

KLEIN-NISHINA ELECTRONIC CROSS SECTION, COMPTON SCATTERING CROSS  
SECTION, LINEAR ATTENUATION COEFFICIENT AND BUILD UP FACTOR OF WAX  
FOR RADIATION PROTECTION AND SAFETY

A RESEARCH PROJECT  
SUBMITTED TO THE GRADUATE SCHOOL  
IN PARTIAL FULFILLMENT OF THE REQUIREMENTS  
FOR THE DEGREE  
MASTER OF ART

BY

MANAR ALENEZI  
ADVISOR: MUHAMMAD MAQBOOL

BALL STATE UNIVERSITY  
MUNCIE, INDIANA  
DECEMBER 2017

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## **Acknowledgements**

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**ABSTRACT**

**RESEARCH PAPER:** Klein-Nishina electronic cross section, Compton scattering cross section, linear attenuation coefficient and build up factor of Wax for radiation protection and safety.

**STUDENT:** Manar Alenezi

**DEGREE:** Master of Physics

**COLLOGE:** Physics and Astronomy

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One of the most effective ways to get rid of a tumor is to treat it with radiation. Radiation can be used to target specific parts of the body to treat cancer. However, radiation can be dangerous and can harm normal tissues if exposed to high dose for long time. Therefore, shielding and protection of body or normal tissues is important when work in radiation area. Different forms of shielding material help to ensure that radiation only reaches the targets and does not damage healthy cells. To achieve the goal of safety it is important to know various properties of shielding material before they are used practically.

The purpose of this work is to study and calculate Klein-Nishina electronic cross section  $e^{\sigma}$ , Compton scattering cross section  $\frac{\sigma}{\rho}$ , and linear attenuation coefficient  $\mu$  and build up factor B of Wax for radiation protection and safety purposes. Gamma rays of certain energies are going to be used to calculate Klein-Nishina electronic cross-sections for wax. The cross sections are further used to calculate Compton scattering coefficients. Build up factors will be calculated using narrow beams and broad beams of gamma radiation under the same conditions. Respective graph will be obtained to analyze the results obtained.

## **Chapter 1**

### **The Problem**

Various people work in different environments, some of which are dangerous to their health, due to the exposure they encounter each day. A good example is people who use radiation-emitting equipments in their work, or people who are generally exposed to different types of radiations. To protect such workers from harmful emissions, radiation-shielding materials are made part of their gears or equipments to reduce the effect of the exposure. One such element used in such kind of shielding is wax together with plenty of protons. This element is cheap, readily available, and effective in its work, which makes it the best, if not one of the most preferable, radiation-shielding candidate. Even so, there are certain crucial details about its properties and characteristics, which are unknown. Yet they are necessary before using a material for radiation shielding. These properties include its scattering coefficients, linear attenuation, and its build up factors, which require absolute investigation before applying wax in radiation shielding or any form of protection. This will ensure that the safety sought is achievable, as well as raising the dependence on the material. With these factors in mind, the purpose of the present work is to investigate some of the stated properties of wax.

### **Values and the Significance of the Problem**

Apart from protection of workers that are exposed in radiation zones, another concern is the dire need of the very radiation in the treatment of different ailments, such as the removal of tumors, which require high frequency radiation. In a similar dilemma, cancer is now the most daunting and prevalent form of ailment, claiming lots of lives, and being caused by about everything around normal living. Even so, the same radiation can be focused on different parts of a body, and particularly the affected parts to eliminate cancer. The problem is that if exposed in the wrong sections or for a longer period or dosage than expected, more tissues and cells may be

damaged. This implies that precaution measures, such as shielding, have to be sought whenever radiation is exposed on body tissues and cells during a medical procedure, to ensure the safety of other organs. With the right methods of radiation control and shielding, the procedure is made to reach only the targeted areas, while at the same time protecting the healthy cells. It is impossible to prescribe the right methods of cancer or tumor removal, without first studying the characteristics and the properties of the materials in the proposed methods.

### **Purpose of the Study**

The objective of this study is studying and calculating the Klein-Nishina electronic cross section, Compton scattering cross section, build up factor, as well as Linear Attenuation Coefficient of wax, as the proposed method and material that ensures protection and safety when dealing with radiation exposure. The radiation that will be used in this study is gamma rays, which will have predetermined energy levels, and will mainly be used to determine the Klein-Nishina electronic cross-section of wax. The derived cross sections will then be used to compute the Compton scattering coefficients. Finally, the buildup factors are going to be obtained from broad beams and narrow beams of gamma radiation as exposed under the same conditions. The results of the study will be analyzed using the respective graphical representations of the data and results obtained.

### **Blocking Gamma Radiations**

The absorption of ionizing radiations that consist of gamma rays depends on the mass per surface area of the target material in the direction of radiation. For this reason, lead is often used to block radiations due to the attribute of low mass per area at small thicknesses (Born, 2013). Similar effects may be achieved by use of a paper, but again a hugely and impractical thickness of the paper has to be used. Considering the high penetrative nature of gamma rays, lead is not a good choice for blocking neutrons. The reason is that a comparatively light neutron bouncing from a comparatively massive lead will lose almost negligible kinetic energy. This has the chances of hitting other parts where the radiation is not needed. To counter this challenge, a material such as paraffin wax is preferred in stopping neutrons.

### ***The Choice of Paraffin Wax in Blocking Gamma Radiations***

Paraffin wax comprises of light atoms, carbon, and a great number of hydrogen. The average charge number of paraffin wax is  $Z=5.257$  and the average mass number is  $A=10.365$ . In these light atoms, electrons are held relatively loose so that the atoms are easily ionized. When gamma rays are shown onto a block of paraffin wax, the scattered waves are observed to exhibit some behaviors (Born, 2013, p. 135). In this case, the scattered gamma-rays develop longer wavelengths, but due to the weakness of the wave theory of light in explaining these effects, the concept of quantum particles, also called photons is often employed. Thus, the elastic collisions between the gamma rays photons hitting the free electrons in the paraffin wax results in an exchange of kinetic energy (Biswas, 2013). Since the scattered photons do move at the speed of light, the subsequent loss of energy by a photon due to the collision results in a decrease in its frequency, but causes an increase in wavelength.

## Chapter 2

### The Klein-Nishina electronic cross section, Compton scattering cross section

#### Method

The first step is to determine the coupling strength from the provided different photon energies. This strength, denoted by the symbol  $\alpha$  determines the potency between photon and electron, and may be described as the ratio of photon's energy, expressed as  $E = h\nu$  to the entire energy of the electron, expressed as  $m_0c^2 = 0.511\text{MeV}$ . In this case, the values of the strength ( $\alpha$ ), corresponding to the given energies of the photon are obtained as shown below.

$$\alpha = \frac{E}{M_0C^2} \text{----- (1)}$$

Table 1

Photon Energy	Coupling Strength $\alpha$
0.662MeV	1.2954
0.835MeV	1.6340
1.17 MeV	2.2896
1.33 MeV	2.6027

With the values of the strength  $\alpha$  obtained, the next step is to compute the Klein-Nishina (K-N) cross-section ( $e^\sigma$ ) per electron in every photon energy using the following equation.

$$e^\sigma = 2\pi r^2 \left\{ \frac{1+\alpha}{1+\alpha} \left[ \frac{2(1+\alpha)}{1+2\alpha} - \frac{\ln(1+2\alpha)}{\alpha} \right] + \frac{\ln(1+2\alpha)}{2\alpha} - \frac{1+3\alpha}{(1+2\alpha)^2} \right\} \text{----- (2)}$$

$$r = \frac{e^2}{M_0C^2} = 2.818 \cdot 10^{-13} \text{ cm (the classical electron radius)}$$

From this point, the cross-section per unit mass ( $e^\sigma/p$ ), which is also the Compton mass attenuation coefficient, would be computed for paraffin wax using the charge number ( $Z=5.257$ ) and mass number ( $A=10.365$ ) in the relation expressed as  $\frac{\sigma}{\rho} = \frac{N_A Z}{A} \times e^\sigma (\text{cm}^2/\text{g}) \text{----- (3)}$ . A sample calculation using equation 3 and the given data.

$$\frac{\sigma}{\rho} = \frac{N_A Z}{A} \times e^{\sigma}$$

$$N_A = 6.022 \times 10^{23} / \text{mole}$$

A=5.257 and Z=10.365, so

$$\text{K-N Cross-section} = 2.5571 \times 10^{-25} \text{cm}^2$$

$$\text{Compton mass coefficient} = (1.2954 \times 10^{23} / \text{mole} \times 5.257) / 10.365$$

$$= 0.0781 \text{ cm}^2/\text{g}$$

The results of calculations conducted performed are given in Table 2.

E in (MeV)	Coupling Strength $\alpha$	K-N electronic Cross-Section $e^{\sigma}$	Compton Mass Attenuation Coefficient $\frac{\sigma}{\rho}$
0.662	1.2954	$2.5571 \times 10^{-25} \text{cm}^2$	$0.0781 \text{cm}^2/\text{g}$
0.835	1.6340	$2.3012 \times 10^{-25} \text{cm}^2$	$0.0702 \text{cm}^2/\text{g}$
1.17	2.2896	$1.9533 \times 10^{-25} \text{cm}^2$	$0.0596 \text{ cm}^2/\text{g}$
1.33	2.6027	$1.8281 \times 10^{-25} \text{cm}^2$	$0.0558 \text{ cm}^2/\text{g}$

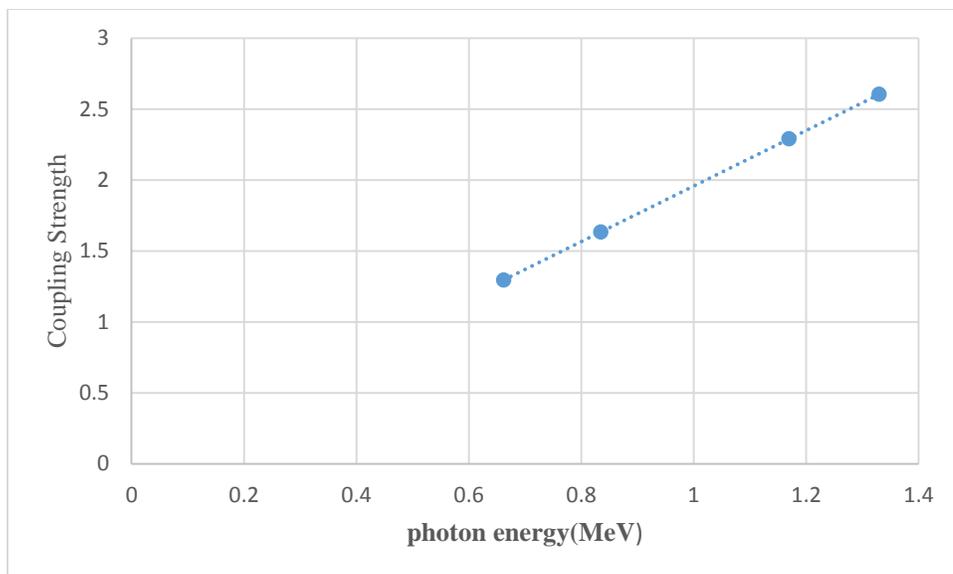


Figure 1. A variation in coupling strength vs photon energy (MeV)

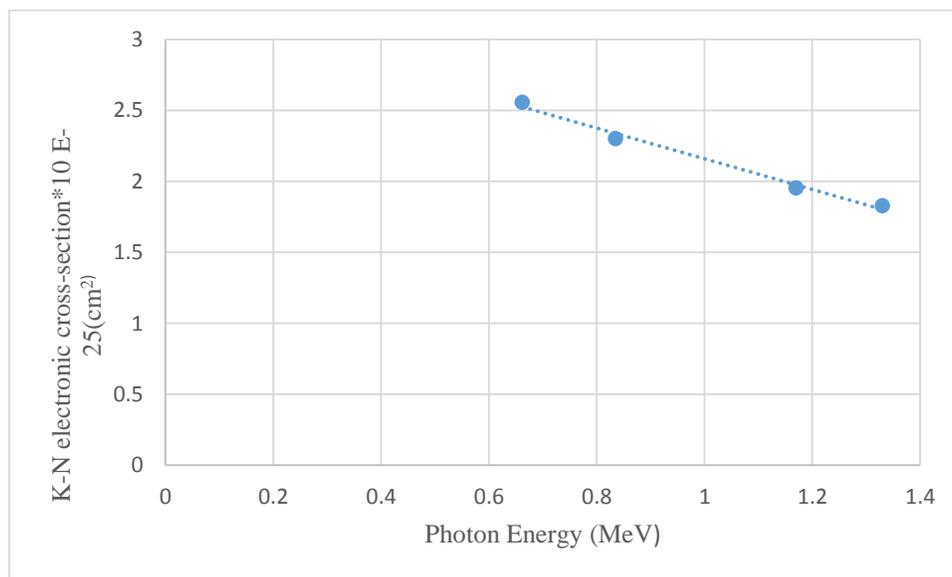


Figure 2. A graph of Klein-Nishina cross-section ( $\times 10^{-25}$ ) vs. Photon energy (MeV)

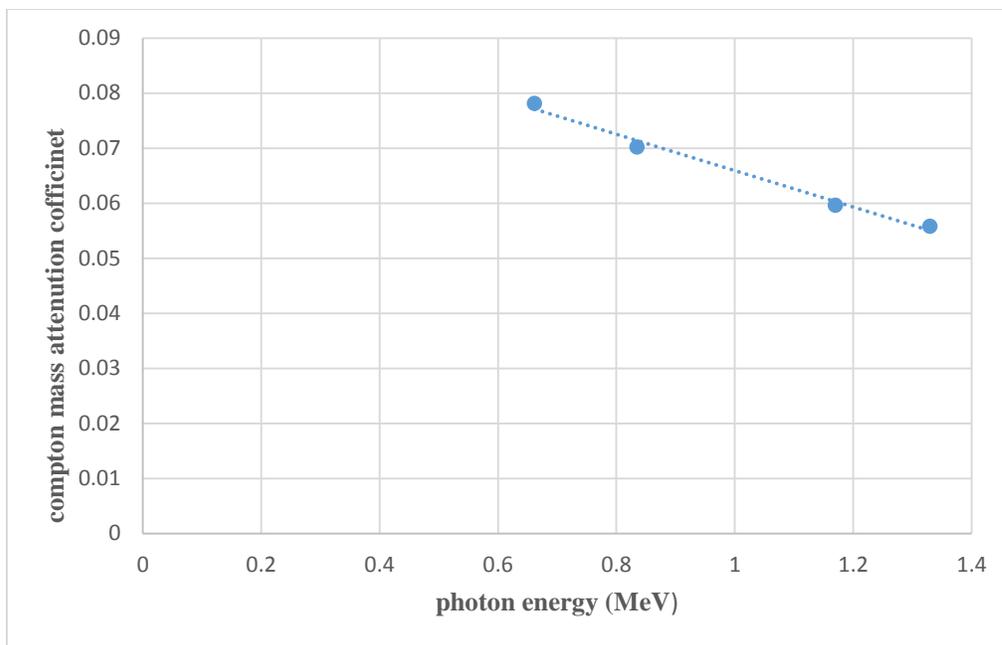


Figure 3. A graph of Compton mass attenuation coefficient ( $\text{cm}^2/\text{g}$ ) vs Photon energy (MeV)

### Analysis

One thing that is evident from the curve is that the K-N electronic cross-section decreases with an increase in photon energy. There are several arguments that may be advanced in favour of the above observation. When one increases the photon energy, there is a tendency to shift from merely removing (dislodging) an electron to an energy level in which pair production (the production of an electron and a positron) becomes more pronounced. This is illustrated below in figure 4

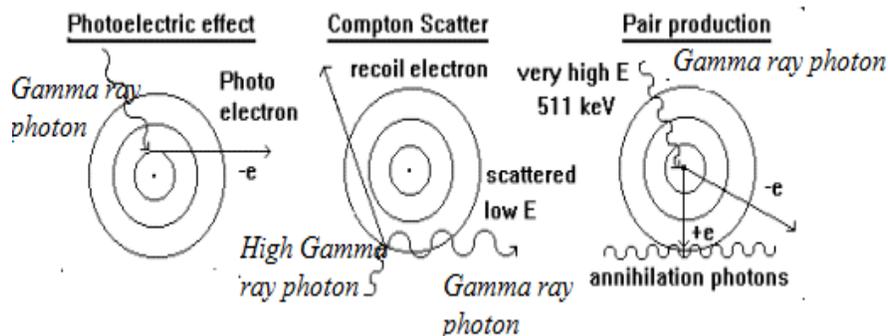


Figure 4 The photoelectric effect

Also, in the electron and positron production reaction, the need for a third body for momentum conservation cannot be ignored. However, at the same time it is known that, unlike wax, heavy body forms one of the nuclei on the surface of the metal. As such, the weight can only allow it to recoil negligibly. Consequently, most of the photon energy is left behind to support the production of electron and positron pairs. It is also correct to argue that most of the pair production takes place at an atomic level rather than in free electrons within the metal. Thus, much energy is expended in recoil effects than in dislodging electrons.

Based on the above arguments, therefore, the combined cross-section necessary for pair production is the total value of the cross-sections related to the Rayleigh scatter and Compton effects reaction pathways. Again, this is illustrated below in figure 5

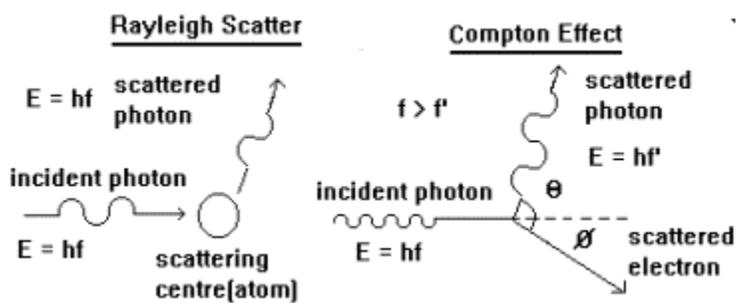


Figure 5: Reaction pathways

Here, the sum of the electron and positron production is the total of two major components, the nucleus and the electrons. The cross-sections are significantly dependent on energy of the incident photon. For instance, at energies in the magnitudes of 100MeV and above, pair

production becomes the most pronounced technique of radiation association with matter. Thus, as one increases the incident energy, it is predictable that there will be less of Compton effect, but more of electron and positron production.

Conclusively, the photo electric energy due to the gamma ray will significantly affect the magnitude of the Compton effect occurring at the wax shield. High photoelectric energy implies that the effect will be high, while low energy implies the effect will be small. Thus, to prevent the adverse effects in this case, it will be important to use a relatively thicker wax shielding material.

## **Chapter 3**

### **Energy Transfer Cross Section for Compton Effect**

#### **Introduction of Energy Transfer Cross Section for Compton Effect**

Gamma rays are highly penetrative. Consequently, they obey the inverse square law in the atmosphere, and are considered dangerous to the body, especially in burning out the internal organs. In this section, to determine how paraffin wax may be used to block gamma radiations from reaching the body organs. That is, the goal is to investigate the energy transfer cross-section for Compton Effect through paraffin wax (Born, 2013). This will help explain the behavior of light as particles and not as waves. Documented studies suggest that when a high frequency monochromatic radiation, such as the gamma ray strikes on, such as say paraffin wax, two types of waves are scattered: one with a high frequency and the other one with a low frequency. In regard to this the former are known as the Compton Scattering and the latter as Thomson scattering (Biswas, 2013, p. 303). Compton Scattering is also known as the K-N energy transfer cross-section and forms the basis of this analysis.

#### **Methodology**

To help accomplish the objectives of this study, hypothetical values for the energy of the photon and the electron energy are used. These are summarized in table 3 below, and are used to derive the secondary values needed to calculate the K-N energy transfer cross-section.

Table 3 A summary of the hypothetical photon energy and electron energy values

Photon Energy	Energy of The Electron
0.662 MeV	0.511MeV
0.835 MeV	0.511MeV
1.17 MeV	0.511MeV
1.33 MeV	0.511MeV

### Analysis and Findings

Equation (4) helps calculate the energy transfer Cross section for Compton Effect, also known as the K-N energy-transfer cross section.

$$e^{\alpha_{tr}} = 2\pi r^2 \left[ \frac{2(1+\alpha)^2}{\alpha^2(1+2\alpha)} - \frac{1+3\alpha}{(1+2\alpha)^2} - \frac{(1+\alpha)(2\alpha^2-2\alpha-1)}{\alpha^2(1+2\alpha)^2} - \frac{4\alpha^2}{3(1+2\alpha)^3} - \left( \frac{1+\alpha}{\alpha^3} - \frac{1}{2\alpha} + \frac{1}{2\alpha^3} \right) \ln(1+2\alpha) \right] \text{----- (4)}$$

Where:  $e^{\alpha_{tr}}$  is the K-N energy-transfer cross section,  $r$  the classical electron radius ( $2.818 \times 10^{-13}$  cm), and  $\alpha$  the coupling strength of the photon. Finding the values for  $e^{\alpha_{tr}}$  involves determining, the corresponding values of the coupling strength of the photon. Theoretically, the coupling strength ( $\alpha$ ) is given by the following equation:

$$\alpha = \frac{E}{M_0 C^2} \text{----- (5)}$$

But,  $E$  is the photon energy and is given by:

$$E = h\nu \text{----- (6)}$$

While  $M_0 C^2$  is the energy of an electron at rest and is denoted by:

$$M_0 C^2 = 0.511 \text{MeV} \text{----- (7)}$$

From this perspective, equation (5) reduces to:

$$\alpha = \frac{h\nu}{0.511MeV} \text{ --- (8)}$$

Therefore, by carrying out relevant substitutions, equation (5) helps calculate the coupling strength of the photons. A sample calculation for the first row in table 3 is given below, while the other values are summarized in the table 4:

$$\alpha = \frac{0.662 \text{ MeV}}{0.511MeV} = \mathbf{1.2954}$$

Table4 A summary of the coupling strength values for the photons

Photon Energy	Coupling Strength $\alpha$
0.662MeV	1.2954
0.835MeV	1.6340
1.17 MeV	2.2896
1.33 MeV	2.6027

Now, from the coupling strength values recorded in table 4, the values of the K-N energy-transfer cross section are calculated and summarized in table 5. Again, a sample calculation for the first low is given below:

$$\begin{aligned}
 e^{\alpha_{tr}} &= 2\pi * (2.818 * 10^{-13})^2 \left[ \frac{2(1 + 1.2954)^2}{1.2954^2(1 + 2 * 1.2954)} - \frac{1 + 3 * 1.2954}{(1 + 2 * 1.2954)^2} \right. \\
 &\quad - \frac{(1 + 1.2954)(2 * 1.2954^2 - 2 * 1.2954 - 1)}{1.2954^2(1 + 2 * 1.2954)^2} - \frac{4 * 1.2954^2}{3(1 + 2 * 1.2954)^2} \\
 &\quad \left. - \left( \frac{1 + 1.2954}{1.2954^3} - \frac{1}{2 * 1.2954} + \frac{1}{2 * 1.2954^3} \right) \ln(1 + 2 * 1.2954) \right] \\
 &= 9.7656 * 10^{-26} cm^2/e
 \end{aligned}$$

Photon Energy	K-N energy-transfer cross section $\alpha_{tr}$
0.662MeV	$9.7656 * 10^{-26}$
0.835 MeV	$9.5499*10^{-26}$
1.17 MeV	$9.0260*10^{-26}$
01.33MeV	$8.7615*10^{-26}$

The K-N energy-transfer cross section and photon energy values are plotted to show the respective correlation. The resulting curve is shown below in figure 6

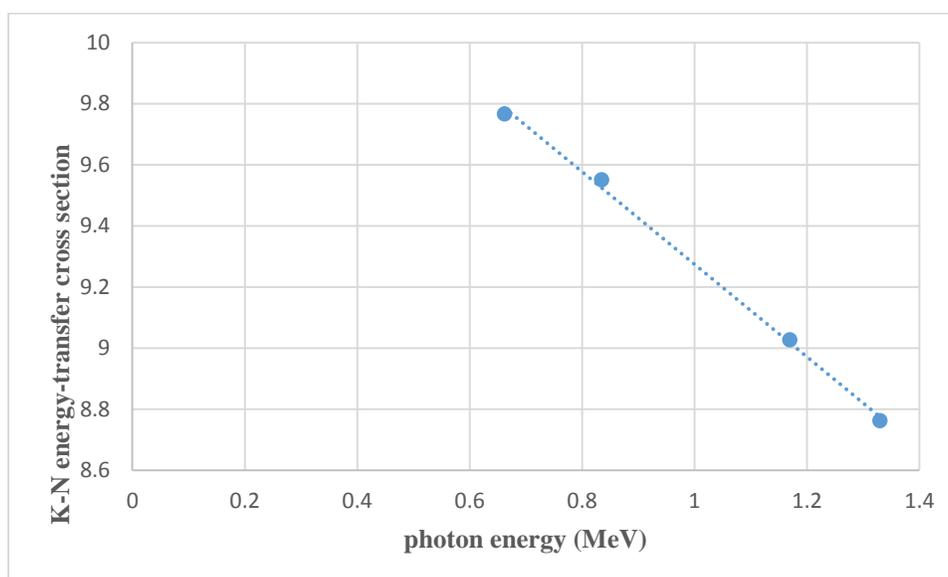


Figure 6 A graph of K-N energy-transfer cross section ( $cm^2/e$ )\* $10E-26$  Vs Photon Energy (MeV)

According to the graph, the K-N energy-transfer cross section and photon energy are inversely proportional. Thus, as the former increases, the latter tends to decrease. Also, the value of the K-N energy-transfer cross section was found to have a negative value. The negative value suggests loss of photon energy by the gamma rays.

### Discussion

According to figure 7 below on the scattering, the incident gamma-rays photon is deflected at an angle  $\Theta$  with respect to its original path and direction. Consequently, the photon

loses part of its energy (photon's frequency), and the phenomenon is known as Compton Effect. For this reason, the photons that hit the paraffin wax material will not have enough energy to penetrate through the body of, say an individual (Biswas, 2013). At the same time, they will lose the energy required to deflect them towards other materials or parts of the body. This scenario may be used to explain what happens when paraffin wax is used to block gamma rays. When the gamma ray photons accelerate towards paraffin wax they hit its electrons, which are assumed to be at rest. It loses some of its energy to the electrons, thereby getting scattered from the original path. A summary of this scenario is presented below in figure 7 The incident photon are the original gamma rays, while the scattered photon represents gamma ray photons that have been scattered.

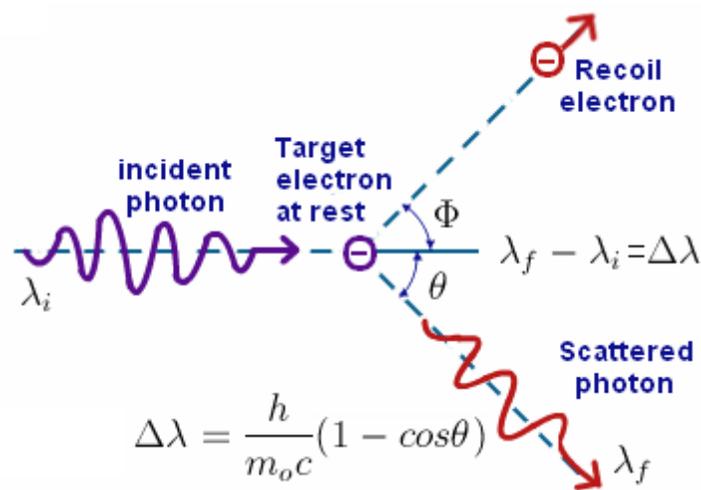


Figure 7 An illustration of the Compton Effect

## Chapter 4

### Linear attenuation coefficient

This section presents a summary of the attenuation coefficient for wax of constant volume for use in radiation protection. The data was used in plotting a curve containing a linear trend line that models the linear attenuation coefficient of wax. This was achieved by firing a beam on the volume of wax and measuring the energy of the beam that passes through the wax. The linear attenuation is an important property of any material. This determines the amount of waves, energy, or particles that can penetrate the volume of a specific material. In this case, the material of interest is wax. The tables below elaborate the relationship between thickness  $X$  (cm) and  $\ln(N/N_0)$ . It is important to note that  $(N/N_0)$  is the ratio of the intensity of the incident beam (unattenuated beam) and the intensity of the exit beam (attenuated beam). From the chart plotted, it is possible to determine the attenuation coefficient of the volume of wax at different energy levels. Based on the information collected it is possible to determine whether the volume of wax is applicable in radiation protection.

The table below shows the data collected when the volume of wax is exposed to a beam with an energy of 1.33 MeV. It details the relationship between thickness  $X$  (cm) and  $\ln(N/N_0)$  for a beam with an energy of 1.17 MeV.

X (cm)	$\ln(N/N_0)$
0	0
0.326	-0.026686326
0.986	-0.071800642
1.312	-0.074641607
1.61	-0.092090584
2.506	-0.111422389
2.922	-0.160997985

Table 6 the relationship between  $X$  (cm) and  $\ln(N/N_0)$  for a beam with an energy of 1.17MeV

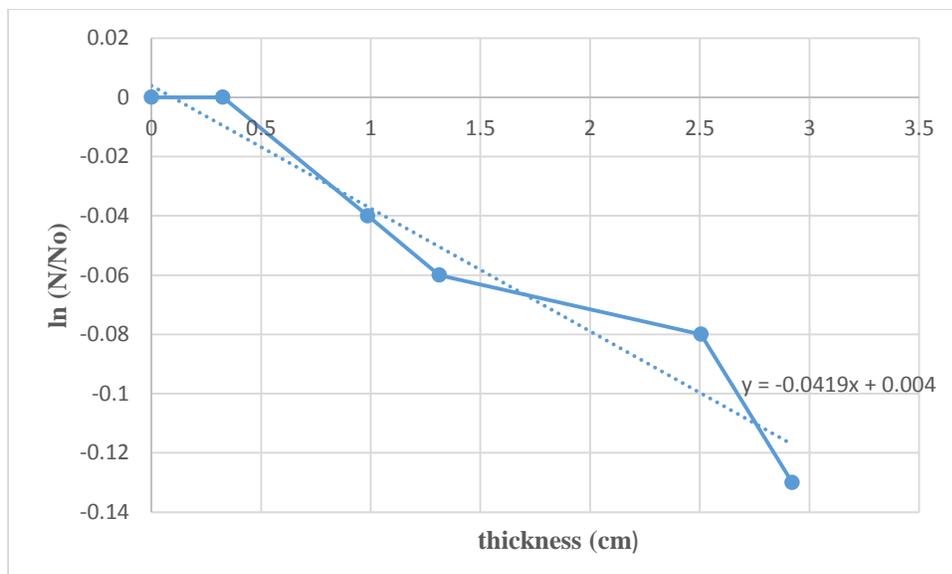


Figure 8 the graph for  $\ln(N/N_0)$  vs. X cm at 1.17 MeV

The table below shows the data collected when the volume of wax is exposed to a beam with an energy of 1.17 MeV. It details the relationship between thickness X (cm) and  $\ln(N/N_0)$  for a beam with an energy of 1.33 MeV.

X (cm)	$\ln(N/N_0)$
0	0
0.326	-0.007581962
0.986	-0.044469045
1.312	-0.052397148
1.61	-0.069231882
2.506	-0.086437786
2.922	-0.137867811

Table 7 the relationship between X (cm) and  $\ln(N/N_0)$  for a beam with an energy of 1.33MeV

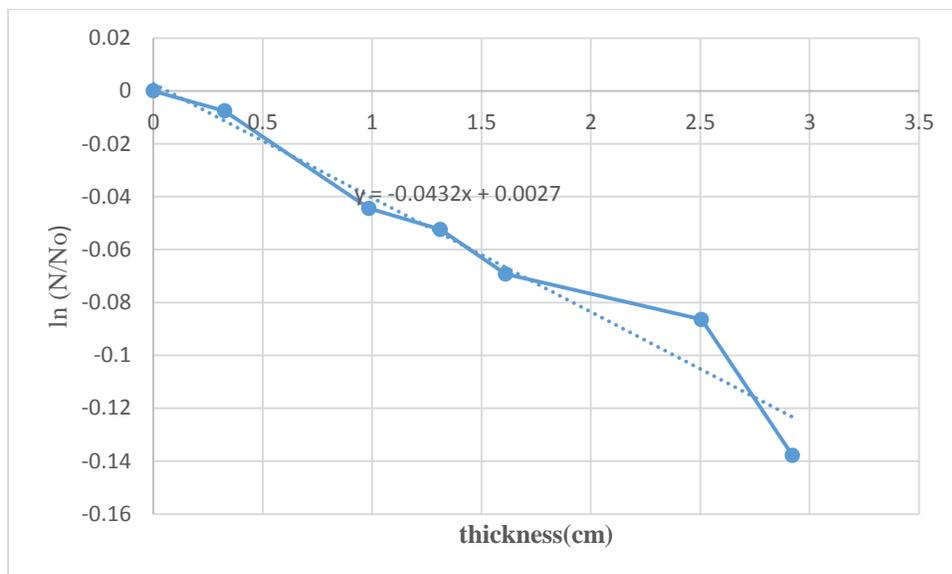


Figure 9 the graph for  $\ln(N/N_0)$  vs. X cm at 1.17 MeV

The data collected can be summarized in a table as shown in table 8 below.

Source	Energy (MeV)	Linear attenuation coefficient ( $cm^{-1}$ )
$^{60}Co$	1.17	0.0419
$^{60}Co$	1.33	0.0485

Table 8 the values of linear attenuation for a volume of wax for beams of different energy

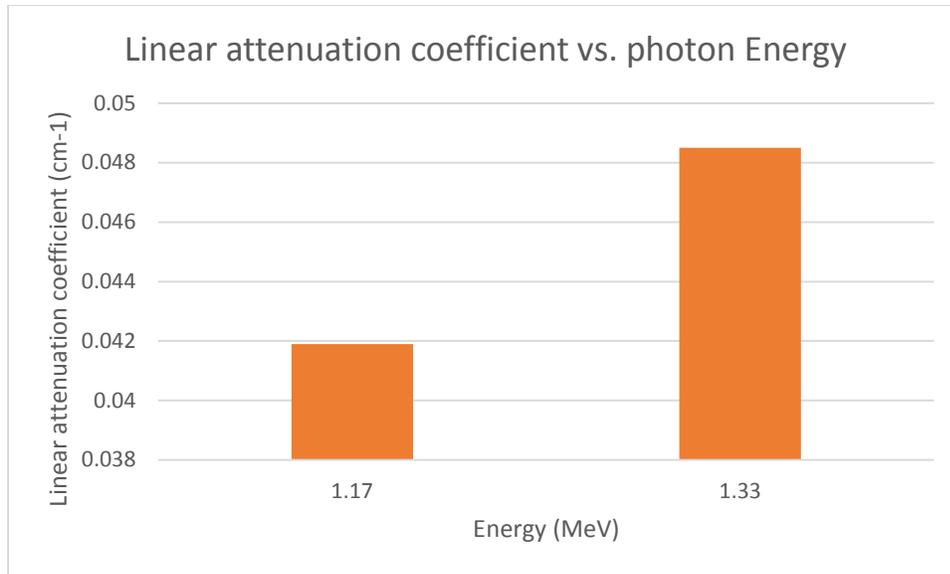


Figure 10 showing the relationship between the linear attenuation coefficient for wax and the energy of the beam used

### Analysis

Examining the data above and the figure 10 it is clear, there is a relationship between the linear attenuation coefficient of wax and the energy of the incident electromagnetic beam as shown in chart 10 above. This relationship is positive in nature since the linear attenuation constant increases with an increase in the beam's energy. It is clear from the data that for the 1.33 MeV beam the attenuation coefficient is equal to 0.0485. On the other hand, for the 1.17 MeV the linear attenuation coefficient is equal to 0.0419. From the plots, it is clear that the relationship between the attenuation coefficient and energy is linear.

One of the reasons for this observation is that as the energy of the photons in the electromagnetic beam increases its wavelength decreases (Clyde, 2007). This is because the electromagnetic waves or beams have a wide range of frequencies and wavelengths (Clyde, 2007). Also, this wide range of frequencies and wavelengths makes up the electromagnetic spectrum. Therefore, as the energy of the photons transmitted in an electromagnetic beam increases, its wavelength decreases while its frequency increases. In addition, when an electromagnetic wave hits a surface it reflects, absorbs, or transmits it through its medium (Clyde, 2007). The proportions of the wave that undergo absorption, transmission, or reflection depend on the wavelength of the incident wave. Therefore, in this case, altering the energy of the

beam alters its wavelength and that change the attenuation coefficient of the wax material. From the data, it is clear that for shorter wavelengths (high energy beams) the attenuation constant increases, meaning less of the beam transmits through the material. On the other hand, for longer wavelengths (lower energy beams) the attenuation constant decreases, meaning, more of the beam transmits through the material.

The other relationship evident from the data is the dependence between thickness  $X$  (cm) and  $\ln(N/N_0)$  (the ratio of the incident intensity of the beam and the exit intensity of the attenuated beam). From chart 8 and 2, it is clear that there is a negative relationship between the two variables. This implies that as the thickness of the attenuator material (wax in this case) increases the ratio between the incident and exit beam decreases. This is also evidenced by the negative value of the slope determined from the two charts. The relationship between the two properties is therefore also linear in nature. As the thickness of the wax increases, photon attenuation increases leading to a lower value of the attenuated beam ( $N$ ). This lowers the ratio  $\ln(N/N_0)$  since the incident beam intensity remains constant. This translates to a decline in the  $\ln(N/N_0)$  ratio as the thickness of the wax increases. It also implies that as expected attenuation increases with an increase in the thickness of the material (Huda & Slone, 2010).

## Chapter 5

### Buildup Factor

#### Introduction of Buildup Factor

The energy absorption and exposure buildup have been examined for different energy ranges (i.e. 0.05-15MeV) for gamma radiation with a variety of penetration depth for the material under study. The research will be examining the buildup factor for gamma photon energy of 1.17 and 1.33 eV. It is evident that humans can be exposed to gamma radiation during their daily routines like in nuclear research facilities and nuclear facility life cycle. The nuclear radiation contains multi-energetic photons that were released in the radiation. Protection against these radioactive particles for those individuals that deal with these radiations becomes necessary (Kucuk, Manohara, Hanagodimath, & Gerward, 2013). The protection against these radiations is achieved by the use of suitable thick-walled material shield for example wax.

This research has been evaluating the abilities of the paraffin wax in shielding. Which contains a lot of hydrogen atoms. The above-mentioned condition causes the atoms to be light, and hence the electrons are loosely held thus they can be easily ionized. When used as a blocking material gamma rays are observed to be scattered proving the effectiveness of the wax in blocking gamma radiation. The photon theory can simply explain the principle underlying the scattering. The theory illustrates that the photons produced by the collision of the gamma ray and the protons lead to an elastic collision, leading to the loss of kinetic energy by the gamma ray.

The use of wax has been widely applied in radioactive shielding. Wax has been used in the nuclear plant to coat lead metals that are employed as moderators and absorbers in the nuclear reactors. The effectiveness of paraffin wax can, therefore, be put into perspective through the study of the buildup factor of gamma radiation in two different energies. This will be done while keeping in mind the interaction of protons with the gamma radiation.

The gamma rays buildup factor is the multiplicative factor that will be developed so as to obtain a corrected response to the number of the uncollided photons via the inclusion of the effect of the scattered photon. Therefore we can explain build up factor as an important

parameter that will be used in the characterization of the distribution of the photon flux in different objects (Kucuk, Manohara, Hanagodimath, & Gerward, 2013). The essence of buildup factor has moved from the characterization of shielding materials, to also being applied in photon transport simulation in the case where the material is being used in any nuclear-related installation desired for shielding calculations.

$$B = 1 + D_x \text{ - - - - - (9)}$$

### **Narrow beam geometry**

The narrow beam geometry is operated through the prevention of the scattered radiation of the secondary particle from being detected by the detector as a result of them reaching the detector (Hopkins, 2010). A collimated light emission radiation will be used to enter the combination of different thicknesses in order to make a narrow beam geometry. The collimator resulted in a narrow beam of gamma rays that reached the attenuator. This setup was instrumental in the determination of the linear attenuation coefficient (Hopkins, 2010). For safe operation during the experiment the lead collimator was tested for gamma radiation leakages (Hopkins, 2010). After ensuring it was radiation proof and there was no detection of gamma leakages then it was concluded that the five-centimeter lead was enough for shielding in this experiment (Hopkins, 2010).

Therefore the buildup factor will be:

$$B = 1$$

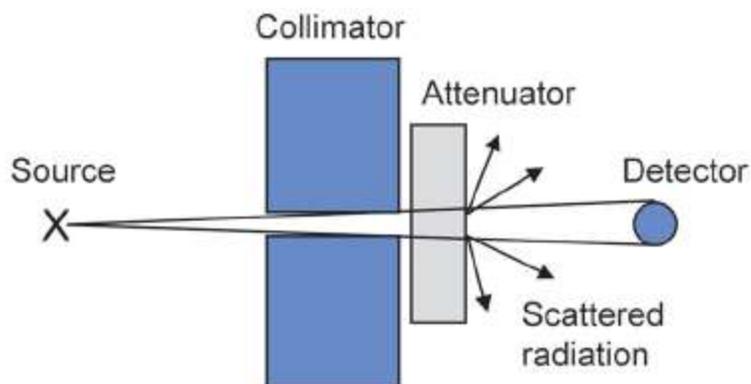


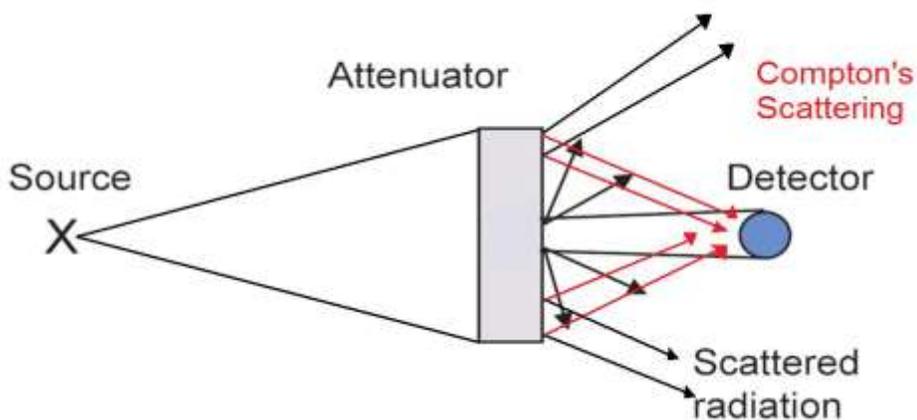
Figure 11 The Narrow beam geometry

### Broad Beam Geometry

In this case, a collimator was not used. This methodology worked by allowing the scattered and the secondary particles to reach the detector as well as the primary beam. Every scattered or secondary particle that is produced by the primary beam at the attenuator will hit the detector. For the case of the broad beam geometry, the buildup factor is given by the intensity of the attenuator  $N$ . Below is the broad beam geometry gamma spectrum.

Therefore the buildup factor will be:

$$B > 1$$



Broad intensity	beam	Narrow beam intensity	Buildup factor (B)	Attenuation thickness (x)
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Table 10 The table for the photon energy  $E1 = 1.33\text{MMeV}$

Broad intensity	beam	Narrow beam intensity	Buildup factor (B)	Attenuation thickness (X)
52303		39153	1.33579	0.326
50369		37737	1.33473	0.986
50079		37439	1.33761	1.312
49185		36814	1.33604	1.6
46903		38186	1.2961	2.506
46110		34372	1.34149	2.922

Table 10 The table for the photon energy  $E2 = 1.17\text{MeV}$

37496	27657	1.355751	0.326
35820	26437	1.354919	0.986
35760	26362	1.356498	1.312
35516	25906	1.370957	1.61
33784	25410	1.329555	2.506
32721	24181	1.35317	2.922

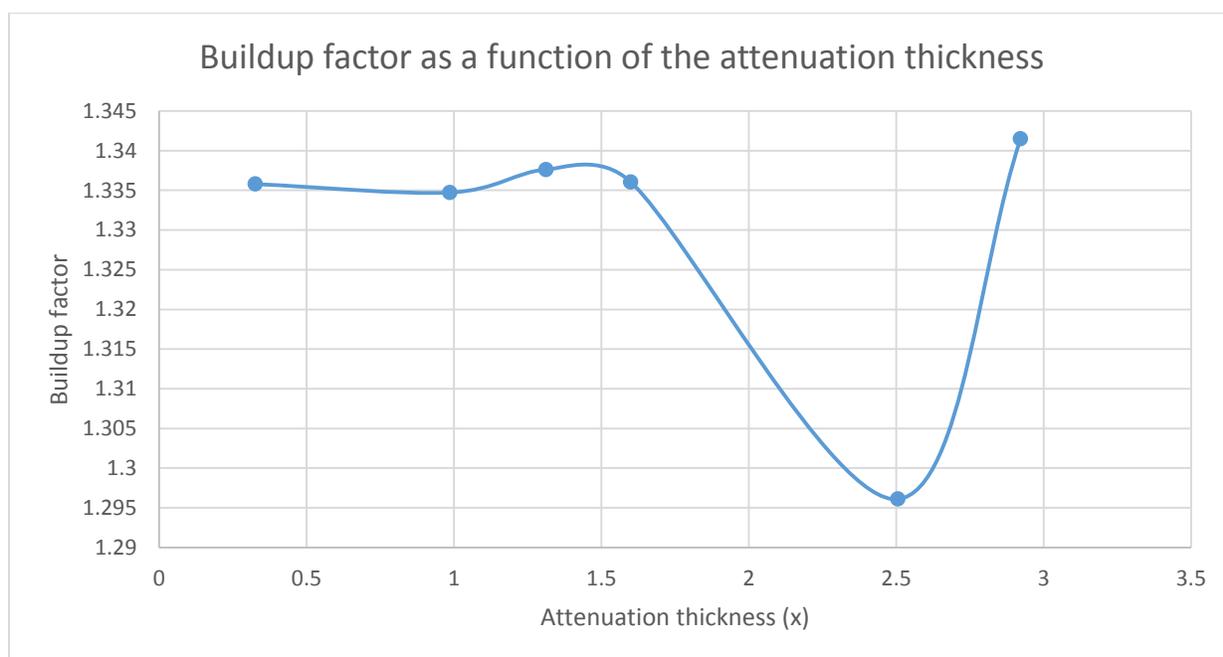


Figure 11 The Graph for the buildup factor as a function of the attenuation thickness for  $E1 = 1.17 \text{ eV}$

Equation of the best fit line

The buildup factor = -0.0012

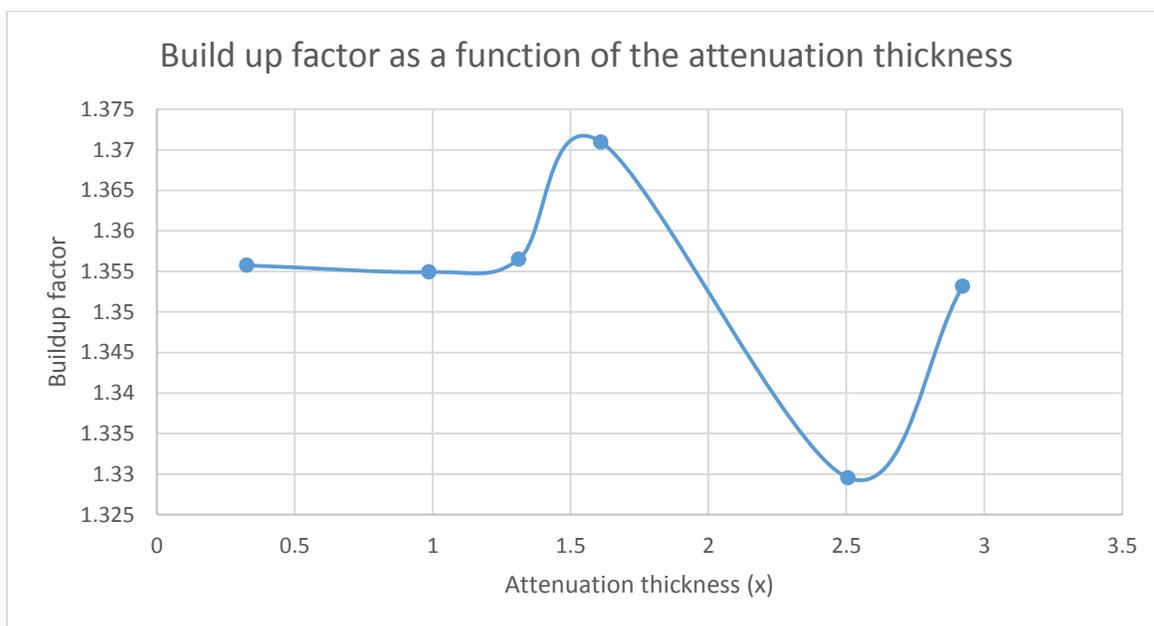


Figure 12 The Graph for the buildup factor as a function of the attenuation thickness for  $E1 = 1.17 \text{ eV}$

Equation of the best fit line

The buildup factor = -0.0057

## Discussion

The linear attenuation coefficient of the beam energy above decreased with an increase in the beam energy. The gamma ray would lead to the attenuation of a reduced number of the photon in the alloy than the lower energy photons. The buildup factor for the various thickness of the alloy was as represented above for the two energy levels (Hopkins, 2010). The result can be explained by the presence of a scattering site on the attenuator. The buildup will only develop due to the scattering of the gamma rays, hence it is vital to point out the existence of the scattering. The occurrence of the Compton scattering will increase the number of scattering sites inside the material and at the same time the number of the electrons (Hopkins, 2010).

The Compton scattering that will occur in this experiment will be proportional to the amount of material that is available for attenuation (Kucuk, Manohara, Hanagodimath, & Gerward, 2013). The volume of the material is directly proportional to the scattering sites that are available, thus contributing positively to the buildup factor (Hopkins, 2010). In this experiment nonetheless, the surface area of the alloy used was constant (Hopkins, 2010).

From the graphs, it is reasonable to say that for the low energies of the beam the buildup factor of the material increase linearly (Hopkins, 2010) and slowly as the calculated gradient of the graph is small (Hopkins, 2010). The increase in the beam energy will also result in an increase in the buildup factor more rapidly (Salehi, Sardari, & Jozani, 2015). It is, therefore, evident that the buildup factor will affect the interaction of the gamma radiation with matter (Saleh & Sharaf, 2015).

The variation in the buildup factor is characterized by low values at the higher attenuation thickness. The maximum values are observed at the intermediate values of the attenuation thickness. The characteristic of the buildup factor is due to the increase in the photoelectric absorption and the pair production process. The above two processes will result in the complete removal of the photons (Kucuk, Manohara, Hanagodimath, & Gerward, 2013). The maximum value for the buildup factor was observed at the intermediate values where the Compton scattering is dominant. In these conditions the incident gamma photons are not completely removed but rather their energies are degraded (Salehi, Sardari, & Jozani, 2015). This process will also alter their directions, therefore resulting in multiple scattered photon. The scattering increases the buildup of the medium in return. The build of the measured wax increases with the

increase in the penetration depth. From the graphs it is evident that with the increase in the penetration depth of the buildup will increase, thus increasing the number of the gamma photons (Salehi, Sardari, & Jozani, 2015).

There is no significant difference in the buildup tested for the narrow-beam and the broad-beam geometries. This was caused by the fact that the material used in this case was wax and the gamma photon behave in the same way when interacting with wax. The variation in the buildup in the two gamma photon energies was also not significant (Salehi, Sardari, & Jozani, 2015).

### **Conclusion of buildup factor**

Finally, the buildup factor for gamma photon was computed for the two energies 1.17 eV and the 1.33 eV. The gamma radiation buildup was examined with the beam incident on the paraffin wax. In all the case it was found that the largest penetration was attained at the intermediate values while the lowest was in the low penetration. The lowest buildup was experienced at the higher attenuation thickness due to the photoelectric absorption of photons and pair production. The highest buildup was experienced in the intermediate value due to the Compton Scattering.

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