Gamma Ray Attenuation In Composite Materials

By

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This Work is Dedicated to
My Family

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Abstract

Attenuation due to scattering or absorbtion of photons in composite materials depend basically up on two factors, the effective atomic number and electronic density of the absorber material. This project discuses recent studies concerning this title (gamma ray attenuation in composite materials). Many researchers use attenuation data to compute effective atomic number, electronic density and other parameters such as absorption coefficient total attenuation cross section of composite materials using their own and reported earlier methods. Most of the studies compiled in this paper have been done in a well-collimated narrow beam of lower and medium energy range of photon where photoelectric absorbtion and compton scattering are dominant photon interaction process. This work also includes photon interaction of selected human body parts and shielding materials from this it is concluded that while exposing large dimensional biological samples to the lower energy care must be taken for buildup photons to protect this shielding is necessary.

Introduction

Gamma ray is a high energy photon, especially as emitted by a nucleus in a transition between two energy levels. So gamma ray photons are particle like manifestation of electromagnetic waves, its energy is proportional to the frequency with planks constant $h = 4.1 \times 10^{-21}$ MeV-sec they are thus electromagnetic radiation with zero mass, zero charge, and velocity that is always the speed of light.

In nuclear reactions a product of nucleus can be formed in excited states having internal energy in excess of its ground state. Gamma photons are emitted within a short period for the nucleus to reach its ground state. The energy of photons is equal to the difference in energy levels between the two states involved in the transition. When there are two or more excited states are available, a cascade of photons occurs from the higher to intermediate stages then to the ground state (Figure 1).

Annihilation radiations, Bremsstrahlung rays and characteristic x-rays are identical to gamma rays in their fundamental nature as electromagnetic radiation. The only difference concerning their interaction with matter is related to the generally higher energy of the gamma rays(Knoll, 2000).

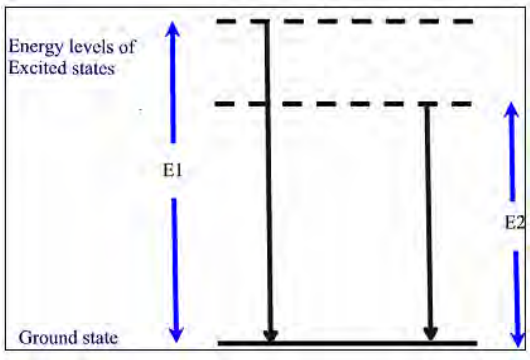

Figure 1: Gamma ray emission from excited state nucleus

Photons are electrically neutral, therefore they do not steadily lose energy, while traversing

a material medium, via columbic interactions with atomic electrons instead they travel some considerable distance before undergoing any kind of interactions. All photon interactions with matter lead to partial or total transfer of the photon energy to electrons that constitute the material.

Thus the history of photon in material is characterized by the sudden disappearance of the photon or by scattering through significant angles with significant energy loss. As photon interacts with matter, it can penetrate the section of the matter without interacting.

There are three main interaction mechanisms of photons with matter and three of them are the means by which photons are detected. The predominant mode of interaction depends on the energy of the incident photons and the atomic number of the material with which they are interacting. At low energies, in high atomic number materials, the photoelectric effect is the main interaction of photons with the material. At intermediate energies in low atomic number materials the dominant interaction is Compton scattering. At very high energies, the main mechanism by which photons are detected is pair production (S.Krane, 1988).

Composites are materials made from two or more constituent elements with significantly different physical or chemical properties which remain separate and distinct on a macroscopic level within the material. The different elements work together to give the composite unique properties different from the constituent elements. Alloys, soils, biological materials, glasses, polymers and solutions are some examples of composite materials. Thus, interaction of photon with composite material is different from ordinary interaction of photon with single element. As the materials are composed of various elements, it is assumed that the contribution of each element of the composite to total photon interaction is additive, yielding the well known 'mixture rule' (Shivalinge Gowda & Ramadrishna, 2004) that represents the total mass attenuation coefficient $(\mu/\rho)_c$ of any composites as the sum of the appropriately weighted proportions of the individual atoms.

The study of gamma ray or photon interaction with composite material has significant importance in industrial, biological, agricultural and medical applications. Accurate values of photon mass attenuation theory based parameterizations,in addition to providing essential data in such diverse fields such as tomography, γ-ray florescence studies and radiation biophysics. The mass attenuation coefficients are also widely used in calculation of photon penetration and energy deposition in biological, shielding and other dosimetric

material. The effective atomic number and electron density of composite materials are very useful parameters in the dosimetric calculation of radiation dose in medical imaging. This work compiles recent studies that are conducted on the attenuation of γ rays with composite materials that. The first chapter of this paper contains the major types of interaction of radiation processes that are interaction of charged particles and gamma ray interaction with matter in detail. The second chapter review of studies on interaction of gamma ray with composite materials and recent studies of γ ray attenuation in composite materials such as, building materials, biological samples and commonly used solvents and other composite materials. The last chapter of this paper contains in detail the interaction of gamma ray with selected human body parts, some biological samples and shielding materials.

Chapter 1
Interaction of Radiation with Matter

Radiation is classified into two main categories, nonionizing and ionizing, depending on its ability to ionize matter. Non-ionizing radiations have not sufficient energy to cause ionization in matter. Ionizing radiation can ionize matter either directly or indirectly.

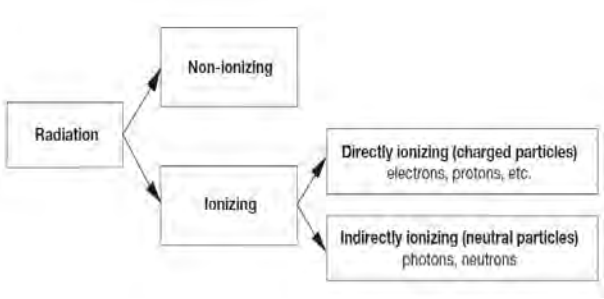

Figure 1.1: Classification of radiation.

Directly ionizing radiation (charged particles): electrons, protons, a particles and heavy ions. Indirectly ionizing radiation (neutral particles): photons (X rays and γ rays), neutrons. Directly ionizing radiation deposits energy in the medium through direct Coulomb interactions between the directly ionizing charged particle and orbital electrons of atoms in the medium.

Indirectly ionizing radiation (photons or neutrons) deposits energy in the medium through a two step process: In the first step a charged particle is released in the medium (photons release electrons or positrons. In the second step the released charged particles deposit energy to the medium through direct Coulomb interactions with orbital electrons of the atoms in the medium. This section discusses how charged particles and photon(γ rays) interact with matter.

1.1 Interaction of Charged Particles with Matter

Charged particles are classified in to two groups heavy charged and light charged particles based on the mass of the particles.

1.1.1 Interaction of heavy charged particles

Heavy charged particles are particles with greater mass as compared with the Light charged particles such as α particles. We will examine how these particles interact in matter and compare their behavior to that of Light charged particles(electrons and beta particles) in terms of energy loss mechanisms, track, range. We will see the difference in mass between the heavy and light charged particles has important consequences for interactions.

Energy loss mechanism

A heavy charged particle traversing matter loses energy primarily through the ionization and excitation of atoms. The moving charged particle exerts electromagnetic forces on atomic electrons and imparts energy to them. The energy transferred may be sufficient to knock an electron out of the atom and thus ionize it, or it may leave the atom in an excited or non ionized state. A heavy charged particle can transfer only a small fraction of its energy in a single electronic collision. Its deflection in the collision is negligible. Thus, a heavy charged particle travels an almost straight path through matter, losing energy almost continuously in small amounts through collisions with atomic electrons, leaving ionized and excited atoms in its wake (A.K.Chaubey, 2010).

In this section we calculate the maximum energy that a charged particle can lose in colliding with an atomic electron. We assume that the particle moves rapidly compared with the electron and that the energy transferred is large compared with the binding energy of the electron in the atom. Under these conditions the electron can be considered to be initially free and at rest, and the collision is elastic. We assume a charged particle of mass (mass M and velocity V) approaching an electron (mass m at rest). After the collision, this for maximum energy transfer is head-on, the particles move with speeds V_1 and v_1 along the initial line of travel of the incident particle. Since the total kinetic energy and momentum are conserved in the collision, we have the two relationships.

$$\frac{1}{2}MV^2 = \frac{1}{2}MV_1^2 + \frac{1}{2}mv_1^2 \tag{1.1}$$

And

$$MV = MV_1 + mv_1 \tag{1.2}$$

or

$$V_1 = \frac{MV - mv_1}{M} \tag{1.3}$$

If we solve Eq. (2) for v and substitute the result into Eq. (1), we obtain

$$V_1 = \frac{(M-m)V}{(M+m)} \tag{1.4}$$

Using this expression for V1, we find for the maximum energy transfer

$$Q_{max} = \frac{1}{2}MV^2 - \frac{1}{2}MV_1^2 = \frac{4mMV}{(M+m)^2} \tag{1.5}$$

Where E = $\frac{1}{2}MV^2$ is the initial kinetic energy of the incident particle. All heavy charged particles travel essentially straight paths in matter. Except at extreme relativistic energies, the maximum fractional energy loss for a heavy charged particle is small. It is a good approximation to calculate Q as though the struck electron were not max bound, the collision then being elastic.

Stopping Power

The average linear rate of energy loss of a heavy charged particle in a medium (expressed, for example, in Mev cm^{-1}) is of fundamental importance in radiation physics and dosimetry. 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 mm^{-1} in water. Stopping power and LET are closely, associated with the dose and with the biological effectiveness of different kinds of radiation. The macroscopic cross section for a 1MeV proton in water is $410\mu m^{-1}$. Using relativistic quantum mechanics, Bethe derived the following expression for the stopping power of a uniform medium for a heavy charged particle:

$$\frac{-dE}{dX} = \frac{4\Pi k_o z^2 e^4 n}{mc^2\beta^2}[\ln\frac{2mc^2\beta^2}{I(1-\beta^2)} - \beta^2] \tag{1.6}$$

Where

- $k_o = 8.99x10^9 Nm^2C^{-2}$
- z = atomic number of the heavy particle
- e = magnitude of the electron charge
- n = number of electrons per unit volume in the medium
- m = electron rest mass
- c = speed of light in vacuum
- β = V/c = speed of the particle relative to c,
- I = mean excitation energy of the medium.

Only the charge z_e and velocity V of the heavy charged particle enter the expression for stopping power. This fact is consistent with the universality of charged-particle energy loss spectra in sudden collisions. For the medium, only the electron density n is important.

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/dx, are MeV cm^2g^{-1}. The mass stopping power is a useful quantity because it expresses the rate of energy loss of the charged particle per density gcm^{-2} of the medium traversed.

Range

The range of a charged particle is the distance it travels before coming to rest. The reciprocal of the stopping power gives the distance traveled per unit energy loss. Therefore, the range R(t) of a particle of kinetic energy T is the integral of this quantity down to zero energy (A.K.Chaubey, 2010):

$$\int (-dE/dX)^{-1} dE \tag{1.7}$$

The latter is expressed in gcm^{-2}; that is,the range in cm multiplied by the density of water ($\rho = 1gcm^{-3}$). Like mass stopping power, the range in $gcm{-}^2$ applies to all materials of similar atomic composition.

1.1.2 Interaction of light charged particles

Light charged particles are positrons and electrons (or beta particles). We will examine how these particles interact in material and compare their behavior to that of heavy charged particles(alpha particles) in terms of energy loss mechanisms of energy loss, track, range, etc. Well see that the very great difference in mass between the heavy and light charged particles has important consequences for interactions.

Energy Loss Mechanism

Collision loss

Like heavy charged particles, an electron also losses energy by interaction with electrons in the medium. This leads to excitation or ionization of the atom. Energy loss by these mechanisms is called collision loss. When we examined the behavior of heavy charged particles We derived that the maximum energy transfers between two particles of masses m and M was:

$$Q_{max} = \frac{4mME}{(M+m)^2} \tag{1.8}$$

Where E is the kinetic energy of the incident particle.But m = M and so Q_{max} =E. Thus, the maximum energy transferred in a single collision is all of it. Clearly this aspect of electron behavior is significantly different from the behavior of heavy particles.

Radiative Loss

A charged particle undergoing a change in acceleration always emits electromagnetic radiation. This radiation is called bremsstrahlung radiation. The larger the change in acceleration, the more energetic the photon. A heavy charged particle, while passing by a charged nucleus, experiences little change in its path. However,light charged particle having such little mass, can be deflected strongly. We thus see significant bremsstrahlung with electrons interacting in material, and negligible bremsstrahlung with heavy particles. If the electron passes close to the nucleus, the deflection is very large and the emitted photon is very energetic. However, if the electron passes far from the nucleus such that the net positive charge is reduced due to screening by orbital electrons between the incoming particle and the nucleus the emitted photon will be less energetic. Thus the bremsstrahlung photons have a continuous energy distribution that ranges downward from a maximum equal to the kinetic energy of the incoming electron.

$$(-\frac{dE}{dX})^{\pm}_{tot} = (-\frac{dE}{dX})^{\pm}_{coll} + (-\frac{dE}{dX})^{\pm}_{rad} \tag{1.9}$$

Unlike the situation with collision energy loss, there is no simple analytic expression for calculating energy loss by bremsstrahlung (radiative energy loss). It is, on the other hand, much easier to measure. Energy loss by radiation behaves quite differently from that by ionization and excitation. The efficiency of bremsstrahlung in elements of different atomic number Z varies nearly as Z^2.

Stopping Power

We can look at the stopping power of an electron or positron beam, that is, the linear rate Of energy loss due to excitations and ionizations (collision energy loss). The stopping power for light charged particles can be written as

$$(-\frac{dE}{dX})^{\pm}_{col} = \frac{4\Pi k_o z^2 e^4 n}{mc^2\beta^2}[\ln\frac{mc^2\tau\sqrt{\tau+2}}{2I}] \tag{1.10}$$

Range

A discussion of light charged particle range is complicated by two factors. First if Y is high, then the range of the energy associated with the initial incident particles is large indeed due to the very large mean free path of the particle. Second, since particles do not have a straight path, we will have to distinguish between distances traveled and penetration distance. To determine distance traveled, we can invert the stopping power equation and integrate from the incident energy down to zero energy. As with heavy charged particles, electron ranges expressed in gcm^{-2} approximately the same in different materials of similar atomic composition. The following empirical equations for electrons in low-Z materials relate the range, R, in gcm^{-2} to the kinetic energy, T, in MeV: For $0.01 \leq \mathrm{T} \leq 2.5\mathrm{MeV}$

$$lnT = 6.63 - 3.24(3.29 - lnR)^{1/2} \tag{1.11}$$

For $\mathrm{T} > 2.5\mathrm{MeV}$

$$T = 1.98R + 0.2 \tag{1.12}$$

1.2 Interaction of Gamma Ray with matter

This section describes the major gamma-ray interactions from microscopic perspectives. Then it will discusses macroscopic observations on gamma attenuation by a material media of different nature (i.e composition)

1.2.1 Interaction Mechanisms

The gamma rays or photons interact with matter by three major processes that are photoelectric absorption, Compton scattering, and pair production. In the photoelectric absorption process, the gamma ray loses all of its energy in one interaction. The probability for this process depends very strongly on gamma-ray energy E_γ and atomic number Z. In Compton scattering, the gamma ray loses only part of its energy in one interaction. The probability for this process is weakly dependent on E and Z. The gamma ray can lose all of its energy in one pair-production interaction.

Photoelectric Absorption

In the photoelectric absorption process, a photon undergoes an interaction with an absorber atom in which the photon completely disappears(Figure 1.2). In its place, an energetic photoelectron is ejected from one of the bound shells of the atom. [The interaction is with the atom as a whole and cannot take place with free electrons since conservation laws would be violated.] For gamma rays of sufficient energy, the most probable origin of the photoelectron is the most tightly bound or K shell of the atom. The photoelectron appears with an energy given by (Knoll, 2000).

$$E_e = E_\gamma - E_b \tag{1.13}$$

The energy of the photoelectron E_e. released by the interaction is the difference between the gamma ray energy Eγ and the electron binding energy E_b (Lilley, 2001):
The interaction leaves an ionized absorber atom with a vacancy in one of its bound shells. This vacancy is quickly filled through the capture of a free electron from the medium and/or rearrangement of electrons from other shells of the atom. Therefore, one or more characteristic X-ray photons may also be generated.
The photoelectric process is the predominant mode of interaction for gamma rays of

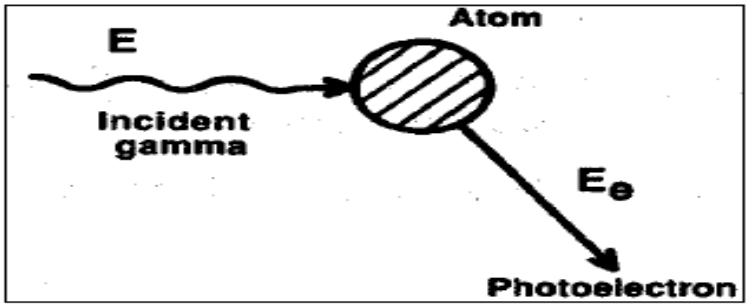

Figure 1.2: schematic representation of photoelectric absorption

relatively low energy. The process is also enhanced for absorber materials of high atomic number Z. No single analytic expression is valid for the probability of photoelectric absorption (τ) per atom over all ranges of E_γ and Z, but a rough approximation can be used.

$$\tau \propto Z^n/E^3 \tag{1.14}$$

where the exponent n varies between 4 and 5 over the gamma ray energy region of interest. This severe dependence of the photoelectric absorption probability on the atomic number of the absorber is a primary reason for the preponderance of high Z materials (such as lead) in gamma ray shields.

The photoelectric interaction is most likely to occur if the energy of the incident photon is just greater than the binding energy of the electron with which it interacts. The photoelectron created in this process, which can sometimes be quite energetic, looses its kinetic energy in exactly the same way as any other light charged particle.

Compton Scattering

The interaction of Compton scattering takes place between the incident gamma ray photon and an electron in the absorbing material(Figure 1.3). In Compton scattering, the incoming gamma-ray photon is deflected through an angle θ with respect to its original direction. The photon transfers a portion of its energy to the electron (assumed to be initially at rest), which is then known as a recoil electron, or a Compton electron. Because all angles of scattering are possible, the energy transferred to the electron can vary from zero to a large fraction of the gamma ray energy.

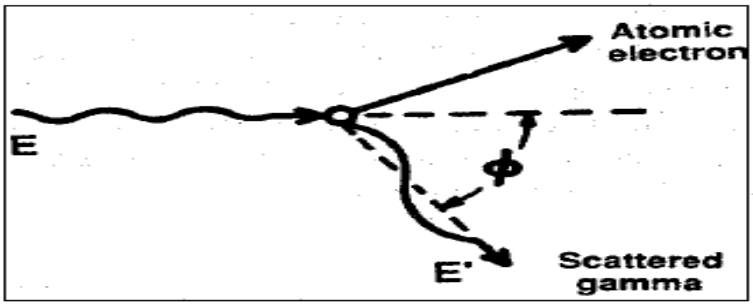

Figure 1.3: schematic representation of compton scattering process.

$$E_e = E_\gamma - E' \tag{1.15}$$

where

- E_e = energy of scattered electron
- E_γ = energy of incident gamma ray
- E = energy of scattered gamma ray.

The expressions that relate the energy transfer and the scattering angle for any given interaction can be derived by writing simultaneous equations for the conservation of energy and momentum (A.K.Chaubey, 2010).

$$E' = \frac{h\nu}{1 + \frac{h\nu}{m_o c^2}(1 - cos\theta)} \tag{1.16}$$

$$E_e = h\nu \frac{m_o c^2 (1 - cos\theta)}{1 + m_o c^2 (1 - cos\theta)} \tag{1.17}$$

`Limits of Energy Loss`:- If the photon interacts with the electron in such a fashion that the angle of recoil is forward at 0^o, then the scattered photon will be scattered straight back; that is, $\theta = 180^o$ and $\theta = 0^o$. This is the interaction that imparts maximum energy to the recoil electron and leaves the minimum energy with the scattered photon. With $\theta = 180^o$, $cos\theta$ = -1 and thus expressions (Equation 1.16) and (Equation 1.17) above simplify to:

For minimum energy transfer, $\theta = 0$, $cos\theta = 1$,Thus $E_e = 0$ and E'=hν.

Energy transfer is not large until the incident photon is in excess of 100 keV or so. The probability of Compton scattering (σ) per atom of the absorber depends on the number of electrons available as scattering targets and therefore increases linearly with Z.

Pair Production

If an energetic photon enters matter and if it has an energy in excess of 1.02 MeV, it may interact by a process called pair production. In this mechanism of energy transfer, the photon, passing near the nucleus of an atom, is subjected to strong field effects from the nucleus and may disappear as a photon and reappear as a positive and negative electron pair(Figure 1.4). The mechanism is one in which the nucleus plays a more or less passive role. Since energy and momentum are not conserved within the system of the disappearing photon and the two emerging electrons, the nucleus is necessary to carry away some energy and momentum. Thus, the state of the nucleus before and after the event is the same, except for a very small change in its kinetic energy and momentum. There is no other excitation of the nucleus.

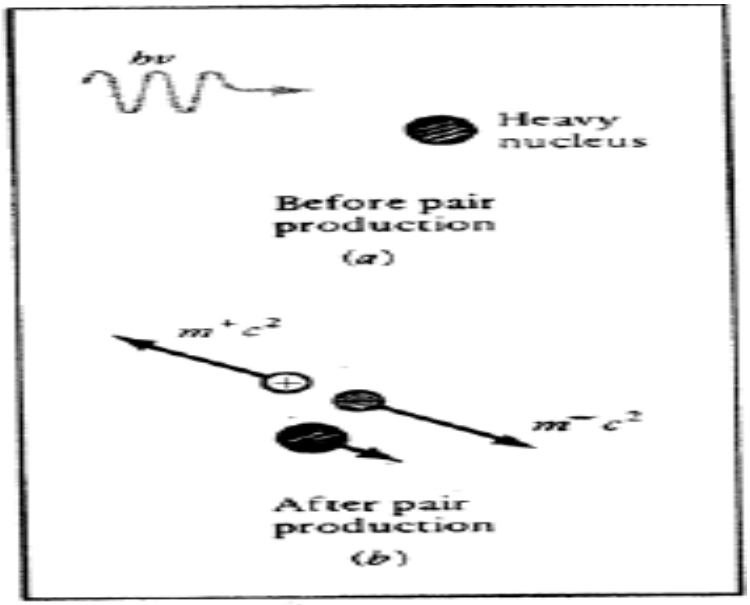

Figure 1.4: The process of positron annihilation.

The probability of interaction of Pair production increased with increasing photon energy and probability (κ) increases with atomic number approximately as Z^2.

Thus based on the relation of incident photon energy with Atomic number of absorbing material we can determine which type of interaction mechanism is dominant. Interaction at low incident photon energy photoelectric absorbtion is the dominant interaction process at the intermediate energy compton scattering is the main interaction process and at the high energy pair production is main interaction precoces. Generally (figure 1.6) simply

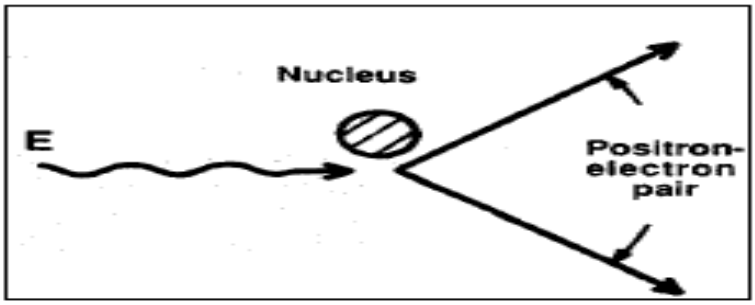

Figure 1.5: Schematic representation of pair production

expresses the idea.

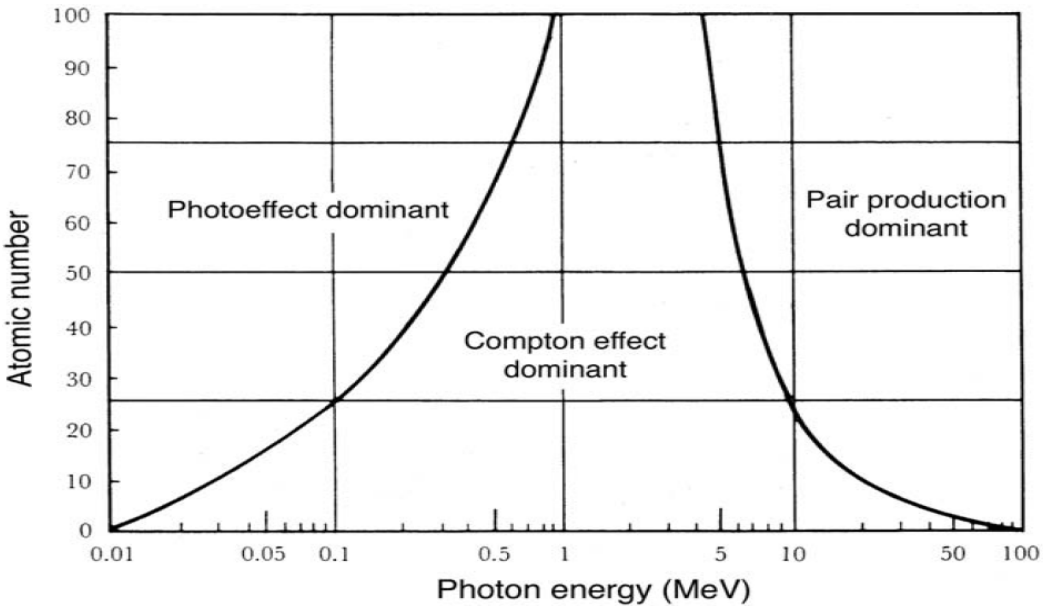

Figure 1.6: Regions of relative predominance of the three main forms of photon interaction with matter.

1.3 Attenuation of Gamma Rays

The intensity I of electromagnetic radiation is the energy hν of a single photon times the number of photons per unit time crossing a unit area perpendicular to the direction of the beam. Thus

$$I = (h\nu)N \tag{1.18}$$

When a photon beam traverses a material, the photon flux N is reduced, because photons

are removed or are deflected from the forward direction. The absorption of photons by a material is shown schematically in (Figure 1.7. Clearly, the probability that a photon will be removed from the beam increases with the number of atoms the beam encounters;

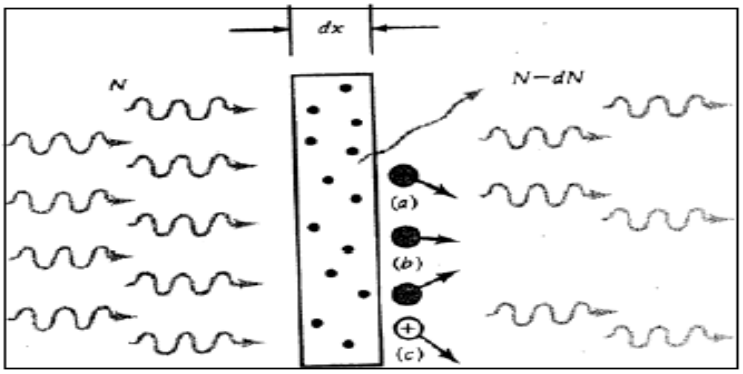

Figure 1.7: Schematic representation of the absorption of photons by material. (a) Compton effect; (b) photoelectric effect; (c) pair production.

therefore, the probability increases with the thickness of the absorber. In (figure 1.8), photons with a flux N are incident on a very thin absorber of thickness dx, and photons with a flux N-dN emerge from the absorber in the forward direction. The number of photons removed per unit time by a unit area of the absorber is then dN. The number of photons removed in encounters with atoms in the absorber dN is proportional to the photon flux N. Further, since the number of atoms the beam encounters is directly proportional to the thickness of the absorber, dN is proportional also to dx.

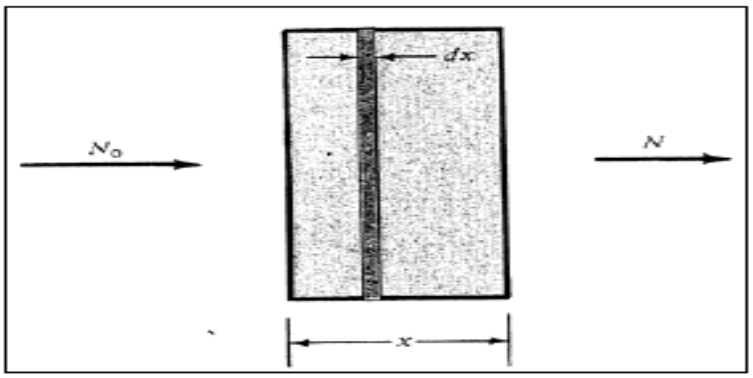

Figure 1.8: Change in photon flux through an absorber.

If we rearrange terms and integrate x over all thickness from 0 to a finite thickness, x(figure 1.8, then

$$\int_{N_o}^{N} \frac{dN}{N} = -\mu \int_{o}^{x} dx \tag{1.19}$$

or

$$N = N_o e^{-\mu x} = N_o e^{-\tau x} e^{-\sigma x} e^{-\kappa x} \tag{1.20}$$

Where (μ=$\tau + \sigma + \kappa$) are the probabilities of survival to pass through a distance x in the absorber with out any photoelectric absorbtion, compton scattering and pair production. Using (equation 1.18) we can write:

$$I = I_o e^{-\mu x} = N(h\nu) = N_o(h\nu)e^{-\mu x} \tag{1.21}$$

where I_o = N_o (hν)is the intensity incident on the absorber and I = (hν)N is the intensity at a distance x from the front surface. This equation shows that the intensity of monoenergetic electromagnetic radiation falls off exponentially through an absorber. The absorption increases with the thickness of the absorber or as the absorption coefficient μ increases.

For a particular photon energy and for a particular absorbing material, the absorption coefficient μ is a constant having the unit reciprocal length. Its value does, however, change from one material to another, and it also depends, for a given absorbing material, on the energy of the radiation.

Mean Free path

Mean free path is the average distance that photon travel in an attenuator without having any king of interaction. This is analogous to the 'mean life' in radioactive decay process. The mean free path or mean path length or relaxation length is the reciprocal of the total linear attenuation coefficient (μ^{-1}). The attenuator thickness may be expressed in units of mean free path. Hence a thickness x may be expressed as x/(μ^{-1})=(μ)x

Good Geometry Arrangement

In (Figure 1.9) below, the detector P is positioned to measure only photons that have not undergone an interaction. This arrangement of source and detector is known as a good geometry measure of attenuation since all interaction events will lead to photon removal or scattering such that the photon will not be detected at the detector location. The other requirement for good geometry is that the beam N in the(Figure 1.9) be physically small.

If a broad beam is used, photons can scatter in from other areas of the attenuator and be included in the definition of N. Thus, good geometry for attenuation measurements uses a small, highly collimated pencil beam of incident photons and a collimated detector system that detects only unscattered photons. This arrangement will lead to measurements reflecting attenuation as described by (Equation 1.20).

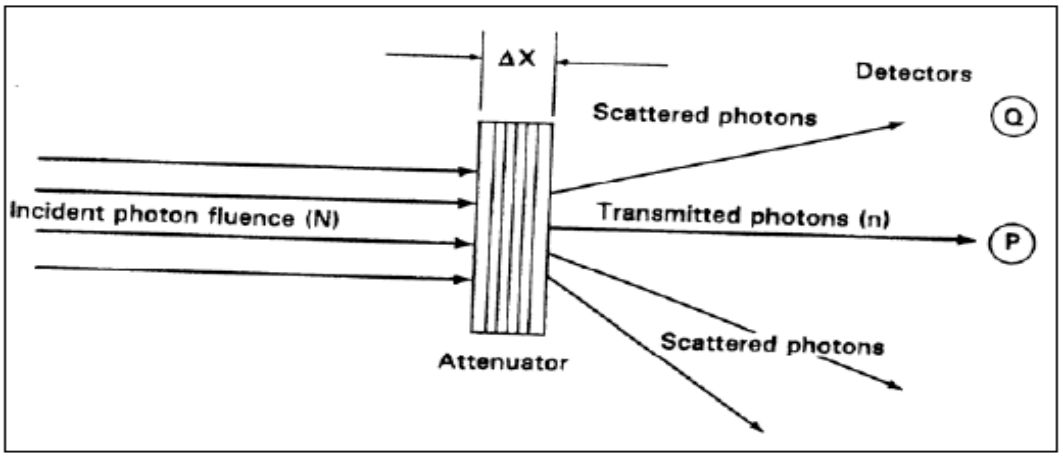

Figure 1.9: Transmission of photons through an absorber of thickness dx. A detector placed at P will measure the transmission under good geometry in which is twill see only photons that are transmitted without scatter. At position Q the detector will measure scattered photons that have interacted in the absorber. This is considered bad geometry or broad-beam attenuation for purposes of evaluating the attenuation coefficient.

Wide Beam Geometry Arrangement

Bad geometry or broad beam geometry describes a large beam and uncollimated detector system such that scattered photons are also detected. Thus many more photons than those predicted by equation (Equation 1.20) are detected. The additional photons resulting from scattering is sometimes referred to as buildup. There is no adequate analytical expression for measurement of attenuation in broad beam conditions. Instead, tables of buildup factors, B, are experimentally obtained as a function of photon energy, material type and material thickness. These factors are then incorporated into the pencil-beam exponential attenuation expression (Equation 1.20) as follows:

$$\frac{N}{N_o} = B(x)e^{-\mu x} \tag{1.22}$$

where B(x) is the buildup as a function of absorber thickness, x. (Equation 1.22) provides an empirical estimate of the photons expected after traversal through a thickness of x.

Table 1.1: Linear Attenuation Coefficients (in cm^{-1}) for a range of materials at gamma-ray energies of 100, 200 and 500 keV.

Absorber	100 keV	200 keV	500 keV
Air	0.000195	0.000159	0.000112
Water	0.167	0.136	0.097
Carbon	0.335	0.274	0.196
Aluminium	0.435	0.324	0.227
Iron	2.72	1.09	0.655
Copper	3.8	1.309	0.73
Lead	59.7	10.15	1.64

1.3.1 Factors Affecting Attenuation

Photon attenuation in matter is affected by different parameters such as atomic number of the material, density of the material,incident photon energy and thickness of the material and these are basic parameters in understanding how gamma ray attenuate in composite material. In this section discuss how this parameters affect photon attenuation.

Energy of the gamma ray

As we vary the energy of the gamma ray beam we would find that the greater the energy of gamma ray the less is the attenuation. As (Table 1.1) the Linear Attenuation Coefficient is characteristic of individual absorbing materials. Some like carbon have a small value and are easily penetrated by gamma-rays. Other materials such as lead have a relatively large Linear Attenuation Coefficient and are relatively good absorbers of radiation:

Atomic Number of the Absorber

Emitting of Intensity dI on two different absorbers of different atomic number Such as (carbon,Z=6 and lead,Z=82) the chances of striking the absorber with large atomic number is much greater than the chance of striking absorber with small atomic number. Therefore the attenuation of high atomic number absorber is greater than that of low atomic number that's why that high atomic number materials are used in radiation protection.

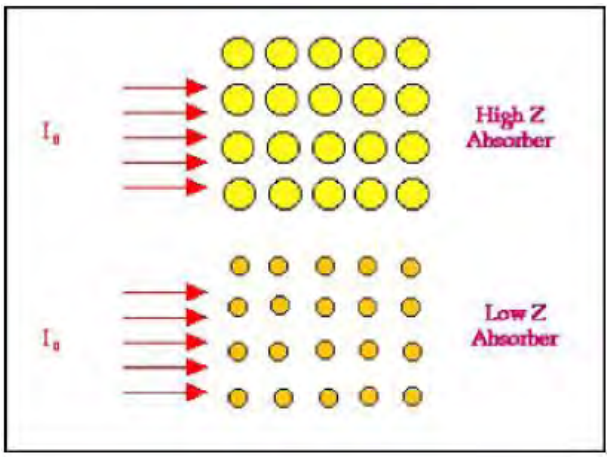

Figure 1.10: The figure illustrates a high atomic number absorber by the large circles which represent individual atoms and a low atomic number material by smaller circles.

Density of the absorber

Similarly as we do in atomic number if we put two absorbers with different density on with higher density the other with lower density on the same intensity dI the probability of interaction with the lower density absorber is less than probability of interacting with higher density, so the attenuation is more in higher density material.

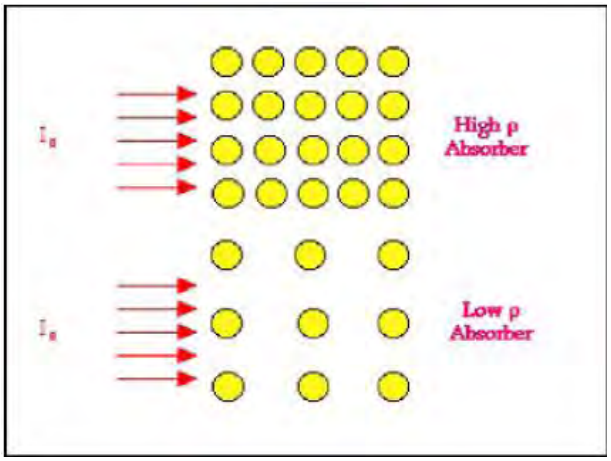

Figure 1.11: The figure illustrates a high density absorber by the large circles which represent individual atoms and a low density material by smaller circles.

Effect of thickness of the absorber

similar to that of density of the material attenuation is greater in thick absorber.

1.3.2 Basic Parameters In attenuation of γ ray in composite materials

Since composite materials are composed of more than one constituent material, interaction of γ ray with the material is not the same as the interaction of single element. The interaction process is with each of the constituent element. To understand this some basic parameters are used such as mass attenuation coefficient, effective atomic number, electronic density and so on.

mass attenuation coefficient

The mass attenuation coefficient (μ_m) is a measure of the number of photons interacting (scattered/absorbed) with the target material. It is the fundamental tool to derive many other parameters of dosimetric interest such as massenergy absorption coefficient, molecular, atomic and electronic cross sections, effective atomic number and electron density.

As the materials are composed of various elements, it is assumed that the contribution of each element of the compound to total photon interaction is additive, that represents the total mass attenuation coefficient $(\mu/\rho)_c$ of any compound as the sum of the appropriately weighted proportions of the individual atoms (Abdullah & Varier, 2008; Shivalinge Gowda & Ramadrishna, 2004). Thus

$$(\frac{\mu}{\rho})_c = \sum_{i=1}^{i=n} w_i (\frac{\mu}{\rho})_i \tag{1.23}$$

Where $(\frac{\mu}{\rho})_c$ is the photon mass attenuation coefficient for the compound, $(\frac{\mu}{\rho})_i$ is the photon mass attenuation coefficient for the individual elements in the compound, and W_i is the fractional weight of the elements in the compound.

Effective atomic number

For photon interactions, it is not possible to assign a single number to composite materials in a way that is similar to the atomic number of elements (Tejbir Singh & Singh, 2007; Shivalinge Gowda & Ramadrishna, 2004). For composite materials, the effective atomic number (Z_{eff}) is calculated from the atomic numbers of the constituent elements, weighted according to the different partial interaction process by which the photon interacts, and hence it is an energy-dependent parameter. It signifies that, at a given energy, a composite

material would interact with photons in the similar way as a single element of atomic number equivalent to that composite material.

Electronic density

The effective electron number or density, N_{el} (number of electrons per unit mass).

Chapter 2
Review of studies on Gamma Attenuation by Composite materials

2.1 Introduction

With the ever-increasing use of gamma rays in various fields such as industry, medicine and agriculture, the study of photon interaction with different composite materials has become a topic of prime importance for radiation physicists. Some parameters of dosimetric interest are the mass attenuation coefficient, effective atomic number and electron density; these help in the basic understanding of photon interactions with composite materials.

The mass attenuation coefficient (μ_m) is a measure of the number of photons interacting (scattered/absorbed) with the target material. It is the fundamental tool to derive many other parameters of dosimetric interest such as massenergy absorption coefficient, molecular, atomic and electronic cross sections, effective atomic number and electron density.

Berger and Hubbell have developed a computer program, XCOM, which calculates photon cross-sections and attenuation coefficients for pure elements and mixtures in the energy range of 1 keV to 100 GeV, whereas work is still in progress to find the mass attenuation coefficients of composite materials. Recently, mass attenuation coefficients have been measured for building materials and different marbles (Tejbir Singh & Singh, 2009).

For photon interactions, it is not possible to assign a single number to composite materials in a way that is similar to the atomic number of elements. For composite materials, the effective atomic number Z_{eff} is calculated from the atomic numbers of the constituent elements, weighted according to the different partial interaction process by which the photon interacts, and hence it is an energy-dependent parameter. It signifies that, at a given energy, a composite material would interact with photons in the similar way as a single element of atomic number equivalent to that composite material.

Many researchers have contributed to finding the effective atomic numbers of composite materials such as alloys, soils, biological materials, glasses, polymers and solutions (Tejbir Singh & Singh, 2007). Some workers have also found Z_{eff} values experimentally for a few composite materials at a few selected energies. A new approach for measuring Z_{eff} experimentally was presented for the first time by Icelli.

Attenuation (due to scattering or absorption) of photons in composite materials depend basically upon two factors, the effective atomic number and the electron density. The effective electron number or electron density N_e is the number of electrons per unit mass of the material. It has been available in the literature only for a few composite materials such as in solutions, thermoluminescent dosimetric compounds and some organic compounds (Shivalinge Gowda & Ramadrishna, 2004).

2.2 Current studies of γ ray attenuation in composite material

In this section we report some recent studies of γ ray attenuation in composite materials that are thermoluminescent compounds, building materials, commonly used solvents and determination of moisture gradient in wood.

2.2.1 A study of photon interaction parameters in some commonly used solvents

The computation of these parameters was carried out in three steps (Cai, 2008). The first step involved the computation of mass attenuation coefficients and atomic cross sections for some elements and selected solvents. The second step dealt with the computation of effective atomic number with the two different methods, and finally, in the third step, electron densities were computed. In this paper two new methods computation of effective atomic number and electronic density are computed using data of mass attenuation coefficient from winxcom package.

Effective atomic number

First method

$$\sigma_{solvent} = \frac{\mu_m}{N \sum_{i=1}^{n} (\frac{w_i}{A_i})} \tag{2.1}$$

Where $N = 6.023x10^{23}$ is Avogadros number in atoms g^{-1}, w_i is the weight fraction of the i^{th} element in a molecule of the compound and A_i the atomic weight of the i^{th} element

in a molecule of the material. w_i and A_i are both dimensionless quantities (Elias Saion & Wagiran, 1983; Tejbir Singh & Singh, 2007; Shivalinge Gowda & Ramadrishna, 2004).

$$Z_{eff} = \frac{Z_1(\log\sigma_2 - \log\sigma) + Z(\log\sigma - \log\sigma_1}{\log\sigma_2 - \log\sigma_1} \tag{2.2}$$

where σ_1 and σ_2 are the elemental cross section (inbarns/atom) in between which the atomic cross section σ of the compound lies and Z_1 and Z_1 are atomic numbers of the elements (dimensionless quantities) corresponding to the cross sections σ_1 and σ_2, respectively (Akkurta, 2005).

The mass attenuation coefficient (μ_m) values of the selected composite materials were obtained using WinXCom computer software; they were further used by our computer programs to compute molecular cross section (σ_m)), atomic cross section (σ_a)) and electronic cross section (σ_e), effective atomic number (Z_{eff}) and effective electron number or density (Ne) of the chosen compound using the following relations: For any compound, a quantity called the effective atomic cross section σ_a, is determined according to. Clearly, in calculating σ_a, averaging is carried out over atoms of all the elements in the compound (Tejbir Singh & Singh, 2007). Thus, we have,

Second method

$$\sigma_m = (\mu_m)_c \frac{\sum_i n_i A_i}{N} \tag{2.3}$$

$$\sigma_a = \frac{\sigma_m}{\sum_i n_i} \tag{2.4}$$

$$\sigma_e = \frac{1}{N}\sum_i \frac{f_i A_i}{Z_i}(\mu_m)_i \tag{2.5}$$

$$Z_{eff} = \frac{\sigma_a}{\sigma_{el}} \tag{2.6}$$

Electronic density

Using the above-obtained mass attenuation coefficient values and computed electronic cross sections for the the material, the electron density can be derived using the following relation (Sonia Reda & Amin, 2006):

$$N_{el} = \frac{(\mu/\rho)_c}{\sigma_{el}} \tag{2.7}$$

The first method has an advantage over the second, namely it is readily applicable for any composite material whose weight fraction is known, whereas to compute the effective atomic number with the second method, the molecular formula of the material is required, i.e. the second method is readily applicable only to compounds. However, the second method can be applied to mixtures by computing the number of atoms of the constituent elements from their fractional weights. Secondly, the first method computes the effective atomic number for partial as well as total photon interaction processes, whereas the second method computes the effective atomic number only for the total photon interaction process.

However, to compute the effective atomic number with the first method i.e. interpolation method, cross section values of a large number of elements are required, which makes it more complex than the second method, in which attenuation coefficient values of just the constituent elements are required. Some intermediate parameters such as electronic cross section, which were computed in the second method, were further utilized in computing some other parameters of dosimetric interest such as electron density.

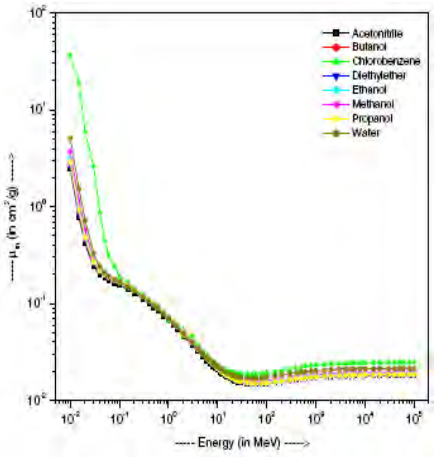

Figure 2.1: Plot of mass attenuation coefficient values versus incident photon energy for some commonly used solvents.

The variation of the mass attenuation coefficients (μ_m) with the incident photon energy of gamma rays is shown in figure 2.1), and it is observed that the μ_m values for all the selected solvents decrease very rapidly with increase in the incident photon energy up to 50 keV. With the further increase in the incident photon energy up to 12 MeV, the μ_m values decrease slowly and are almost the same for all the solvents within statistical errors.

Beyond 12 MeV, the μ_m values start increasing very slowly and become almost constant as the incident photon energy approaches 1 GeV. This may be due to the dominance of different partial interaction processes.

The rapid decrease in μ_m values below 50 keV can be explained on the basis of the dominance of the photoelectric effect, whose cross section depends on atomic number as Z^4 (for low incident photon energy) and E^5 (for high incident photon energy) and is inversely proportional to the incident photon energy as $E^{3.5}$. Beyond 50 keV, the Compton scattering process becomes dominant, whose cross section varies linearly with Z and is inversely proportional to the incident photon energy; thus the μ_m values for all the solvents become almost the same and decrease slowly up to 10MeV.With the further increase in incident photon energy, the pair production process starts dominating whose cross section depends on atomic number as Z^2 and is proportional to the incident photon energy as log E, and hence the μ_m values increase slowly and become almost constant.

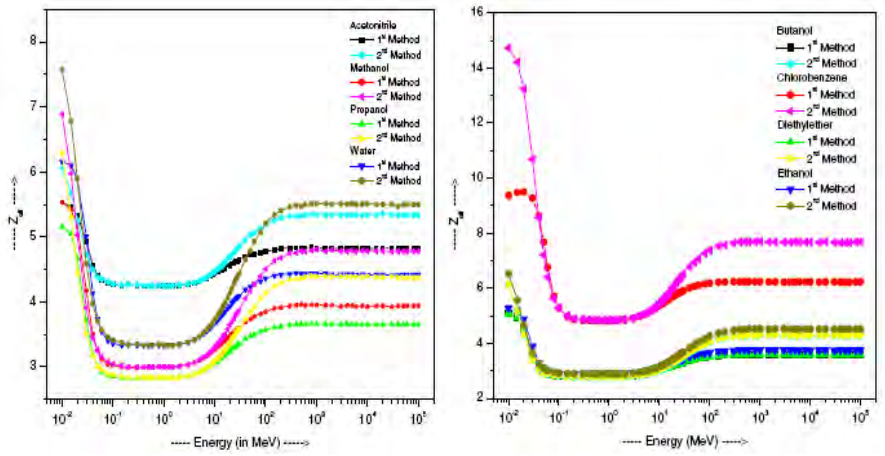

Figure 2.2: Plot of effective atomic number computed with the two different methods versus incident photon energy for some commonly used solvents.

For comparative studies, the variation of effective atomic number values computed with the two different methods with incident photon energy are shown graphically in (figure 2.2). From both figures, it is clear that the effective atomic number values computed with both methods are in good agreement in the energy region (50 keV to 10 MeV) where the Compton process dominates. The constancy of the effective atomic number values in this medium energy region of all the solvents is in good agreement with the findings of other studies, whereas in the lower-energy region (10 to 50 keV) as well as in the higher-energy

region (10 MeV to 100 GeV), a significant variation is observed in the effective atomic number values for different solvents computed with the two different methods. However, a similar trend is observed for the effective atomic number of all the selected solvents with the incident photon energy, which may be due to the dominance of different partial interaction processes as explained above.

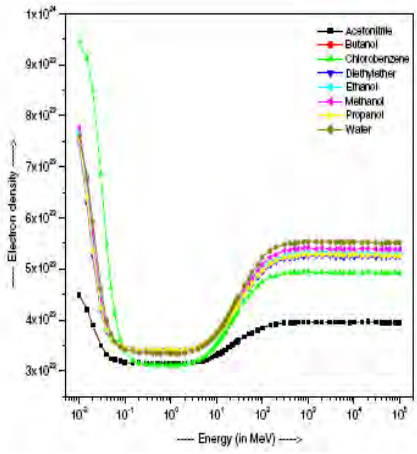

Figure 2.3: Plot of electron density versus incident photon energy for some commonly used solvents.

Finally, the variation of electron densities with incident photon energy is shown graphically in (figure 2.3). The trends observed are almost similar to the trends observed in (figure 2.2) for effective atomic numbers; hence the variation can be explained on the similar basis of dominance of different partial interaction processes.

2.2.2 A study of photon interaction parameters in thermoluminescent compounds

This paper discuses photon interaction of thermoluminescent compounds using well collimated narrow beam geometry setup of energy of range from 279.2 keV to 1332.5. The attenuation data were then used to compute the effective atomic number and electronic density of thermoluminescent compounds and then total attenuation cross-sections of photons of energy E in elements of atomic number Z was performed using the logarithmic regression analysis of the data measured by the authors and reported earlier.

From the measured values of unattenuated photon intensity I0 (with empty plastic container) and attenuated photon intensity I (with sample), the mass attenuation coefficients $(\mu/\rho)_c$ of all TLD compounds were calculated by using the relation

$$(\mu/\rho) = (\frac{\ln \frac{I_o}{I}}{\rho t}) \tag{2.8}$$

where ρt = mass per unit area in g/cm^2. The values of the mass attenuation coefficients so obtained for all compounds are listed in table 1 along with the XCOM values obtained at all photon energies.

The effective atomic number for each sample was determined by using the effective atomic cross-section σ_a. In this method, the effective atomic number of the sample was simply taken to be the value of the atomic number of an element whose σ_a matched with that of the sample in a given energy range.

$$\sigma = A(Z)E^{B(Z)} \tag{2.9}$$

$$\ln \sigma = \ln A(Z) + B(Z) \ln E \tag{2.10}$$

and it represents a straight line with slope B(Z) and intercept $\ln A(Z)$.

For presentation of results, the photon energy region of interest was divided into three. (a) 279.2 to 320.07 keV, (b) 514.0 to 661.6 keV and (c) 1115.5 to 1332.5 keV. Within each of these regions, the values of ln were found to vary linearly with $\ln E$. So, a logarithmic regression analysis was performed between $\ln \sigma$ and $\ln E$ in all th three energy regions and the best fit values of the slope B(Z) and the intercept $\ln A(E)$ were determined. Further, we assume that the values of $\ln A(E)$ and B(Z) are simple functions of atomic number and are given by the relations

$$\ln A(Z) = \ln A_1 + B_1 \ln Z \tag{2.11}$$

and

$$B(Z) = \ln A_2 + B_2 \ln Z \tag{2.12}$$

This ensures the linearity in the selected region so that the best-fit values of $\ln A_1$;B_1; $\ln A_2$ and B_2 could be obtained for the E and Z region of interest. These values are shown in (table 2.1). Using these best-fit values further, we obtained the formula for Z_{eff} of the form

$$Z_{eff} = [\frac{\sigma_a}{A_1} E^{\ln A_2}]^{1/d} \tag{2.13}$$

Table 2.1: Best-fit coefficient values of $\ln A_1$; $\ln A_2$;B_1 and B_2.

Photon energy range (keV)	Range of atomic number (Z)	Intercept $\ln A_1$	Slope B_1	Intercept $\ln A_2$	Slope B_2
279.2–320.07	3–8	2.23659	0.28653	−0.57359	0.12472
	8–13	−2.64248	2.72379	0.26684	−0.29537
	13–28	−2.79248	2.60672	0.23994	−0.25253
514.0–661.6	3–8	5.95289	−1.40309	−1.1367	0.37561
	8–13	1.83758	0.73173	−0.54863	0.06533
	13–28	−2.44084	2.19505	−0.00367	−0.12231
1115.5–1332.5	3–13	2.00451	0.98356	−0.51726	0.00362
	13–28	1.90538	1.05616	−0.51735	−0.00146

Table 2.2: Effective atomic number, measured for some TLD compounds.

	Photon energy (keV)						
Compound	279.2	320.07	514.0	661.6	1115.5	1173.2	1332.5
LiF	5.979 ± 0.178	5.931 ± 0.176	5.987 ± 0.180	5.988 ± 0.178	5.973 ± 0.177	5.924 ± 0.178	5.966 ± 0.177
$CaSO_4{\cdot}2H_2O$	7.427 ± 0.221	7.377 ± 0.220	7.371 ± 0.220	7.361 ± 0.215 7.320 ± 0.146*	7.358 ± 0.216	7.374 ± 0.216	7.320 ± 0.215
$CaCO_3$	10.062 ± 0.301	10.015 ± 0.300	10.111 ± 0.302	10.052 ± 0.302	10.010 ± 0.300	10.025 ± 0.301	10.042 ± 0.300
$C_4H_6BaO_4$	12.511 ± 0.373	11.450 ± 0.342	9.382 ± 0.280	8.928 ± 0.261 8.908 ± 0.178*	8.173 ± 0.243	8.266 ± 0.247	8.163 ± 0.244
$3CdSO_4{\cdot}8H_2O$	11.360 ± 0.340	10.780 ± 0.322	9.654 ± 0.290	9.383 ± 0.275 8.824 ± 0.176*	8.950 ± 0.267	9.033 ± 0.271	8.914 ± 0.266
$CaSO_4$	11.404 ± 0.341	11.374 ± 0.341	11.316 ± 0.338	11.275 ± 0.337	11.311 ± 0.339	11.344 ± 0.340	11.351 ± 0.340
$SrSO_4$	15.668 ± 0.470	15.309 ± 0.458	15.423 ± 0.462	14.971 ± 0.439 15.187 ± 0.303*	14.442 ± 0.432	14.509 ± 0.435	14.508 ± 0.434
$CdSO_4$	19.985 ± 0.600	19.027 ± 0.571	17.274 ± 0.516	16.683 ± 0.500	16.270 ± 0.487	16.441 ± 0.493	16.349 ± 0.490
$BaSO_4$	25.221 ± 0.756	23.493 ± 0.703	19.116 ± 0.571	18.371 ± 0.545 19.118 ± 0.382*	17.923 ± 0.535	18.026 ± 0.540	17.975 ± 0.538

Where $d = B_1 + B_2 \ln E$ and E is the photon energy expressed in keV.

In obtaining this formula, we have assumed the equivalence between Z_{eff} of the sample and the Z of the equivalent element as discussed earlier.

Using the so-calculated Z_{eff} the effective electron density was calculated using the relation

$$N_e = \frac{Z_{eff}}{M} N_A \sum_i n_i \tag{2.14}$$

In addition to this studies other recent studies of gamma ray attenuation in composite

Table 2.3: Effective electron density, measured for some TLD compounds

Compound	Photon energy (keV)						
	279.2	320.07	514.0	661.6	1115.5	1173.2	1332.5
LiF	2.778 ± 0.083	2.756 ± 0.082	2.780 ± 0.082	2.781 ± 0.083	2.774 ± 0.081	2.751 ± 0.082	2.771 ± 0.081
$CaSO_4{\cdot}2H_2O$	3.113 ± 0.093	3.091 ± 0.091	3.089 ± 0.093	3.085 ± 0.093	3.084 ± 0.090	3.091 ± 0.093	3.068 ± 0.092
$CaCO_3$	3.027 ± 0.091	3.013 ± 0.090	3.047 ± 0.090	3.024 ± 0.089	3.012 ± 0.090	3.016 ± 0.089	3.021 ± 0.088
$C_4H_6BaO_4$	4.425 ± 0.132	4.097 ± 0.121	3.318 ± 0.099	3.157 ± 0.093	2.906 ± 0.086	2.923 ± 0.088	2.887 ± 0.086
$3CdSO_4{\cdot}8H_2O$	3.734 ± 0.111	3.543 ± 0.105	3.173 ± 0.095	3.084 ± 0.092	2.942 ± 0.085	2.969 ± 0.088	2.930 ± 0.087
$CaSO_4$	3.027 ± 0.090	3.019 ± 0.091	3.004 ± 0.090	2.993 ± 0.089	3.008 ± 0.088	3.011 ± 0.089	3.013 ± 0.087
$SrSO_4$	3.084 ± 0.091	3.012 ± 0.089	3.034 ± 0.090	2.945 ± 0.087	2.841 ± 0.085	2.854 ± 0.084	2.854 ± 0.086
$CdSO_4$	3.464 ± 0.103	3.298 ± 0.099	2.994 ± 0.090	2.892 ± 0.085	2.820 ± 0.085	2.849 ± 0.083	2.833 ± 0.084
$BaSO_4$	3.905 ± 0.115	3.637 ± 0.109	2.960 ± 0.087	2.845 ± 0.085	2.775 ± 0.082	2.791 ± 0.084	2.783 ± 0.083

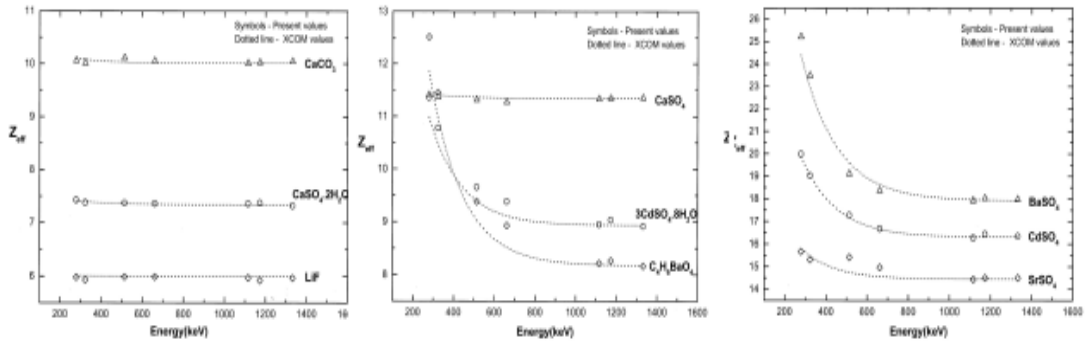

Figure 2.4: Variation of effective atomic number with energy for TLC

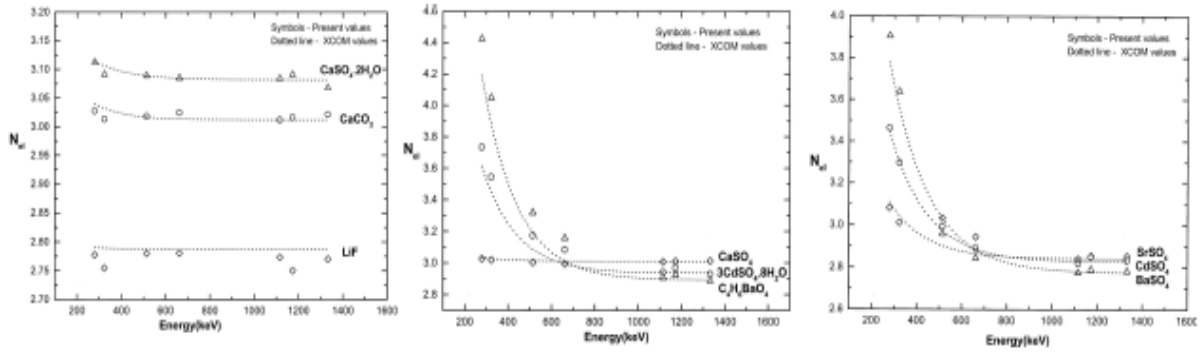

Figure 2.5: Variation of effective electron number with energy for TLC

materials works are include in the next chapter.

Chapter 3
Gamma Interaction of Selected Human Body Parts and Shielding Materials

3.1 Gamma interaction of selected human body parts

With the ever increasing use of gamma rays, particularly in medical fields, the interaction of gamma ray photons with different type of biological materials (body organs and tissues) is of utmost importance. Radiation therapy is a modern treatment technique where the results are faster. In radiation therapy treatment, penetrating gamma ray photons are allowed to incident on the affected region of human body to destroy harmful cells.

Human body is one type of composite material it composed of different kind of cells with variable chemical composition. To understand interaction gamma ray with human body let us discuss interaction of gamma ray with some selected human body parts bone, cholesterol, flesh, glucose, haemoglobin, muscle, uric acid) based on variation of incident photon energy with some basic dosimetric parameters such as mass attenuation coefficient μ_m, effective or equivalent atomic number Z_{eq} and energy absorption buildup factor B_{abs}.The information about various parameters has been discussed in chapter one. The mass attenuation coefficient (μ_m) values for the selected biological samples have been generated using XCom database of Berger and Hubbell.

3.1.1 Variation of Photon energy with Mass attenuation coefficient

The variation for μ_m with incident photon energy is shown in (Figure 3.1). The probability of photon interaction is more for lower gamma ray photon energy due to higher values of Z_{eq}. With the increase in incident photon energy, μ_m values decreases, which may be due to the reason that in the selected energy range, there are two main photon interaction processes, photoelectric absorption and Compton scattering and as we discussed in chapter one dominance of both processes decreases with the increase in energy. Among the selected biological samples, bone has maximum Z_{eq} due to significant contribution of

^{20}Ca (14.7 percent), whereas minimum Z_{eq} has been observed for cholesterol due to major contribution of ^{6}C (75.0 percent). At lower photon energy (59.54 keV) in case of bone, due to its higher Z_{eq}, it has got maximum value for μ_m 0.207cm2/g. Because at low photon energy, photoelectric absorption which varies with atomic number as $Z^{4.5}$ is the dominant photon interaction process hence results in major contribution to total μ_m (Paramjeet Kaur & Singh, 2009).

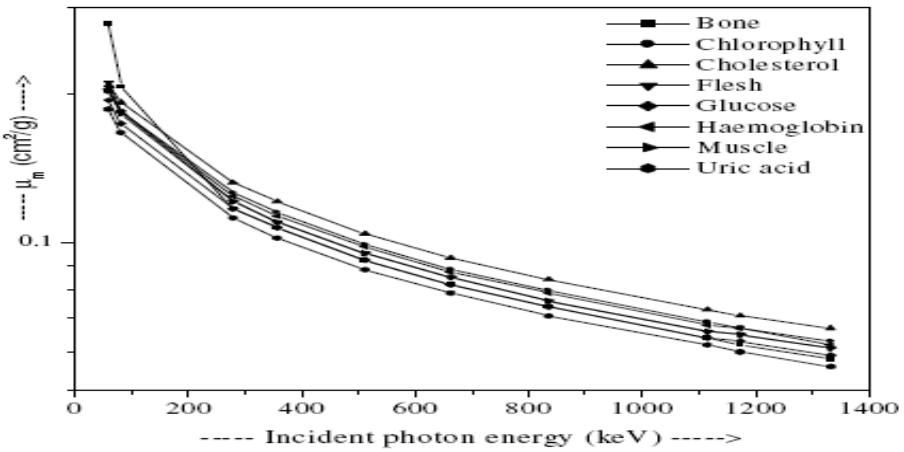

Figure 3.1: Variation of μ_m with incident photon energy for some biological samples

3.1.2 Variation of Photon Energy with Energy Build Up factor

B_{abs} has been investigated as a function of photon energy for fixed penetration depth of biological samples for 5mfp as shown in (Figure 3.1). It has been observed that among the selected biological samples, B_{abs} has its maxima at about 81 keV (except for cholesterol and bone) and it decreases with increase in incident photon energy. As photon energy approaches 1 MeV, for all selected samples becomes almost same (i.e. becomes independent of biological samples). Higher value of B_{abs} means that gamma photon will suffer more Compton scattering and will remain in the interacting material for longer span of time for further degradation of energy. So when the human body is exposed to the lower energy radiations, the photons will buildup in the sample i.e. exist in sample for longer time. Similar trend has been observed at other penetration depths of biological samples.

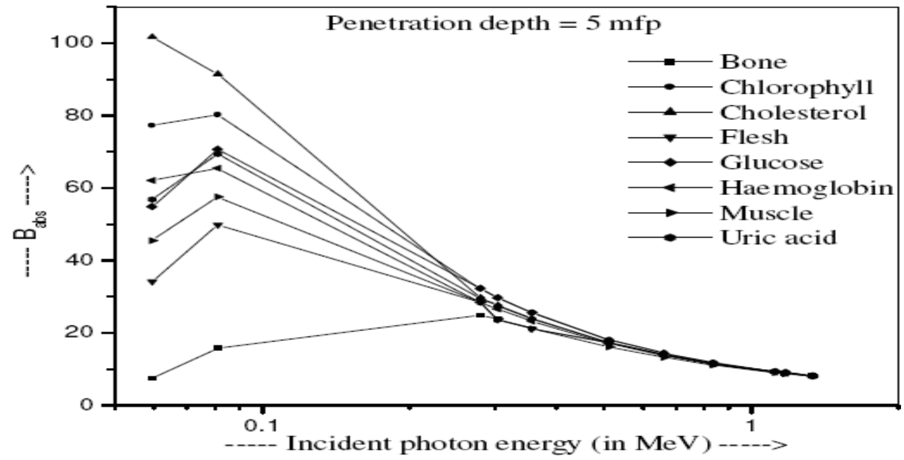

Figure 3.2: Variation of B_{abs} with incident photon energy for some biological samples

3.1.3 Variation of Energy Build Up factor with penetration depths of the biological samples

(Figure 3.3) shows the variation of B_{abs} with penetration depth of the biological samples. For all biological samples, B_{abs} increases with increase in penetration depth of the sample. It is due to the reason that increase in penetration depth of sample provides more possibilities of multiple interactions. Thus photons will buildup more in case of large dimensional biological sample as compared to smaller dimensional sample (Paramjeet Kaur & Singh, 2009).

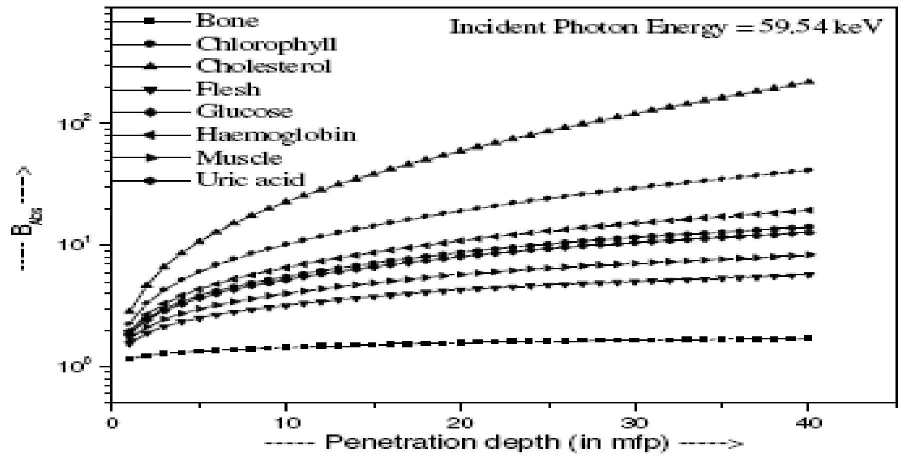

Figure 3.3: Variation of B_{abs} with incident penetrating depth for some biological samples

3.2 Shielding Materials

The use of gamma rays in different fields such as in medicine, agriculture, industry and research is increasing abruptly, however its exposure for longer duration can be very harmful for living objects. The attenuation of radiation can be achieved by either placing the source of radioactivity at a distance from the personnel and objects surrounding it or by constructing a shield effective enough to absorb most of the radiation before it penetrates the matter. Mostly high atomic number and high density materials such Various materials which are used for shielding include lead, copper, bismuth, steel, concretes and organic compounds such as oils, paraffins, plastics and rubber. The shields could take different forms like blocks, plates, rods, pellets etc, which can act as fillers for ducts, trenches and penetrations. Shielding pellets are useful in areas that are irregular in (Rizwan Hussain & Mohammed, 1997).

3.2.1 Shielding types

As we discussed in chapter one, gamma radiation is attenuated exponentially when it passes through a shielding material. Therefore, theoretically, gamma rays are never completely absorbed no matter how thick the shield. Nevertheless, we can choose a shield thickness which reduces the dose rate to an acceptable level.

Thin shield

The dose rate due to gamma radiation emerging from a shield can be written as:

$$D_t = D_o e^{-\mu t} \tag{3.1}$$

where D_o is the dose rate without shielding, D_t is the dose rate after passing through a shield of thickness t, and μ is the linear absorption coefficient of the shielding material. The linear absorption coefficient μ is a function of the type of material used for the shield and the energy of the gamma radiation. It has dimensions of $(\text{length})^{-1}$.

Thick shield

(Equation 3.1) is useful for calculating the dose rate for a narrow beam source geometry. However, this equation underestimates the required shield thickness for broad beam source geometry or for thick shields because it assumes that every gamma ray that interacts with the shield is removed from the beam, and thus does not contribute to the dose rate.

$$D_t = D_u + D_s \tag{3.2}$$

where D_u is the dose rate from the unscattered gamma rays and D_s is the dose rate from the scattered gamma rays and generated gamma rays. Instead of calculating D_s we usually introduce a term to (Equation 3.1) called the dose buildup factor B, such that:

$$D_t = B(\mu t, E) D u e^{-\mu t} \tag{3.3}$$

where D_u is the dose rate without shielding, D_t is the dose rate after passing through a shield of thickness t, μ is the linear absorption coefficient of the shielding material, and B is the dose buildup factor.

The value of B is a function of the energy of the incident gamma rays, shield material, source geometry, and shield thickness. Values for B are usually looked up in tables and not calculated. For example, the Radiological Health Handbook provides a table of dose buildup factors for various gamma ray energies and materials.

3.2.2 Buildup factor of composite shielding

The effect of the scattered is allowed for by means of what is referred to as the "buildup factor," which is a function of the shield material and thickness and the energy of the radiation, and also of the particular quantity being observed.

for a given shield and radiation the value of the build up factor would be different for the

- The number of flux
- The energy flux
- The dose rate

In calculations involving gamma rays attenuation, it is useful to express the buildup factor in analytical form:

$$B(\mu t, E) = 1 + b(\mu t) \tag{3.4}$$

Where b is obtained from (Table 3.1). For instance when (μx) is 10, and the gamma ray energy is 4 MeV, the buildup factor coefficient b for water is 6.94,so that B is 7.94 (M.Ragheb., 2007).

Table 3.1: Linear equation coefficients b, for dose buildup factors for gamma ray isotropic point source.

	(μx)	Gamma ray energy [MeV]						
		1	2	3	4	6	8	10
H_2O	1	2.13	1.83	1.69	1.58	1.46	1.38	1.33
	2	3.17	2.77	2.42	2.17	1.91	1.74	1.63
	4	7.68	4.88	3.91	3.34	2.76	2.40	2.19
	7	16.2	8.46	6.23	5.13	3.99	3.34	2.97
	10	27.1	12.4	8.63	6.94	5.18	4.25	3.72
	15	50.4	19.5	12.8	9.97	7.09	5.66	4.90
	20	82.2	27.7	17.0	12.9	8.85	6.95	5.98
Concrete 2.35 [gm/cm^3]	1	2.2	1.7	1.65	1.6	1.55	1.4	1.35
	2	3.6	2.8	2.4	2.25	1.95	1.75	1.65
	4	7.8	4.9	3.8	3.3	2.75	2.4	2.2
	7	15.0	8.4	6.2	5.0	4.0	3.3	3.0
	10	24	12.3	8.6	6.8	5.2	4.3	3.8
	15	43	19	12.6	9.9	7.1	5.7	5.1
	20	70	27	17	13	9.1	7.3	6.3
Fe	1	1.87	1.76	1.55	1.45	1.34	1.27	1.20
	2	2.89	2.43	2.15	1.94	1.72	1.56	1.42
	4	5.39	4.13	3.51	3.03	2.58	2.23	1.95
	7	10.2	7.25	5.85	4.91	4.14	3.49	2.99
	10	16.2	10.9	8.51	7.11	6.02	5.07	4.35
	15	28.3	17.6	13.5	11.2	9.89	8.5	7.54
	20	42.7	25.1	19.1	16.0	14.7	13.0	12.4

Buildup factor for homogeneous shield mixtures

Homogeneous shield mixtures of elements of various atomic masses such as concrete are encountered in shield calculations. This would also apply to layered shields if the thicknesses of the layers do not exceed the mean free path of the considered rays at the energy of interest. In this case, the effective values of the attenuation coefficients can be determined from (M.Ragheb., 2007):

$$\mu_{eff} = \sum_{i=1}^{n} \mu_i(E) \frac{N_i}{N_{io}} \tag{3.5}$$

Or

$$\mu_{m,eff} = \sum_{i=1}^{n} \mu_{io}(E) \sigma_i \tag{3.6}$$

Where:N_i is the nuclide density of the i^{th} element, N_o is the nuclide density of the pure element a_i is the fraction of the mixture by weight made up by the i^{th} element.

Buildup factor for heterogeneous shield mixtures

Most shields contain mixtures of different elements such as lead and water or iron and water. We consider a two layer heterogeneous shield and the case of a point source. The dose build up factor in this case depends on the order of the layers (M.Ragheb., 2007). If the layer closer to the source consists of a low (L) atomic number Z, the buildup factor can be represented as that of a slab of the high Z component(H) with a thickness equal to that of the composite shield:

$$B_{H+L} = B_H(\mu_L X_L + \mu_H X_H) \tag{3.7}$$

If the layer of high Z substance is closer to the source, the build up factor for the composite shield should be taken as the product of the buildup factors of the two components:

$$B_{H+L} = B_H(\mu_H X_H) B_L(\mu_L X_L) \tag{3.8}$$

The argument for these choices is based on the observation that the buildup factor for the low Z components such as water, id very large as a consequence of the small probability of absorption of the gamma photons that have been slightly degraded in energy by Compton scattering. This results from the cross sections for the photoelectric absorption of a low Z element being small. If the high Z element is outside the low Z component the gamma rays lose energy by scattering in the low Z component, and are effectively absorbed in the high Z component. The effective build up factor of such a combination is less than of the High Z component, hence Equation 3.2.2 can be used. If the high Z element is closer to the source, gamma rays scattered in the high Z component are slightly degraded in energy and are weakly absorbed in the low Z component. The effective build up factor of the combination is consequently close to the product of the build up factors of the layers, and Equation 3.2.2 can be used. If the shield contains large number of layers, the effective build up factor can be taken as the product of the build up factor for the high Z layers and the sum of the build up factors for the low Z components.

$$B_{composite} = B_H(\mu_H X_H) B_{L,i}(\mu_{Li} X_{Li}) \tag{3.9}$$

Investigations of Building Materials as Gamma Ray Shielding Materials

The use of gamma rays in different fields such as in medicine, agriculture, industry and research is increasing abruptly, however its exposure for longer duration can be very harmful for living objects. For the safer use of these highly penetrating gamma ray photons, proper shielding materials play very important role. Mostly high atomic number and high density materials such as lead (Z = 82) and mercury (Z = 80) are used for such purposes. However, the cost of these materials often put a constraint on using these at large dimensions.

So, an attempt has been made to check the feasibility of the use of some building materials with lower equivalent atomic number materials $Z_{eq} < 20$ such as cement, lime, plaster of paris and sand as gamma ray shielding materials. Since, these materials are available in abundance and can be easily designed as required. Moreover, in case of nuclear accidents, such data is very important as it tells about how safe we are in buildings made up of such materials. For the present investigations, some parameters of dosimetric interest mass attenuation coefficient and exposure buildup factor have been computed for the selected building materials (Tejbir Singh & Singh, 2009).

The variation of mass attenuation coefficient with photon energy

Figure 3.4 shows the variation of mass attenuation coefficient with photon energy for all the selected materials. The mass attenuation coefficient values for all the selected materials show maximum value initially at the lower photon energy of 59.54 keV and decreases with the increase in incident photon energy up to 1332 keV. This decreasing trend of mass attenuation coefficient with incident photon energy can be explained on the basis of dominance of different partial photon interaction processes.

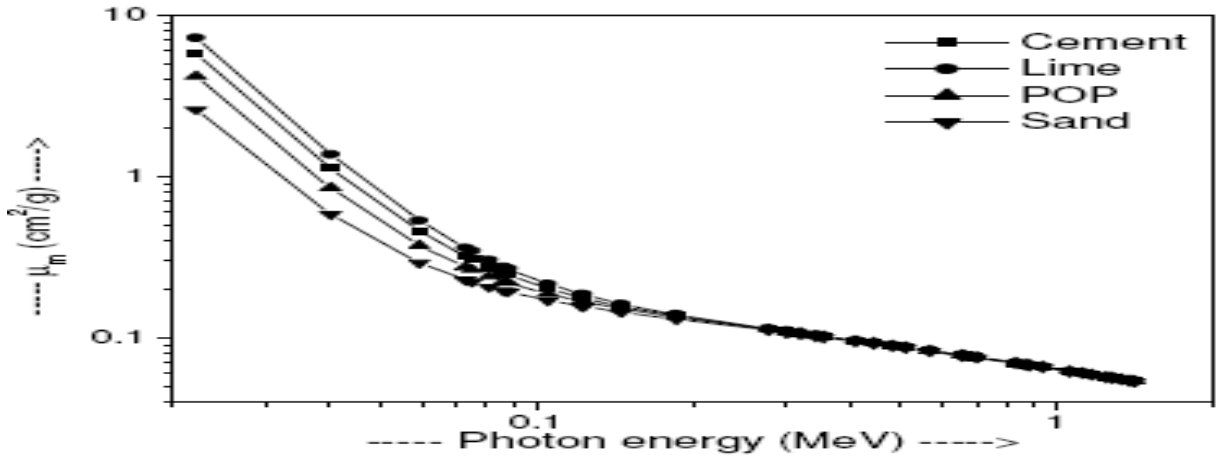

Figure 3.4: Variation of μ_m with photon energy for building materials

Among the selected building materials, lime has maximum mass attenuation coefficient values due to major contribution of ^{20}Ca (71.47 percent, hence higher equivalent atomic number), whereas sand has minimum mass attenuation coefficient due to major contribution of 8O (51.28 percent, hence lower Equivalent atomic number).Comparing the mass attenuation coefficient values for photoelectric absorption and Compton scattering, it has been observed that at a particular photon energy (50-80 keV) for the selected materials, there is almost

equal probability for a photon to interact via photoelectric and Compton effect. Above this energy region, photon has more probability for interaction via Compton scattering, which results in energy degradation only (not completely absorbed). So, photon will undergo multiple scatterings and remain in medium for longer time.

The variation of Exposure buildup factor with photon energy

Exposure buildup factor determines the extent of such multiple scattered photons, which had crossed the thick layer of interacting medium and hence is a very important parameter while designing gamma ray shielding. In Figure 3.6, Exposure buildup factor values are observed to be minimum initially, increases with the increase in incident photon energy up to 300 keV. Above 300 keV, it decreases with the further increase in incident photon energy up to 1332 keV. It may be due to scattering process and in the lower as well as higher energy regions, absorption process is dominant (photoelectric absorption in lower energy region and pair production in higher energy region). Further, sand (lower Equivalent atomic number) has maximum value for Exposure buildup factor at all chosen photon energies, whereas minimum value for Exposure buildup factor has been observed for lime (higher Equivalent atomic number).

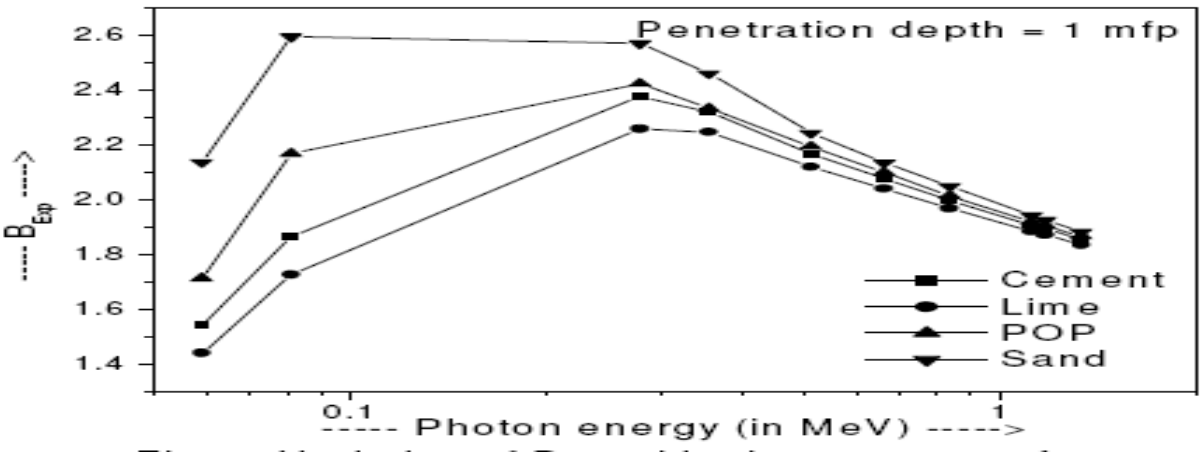

Figure 3.5: Variation of B_{Exp} with photon energy for some building materials (1 mfp).

Comparison of (Figure 3.5) and (Figure 3.6), shows that with increasing the penetration depth of the material, Exposure buildup factor values increases significantly. For 1 mfp of selected building materials, Exposure buildup factor lies in between 1.4-2.6. Whereas for 10 mfp, Exposure buildup factor lies in between 10-50. This shows that thickness of interacting material contribute significantly in multiple scattering of photons.

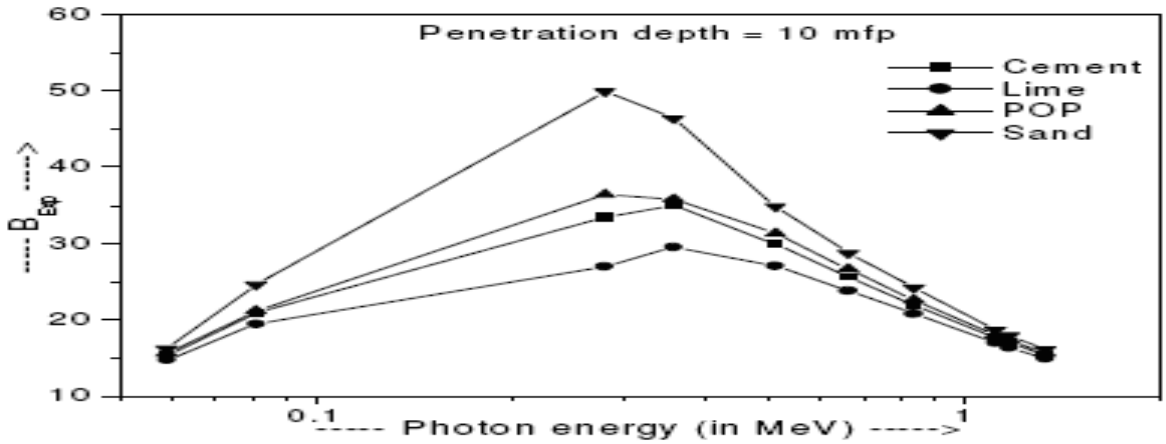

Figure 3.6: Variation of B_{Exp} with penetrating depth for some building materials (10 mfp).

Chapter 4
Summary and Concluding Remarks

Radiation is classified in to ionizing radiation and non ionizing. Gamma ray is one the ionizing radiation when interact with matter it can ionize by transferring part or all of the energy to electron which the matter composed. Attenuation of gamma ray in matter is the absorbtion of the energy by the matter or scattering of from the matter.

The predominant mode of interaction depends on the energy of the incident photons and the atomic number of the material with which they are interacting. At low energies, in high atomic number materials, the photoelectric effect is the main interaction of photons with the material. At intermediate energies in low atomic number materials the dominant interaction is Compton scattering. At very high energies, the main mechanism by which photons are detected is pair production.

Investigation of interaction of gamma ray in different composite materials must be determined on the basic parameters especially mass attenuation coefficient, effective atomic number and electron density. From the present observations, it can be concluded that the mixture rule is applicable only in the intermediate-energy region, where only Compton scattering is the dominant photon interaction process, and hence the results for effective atomic numbers for different materials have been found to be in good agreement in this energy region.

With ever increasing use of gamma rays particularly in medical fields the interaction of gamma ray photons with different type of biological samples is of utmost importance. In radiation therapy treatment penetrating gamma ray photons are allowed to incident on the affected region body to destroy harmful cells,therefor care must be taken while exposing large dimensional biological samples to lower energy incident photons due to large buildup factors.Therefor, such risks should be considered during treatment precaution by careful computation of gamma ray photon interaction parameters and shielding should be done to reduce the treatment-related complications.

The effect of the scattered radiation is allowed for by means of what is referred to as the buildup factor,which is a function of the shield material and thickness and the energy of the radiation, and also of the particular quantity being observed. for a given shield and radiation of the buildup factor would be different for the number flux. Shielding should be of high density and high atomic number so that they have high total linear attenuation coefficient and high photon electric absorption probability. Radiation shielding effects for them have been investigated by means of gamma ray transmission method and buildup factor.

The photoelectric and compton scattering cross sections increase with energy, whereas the pair production cross section increases with energy, a minimum in the total attenuation cross section may occur. This minimum provides and energy window at which radiation can leak from a given field. The use of a mixture of materials becomes necessary in shielding applications to close such energy windows.

Bibliography

Abdullah, Ramachandran, A. J. & Varier (2008). Attenuation studies near k-absorption edges using compton scattered ^{241}am gamma rays. *Pramana journal of physics*, *70*, 633–641.

A.K.Chaubey, P. (2010). Notes on Radiation detection and measurements. Lecture Notes, Addis Ababa University, Department of Physics.

Akkurta, Mavia, A. B.-K. Y. (2005). Study on z dependence of partial and total mass attenuation coefficients. *Asian Journal of Chemistry*, *94*, 379–385.

Cai, Z. (2008). A new method of determining moisture gradient in wood. *Forest products journal*, *58*, 41–45.

Elias Saion, Zainal Abidin Sulainman, A. A. & Wagiran, H. (1983). Determination of effective atomic number of rubber,. *Journal of Health Physics*, *6*(3), 95–98.

Knoll, G. F. (2000). *Radiation Detection and Measurment* (Third edition ed.). University of Michigan: John Wiley and Sons,Ltd.

Lilley, J. (2001). *Nuclear physics priciples and applications* (Third edition ed.). The University of Manchester: John Wiley and Sons, Ltd.

M.Ragheb. (2007). *Radiation Physics* (Third edition ed.). University of Michigan: John Wiley and Sons,Ltd.

Paramjeet Kaur, T. S. & Singh, P. S. (2009). Interaction of gamma ray photons with some biological samples. *Asian Journal of Chemistry*, *21*, 229232.

Rizwan Hussain, Z.-u.-h. & Mohammed, D. (1997). A study of the shielding propertis of poly ethylene glycole lead oxyde composite. *Journal of Islamic Academy of Sciences*, *9*(3), 369–373.

Shivalinge Gowda, Krishnaveni, Y.-U. & Ramadrishna (2004). Photon mass attenuation coefficients, effective atomic numbers and electron densities of some thermoluminescent dosimetric compounds. *Pramana journal of physics*, *63*, 529–541.

S.Krane, K. (1988). *Introductory Nuclear Physict* (Second edition ed.). Oregon State University: Jhon Weily and Sons.

Sonia Reda, E. M. & Amin, E. (2006). Monte caro dose calculations for breast radiotherapy using ^{60}co gamma rays. *Journal of Nuclear and Radiation Physics*, *1*, 61–72.

Tejbir Singh, P. K. & Singh, P. S. (2007). A study of photon interaction parameters in some commonly used solvents. *Asian Journal of Chemistry*, *10*, 822–824.

Tejbir Singh, P. K. & Singh, P. S. (2009). Investigations of building materials as gamma ray shielding materials. *Asian Journal of Chemistry*, *21*, 225–228.

DECLARATION

I the under signed declare that the Project is my original work, has not been presented for a degree in any other university and that all sources of material used for the Project have been duly acknowledged.

Name: _____

Signature: _____

This Project has been submitted for examination with my approval as university advisor.

Name: _____

Signature: _____