Republic of Iraq
Ministry of Higher Education
& Scientific Research
Al- Nahrain University
College of Science
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A Study of Gamma Ray Dose Buildup Factors in Water and Graphite, in the Energy Range (4-10) MeV

A thesis
Submitted to the College of Science
University of Al-Nahrain
In partial Fulfillment of the Requirements for the
Degree of Master in Physics

By

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January, 2017 **Rabi`2, 1438**

بِسمِ اللهِ الرَّحمَٰنِ الرّحِيَمِ

﴿أَلَمْ نَشْرَحْ لَكَ صَدْرَكَ * وَوَضَعْنَا عنكَ وِزْرَكَ * الَّذِي أَنقَضَ ظَهْرَكَ * وَرَفَعْنَا لَكَ ذِكْرَكَ * فَإِنَّ مَعَ الْعُسْرِ يُسْرًا * إِنَّ مَعَ الْعُسْرِ يُسْرًا * فَإِذَا فَرَغْتَ فَانصَبْ * وَإِلَى رَبِّكَ فَارْغَبْ﴾.

صدقَ اللهُ العَظيم

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Acknowledgement

*I would like to express my sincere thanks and deep gratitude to my supervisor, **Prof. Dr. Laith A. Al-Ani**, for his supervision and constant support. As well as giving me freedom during the preparation of my thesis and the chance to work under his supervision. Also, I would like to express my appreciation to Head of Physics Department and the staffs for their kind attention.*

Sincere thanks to all my friends, for their kindness and moral support during my study. Thanks for the friendship and memories. Deep thanks to Mrs. Marwa M. for help me in this work. Last but not least, my deepest gratitude goes to my beloved mother; for her endless love, prayers and encouragement.. Also not forgetting my husband" Maher" for his love and care. To those who indirectly contributed in this research, your kindness means a lot to me. Thank you very much.

Hanan

Abstract

Several studies have been conducted to measure different type of gamma ray buildup factor for its importance in measuring the dose resulting from Electromagnetic rays use and its shielding

In this study gamma ray buildup factor for two shielding materials water (Z_{eff} =7.42) and graphite (Z=6) within the energy range 4-10 MeV and up to 5 thickness mean free path has been studied. To achieve this study a simulation computer program has been written (Visual Basic language version G) and applied depending on Monte Carlo simulation method.

The basic idea of the program includes real radiation behavior description and prediction of its random movement through the media. This method can be used to simulate a traditional problem (classic) resulting from the fall of the beam on the flat slide works as attenuator for gamma rays. The radioactive source geometry adopted in the study is mono energetic normal plane source

In this research the contribution of annihilation effect on the calculation of gamma ray dose buildup factor has been studied in the same energy and within the studied energy range. This study also examining a number of variables related to the program design called simulation variables like number of gamma scenarios, number of divisions for energy. This research is also including study the effect of energy for the incident photon, shield thickness, and atomic number for shielding material on the calculation of gamma ray buildup factor.

The results indicated that the gamma ray dose buildup factor is inversely proportional with energy increase. This behavior means that when the energy within the studied energy range is increased, the

probability of Compton effect decrease, since the Compton effect is inversely proportional with energy. Second, the penetrating ability for gamma radiation is also increase and this leads to an decrease in the probability of scattering with small angels and finally it is reflected on the calculation of dose buildup factor (the scattering with small angels plays a very important role in the calculation of buildup factor).

For both graphite and water, although the results indicated that the calculated values of dose buildup for plane source when the contribution of pair production is ignored, less in comparison when the contribution of pair production is taken in consideration but the contribution of Compton effect is still more predominant than the effect of annihilation within the range of energy (4-10) MeV.

The results obtained from the performed Monte Carlo simulation program in this study are very closer to the published experimental results (error = 10.4%) in comparison with Monte Carlo simulation results (error = 40.58%) obtained from some published researches. The comparison with experimental result is the best way to judge on the accuracy of the results obtains theoretically.

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Introduction and Literature Review

Chapter One

Introduction and Literature Review

1.1 Introduction

Becquerel and Villard in 1900 were first founded Gamma rays as a component of radiation from uranium and radium that had a considerable of higher permeability than alpha and beta particles**.** Gamma beams represent the highest energy on the electromagnetic spectrum rays and nearly penetrate everything. It is a type of high intensity ionizing radiation and has no electric charge. They cannot be influenced by electric and magnetic fields; therefore, they are similar character to light, but of a much higher energy, and may interact with the absorbent as a particle, however it'll be to boot acts as a wave. The Gamma rays are provided from the nuclei of excited atoms following radioactive Transitions [L'Ann 03].

The heavy elements with high atomic number are usually used to stop radiation. There are many heavy elements which can stop gamma radiation; however, lead is more commonly used. The Platinum can be used instead of lead, but it is more expensive thousands of times [knol 01].

In shielding calculations, the essential property of the attenuation of radiation is that the exponential decrease of its radiation intensity as a homogeneous beam of radiation passes through the block of the matter. This decrease is valid only when the beam of radiation is narrow. Therefore, the foremost wide used technique of determination of the general result on that radiation at the purpose of interest makes use of a parameter called "Buildup Factor (B)". In principle, the buildup factor conception is applicable to the gamma and neutron attenuation, but in observe it is found to be abundant less self-created once applied to the neutrons and consequently it's abundant decreased conception within the context of neutron shielding calculation within the field of radiation shielding, the buildup factor are often assumed to refer to gamma radiation [Knol 10].

1.2 Interaction of gamma rays with matter

Gamma beams interact with matter in several ways. There are three essential processes must be taken in our thought. These are the photoelectric effect and Compton scattering and pair production. These processes cause fractional or complete transfer of the gamma ray photon energy to electron energy. Every process of interaction dominates at certain energy. Photoelectric interactions are dominant at low energies and high atomic number materials. The cross sections for Compton scattering having the highest at mid-energy range and low-atomic number materials. At high photon energies the effects of pair production interaction become more effective than the other types of gamma interactions. These essential processes may be illustrated in (fig.1.1) [knol 10]

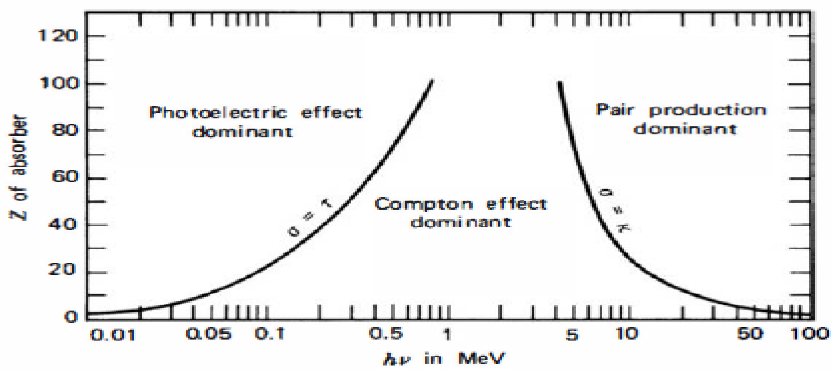

Fig (1.1) the relative importance of the three major types of gamma-ray interaction [knol 10]

1.2.1 Photoelectric Effect

The energy of a photon in this interaction is completely absorbed by an atom and transferred to the electron that is ejected from its shell and emerges from the atom as a photoelectron. The kinetic energy for photoelectrons can be expressed by the following relationship [Scha 73].

$$T = E_{\gamma} - E_b \tag{1.1}$$

Where T represent ejected electron energy, E_{γ} represent the incident photon energy and E_b represent the orbital electron binding energy or the energy required removing the electron from its orbit in the atom.

When an electron is ejected from an inner atomic K or L shell, electrons from their higher energy states of the outer shells falls and fill the ensuing gap. These transitions liberate electromagnetic rays with low energy [L'ann 03]. Figure (1.2) illustrates the process of photo electric effect.

The cross section (σ_E) for every atom within the photoelectric absorption within the K shells represents 80% of the total reaction with different shells. The photoelectric cross section depends on atomic number (Z) and incident gamma-ray energy, $h\nu$, it may be represented by the following relationship [Chil 84].

$$\sigma_E = \text{constant}\ \frac{Z^3}{(h\nu)^n} \tag{1.2}$$

Where:

$$n = \begin{cases} 3 \text{ for } h\nu < 0.5\ MeV \\ 1 \text{ for } h\nu \geq 0.5 \text{ MeV} \end{cases}$$

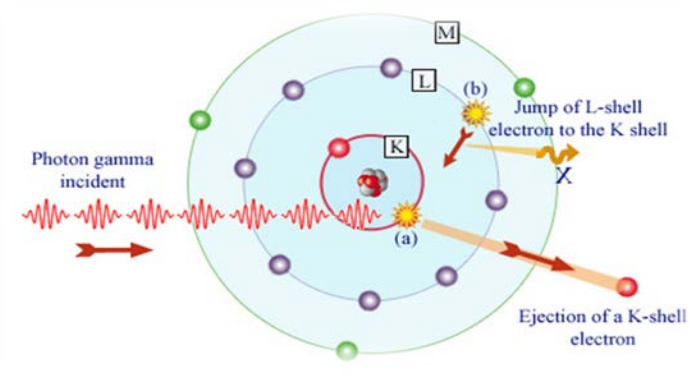

Fig (1.2) diagram illustrating the Photoelectric effect [khan 03]

1.2.2 Compton Scattering

In the Compton procedure, the photon interacts with an atomic electron like it was a "free electron. The term free here means that the binding energy of the electron is much a way. In this interaction, the electron getting some energy from the photon and is sent out at an angle φ (Fig. 1.3). The photon, with minimize energy, is scattered at an angle Ɵ [khan 03].

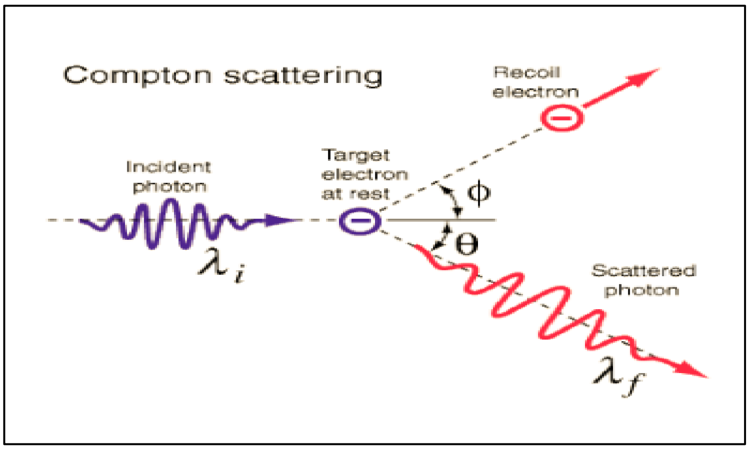

Fig (1.3) diagram illustrating the mechanism of Compton effect [khan 03]

The expression that relates the energy transfer and the scattering angle for any given interaction will simply be derived by writing simultaneous equations for the conservation of energy and momentum [Knol 10].

$$E_e = h\nu - h\nu^{`} \tag{1.3}$$

Where, E_e = energy of rejection electron, $h\nu$ = energy of incident photon and $h\nu^{`}$ = energy of scattered photon

The energy of scattered photon is given by

$$h\nu^{`} = \frac{h\nu}{1+[(1-\cos\theta)h\nu/m_{\circ}c^2]} \tag{1.4}$$

Where $m_{\circ}c^2$ electron rest mass energy

The probability that Compton scattering will happen is called the Compton coefficient or the Compton cross section. It is a complicated function of the photon energy, the probability of Compton scattering per atom of the absorbent material depends on the number of electrons accessible as scattering objectives and thus will increase linearly with Z. however it should be written in the form [Tsou 95].

$$\sigma\,(m^{-1}) = NZf(E_{\gamma}) \tag{1.6}$$

Where, σ = probability for Compton interaction to occur per unit distance, f (E_{γ}) is a complicated function of photon energy (E_{γ}) and atom density (N) [Tsou 95].

1.2.3 Pair Production

Pair production interaction occurs between a photon and the field of the nucleus. As a result of this interaction, the photon vanishes and a couple of electron-positron appears (Fig. 1.4) [Tsou 95].

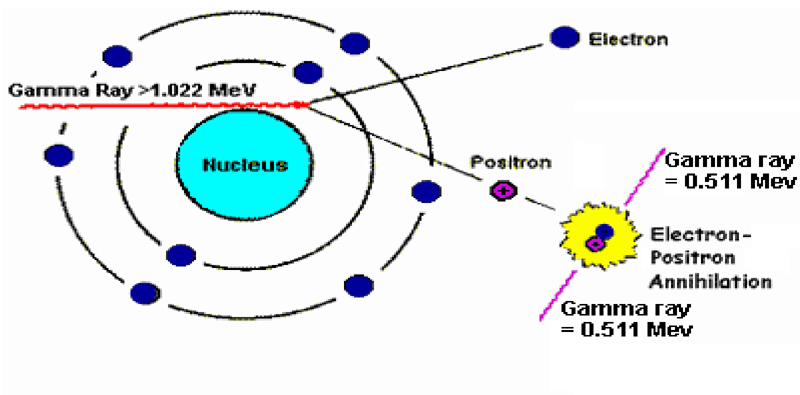

Fig (1.4) diagram illustrating the pair production process [khan 03].

The threshold energy for pair-production process is $2m_0c^2$, or 1.022 MeV. Any excess energy of the incident photon is given to the kinetic energies of the two charged particles created in the process and to the recoiling nucleus. The pair production procedure is an example of an event throughout that energy is converted into mass, obviously by Einstein's equation ($E = mc^2$). The reverse method (annihilation radiation) represents the conversion of mass into energy, when the positron combines with an electron to produce two photons [khan 03].

The pair production cross section is zero for photons energies less than 1.022 MeV. For larger energies, it will increase at first slowly, then more rapidly. This increase is proportional to Z^2 so that for a given photon energy, pair formation increase quite quickly with atomic number [Kabl 77].

$$\sigma_{pp} = \mathrm{N}\,\mathrm{Z}^2\,\mathrm{f}(\mathrm{E},\mathrm{Z}) \tag{1.7}$$

Where, $\mathrm{f}(\mathrm{E},\mathrm{Z})$is a function depends on E and Z.

1.3 Attenuation of Gamma Rays

When a photon penetrating the matter, it's going to interact through any of the three major ways that mentioned earlier. There are other interactions, but they are not mentioned here because they are not adopted in this research work.

The attenuation of a beam of gamma rays through an absorber is fundamentally different from that of a beam of heavy charged particles. If gamma rays pass through a matter, each gamma ray either does not interact at all, or it is removed completely from the beam by absorption or scattering which will cause an exponential decrease in gamma rays intensity as the absorber thickness is increased [Meye 67].

Consider, as a typical state of affairs, a block of fabric has a thickness x located between collimated mono-energetic gamma ray photons source and collimated detector, as appear in (Fig. 1.5).

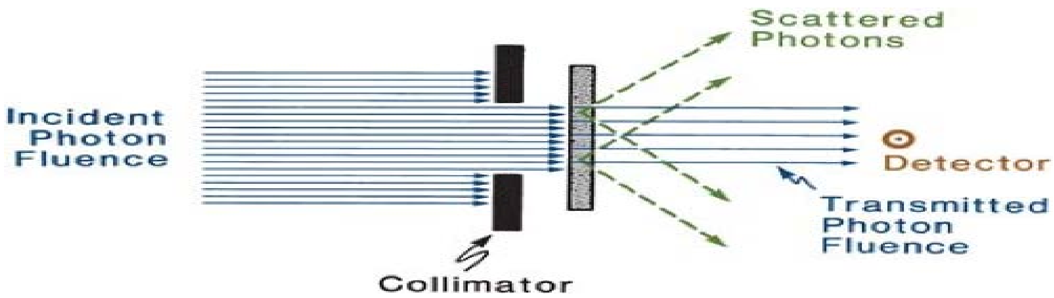

Fig (1.5) experimental arrangement for narrow beam geometry [Khan 84]

The resulting fractional reduction of the beam intensity, $-\frac{dI}{I}$, is proportional to the "narrow beam" attenuation coefficient μ, and to the layer thickness, *dx*, i.e. [Hubb 68].

$$\frac{dI}{I} = -\mu\, dx \tag{1.8}$$

Where, μ is the total attenuation coefficient. It is proportional to cross section σ ($\mu = N\sigma$), where, *N* is the number of atoms per unit volume. The minus sign indicates that the number of photons increases when the absorber thickness decreases. .

If thickness x is represented a length, then μ is termed the linear attenuation coefficient (m^{-1}). The linear attenuation coefficient μ depends on the energy of the photons and the nature of the material [khan 03].

When a photon is traversing a material in which the total linear attenuation coefficient is μ, then the distance 1/μ (m) is called the mean free path (mfp). The mean free path is used in calculation to avoid the effect of density for different material [Al-An 89].

By integrating equation (1.8), we obtain: [Khan 84]

$$I_{(x)} = I_o\, e^{-\mu x} \tag{1.9}$$

Where I(x) is the emerging intensity of gamma ray,

I_0 is the incident intensity of gamma ray, This relation is correct only for narrow beam geometry.

1.4 Good Geometry and Poor Geometry

The experiment of gamma attenuation, in which the gamma beam are collimated to a narrow beam before striking the absorbent material, is described as a "narrow beam" or "good geometry" measurement. The fundamental characteristic is that only gamma beams from the source arriving and counted by the detector will be primary gamma photon. Real measurements are usually administrated under different circumstances (as sketched in Fig 1.6) [Knol 10].

When a large part of scattered and subsidiary radiation is arrived to the detector, then the arrangement is called “broad beam” or “poor geometry” as shown in Fig. (1.7), so Eq. (1.10) will become

$$I / I_o = B\, e^{-\mu x} \qquad (1.10)$$

Where B, is defined as the buildup factor which is a dimensionless quantity.

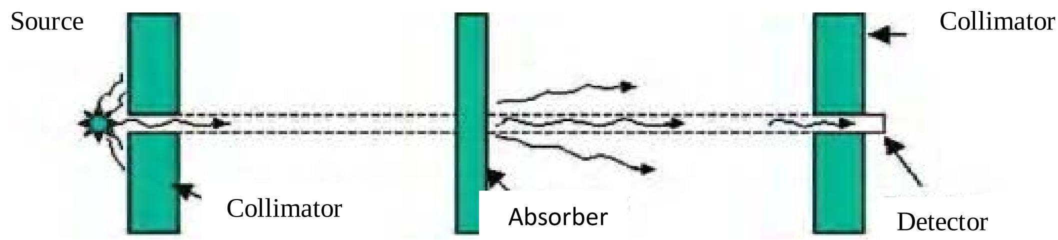

Fig (1.6) the good geometry arrangement

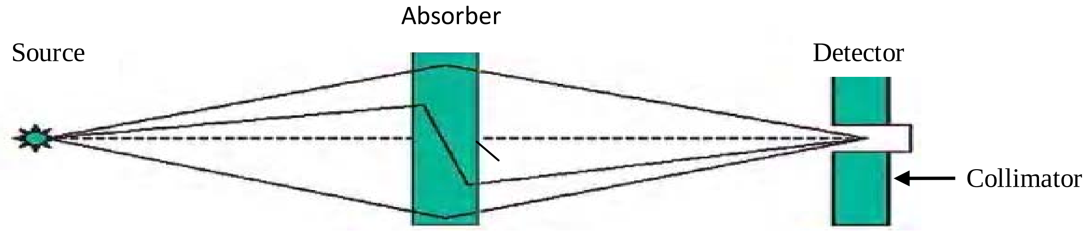

Fig (1.7) the poor geometry arrangement

1.5 The Basic Idea of the Buildup Factor

Experimental and theoretical results on the transmission of photon through thick absorbers are described conveniently in terms of the so called buildup factor universally denoted by the symbol B, which is defined as:

" The ratio of the detector response of the radiation at the point of interest to the detector response to the un-collided radiation at the same point", [Evan 55, Gold 54].

$$B = \frac{\text{detector response to the radiation at the point of interest}}{\text{detector response to the uncollided radiation at the same point}}$$

In practical gamma ray shielding calculations, the most extensively used method of determining the total effect of the radiation at the point of interest utilizes an accumulation a buildup factor B [Wood 81].

1.5.1 Types of Buildup Factor

The buildup factor may be expressed in terms of various quantities [Hatt 94].

1. The number buildup factor

$$B_n = 1 + \frac{\text{scattered photons}}{\text{unscattered photons}} \tag{1.11}$$

2. The energy buildup factor

$$B_e = 1 + \frac{\text{scattered energy flux recorded at the detector}}{\text{unscattered energy flux recorded at the detector}} \tag{1.12}$$

3. The dose buildup factor

$$B_d = 1 + \frac{\text{absorbed dose from scattered photons}}{\text{absorbed dose from unscattered photons}} \tag{1.13}$$

It is easy to conclude from equations (1.11), (1.12) and (1.13) that in the case where no scattering medium exists, there will not be scattering photons, and this made buildup factor approach unity.

1.5.2 The Dependence of Buildup Factor

Some theoretical investigations have shown that the value of buildup factor depends on the following conditions [Chil 84]

1. The thickness of shielding material in mfp
2. The energy and geometry of radioactive source
3. The type of shielding material expressed in terms of the atomic number Z.
4. The type of instrument response such as energy flounces, exposure, and absorbed dose.
5. The main incident angle on the shield
6. The geometric arrangement of shielding material, radioactive source, and detector position

1.6 Types of Gamma Shields

The gamma shields may be classified into two types:

1. Single layer shields:

a. Pure single shields: this type of shields composed of one pure element as (Aluminum, Iron and Lead).

b. Homogeneous mixture: This shields used as saving shields from gamma ray, it is consist of alloys homogeneous mixture.

2. Multi- layer shields:

The value of gamma rays buildup factor is different when the shield is multi layer from the single layer shields. Some of reactors shields consist of multi-layer shields of different materials and the buildup factor is taken varied values according to the layer that penetrated previously [Wood 81].

1.7 Method of Calculation of Gamma Ray Buildup Factor

The buildup factor is usually studied either by experimental measurements or by theoretical calculation based on the attenuation coefficient [Hubb 69].

The experimental studies are scarcer in the literature and this can be attributed to the difficulties of measuring procedure, highly active sources are needed, and the absorber thickness is limited to not more than a few mfp. Most of the experimental measurements are based on the measuring the absorption coefficients and deducing B from them. Due to these difficulties in the experimental measurement of gamma ray buildup factor, the attenuation was focused on the theoretical calculation [Al-An 01].

The theoretical approach was developed continuously in the literature, and become more advanced due to the use of highly efficient computers which increased the possibilities of handling large number of data [wood 81]. Many efforts within the calculation of gamma rays build up factor are carried out within the last decades. As a general classification, the calculation of gamma rays build up factor will be divided into three groups: [Chil 84].

1.7.1. Analytical method

The calculation of buildup factor analytically can be performed by solving Boltzmann transport equation.

1.7.2. Empirical Formula for B (μx)

In calculations involving the buildup factor (B), it is convenient to own a mathematical expression for B, and arrange of such formula have been proposed for a single layer shields [Wood 81].

a. Linear Formula

This is one of the simplest and least accurate approximations; it should not be used for thick shields. Its principal usefulness is didactic.

Probably the earliest used formula for a buildup factor was the linear form. That is, the buildup factor is given by

$$B(E,\mu x)=1+ K(E)\ \mu x \tag{1.14}$$

Where the constant k is calculated as follows:

$$k = B\ (1) - 1$$

k = Constant depends on source energy and atomic number of the shield, and μx = thickness of shielding materials in (mfp).

b. Berger's Formula[Chil 80]

For low Z media, the Berger formula provides a very good fit for high source photon energies (at ~ 1 MeV, and higher) and for low energies below ~ 0.06 MeV. The buildup factor according to this formula is given by [chil 84]:

$$B = 1 + a\ (\mu x)\ \exp\ [- b\ (\mu x)] \tag{1.15}$$

where, a, and b are the parameters, function of source photon energy and attenuating medium. This two parameter formula is only slightly more complicated than the linear form but provides better accuracy.

c. Capo's Formula

In this formula, the buildup factor is given by [Wood 81]:

$$B(E_O,\mu x) = \sum_{i=0}^{3} B_i (\mu x)^i \tag{1.16}$$

Where;

$$B_i = \sum_{j=0}^{4} C_{ij} (\frac{1}{E_O})^j$$

The coefficients values of Eq. (1.16) were published [Capo58] for many materials. The equation stated that B_i can be considered as a function for the primary photons energy E_0 and the rate of the atomic number of the medium C_{ij}.

d. Taylor s formula

$$B = A \exp(-\alpha_1 \mu x) + (1-A) \exp(-\alpha_2 \mu x) \qquad (1.17)$$

The advantage of this formula is that it fit, without difficulty, into any point kernel which already contains an exponential attenuation function.[Chil 84].

The coefficients values of A, $\alpha_1$and α_2 in Eq. (1.17) were published for many materials; the importance of this equation comes from its simplicity, therefore it is considered in a wide range of applications [Shur 79 and Wood 81].

In case of multi-layered shields the change in spectrum of energy and in angular distribution particularly near to the region boundaries happened to be taken under consideration. This implies that the buildup factor depends on previously penetrated layers in addition to the layer under consideration. There are many theories taken them under consideration because the transients near the region boundaries are not well defined, among them are, Blizzard Method, Goldstein method, Border Formula and Kalos Method [Rich 68]. These methods are summarized in [Makk 09].

1.7.3. Statistical Calculation (Monte Carlo Method)

The Monte Carlo technique is currently the foremost strong and ordinarily used technique for analyzing complicated issues [Rubi 81].

The Monte Carlo methods are typical products of the modern computer age. By means of high speed computers, individual particles of radiation, gammas or neutrons are allowed to travel through a medium by making several collisions with electrons or atoms in their paths of flight. In order to obtain a good statistical representation of the physical event, many particle histories are followed through the medium until the particle emerges, "dies" by absorption or by degeneration of its energy as in the case of gamma rays, or becomes thermalized as in the case of neutrons. Although the present state of development of high-speed digital computers allows many thousands or millions of calculations in a second, computer economy must be considered in setting up a new code. In order to achieve maximum computer economy many techniques are used. A simple approach is to terminate the life history of a particle as soon as possible and score some results from its history.

For instance, in the case of a gamma albedo calculation, the life history of a particle may be terminated and subsequently a new history started when:

- a particle emerges from the surface of incidence;
- the particle is transmitted through other boundaries of the system;
- the particle is absorbed in a collision;
- the energy of the particle after a collision is below a certain limit (cut-off energy), outside of the field of interest [Jaeg 68].

1.8 Literature Survey

The interest within the buildup factor started within the early of 1950, when the primary study as well as its measure had been revealed. In light of the depending of buildup factor on several factors, the nature of studies varied. Here we have a historical review on the most important performed studies.

I-Experimental method

In 1950 G.R. White started a first study for the buildup factor for water. She used the ^{60}Co source (average energy 1.25 MeV) with two types of detectors (Geiger Muller tube and ionization chamber). The results showed that the buildup factor increased exponentially with increasing the thicknesses of the water that were used in this study, she was found that the value of buildup factor for 46 cm thickness of water was 4.51 [Whit 50].

In the middle of 1960s, Furuta et. al obtained experimentally the dose buildup factors for plane parallel barriers composed of water, graphite, ordinary glass and concrete, heavy concrete, aluminum, , iron and lead. Monte-Carlo calculations were applied for water only. In addition to this calculation, a theoretical treatment was included in this study to get dose buildup factors for finite barriers to discover whether the experimental results believe with the theoretical calculation [Furu 66].

Burke and Beck in 1973 measured dose buildup factor for normally incident(0.662 MeV) gamma rays penetrating lead slab, they also calculated buildup factors from normally incident for the same gamma source penetrating multi-layer Aluminum-lead slabs for various combination using thermo luminescence dosimeters. Their results were compared with calculated values obtained from a gamma rays transport code and with values inferred from a Simi empirical formula using single layer slab buildup factor [Burk 73].

In 1989 Al-Ani was made an investigation of buildup factor calculation on (Fe, Cu, Al, and concrete) using two radioactive sources

(^{60}Co and ^{137}Cs). This study included the effect of geometrical factor (collimating angels, and the distance between source and detector) on the buildup factor in addition to the effect of detector type [Al-An 89].

Bakos in 1995 studied for the angular properties of the scattered photons for combined 1.43 and 2.75 MeV source photons penetrating single and double-layer shields. He determined experimentally angular flux spectra for these energies. From his work, he noticed that for any given polar angle, the scattered photon properties decrease exponentially with increasing shield thickness [Bako 95].

In 1994 in Baghdad University the buildup factor was measured for (Aluminum, iron, Copper, Brass, and lead) by using the ^{137}Cs and ^{60}Co energy sources with NaI (*Tl*) detector. A hierarchical method was introduced in this study to calculate gamma ray build up factor [Hatt 94].

In 2001 AlAni, the buildup factors for gamma rays in four shielding materials, aluminum, concrete, stainless steel and copper were measured using Geiger-Muller tube and Nal (*Tl*) scintillation detector (5.1*5.1) cm with two radioactive sources ^{137}Cs and ^{60}Co. An approximated method is suggested to facilitate the comparison between the theoretical and experimental results near 1MeV. Energy region and few mean free path thicknesses. Effects of some of the parameters measured in the work coincide with the theoretical predictions [Al-An 01].

In 2015 Mohammed et. al, have been used Geiger-Muller counter tube detector (Type ABG, hi-energy), with cobalt-60 radioactive gamma source to calculate buildup factor using lead and aluminum materials. Effect of material atomic number and thickness of the shield material on buildup factor value of gamma rays has been studied. Five types of shields were studied as follow: Two single-layer shields of both lead and aluminum, Two dual-layers shields composed of (Pb-Al) and (Al-Pb) and Multi-layers shield (Pb-Al) have been used which composed of successive layers of lead and aluminum, respectively, with thickness of (0.5cm) for each layer [Moha 15].

II- Theoretical Methods

In 1970, Monte Carlo and moment method, were adopted by Morris and Chilton to calculate the gamma ray buildup factor for the water using two point sources of energies 0.5 and 1 MeV. The discrepancy between the published experimental results and these methods was less than 5% [Morr 70].

Morris et.al, in 1975, adopted moment method to calculate exposure buildup factor in water and aluminum and concrete for mono-energetic, isotropic purpose gamma sources. The result was tabulated for energies from 0.03 to 10 MeV, and up to 50mfp from the supply. They were developed Berger's empirical formula used in calculation buildup. All fitting parameters were tabulated for every material as a function of energy [Morr 75].

Metghalchi, in 1978, had determined the coefficients of Berger's formula for gamma rays buildup factor in ordinary concrete, his work showed that the coefficients available for Taylor formula has improved considerably. He depended on the Chilton's conclusion which illustrate that "the accuracy that can be achieved using fitted values of two parameters is better in general than previously suggested formulas of three parameters or less" [Metg 78].

In 1980, Chilton et.al calculated the buildup factor for photons of point isotropic source in infinite homogenized samples of air, water and iron by moment's method. The results provide the parameters within the Berger chemical formula for buildup factors are evaluated. The Berger formula was shown to fit the computations results for low atomic number materials at energies higher than 1MeV and less than 0.06 MeV. They found that the differences between the results reach to 40% in mid energy range. The concrete buildup factor data have been fitted to both the Taylor and the Berger empirical formulae [Chil 80].

Musilek in 1980 studied the buildup factor and the factors affecting it using Monte Carlo method. This study showed that the buildup factor value depends on the atomic number of the shield, the exposure area of the shield and the geometry factor (the distance between the shield and detector). The results appeared that the diameter of detector has not any effect on the buildup factor values [Musi 80].

In 1981, Foderaro and Hall suggested a new formulation for fitting the results of buildup factor because of the high relative standard deviation for the Taylor and Berger formula when thickness is increased. This new formula was called "the three-exponential representation"; its fit for the buildup factor data of water was better than either of the Berger or the Taylor representation [Fode 81].

Monte Carlo method (code RADAK) was used by Bishop in 1987 to calculate the exposure buildup factor for source of energy 2.75 MeV in the double layer shielding of lead iron and aluminum. He showed that for double layer shield, the increase of buildup factor values when using a material of low atomic number in the beginning following it a material of height atomic number, is differ from using just a material of low atomic number with the same thickness by the (mfp) units [Bish 87].

In 1987, Hirayama adopted PALLAS-PL, SP-Br and ANISN codes to present a comparison between the results of exposure and absorbed dose buildup factors for point source in infinite beryllium at energy range (0.03 to 0.3) MeV, for penetration depths up to 40 mfp. Hirayama found that the results up to 10 mfp were in good agreement for point sources with results that obtained from EGS4 code as a test standard by the point Monte Carlo method [Hira 87].

In 1989, Min-Fungus and Shaing- Huei Jiang studied gamma rays buildup factors for a point isotropic source in stratified spherical shields. They used for this study the one-dimensional gamma rays transport code BIGGI-4T. The authors concluded that in the calculation of stratified shields with a special adjustment, the density variation effect could be eliminated [Fong 89].

Bakos in 1994 presented a study of buildup factors at energies 1.6, 6.13 and 7.10 MeV penetrate multi-layer shield. Theoretical and experimental calculation of dose was determined for penetrations through various thicknesses of (Al), (Fe), and (Pb). He concluded that when lead layer forms the outer layer, the buildup factor is reduced. Whereas in case Fe forms the outer layer the dose buildup factor approached the buildup factor of an all steel shield of the same total mfp penetration [Bako 94].

In 1998, Kadotani and Chimizu presented an investigation of buildup factor for homogenous semi–infinite medium for (water, ordinary and heavy concrete, soil, iron, tin and lead), the invariant impeding method was the procedure of calculation employed in this study, which has developed to solve the classical particle transport problems in homogenous medium. The precision of the calculated gamma rays albedo was found out by comparing with the Monte Carlo calculations (MCNP4A and EGS4) [Kado 98].

Shimizu in 2000 developed a new semi-analytical method for classical transport problems in medium called "angular Eigen value method and its application to the penetration of gamma rays in slabs". His method is characterized by its application to the deep penetration of radiation more easily than other related methods. The solution was expressed analytically as a function of the medium thickness. It was concluded that the this method could provide solutions with accuracy comparable with other related methods such as the moment and Monte Carlo method [Shim 00].

A new code for Monte Carlo (EBUF) was developed by Chibani in 2001 to calculate exposure buildup factors in media. Variance reduction procedures were applied to achieve this calculation up to 60 mfp. This study presented set of exposure buildup factors in (Aluminum, Iron, Lead, Concrete, Water, and Air) [Chib 01].

In 2001 Al-Baiti had measured the buildup factor for single and multi-layer shield for Al, Fe, and Copper, Brass, and Pb materials. He calculated the Build-Up Factor (BUF) by using the moment method with the information of the linear formula. He used Kalos method for calculating the buildup factor for double layers shield [Al-Ba 01].

Al-Samaraey in 2002 presented a study about the calculation of gamma rays buildup factor for the conical beam using Monte Carlo method for three different materials (Aluminum, Iron, and Lead). The number buildup factor from ^{137}Cs and^{60}Co was calculated by using Monte Carlo method [Al-Sa 02].

In 2002 Shim developed a technique of angular eigen value for penetration problems of gamma rays, as a new semi-analytical method for classical particle transport problems in slabs. He determined the exposure buildup factors for concrete slabs under slant incidence conditions by the presented method. The yielded results were found in good agreement with Monte Carlo calculations by Fourine and Chilton up to the thickness of 10 mfp. He found throughout his study that this method could provide solutions with accuracy comparable with related method [Shim 02].

In 2003, Al-Rawi used Monte Carlo method to calculate buildup factor for two materials, water and lead for two energies 1.25MeV and 0.066 MeV, (The energies for ^{60}Co and ^{137}Cs radioactive source respectively). This study concluded the effect of energy, thickness, and atomic number on the buildup factor values [Al-Ra 03].

Makki in 2009 measured the buildup factor for double layers shield (water and lead) using the source energy ^{137}Cs and ^{60}Co, she is found that the buildup factor increase with the increase of the total thickness of the shield. For three layers shield, the value of buildup factors approximates rapidly that of the outer material. Buildup factor for Water followed Lead shield is higher than that for Lead followed by Water for an equivalent thicknesses [Makk 09].

In 2009 Sardari et al, computed buildup factor of gamma and X-ray photon in the energy range 0.2–2 MeV in water and soft tissue (MCNP4C) code. The compared between results and the buildup factor data of pure water. They reported a new relationship can be used to estimate buildup factor as a function of penetration depth with 5 % deviation compared with the existing data [Sard 09].

In 2010 Manohara et al, computed energy absorption buildup factors using geometric progression (G-P) fitting formula of five parameter within the energy range (0.015–15) MeV, and for penetration depths up to (40) mfp for seven Thermo Luminescent Dosimetric (TLD) materials. They terminated that the effective atomic number, Z_{eff}, of BeO and LiF matches with that of cortical bone, and hence these compounds is additionally used as tissue equivalent materials for cortical bone within the energy range 0.2–2 MeV [Mano 10]

In 2011 Yuksel et al. calculated gamma ray energy absorption and exposure buildup factors for a few essential amino acids, fatty acids and carbohydrates within the energy region (0.015–15) MeV and up to 40) mfp penetration depth. This study was carried out by using the five parameter geometric progression (G-P) fitting approximation [Yuks 11].

Shirani and Alamatsaz in 2013 adopted Monte Carlo method to calculate exposure buildup factors for point isotropic gamma ray sources in the energy range from 0.04 MeV to 10 MeV, penetrating a spherical shield thicknesses from 1 to 10 mfp for water surrounded by lead with different combination. The results showed that at low gamma ray energies (less than 0.5 MeV), photoelectric effect is dominant, the best combination is zero mfp water -10 mfp lead (lead alone). The optimum combination at mid energies (1-3) MeV, Compton scattering is dominant, is 5 mfp water-5 mfp. Finally at energy 10 MeV, bremsstrahlung is dominant in lead, the best combination is 10 mfp water alone [Shir 13].

In 2013 Singh et.al adopted five parametric geometric progression (G.P.) fitting method in the energy range of 0.015 to 15.0MeV to calculate exposure buildup factor for some ceramics materials up to the penetration depth of 40 mfp, such as boron nitride (BN), magnesium diboride (MgB_2), silicon carbide (SiC), titanium carbide (TiC), and ferrite (Fe_3O_4) [Sing 13].

In 2013 Kulwinder Singh Mann and Turgay Korkut Singh adopted five parametric geometric progressions (G.P.) fitting method in the energy range of 0.015 to 15.0MeV to calculate extrapolation exposure buildup factor for some silicate samples (applied in reference [Sing 13]) for penetration depth from 40 to 100 mfp. The obtained results for all samples compared and verified by using WinXCom software and GEANT4 code [Kulw 13].

In 2014 (Mahdi) used Monte Carlo method to calculate dose buildup factor for plane radioactive source in the absence and presence pair production effect up to 5 mfp thickness and for selected energy (4-10) MeV for Lead and Aluminum. The results showed that in the presence of pair production effect, the dose buildup factor is higher than dose buildup factor in the absence of pair production effect and the deviation between these values increased when the energy is increased within the studied energy range [Mahd 14].

Manmohan Singh, Asha in 2016 designed a computer program (BUF-toolkit) to calculate exposure buildup factors for point isotropic gamma-ray sources for some normally available engineering materials at four energies with varied combinations up to 8 mfp. The results show that the empirical formula given by Lin and Jiang used to compute exposure buildup factor by G.P. fitting formula is the most correct and easiest method for double layer computations. The results showed at selected energies for two layered slabs (high-Z material followed by low-Z material) higher than the opposite orientation. In this study EGS4-code and Geometric Progression (G.P.) fitting point kernel methods is applied foe comparative purpose [Manm 16].

In 2016 (E Adamides et. al constructed an apparatus called 'Buildup Minimizing Assembly' (BMA), which may be used to attain narrow beam, (good geometry characteristics) in γ-ray attenuation measurements to minimize the buildup contribution. The apparatus is simple to construct and can be carried out in undergraduate laboratory experiments [Adam16].

In 2016 Ozdemir, measured the photon interaction parameters such as mass attenuation coefficient, effective atomic number, and effective electron density. During this study photon buildup factor for many compounds using ^{137}Ba, ^{157}Gd and ^{241}Am γ-rays sources were obtained by changing collimator diameters in the different photon energies. He observed that the buildup factor increased for all sources used with the increasing of the collimator diameter [Ozde 16].

1.9 Aim of this research

The aim behind the present project is to design a computer program based on Monte Carlo method for gamma photon transport, and simulates the transmission and reflection of incident gamma rays on a slab of homogeneous shielding material. This simulation computer program will be write in Visual Basic language version G and will utilize to calculate gamma ray dose buildup factor. The basic ideas of the program include real radiation behavior description and prediction of its random movement through the shielding material.

In this study gamma ray dose buildup factor for two slabs of shielding materials water (Z_{eff} =7.42) and graphite (Z=6) within the energy range (4-10) MeV and up to 5 thickness mean free path will be calculated. The radioactive source geometry that will be adopted in the study is mono energetic normal plane source.

This study will be examining a number of variables related to the program design called simulation variables like number of gamma scenarios, number of divisions for energy. This research will also include study of the effect of energy for the incident photon, shield thickness, and atomic number for shielding material on the calculation of gamma ray dose buildup factor. also the contribution of annihilation effect on the calculation of gamma ray dose buildup factor will be studied in the same energy and within the proposed energy range.

Chapter Two

Theory

Chapter Two

Theory

2.1 Introductions

This chapter presents the concepts behind the simulation and Monte Carlo techniques. Monte Carlo techniques were connected to mathematical methods category. This technique used at first time in Los Alamos in 1940s by some researchers dealing with the improvement of atomic weapons. The significance behind this technique is inventing games of probability utilized to study some interesting phenomena. While there is no importance relationship to computers, the effectiveness of numerical or simulated gambling as a significant scientific effort is widely increased by the availability of recent digital computers [kalo 08].

Many numerical issues in science are solved through Monte Carlo methods because those methods continues in developing, and new strategies are developed in quick succession, the amazing number of associated method, ideas, concepts, and algorithms makes it troubled to deal with a general picture of the Monte Carlo approach. In addition to that, the Monte Carlo techniques investigation requires wide knowledge in an extensive variety of fields. This knowledge may not generally accessible to the Monte Carlo specialist or expert [kalo 08].

As it was specified in the first chapter, the calculation of gamma attenuation when it passes through a shield of material can be performed using simulation model based on the Monte Carlo method. The theoretical background of this method will be described, and then a detailed explanation of the program used to calculate buildup factor by Monte Carlo method will be presented and discussed in this chapter.

2.2 Simulation and the Monte Carlo Method

The Monte Carlo method can be defined as mathematical tool dealing with random numbers or pseudorandom numbers. This makes that the simulation of any procedure influenced by random number is possible. Random numbers are essentially independent random variables and uniformly distributed over the unit interval (0, 1).

The simulation with Monte Carlo is widely used in many scientific fields (a supersonic jet flight, a telephone communication system, a wind tunnel, a large-scale military battle). The continuous development in computational power and software solutions allow its application to complex systems and problems. This method can obtain precis results for solution of a model related to the absorption, backscattering and transmission of the photons, electrons penetrating thin films, and can also provide implantation profiles of the absorbed electrons or photons, the energy and the angular distributions of backscattered and transmitted photons, and the spectra of secondary electrons. Thus we can consider the Monte Carlo technique as a universal method of solving complex multi-dimensional problems [Dapo 03, Rubi 81, Sobo 75].

Particles stopping powers mean free paths, and most of interaction probability (cross-sections) can be accurately calculated by the Monte Carlo technique in order to observe the macroscopic characteristics of the interaction processes. These methods start by simulating a large number of particle trajectories and averaging them. However, as this method is statistical, the precision of its results depends upon the simulated trajectories number. Recent development in computer calculation capability implies we are presently ready able to get statistically significant results at very short times of calculation [Dapo 03].

The simulation with Monte Carlo Simulation method has many advantages these are:

- The direct use of nuclear information like angular distributions and cross sections as a function of energy, with no need to introduce approximations.
- The plausibility of considering very complicated geometries with no need of presenting improving, unreliable assumptions like the homogenization of heterogeneous areas.

The disadvantages of the Monte Carlo Simulation method required the following:

- Large capacity of memory to accommodate the nuclear data like the cross sections and angular distributions that should be available for all nuclides and for all energies within the scope of research.
- Long time of calculation, which rapidly diverge with required accuracy [Zio 12].

2.3 The Simulation Model Construction

There are three major steps to build the required simulation model by using Monte Carlo strategy, these steps can be summarized as the following [Robe 99] :

1- Replace each undefined input values with independent random numbers generated from random number generator or function. This independent random number must be built in distribution relative to the distribution that we have prior knowledge.

2- Execute the constructed simulation model to investigate the desired goal up to (thousands up to million) times.

3- Analyze the output results.

2.4 Major Components of Monte Carlo Algorithm

As we mentioned before, Monte Carlo algorithm is used to find mathematical problems solutions with many variables that cannot easily be solved analytically, (integral and differential calculus, or other numerical methods). The essential components that typically compose a Monte Carlo algorithm can be summarized and presented by the following points:-

1. The system must be defined by a set of probability distribution functions (pdfs).
2. The generated random number from random number function or generator are uniformly distributed on the unit interval must be available.
3. The sampling model from the particular pdfs requiring the availability of random numbers on the unit interval.
4. The quantities of interest must accumulate into overall scores.
5. The variance (statistical error) as a function of trials number and other quantities of interest must be defined.
5. Choose methods used for reducing the variance of the estimated solution, or used to reduce the computational time for Monte Carlo simulation.
6. For efficient utilization use advanced computer architectures.

2.5 Particle Trajectory

The historical background of particles is started from the instance of getting their directions to the instance that particles system elaboration in itself is of great importance.

A concept of the path of a particle described its journey throughout the medium (shield). Since the typical particle scatters many times throughout its travelling and the path has "zigzag" form as shown in figure (2.1).

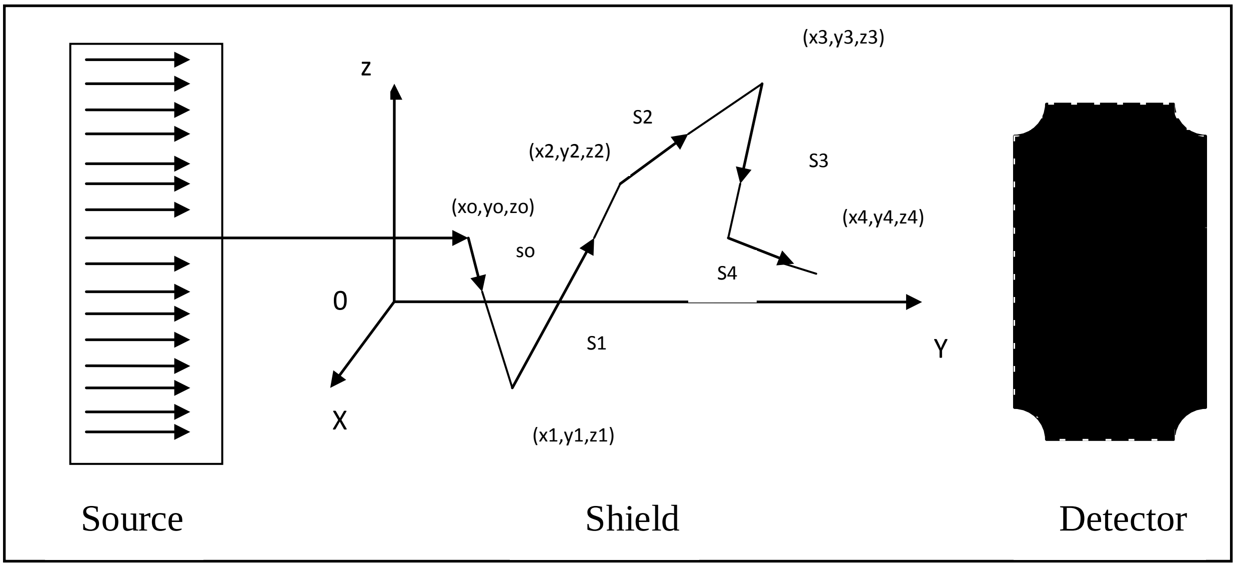

Fig (2.1) path behavior for a typical particle throughout the medium

There is different mode of interaction when the particles collide with an atom of substance medium. Here and with this example suppose that there are two modes of interactions, absorption and scattering In case of absorption mode, the particle terminated its journey in substance medium. The second mode type, when a particle continues in its journey through the medium, in this case the particle changed its direction with new energy or wavelength. The second mode is statistical process because there is non-unique energy or direction after each scattering. Because the scattering mode is statistical, the continuous change in energy and direction can be described by certain distribution function known as probability distribution function (pdf). After the first scattering (first event), the particle has more than probability to get the second event, either it is absorbed or scattered again and again until its recorded when its reach the point of interest or leave the medium before its reach the point of interest (completely escaped) or its energy not support it to complete its journey.

In order to follow the particle throughout its traveling we must require know its direction (spatial coordinates (x, y, z) and the spherical coordinates (θ, ϕ)) suitable its energy E. These variables are suitable to define particle state (α) where,

$$\alpha = \alpha\ (x, y, z, E, \theta, \phi) \qquad (2.1)$$

The spherical coordinate system for defining the particle's direction is illustrated in figure (2.2).

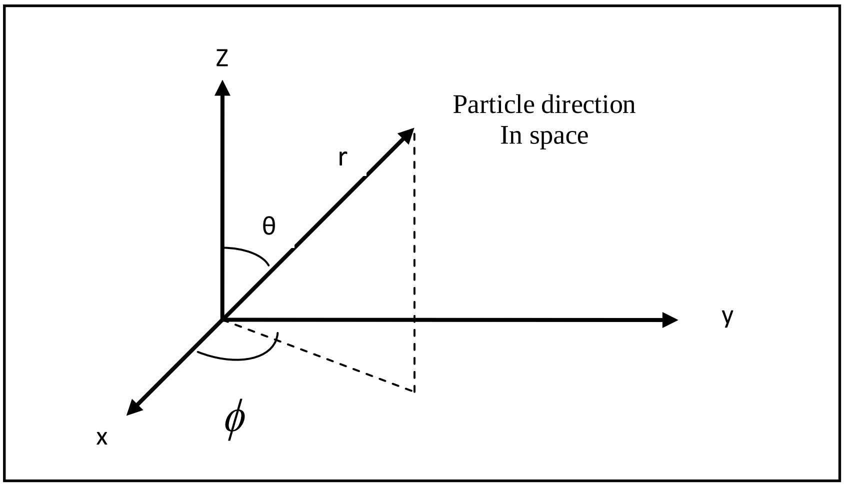

Fig (2.2) particle's direction in spherical coordinates (θ, ϕ)

The trajectory of the particle from collision to another can be constructed as a progression of states α_o, α_1, …, α_n, where the i^{th} state is

$$\alpha_i \equiv \alpha_i\ (x_i, y_i, z_i, E_i, \theta_i, \phi_i) \qquad (2.2)$$

That is, in the i_{th} state, a particle has the spatial coordinates of the i_{th} collision point and the energy and direction of the particle after the i_{th} collision. With the exception of the initial state, each successive state is a function only of the previous state and the scattering laws obeyed by the particle in the material of interest. Thus one could commence with initial, or sources, conditions which define α_0 choose by random sampling from the relevant probability distributions the new values of the variables which determine α_1, and so on. In most Monte Carlo calculations it is not necessary to store at the same time each detail of the life history of every particle studied: sometimes all that is needed is the latest state of the particle being currently followed.

Obviously, what we need are specific mathematical procedures for choosing the position of successive collision point, and the new energy and direction of the particle if it survives that collision. Let us consider a particle that has just undergone it's in collision (a scattering), and begin by finding the spatial coordinates of its next collision point.

If we denote by (s) the path-length of the particle to the next collision point, the probability of a particle travelling a distance s while not having an interaction is $e^{-\Sigma s}$ .The probability that a particle will have an interaction in the interval ds is Σds. Therefore, the probability that a particle will have an interaction between s and s + ds is

$$\int_0^\infty \Sigma e^{-\Sigma s} ds = 1 \qquad (2.3)$$

Where Σ is the particle's total cross section (denoted by μ in the case of photon). Hence we tend to should establish a procedure for picking at random a value of s from the probability function implied by the expression (2.3). For the moment we shall assume that such a procedure is accessible which we have designated specific value of s to assign to S_i. The general problem of sampling from arbitrary probability functions is considered in the next section. Once the value of S_i is determined, the coordinates of the next collision point are without delay found from

$$\begin{aligned} x_{i+1} &= x_i + s_i (\sin\theta_i \cos\phi_i) \\ y_{i+1} &= y_i + s_i (\sin\theta_i \sin\phi_i), \\ z_{i+1} &= z_i + s_i (\cos\theta_i). \end{aligned} \qquad (2.4)$$

The type of interaction should be decided, again by sampling from the applicable probability function. Let us for the sake of illustration assume that it is once more a scattering event. The particle's energy and direction after scattering are obtained by sampling from the applicable scattering function. For example, in the case of a photon the scattering process is Compton scattering, and the probability function is given by the Klein-Nishina theory. By sampling, then, from the appropriate scattering law, the new energy, E_i, can be determined. Also the 'local1 angles of the scattering event (θ_o, ϕ) can be determined (see Fig. 2.3).

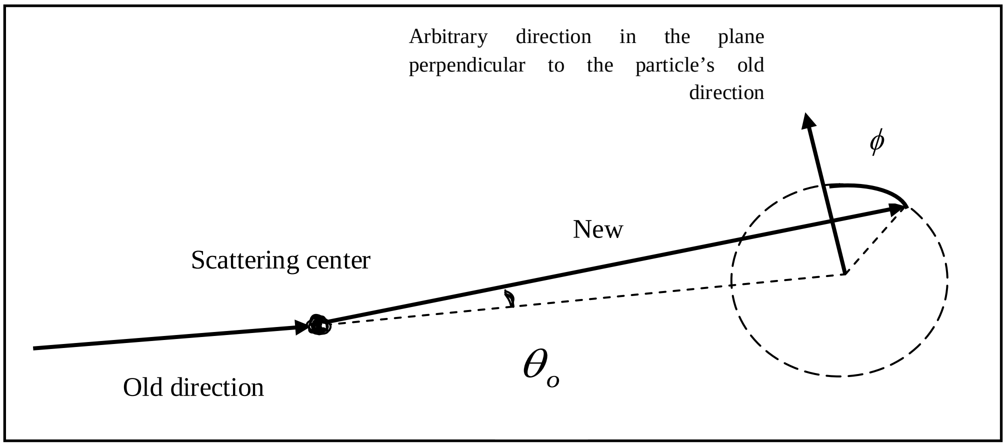

Fig (2.3) particle's 'local' angles of scattering. θ_o is the deflection angle, ϕ is the azimuthally angle. Usually the angle ϕ can be assumed to be randomly distributed in the range 0 to 2π

The final problem is how to relate the particle's old direction (θ_{i-1}, ϕ_{i-1}) and the local angles (θ_0, ϕ) to determine the new direction of the particle (θ_i, ϕ_i).A convenient (but not the only) method of doing this is to consider the spherical triangle defined on the unit sphere by the intersection of the surface of the sphere with the particle's old and new directions and the direction of the reference polar axis of the system. The scattering point considered the center of the unit sphere as in the following figure (2.4)

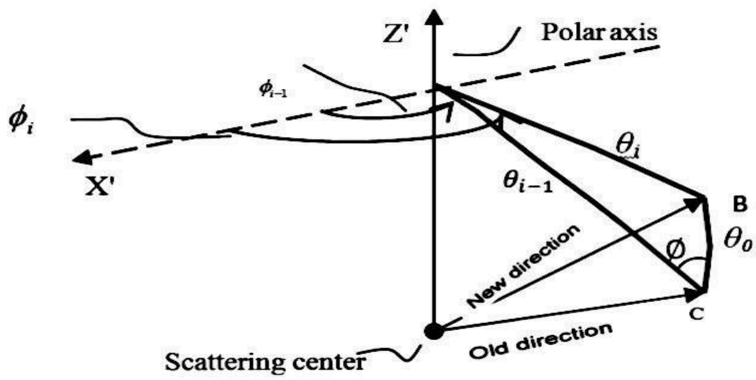

Fig (2.4) the spherical triangle formed by the photon's previous direction and its new direction after a Compton scattering. Ɵ is the Compton angle of scattering.

By considering this spherical triangle and by utilizing standards relationships of spherical trigonometry, sines and cosines of θ_i and ϕ_i can be determined for use in eq (2.4), as follows:

From the law of cosines for spherical triangle, [Wood 81]

$$\cos\theta_i = \cos\theta_{i-1}\cos\theta_0 + \sin\theta_{i-1}\sin\theta_0\cos\phi \tag{2.5}$$

From which $\cos\theta_i$ can be determined. Next $\sin\theta_i$ can be determined from the well-known identity:

$$\sin^2\theta_i + \cos^2\theta_i = 1 \tag{2.6}$$

Now, applying the law of sines gives:

$$\sin(\theta_i - \theta_{i-1}) = \frac{\sin\theta_0 \sin\phi}{\sin\theta_i} \tag{2.7}$$

Reapplying the law of cosines to get:

$$\cos\theta_0 = \cos\theta_{i-1}\cos\theta_i + \sin\theta_{i-1}\sin\theta_i\cos(\phi_i - \phi_{i-1}) \tag{2.8}$$

From which $\cos(\phi_i - \phi_{i-1})$ can be calculated.

Finally, the value of $\sin\phi_i$ and $\cos\phi_i$ can be deduced from the standard trigonometric formulas:

$$\sin\phi_i = \sin(\phi_i - \phi_{i-1})\cos\phi_{i-1} + \cos(\phi_i - \phi_{i-1})\sin\phi_{i-1} \tag{2.9}$$

$$\cos\phi_i = \cos(\phi_i - \phi_{i-1})\cos\phi_{i-1} - \sin(\phi_i - \phi_{i-1})\sin\theta_{i-1} \tag{2.10}$$

This completes the description of a set of a systematic procedure for constructing theoretical trajectories of the particles as they diffuse through the medium. Each particle is traced until its life history is terminated. When one particle is terminated (and score), a new particle life history started from the source and it is traced. What remains to be clarified in this connection, are procedures for sampling from known probability functions.

2.6 Generating Random Numbers

A random number generator is a computational or physical device designed to generate a sequence of numbers that appear to be independent draws from a population, and that also pass a series of statistical tests. They are also called Pseudo-random number generators, since the random numbers generated through this method are not actual, but simulated. In this article, we will consider RNG's which generate random numbers between 0 and 1, also called uniform RNG's. The term random number is used instead of uniform random number.

Many techniques for generating random numbers have been suggested, tested, and used in recent years. Some of these are based on random phenomena, others on deterministic recurrence procedures.

Nowadays, random numbers are used in many ways associated with computers. These include, for example, computer games and generation of synthetic data for testing. A definition of a Monte Carlo method would be one that involves deliberate use of random numbers in a calculation that has the structure of a stochastic process. By *Stochastic process* we mean a sequence of states whose evolution is determined by random events. In a computer, these are generated by a deterministic algorithm that generates a sequence of pseudorandom numbers, which mimics the properties of truly random numbers [kalo 08].

2.7 Variance Reduction Technique

In mathematics, more specifically in the theory of Monte Carlo methods, variance reduction is a procedure used to increase the precision of the estimates that can be obtained for a given number of iterations. Every output random variable from the simulation is associated with a variance which limits the precision of the simulation results. In order to make a simulation statistically efficient, i.e., to obtain a greater precision and smaller confidence intervals for the output random variable of interest, variance reduction techniques can be used. The main ones are: common random numbers, antithetic variates, control variates, importance sampling and stratified sampling. Under these headings are a variety of specialized techniques; for example, particle transport simulations make extensive use of "weight windows" and "splitting/Russian roulette" techniques, which are a form of importance sampling.

2.7.1 The method of Survival Weights

This device is one of the subtle concepts used in the program. The use of this device is best described by reference to theoretically computing the transmission ratio and spectrum of the photons that escape through shielding material placed in front of a source of radiation. In the Monte Carlo analogue of the problem, if the slab is thick, relatively few of the particles that are started from the source would escape from the slab - most would be absorbed in the slab and thereby contribute very little data on the energy of escaping particles. It is intuitively obvious that it would be more efficient to follow only those particles that experience only scattering collisions: since these have the most effective chance of ultimately penetrating the slab.

However, if the particles were only permissible to scatter in the Monte Carlo schematization, the results of the calculation would be distorted (i.e. the computer-experiment results would no longer be representative of the physical situation of interest). To counteract this, the particle's 'survival weight' is adjusted after each collision (which is perforce a scattering collision). For example, when the particle leaves the source it is allotted a survival weight of unity. After its first collision its survival weight is increased by the factor ($\mu_c(E) / \mu(E)$) that is simply the probability, obtained by analytical averaging, that the interaction is a scattering event. Following every subsequent collision, the particle's existing weight is similarly adjusted. This is accomplished by equipping the particle with an additional 'state' variable known as weight.

With the introduction of this scheme into a Monte Carlo calculation, the particles survive every collision and it is necessary in observe to ascertain additional criteria (other than escaping the system) for terminating a life history. One possible criterion is to 'kill' the particle when its energy becomes less than some pre-assigned cut-off energy [Wood 81].

The method used is that the Monte Carlo technique, in which the life histories of a large number of particles (photons) are followed using random sampling techniques to sample the probability laws that describe the particle’s behavior, and to trace out step by step the particle’s random walk through the medium. In the particular variety of the Monte Carlo method used here, there is a detailed analogy between the physical particles and the mathematical particles followed by the program. The main complexity utilized is that the thought survival weights. Thus one will not enable absorption of the photons as such; all collisions are forced to be Compton scatterings. The effect of absorption is accounted for by modifying the weight of the particle after every collision. That is the actual weight after a collision is that the weight before collision multiplied by the survival ratio, $\mu_C(E) / \mu(E)$, which is of course the probability that a collision will be a Compton scattering. It is important to understand that in this, the basic form of the program, the pair production event is regarded as a purely absorptive interaction- the contribution from the resulting annihilation gamma rays is not considered.

In this designed program, the history of each particle is followed until the particle either escapes from the system, or, due to successive scatters, its energy drops below suggested minimum energy; in either event a 'new' photon is started with an initial weight of unity.

2.8 Program Design

In this study, a computer program is designed, written by using the Visual Basic computer language and utilized for simulating the classic problem of gamma rays beam incident on a finite plane slabs of different absorbing materials and calculate gamma rays buildup factor for single layer shield of different materials. A computer program "MONTRY" [Alra 03] was redesigned and improved so as to include the continuity of energy. The geometry of source used in this program is plane traditional source as illustrated in figure (2.5). This problem is a mathematical problem supported statistical probability theory. It is utilized in gamma transport problem. The penetration of radiation income by compiling life histories of individual gamma rays as they move about, from the point where they are either absorbed in the shield or pass through it.

The basic plan within the program is to compose a series of life histories of the source particles by using random sampling techniques to sample, the probability laws that describe the important particles behavior, and to trace out the steps of the particle's "random movement" through the medium. The applicability of the Monte Carlo technique arises from the very fact that the gross cross section could also be considered the probability of the specific interaction per unit distance traveled by gamma photon. A group of photons histories is generated by tracing individually the photons through sequent collisions which results in scattering or absorbing.

To start the history of the primary photon, it is necessary to determine where the photon has its first photon collision. This can be done by sampling the primary collision probability distribution function $\rho(x)=\sum_t e^{-\Sigma_t x}$ wherever $\sum_t$ (total macroscopic cross section) is evaluated at the energy E_0, the method for sampling such distribution function in random manner are going to be discussed later. Suppose that the chosen value of (x) is x_1, and therefore the thickness of (n) shield layers of various material are ($t_1,t_2,t_3,\ldots.t_n$), then if a represent the full shield thickness, it is necessary to check x_1 thus::

i. If $x_1 > a$, then the photon has penetrated the shield without a collision, this journey is registered, and the history is terminated.

ii. If $x_1 < a$, a collision occurred within the shield at the point x_1. Now to determine in which layer x_1 lies, another comparison is made with different layers thicknesses: if $x_1 \leq t_1$ then the photon is traveling in the first layer but if $x_1 > t_1$ it does not, and the same thing for the remaining layers till the position of collision point is determined.

The method used is that the Monte Carlo techniques during which life histories of a large number of particles (photons) followed. In the particular form of the Monte Carlo method used here, there is a detailed analogy between the physical particles and the 'mathematical particles' followed by the program. The only sophistication used is that the idea of survival weights. Thus, absorption of the photons is not allowed as such; all collisions are forced to be Compton scattering. The effect of absorption is accounted for by modifying the weight of the particle after every collision. That is; a particle weight after a collision is getting by multiplying the weight before collision by the survival ratio, $\mu_C / \mu(E)$ which is of course the probability that a collision are going to be a Compton scattering. It is important to refer that within the basic form of the program, the pair production interaction in this study can be summarized as follows, assuming that the pair production event can occur (i.e. E $\geq$ 1.022 MeV), then pair production is considered to occur if $\xi > \mu_c / (\mu_c + \mu_{pp})$, where ξ is a random number lying between 0 and 1, otherwise, a Compton scattering take place. In other event, the survival weight factor is given by SURV= $(\mu_c + \mu_{pp})/\mu(\mathrm{E})$. If pair production occurs, the original gamma photon is completely removed and replaced by 2 annihilation gamma photon of 0.511 MeV.

In this study, the history of each particle is traced till the particle either escapes from the system, or its energy drops below some preset minimum due to consecutive scatters. In either event, a new photon is started with an initial weight of unity.

The position and direction of a photon are defined by the 4- variables (y, z, θ, ϕ), which are referred to as the coordinate systems shown in figure (2.2).

The principal quantity computed and output by the program is the buildup factor, which is a measure of how the transmitted photons are enhanced by the Compton scatterings and pair production interactions.

An instructive feature of the program is that a record of the number of particles that suffer every of the possible fates is kept to facilitate checking that every one particles started from the source are correctly accounted for. The program has been deliberately written in a modular form, each subroutine or subprogram will readily be known with a distinctive physical event of the photon career.

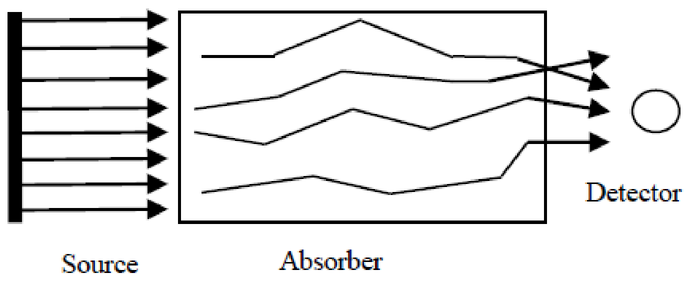

Fig (2.5) geometry of plane normal source and shielding slabs considered by modified program.

2.9 The Essential Subroutines Used in the Program

The program is divided into subprograms. This program is shown in figure (2.6). The purpose of each subroutine used in this program will be illustrated in form of a flow diagram is shown in the following paragraphs.

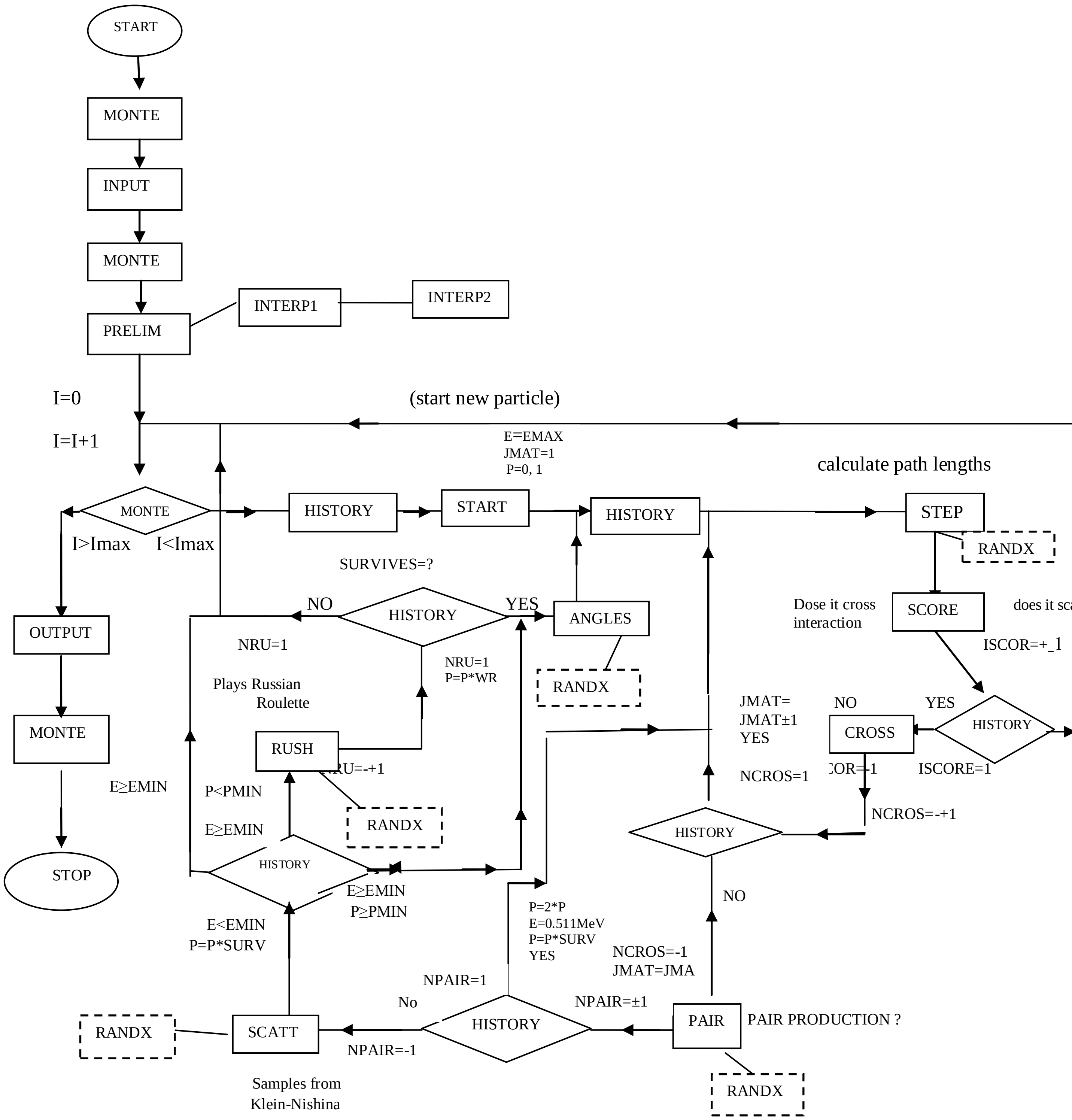

Fig (2.6) the flow diagram of modified program

Table (2-1) glossary of Main Variable Names Considered in the Flow Diagram of Modified Program

I	**Index labeling i^{th} particle history.**
IMAX	**Maximum number of particle histories to be studied**
E	**Photon energy in MeV.**
EMAX	**Maximum photon energy in problem, i.e. the source energy. (EMAX ≤ 10).**
JMAT	**Counter stores the number of occurred "pair production" process.**
NRU	**It is a flag value used to refer the occurrence of RUSH step intermediate.**
P	**Photon's survival weight.**
WRU	**The weight of Russian Roulette.**
PMIN	**The minimum value of photon's survival weight.**
EMIN	**Cut-off energy in MeV.**
NPAIR	**A flag referring to occurrence of pair production.**
SURV	**The survival ratio: the probability for a photon of given energy which suffers a collision that the interaction will be a Compton scattering.**
NCROS	**A flag refer to the instance of "crossing the bar"... intermediate flag.**

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2.9.1. MONTE

This is the section of the program in which the calculation commences and ends. The principle function of MONTE is to make sure that the main sequence of the scheme is properly followed. In furtherance of this, MONTE monitors the number of latest particles started.

2.9.2 INPUT

This subroutine is concerned with reading in, in a formatted form, the basic shared data and control parameters required by the program. This includes the simulation parameters and the energy dependent parameters (Compton cross section). This subroutine is repeated according to the number of layers considered in the simulated experiment.

2.9.3 PRELIM

Due to large number of particles followed in a typical Monte Carlo calculation, it is obviously desirable to minimize the amount of computation associated with each stage of a photon's history. The efficiency of the corresponding program is greatly increased by: firstly, performing certain "once for all" type calculations, secondly, storing the results in a convenient form for subsequent usage. 'It is the task of this subroutine to carry out these preparatory calculations in MONTERAY.

It can be unrealistic to presume that the cross section data can be input in such detail that, no matter what photon energy (i.e. wavelength) after a Compton scattering, there will be a corresponding value of, say, the linear attenuation coefficient immediately available from the basic data table. The procedure that we have adopted to cope with this problem is to read in the basic data for a widely-spaced energy mesh, and have the program build its own detailed data tables for a fine-wavelength mesh by interpolation in the basic data. The info corresponding to any photon wavelength (in the allowable range) is then efficiently obtained by 'table look-up1. The major function of PRELIM is to build detailed cross section data tables. For this purpose it requires an interpolation procedure - which is implemented in the auxiliary subroutines INTRP.

Other tables build in PRELIM are

(i) values of the sine and cosine of an angle in degrees;

(ii) The energy mesh tables for storing the photon spectra at exit from the system.

As mentioned earlier, this subroutine also repeats the calculation for each and every layer considered in the shield.

2.9.4 HISTORY

The particular path taken by every photon through the slab is controlled by this software. The route followed depends on various choices taken by HISTORY: These decisions depend mainly on the photon's wavelength (or energy) and whether it escapes from the system. In particular, if the photon does not escape from the system, it must be made to scatter once more. To escape completely from the system, a photon traveling to the right must penetrate the thickest slab into consideration.

2.9.5 START

Those variables which outline a photon's state are given their initial values here. Thus the particular kind of source considered is imposed in this subroutine. Now, the photon is thought of to start his journey from the first layer of the shield.

2.9.6 STEP

The tasks of the STEP module are to achieve three important functions:

(i) It establishes, after a collision, the position of the photon in the fine-mesh wavelength table, for subsequent look-up of the cross section tables,

(ii) It selects, at random, the path length of the photon to the next (postulated) collision point, using for this purpose the technique of inverse additive function which will be represented later.

(iii) By means of eq. (2.4), it computes the coordinates of the next (postulated) collision point.

In connection with (i) it is essential that the method used is compatible with the tables constructed in subprogram PRELIM: this can be an important point to remember ought to ever be thought necessary to alter the existing wavelength structure.

(ii.a) The Inverse Cumulative Function Method

This method is used to select randomly the trail of the photon to the next collision point in routine STEP. One of the most important and mathematically attractive method for choosing variates relies on the fact that random variable from any given pdf (probability distribution function) can be expressed as a function of another random variable that is uniformly distributed between zero and one. (i.e. from the canonical distribution) [Wood 81].

Consider x distributed as p(x).and Let y = f(x) denote a monatomic increasing function of x, and let g(y) denote the distribution of the random variable y, now clearly, when $x \le a$, then $y \le f(a)$. This can be interpreted as,

$$\text{Prob}\,(x \le a) = \text{Prob}\,(y \le f(a))$$

Restating this equality in terms of the respective cumulate distribution function (cdf) gives the probability that the random variable *x* has a value less than or equal to some fixed value. It is given by

$$P(a) = \int_{-\infty}^{a} P(x)dx = \int_{-\infty}^{f(a)} g(y)dy \tag{2.11}$$

Now, if we choose g(y) = 1, for $0 \le y \le 1$ (i.e. g (y) is the canonical distribution), then,

$$P(X) = \int_{-\infty}^{X} P(x')\,dx' = \int_{-\infty}^{\xi} dy = \xi \tag{2.12}$$

i.e

$$x = P^{-1}(\xi) \qquad (2.13)$$

That is, from any arbitrary pdf by transforming, by means of the inverse cumulative distribution function (P^{-1}), a random number from the canonical distribution can be sampled. In practice, this method is only applicable if we can fairly easily perform the 'inverse operation' required by eq (2.13).

To show that the sample values of x obtained from eq (2.13) are indeed from the desired pdf, consider the graph in fig (2.7) which illustrates the procedure.

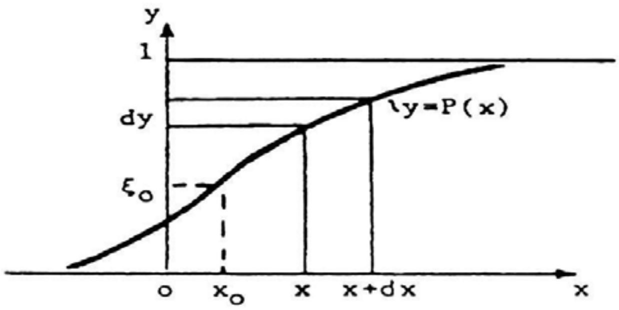

Fig (2.7) graph of cdf p(x). The random number ξ_0 determines x_0 [Wood 81].

From fig (2.7), it is clear that:

Probability that x lies in the interval (x, x+Δx)

= probability that y lies in dy

= g(y) dy = dy, (since g(y) =1) = dp(x)

= p(x) dx (since dp $(x)/dx$ = p(x))

Thus, the sample values of x have the required distribution. In the discussion of particle trajectory, the path length of a particle (photon) tothe next collision point was obtained by sampling the pdf,

$$P(x) = \mu e^{-\mu x},\ 0 \le x \le \infty \qquad (2.14)$$

Where, μ is the linear attenuation coefficient of the medium. By substituting equation (2.13) in eq (2.14) it can be concluded that

$$x=-\frac{1}{\mu}\log_e(1-\xi) \tag{2.15}$$

But (1-ξ) is distributed as ξ, therefore

$$x=-\frac{1}{\mu}\log_e \xi \tag{2.16}$$

Hence, the x-values obtained from eq (2.16) are equivalent to randomly sampling from the pdf which cover the photon's path length in homogenous medium, and this is the procedure used in subroutine STEP.

2.9.7 SCATT

In this subroutine, the new wavelength after a Compton scattering is chosen by sampling from the K-N (Klein – Nishina) distribution. The particular sampling technique used is that of Khan (which are represented later); once the new wavelength is found, the Compton angle of scattering θ is readily determined. Another function of SCATT is to modify the particle weight P to its new worth when a scattering. It should be mentioned that, in the Compton scattering interaction, a primary photon is absorbed via its interaction with an orbital electron. The latter is freed and a secondary or scattered photon of energy lower than the primary is created. The basic theory of this effect, which assumes the electron to be free and at rest is that of Klien and Nishina (1929). This basic theory has been well confirmed experimentally. It is true that some departures from it is going to occur for low and high energies of the incident photon. From the point of view of shielding applications in most of the energy very wherever Compton scattering could be a major contribution within the total cross section, the Klien – Nishina (K-N) theory is directly applicable.

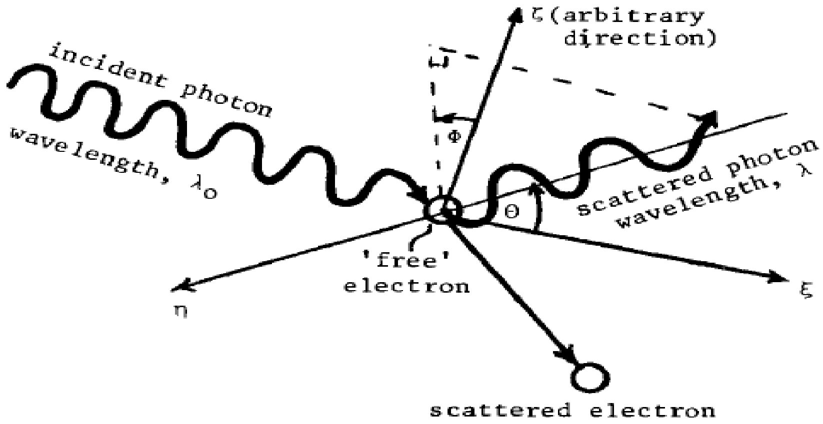

Fig (2.8) geometrical relation in a Compton scattering events. The local orthogonal axis (ξ, η, ζ) are constructed such that ξ lies along the original direction of the photon's travel [Wood 81].

In figure (2.8), θ is the Compton angle scattering, and ϕ is the azimuthally angle of scattering. The shielding studies indicate that ϕ is uniformly distributed between 0^0 and 360^0 [Evan 55].

Compton cross section (σ_c) is usually expressed in units of barn per electron (b/electron). A simple conversion factor can then be used to calculate the contribution of Compton effect (μ_c) to the total cross section for a specific material. K-N theory also provides a result that is basically required in Monte Carlo simulation of photon transport, namely the scattering probability density function f(E). As has been detected, a key feature of Monte Carlo method is that the use of random numbers to sample from the probability density functions that are considered to describe the physical behavior of the particles.

The pdf f(E) for the photon energy E after Compton scattering is directly deductive from K-N theory. In practice, instead of using energy variable E, it is sometimes a lot of convenient with an energy connected variable x (which is defined latter), and to sample at random from the K-N pdf f(x). Even then the shape of f(x) is relatively complicated and simple sampling techniques do not prevail.

2.9.7.1 The Klein-Nishina Formula

To relationship between photon deflection and energy loss for Compton scattering, assuming the electron to be free and stationary, which is decided from thought of conservation of momentum and energy between the photon and recoiling electron. This relationship are often expressed as

$$\frac{E}{E_0} = \frac{1}{1+(\frac{E_0}{m_e c^2})(1-\cos\theta)} \qquad (2.17)$$

Where E_0 and E are, respectively, the energies of the photon before and after the collision in MeV, m_0c^2 is the electron rest energy and θ is the photon deflection angle (see Fig. 2.8).

In gamma ray transport calculations it is typically more convenient to use, rather than the energy variable, the wavelength of the photon in Compton units, namely, λ=0.511/E, wherever E is that the photon energy in MeV. The increase in the wavelength associated with a Compton scattering event, in these units, is

$$\lambda - \lambda_0 = 1 - \cos\Theta \qquad (2.18)$$

Where λ_0 and λ are in Compton units, and λ_0 is the wavelength of the photon before scattering and λ is the wave length after scattering. Clearly the maximum shift in wave length is two Compton units. It occurs when the photon has been deflected through 180^0. In Monte Carlo simulation of photon transport, it is necessary to understand, after a Compton scattering, the angle of scattering θ, and therefore the new value of the wavelength λ. The most commonly used procedure for getting these quantities is by sampling using the K-N pdf f(x) to find the value of (x) after a scattering, and deduce θ from equation (2.18),where x is defined as x= λ/λ_0.

When the angular dependence of the scattered photon has been removed by integration, in terms of the dimensionless variable x, the Klein-Nishina differential cross section takes the compact form

$$d\sigma = k\left(A + \frac{B}{x} + \frac{C}{x^2} + \frac{D}{x^3}\right)dx \qquad 1 \leq x \leq 1 + 2\alpha_o \tag{2.19}$$

Where

$$\alpha_o = \frac{1}{\lambda_o} = \frac{E_o}{0.511} \tag{2.20}$$

$$x = \frac{\lambda}{\lambda_o} = \frac{E_o}{E}$$

And E_0 is the incident photon energy in MeV.

Additionally,

$$k = \pi\frac{r_e^2}{\alpha_0}, \quad (r_e^2 = (\frac{\mu_0 e^2}{4\pi m_e})^2 = 7.94077 * 10^{-26} cm^2) \tag{2.21}$$

also,

$$A = \frac{1}{\alpha_0^2}, \quad B = 1 - 2\frac{(\alpha_0 + 1)}{\alpha_0^2}, \quad c = \frac{(1 + 2\alpha_0)}{\alpha_0^2}, \quad \text{and } D = 1.$$

The total Compton cross section is obtained by integrating eq. (2.19), hence

$$\sigma_C = \int_1^{1+2\alpha_0} d\sigma$$

$$= k' \left[\frac{4}{\alpha_0} + \left(1 - \frac{1-\beta}{\alpha_o^2}\right) + \frac{\gamma}{2}\right] \quad \text{[b/electron]} \tag{2.22}$$

Where

$K' = K \times 10^{24}$

$ß = 1 + \alpha_0$

and $\gamma = 1- ß^{-2}$

It is clear from eq (2.22) that σ_C is a function only of the incident energy of the photon. The pdf f(x) for the Compton scattering process correspond to $\frac{d\sigma / dx}{\sigma_C}$, and it therefore has the form

$$f(x) = \begin{cases} H(A + \frac{B}{x} + \frac{C}{x^2} + \frac{D}{x^3}) & \text{if } 1 \le x \le 1 + 2\alpha_0 \\ 0, & \text{else where} \end{cases} \tag{2.23}$$

Where $H = k' / \sigma_C$.

The pdf's in the variables E and x are simply related, as follows

$$f(E)dE = f(x)dx \tag{2.24}$$

From the previous definitions of σ_C and f(x), it is immediately apparent that f(x) satisfies the basic requirement for every pdf, namely,

$$\int_{-\infty}^{\infty} f(x)dx = 1 \tag{2.25}$$

For completeness we mention at this point that to see the photon's new direction in space, it is necessary to know, additionally to Θ, the azimuth angle φ see Fig. 2.8). This can be promptly obtained by sampling, at random, for any angle lying between 0° and 360° with equal likelihood, and therefore presents no practical difficulty [wood81].

2.9.7.2 The Khan Method

Khan method is the most generally used technique for sampling the K-N pdf. It does not believe any approximation and is valid for any energy of the incident photon. But it will allow perennial rejection before an acceptable value of x is found, consequently it is relatively expensive in its use of random numbers and computing time.

The method is based upon the composition-rejection technique; summarization of this technique will be described as follows:

Suppose that a given probability is capable to being expressed in the form of a finite sum of terms, thus

$$P(x) = \text{constant} \times \sum_{i=1}^{N} \alpha_i g_i(x) h_i(x), \tag{2.26}$$

Where $\sum_{i=1}^{N} \alpha_i = 1$

And for the range of x upon which P(x) is defined g_i and h_i has the following properties:

$g_i(x)$ is a pdf, and hence $\int g_i(x)dx = 1$

$0 \leq h_i \leq 1$, for i = 1,2,…..N

Then sampling can be made from P(x) in the following manner. Select a value of i with probability α_i and sample from $g_i(x)h_i(x)$ by the generalized rejection method, that is sample from pdf $g_i(x)$ by the inverse cumulative function method and from $h_i(x)$ by the rejection method.

2.9.8 ANGLES

This subroutine performs the vital task of determining the variables (θ_{n+1}, ϕ_{n+1}) which define the photon's new direction after a Compton scattering. The trigonometric relationships for the spherical triangle depicted in Fig (2.4) the trigonometric relationships can be solved to obtain the new values, because the program has knowledge of:

(a) The previous values of the angles Θ, φ (namely, θ_n, ϕ_n).

(b) The latest scattering angle (θ).

(c) The azimuthally angle of scattering (ϕ) which is assumed to be distributed uniformly in the range between ($0^0 - 360^0$).

2.9.9 SCORE

If a photon penetrates a slab thickness, its contribution to the score at the appropriate boundary should be recorded; this can be the essential purpose of SCORE. Therefore this subroutine should get answers to the following questions with respect to the next (postulated) collision point.

(a) Does the photon cross an interface, if so; the score at that interface must be appropriately adjusted.

(b) Can the photon still scatter once more in the system, bearing in mind that a number of slab thicknesses are being at the same time considered, or does the photon escape entirely.

To assist SCORE in these considerations, it is important to determine immediately on entry to the subroutine, the direction in which the photon is travelling (i.e. to the right or to the left).

The scoring photons are classified twice: (1) according to their z-value when they cross a boundary, (2) according to their position in the energy spectrum table.

This information is passed to subroutine OUTP for process in the final stages of the calculation. Recording a particle's contribution to the quantities of interest is an important part of any Monte Carlo treatment. The flow diagram for subroutine SCORE is shown in Fig. 2.9.

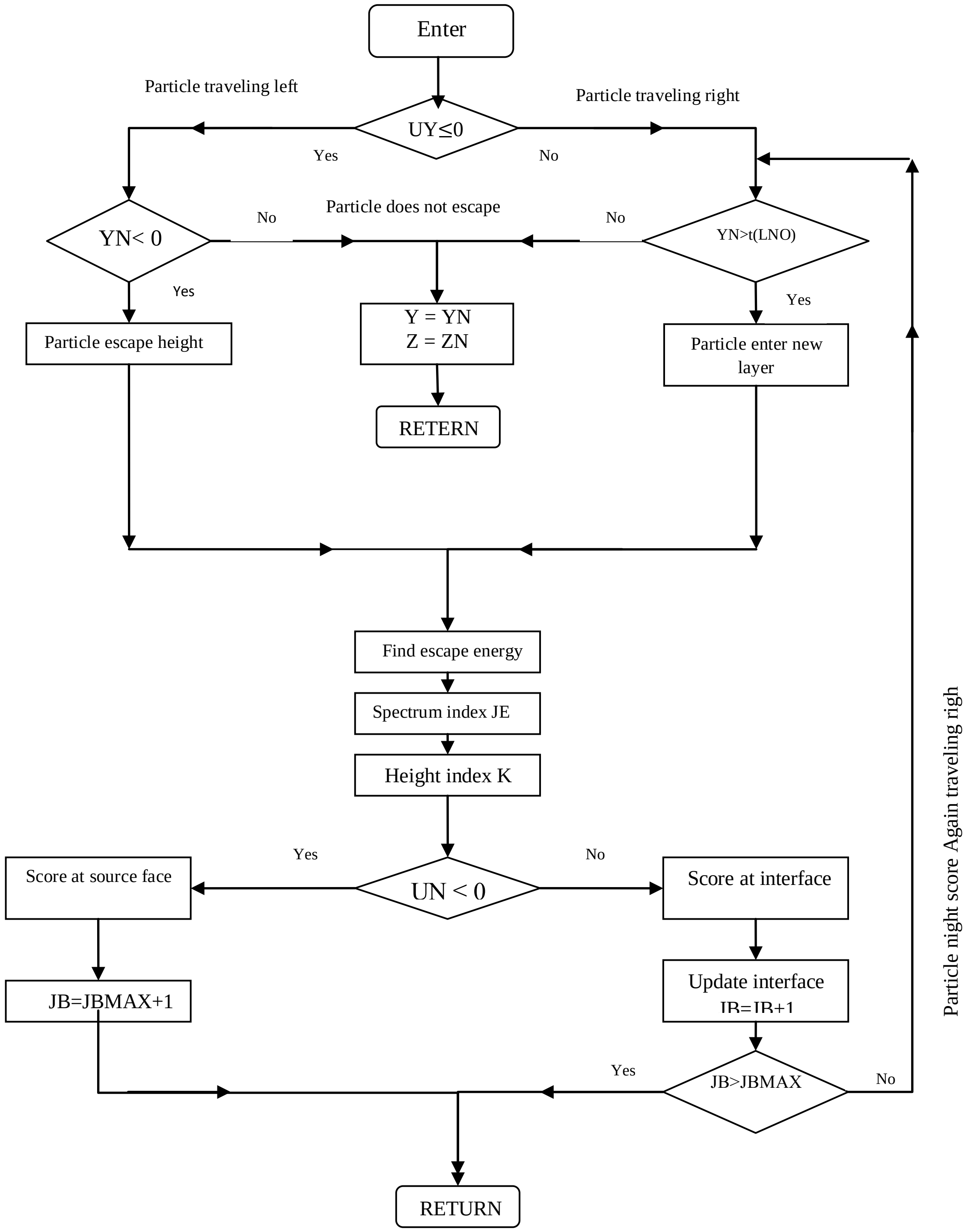

Fig (2.9) flow diagram of subroutine SCORE in modified program.

2.9.10 PAIR

The developed strategy of PAIR work flow is summarized in this section. Assuming that the pair production event will occur (E larger or equal to 1.022MeV), then pair production is considered to occur if ξ

$>\mu_c/(\mu_c+\mu_{pp})$, where ξ is a random number, lying between (0 and 1); otherwise, a Compton scattering takes place. In either event, the survival weight factor is given by SURV = $(\mu_c+\mu_{pp})/\mu$, where μ_c *and* μ_{pp} are given by:

$$\mu_c = (\frac{A_v}{A})\ Z\sigma_c \tag{2.27}$$

$$\mu_{pp} = (\frac{A_v}{A})\ \sigma_{pp} \tag{2.28}$$

Where

μ_c = attenuation cofficient of compton scattering

μ_{pp} = attenuation cofficient of pair production

A_v = Avogadro's number.

Z= Atomic number.

A = mass number.

σ_c = Compton cross section

σ_{pp} = pair production cross section.

The Compton cross section [Gold 59] and pair production cross section [Evan 55] are given by :

$$\sigma_c = \frac{3}{4}\left\{\frac{1+E}{E^3}\left[\frac{2E(1+E)}{1+2E}\ln(1+2E)\right]+\frac{1}{2E}\ln(1+2E)-\frac{1+3E}{(1+2E)^2}\right\} \tag{2.29}$$

$$\sigma_{PP} = \sigma_c Z^2\left(\frac{28}{9}\ln\left(\frac{2E}{m_0c^2}\right)-\frac{218}{27}\right) \tag{2.30}$$

2.9.11 RUSH

This subroutine is involved with a low weight or weak particle and decides its fate, weather continues its life history or not. Suppose that after a scattering collision a particle's survival weight is tested and found to be less than the low weight particle(given as p_{min}), say, a 1 in 10 chance of survival , this is implemented in the computer as follows : a random number $\xi 1$ within the range 0 to 1 ,is selected. If it is equal to or less than 0.1, the particle survival and, to avoid biasing, its weight is multiplied by 10 .if $\xi 1$ is greater than 0.1, the particle is killed and its life history is terminated this method called Russian roulette.

Russian roulette is that the colorful name given to a game. It could be argued that Russian roulette is not to be precise a variance reduction technique as it introduces an additional degree of randomness into the calculation. While this could be true in theory, the method is in practice, a very helpful mechanism whereby unimportant calculations may be considerably reduced and computing time significantly saved.

2.9.12 Interpolation “Intrp routine”

This is an auxiliary subroutine called “Intrp routine”. This routine is used to estimate unknown quantity between two known quantities. Interpolation method is useful when the data surrounding the missing data is available.

Lagrange Interpolation Polynomial method was applied on the basic data requird to construct the detailed data table of the attenuation absorption cofficients (μ).

Particular application, we generally require to interpolate in two-variables (energy E and attenuation absorption coefficient μ), the interpolation process can be performed in two stages. This “double interpolation procedure is readily understood when considering of Fig. (2.10):

Stage 1:

By interpolating with $E=E_{ph}$, for successive fixed values of μ, i.e., μ_1 , μ_2,

Stage 2:

The data represented by these new points are then interpolated for μ, $\bar{\mu}$ to find $\bar{\alpha}$.

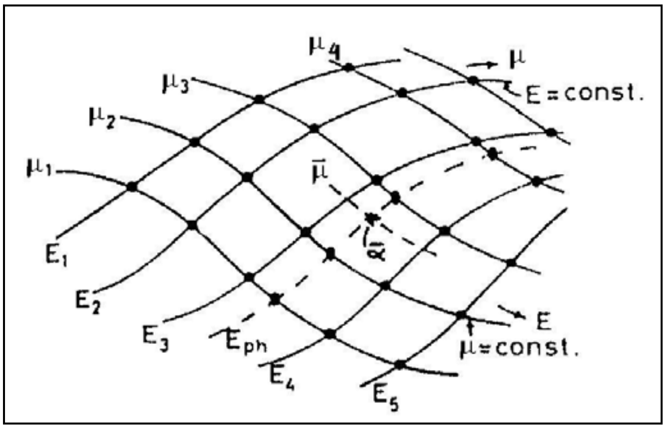

Fig (2.10) the surface formed by the data points. The points (●) are formed by interpolating along each curve μ=constant.

2.9.13 RANDX

This function provides the random numbers that are essential to the Monte Carlo method. The function RND [(n)] in this subroutine using Visual Basic program generates a single-precision random number between 0 and 1. In this function n is a numeric expression that specifies a value less than zero, zero, or more than zero. The RND function interprets every of these types of values as follows [MSDN]:

(i) If $n < 0$ supplies the same random number every time.

(ii) If $n = 0$ provides the last random numbers generated.

(iii) If $n > 0$ generates a new random number.

In our program, the value of (n) is chosen to be greater than zero.

Chapter Three

Results and Discussion

Chapter three

Result and Discussion

3.1 Introduction

This chapter carries a description and tabulations of the individual cross sections for scattering, absorption, and pair production that enter into the computation of the dose buildup factor using Monte Carlo simulation program.

This chapter is also devoted to supply well-established computer program that is based on the outcomes of Monte-Carlo approach to calculate the buildup factor of gamma ray for water and graphite as a protecting material. The selection of this protecting material is due to their importance in reactor shielding. The calculated values for buildup-factors are tabulated for energy range (4 to 10) MeV and for penetration depths from (1 to 5) mfp.

The variables that be studied are categorized in terms of abroad scale into two types. The first kind includes the variables combined within the accuracy of the results obtained through the application of the computer program of Monte Carlo simulation approach like number of scenarios (number of life histories for incident gamma rays), and number of interval energy slices used to partition the photon energy spectrum. These variables are known as simulation variables. The second type of variables are related to the physical properties (physical variables) that have affecting on the calculation of gamma rays buildup factor like the shield thickness, atomic number of the shield and the gamma ray energy. The physical variables are studied in the presence and absence the effect of pair production interaction. Before presenting the results, we will demonstrate the data entry to the simulation program that was designed and applied during this study.

3.2 Input Data

These entry data in the design computer program will be also categorized into two entry data sets:-

1. Table (3.1) lists the values of total mass attenuation coefficient data for air, in (cm^2/g) which corresponding to the energies values (the concept of exposure and exposure rate applies only to gamma rays or X-rays in air).

Table (3.1) the mass attenuation coefficient (μ /ρ) data for air in cm^2/g Corresponding to their energies values (in MeV) [wood 81]

Energy in MeV	μ_{air}/ρ	Energy in MeV	μ_{air}/ρ
30	0.0146	0.5	0.0297
20	0.0145	0.4	0.0295
15	0.0155	0.3	0.0287
10	0.0156	0.2	0.0268
8	0.0163	0.15	0.025
6	0.0173	0.1	0.0234
5	0.0182	0.08	0.0243
4	0.0195	0.06	0.0305
3	0.0211	0.05	0.0406
2	0.0237	0.04	0.0668
1.5	0.0256	0.03	0.148
1	0.028	0.02	0.512
0.8	0.0289	0.015	1.27
0.6	0.0296	0.01	4.63

2. Table (3.2) lists the mass attenuation coefficients data, in cm^2/g, for water and graphite. Figures (3.1 A and B) indicating the behavior of total mass attenuation coefficients with Compton scattering, photoelectric absorption and pair production as functions of energy. The mass

attenuation coefficients for water and graphite and presented in table (3.2) is calculated by using Xcom program [Xcom].

Table (3.2) the total mass attenuation coefficient μ/ ρ (cm^2/g) for Compton scattering μ_c/ρ and pair production μ_{pp}/ρ for water and graphite corresponding to energy interval (in MeV) mesh data [Xcom]

Energy in	H_2O			C		
MeV	μ_c/ρ	μ_{pp}/ρ	μ_{total}/ρ	μ_c/ρ	μ_{pp}/ρ	μ_{total}/ρ
0.5	0.09663	0	0.09665	0.08699	0	0.08700
0.6	0.08939	0	0.0894	0.08047	0	0.08048
0.8	0.07856	0	0.07857	0.0707	0	0.07070
1	0.07066	0	0.07066	0.06358	0	0.06358
1.022	0.06991	0	0.06991	0.06292	0	0.06293
1.25	0.06318	0.000017	0.0632	0.05686	0.0000143	0.05687
1.5	0.05742	0.000098	0.05752	0.05169	0.0000799	0.05117
2	0.04901	0.00039	0.0494	0.0441	0.0003187	0.04442
3	0.03855	0.001117	0.03968	0.0347	0.000912	0.03562
4	0.03216	0.001812	0.03402	0.02894	0.001482	0.03047
5	0.0277	0.00243	0.03031	0.02499	0.001988	0.02708
6	0.02454	0.002987	0.0277	0.02209	0.002445	0.02469
7	0.02206	0.003482	0.02577	0.01985	0.002851	0.02291
8	0.02008	0.003927	0.02429	0.01807	0.003218	0.02154
9	0.01846	0.004334	0.02313	0.01661	0.003551	0.02047
10	0.0171	0.004699	0.02219	0.01539	0.003854	0.01956

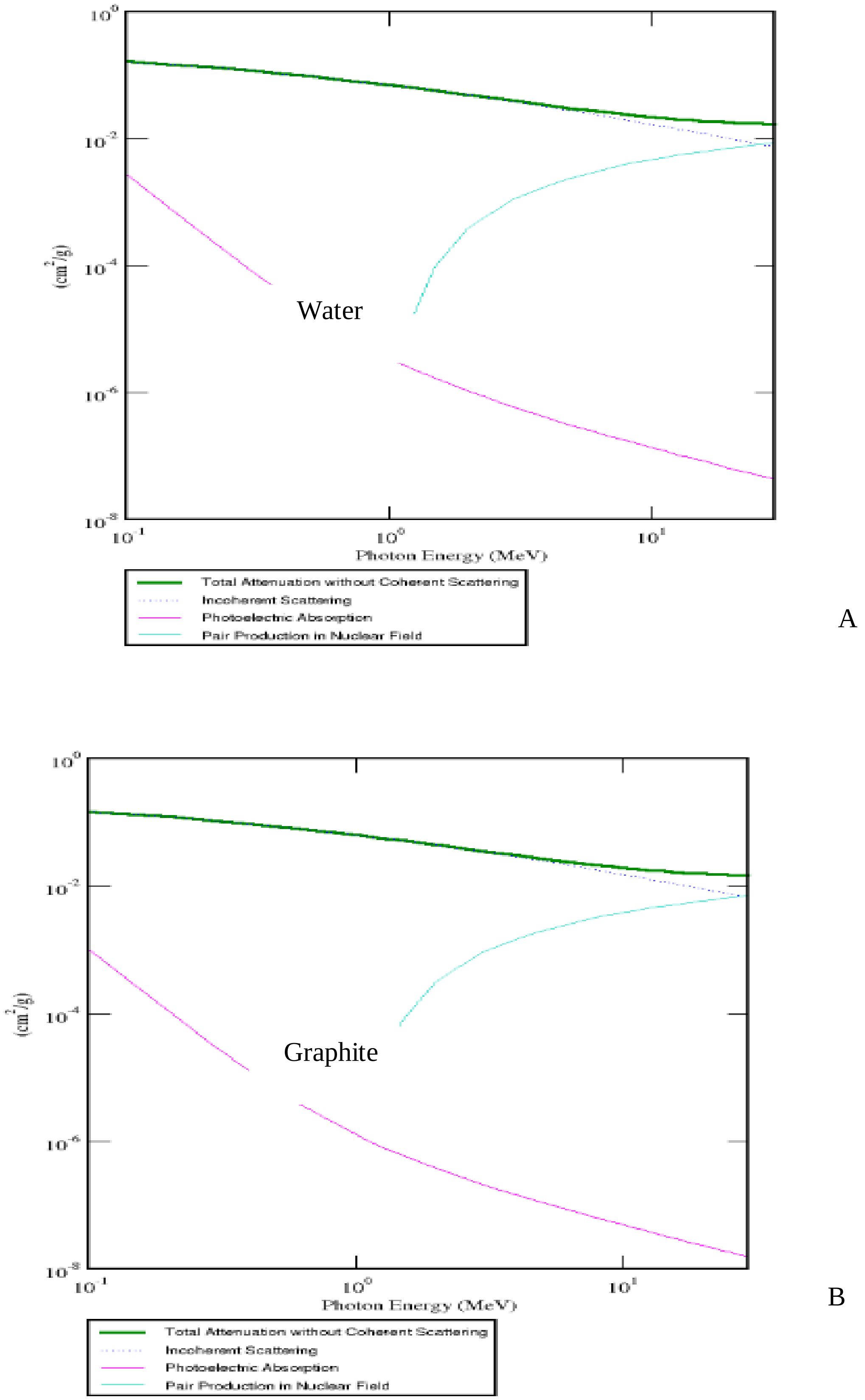

Fig (3.1) the behavior of mass attenuation coefficient versus photon energy, for (A) water, (B) Graphite

3. Compton cross section and Pair production cross section; the corresponding cross section data at each energy interval mesh (0.5 – 10) MeV in (barn/atom) were extracted and tabulated in table (3.3) for water and graphite. The cross section for water and graphite and presented in table (3.3) is calculated by using Xcom program [Xcom].

Table (3.3) the cross section (barn/atom) for Compton scattering σ_c and pair production σ_{pp} for water and graphite corresponding to energy interval in MeV mesh data [Xcom]

Energy in MeV	H_2O (barn/atom)			C (barn/atom)		
	σ_c	σ_{pp}	σ_{total}	σ_c	σ_{pp}	σ_{total}
0.5	2.8905	0	2.8905	1.735	0	1.735
0.6	2.6739	0	2.6739	1.605	0	1.605
0.8	2.3481	0	2.3481	1.410	0	1.410
1	2.1136	0	2.1136	1.268	0	1.268
1.022	2.0912	0	2.0912	1.255	0	1.255
1.25	1.88989	0.000508	1.8904	1.134	0.000287	1.134
1.5	1.7175	0.002931	1.7205	1.031	0.001594	1.033
2	1.466	0.01166	1.4777	0.8795	0.006356	0.8859
3	1.15309	0.03323	1.1863	0.692	0.0182	0.7104
4	0.9619	0.05384	1.0158	0.5772	0.02955	0.6077
5	0.8304	0.0726	0.903	0.4985	0.03966	0.5401
6	0.734	0.08914	0.82321	0.4406	0.04876	0.4924
7	0.6598	0.1041	0.7708	0.3960	0.05686	0.4570
8	0.60066	0.11746	0.71812	0.3604	0.06418	0.4297
9	0.5521	0.1296	0.6918	0.3312	0.07082	0.4082
10	0.51151	0.14056	0.65207	0.3069	0.07686	0.3908

3.2.1 Simulation variables

The following simulation parameters were considered as:

1. The Maximum number of life histories for gamma rays should be determined with minimum error or acceptance accuracy. This variable was taken in our consideration and will be displayed later.
2. Total numbers of coarse mesh energies corresponding to the basic cross section information should be assigned in the simulation program. In this study the applied energy is partition into 28 coarse mesh interval which cover the energy range (0.01 – 30) MeV.
3. Number of photon intervals needed in the photon energy spectrum table. This variable was taken in our consideration and will be displayed later.

3.2.2 Physical parameters

The following physical parameters were considered:

1. Thickness of the shield material in terms of mean free path: the range of shield thickness values was taken up to 5 mfp.
2. Density of the shielding materials: the density for the selected shielding materials are (1 and 7.8) g/cm^3 for water and graphite respectively.
3. The atomic number (Z) for selected shielding materials, in this study two shielding materials were chosen water (effective atomic number Z_{eff} = 7.42) and graphite (Z= 6).
4. Cutoff energy; when photon energy becomes less than cutoff energy, its life history is terminated. In this work, the cutoff energy is taken to be 0.019MeV for water and 0.022MeV for graphite.
5. Conservation factor for the slab materials (from barn/atom to cm^2/g) is set equal to N_A*10^{-24}/A; so, for water = 0.03343 and for graphite equal to 0.05014 for the interaction of gamma with the matter.

3.3 The Effect of the Shielding Design Parameters

These parameters are concerned with the accuracy of the program results obtained through the application of the method of Monte Carlo. It ought to be mentioned that these parameters were studied in the absence and presence the effect of Compton scattering and pair production interactions.

3.3.1 The number of photons scenarios

Iteration is that the act of repetition process, either to generate a boundless sequence of outcomes, or with the aim of approaching a desired goal, target or result. Every repetition of the process is also called "iteration". The results of one iteration are used as the starting point for subsequent iteration.

Table (3.4) illustrates the values of the standard deviation of buildup-factor of a simulation versus the iteration number for graphite layer with thickness 1mfp; the selected photon energy is 10 MeV.

Figures (3.2) and (3.3), present the behavior of standard deviation versus photon scenarios number for graphite layer with thickness (1mfp) for photon energy 10 and 1 MeV respectively.

It is clear from these figures that the accuracy of calculation in our simulation program is based on the number of iteration (number of photons scenarios), more iteration will lead to more convergence (i.e., stability) in the calculation of the simulated buildup factor.

However, the analyst should decide what degree of precision needed. It is important to take into consideration that large numbers of photons simulate mean more runtime.

In this study 20000 number of life histories are adopted for gamma rays (number of photons scenarios) to get simulated value of gamma ray buildup factor with more convergence. This value of iteration corresponds to 0.00835 standard deviation value

Table (3.4) the standard deviation of buildup factor versus the number of iteration for Graphite layer with 1mfp and E= 10MeV

No.	Iteration number	Standard deviation (STD)	No.	Iteration number	Standard deviation (STD)
1	100	0.1215	12	15000	0.0096
2	200	0.0834	13	20000	0.0083
3	400	0.0595	14	25000	0.0074
4	600	0.0489	15	30000	0.0068
5	800	0.0421	16	35000	0.0063
6	1000	0.0376	17	40000	0.0055
7	2000	0.0266	18	45000	0.0055
8	4000	0.0187	19	50000	0.0052
9	6000	0.0153	20	55000	0.0055
10	8000	0.0132	21	60000	0.0052
11	10000	0.0118			

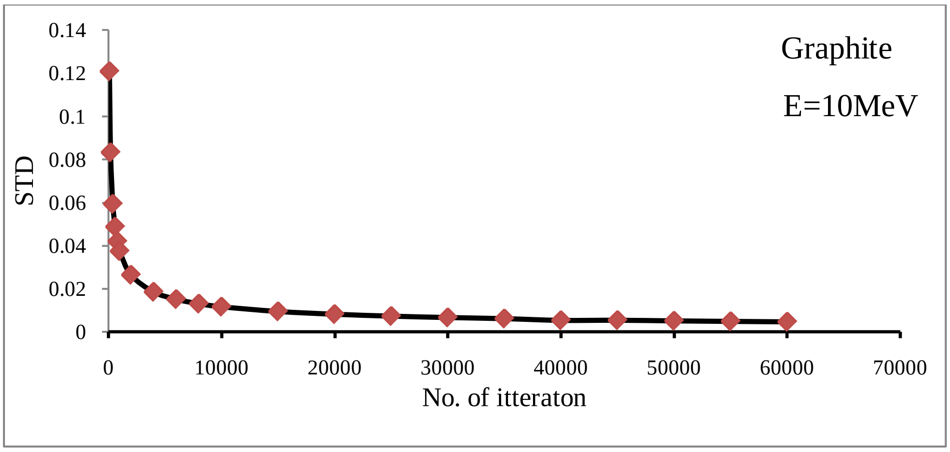

Fig (3.2) the variation on iteration numbers versus of the standard deviation of the simulated buildup-factor for Graphite layer with 1 mfp and E=10MeV

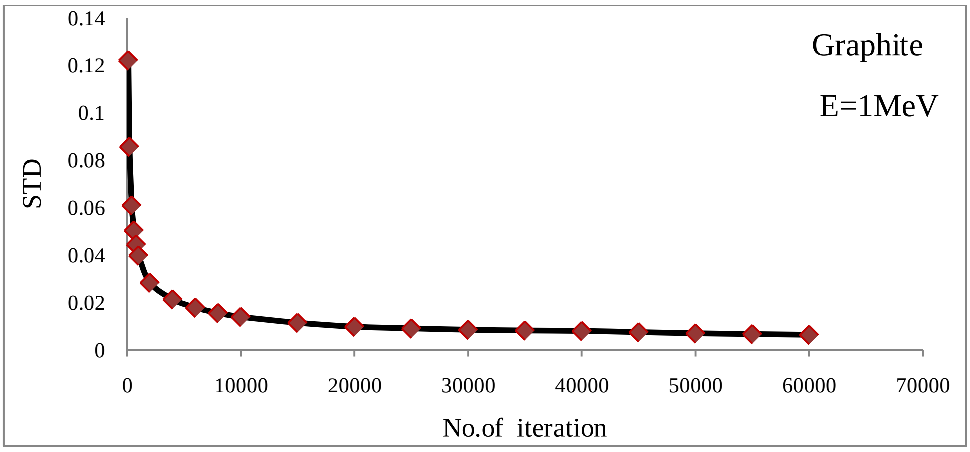

Fig (3.3) the variation on iteration numbers versus of the standard deviation of the simulated buildup-factor for Graphite layer with 1 mfp and E= 1MeV

3.3.2 Number of energy intervals

This parameter represents the number of intervals used to describe the range of photon energy spectrum. Figure (3.4) shows the effect of the standard deviation of buildup factor as a function of interval number. This figure is taken for graphite material for energy 10 MeV and thickness 1 mfp.

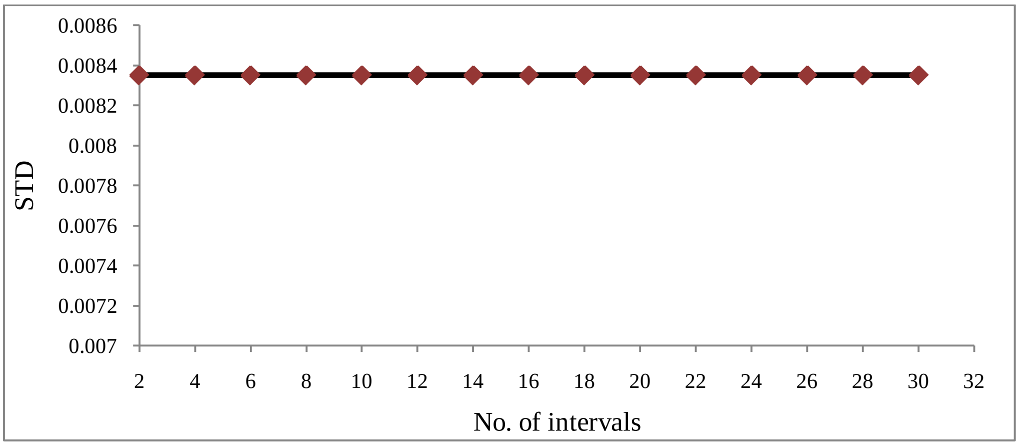

Fig (3.4) the effect of standard deviation of buildup factor as a function of interval number for Graphite layer with 1 mfp and E= 10MeV

It is clear from figure (3.4) that there is no difference in standard deviation of the simulated buildup factor when the interval number increased or decreased. As a result, the interval value is set 12 and considered as fixed parameter in all the present work calculations.

3.4 Test Run of the simulated program

Before we start to present the results of the physical parameters, it has been testing the initial run of the simulation program to calculate the gamma ray buildup-factor for graphite layer with a thickness below to 5 mfp and for photon energies 1 MeV and 10 MeV.

10 MeV means that the pair production effect plays a very important role in the interaction of gamma rays. For this reason we expect that the result of a buildup-factor of gamma ray will be affected accordingly. The tabulation of the results of the calculation the buildup for thickness and energy mentioned above presented in table (3.5)

Table (3.5) gamma ray Buildup factors with and without pair production for Graphite layer below to 5 mfp at energies 1MeVand 10MeV

Thickness mfp	E= 1MeV		E= 10MeV	
	B with pair production	B without pair production	B with pair production	B without pair production
1	1.7976	1.7976	1.337	1.293
1.5	2.2615	2.2615	1.499	1.421
2	2.8397	2.8397	1.642	1.569
2.5	3.477	3.477	1.789	1.712
3	4.219	4.219	1.938	1.811
3.5	4.998	4.998	2.027	1.962
4	5.908	5.908	2.177	2.023
4.5	7.0938	7.0938	2.251	2.263
5	8.369	8.369	2.447	2.179

3.5 The Effect of Physical Parameters on Buildup Factor

There are many variables (shield thickness, type of the shield, energy of radioactive source,...) affect the values of gamma ray dose buildup factor. In this section, some of these variables will be taken in our consideration and be presented as follows:

3.5.1 Thickness effect

Before we start to present the effect of layer thickness of shielding material, it will present the result of shielding thickness in cm for 1mfp as a function of energy for water and graphite. Table (3.6) presents the results of this effect for water within energy range (1-10) MeV for 1 mfp thickness.

Table (3.6) the variation of shielding thickness in cm corresponding 1 mfp within the energy range (1-10) MeV for water and graphite

Water (1mfp)		Graphite(1mfp)	
E(MeV)	X(cm)	E(MeV)	X(cm)
1	14.152	1	15.728
4	29.394	4	32.81
6	36.101	6	40.5
8	41.203	8	46.99
10	45.065	10	51.97

Figure (3.5) present the relation between graphite shielding thickness in cm corresponding to 1mfp as a function of energy range (1-10) MeV.

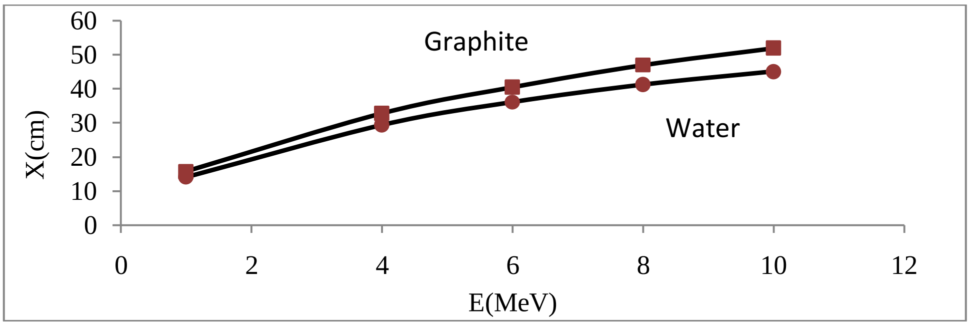

Fig (3.5) the variation of shielding thickness in cm corresponding 1 mfp within the energy range (1-10) MeV for water and graphite.

It is clear from table (3.6) for water and figure (3.5) for graphite that the thickness in cm corresponding to 1 mfp increased when the photon energy increased. This behavior can be interpreted as follows, increasing photon energy means that the photon has the ability to penetrate in the material before it reach to the next collision.

The next tables and figures present the effect of thickness on the calculation of gamma ray dose buildup factor. The calculated values of dose buildup factor for water and graphite with different thickness values (1 – 5) mfp for energies up to 10 MeV are presented in tables (3.7) and (3.8) respectively.

The results in tables (3.7) and (3.8) are reflected in figures (3.6) and (3.7) respectively.

Table (3.7) effect of thickness on Buildup factor with pair production of water layer for different energy values

Thickness in mfp	buildup factor			
	4MeV	6MeV	8MeV	10MeV
1	1.460 ± 0.008	1.368 ± 0.008	1.304 ± 0.008	1.244 ± 0.008
1.5	1.682 ± 0.012	1.531 ± 0.012	1.422 ± 0.012	1.353 ± 0.012
2	1.914 ± 0.018	1.689 ± 0.018	1.538 ± 0.018	1.458 ± 0.018
2.5	2.119 ± 0.025	1.869 ± 0.025	1.666 ± 0.025	1.555 ± 0.024
3	2.308 ± 0.035	1.979 ± 0.034	1.760 ± 0.033	1.661 ± 0.032
3.5	2.513 ± 0.048	2.085 ± 0.045	1.832 ± 0.043	1.702 ± 0.042
4	2.719 ± 0.064	2.284 ± 0.061	1.934 ± 0.057	1.759 ± 0.055
4.5	2.903 ± 0.085	2.522 ± 0.083	2.114 ± 0.077	1.810 ± 0.071
5	3.062 ± 0.111	2.708 ± 0.108	2.237 ± 0.100	1.959 ± 0.093

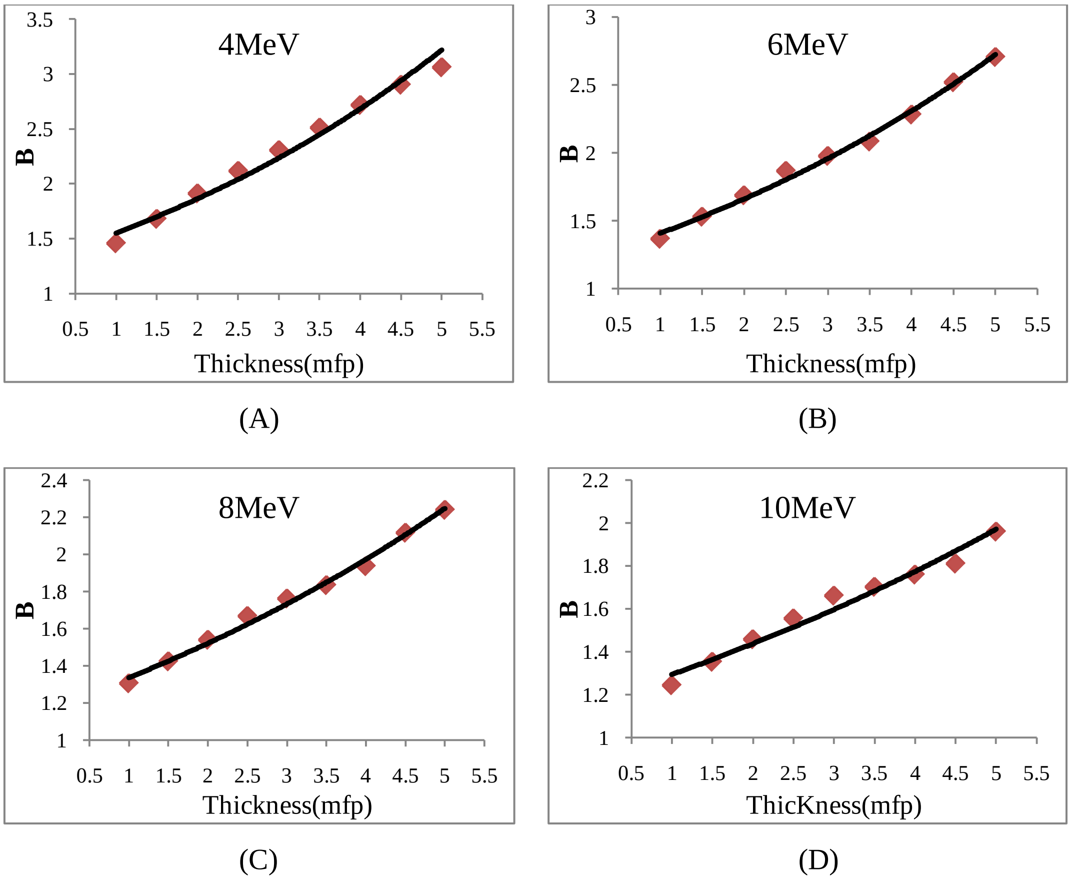

Fig (3.6) dependence of buildup factor on the thickness of the water layer for energies (A) 4MeV, (B) 6 MeV, (C) 8 MeV and (D) 10 MeV.

Table (3.8) effect of thickness on Buildup factor for pair production of graphite layer for different energy values

Thickness in mfp	Buildup factor			
	4MeV	6MeV	8MeV	10MeV
1	1.601 ± 0.008	1.486 ± 0.008	1.409 ± 0.008	1.337 ± 0.008
1.5	1.905 ± 0.013	1.715 ± 0.013	1.579 ± 0.013	1.499 ± 0.013
2	2.214 ± 0.020	1.931 ± 0.019	1.756 ± 0.019	1.642 ± 0.018
2.5	2.498 ± 0.029	2.193 ± 0.028	1.929 ± 0.026	1.789 ± 0.026
3	2.764 ± 0.040	2.359 ± 0.038	2.028 ± 0.036	1.938 ± 0.035
3.5	3.083 ± 0.056	2.533 ± 0.051	2.203 ± 0.048	2.027 ± 0.046
4	3.371 ± 0.077	2.827 ± 0.071	2.351 ± 0.065	2.177 ± 0.061
4.5	3.691 ± 0.105	3.128 ± 0.096	2.613 ± 0.088	2.251 ± 0.085
5	3.897 ± 0.137	3.441 ± 0.130	2.793 ± 0.116	2.447 ± 0.106

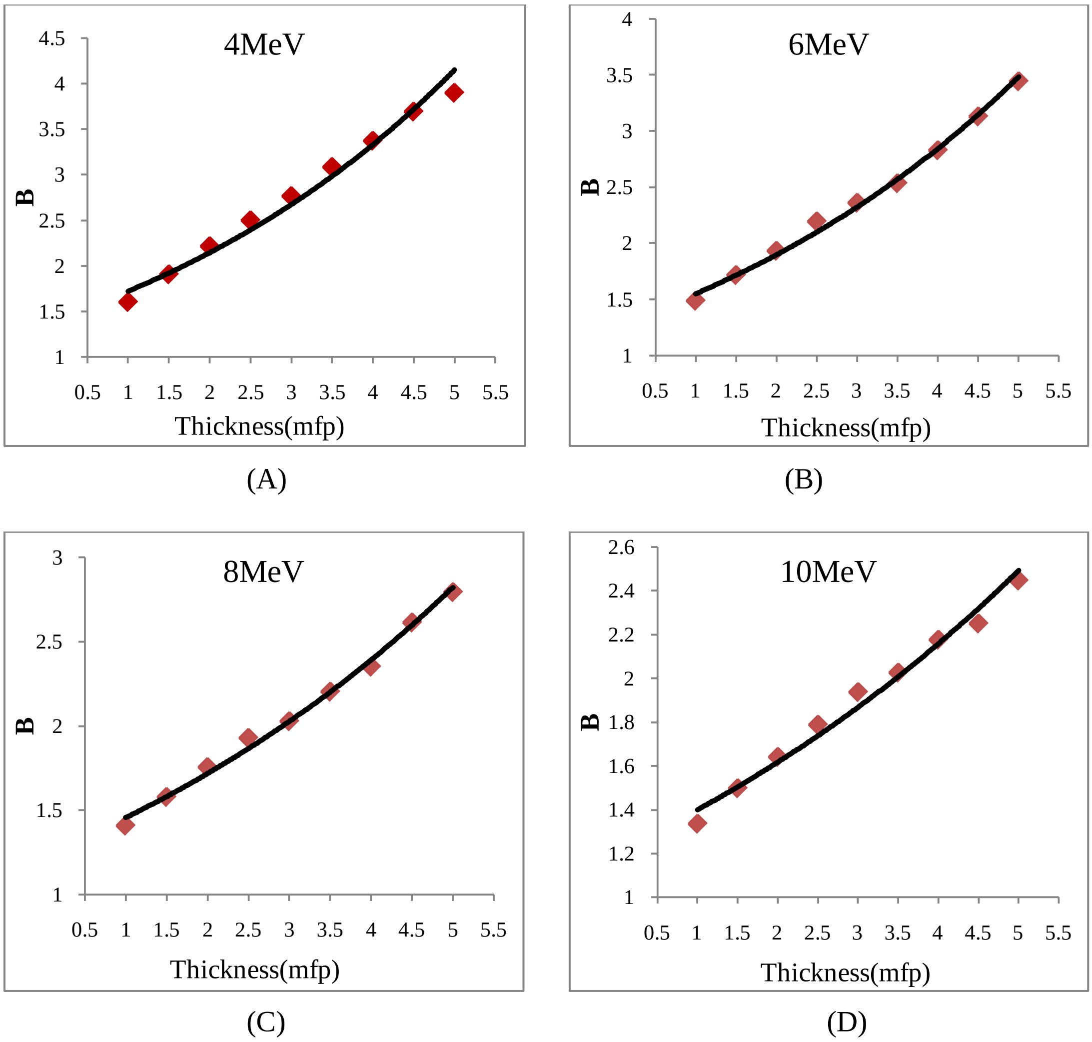

Fig (3.7) dependence of buildup factor on the thickness of the graphite layer for energies (A) 4MeV, (B) 6 MeV, (C) 8 MeV and (D) 10 MeV.

It is clear from these figures that the gamma ray dose buildup factor increases when the shield thickness increased. This behavior can be seen for both water and graphite. The justification behind the increasing of gamma ray dose buildup factor when the shielding thickness of the material is increasing, due to the probability of the scattering within the little angles with increasing of thickness.

3.5.2 Atomic number effect

To study the effect of shielding atomic number (Z) on the calculation of gamma ray dose buildup factors. A set of test results from the simulation program were tabulated in table (3.9) to discuss this effect for water (effective atomic number Z_{eff} = 7.42) and graphite (Z = 6) for the energy 10 MeV and shielding thickness up to 5 mfp.

Table (3.9) buildup factor for Graphite and Water at energy 10 MeV

E = 10MeV		
Thickness in mfp	Buildup factor	
	C	H_2O
1	1.337 ± 0.008	1.244 ± 0.008
1.5	1.499 ± 0.013	1.353 ± 0.012
2	1.642 ± 0.018	1.458 ± 0.018
2.5	1.789 ± 0.026	1.555 ± 0.024
3	1.938 ± 0.035	1.661 ± 0.032
3.5	2.027 ± 0.046	1.702 ± 0.042
4	2.177 ± 0.061	1.759 ± 0.055
4.5	2.251 ± 0.085	1.810 ± 0.071
5	2.447 ± 0.106	1.959 ± 0.093

It is clear from the results presented in table (3.9) that the dose buildup factor for graphite higher than that for water for all the cases of the thickness in mfp at energy 10 MeV. The same behavior can be noticed for energy 8, 6, 4 and 1 MeV as shown in tables (3.7), (3.8) and figure (3.8). The interpretation behind this behavior agrees with what be discussed before in chapter one, since the contribution of Compton effect (the main factor affecting on the calculation of gamma ray build up factor) relative to the total effect increases when the atomic number decreases. This behavior is very clear at energy 1 MeV in figure (3.8) for both shielding materials graphite and water because the contribution of Compton scattering effect increases when the energy decreases.

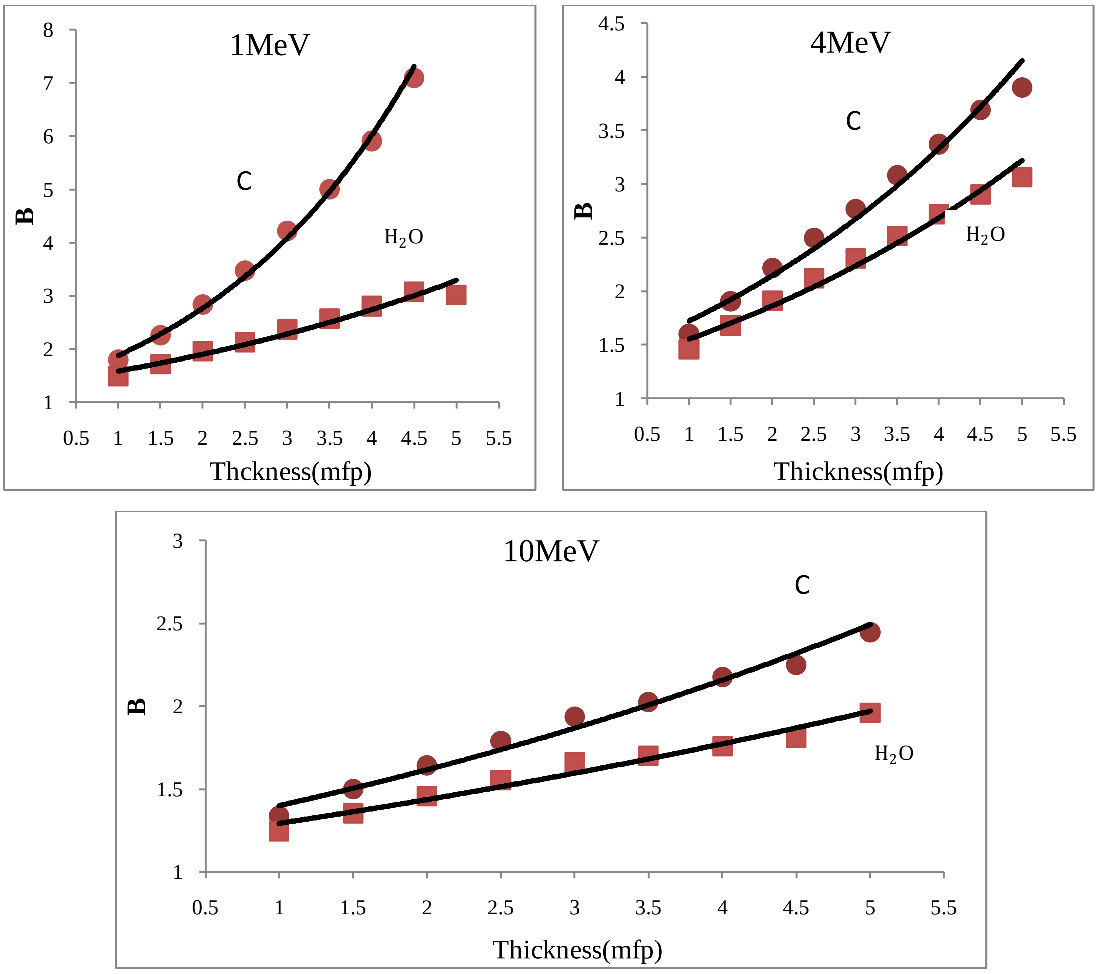

Fig (3.8) dependence of Buildup factor on thickness of the material layer for Graphite and water for 1MeV, 4 MeV and 10 MeV

3.5.3 Energy effect

To study the effect of energy for plane isotropic source in finite medium on the calculation of gamma ray dose buildup, four initial energy values 4, 6, 8 and 10 MeV were applied for the two adopted shielding materials and for thicknesses up to 5 mfp. This range of energy have been chosen because the effect of pair production interaction start to be predominant compared with the other type of gamma interactions (see figure (3.1)), and this is one of the most necessary objective in this study.

The results tabulated in table (3.7) and presented in figure (3.9) for water, and table (3.8) and presented in figure (3.10) for Graphite, indicated that the gamma ray dose buildup factor is inversely proportional with energy. Among the studied energy range (4 - 10) MeV this act was detected for the two materials which are studied in this research and within the range of energy (4 - 10) MeV.

This behavior may be interpreted as follows. First, when the energy is increased, the probability of Compton effect decrease, this fact is also discussed in chapter one, since the Compton effect is inversely proportional with energy. Second, the penetrating ability for gamma radiation is also increase and this, in turn; leads to an decrease in the probability of scattering with small angels and finally it is reflected on the calculation of buildup factor (the scattering with mall angels plays a very important role in the calculation of buildup factor).

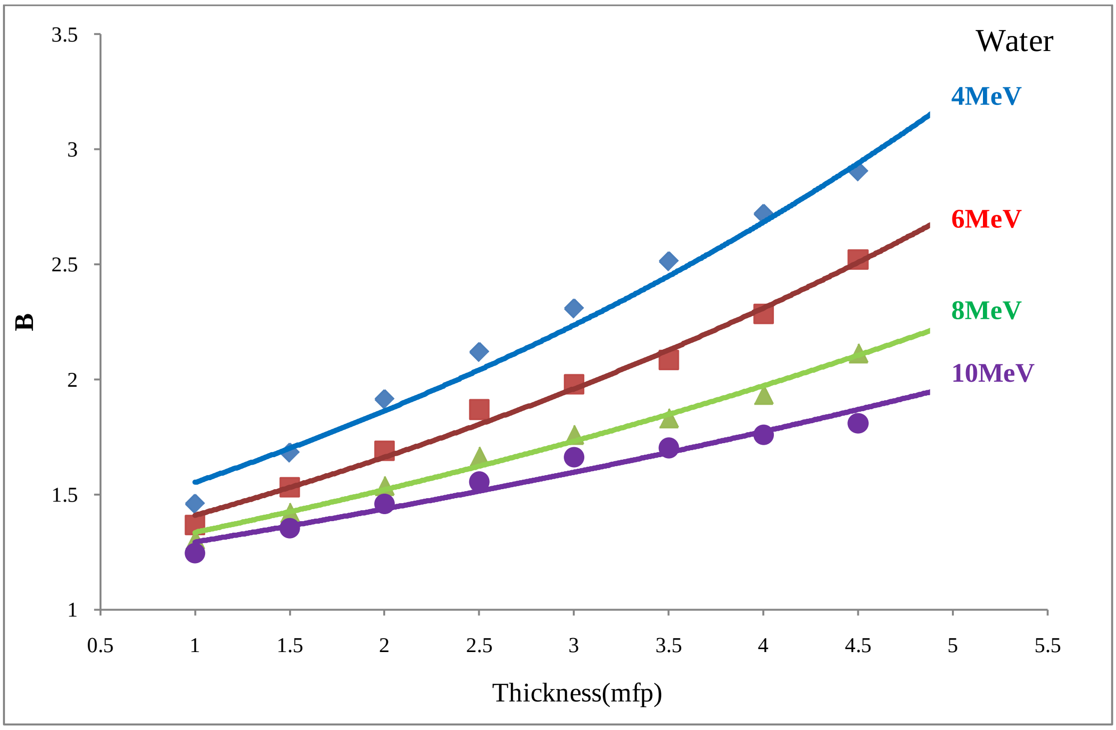

Fig (3.9) effect of source energy on the calculation of gamma dose buildup factor for Water layer

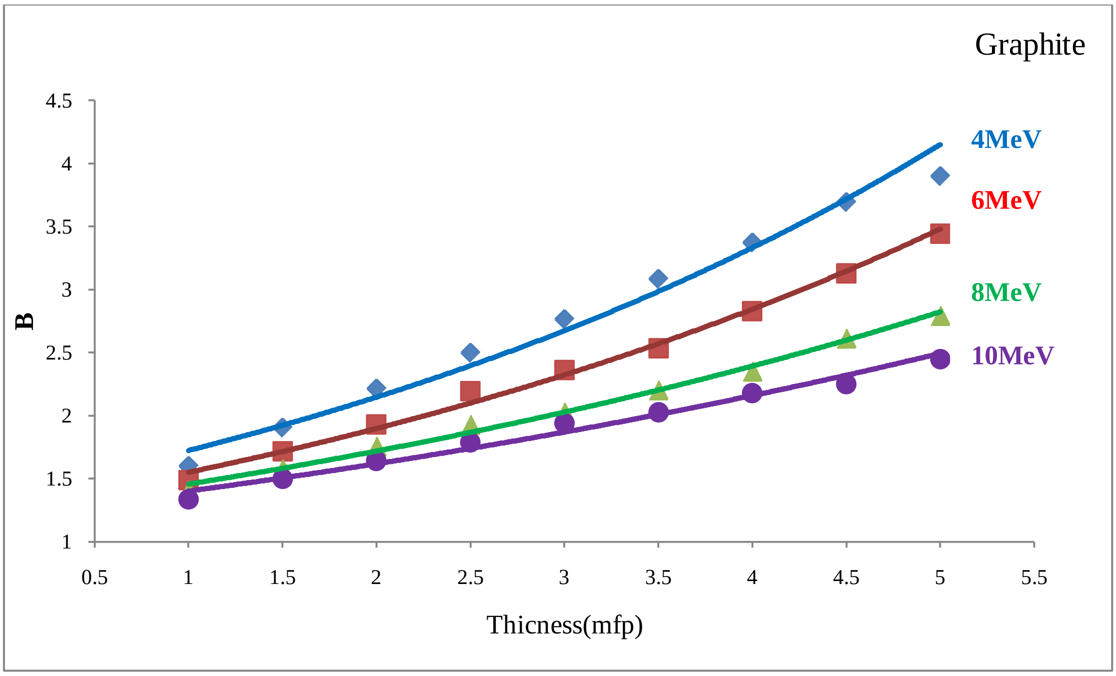

Fig (3.10) effect of source energy on on the calculation of gamma dose Buildup factor for Graphite layer

3.6 Buildup factor in the Presence and Absence Annihilation

In order to examine the variations between the buildup factor values of gamma ray in the absence and presence the effect of annihilation, the simulation program was executed in the absence of annihilation effect (i.e., considering the contribution of Compton scattering interaction only).This check is accomplished by ignoring the contribution effect of pair production, at first, and only taking in the consideration the effect of Compton scattering. The second check, both interactions contribution (Compton and annihilation) are taken into consideration.

In both cases, the program was executed for the two selected material and for the energy range (4 - 10) MeV and for thickness up 5mfp. The results of this effect demonstrated in figures (3.11) and (3.12) for water and graphite respectively. It is clear from these figures that the calculated values of dose buildup when the contribution of pair production is ignored less in comparison when the contribution of pair production is taken in consideration.

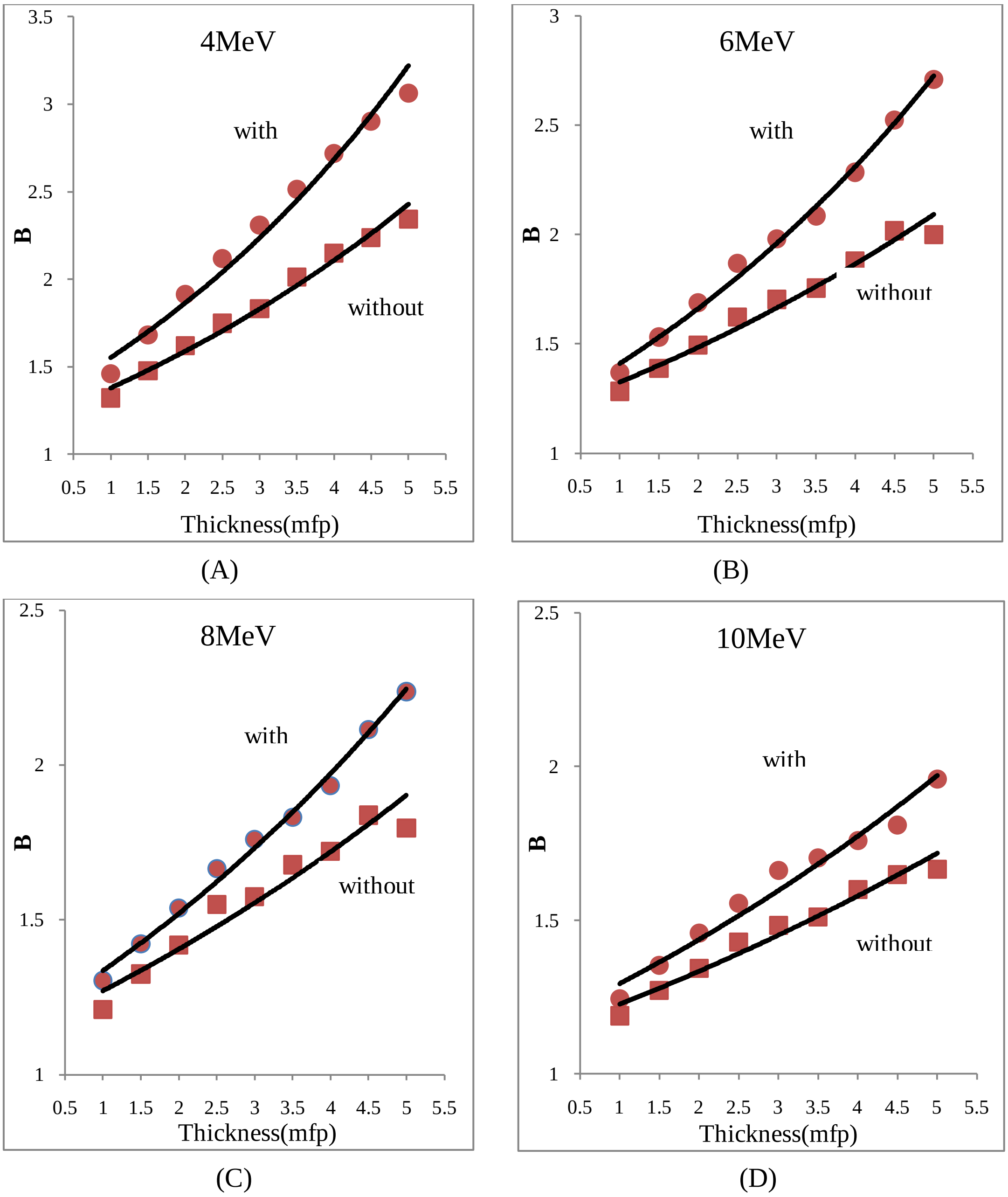

Fig (3.11) comparison The Buildup factor with and without effect of pair production, for water layer at source energy is (A) 4MeV, (B) 6MeV ,(C) 8MeV and (D) 10MeV

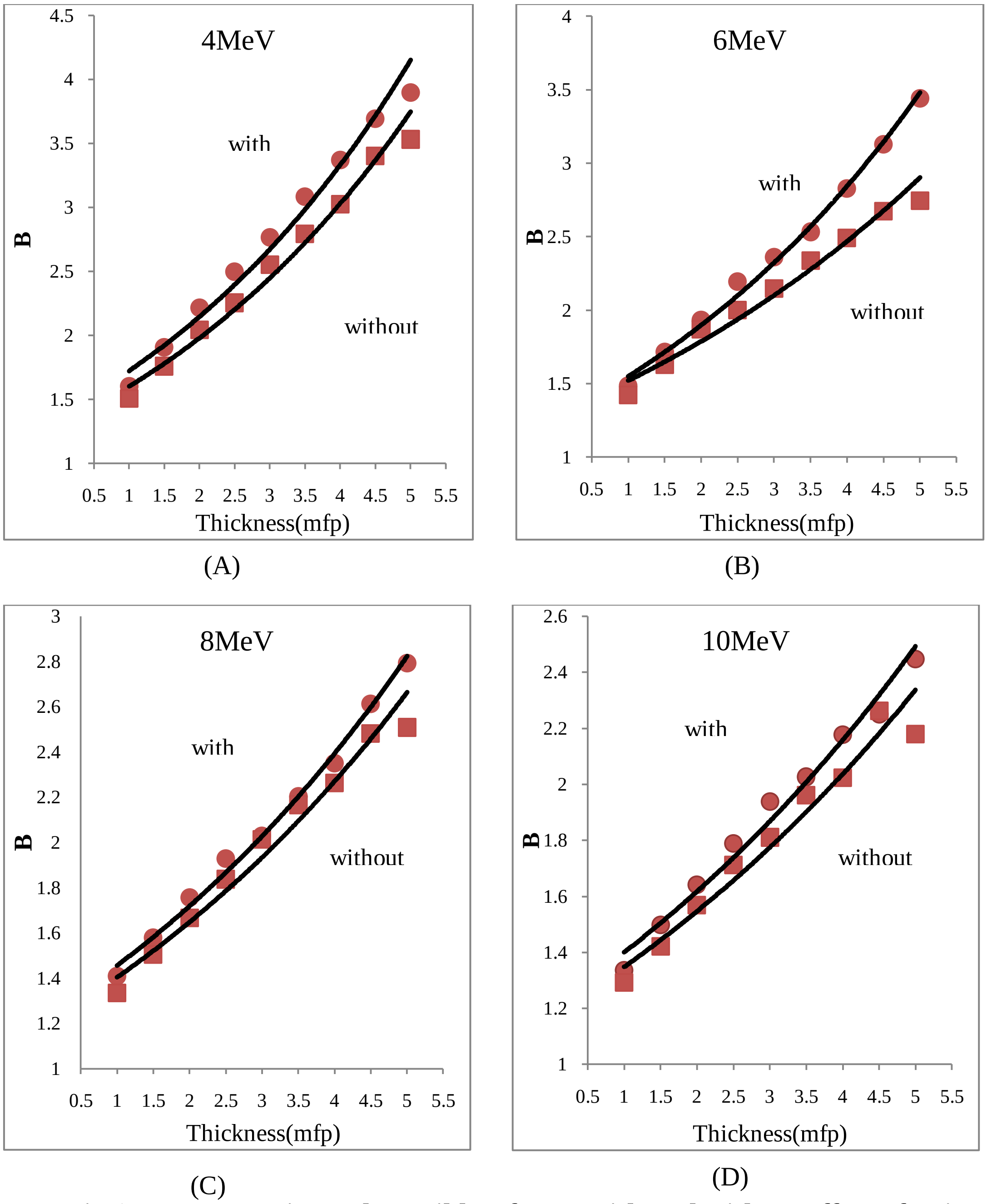

Fig (3.12) comparison The Buildup factor with and without effect of pair production, for graphite layer at source energy is (A) 4MeV, (B) 6MeV, (C) 8MeV and (D) 10MeV

To understand the amount of this contribution with energy, the relationship between the ratio for dose build up factor in presence the contribution of annihilation and dose build up factor in absence the contribution of annihilation as a function of energy is calculated and demonstrated in figures (3.13) and (3.14) for water and graphite respectively.

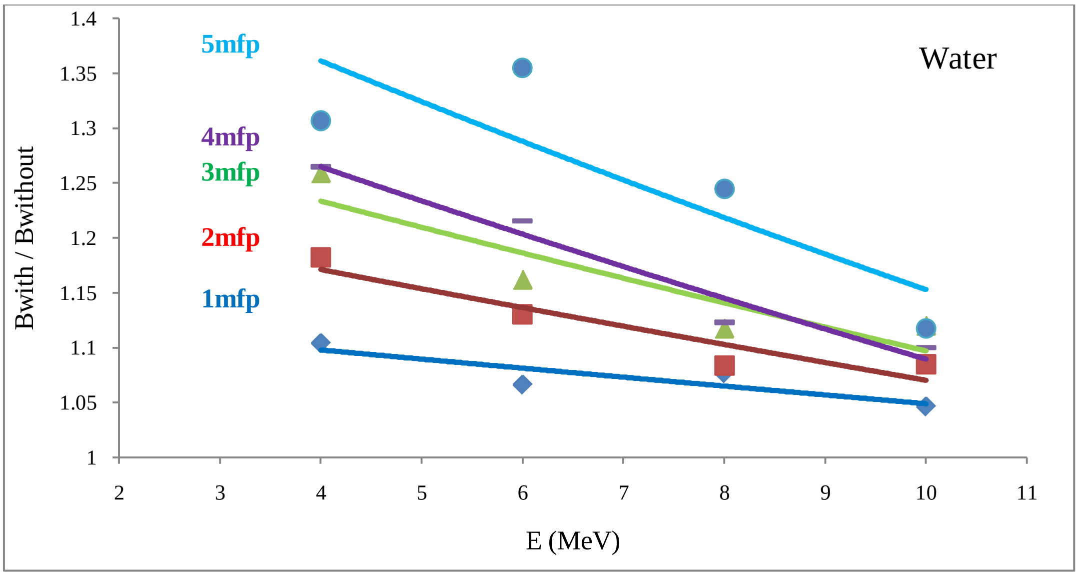

Fig (3.13) the ratio between dose buildup factor with and without the contribution of annihilation effect as a function of energy for water for different cases thickness in mfp

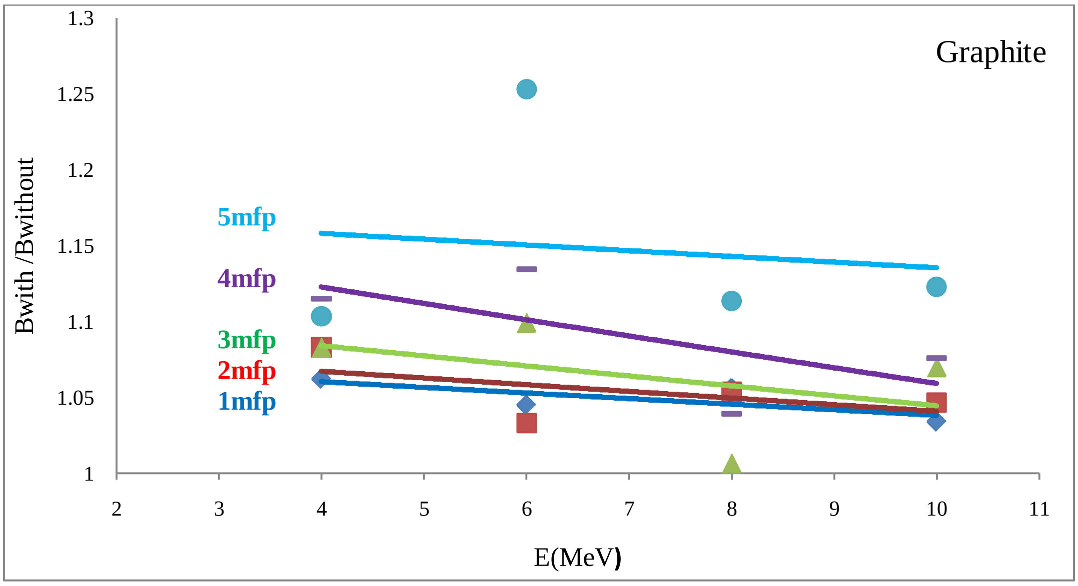

Fig (3.14) the ratio between dose buildup factor with and without the contribution of annihilation effect as a function of energy for graphite for different cases thickness in mfp

It is clear from figures (3.13) and (3.14) the ratio decreases when the energy increases, this means that contribution of Compton effect is still more predominant than the effect of annihilation within the range of energy adopted in this research.

Finally, a comparison of the results which can be obtained from the simulation program performed in this research and the previously publish results is shown in figure (3.15).

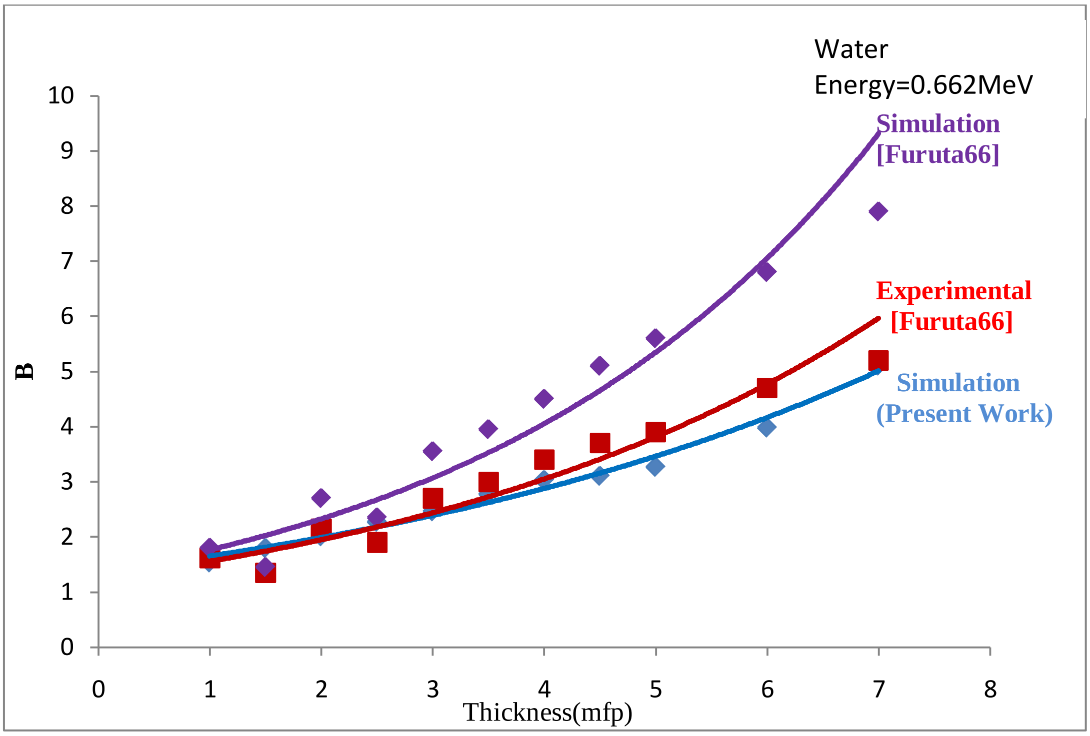

Fig (3.15) some of compassion between the results of the previous work and the results which can be obtained from the present work

It is clear from figure (3.15) that the results obtained from the performed Monte Carlo simulation program in this study are very closer to the published experimental results (error = 10.4%)[Furuta 66] in comparison with Monte Carlo simulation results obtained from [Furuta 66] at energy 0.662 MeV (error = 40.58%). It should be mentioned that the comparison with experimental result is the best way to judge on the accuracy of the results obtain theoretically.

Chapter Four

Summary, Conclusions and Suggestions for Future Works

Chapter Four

Summary, Conclusions and Suggestions for Future Work

4.1 Summary

In this study gamma ray buildup factor for two shielding materials water (Z_{eff} =7.42) and graphite (Z=6) within the energy range 4-10 MeV and up to 5 thickness mean free path has been studied. To achieve this study a simulation computer program has been written (Visual Basic language version G) and applied depending on Monte Carlo simulation method.

The essential thought of the program include real radiation behavior description and prediction of its random movement through the media. This strategy can be utilized to simulate a traditional problem (classic) resulting from the fall of the beam on the flat slide works as attenuator for gamma rays. The radioactive source geometry adopted in the study is mono energetic normal plane source

This study has been examining a number of variables related to the program design called simulation variables like number of gamma scenarios, number of divisions for energy.

This research has been included the study of the effect of some physical variables like, energy for the incident photon, shield thickness, and atomic number for adopted shielding material on the calculation of gamma ray dose buildup factor.

In this research the contribution of annihilation effect on the calculation of gamma ray dose buildup factor has been studied within the adopted energy range.

4.2 Conclusions

The main conclusion can be yielded from the results dose build up factor obtained from designed Monte Carlo simulation can be shown as follow:

1- Dose Buildup factor increased for all types of the selected shielding material with the shield thickness increase. This is due to the increasing of scattering photons with small angles and increasing shield thickness.

2- In this study gamma ray dose buildup factor is inversely proportional with energy increase. The interpretation behind this behavior is due to the following facts

   - When the energy within the studied energy range (4-10) MeV is increased, the probability of Compton effect decrease, since the Compton effect is inversely proportional with energy.
   - The penetrating ability for gamma radiation is also increased when the energy is increased, and this leads to an decrease in the probability of scattering with small angels and finally it is reflected on the calculation of dose buildup factor (the scattering with mall angels plays a very important role in the calculation of buildup factor)

3- For both graphite and water, although the results indicated that the calculated values of dose buildup for plane source when the contribution of pair production is ignored less in comparison when the contribution of pair production is taken in consideration but the contribution of Compton effect is still more predominant than the effect of annihilation within the range of energy (4-10) MeV.

4- In this study ,the results obtained from the performed Monte Carlo simulation program are very close to some published experimental results in comparison with Monte Carlo simulation results obtained from some published researches. The comparison with experimental result is the best way to judge on the accuracy of the results obtains theoretically.

.4.3 Future work

1. Study the effect of angular distribution in the calculation of dose buildup factor utilizing Monte Carlo simulation method.
2. More studies can done about the effect of source geometry on the calculation of buildup factor like, spherical, point, cylindrical, .,etc.)
3. The simulation program can be modified to study buildup factor for multi layers shield thickness.

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الخلاصة

لقد اجريت دراسات عديدة لقياس عامل التراكم لأشعة كاما بأنواعه المتعددة لما له من اهمية في قياس الجرع الناتجة من استخدام الاشعة الكهرومغناطيسية وفي تدريعها.

في هذه الدراسة تم حساب عامل تراكم أشعة كاما لاثنين من مواد التدريع (الماء والكرافيت) ضمن مدى الطاقة (10-4) مليون إلكترون فولط، ولغاية سمك 5 معدل مسار حر، لتحقيق هذه الدراسة تم كتابة و تنفيذ برنامج محاكاة باستخدام لغة Visual Basic language اصدار G وتطبيقه اعتماداً على أسلوب محاكاة مونتي كارلو.

الفكرة الأساسية للبرنامج تشمل وصف السلوك الحقيقي للإشعاع والتنبؤ بحركتة العشوائية خلال الوسط. يمكن استخدام هذا الأسلوب لمحاكاة المسالة التقليدية (الكلاسيكية) الناتجة عن سقوط الاشعاع على شريحة مسطحة تعمل كموهن لأشعة كاما. الشكل الهندسي للمصدر المشع الذي اعتمد في هذه الدراسة هو مصدر مستوى عمودي احادي الطاقة.

في هذا البحث تم دراسة عامل تراكم الجرعة لأشعة كاما بوجود وعدم وجود تأثير انتاج الزوج ولنفس الطاقة. كما تم دراسة عدد من المتغيرات المتعلقة بتصميم البرنامج والمسماة متغيرات المحاكاة والتي تتضمن عدد اشعة كاما التي يمكن تتبعها و عدد تقسيم مدى الطاقة .

تم دراسة اعتماد عامل التراكم على كل من طاقة الفوتون الساقط، عمق الاختراق و العدد الذري لمادة الدرع في حساب عامل تراكم اشعة كاما

اظهرت النتائج أن عامل تراكم الجرعة لأشعة كاما يتناسب عكسيا مع زيادة الطاقة. و يمكن تبرير هذا السلوك بما يلي : عند زيادة الطاقة (ضمن مدى الطاقة المدروس) فان احتمالية استطارة كومبتن تتناقص، لأن تأثير كومبتون يتناسب عكسيا مع زيادة طاقة. كذلك فان زيادة الطاقة تؤدي الى زيادة قدرة اختراق اشعة كاما في الوسط وهذا يؤدي إلى انخفاض احتمالية الاستطارة بزوايا صغيرة وهذا ينعكس على حساب عامل تراكم الجرعة (حيث انة الاستطارة بزوايا صغيرة لها دور كبير في حساب عامل التراكم).

لكل من الكرافيت والماء، اظهرت النتائج إلى أن القيم المحسوبة من عامل تراكم الجرعة لاشعة كاما عند عدم وجود تاثير إنتاج الزوج أقل مقارنة عند وجود تاثير إنتاج الزوج حيث

تبقى مساهمة استطارة كومبتن هي الغالبة مقارنة مع تأثيرالفناء(تأثير انتاج الزوج) ضمن مدى الطاقة (4-10) مليون إلكترون فولط .

النتائج التي تم الحصول عليها بالنسبة للماء من برنامج محاكاة مونتي كارلو في هذه الدراسة كانت قريبة جدا الى بعض النتائج التجريبية المنشورة بالمقارنة مع نتائج محاكاة مونتي كارلو التي تم الحصول عليها من بعض الابحاث المنشورة. حيث تعتبر المقارنة مع النتائج التجريبية افضل وسيلة للحكم على النتائج المستحصلة نظرياً.

جمهورية العراق
وزارة التعليم العالي والبحث العلمي
جامعة النهرين
كلية العلوم

دراسة عامل تراكم الجرعة لأشعة كاما في الماء والكرافايت ضمن مدى الطاقة (10-4) م. أ. ف

رسالة مقدمة الى
كلية العلوم – جامعة النهرين
وهي جزء من متطلبات نيل درجة ماجستير علوم في الفيزياء

من قبل

حنان محمد جواد

(بكالوريوس علوم في الفيزياء 2013)

بأشراف

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