



**STUDY OF MASS ATTENUATION COEFFICIENTS OF SOME
HUMAN TISSUES USING X-COM**

BY

MOHAMMED ABAJIHAD

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ADVISOR: Dr. TILAHUN TESFAYE

BY MOHAMMED ABAJIHAD

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COLLEGE OF NATURAL AND COMPUTATIONAL SCIENCES
DEPARTMENT OF PHYSICS

The under signed here by certify that they have read and recommend to the college of Natural science for acceptance a project entitled ” **STUDY OF MASS ATTENUATION COEFFICIENTS OF SOME HUMAN TISSUES USING XCOM**” by MOHAMMED ABA JIHAD in partial fulfillment of the requirements for the degree of Master of Science in physics (Nuclear Physics).

By Mohammed Aba Jihad

ADDIS ABABA, ETHIOPIA
OCTOBER 2021

Approved by the Examination Committee:

Advisor: _____

Dr. Tilahun Tesfaye (PHD)

Examiner: _____

Prof. A.K Chaubey (PHD)

Examiner: _____

Dr. Belayneh Mesfin (PHD)

Chair Person: _____

ADDIS ABABA UNIVERSITY

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Author: Mohammed Aba Jihad

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ABBREVIATION & Symbol

- NIST =National Institute of Standards &Technology
- ICRU= International Commission on Radiation Units & Measurement
- EDXS=Energy dispersive x-ray system
- μ_{ph} = photo electric cross section
- DNA=Deoxyribonucleic acid
- SDD=Silicon drift detector
- NaI=sodium iodide
- MeV= Mega electron Volt
- KeV=Kilo electron volt
- HPGe= High purity germanium
- N_A = Avogadro`s number
- MCNP =Monte Carlo N –Particle
- μ/ρ = Mass attenuation coefficient
- ρ = density
- STM=Soft Tissue Model
- ICRP= International Commission on Radiological Protection
- GBq = Giga Becquerel
- IUPAC=International Union of Pure and Applied Chemistry
- B E = Binding Energy

Abstract

The mass attenuation coefficient of some tissues such as muscle(ICRU),adipose(ICRP) and blood(whole) and tissue equivalents such as soft tissue model ($H_{63}C_6O_{28}N$) And water were investigated theoretically at different photon energies using XCOM computer program (version 3.1) in the energy range of 1keV-2MeV. Specifically, the mass attenuation coefficients obtained theoretically (XCOM computed coefficients) were compared with experimental results for 59.5, 81.0, 356.5, 661.6, 1173.2 and 1332.5keV photon energies. The mass attenuation coefficient the XCOM computed were compared to the experimental values, between the two with uncertainties about 5% that is the XCOM program is essential in the calculation of photon mass attenuation coefficient of some human tissues as the other found in literature.

Key-word: Mass Attenuation coefficient, X-COM and Penetration of gamma ray

CHAPTER 1

1. INTRODUCTION

The study of mass attenuation coefficient in different tissues of human organs plays important role in the radiotherapy and medical diagnosis. And mass attenuation coefficients were calculated with help of WinX-COM program. Boke[1] computed linear attenuation coefficients of tissues for liver, kidney, muscle, fat for x-ray energies. Ekinci and Astam[2] measured mass attenuation coefficients of biological materials by energy dispersive and x-ray fluorescence spectrometry. Akar[3], *et.al* measured linear and mass attenuation coefficients for bone, muscle, fat and water at 140 keV, 364 keV, and 662 keV energies using the medical spectrometer. Bahri Spyrou[4] determined linear attenuation coefficients and water content of normal and pathological breast tissues using a high purity germanium detector (HPGe) at energy 59.5 keV. Manjunatha, [5] studied the photon interaction parameters such as mass attenuation coefficient (μ/ρ), effective atomic number, and effective electron density (N_e) in lung tissue substitutes. Manjunatha and Rudraswamy[6], computed the photon interaction parameters such as effective atomic numbers and electron densities in bone.

In the biological and medical context, mass attenuation coefficient as a key parameter used to characterize the radiological properties of various dose-metric materials [7]. Since it is defined by taking into account the weight of different partial radiation mechanisms in different energy region, it is considered as energy dependent parameter and it also varies with respect to the chemical composition of a given tissue (material). Knowledge on the μ/ρ in complex medium, especially in human body, is of importance because, for example, when photons degrade their energy in tissues, the radiation dose can be estimated based on mass attenuation coefficients. The term of soft tissues refers to tissues that connect, support, or surround other structures and organs of human or animal body. Thus, the soft tissues include muscles, tendons, ligaments, facial, nerves, fibrous tissues, adipose, blood and synovial membranes.

The XCOM can be carried out to estimate the μ/p for various tissues and energy is in computer environment that gives flexibility & ease of use, instead of performing experiments[8]. For this reason, XCOM methods would be useful for further experiments which sometimes cannot be implemented: the model can be used through micro file to determine μ/p of different materials & mixture over a wide range of energies.

Recently, several authors have made extensive successful contributions that were based on xcom simulations for determining the mass attenuation coefficients in different materials [9]. In literature, several publications have been considered the study of soft tissue and compared with water by using various methods and different models for the soft tissues. Salehi et al. calculated the energy absorption coefficient, k_{rel} relative to air for the soft tissue [2]. This theoretical study was carried out by NIST-XCOM database. Sardari et al. estimated the photon build-up factor in soft tissue with Monte-carlo methods [3] using MCNP4C code. Aslam et al. assessed the soft tissue and water substitutes for multiple mega-voltage photon beams by using the simulation of the linac head using BEAMnrc [4].

In this present work, an investigation regarding different types of soft tissue such as muscle, adipose & blood to show the better tissue equivalents for these tissues has been achieved. For this purpose, NIST-XCOM database simulation has been carried out to determine the mass attenuation coefficient for the samples involved. These parameters were also calculated relative to water.

The results of this study have been compared with the experimental value. Also, the tissue equivalence properties of the studied tissues are discussed. The importance of such work arises from the fact that in the medical applications of radiation, the studied tissues are usually approximated by soft tissue equivalents and/or water.

It is difficult to measure the basic photon interaction parameters in tissues of human organs because many chemical and biological reactions take place simultaneously. Thus there is a need to estimate these parameters theoretically. Hence in the present work I have studied the basic photon interaction parameters such as attenuation coefficient, linear attenuation coefficient, and mass attenuation coefficient of some tissues of human organs (muscle, Adipose tissue, blood, and STM) in the energy region 1 keV-2 MeV. Using different types of materials as soft tissue-simulating materials are necessary to verify the best material to simulate the human tissue (Ferreira et al., 2010). Tissue-equivalent or soft tissue model ($\text{H}_{63}\text{C}_6\text{O}_{28}\text{N}$), Water, muscle-equivalent, and adipose-equivalent) were tested, through their attenuation (linear attenuation coefficient) and scattering (scattering profile) properties, (Wenderet).

Gamma rays and x-rays radiations produced by man-made used in different applications such as analysis of food products screening of baggage's, medical imaging tests, cancer treatment, and airport security scanners. When the electromagnetic radiation passes through matter (tissue), it suffers attenuation and reduction in intensity, this reduction obtained by two processes scattering and absorption (attenuation). The scattering of x-ray photon at attenuator material atoms causes a part of the x-ray radiation to change its direction. This phenomenon reduces the intensity in the original

direction. The scattering happens either elastic or inelastic. In absorption the entire energy of the x-ray quanta transferred to the atoms of molecules of the irradiated material (tissue) as excitation or ionizing energy and causes damage the tissues also effects onDNA.[10]

1.1 Objectives of Study

1.1.1 General objectiveofthe study

- Thegeneralpurposeofthisstudywillbetoinvestigatethemassattenuationcoefficientsfor some Human tissue forphotonenergies in therangeof1keV – 2 MeV.

1.1.2 Specific objectiveofthe study

TheSpecific objectives of this study are:

- Tocalculatethemassattenuationcoefficients of Muscle, Soft tissue, Adipose tissue, Blood and also, for Water theoreticallyforphotonenergies in therangeof 59.5keV-1332.5k eV
- Tocomparethemassattenuationcoefficientsobtainedtheoreticallywithexperimental results forthe correspondingphoton energies 59.5, 81.0, 356.5, 661.6, 1173.2 and 1332.5keV.

CHAPTER 2

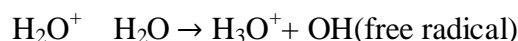
2. LITERATURE REVIEW

2.1. The penetration of gamma rays in matter

2.1.1 Electromagnetic Radiation

Electromagnetic radiation is a radiation that has both electric and magnetic fields and travels through space and waves at constant speed at same speed of the light in vacuum by carrying energy [11]. A gamma ray is a packet (or photon) of electromagnetic radiation emitted from the nucleus during radioactive decay and occasionally accompanying the emission of an alpha or beta particle. Gamma rays are identical in nature to other electromagnetic radiations such as light or microwaves but are of much higher energy, zinc-65, cesium-137 and radium-226. Because gamma radiation loses energy slowly, gamma rays are able to travel significant distances. Depending upon their initial energy, gamma rays can travel tens or hundreds of meters in air. [12]

Gamma radiation is typically shielded using very dense materials (or the denser material, the more chance that a gamma ray will interact with atoms in the material) such as lead or other dense metal. Gamma radiation particularly can present a hazard from exposures external to the human body. Electromagnetic radiation includes x-rays and gamma rays, all moving at the speed of light but having different wave length and, therefore, different energies. When x-rays or gamma rays are absorbed by the body energy is deposited as the photon is dissipated. Electromagnetic photons are considered to be ionizing radiation includes alpha, beta, and positron particles plus other particles that are not concern to nuclear pharmacy. Radiation can be directly or indirectly ionizing charged particles are directly ionizing electron. When photons are absorbed, so is their energy, which can be converted to carped particles by mechanisms such as the Compton and photo electric effects. Directly and indirectly, ionizing redaction can cortex free radicals, which, being very reactive chemically can cause damage in the cell or in DNA. An example of initial free radical traction can occur with water



The smaller the area of focus of exposure to radiation the higher the probability of interaction b/n radiation and the targets, such as DNA, water molecules and other molecules. Damage to

DNA can cause cell death, mutations or carcinogenesis. Usually, a single-stranded break is easily repaired by the cell using the opposite strand as a template. If a double stranded break occurs, especially in slightly of set portions of DNA, the DNA can miss-repair (improperly rejoin) leading to cell death or cancerous growth [13]. Therefore radiation exposure and absorption must be measured.

Gamma energies usually are larger than chemical bond energies. Recall that gamma photons can cause ionization and excitation, though not as effectively as alpha and beta particles. Shielding requirements for gamma-emitting isotopes depend on the energy of the gamma rays. Low-energy gamma rays require only plastic containers, while high-energy gamma rays require the use of lead or materials of high Z number. Gamma photons penetrate skin and tissue easily. The photoelectric effect occurs mostly in tissue. There is no 'safe' level of exposure to gamma radiation. However of the topic emission encounter in nuclear pharmacy, gamma radiation is the least worrisome regarding tissue damage.

Types of radiation differ in their ability to penetrate material. Gamma radiation composed of high energy photons, which are weakly ionizing but, have high penetrating power (more than the X-ray photons used in radio diagnosis), can travel through hundreds of meters of air. Thick concrete shielding or lead helps to protect personnel. Fig.1 below indicates that the X-ray penetrate through paper easily, but, shielded by aluminum while the gamma ray penetrate through paper, aluminum easily until shielded by lead. Gamma radiation is primarily responsible for external exposure. As far as internal radiation exposure hazard is concerned, the high penetrating power means that the energy released by gamma rays and taken up by a small volume of tissue is comparatively small. Therefore, the internal radiation exposure hazard caused by gamma rays is not as severe as that induced by other types of radiation (alpha and beta). The X-rays are emitted from outside the nucleus, but gamma ray originates inside the nucleus. They also are generally lower in energy and, therefore, less penetrating than gamma rays. The difference penetrating potential of gamma ray and x-ray radiations are shown as figure 1 below.

Radioactive source

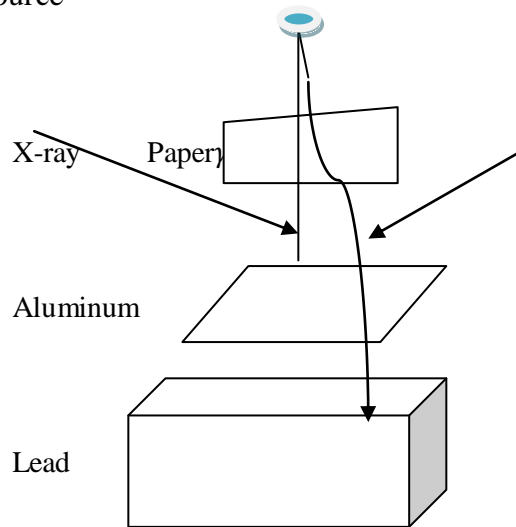


Figure 1 Penetration potential of radiation(X-or γ -ay)

2.1.2 X-Ray

Like a gamma ray, An X- ray is a packet (or photon) of electromagnetic radiation emitted from an atom, except that the x-ray is not emitted from the nucleus. X-rays are produced as result of changes in the position of the electron orbiting the nucleus, as the electrons shift to different energy levels. Examples of x-ray emitting radioisotopes are iodine-125 and iodine131. X-rays can be produced during the process of radioactive decay or as bremsstrahlung radiation.[14]Bremsstrahlung radiation are x-rays produced when high energy electrons strike a target made of a heavy metal ,such as tungsten or copper. As electrons collide with this material, some have their paths deflected by the nucleus of the metal atoms. This deflection results in the production of x- rays as the electrons lose energy. This processwhich an x-ray machine produces x-rays. Like gamma rays are typically shielded using very dense materials such as lead or other dense materials-rays particularly can present a hazard from exposures external to the body. Radiation, in our context, is energy in the form of high speed particles and electromagnetic waves.

Radiation is further defined into ionizing and non-ionizing radiation.

- (i) Ionizing radiation is radiation with enough energy so that during an interaction with an atom, it can remove bound electrons, i.e. it can ionize atoms. Examples are X-rays and electrons
- (ii) Non-ionizing radiation without enough energy to remove bound electrons from their orbits around atoms. Examples are microwave and visible light.

Gamma radiation is one of the three types of natural radioactivity. Gamma rays are electromagnetic radiation, X-rays. The other types of natural radioactivity are alpha and beta radiation, which are in the form of particles. Gamma rays are the most energetic form of electromagnetic radiation, with a very short wavelength of less than one-tenth of a nanometer. Depending upon the ratio of neutrons to protons within its nucleus, an isotope of a particular element may be stable or unstable. When the binding energy is not strong enough to hold the nucleus of an atom together, the atom is said to be unstable. Atoms with unstable nuclei are constantly changing as a result of the imbalance of energy within the nucleus. Over time, the nuclei of unstable isotopes spontaneously disintegrate, or transform, in a process known as radioactive decay. Various types of penetrating radiation may be emitted from the nucleus and (or its surrounding electrons). Nuclides which undergo radioactive decay are called radionuclide. Any material which contains measurable amounts of one or more radionuclide is a radioactive material. A nucleus which is in an excited state may emit one or more photons (packets of electromagnetic radiation) of discrete energies. The emission of gamma rays does not alter the number of protons or neutrons in the nucleus but instead has the effect of moving the nucleus from a higher to a lower energy state (unstable to stable). [15] A photon can interact with matter by a number of competing mechanisms. The interaction can be with the entire atom, as in the photoelectric effect, or with one electron in atom, as in the Compton effect or with the atomic nucleus (as in pair production).

The probability for each of these competing independent processes can be expressed as a collision cross section per atom, per electron, or per nucleus in the absorber. The sum of all these cross sections, normalized to a per atom basis, is then the probability that the incident photon will have an interaction of some kind while passing through a very thin absorber which contains

one atom per cm^2 of area normal to the path of the incident photon .Detection of gamma radiation is one of the most important research tools in nuclear physics. Detection of gamma radiation yields information on various properties (excitation energies, angular momentum, decay properties etc.) of states in nuclei. A knowledge of gamma-ray detection and attenuation. A gamma ray must interact with a detector in order to be 'seen'. Although the major isotopes of uranium and plutonium emit gamma ray at fixed energies and rates, the gamma-ray intensity measured outside a sample is always attenuated because of gamma-ray interactions with the sample.[16]This attenuation must be carefully considered when using gamma-ray nondestructive testing instruments.

2.3 Gamma –Ray Attenuation

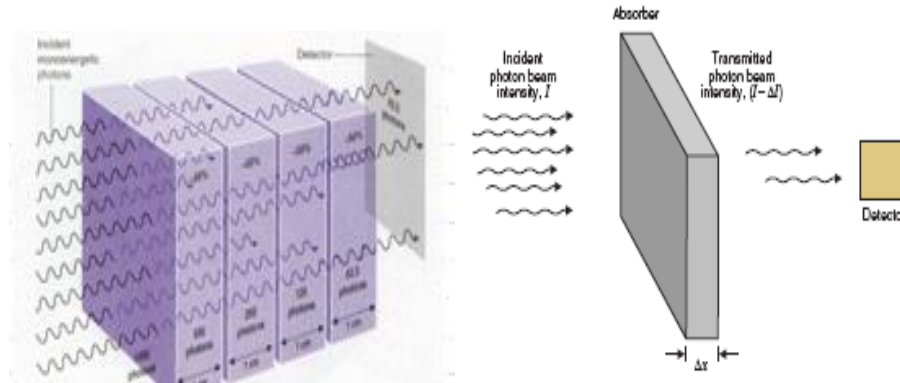
2.3.1 Attenuation

Attenuation is the gradual reduction in the intensity of a signal or a beam of wave which is penetrating through a matter or a tissue. As a photon makes its way through matter (tissue), there is no way to predicate precisely either how far it will travel before engaging in an interaction or the type of interaction it will engage in. In clinical applications we are generally not concerned with the fate of an individual photon but rather with the collective interaction of the large number of photons. In most instances we are interested in the overall rate at which photons interact as they make their way through a specific material. The interactions, either photoelectric or Compton remove some of the photons from the beam in a process known as attenuation. Under specific conditions, a certain percentage of the photons will interact, or be attenuated, in 1 unit thickness of material (tissue)[17]. Attenuation is the reduction of x-ray or gamma photon as they pass through matter (tissue). It may be expressed as

Primary radiation minus attenuation equal to remnant (exit radiation). Or

Primary radiation - attenuation = remnant or exit radiation

Attenuation of x-ray photon



a

b

Figure 2 photon beam transmission measurement

2.3.2 Attenuation Coefficients

When a photon passes through a thickness of absorber material, the probability that it will experience an interaction depends on its energy and on the composition and thickness of the absorber. The dependence on thickness is relatively simple; the thicker the absorber, the greater the probability that an interaction will occur. The dependence on absorber composition and photon energy, however, is complicated. Consider the photon transmission measurement diagrammed in fig2b. A beam of photons of intensity I (photons/cm².sec) is directed on to an absorber of thickness Δx .

Because of composition and photon energy effects, it will be assumed for the moment that the absorber is composed of a single element of atomic number Z and that the beam is monoenergetic with energy E . A photon detector records transmitted beam intensity. It is assumed that only those photons passing through the absorber without interaction are recorded.

For a “thin” absorber, such that beam intensity is reduced by only a small amount ($\leq 10\%$), it is found that the fractional decrease in beam intensity ($\Delta I/I$) is related to absorber thickness Δx according to

$$\frac{\Delta I}{I} = -\mu_l \Delta x \quad (1)$$

The minus sign indicating beam intensity decreases with increasing absorber thickness. The quantity μ_l is called the linear attenuation coefficient of the absorber. It has dimensions (thickness)⁻¹ and usually is expressed in cm⁻¹. This quantity reflects the “absorptivity” of absorbing material (tissue). [18] The quantity μ_l is found to increase linearly with absorber density ρ . Density effects are factored out by dividing μ_l by density ρ :

$$\mu_m = \frac{\mu_l}{\rho} \quad (2)$$

The quantity μ/ρ has dimensions of cm²/g and called the mass attenuation coefficient of the absorber. It depends on the absorber atomic number Z and photon energy E . This sometimes is emphasized by writing it as $\mu_m(Z, E)$.

The mass attenuation coefficient for a mixture of elements can be obtained from the values of for its component elements according to

$$\mu_m(\text{mix}) = \mu_{m1}f_1 + \mu_{m2}f_2 + \dots \quad (3)$$

Where $\mu_{m1}f_1$, $\mu_{m2}f_2$ are the mass attenuation coefficient for elements 1, 2, ..., and f_1, f_2 are the fractions by weight of these elements in the mixture. For example, mass attenuation coefficient for water (2/18H, 16/18O, by weight) is given by

$$\mu_m(\text{water}) = \left(\frac{2}{18}\right)\mu_m(\text{H}) + \left(\frac{16}{18}\right)\mu_m(\text{O}) \quad (4)$$

The mass attenuation coefficient (μ_m) can be broken down into components according to

$$\mu_m = \tau + \sigma + \kappa \quad (5)$$

Where τ is that part of μ_m caused by the photon electric effect is the part caused by Compton scattering, and κ is the part caused by pair production. Thus, for example would be the mass

attenuation coefficient of an absorber in the absence of Compton scattering and pair production. But μ_m involves both absorption and scattering processes.[19] Thus, μ_m is properly called an attenuation coefficient rather than an absorption coefficient

The relative magnitudes of τ , σ and κ vary with atomic number Z and photon energy E .

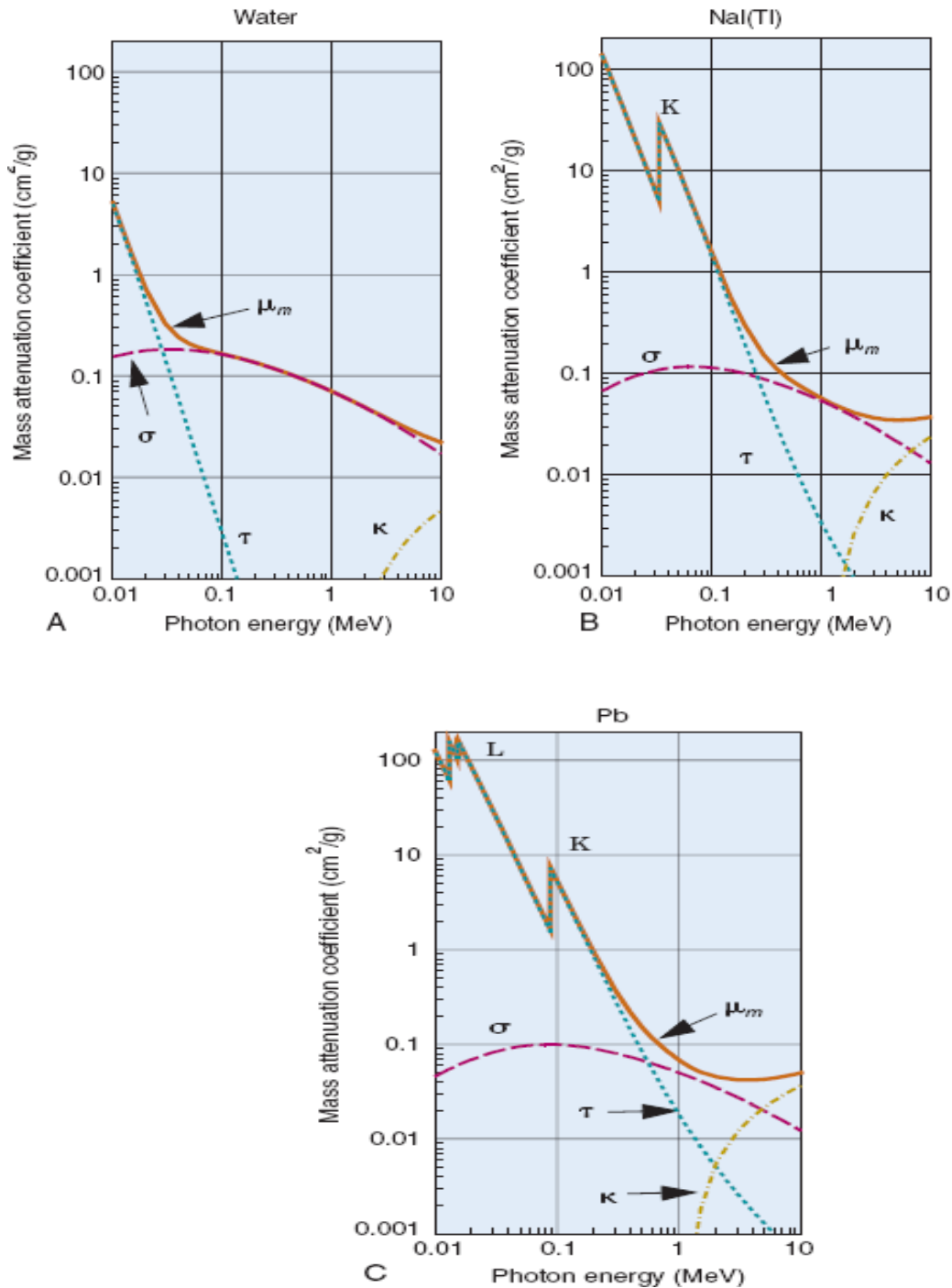


Figure 3(A,B,C) Photoelectric (τ), Compton (σ), pair-production (κ), and total (μ_m) mass attenuation coefficients (square centimeters per gram) for water (A), NaI(Tl) (B), and Pb(C) from 0.01 to 10 MeV. K and L are absorption edges.

Data taken from reference [21]. Curves for μ_m can be obtained by multiplying by the appropriate density values.

Fig.3 (A,B,C), above shows graphs of μ_m and its components, τ , σ , and κ versus photon energy from 0.01-10MeV in water, NaI(Tl), and lead. The following points are illustrated by these graphs:

1. The photoelectric component τ decreases rapidly with increasing photon energy and increases rapidly with increasing atomic number of absorber.

$$\tau \propto Z^4/E^3 \quad (6)$$

Where τ = photoelectric mass attenuation coefficient. As the gamma-ray energy decreases, the probability of photoelectric absorption increases rapidly. Photoelectric absorption is the predominant interaction for low energy gamma. The photoelectric effect is thus the dominating effect in heavy elements at low photon energies. The photoelectric component also increases abruptly at energies corresponding to orbital electron binding energies of the absorber elements. At the K-shell binding energies of iodine (B.E=33.4keV) and lead (B.E=87.0keV), the increase is a factor of 6-7. These abrupt increases are called K absorption edges. They result from the fact that photoelectric absorption involving K-shell electron cannot occur until the photon exceeds the K-shell binding energy. L absorption edges also are seen at $E \sim 12-15$ keV in the graph for lead. L absorption edges in water and iodine and the K absorption edge for water also exist, but they occur at energies less than those shown in the graphs.

2. The Compton-scatter component σ decreases slowly with increasing photon energy E and with increasing absorber atomic number Z . The changes are so small that for practical purposes σ usually is considered to be invariant with Z and E . Compton scattering is the dominating interaction for intermediate values of Z and E . At the K-shell binding energies of lead (B.E=91.4keV) and iodine (B.E=33.2keV), the increase is a factor of 5-6. These abrupt increases are called K absorption edges. They result from the fact that the Compton-scatter

component involving K-shell electron cannot occur until the photon exceeds the K-shell binding energy. L absorption edges also are seen at $E \sim 10-18$ keV in the graph for lead. L absorption edges in water and iodine and the K absorption edge for water also exist, but they occur at energies less than those shown in the graphs.

3. The pair-production component κ is zero for photon energies less than the threshold energy of 1.02MeV for this interaction; then it increases logarithmically with increasing photon energy and with increasing atomic number of the absorber ($\kappa \propto Z \log E$). Pair-production is the dominating effect at higher photon energies in absorbers of high atomic number.

2.3.3 Narrow-Beam Geometry Attenuation

The transmission of a photon beam through a “thick” absorber- that is one in which the probability of photon interaction is not “small” ($\geq 10\%$) depends on the geometric arrangement of the photon source, absorber and detector. Specifically, a transmission depends on whether scattered photons are recorded as part of the transmitted beam. An arrangement that is designed to minimize the recording of scattered photons is called narrow-beam geometry (or good geometry). Conversely, an arrangement in which many scattered photons are recorded is called broad-beam geometry (or poor geometry). Figure 4 shows examples of these geometries. [21]

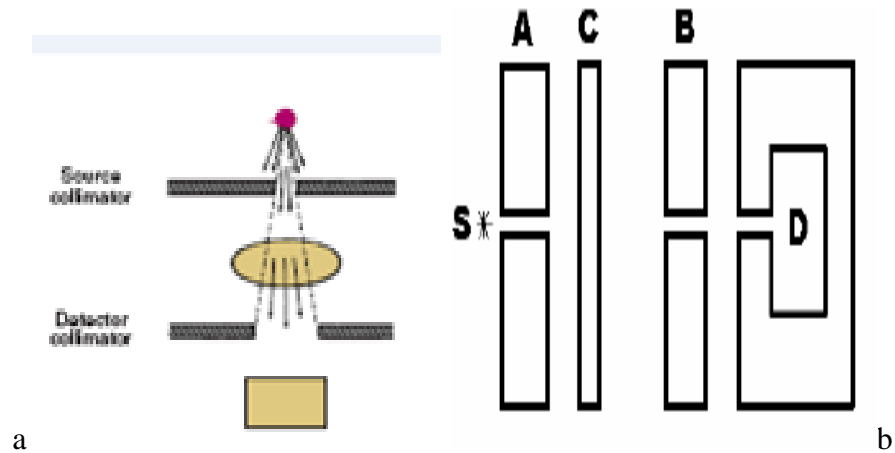
Condition of narrow-beam geometry usually requires that the beam be collimated with a narrow aperture at the source, so that only narrow beam photons are directed on to absorber. This minimizes the probability that photons will strike neighboring objects (for instance the walls of the room or other parts of the measurement apparatus) and scatter toward the detector. Matching collimation on the detector helps prevent photons that are multiple scattered in the absorber from being recorded. In addition, it is desirable to place the absorber approximately halfway between the source and the detector.

Under conditions of narrow-beam geometry, the transmission of a mono-energetic photon beam through an absorber is described by an exponential equation. [22]

$$I(x) = I_0 e^{-\mu_l x} \quad (6)$$

Where $I(x)$ is the beam intensity transmitted through a thickness x of absorber (tissue), I_0 is the intensity recorded with no absorber present, μ_l is the linear attenuation coefficient of the

absorber at the photon energy of interact and quantity $e^{-\mu x}$ is the fraction of beam intensity transmitted by absorber is called its transmission factor. Narrow-beam geometry is designed to minimize the number of scattered photons recorded



(Where, S=source, D= Detector A, B=Collimators, C = Attenuator)

Figure 4 Narrow beam geometry

In narrow beam geometry, fig.4b, The radiation source is placed at S, and beam is collimated by the collimator A. it then passes through an absorber C, through a interaction in C will appear as complete attenuation at the detector D, since scattered radiation cannot enter the detector because of the collimator B and into the detector D. under good collimating conditions, any interaction radiation cannot enter the detector because of the collimator B.

And also, in narrow beam geometry, a collimated beam of radiation is considered to be incident on a block of material containing N atomic/cm³ As a result of interaction the intensity I of γ -ray reduces as the beam travels in the shielding medium.

The reduction in the intensity, dI , in crossing a thickness dx in the shield is given by

$$dI = -I N \sigma_{tot} . dx \quad (7)$$

The integrations gives;

$$I = I_0 \exp (-N \sigma_{tot} . X) \quad (8)$$

Where I_0 is the incident intensity and I is the residual intensity after passing a material of thickness “ X ”. And $N\sigma_{tot}$ is the macroscopic interaction cross-section, and is alternatively known as μ_1 , the linear attenuation coefficient. [23]

Equation (8) then becomes,

$$I = I_0 \exp(-\mu_1 x) \quad (9)$$

2.3.4 Broad-Beam Geometry Attenuation of Photon

Any attenuation geometry in which some primary rays reach the detector, In ideal broad-beam geometry energy scattered or secondary uncharged particle strikes the detector, but only if generated in the attenuator by a primary particle on its way to the detector, or by a secondary charged particle resulting from such a primary.

The requirements are attenuated be thin to allow the escape of all uncharged particle resulting from first interaction, plus the x-rays emitted by secondary charged particles.

Practical problems of photon –beam attenuation in nuclear medicine usually involve broad-beam conditions. Examples are the shielding of radioactive materials in lead containers and the penetration of body tissues by photons emitted from radioactive tracers localized in internal organs. In both of these examples, a considerable amount of scattering occurs in the absorber material surrounding or overlying the radiation source.

The factor by which transmission is increased in broad-beam conditions, relative to narrow-beam conditions, is called the buildup factor B . Thus the transmission Factor T for broad-beam conditions is given by

$$T = B e^{-\mu_l x} \quad (10)$$

Where μ_l and x are the linear attenuation coefficient and thickness, respectively, of the absorber. And also B depends on photon energy and on the product $\mu_l x$ for the absorber.

For broad and complicated source geometry beam attenuation, fig.5b shows the dose at any point P after a shield will be greater than that predicted by narrow beam attenuation calculations, since these calculations take no account of scattered radiation.

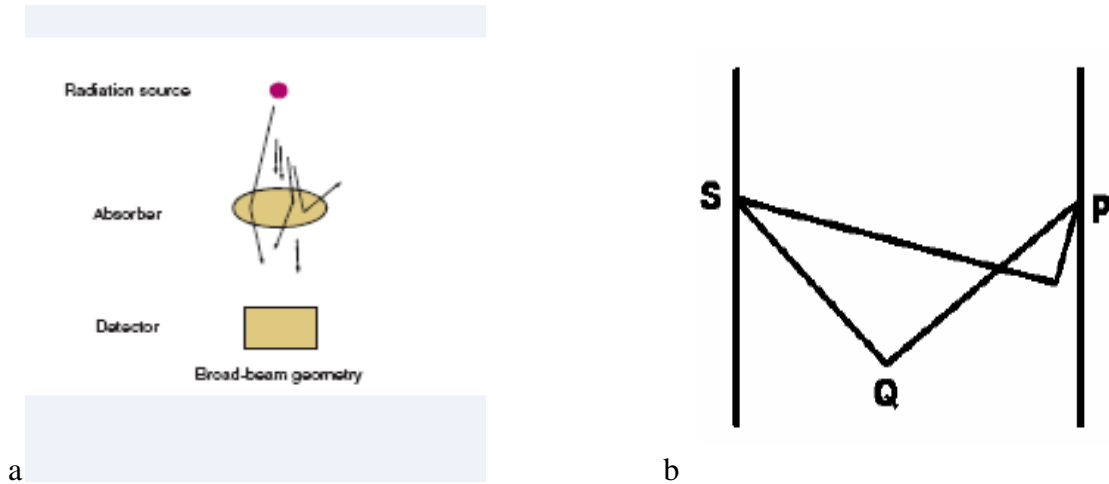


Figure 4. Broad beam geometry.

The dose at P will be the sum of the uncollided flux ($I_0 \exp(-\mu x)$), at P and, radiation which undergoes scattering at Q and reaches P. since the scattered radiation results from Compton processes, the effect will be more significant for the lighter elements where the Compton effect is the dominant process .

Allowance for this build-up of radiation intensity due to scattered radiation is made by the introduction of a build-up factor.[24]

2.3.5 The Buildup Factor, B

The buildup factor B is a unitless value used to account for secondary and scattered radiation in a broad-beam system. It can be applied with respect to any specified geometry, attenuator, or physical quantity in radiological physics.

Buildup factor is one of those important properties of a material used for beam collimation, tissue compensation or radiation shielding and protection. It directly affects the dose quantity and, hence, correct and precise dose delivery to a tissue or a matter is not possible without knowing the buildup factor of a material for tissue compensation purpose.[25]

$$B = \frac{\text{Total Broad Beam Counts}}{\text{Total Narrow Beam Counts}} \quad (11)$$

In other words,

$$B = \frac{\text{Quantity due to primary+scattered secondary radiation}}{\text{Quantity due to primary radiation alone}} \quad (12)$$

So that $B=1$ for narrow beam geometry

$B > 1$ for broad-beam geometry

For broad-beam

For $L=0$ (no attenuation b/n source and detector)

$$B=B_0 = \frac{\psi L}{\psi_0} = \frac{I}{I_0} \quad (13)$$

The gamma- ray attenuation , in which gammas –ray are collimated to narrow beam before striking the absorber, is sometimes characterized as” narrow-beam” or “good geometry” measurement.

The essential characteristic is that only gamma rays from the source that escape interaction in the absorber can be counted by the detector. Real measurements are often carried out under different circumstance.(as sketched below) in which the severe collimation of the gamma rays is absent.

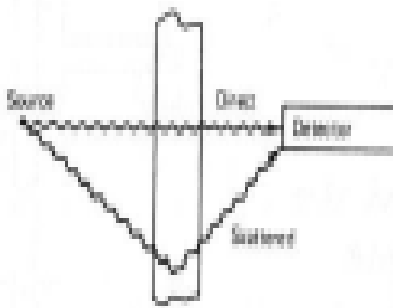


Fig.5 broad beam geometry

Now the detector can respond either to gamma rays directly from the source to gamma rays that reach the detector after having scattered in the absorber, or other types of secondary photon radiation. Many types of detectors will be unable to distinguish between these possibilities, so

that the measured detector signal will be larger than that recorded under equivalent “good geometry” conditions [26]. The conditions that lead to the simple exponential attenuation ($\frac{I}{I_0} = e^{-\mu_l x}$) are therefore, violated in this “broadbeam” or “bad geometry” measurement because of the additional contribution of the secondary gamma rays. This situation is usually handled by replacing simple exponential attenuation by the following

$$\frac{I}{I_0} = B e^{-\mu_l x} \quad (14)$$

$I = I_0 B e^{-\mu_l x}$ For broad geometry ($B > 1$) And

$I = I_0 B e^{-\mu_l x}$ For narrow geometry ($B = 1$)

Where, the factor B is called the buildup factor. The exponential term is retained to describe the major variation of the gamma-ray counting rate with absorber thickness and the buildup factor is introduced as a simple multiplicative correction. The magnitude of the buildup factor depends on the type of gamma ray detector used, because this will affect the relative weight given to the direct and secondary gamma rays. (With a detector that responds only to the direct gamma rays, the buildup factor is unity).

The buildup factor also depends on the specific geometry of the experiment. As a rough rule of thumb, the buildup factor for thick slab absorbers tends to be about equal to the thickness of the absorber measured in units of mean free path of the incident gamma rays, provided the detector responds to a broad range of gamma ray energies. [27]

2.3.6 Linear Attenuation coefficient

The linear attenuation coefficient (μ_l) is the actual fraction of photons interacting per 1 unit thickness of material (tissue). In our example the fraction that interacts in the 1cm thickness is 0.1 or 10 percent. And the value of the linear attenuation coefficient is 0.1 per cm. Linear attenuation coefficient values indicate the rate at which photons interact as they move through material and are inversely related to the average distance photons travel before interacting. [28]

The photons interact (attenuation coefficient value) is determined by the energy of the individual photons and the atomic number and density of material (tissue).

2.4 Mass Attenuation Coefficient

The mass attenuation coefficient is a measure of the probability per unit path length for interactions between the incident photon and the matter. It is also a measurement of how strongly a chemical species or substance absorbs or scatters light at a given wave length per unit mass. The values of mass attenuation coefficient for medical and health physics are known to be essential quantities in calculating of the penetration and absorbed dose of energetic photons in biological and materials[23]

Theoretical calculation process of the mass attenuation coefficient of any matter having more than one element can be computed by the following equation

$$\left(\frac{\mu}{\rho}\right)_{\text{matter}} = \sum_{i=1} W_i \left(\frac{\mu}{\rho}\right)_i \quad (15)$$

In the equation, W_i and $\left(\frac{\mu}{\rho}\right)_i$ imply the weight fraction and mass attenuation coefficient of related element in the matter, respectively. This equation is also known as mixture rule. According to the rule, the mass attenuations coefficient of matter is the sum of the mass attenuation coefficients contributed by the weight fraction of each element in matter (tissue). In the present study, these calculations were achieved with the help of the Win XCOM program. As is well known, the mass attenuation coefficient depends on the phase state of the matter (tissue) [29]. Another parameter independent of the phase state of matter (tissue) and associated with the mass attenuation is linear attenuation coefficient. It can be obtained from the mathematical multiplication of the mass attenuation coefficient and density of matter.

Use of the linear attenuation coefficient is limited by the fact that it varies with the density of the absorber, even though the absorber material is the same. Therefore, the mass attenuation coefficient is much more widely used and is defined as

$$\text{Mass attenuation coefficient} = \frac{\mu}{\rho}$$

Where ρ represents the density of the medium, and μ represent linear attenuation coefficient of medium. For a given gamma-ray energy, the mass attenuation coefficient does not change with the physical state of a given absorber. For example, it is the same for water whether present in liquid or vapor form. The mass attenuation coefficient of a compound or mixture of elements can be calculated from

$$\left(\frac{\mu}{\rho}\right)_c = \sum_{i=1} W_i \left(\frac{\mu}{\rho}\right)_i \quad (16)$$

Where, W_i factors represent the weight fraction of element c in the compound or mixture.

In some situation it is more desirable to express the attenuation rate in terms of the mass of the material encountered by the photons rather than in terms of distance. The quantity that affects attenuation rate is not the total the mass of an object but rather the area mass. Area mass is the amount of material behind a 1 unit surface area. The area mass is the product of material thickness and density.

$$\text{Area mass (g/cm}^2\text{)} = \text{Thickness(cm)} \times \text{Density(g/cm}^2\text{)}.$$

The mass attenuation coefficient is the rate of photon interaction per 1 unit(g/cm^2) area mass. If we compare two piece of tissue with different thicknesses and densities but the same area mass .Since both attenuate the same fraction of photons, the mass attenuation coefficient is the same for the two materials. They do not have the same linear coefficient values. The relationship between the mass and linear coefficient is

$$\text{Mass Attenuation Coefficient} \left(\frac{\mu_l}{\rho}\right) = \text{Linear Attenuation Coefficient} (\mu_l) / \text{Density}(\rho).$$

Note that the symbol for mass attenuation coefficient(μ_l/ρ) is derived from the symbols for the linear attenuation coefficient(μ_l) and symbol for density (ρ). We must be careful not be missed by the relationship stated in this manner. Confusion often arises as to the effect of material(tissue) density on attenuation coefficient values .Mass attenuation coefficient values are actually normalized with respect to material density, and therefore do not change with changes in density. Material density does have a direct effect on linear attenuation coefficient values.

The total attenuation rate depends on the individual rates associated with photoelectric, pair production and Compton interactions. The respective attenuation coefficients are related as follows:-

$$\mu \text{ (total)} = \mu \text{ (photoelectric)} + \mu \text{ (Compton)} + \mu \text{ (pair production)}$$

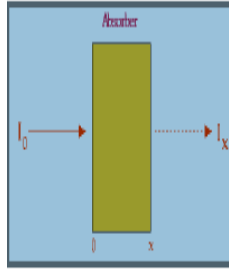
Let us now consider the factor that affect attenuation rates and the competition between photoelectric and Compton interactions. Both types of interactions occurs electrons within the material. The chance that a photon will interact as it travels a 1 unit distance depends on twofactors.

One factor is the concentration, or density of electrons in the material (tissue).Increasing the concentration of electrons increases the chance of a photon coming close enough to an electron to interact. The electron concentration was determined by the physical density of material. Therefore, density affects the probability of both photoelectric and Compton interactions. All electrons are not equally attractive to a photon .What makes an electron more or less attractive is binding energy. The two general rules are:

1. Photoelectric interaction occur most frequently when the electron binding energy is slightly less than the photon energy
2. Compton interactions occur most frequently with electrons with relatively low binding energies

2.4.1 Total Mass Attenuation Coefficient

The three interaction processes described above all contribute to the total mass attenuation coefficient. The relative importance of the three interactions depends on gamma ray energy and the atomic number of the absorber.



$$I = I_0 e^{-\mu x}$$

Figure 5 The fundamental law of gamma ray attenuation

All elements except hydrogen show sharp, low energy rise that indicates where photoelectric absorption is the dominant interaction. The position of the rise is very dependent on atomic number. Above the low energy rise, the value of the mass attenuation coefficient decreases gradually, indicating the region where Compton scattering is the dominant interaction. The mass attenuation coefficients for all elements with atomic number less than 25(iron) are nearly identical in the energy range 200 to 2000keV. The attenuation curves converge for all elements in the range 1keV to 2MeV. The shape of mass attenuation curve of hydrogen shows that it interacts with gamma rays with energy greater than 10keV almost exclusively by Compton scattering [29]. Above 2MeV, the pair-production interaction becomes important for high Z elements and the mass attenuation coefficient begins to rise again. The interaction and transfer of energy from photons to tissue has two phases.

The first is the "shot-one" interaction between the photon and an electron in which all or a significant part of the photon energy is transferred, the second is the transfer of energy from the energized electron as it moves through the tissue. This occurs as a series of interactions, each of which transfers a relatively small amount of energy. Several types of radioactive transitions produce electron radiation including beta radiation, internal conversion(IC) electrons and Auger electrons. These radiation electrons interact with matter (tissue) in a manner similar to that of electrons produced by photon interactions. In the photoelectric interactions, the energy of the electron is equal to the energy of the incident photon less the binding energy of the electron within the atom. In Compton interactions, the relationship of the electron energy to that of the photon depends on angle of scatter and the original photon energy. The electrons set

free by these interactions have kinetic energies ranging from relatively low values to values slightly below the energy of the incident photons.

As the electrons leave the interaction site, they immediately begin to transfer their energy to the surrounding material (tissue). Because the electron carries an electrical charge, it can interact with other electrons without touching them. As it passes through the material or tissue, the electron, in effect, pushes the other electrons away from its path. If the force on an electron is sufficient to remove it from its atom, ionization results. In some cases, the atomic or molecular structures are raised to a higher energy level, or excited state. Regardless of the type of interaction, the moving electron loses some of its energy. Most of the ionization produced by x-ray and gamma radiation is not a result of direct photon interactions, but rather of interactions of the energetic electrons with the tissue (material). For instance, in air, radiation must expend an average of 32. eV per ionization. Consider a 51 keV x-ray photon undergoing a photoelectric interaction, the initial interaction of the photon ionizes one atom, but the resulting energetic electron ionizes approximately 1500 additional atoms.[30]

2.4.2 Exponential attenuation

Gamma rays were first identified in 1900 by Becquerel and Villard as a component of the radiation from uranium and radium that had much higher penetrability than alpha and beta particles. In 1909, Soddy and Russell found that gamma-ray attenuation followed an exponential law and that the ratio of the attenuation coefficient to the density of the attenuation material (tissue) was nearly constant for all material(tissue).when gamma radiation of intensity I_0 is incident on an absorber of thickness L , the emerging intensity(I) transmitted by the absorber is given by the exponential expression[31]

$$I = I_0 e^{-\mu_l x} \quad (17)$$

Where μ_l is the attenuation coefficient (expressed in cm^{-1}). The ratio I/I_0 is called the gamma - ray transmission. Figure 6 illustrates exponential attenuation for three different Gamma-ray energies and shows that the transmission increases with increasing gamma-ray energy and decreases with increasing absorber thickness. Measurements with different sources and absorber show that the attenuation coefficient μ_l depends on the gamma-ray energy and the atomic number (Z) and density(ρ) of the absorber. For example, lead has a high density and

atomic number and transmits a much lower fraction of incident gamma ray radiation than does a similar thickness of aluminum or steel. The attenuation coefficient in above equation is called linear attenuation coefficient.

2.4.3 Simple exponential attenuation

For mono energetic parallel beam and for Ideal case (simple absorption, no scattering or secondary radiation) and for large number of N_0 (uncharged particles incident) perpendicularly on a flat plate of material of thickness L .

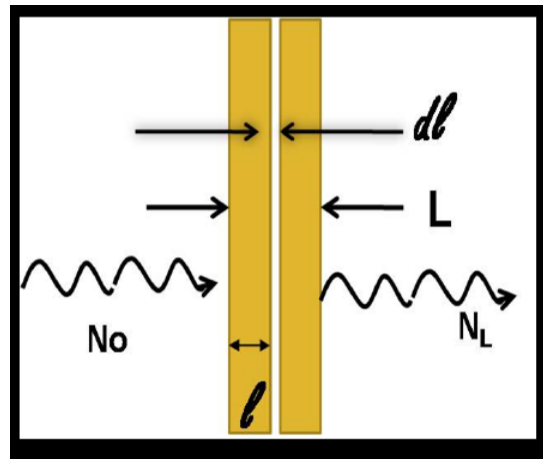


Figure 6 Simple exponential attenuation

If each particle either completely absorbed in simple interaction, producing no secondary radiation, or passes straight through the entire plate unchanged in energy or direction.

When real beam of photons interact with matter by processes that may generate .A charged or uncharged secondary radiations

Scattering primary either with or without loss of energy. So, the total no of particle that exit from the slab is greater than the unscattered primaries take fig.7 above.

Secondary charged particles (N_L) Not to be counted as unchanged particles, they are less penetrating, and thus tend to be absorbed in the attenuator, those that escape can be prevented from entering the

detector by enclosing it in a thick enough shield, so, energy given to charged particles is absorbed and does not remain part of the uncharged radiation beam.

2.4.4 Law of exponential attenuation

Let (μ) be the probability that an individual particle interacts in unit thickness of material. So, the probability that it will interact in dL is μdl . [32] If N particles are incident upon dl , The change dN in the number N due to absorption is become.

$$dN = -\mu N dl \quad (18)$$

$$\frac{dN}{N} = -\mu dl$$

$$\int_{N_o}^{N_L} \frac{dN}{N} = - \int_{l=0}^L \mu dl \quad (19)$$

$$\ln N_L - \ln N_o = \ln \frac{N_L}{N_o} = -\mu L$$

$$\frac{N_L}{N_o} = e^{-\mu L} \quad (20)$$

where μ is linear attenuation coefficient and L is thickness of absorber.

2.5 Interaction processes of gamma radiation in matter

Detection of gamma radiation is based on the interaction between the radiation and the detector material. The photon scatters from the electrons of the material and in each scattering process it loses a part its energy. If the piece of tissue or material is large enough and the scattering take place suitably, all the energy of the initial gamma ray is absorbed in tissue. Thus, the energy of the photon is found by measuring the energy absorbed by the tissue. How this energy is determined, depends on the detector type and its functioning.

Probabilities of various processes depend on the energy of the photon, the used detector material and the size of the detector. If we recall that photons are individual units of energy. As an x-ray beam or gamma radiation passes through an object, three possible fates await each photon:

- i. It can penetrate the section of tissue without interacting
- ii. It can interact with the matter (tissue) and be completely absorbed by depositing its energy
- iii. It can interact and be scattered or deflected from its original direction and deposit part of its energy. Photons entering the Human Body will either Penetrate, be Absorbed, or Produce Scattered Radiation. There are two kinds of interactions through which photons deposit their energy, both are with electrons. In one type of interaction the photon loses all its energy, in the other, it loses a portion of its energy and the remaining energy is scattered.

Although a large number of possible interaction mechanism are known for gamma rays in matter only three major types play an important role in radiation measurements with detectors and absorber:

- There are three processes have been identified by which gamma rays interact with matter, for the purposes of radiation shielding .These are:
 - i. The photoelectric Effect (σ_{pe})
 - ii. Compton Scattering (σ_c)
 - iii. Electron – positron Pair Production ($\sigma_{\rho\rho}$)

The principal interaction processes for *gamma* radition in the range 0.1-10 Mev that are responsible for their attenuation are briefly given below

2.5.1 Photoelectric Effect

In the effect the incident photons disappears and an orbital electron is ejected from the atom. The electron carries away all the energy of the photon minus the binding (ionization) energy of the electron in the atom. This is an important mode of interaction for low energy photons in materials with high atomic numbers. The process can be regarded effectively as purely absorptive, since neither the photoelectrons nor the fluorescent radiation released as a consequence of photoelectric effect have sufficient energy to warrant independent study in shield analysis. The photoelectric cross- section depends strongly on Z, varying as

$$\mu_{pe} \sim Z^n$$

where n is the function of E . Because of the strong dependence of μ_{pe} on Z , the photoelectric effect is of greatest importance for the heavier atom such as lead, especially at lower energies [33].

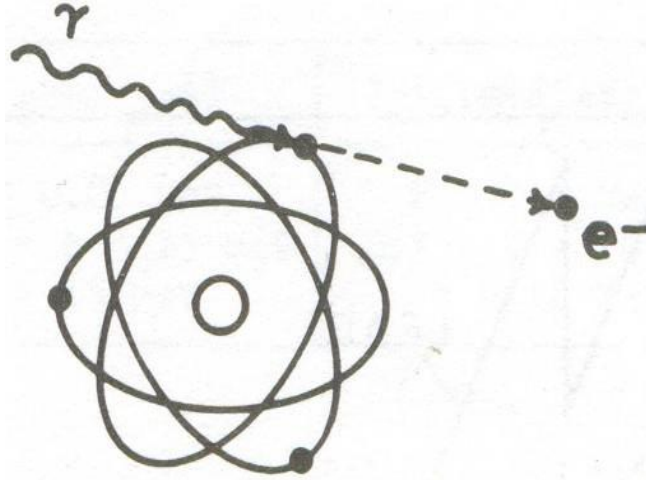


Figure 7 Schematic diagram of the photoelectric effect. The incident photon is ‘destroyed’.

2.5.2 Compton Scattering

In this process a photon collides with an atomic electron loses some of its energy and is deflected from its original direction. It has an effect on the incident photon that is somewhat analogous to the effect that elastic scattering by an atomic nucleus has on a neutron – in both cases the incident particle survives the collisions. Compton scattering is the predominant reaction for gamma photons with energies in the range 1 Mev- 10 Mev for elements of low and intermediate atomic numbers. The main theoretical difficulty in gamma attenuation calculation is attributable to the ramifications of radiation shielding.

The Compton cross – section per atom, is equal to the number of electron in the atom – namely, Z – multiplied by $e\sigma_c$. Thus,

$$\sigma_c = Ze\sigma_c$$

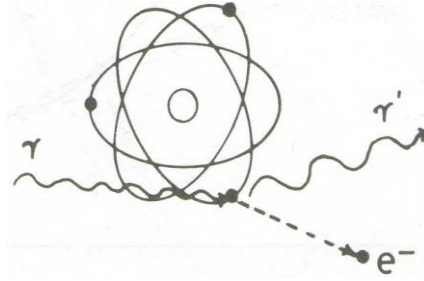


Figure 8 Schematic diagram of the Compton Effect the incident photon is survives.

2.5.3 Pair production

In this effect, which is the most likely interaction process for high energy photons, the incident photon disappears in the field of a charged particle, and an electron – positron pair appears. The cross section of this process varies as the square of the charge of the target particle – which may be an atomic electron, or, more usually, atomic nucleus. In the former event the partial cross section is proportionally to Z and in the later it is proportional to Z^2 . Thus the total pair production cross – section increases rapidly with atomic number. To first order approximation the pair production event can be considered absorptive and the total energy of the incident photons assumed dissipated in the immediate vicinity of the interaction. Closer investigation reveals, however, that “annihilation gamma rays”, of relatively low energy, are generated as a consequence of the pair production process. In more exacting attenuation studies it is sometimes necessary to include explicitly these annihilation gamma rays.

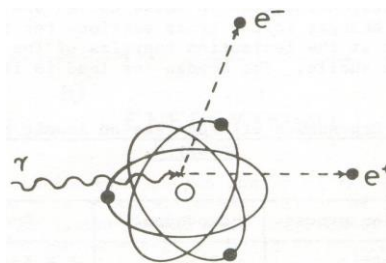


Figure 9 Schematic diagram of the pair production.

This interaction can only occur if the incident photon has an energy exceeding 1.02 Mev. The incident photon is ‘destroyed’.

The total photon cross section per atom is obtained as the sum of these three partial cross sections, and we may write

$$\sigma = \sigma_{pe} + \sigma_c + \sigma_{pp} \quad (21)$$

And therefore, using an obvious notation

$$\frac{\mu}{\rho} = \frac{\mu_{pe}}{\rho} + \frac{\mu_c}{\rho} + \frac{\mu_{pp}}{\rho} \text{ And}$$

$$\mu = \mu_{pe} + \mu_c + \mu_{pp} \quad (22)$$

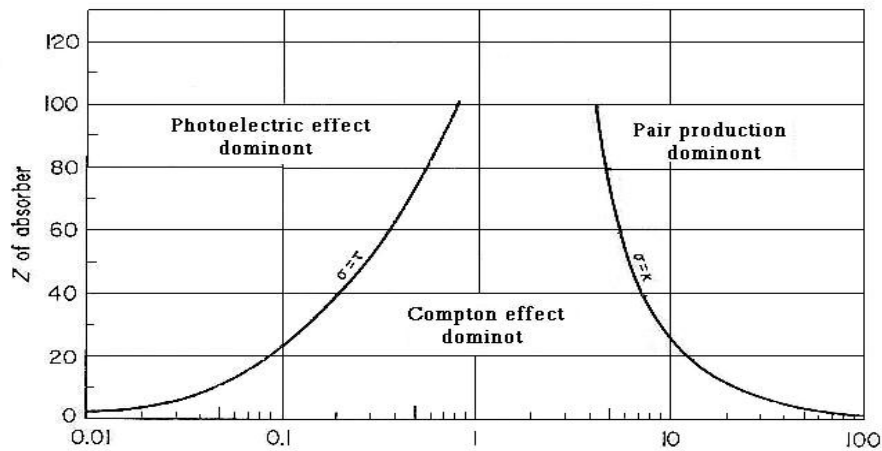


Figure 10Relative importance of the three major types of gamma – ray interaction

Fig. 11 shows the relative importance for the three major types of gamma –ray interaction. The lines show that the value of Z and $h\nu$ (Photon energy) for which the two neighboring effects are just equal.

And also, fig 11 shows the dominating (most probable) interaction versus photon energy E and absorber atomic number Z. The Compton scattering is the dominating interaction for $Z \leq 20$ (body tissues) over most of the nuclear medicine energy range.

CHAPTER3

3. CALCULATION METHODS OF MASS ATTENUATION COEFFICIENTS

The chemical composition weight fractions of the constituent elements and densities for tissues and tissue equivalents studied in the present work are given in the table 1. These values are taken from the ICRP publication [34] 89 ICRU Report [35] 44 which are reference data that provide needed input to prospective dosimeter calculations for radiation protection purposes.

3.1 XCOM

The mass attenuation coefficient values of tissue and tissue equivalent materials have been calculated by using XCOM program. The atomic numbers the atomic mass of the tissue constituent elements were taken from recent IUPAC report [36] the data base of XCOM program is for in coherent & coherent scattering [37,38], and for photo electric absorption [39] and the pair production process [40]. The authors state that the uncertainties in the value of mass attenuation coefficient provided are rather difficult to estimate depending on the energy range of the photons, they range from 1.25% to 15% with the lowest and highest energy regions associated with larger uncertainties [41]

The difficulties for measuring these uncertainties come from that since photo electric effect is the dominant interaction at low photon energies. Where the uncertainties are the largest, these very approximate percent uncertainties can be taken as a rough guide the uncertainties of the mass attenuation coefficient. In the region 59.5keV to 661.6keV where the photo nuclear giant dipole resonance occurs in the photo nuclear cross-section σ_{ph} neglect this cross section can make errors in μ_m in excess of 7%, at the peak of this resonance. This σ_{μ} on peak energy varies with both and the particular isotope of that element [42, 43]

Table 1 Chemical compositions tissues and tissues-equivalent

Tissue/ Tissue equivalents	Chemical formula or weight fraction (%)	Density (g/cm ³)
Muscle	H(0.102), C(0.123), N(0.035), O(0.729), Na(0.0008), Mg(0.0002), P(0.002), S(0.005), K(0.003).	1.04
Adipose	H(0.114), C(0.598), N(0.007), O(0.278), Na(0.001), S(0.001), Cl(0.001).	0.95
Blood	H(0.102), C(0.110), N(0.033), O(0.745), Na(0.001), S(0.002), Cl(0.003), K(0.002), Fe(0.001).	1.06
Soft tissue	H ₆₃ C ₆₀ O ₂₈ N	1.02
Water	H ₂ O	1

These data values are taken from the ICRP publication [35] 89 ICRU Report [36] 44

Table 2 Calculated and measured Mass attenuation Coefficients of the some Human Tissues

Energy (keV)	Tissues sample									
	Muscle		Water		Soft tissue		Adipose- tissue		Blood	
	Xcom	Exp.	Xcom	Exp.	Xcom	Exp.	Xcom	Exp.	Xcom	Exp.
							m			

59.5	0.177	0.1600 ±0.015	0.1524	0.1249 ±0.031	0.200	0.195±0 .019	0.385	0.350±0.028	0.1342	0.1237± 0.034
81.0	0.110	0.093 ± 0.013	0.1101	0.0877±0 .0031	0.100	0.091±0 .016	0.243	0.221±0.020	0.1401	0.1225±0.0 32
356.5	0.085	0.081 ± 0.012	0.0856	0.0768±0 .0023	0.076	0.072±0 .015	0.100	0.097±0.015	0.1301	0.1201±0.0 31
661.6	0.065	0.061 ± 0.011	0.0782	0.0781±0 .0021	0.058	0.051±0 .011	0.076	0.065±0.012	0.110	0.110±0.02 91
1173.3	0.061	0.056 ± 0.010	0.0674	0.0672±0 .002	0.054	0.045±0 .010	0.058	0.056±0.011	0.018	0.0179±0.0 27
1332.5	0.014	0.012 ± 0.005	0.0552	0.0432±0 .003	0.022	0.017± 0.004	0.054	0.050± 0.010	0.016	0.015±0.01 0

Before calculating the total mass attenuation coefficient, it is necessary to obtain the elemental compositions or (mass fraction of each element) of tissues (or sample). For obtaining the mass fraction of Nitrogen(N), Hydrogen(H), Carbon(C), Sulfur(S), Potassium(K), Oxygen(O) and Calcium(Ca) Which tissues (samples) contained. It is used to elemental analyzer(Euro –EA) which is explained in figure below. For instance,Soft tissues is basically composed of these elements (H,C,O,N) (young et al .,2005)-(Kaginell S. et al.,2009) [50,51]. The total mass attenuation coefficient can be obtained through the total cross section for photons equation(29, 30). To calculate the total mass attenuation coefficient, the software XCOM was utilized (Berger and Hubbel,1987) [24] and (Hubbell and Seltzer,1995) [49] .The mass fraction of each element inserted as input data and XCOM used to calculate the total mass attenuation coefficient.

Elemental Analyzer is a device that used to determine the elemental or isotopic composition of a test sample. An elemental analyzer can determine what elements are present, known as qualitative analysis, or how much of each element is present in sample, known as quantitative analysis. And also Elemental analyzer used for quantitative determination in organic samples containing Carbon, Hydrogen, Nitrogen, Sulfur and Oxygen as the basic elements of nature.

How Elemental Analyzer work?

Elemental analyzer works by heating an element quickly to a sufficiently high temperature, sothat it combusts. It is then passed through the analyzer in its gaseous state. A detector detects

the elements present, and the researcher simply reads this information on a computer screen.[48]



Figure12.Elemental analysis (Euro-EA)

3.2.Experimental data

- Experimental data for μ/ρ of the materials (tissues) are available for limited photon energies of 59.5, 81.0, 356.5, 661.6, 1173.2, and 1332.5 keV that emitted by ^{241}Am (2.78 GBq), ^{133}Ba (2.92 GBq), ^{137}Cs (3.14 GBq), and ^{60}Co (3.7 GBq) radioactive point source.

The results of present work have been compared with experimental data available in the literatures [22, 23]. The first experiment was performed by using summary spectrometry system consisting of HP Ge detector (canberra model) coupled with analog digital

converter (ADC), high voltage 5000V with negative polarity and relative efficiency of 70%.

Genie 2000 software (Canberra Industries, Meriden, USA) with analyzer cart was used to record the intensity of the incident and the transmitted gamma rays. Automatic pulses shopping and pole-zero correction settings were used and the energy scale was calibrated using point radioactive source. The measuring time is ranged from 5 to 10 min depending upon the photon energy about ground noise.

- The background was counted in the same manner of measuring intensity of attenuated photons in the samples. The second one was implanted by using energy dispersive X –ray system (EDXS) with two detection system ; cadmium telluride (CDTe) detector and a silicon drift detector (SDD). Acquisition times almost 1000 second were utilized to achieve adequate counting stat list, with uncertainties in the photon count smaller than 5% in both transmitted & scattered spectra.

3.3 Theoretical Calculation Method

3.3.1 Theoretical calculation of mass attenuation:

When ionized radiation passes through any matter (tissue), its intensity progressively reduces as consequence of a complex series of interactions between radiation and atoms of the attenuating medium such as x rays and gamma-rays. The photons of x-rays are either absorbed or scattered out of the beam. There are three mechanisms exist.

i. Photoelectric absorption:-

In this case there is poor data on the molecular photoelectric cross-section (σ_{ph}) for a test objects, then could be calculated according to the formula (Hubbell,2006).

$$\sigma_{ph} = \rho N A \sum \frac{W_i}{A_i} \sigma_i \quad (23)$$

Where NA is Avogadro's number, ρ is the density of the material, and A_i, W_i, σ_i are the atomic mass, the friction by weight, and the atomic cross-section of the i^{th} component of the medium respectively.

ii. Incoherent (Compton) scattering:

The total incoherent scattering cross-section per atom for inelastic scattering can be written as

$$\sigma_{inc} = \int_{\theta=0}^{\theta=\pi} d\sigma KN(\theta) S(x, Z) \quad (24)$$

$S(x, Z)$ is incoherent scattering function taken from the tables of (Hubben, 2006)

3. Coherent (Rayleigh) Scattering:-

The coherent (Rayleigh) scattering cross-section can be derived by integrating the differential cross-section over all possible scatter angles per atom given as (king at 21. , 2011)

$$\sigma_{coh} = \int_{\theta=0}^{\theta=\pi} d\sigma^T(\theta) [F(x, z)]^2 \quad (25)$$

Where $d\sigma^T$ is the classical or Thomson (1906)[41] cross-section for single free electron, the atomic form factor $F(x, z)$ is a function of the variable x , which x equal to $\sin^{-1}(\frac{\theta}{2\lambda})$.

The x-ray photons are suffer two process absorbed and scattered out of the beam. If the single-pack photonic energy incidents on material, photon and matters interaction happen immediately, as a result of interactions, if we assume, that the properties of the incident radiation remain unchanged in spite of attenuation, an increase in the thickness x by the amount(dx) will cause a decrease in the incident(I) by the amount (dI). The relative reduction in intensity is proportional to the absolute increase in thickness

$$-dI = I_0 \mu dx \quad (26)$$

The proportionality factor μ is referred to as the linear coefficient attenuation. As the intensity $I=1$ for $x=0$. Integration of equation (4) given as

$$I = I_0 e^{-\mu x} \quad (27)$$

Equation (27) becomes

$$\mu = -\frac{1}{x} \ln \frac{I}{I_0} \quad (28)$$

This relationship is known as Lambert's law of attenuation. It also illustrates that the attenuation depends on the attenuating material and the wavelength of x-ray.

If the path length of photons a cross the attenuator measured in unit (cm), then the linear attenuation coefficient μ_l calculated in (cm^{-1})

$$\mu_l = \frac{1}{x} \ln \frac{I_0}{I} \quad (29)$$

And if the path length of photons cross the attenuator measured in mass per unit area

(g/cm^2), then the mass attenuation coefficient μ_M calculated in (cm^2/g)

$$\mu_M = \frac{\mu_L}{\rho} = \left(-\frac{1}{\rho x}\right) \ln \left(\frac{I}{I_0}\right) \quad (30)$$

Where ρ density of medium

Theoretical values of mass attenuation coefficients are obtained by (Hubbell, 2006)

$$\mu/\rho = \frac{\sigma_{total}}{\mu A} \quad (31)$$

Where $u=1.660\ 540 \times 10^{-24}$ g is the atomic mass unit, A is the relative atomic mass of the sample,

The total cross section can be written as the sum over contributions from the principal photon interaction.

$$\sigma_{total} = \sigma_{ph} + \sigma_{inc} + \sigma_{co} \quad (32)$$

CHAPTER 4

4. RESULT AND DISCUSSION

The mass attenuation coefficient of the selected tissue is shown in fig1-3. The μ/ρ values using theoretical XCOM and experimental data at photon energy 59.5, 81.0, 356.5, 661.6, 1173.2 and 1332.5 keV were plotted in the same graphs along with XCOM results for comparison. It is clear that the XCOM results are very good agreement with the experimental data. However, the experimental values tend to be lower than theoretical value.

Discrepancy of these results could be due to deviations from narrow beam geometric in the source detector arrangements. This may attribute, to lower counting rates and the error because the errors of mass attenuation coefficient (μ/ρ) measurements mainly system from counting statistics, impurity of the samples, non-uniformity of the absorber and the scattered photons reaching the detector [24]. Furthermore, almost in all entries the experimental values are lower than the corresponding values of XCOM of each tissue. The high values of XCOM program return to the effect of chemical composition of tissues and mixture rule without neglecting effects of the atomic wave function of molecular bonding which can reduce the μ/ρ [36, 38]. The XCOM findings according to experimental result data are similar to results of [33, 34, 39] which have reported the same study of μ/ρ for steel alloys, scintillation detectors and bimolecular respectively.

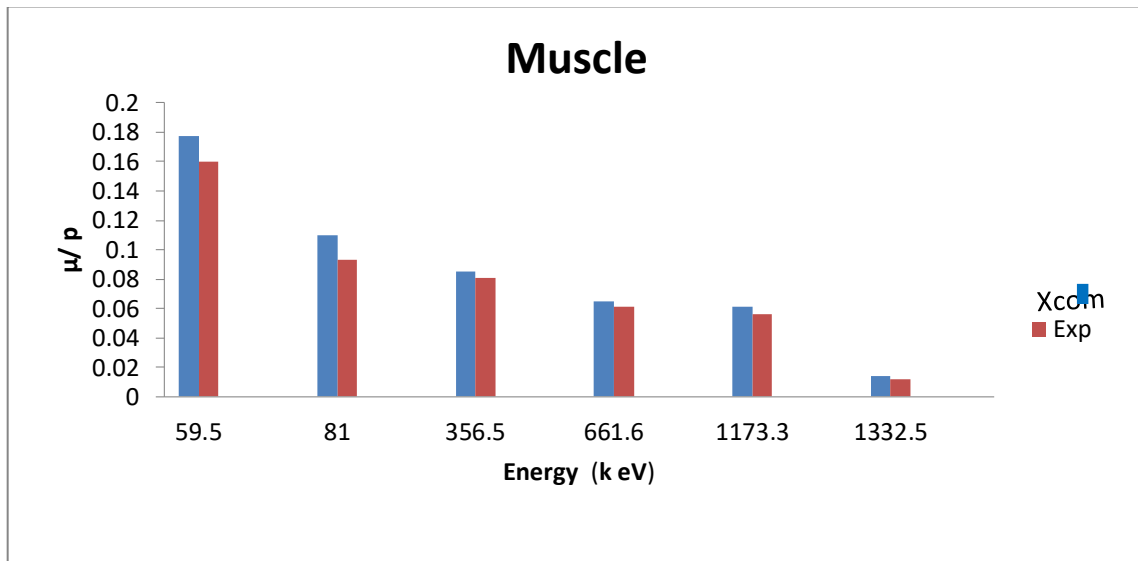


Figure 11 The mass attenuation coefficients (μ/ρ) as a function of photon energy for muscle, XCOM program data and experimental data.

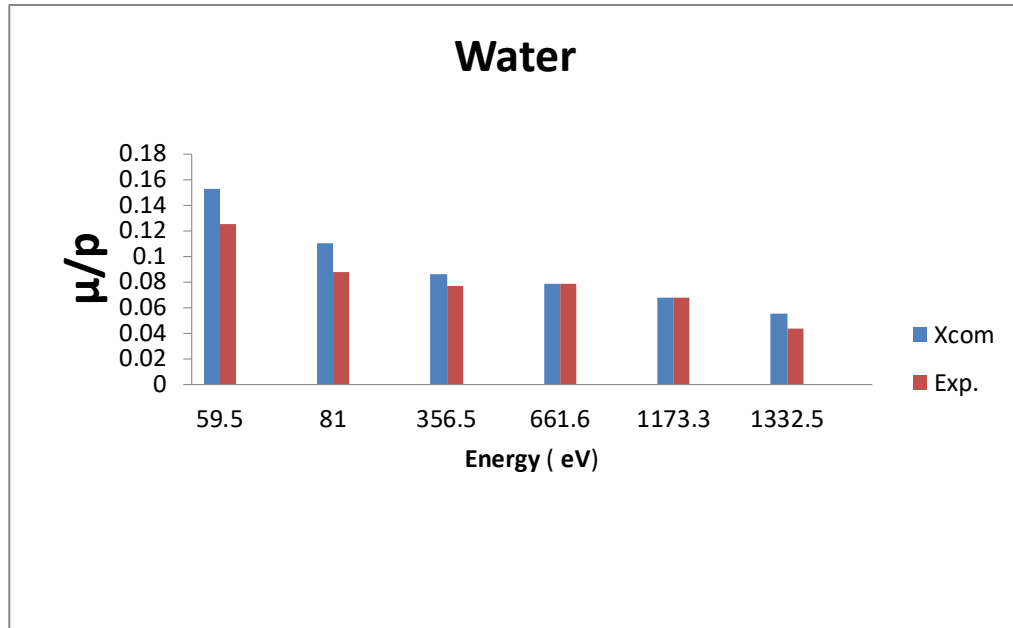


Figure 12 The mass attenuation coefficients (μ/ρ) as a function of photon energy for water XCOM and experimental data.

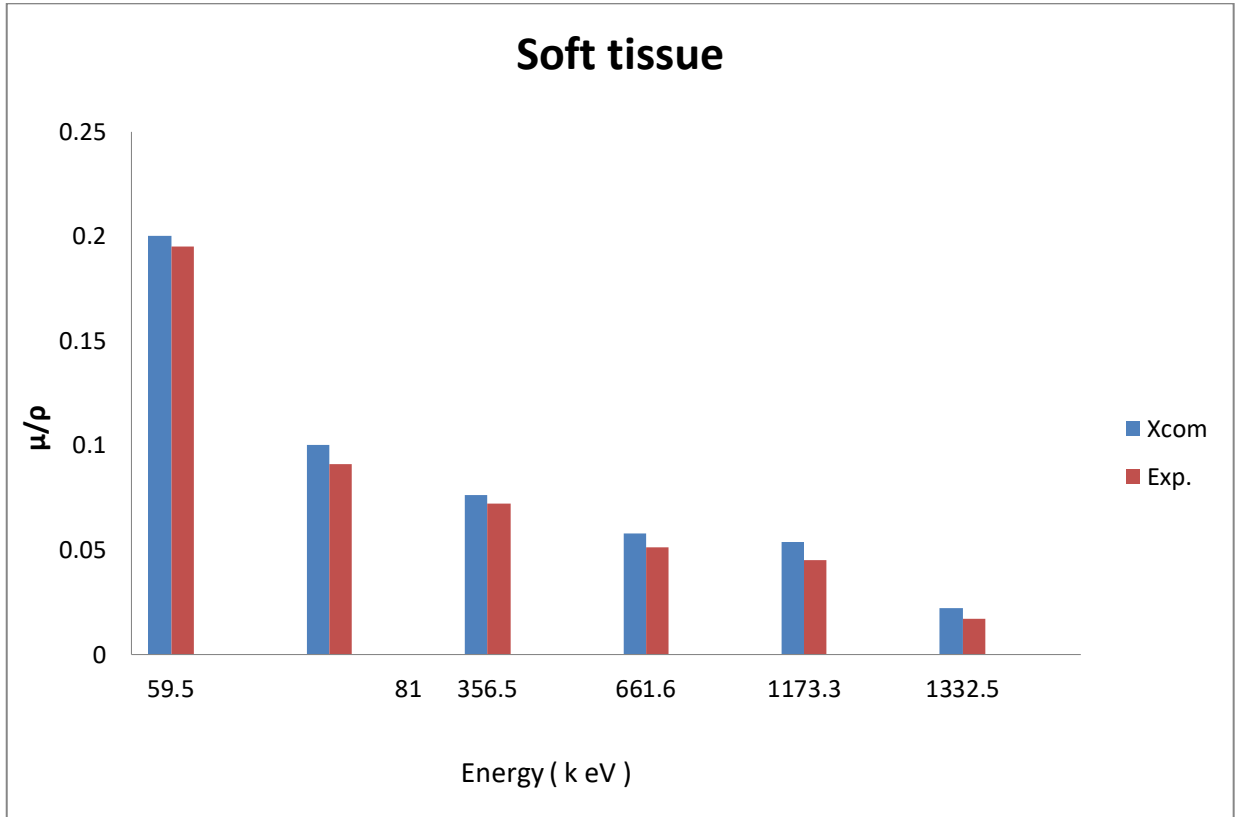


Figure 13 The mass attenuation coefficients (μ/ρ) as a function of photon energy for soft tissue, XCOM program and experimental data

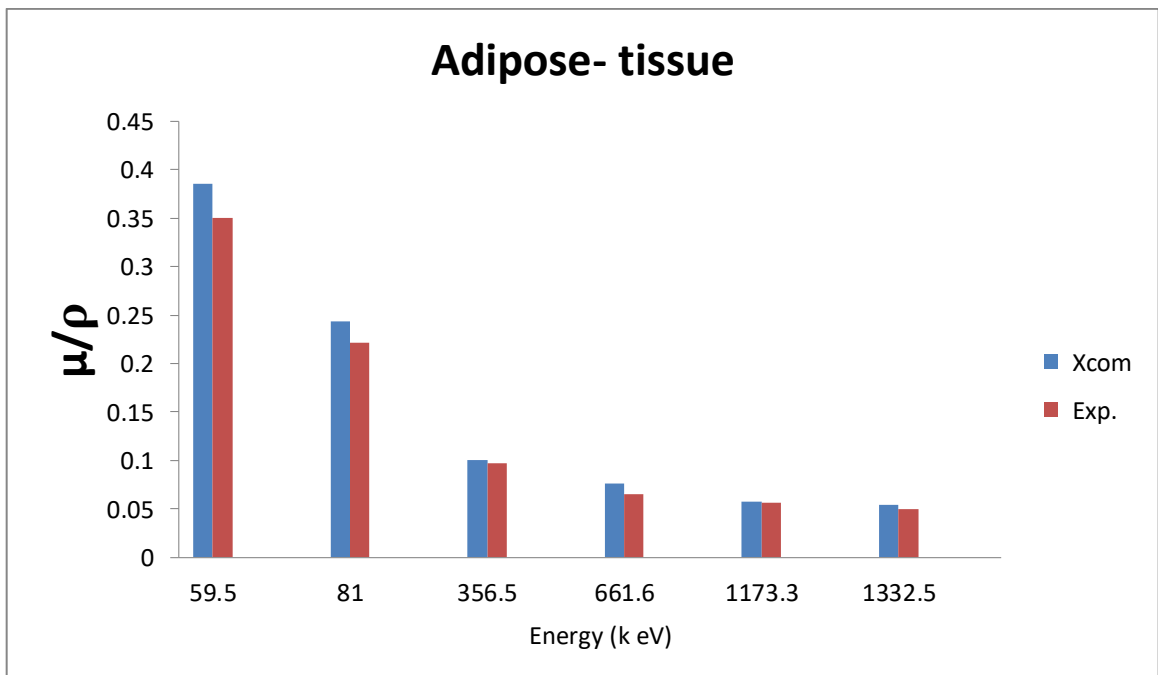


Figure 14 the mass attenuation coefficients (μ/ρ) as a function of photon energy for Adipose-tissues XCOM program and experimental data

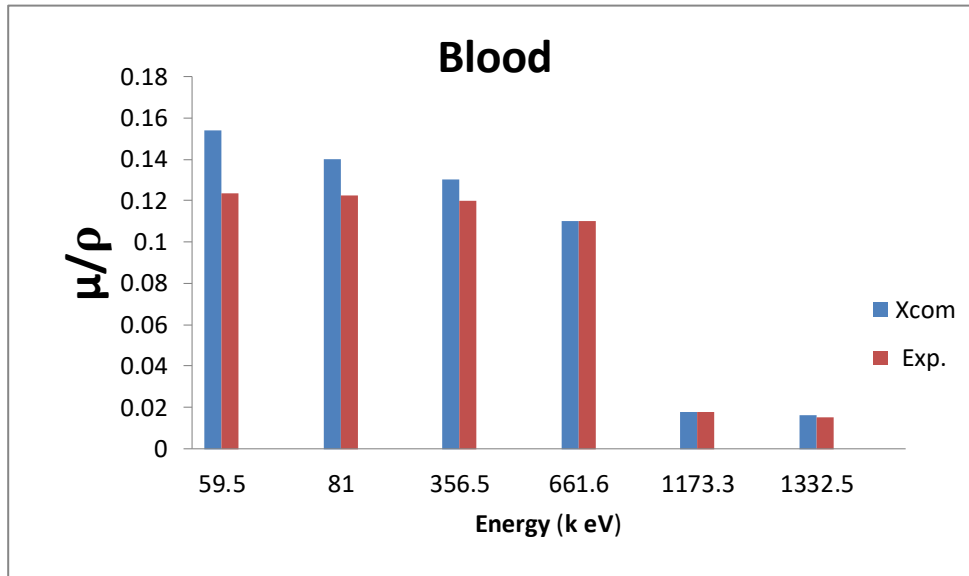


Figure 15 the mass attenuation coefficients (μ/ρ) as a function of photon energy for Blood by using, XCOM program

- From figs 13-17 it can be easily seen that .Three energy ranges related to dominant photon interactions (photo electric absorption, Compton scattering & pair production) are the dominating attention processes. The energy dependency μ/ρ values is storing below 59.5keV, weak b/n 59.5 – 356.5keV and almost constant above 661.6keV. These variations are interpreted as being due to photo electric absorption is the dominating at low energies and it is directly proportional to Z^n when n is approximately 4 for high Z materials, (tissues). And closer to 5 for low Z materials (tissues) [26, 27], and inversely to E^3 . At medium photon energies, Compton scattering becomes the dominating process and it varies with Z and E^{-1} . Upon increasing the photon energy, the attention is mainly due to pair production which varies with Z^2 and $\log E$. μ/ρ relative to water has been also calculated for the tissues and soft tissue model (STM) under consideration and the tissues that show better water equivalence in the entire energy region have been determined [fig. 14]. A maximum difference of 15% is observed at 59.5keV for blood tissue, 3.3% at 1173.3keV. These differences are found to decrease when the energy increases up to approximately 356.5keV. Above 661.5keV, the tissues show quite good equivalence properties except for Soft- tissue that experiences drastic change above 661.5keV.

CHAPTER 5

5 CONCLUSIONS

- For water and tissue equivalence properties of some tissues such as muscle (ICRU-44), adipose (ICRP) and blood (whole) have been investigated over wide range of photon energies from 1keV to 1GeV. The XCOM have been carried out to determine the mass attenuation coefficient (μ/ρ) for the samples involved. The applicability of this program is mainly dependent of on the accuracy of geometry model, composition and density distribution of the sample. The obtained value of the mass attenuation coefficient is to experimental values. This is obtained by X-COM program. The obtained results indicate the XCOM is suitable to Compare experiment for this kinds of Studies and it can be applied to estimate Mass attenuation coefficients for various attenuators and energies. Also, Mass attenuation coefficient relative to water has been calculated in the entire energy region for the tissues, Muscle, Adipose tissue and Blood show quite very good water equivalent properties, The difference between Water and Blood massattenuationcoefficientisusuallymorefewpercent. Furthermore, Muscle tissue and blood can be substituted by STM in radiological laboratories and clinical application whenmeasurements are made under radiation conditions where the photon attenuation is difficult to assess.
- From this project, I compare the calculated results by XCOMand with the experimental values that used to calculate the mass attenuation coefficient of some sample of human tissues. From this the XCOM program is suitable to determine the value of mass attenuation coefficient easily rather than the experimental method. Because, it is not consume time, when the data is input into program it gives results in a second .which is more close to the experimental value.
- The Xcom was used to calculate mass attenuation coefficients of different types of some human tissues in the 59.5-1332.5 key photon energy range. Thetheoretical Xcom program show that the calculated mass attenuation coefficient valuesare vary from minimum 1.25% to maximum 15% with experimental values. These results conclude that Xcom program can be applied to estimate the fundamental parameter mass attenuation coefficients for various attenuator and energies. Therefore, It is possible to conclude that the xcom program is better theoretical method for evaluation of photon interaction parameters of the different type of tissues (or matter).

Declaration

I declare that the thesis work hereby submitted to Addis Ababa University for the degree of Master of science in Physics has not been previously submitted by me for a degree at this or any other university, and it is my own work both in design and execution, and that all material contained herein has been duly acknowledged.

Name: Mohammed Aba Jihad Aba Dega

Signature: _____

This M Sc. This project has been submitted to for examination with my approval as University

Advisor: Name: _____ (PhD)

Signature: _____

Place and Date of Submission: Addis Ababa University

Department of Physics

October, 2021

APENDAX 1

How XCOM program work briefly displayed as the following:



Element/Compound/Mixture Selection

In this database, it is possible to obtain photon cross section data for a single element, compound, or mixture (a combination of elements and compounds). Please fill out the following information:

[Help](#)

Identify material by:

Element
 Compound
 Mixture

Method of entering additional energies: (optional)

Enter additional energies by hand
 Additional energies from file (*Note: Your browser must be file-upload compatible*)



Fill out the form to select the data to be displayed:

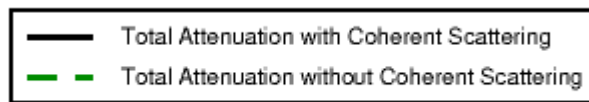
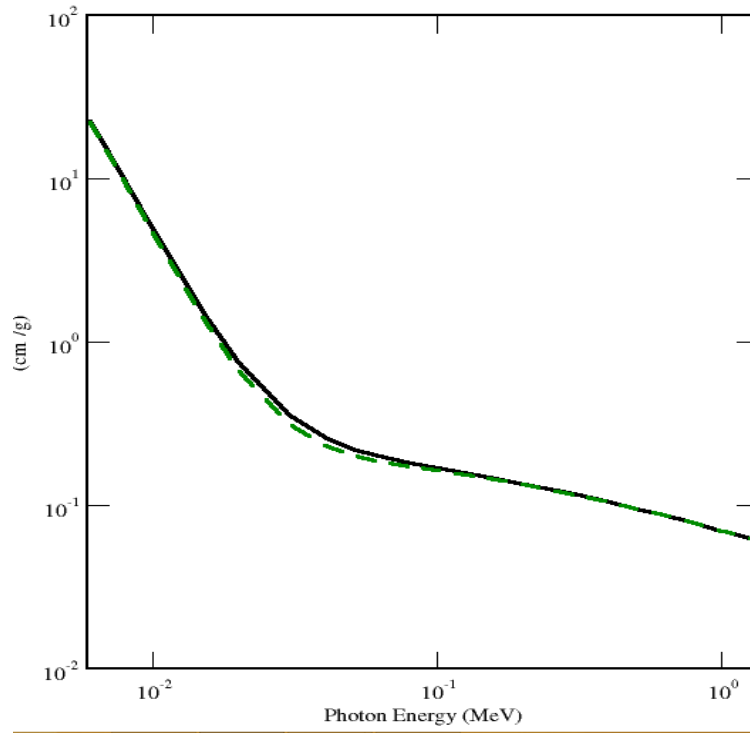
[Help](#)

<p>Select by: (only elements 1 - 100)</p> <p>Atomic Number: <input type="text"/></p> <p>or</p> <p>Symbol: <input type="text"/></p>	<p>Options for output units:</p> <p><input checked="" type="radio"/> All quantities in cm^2/g <input type="radio"/> All quantities in $barns/atom$ <input type="radio"/> Partial interaction coefficients in $barns/atom$ and total attenuation coefficients in cm^2/g</p>
<p>Graph options:</p> <p><input checked="" type="checkbox"/> Total Attenuation with Coherent Scattering <input type="checkbox"/> Total Attenuation without Coherent Scattering <input type="checkbox"/> Coherent Scattering <input type="checkbox"/> Incoherent Scattering <input type="checkbox"/> Photoelectric Absorption <input type="checkbox"/> Pair Production in Nuclear Field <input type="checkbox"/> Pair Production in Electron Field</p> <p><input type="checkbox"/> None</p>	<p>Additional energies in MeV: (optional) (up to 100 allowed)</p> <p>Note: Energies must be between 0.001 - 100000 MeV (1 keV - 100 GeV) (only 4 significant figures will be used). One energy per line. Blank lines will be ignored.</p> <p><input type="text"/></p> <p><input checked="" type="checkbox"/> Include the standard grid</p> <p>Energy Range:</p> <p>Minimum: <input type="text" value="0.001"/> MeV</p> <p>Maximum: <input type="text" value="100000"/> MeV</p>

APPENDAX 2



mass attenuation coefficient of soft tissue



APPENDEX 3
FOR SOFT TISSUE

Constituents (Atomic Number : Fraction by Weight)

Z=1 : 0.106267
Z=6 : 0.120601
Z=7 : 0.023440
Z=8 : 0.749692

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