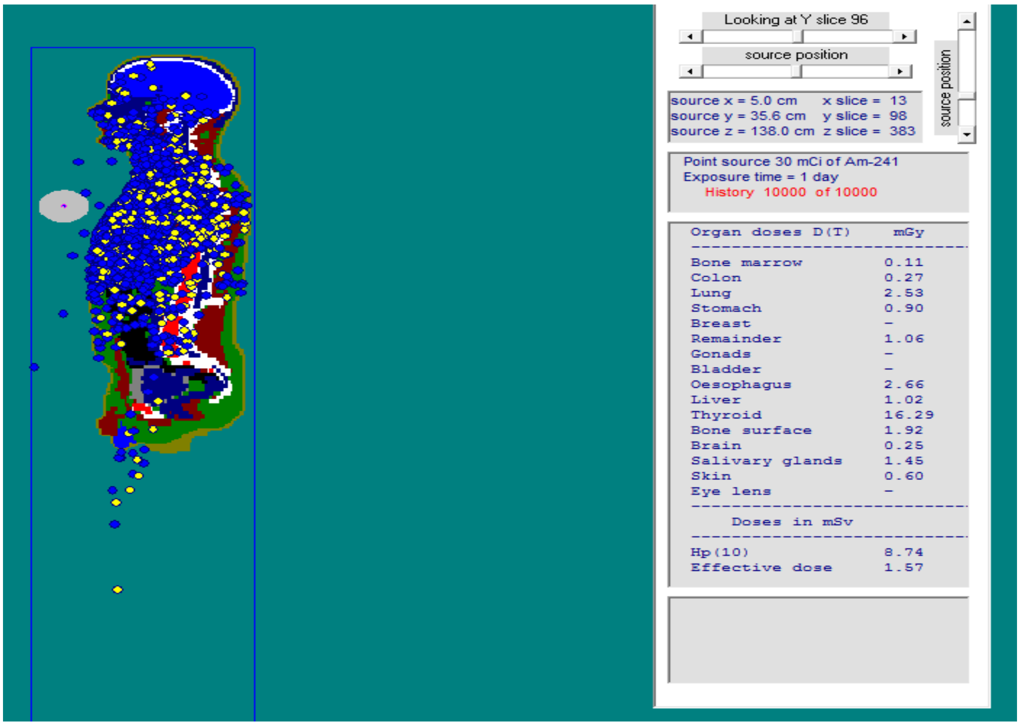
Figure(5.25) : Range of electron in Blood



Figure(5.26) : Range of electron in Skin



Figure(5.27): The Figure above represents the graphics of the dose calculation of a 20 keV source put in the shirt pocket.



Figure(5.28) point source of 30 mCi Am-241at x= 5cm, y= 36 cm from human body

Conclusion:

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 proton , electron and 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) Heavy particles are less scattered than electrons due to their heavy masses and the beam shows significantly better spatial resolution.

5) 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. The energy of the particles (with an initial energy E_i*)* at a certain depth *d* can be derived by:

$$E(d) = E - \int_0^x \frac{dE}{dx} dx$$

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.

Stopping power of electron in the energy range from 0.01Mev to 100Mev for number of elements. For low Z substances, dE/dx is almost constant between 0.5Mev and several Mev .The rise of the curves at high energies is due to increasing bremsstrahlung (radiation due to acceleration change) probability.

Body tissue is typically low Z material and the range can be approximated,

Range of 100Kev and 1.0Mev electron in muscle tissue is $1.33x10^{-2}g/cm^2$ & $0.412g/cm^2$,respectively

The Monte Carlo method as applied to Visual Monte Carlo is the simulation through mathematics of real elementary particles called photons. These photons, in the form of gamma rays or X-rays, have enough energy to cause ionization in the human body, and can therefore cause a radiation dose. For high doses, such as those seen during accidents, the radiation can cause short term biological effects such as burns to the skin. These effects are called deterministic effects, and will require specialized medical treatment.

The photons interact with the body tissues through the Photoelectric, Compton or Pair production interactions. The mathematical simulation, made through the use of mathematical equations on a computer, reproduces as closely as possible the real interactions suffered by the photons. The range of photon energies considered in VMC is from 10 keV to 3 MeV. The small contribution to the dose from pair production interactions due to photons with energy above 1.02 MeV, around 1% or less, is not considered in the simulation.

As a result of the photoelectric and Compton interactions, charged particles in the form of electrons are produced. The maximum range in human tissue of electrons is small, around 4 mm for a 1 MeV electron.

Glossary

A

absorbed dose: The amount of energy absorbed by irradiated matter per unit mass. This reflects the amount of energy deposited by ionizing radiation as it passes through a medium (such as air, water or living tissue) Unit: gray. Symbol: Gy.

activity: The number of nuclear disintegrations in a radioactive material per unit time. Used as a measure of the amount of a radionuclide present. Unit: becquerel. Symbol: Bq. 1 Bq = 1 disintegration per second.

acute dose: Exposure received within a short period of time (hours or days). The term "acute" refers only to the duration of exposure and does not imply anything about a dose's magnitude.

alpha particle: A positively charged particle consisting of two protons and two neutrons that is emitted by the nuclei of some radioactive elements as they decay. An alpha particle is relatively large and may be stopped by skin or a sheet of paper. An alpha particle is identical to a helium nucleus.

amino acids: The building blocks of proteins. They are organic molecules containing both an amino group (NH2) and a carboxyl group (COOH).

artificial radiation: Radiation created by human activities and that adds to naturally occurring background radiation.

atom: Unit of matter consisting of a single nucleus surrounded by a number of electrons (equal to the number of protons in the nucleus). The atom is the smallest portion of an element that can combine chemically with other atoms. All atoms other than hydrogen-1 also have neutrons in the nucleus.

atomic mass: The mass of an isotope of an element expressed in atomic mass units, which are defined as 1/12 the mass of an atom of carbon-12. An atomic mass of 1 is equivalent to about 1.66 x 10-27kg.

atomic number: The number of protons in the nucleus of an atom. Symbol: Z.

B

becquerel: The SI unit of activity of a radioactive substance. The becquerel supersedes the non-SI unit of the curie (Ci). Symbol: Bq. 1 Bq is equal to one nuclear disintegration (decay) per second; 1 Bq = 27 pCi (2.7 × 10–11 Ci) and 1 Ci = 3.7 × 1010 Bq. (see “SI”)

beta particle: An electron (negatively charged particle) or a positron (positively charged particle) that is emitted by the nuclei of some radioactive elements as they decay. A beta particle is relatively small and may be stopped by a sheet of aluminum or plastic a few millimetres thick.

bioassay (radiological): Any procedure used to determine the nature, activity, location or retention of radionuclides in the body by direct measurement *(in vivo)* or by analysis of material excreted or otherwise removed from the body *(in vitro).*

C

cancer: A large group of diseases caused by an uncontrolled division of abnormal cells.

cell: The smallest structural and functional unit of all known living organisms

Cosmic radiation: radiation produced in outer space when heavy particles from other galaxies bombard the earth.

D

Dose (radiation): the amount of radiation absorbed by a person’s body.

Dose rate: the radiation dose delivered per unit of time.

E

Electron: an elementary particle with a negative electrical charge and a mass 1/1837 that of the proton. Electrons surround the nucleus of an atom because of the attraction between their negative charge and the positive charge of the nucleus. A stable atom will have as many electrons as it has protons. The numbers of electrons that orbit an atom determine its chemical properties.

Exposure (radiation): a measure of ionization in air caused by x-rays or gamma rays only. The unit of exposure most often used is the roentgen.

Exposure rate: a measure of the ionization produced in air by x-rays or gamma rays per unit of time (frequently expressed in roentgens per hour).

External exposure: exposure to radiation outside of the body.

G

Gamma rays: high-energy electromagnetic radiation emitted by certain radioactive materials. These rays have high energy and a short wave length. Gamma rays penetrate tissue farther than do beta or alpha particles. Gamma rays are very similar to x-rays.

H

Half-life: the time any substance takes to decay into half of its original amount.

I

Internal exposure: exposure to radioactive material that has entered into the body.

Iodine: There are both radioactive and non-radioactive types of iodine. Radioactive types of iodine are widely used in medical applications. Radioactive iodine is a fission product and is the largest contributor to people’s radiation dose after an accident at a nuclear reactor.

Ion: an atom that has fewer or more electrons than it has protons causing it to have an electrical charge and, therefore, be chemically reactive.

Ionization: the process of adding one or more electrons to, or removing one or more electrons from, atoms or molecules, thereby creating ions. High temperatures, electrical discharges, or radiation can cause ionization.

Ionizing radiation: any radiation capable of removing electrons from atoms, thereby producing ions.

Irradiation: exposure to radiation.

N

Neutron: a small atomic particle possessing no electrical charge typically found within an atom's nucleus. Neutrons are neutral in their charge (they are positively nor a negatively charged). A neutron has about the same mass as a proton.

Non-ionizing radiation: radiation that has lower energy levels and longer wavelengths than ionizing radiation. It is not strong enough to affect the structure of atoms it contacts

but is strong enough to heat tissue and can cause harmful biological effects. Examples include radio waves, microwaves, visible light, and infrared from a heat lamp.

Nuclear energy: the heat energy produced by the process of nuclear fission within a nuclear reactor or by radioactive decay.

Nuclear Reactor: A device in which a fission chain reaction can be initiated, maintained and controlled.

Nuclear Regulatory Commission (NRC): Federal agency responsible for regulating the use of radioactive material.

Nucleus: the central part of an atom that is positively charged and contains protons and neutrons. The nucleus is the heaviest part of the atom and contains almost all of its mass.

R

Rad (radiation absorbed dose): a unit of absorbed radiation dose. It is a measure of the amount of energy absorbed by the body. The rad is the traditional unit of absorbed dose.

Radiation: energy moving in the form of particles or waves. Non-ionizing forms are heat, light, radio waves, and microwaves. Ionizing radiation is a very high-energy form of electromagnetic radiation.

Radiation sickness: See acute radiation syndrome (ARS)

Radiation warning symbol: a symbol prescribed by the U.S. Code of Federal Regulations. It is a magenta or black trefoil on a yellow background. It must be displayed where certain quantities of radioactive materials are present or where certain doses of radiation could be received.

Radioactive contamination: the deposition of unwanted radioactive material on the surfaces of structures, areas, objects, or people. It can be airborne, external, or internal.

Radioactive decay: the spontaneous disintegration of the nucleus of an atom.

Radioactive half-life: the time required for a quantity of a radioactive material to decay by half.

Radioactive material: material that contains unstable (radioactive) atoms that give off radiation as they decay.

Radioactivity: It is the process of emission of radiation from a material. The process of spontaneous transformation of the nucleus, generally with the emission of alpha or beta particles often accompanied by gamma rays.

Radiological or radiologic: related to radioactive materials or radiation. Radiological sciences focus on the measurement and effects of radiation.

Radiological dispersal device (RDD): a device that disperses radioactive material by conventional explosive or other mechanical means, such as a spray.

Rem: a unit of equivalent dose. Not all radiation has the same biological effect, even for the same amount of absorbed dose. Rem relates the absorbed dose in human tissue to the effective biological damage of the radiation. The rem is the traditional unit of equivalent dose.

Roentgen (R): a unit of exposure to x-rays or gamma rays. One roentgen is the amount of gamma or x-rays needed to produce ions carrying 1 electrostatic unit of electrical charge in 1 cubic centimeter of dry air under standard conditions.

S

Sievert (Sv): The unit of **equivalent dose ,**1 mSv : the annual dose to the most exposed nuclear industry worker half the natural dose from natural radiation in Britain 100 x the dose that would be absorbed by flying to Spain by jet**.**

X

X-ray: electromagnetic radiation caused by deflection of electrons from their original paths, or inner orbital electrons that change their orbital levels around the atomic nucleus. X-rays, like gamma rays can travel long distances through air and most other materials. X-rays can penetrate the body and thus require more shielding. X-rays and gamma rays differ primarily in their originate in the nucleus

Appendix A

Disk File Name = SRIM Outputs\Hydrogen in Water_Liquid

Ion = Hydrogen [1] , Mass = 1.008 amu

Target Density = 1.0000E+00 g/cm3 = 1.0029E+23 atoms/cm3

======= Target Composition ========

Atom Name	Atom Numb	Atomic Percent	Mass Percent
H	1	066.67	011.19
O	8	033.33	088.81

====================================

Bragg Correction = -6.00%
Stopping Units = MeV / (mg/cm2)
See bottom of Table for other Stopping units

Ion Energy	dE/dx Elec.	dE/dx Nuclear	Projected Range	Longitudinal Straggling	Lateral Straggling
10.00 keV	4.283E-01	8.660E-03	2625 A	697 A	723 A
11.00 keV	4.480E-01	8.097E-03	2826 A	718 A	754 A
12.00 keV	4.667E-01	7.610E-03	3021 A	737 A	783 A
13.00 keV	4.845E-01	7.185E-03	3211 A	754 A	810 A
14.00 keV	5.014E-01	6.810E-03	3395 A	770 A	834 A
15.00 keV	5.176E-01	6.477E-03	3574 A	784 A	858 A
16.00 keV	5.330E-01	6.178E-03	3749 A	798 A	879 A
17.00 keV	5.478E-01	5.908E-03	3920 A	810 A	900 A
18.00 keV	5.620E-01	5.663E-03	4088 A	821 A	919 A
20.00 keV	5.886E-01	5.236E-03	4412 A	843 A	955 A
22.50 keV	6.189E-01	4.793E-03	4802 A	866 A	995 A
25.00 keV	6.463E-01	4.425E-03	5176 A	887 A	1031 A
27.50 keV	6.710E-01	4.115E-03	5537 A	905 A	1064 A
30.00 keV	6.934E-01	3.849E-03	5888 A	921 A	1094 A
32.50 keV	7.135E-01	3.618E-03	6229 A	936 A	1122 A
35.00 keV	7.317E-01	3.416E-03	6562 A	949 A	1148 A
37.50 keV	7.480E-01	3.238E-03	6889 A	962 A	1172 A
40.00 keV	7.626E-01	3.078E-03	7209 A	973 A	1195 A
45.00 keV	7.871E-01	2.806E-03	7836 A	996 A	1237 A
50.00 keV	8.063E-01	2.582E-03	8447 A	1016 A	1276 A
55.00 keV	8.207E-01	2.393E-03	9047 A	1035 A	1311 A
60.00 keV	8.312E-01	2.233E-03	9640 A	1052 A	1345 A
65.00 keV	8.382E-01	2.094E-03	1.02 um	1068 A	1376 A
70.00 keV	8.422E-01	1.973E-03	1.08 um	1083 A	1406 A
80.00 keV	8.431E-01	1.771E-03	1.20 um	1117 A	1463 A
90.00 keV	8.367E-01	1.609E-03	1.32 um	1150 A	1517 A
100.00 keV	8.252E-01	1.476E-03	1.43 um	1181 A	1568 A
110.00 keV	8.102E-01	1.365E-03	1.56 um	1211 A	1618 A
120.00 keV	7.929E-01	1.271E-03	1.68 um	1241 A	1667 A
130.00 keV	7.743E-01	1.189E-03	1.80 um	1271 A	1716 A
140.00 keV	7.550E-01	1.119E-03	1.93 um	1301 A	1765 A
150.00 keV	7.355E-01	1.056E-03	2.07 um	1331 A	1814 A
160.00 keV	7.161E-01	1.001E-03	2.20 um	1362 A	1864 A
170.00 keV	6.971E-01	9.518E-04	2.34 um	1393 A	1914 A
180.00 keV	6.787E-01	9.074E-04	2.49 um	1425 A	1966 A
200.00 keV	6.437E-01	8.307E-04	2.79 um	1520 A	2071 A
225.00 keV	6.041E-01	7.524E-04	3.19 um	1663 A	2208 A

375.00 keV	4.437E-01	4.878E-04	6.11 um	2612 A	3203 A
400.00 keV	4.258E-01	4.616E-04	6.68 um	2785 A	3399 A
450.00 keV	3.949E-01	4.173E-04	7.90 um	3366 A	3814 A
500.00 keV	3.691E-01	3.812E-04	9.20 um	3934 A	4261 A
550.00 keV	3.472E-01	3.512E-04	10.59 um	4497 A	4739 A
600.00 keV	3.283E-01	3.258E-04	12.07 um	5060 A	5244 A
650.00 keV	3.119E-01	3.040E-04	13.62 um	5623 A	5777 A
700.00 keV	2.976E-01	2.851E-04	15.26 um	6189 A	6336 A
800.00 keV	2.738E-01	2.539E-04	18.75 um	8114 A	7525 A
900.00 keV	2.551E-01	2.292E-04	22.52 um	9909 A	8800 A
1.00 MeV	2.402E-01	2.090E-04	26.55 um	1.16 um	1.02 um
1.10 MeV	2.328E-01	1.923E-04	30.76 um	1.33 um	1.16 um
1.20 MeV	2.258E-01	1.782E-04	35.11 um	1.48 um	1.30 um
1.30 MeV	2.162E-01	1.662E-04	39.62 um	1.64 um	1.44 um
1.40 MeV	2.072E-01	1.557E-04	44.33 um	1.79 um	1.60 um
1.50 MeV	1.989E-01	1.465E-04	49.24 um	1.94 um	1.75 um
1.60 MeV	1.911E-01	1.385E-04	54.36 um	2.10 um	1.91 um
1.70 MeV	1.838E-01	1.313E-04	59.68 um	2.26 um	2.08 um
1.80 MeV	1.769E-01	1.248E-04	65.21 um	2.41 um	2.25 um
2.00 MeV	1.643E-01	1.137E-04	76.92 um	2.98 um	2.60 um
2.25 MeV	1.507E-01	1.025E-04	92.77 um	3.78 um	3.08 um
2.50 MeV	1.392E-01	9.334E-05	110.00 um	4.56 um	3.59 um
2.75 MeV	1.294E-01	8.578E-05	128.58 um	5.33 um	4.13 um
3.00 MeV	1.210E-01	7.940E-05	148.51 um	6.10 um	4.71 um
3.25 MeV	1.138E-01	7.394E-05	169.77 um	6.87 um	5.33 um
3.50 MeV	1.074E-01	6.922E-05	192.34 um	7.65 um	5.98 um
3.75 MeV	1.017E-01	6.509E-05	216.21 um	8.45 um	6.67 um
4.00 MeV	9.673E-02	6.145E-05	241.35 um	9.25 um	7.39 um
4.50 MeV	8.818E-02	5.532E-05	295.39 um	12.16 um	8.92 um
5.00 MeV	8.114E-02	5.034E-05	354.39 um	14.91 um	10.59 um
5.50 MeV	7.523E-02	4.622E-05	418.26 um	17.61 um	12.39 um
6.00 MeV	7.020E-02	4.276E-05	486.93 um	20.30 um	14.32 um
6.50 MeV	6.586E-02	3.979E-05	560.32 um	23.01 um	16.37 um
7.00 MeV	6.207E-02	3.723E-05	638.38 um	25.74 um	18.54 um
8.00 MeV	5.576E-02	3.302E-05	808.08 um	35.59 um	23.24 um
9.00 MeV	5.071E-02	2.969E-05	995.82 um	44.82 um	28.41 um
10.00 MeV	4.657E-02	2.700E-05	1.20 mm	53.88 um	34.05 um

Multiply Stopping by	for Stopping Units
9.9997E+00	eV / Angstrom
9.9997E+01	keV / micron
9.9997E+01	MeV / mm
1.0000E+00	keV / (ug/cm2)
1.0000E+00	MeV / (mg/cm2)
1.0000E+03	keV / (mg/cm2)
9.9706E+00	eV / (1E15 atoms/cm2)
4.4209E+00	L.S.S. reduced units

Table (A.1):stopping power and rang for(H in water)

Appendix B

(required) Kinetic Energy (MeV)	Stopping Power (MeV cm^2/g)			Range		
	Electronic	Nuclear	Total	CSDA (g/cm^2)	Projected (g/cm^2)	Detour Factor Projected / CSDA
1.000E-03	1.694E+02	2.551E+02	4.245E+02	2.619E-06	1.505E-06	0.5748
1.500E-03	2.042E+02	2.310E+02	4.351E+02	3.778E-06	2.244E-06	0.5939
2.000E-03	2.333E+02	2.115E+02	4.448E+02	4.915E-06	3.000E-06	0.6104
2.500E-03	2.588E+02	1.956E+02	4.545E+02	6.027E-06	3.765E-06	0.6247
3.000E-03	2.818E+02	1.824E+02	4.642E+02	7.116E-06	4.534E-06	0.6372
4.000E-03	3.224E+02	1.615E+02	4.839E+02	9.225E-06	6.075E-06	0.6585
5.000E-03	3.581E+02	1.456E+02	5.037E+02	1.125E-05	7.606E-06	0.6761
6.000E-03	3.902E+02	1.330E+02	5.232E+02	1.320E-05	9.120E-06	0.6910
7.000E-03	4.197E+02	1.227E+02	5.425E+02	1.508E-05	1.061E-05	0.7039
8.000E-03	4.472E+02	1.141E+02	5.613E+02	1.689E-05	1.208E-05	0.7153
9.000E-03	4.729E+02	1.068E+02	5.797E+02	1.864E-05	1.352E-05	0.7254
1.000E-02	4.972E+02	1.006E+02	5.977E+02	2.034E-05	1.494E-05	0.7345
1.250E-02	5.529E+02	8.801E+01	6.409E+02	2.438E-05	1.837E-05	0.7537
1.500E-02	6.032E+02	7.858E+01	6.818E+02	2.816E-05	2.166E-05	0.7693
1.750E-02	6.494E+02	7.118E+01	7.206E+02	3.172E-05	2.481E-05	0.7822
2.000E-02	6.924E+02	6.520E+01	7.576E+02	3.510E-05	2.784E-05	0.7932
2.250E-02	7.327E+02	6.026E+01	7.929E+02	3.833E-05	3.077E-05	0.8027
2.500E-02	7.707E+02	5.609E+01	8.268E+02	4.142E-05	3.359E-05	0.8111
2.750E-02	8.068E+02	5.252E+01	8.593E+02	4.438E-05	3.632E-05	0.8184
3.000E-02	8.413E+02	4.942E+01	8.907E+02	4.724E-05	3.897E-05	0.8250
3.500E-02	9.060E+02	4.430E+01	9.503E+02	5.267E-05	4.405E-05	0.8363
4.000E-02	9.661E+02	4.024E+01	1.006E+03	5.778E-05	4.887E-05	0.8458
4.500E-02	1.022E+03	3.692E+01	1.059E+03	6.262E-05	5.346E-05	0.8538
5.000E-02	1.075E+03	3.416E+01	1.109E+03	6.723E-05	5.787E-05	0.8607
5.500E-02	1.125E+03	3.182E+01	1.157E+03	7.165E-05	6.210E-05	0.8667
6.000E-02	1.173E+03	2.980E+01	1.203E+03	7.588E-05	6.617E-05	0.8720
6.500E-02	1.219E+03	2.805E+01	1.247E+03	7.997E-05	7.012E-05	0.8768
7.000E-02	1.262E+03	2.651E+01	1.289E+03	8.391E-05	7.393E-05	0.8811
7.500E-02	1.304E+03	2.515E+01	1.329E+03	8.773E-05	7.764E-05	0.8850

(required) Kinetic Energy (MeV)	Stopping Power (MeV cm^2/g)			Range		
	Electronic	Nuclear	Total	CSDA (g/cm^2)	Projected (g/cm^2)	Detour Factor Projected / CSDA
8.000E-02	1.344E+03	2.393E+01	1.368E+03	9.144E-05	8.125E-05	0.8885
8.500E-02	1.383E+03	2.284E+01	1.406E+03	9.504E-05	8.476E-05	0.8918
9.000E-02	1.420E+03	2.185E+01	1.442E+03	9.856E-05	8.818E-05	0.8948
9.500E-02	1.456E+03	2.094E+01	1.477E+03	1.020E-04	9.153E-05	0.8975
1.000E-01	1.491E+03	2.012E+01	1.511E+03	1.053E-04	9.481E-05	0.9001
1.250E-01	1.650E+03	1.688E+01	1.667E+03	1.211E-04	1.102E-04	0.9107
1.500E-01	1.787E+03	1.459E+01	1.802E+03	1.355E-04	1.244E-04	0.9186
1.750E-01	1.907E+03	1.289E+01	1.920E+03	1.489E-04	1.377E-04	0.9249
2.000E-01	2.012E+03	1.157E+01	2.023E+03	1.616E-04	1.503E-04	0.9299
2.250E-01	2.104E+03	1.051E+01	2.115E+03	1.736E-04	1.622E-04	0.9342
2.500E-01	2.185E+03	9.638E+00	2.195E+03	1.852E-04	1.737E-04	0.9378
2.750E-01	2.256E+03	8.911E+00	2.265E+03	1.965E-04	1.849E-04	0.9410
3.000E-01	2.317E+03	8.294E+00	2.326E+03	2.073E-04	1.957E-04	0.9437
3.500E-01	2.417E+03	7.298E+00	2.424E+03	2.284E-04	2.166E-04	0.9484
4.000E-01	2.489E+03	6.529E+00	2.496E+03	2.487E-04	2.368E-04	0.9523
4.500E-01	2.539E+03	5.916E+00	2.545E+03	2.685E-04	2.566E-04	0.9555
5.000E-01	2.571E+03	5.415E+00	2.577E+03	2.880E-04	2.760E-04	0.9583
5.500E-01	2.588E+03	4.996E+00	2.593E+03	3.074E-04	2.953E-04	0.9607
6.000E-01	2.592E+03	4.642E+00	2.597E+03	3.266E-04	3.145E-04	0.9628
6.500E-01	2.587E+03	4.338E+00	2.591E+03	3.459E-04	3.337E-04	0.9648
7.000E-01	2.573E+03	4.073E+00	2.577E+03	3.652E-04	3.530E-04	0.9665
7.500E-01	2.554E+03	3.841E+00	2.558E+03	3.847E-04	3.724E-04	0.9681
8.000E-01	2.529E+03	3.635E+00	2.533E+03	4.044E-04	3.920E-04	0.9695
8.500E-01	2.500E+03	3.451E+00	2.504E+03	4.242E-04	4.119E-04	0.9709
9.000E-01	2.468E+03	3.287E+00	2.472E+03	4.443E-04	4.319E-04	0.9721
9.500E-01	2.434E+03	3.138E+00	2.437E+03	4.647E-04	4.523E-04	0.9733
1.000E+00	2.398E+03	3.003E+00	2.401E+03	4.853E-04	4.729E-04	0.9743
1.250E+00	2.213E+03	2.478E+00	2.215E+03	5.937E-04	5.811E-04	0.9788
1.500E+00	2.035E+03	2.117E+00	2.037E+03	7.114E-04	6.987E-04	0.9821
1.750E+00	1.874E+03	1.852E+00	1.876E+03	8.394E-04	8.265E-04	0.9847

(required) Kinetic Energy (MeV)	Stopping Power (MeV cm^2/g)			Range		
	Electronic	Nuclear	Total	CSDA (g/cm^2)	Projected (g/cm^2)	Detour Factor Projected / CSDA
2.000E+00	1.731E+03	1.648E+00	1.732E+03	9.782E-04	9.652E-04	0.9867
2.250E+00	1.605E+03	1.487E+00	1.607E+03	1.128E-03	1.115E-03	0.9884
2.500E+00	1.499E+03	1.356E+00	1.500E+03	1.289E-03	1.276E-03	0.9897
2.750E+00	1.408E+03	1.247E+00	1.409E+03	1.461E-03	1.448E-03	0.9908
3.000E+00	1.328E+03	1.156E+00	1.329E+03	1.644E-03	1.631E-03	0.9918
3.500E+00	1.197E+03	1.009E+00	1.198E+03	2.041E-03	2.027E-03	0.9932
4.000E+00	1.091E+03	8.968E-01	1.092E+03	2.479E-03	2.465E-03	0.9943
4.500E+00	1.004E+03	8.080E-01	1.005E+03	2.957E-03	2.942E-03	0.9951
5.000E+00	9.322E+02	7.359E-01	9.329E+02	3.473E-03	3.459E-03	0.9958
5.500E+00	8.707E+02	6.762E-01	8.714E+02	4.028E-03	4.013E-03	0.9963
6.000E+00	8.178E+02	6.257E-01	8.184E+02	4.621E-03	4.605E-03	0.9967
6.500E+00	7.715E+02	5.826E-01	7.721E+02	5.250E-03	5.234E-03	0.9970
7.000E+00	7.308E+02	5.453E-01	7.313E+02	5.916E-03	5.900E-03	0.9973
7.500E+00	6.945E+02	5.127E-01	6.950E+02	6.617E-03	6.601E-03	0.9975
8.000E+00	6.621E+02	4.839E-01	6.626E+02	7.354E-03	7.338E-03	0.9977
8.500E+00	6.329E+02	4.583E-01	6.333E+02	8.126E-03	8.109E-03	0.9979
9.000E+00	6.064E+02	4.354E-01	6.068E+02	8.933E-03	8.916E-03	0.9980
9.500E+00	5.823E+02	4.148E-01	5.827E+02	9.774E-03	9.756E-03	0.9982
1.000E+01	5.602E+02	3.961E-01	5.606E+02	1.065E-02	1.063E-02	0.9983
1.250E+01	4.728E+02	3.239E-01	4.731E+02	1.552E-02	1.550E-02	0.9987
1.500E+01	4.107E+02	2.746E-01	4.110E+02	2.121E-02	2.119E-02	0.9989
1.750E+01	3.643E+02	2.387E-01	3.645E+02	2.768E-02	2.766E-02	0.9991
2.000E+01	3.280E+02	2.113E-01	3.282E+02	3.492E-02	3.489E-02	0.9992
2.500E+01	2.748E+02	1.722E-01	2.750E+02	5.164E-02	5.160E-02	0.9993
2.750E+01	2.547E+02	1.578E-01	2.549E+02	6.109E-02	6.105E-02	0.9994
3.000E+01	2.376E+02	1.456E-01	2.377E+02	7.125E-02	7.121E-02	0.9994
3.500E+01	2.099E+02	1.263E-01	2.100E+02	9.368E-02	9.363E-02	0.9994
4.000E+01	1.884E+02	1.116E-01	1.885E+02	1.189E-01	1.188E-01	0.9995
4.500E+01	1.712E+02	9.998E-02	1.713E+02	1.467E-01	1.466E-01	0.9995
5.000E+01	1.572E+02	9.061E-02	1.573E+02	1.772E-01	1.771E-01	0.9995

(required) Kinetic Energy (MeV)	Stopping Power (MeV cm^2/g)			Range		
	Electronic	Nuclear	Total	CSDA (g/cm^2)	Projected (g/cm^2)	Detour Factor Projected / CSDA
5.500E+01	1.455E+02	8.286E-02	1.455E+02	2.103E-01	2.102E-01	0.9996
6.000E+01	1.355E+02	7.634E-02	1.356E+02	2.459E-01	2.458E-01	0.9996
6.500E+01	1.269E+02	7.079E-02	1.270E+02	2.840E-01	2.839E-01	0.9996
7.000E+01	1.195E+02	6.600E-02	1.195E+02	3.246E-01	3.245E-01	0.9996
7.500E+01	1.129E+02	6.183E-02	1.130E+02	3.677E-01	3.675E-01	0.9996
8.000E+01	1.071E+02	5.816E-02	1.072E+02	4.131E-01	4.129E-01	0.9996
8.500E+01	1.020E+02	5.491E-02	1.020E+02	4.609E-01	4.608E-01	0.9996
9.000E+01	9.731E+01	5.201E-02	9.736E+01	5.111E-01	5.109E-01	0.9996
9.500E+01	9.311E+01	4.940E-02	9.316E+01	5.636E-01	5.634E-01	0.9996
1.000E+02	8.930E+01	4.705E-02	8.934E+01	6.185E-01	6.182E-01	0.9996
1.250E+02	7.446E+01	3.800E-02	7.450E+01	9.264E-01	9.260E-01	0.9996
1.500E+02	6.424E+01	3.187E-02	6.427E+01	1.289E+00	1.288E+00	0.9997
1.750E+02	5.674E+01	2.745E-02	5.677E+01	1.704E+00	1.703E+00	0.9997
2.000E+02	5.099E+01	2.411E-02	5.102E+01	2.169E+00	2.168E+00	0.9997
2.250E+02	4.644E+01	2.151E-02	4.646E+01	2.683E+00	2.682E+00	0.9997
2.500E+02	4.274E+01	1.941E-02	4.276E+01	3.245E+00	3.244E+00	0.9997
2.750E+02	3.968E+01	1.768E-02	3.969E+01	3.852E+00	3.851E+00	0.9997
3.000E+02	3.709E+01	1.623E-02	3.710E+01	4.504E+00	4.502E+00	0.9997
3.500E+02	3.296E+01	1.394E-02	3.298E+01	5.937E+00	5.935E+00	0.9997
4.000E+02	2.981E+01	1.223E-02	2.982E+01	7.534E+00	7.531E+00	0.9997
4.500E+02	2.733E+01	1.089E-02	2.734E+01	9.287E+00	9.284E+00	0.9997

Table (A.2):stopping power and rang for(Helium in Adipose tissue) By Astar [35] .

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ملخص

الطاقة الاشعاعية مقدمة طبيعيا في البيئة المحيطة ومتواجدة منذ مولد هذا الكون . تأتي هذه الطاقة من الفضاء الخارجي (الكوني) و الأرض (دنيوي) وأيضا من خلال أجسادنا . تقدم هذه الطاقة في الهواء الذي نتنفسه ، في الطعام الذي ناكله ، في الماء الذي نشربه وأيضا المواد البنائية التي نستخدمها في البناء بيوتنا .

تنتشر الجرعات –أقل من 10,000 mrem (100 mSv) على مدة طويلة من الزمن (سنوات) ، هذه الجرعات لا تسبب مشكلة فورية لأي عضو من أعضاء الجسم .تأثير هذه الجرعات من الطاقة الاشعاعية إن حصل ، فسيكون على مستوى الخلية وبالتالي فإن التغيرات ربما لن يتم ملاحظتها لسنوات عدة (٥-٢٠ سنة) بعد التعرض .

بالرغم من أن الطاقة الاشعاعية ذات الجرعات العالية أو المعدل العالي قد تسبب السرطان ، لكن حاليا لا توجد أي بيانات تثبت بحصول السرطان بشكل لا لبس فيه بعد التعرض لكميات صغيرة او معدل الكميات أقل بحوالي 10,000 mrem (100 mSv).

في هذه الدراسة ، درسنا التفاعل بين المادة وأنواع مختلفة من الطاقة الاشعاعية ، تم حساب الطاقة المتوقفة- الثابتة- (in MeV cm٢ /g) من معادلة نظرية Bethe-Bloch .. ، وايضا تم حساب المدى والكمية كما هو وارد في المرجع 15 . لقد تم اتمام ذلك لمواد مستهدفة كالمواد البيولوجية للجسم البشري مثل الماء ، العظام ، العضلات ، الانسجة وطاقات مختلفة من الإلكترونات والأيونات .

كل هذه الحسابات تمت باستخدام برامج متعددة مثل :- STAR , SRIM وMatlab . والنتائج سوف يتم عرضها في الفصل الأخير من (المدى ضد الطاقة) و (الطاقة المتوقفة-الثابتة- ضد الطاقة)

لقد تم حساب الطاقة الثابتة-المتوقفة- لتجمعات بيولوجية للإلكترونات على مجال الطاقة من $١٠^{-٢}$ MeV الى $١٠^{٣}$ MeV ، والحصول عليها من خلال اجمال الطاقة الالكترونية الثابتة (التصادم) ومن الطاقة الاشعاعية الثابتة للمواد المستهدفة ، ومن ثم تطبيق التقريب البطئ المستمر (CSDA) لحساب طول المسار (المدى).

مجموع الطاقة الثابتة متناسب من Z/A, Z^2 و I, يزداد بسرعة بطاقات منخفضة ليصل الى أقصى حد ، وينخفض بالتدريج مع الطاقات المرتفعة .

أخيرا ، يتم حسابة الكميات أيضا بتقنيات المحاكاة (مونتو كارلو) ، VMS .. هذه الفوتونات (التي تكون على شكل gamma rays أو X–rays) لديها طاقة كافية لتسبب التأين في جسم الانسان البشري والتي بدورها تسبب جرعة اشعاع . سيتم عرض بعض النتائج لحساب الجرعات على قضايا مختلفة باستخدام كود VMS

الجامعــة الإســلامية – غـزة
عمـــادة الدراســات العلـــيا
كليـــة العلــــــــوم
قـــســم الفيزيـــــــاء

التأثيرات الطبية لتفاعلات الأشعة

مقدمة من الطالبة

مي ياســـر الـشـاعر

تحت إشراف

د. ماهــــــر الغصـين

رسالـــــة

مقدمــة لقســم الفيزياء بكلية العلوم بالجامعة الإسلاميــة كمتطلب تكميلي لنيل درجة الماجستير في الفيزيـاء

١٤٣٦هـ /٢٠١٥م