بسم الله الرحمن الرحيم

كلية الدراسات العليا

Sudan University of Science and Technology

College of Graduate Studies

Assessment of X-Ray Attenuation Coefficients for Some Materials

تقييم معاملات التوهين للأشعة السينية لبعض المواد

A Thesis Submitted for the Partial Fulfillment of the Requirements of M.Sc. Degree in General Physics

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الآية

قــال تعــالى : ﴿وَقُـلِ اعْمَلُـوا فَسَـيَرَى اللَّهُ عَمَلَكُـــمْ وَرَسُـــولُهُ وَالْمُؤْمِنُـــونَ ۖ وَسَـتُرَدُّونَ إِلَـىٰ عَـالِمِ الْغَيْـبِ وَالشَّـهَادَةِ فَيُنَبِّئُكُم بِمَا كُنتُمْ تَعْمَلُونَ﴾

صدق الله العظيم

سورة االتوبة (105)

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Abstract

This work focuses on Study of linear and mass attenuation coefficient for radiation safety. Present study is intended to investigate the attenuation coefficient for the various materials of different thickness as absorbers for x-ray source and establish the relations among linear attenuation coefficient, mass attenuation coefficient. Glass, wood, plastic and cork materials are used as absorber. The materials were cut with different thicknesses, Then each material was studied separately by placing the specific Thickness inside the x-ray machine and reading the intensity of the x-rays transmitted from the Thickness in question, then increasing the thickness and reading the intensity. The results showed that the linear attenuation coefficient for glass, wood, plastic and cork is 0.6814, 0.3044, 0.04625, and 0.00614 respectively, and the mass attenuation coefficient for them is 0.000272, 0.000435, 0.0000492 and 0.0000256 respectively.

By comparing the results of previous studies on this topic, we find that there is a variation in the results, as a result of the difference in the intensity of rays in terms of voltage and current, or a difference in the thickness of the materials used. This show the glass is better absorber of materials were used in the study. This means that the glass is the best in shielding systems from X-rays.

المستخلص

يركز هذا العمل على دراسة معامل التوهين الخطي والكتلي من أجل السلامة من الإشعاع. تهدف الدراسة الحالية إلى دراسة معامل التوهين للمواد المختلفة ذات السماكة المختلفة كمواد ممتصه لمصدر الأشعة السينية وإقامة العلاقات بين معامل التوهين الخطي ومعامل التوهين الكتلي. أستخدمت مواد الزجاج والخشب والبلاستيك والفلين كمواد ممتصه . تم تقطيع المواد بسماكات مختلفه من ثم دراسة كل ماده على حده بوضع السمك المعين داخل جهاز الاشعه السينيه وقراءة شدة الاشعه السينيه النافذه من السمك المعني ومن ثم زيادة السمك وقراءة الشده وهكذا تكرر هذه الخطوات مع المواد المذكوره اعلاه ثم تحليل النتائج المتحصل عليه أظهرت النتائج أن معامل التوهين الخطي للزجاج والخشب والبلاستيك والفلين هو 0.6814 و ,0.3044 و0.04625و 0.00614 على التوالي ، وأن معامل التوهين الكتلي بالنسبة لهم هو 0.272 و 0.435 و 0.0492 و 0.0256 على التوالي.وبمقارنة نتائج الدراسات السابقه نجد أن هنالك تباين في النتائج, وذلك قد يكون نتيجة لإختلاف شدة الأشعه من حيث الجهد والتيار أو إختلاف في سمك المواد المستخدمه.

من النتائج المتحصل عليها نستخلص أن الزجاج أفضل ممتص للإشعاع من بين المواد التي أستخدمت في الدراسه. هذا يعني أن الزجاج هو الأفضل في أنظمة التددريع من من الأشعه السينيه .

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Chapter One

1.1 Introduction

X-ray linear and mass attenuation coefficients for materials are required in almost all fields in which the interaction of X-ray with matter .As x-ray photons passes through material sample, the probability that interaction will occur.

This interaction can be absorption of the photons or scattering (change of the photon direction).This absorption and scattering process is called attenuation.

Other photons travel completely through the object without interacting with any of the materials particles. The number of photons transmitted through a material depends on the thickness, density, composition of the material, and the energy of the photons.

X-ray attenuation is also usable in other fields. For example, the linear attenuation coefficient of unknown material when exposing it to an x-ray of a known energy can also help slightly different attenuation coefficient.

This application is very helpful in disciplines such as materials science, where one may want to try to investigate a sample of material without damaging it completely.

1.2 Research problem

Two main approaches to reduce radiation damage by reducing the amount of energy depotsited in the sensitive material or modification of the material to be less sensitive to radiation damage. Some degree of protection may be obtained by shielding, usually with the interposition of high density materials between the radiation source and areas to be protected.

1.3 Specific objectives

The aim of the study is to find a material that is highly protected from X-rays and is less expensive to use in X-ray shielding systems.

Chapter Tow

Scientific Background and Previous Studies

2.1 Introduction

All life has evolved in an environment filled with radiation. The forces at work in radiation are revealed upon examining the structure of atoms. Atoms are a million times thinner than a single strand of human hair, and are composed of even smaller particles – some of which are electrically charged.

2.2 Types and Sources of Radiation

Radiation is energy in the form of waves of particles. There are two forms of radiation – non-ionizing and ionizing – which will be discussed in sections 2.2.1 and 2.2.2, respectively.

2.2.1 Non-ionizing radiation

Non-ionizing radiation has less energy than ionizing radiation; it does not possess enough energy to produce ions. Examples of non-ionizing radiation are visible light, infrared, radio waves, microwaves, and sunlight. Global positioning systems, cellular telephones, television stations, FM and AM radio, baby monitors, cordless phones, garage-door openers, and ham radios use non-ionizing radiation. Other forms include the earth's magnetic field, as well as magnetic field exposure from proximity to transmission lines, household wiring and electric appliances. These are defined as extremely low-frequency (ELF) waves and are not considered to pose a health risk.

2.2.2 Ionizing radiation

Ionizing radiation is capable of knocking electrons out of their orbits around atoms, upsetting the electron/proton balance and giving the atom a positive charge. Electrically charged molecules and atoms are called ions. Ionizing radiation includes the radiation that comes from both natural and man-made radioactive materials [1].

Gamma rays, X-rays, and the higher ultraviolet part of the electromagnetic spectrum are ionizing, whereas the lower ultraviolet part of the electromagnetic spectrum, and also the lower part of the spectrum below UV, including visible light (including nearly all types of laser light), infrared microwaves, and radio waves are all considered non-ionizing radiation. The boundary between ionizing and non-ionizing electromagnetic radiation that occurs in the ultraviolet is not sharply defined, since different molecules and atoms ionize at different energies. Conventional definition places the boundary at photon energy between 10eV and 33eV in the ultraviolet (see definition boundary section below). [2]

Spectral region	**Approximate wavelength rang**	**Approximate range of photon energies**
Radio wave	10000eV-1mm	1×10^{-14}eV-0.001eV
Infrared rays	1mm-0.75µm	0.001eV-1.7eV
Visible light	0.75µm-0.4µ	1.7eV-3.1eV
Ionizing electromagnetic radiation		
Ultraviolet light	0.4µm-10nm	3.1eV-100eV
X-rays radiation	10nm-0.001nm	100eV-1MeV
Gamma radiation	<0.1nm	>10KeV

Table2.1. the scale of wavelengths of electromagnetic radiation

2.3X-rays

X-rays are a form of light, but much more energetic than the light detected by our eyes. The energy of an X-ray photon (light particle) is ~1000 times that of a photon of visible light. They are part of the electromagnetic spectrum which includes visible light, radio waves, microwaves and infra-red radiation.

2.3.1 Nature of X-rays

X-rays with energies ranging from about 100 eV to 10 MeV are classified as electromagnetic waves, which are only different from the radio waves, light, and gamma rays in wavelength and energy. X-rays show wave nature with wavelength ranging from about 10 to 10^3 nm. According to the quantum theory, the electromagnetic wave can be treated as particles called photons or light quanta.

The essential characteristics of photons such as energy, momentum, etc., are summarized as follows.

The propagation velocity C of electromagnetic wave (velocity of photon) with frequency and wavelength is given by relation.

$$c = \lambda v \text{(Ms-1)} \qquad (2.1)$$

The velocity of light in the vacuum is a universal constant given as C=299792458 m/s (≈2.998×10^8 m/s). Each photon has an energy E, which is proportional to its frequency,

$$E = hv = \frac{hc}{\lambda} \qquad (2.2)$$

Where h is the Planck constant (6.625×10^{-34}Js), with E expressed inkeV, and λ in nm, the following relation is obtained:

$$E(keV) = \frac{1.240}{\lambda(nm)} \qquad (2.3)$$

The momentum P is given by mv, the product of mass m, and its velocity v. The de Broglie relation for material wave relates wavelength to momentum.

$$\lambda = \frac{h}{p} = \frac{h}{mv} \qquad (2.4)$$

The velocity of light can be reduced when traveling through a material medium, but it does not become zero. Therefore, a photon is never at rest and so has no rest mass me. However, it can be calculated using Einstein's mass-energy equivalence relation $E = mc^2$.

$$E = \frac{me}{\sqrt{1-(\frac{v}{c})2}} c^2$$

(2.5)

It is worth noting that (2.5) is a relation derived from Lorentz transformation in the case where the photon velocity can be equally set either from a stationary coordinate or from a coordinate moving at velocity of v (Lorentz transformation is given in detail in other books on electromagnetism: for example, P. Corneille, Advanced Electromagnetism and Vacuum physics, World Scientific publishing, Singapore, (2003)). The increase in mass of photon with velocity may be estimated in the following equation using the rest mass m_e:

$$E = m\mathrm{c}2 - \mathrm{me}\mathrm{c}2 = \frac{me}{\sqrt{1-(\frac{v}{c})2}} c^2 - m_e c^2 \qquad (2.6)$$

$$v = c. \sqrt{1 - \left(\frac{me\mathrm{c}2}{E + me\mathrm{c}2}\right) 2} \qquad (2.7)$$

For example, an electron increases its mass when the accelerating voltage exceeds 100kV, so that the common formula of $1/2mv^2$ for kinetic energy cannot be used. In such case, the velocity of electron should be treated relativist ally as follows: The value of me is obtained, in the past, by using the relationship of

m=h/(cƛ) from precision scattering experiments, such as Compton scattering and $m_e = 9.109 \times 10^{-31}$kg is usually employed as electron rest mass. This also means that an electron behaves as a particle with the mass of 9.109×10^{-31}kg and it is also a relationship between mass, energy, and momentum

$$\left(\frac{E}{c}\right)2 - p2 = (meC)2 \qquad (2.8)$$

It is useful to compare the properties of electrons and photons. On the one hand, the photon is an electromagnetic wave, which moves at the velocity of light sometimes called light quantum with momentum and energy and its energy depends upon the frequency υ. The photon can also be treated as particle. On the other hand, the electron has "mass" and "charge". It is one of the elementary particles that is a constituent of all substances. The electron has both particle and wave nature such as photon. For example, when a metallic filament is heated, the electron inside it is supplied with energy to jump out of the filament atom. Because of the negative charge of the electron,(e=1.602×10^{-19}C), it moves toward the anode in an electron field and its direction of propagation can be changed by a magnetic field.[3]

2.3.2 Production of X-rays

A current is passed through the tungsten filament and heats it up. As it is heated up the increased energy enables electrons to be released from the filament through thermionic emission **.**The electrons are attracted towards the positively charged anode and hit the tung sten target with a maximum energy determined by the tube potential (voltage). As the electrons bombard the target they interact via Bremsstrahlung and characteristic interactions which result in the conversion of energy into heat (99%) and x-ray photons (1%). The x-ray photons are released in a beam with a range of energies (**x-ray spectrum**) out of the window of the tube and form the basis for x-ray image formation.

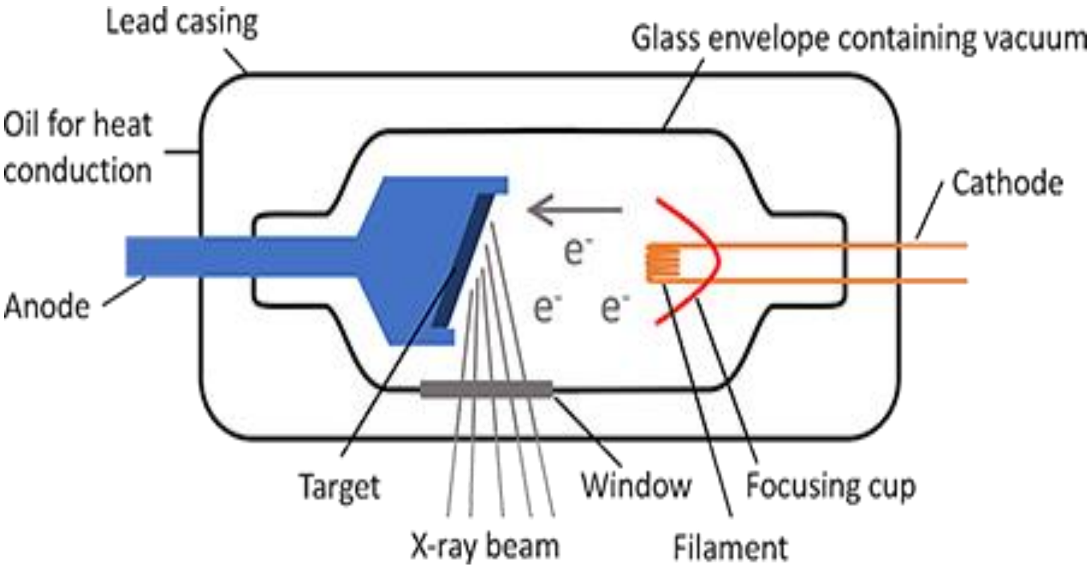

Figure (2.1): Production of X-rays

Cathode:

Filament

Made of thin (0.2 mm) tungsten wire because tungsten:

Has a high atomic number (A 184, Z 74)

Is a good thermionic emitter (good at emitting electrons?)

Can be manufactured into a thin wire

Has a very high melting temperature (3422°c)

The size of the filament relates to the size of the focal spot. Some cathodes have two filaments for broad and fine focusing

Focusing cup

Made of molybdenum as: high melting point

Poor thermionic emitter so electrons aren't released to interfere with electron beam from filament negatively charged to focus the electrons towards the anode and stop spatial spreading.

Anode

Target made of tungsten for same reasons as for filament

Rhenium added to tungsten to prevent cracking of anode at high temperatures and usage

Set into an anode disk of molybdenum with stem

Positively charged to attract electrons

Definitions

Target, focus, focal point, and focal spot: where electrons hit the anode

Actual focal spot: physical area of the focal track that is impacted

Focal track: portion of the anode where the electrons bombard. On a rotating anode this is a circular path

Effective focal spot: the area of the focal spot that is projected out of a tube. [4]

2.3.3 Absorption of X-rays

The x-ray photons interact with matter through the photoelectric effect and Compton scattering. The photoelectric effect increases rapidly with Z, the atomic number of the target material. The photoelectric interaction probability is proportional to Z5 and is the greatest for low-energy photons. The Compton effect is relatively independent of energy and the atomic number of the absorber. These two processes determine the *absorption coefficient* of the material for x rays. The intensity x rays passing through a material of thickness *x* can be expressed as an exponential function,

$$I=I_0 e^{-\mu x} \qquad (2.9)$$

I is the x-ray intensity at a distance *x* in the material,μ is absorption coefficient of the material, *x* is the thickness of the material, and I_0 is the incident intensity of the x rays in joules per unit area per second.

For soft x rays (those with energy less than 50 keV) the photoelectric effect is the important factor in x-ray absorption, while for hard x-rays (those with energy greater than 100 keV) the Compton effect contributes significantly to the absorption. The absorption coefficient as a function of energy for water (approximately the same as that of biological material) and for lead are shown in Figure 2.2

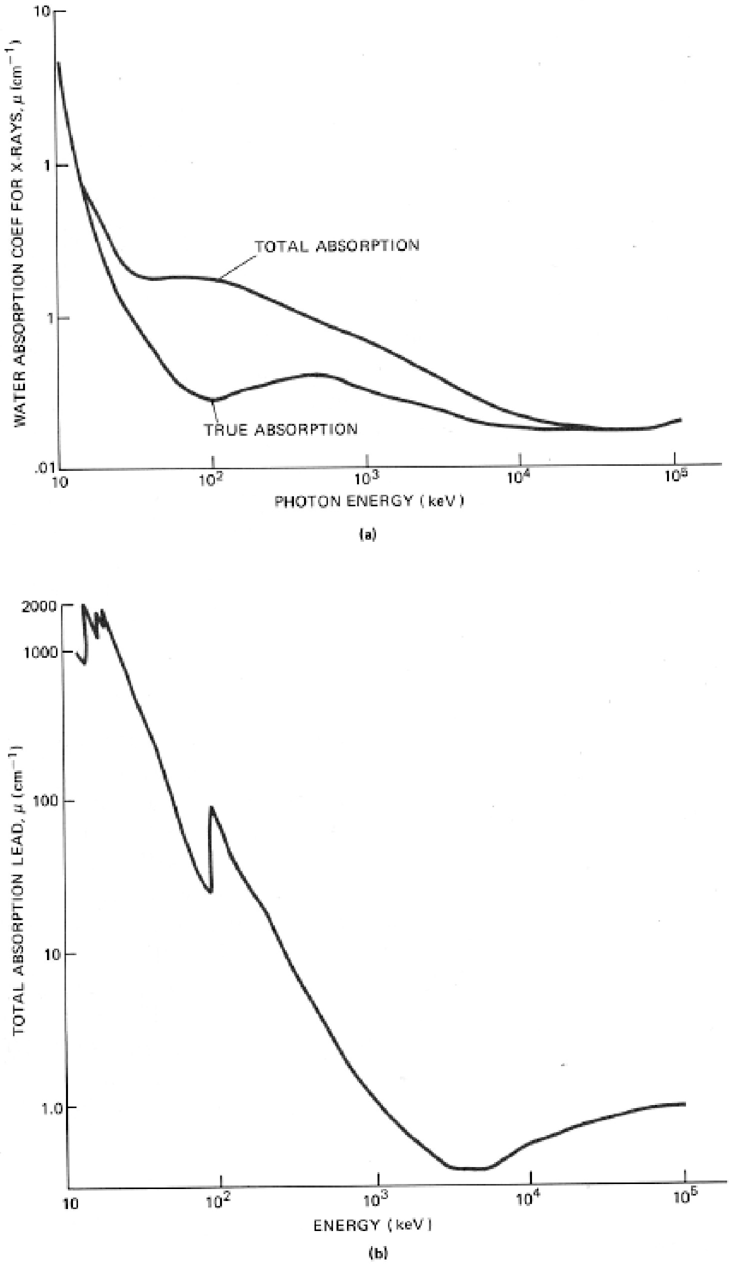

Figure (2.2): Absorption of X-rays

2.3.4 Detection of X-Rays

The detection of x rays results from the effects of the energy absorbed in the detector.

The fluoroscope uses the emission of visible light from a material when it is subjected to x rays. The photons emitted by the fluoroscope screen are in the visible region, and the observer sees a picture of the material through which the x rays pass before reaching the fluoroscope.

Photographic film is also used to record x rays. Small film badges are worn by Persons in potential radiation areas as reliable detectors of radiation exposure.

An ionization chamber can be used to monitor the presence of x rays. A simple Ionization chamber is represented in Figure 30.4. The chamber between a pair of Parallel plates are filled with a gas at low pressure. The plates are connected in series with a source of DC potential of the order of 1000 V and with a current measuring device. A beam of x rays is directed along the long axis of the tube. The x rays are an ionizing agent, and as the atoms of the gas are ionized, the ions and the free electrons are subjected to an electric field. The positive ions are accelerated toward the cathode and the electrons and negative ions are accelerated toward the anode. This flow of ions produces an electric current between the plates and hence through the circuit. The current is proportional to the ions produced and thus to the energy of x rays absorbed.[5]

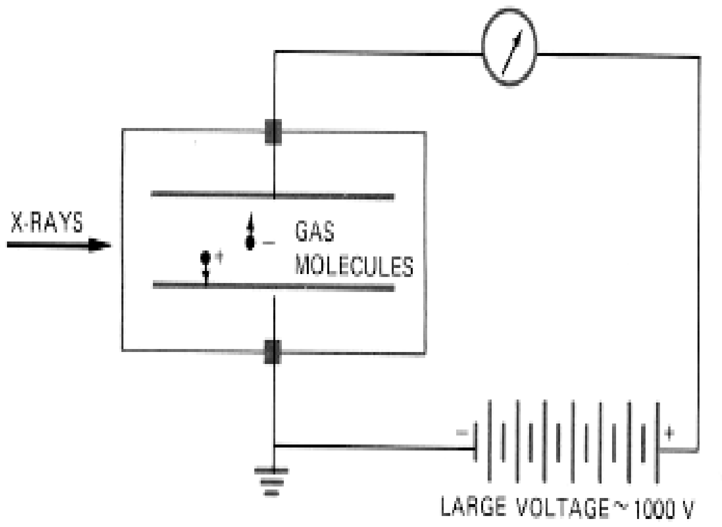

Figure (2.3): Simple ionization detector.[5]

Different types of ionization chambers are used in the detection of x rays. These differ in the geometry of the chamber and the magnitude of the applied voltage between the electrodes. One which is very useful in the detection of x-rays is the Geiger- Mueller (G-M) counter. These counters are relatively economical, sensitive to x-rays, rugged, and portable. They are generally made in a glass tube. The inside of the tube is coated to serve as the cathode and a coaxial wire serves as the anode. [5]

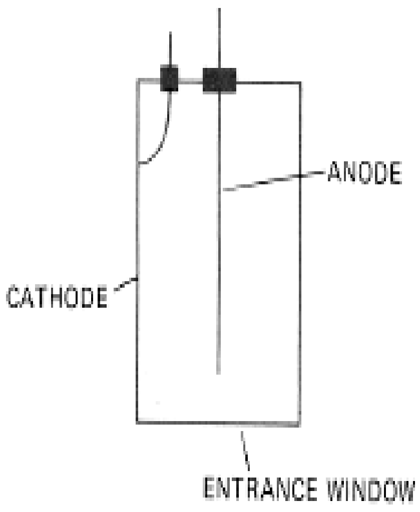

Figure (2.4): Simple Geiger Muller tube.[5]

2.3.5 Half value layer

A useful way to characterize the penetrating quality of an x-ray beam by its half- value layer (HVL). The HVL is the thickness of an absorber, such as aluminum, required to reduce by one half the number of x-ray photons passing through it. As the average energy of x-ray beam increases, so does it HVL. The term quality refers to the mean energy of an x-ray beam.[6]

2.3.6 Inverse square law

The radiation Intensity is inversely proportional to the square of the distance. Notice in the diagram that as the distance doubles, the area quadruples and thus, the initial radiation amount is spread over that entire area and is therefore reduced, proportionately. Imagine we are trying to expose a piece of x-ray film (radiograph) and we move the x-ray source twice as far away on each shot, will the film be more or less exposed ? Therefore, while the inverse square law pertains to radiation safety, it also helps us to determine source to film distances (SFD), time of x-ray exposure, and the intensity (KV) of our x-ray tube.[6]

$$I_1/I_2=D_2^2/D_1^2 \qquad (2.10)$$

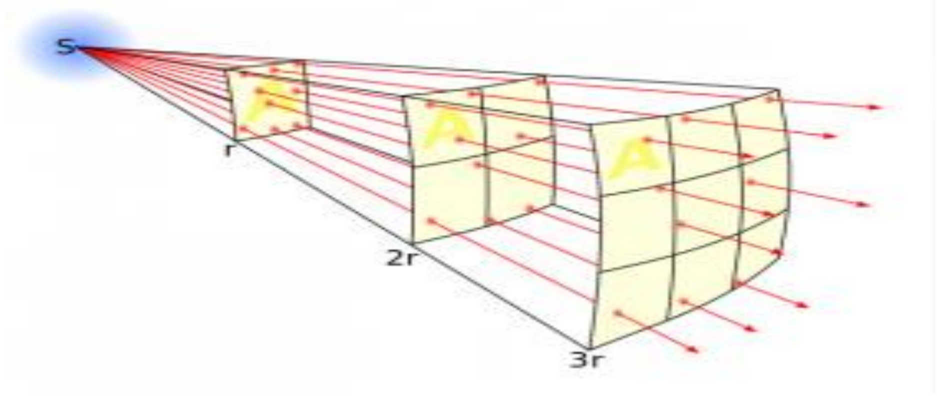

Figure (2.5): Across section diagram of invers square.[6]

I_1 = Intensity with a distance measured as (R/hr or mR/hr)

D_1 = Distance with an intensity (usually measured in feet)

I_2 = Intensity without a Distance

D_2 = Distance without Intensity

2.3.7 Interaction of X-Rays with Matter

Early experiments showed that x rays would penetrate matter. In fact, within one month after the discovery of x rays, two French physicists had produced a photograph showing the bones in a human hand. From experiments it has been found that the number of x-ray photons is diminished by passage through matter, particularly if they are passing through a material of high atomic number. It has also been found that some of the photons that emerge have the same energy as the incident energy, even though the number that emerge decreases as the thickness increases. For photons in x-ray energy range there are two physical processes that are of importance in reducing the number of x rays that pass through a material. These processes are the photoelectric effect and the Compton effect (scattering),.

First, the photoelectric effect as you recall is an interaction between the photon and an electron that is bound in an atom. The larger number of electrons in an atom, the greater the probability that the photoelectric effect will occur. In the photoelectric effect the incident photon gives up its energy to a bound electron in an atom. The basic energy equation for this interaction is that the kinetic energy of the energy equation for this interaction is that the kinetic energy of the ejected electron is equal to the energy of the incident photon energy minus the energy required to remove the electron from its atom.

In many cases, the work function is much smaller than x-ray photon energy, and the photoelectron has nearly the same energy as the incident photon. The photoelectron may also interact with matter. Secondly, the Compton Effect is the interaction between a photon and a free electron. In this interaction the photon loses only a fraction of its energy. This loss of energy is imparted to the free Electron In general, the photon and the free electron are scattered at angles relative to the incident direction. The energy of the free electron depends upon the energy of the incident photon and the angles of scattering. As the atomic number of the material increases, the photoelectric effect becomes predominant over the Compton Effect in reducing the x-ray intensity.[5]

2.3.8 Energy Transfer

There are two basic types of energy transfer that may occur when X-rays interact with matter:

- Ionization in which the incoming radiation cause the removal of an electron from an atom or molecule leaving the material with a net positive charge.

- Excitation, in which some of x-rays energy is transferred to the target material leaving it in an excited (or more energetic) state.

Theoretically there are twelve processes that can occur when X-rays interact with matter, but only three of these processes are important. These processes are:

*The photoelectric effect.

*The Compton Effect.

*Pair production.

Which process dominates is dependent on the mass absorption characteristics of the target (directly related to the atomic weight,Z) and the energy of the X-rays, shown schematically in the graph below.[6]

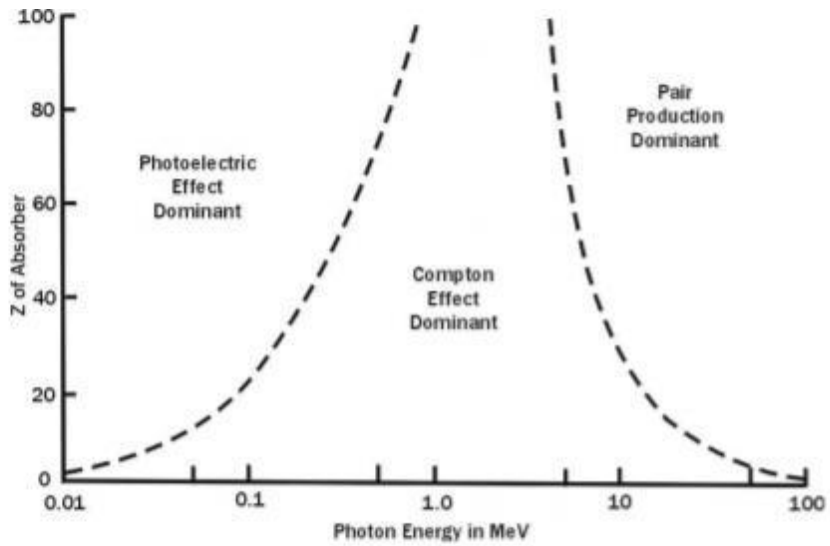

Figure (2.6): Mass absorption process

2.3.9 The Photoelectric Effect

The photoelectric effect occurs when photons interact with matter with resulting ejection of electrons from the matter. Photoelectric (PE) absorption of x-rays occurs when the x-ray photon is absorbed resulting in the ejection of electrons from the atom. This leaves the atom in an ionized (i.e., charged) state. The ionized atom then returns to the neutral state with the emission of an x-ray characteristic of the atom. PE absorption is the dominant process for x-ray absorption up to energies of about 500keV. PE absorption is also dominant for atoms of high atomic numbers.

The photoelectric effect is responsible for the production of characteristic x-rays in the x-ray tube, but the process is also important as a secondary process that occurs when x-rays interact with matter. An x-ray photon transfers its energy to an orbital electron, which is then dislodged and exits the atom at high speed with a kinetic energy equal to:

$$KE = E_X - P \qquad (2.11)$$

Where

KE is the kinetic energy of the photoelectron

E_x is the energy of the incident X-ray photon

P is the energy required to remove the electron. This is equivalent to its binding energy in the atom.

The energy equivalent of the rest mass of an electron is m_0c^2 , and is equal to about 0.51 MeV (m_0 is the rest mass of an electron and c is the speed of light). When E_x is much lower than this value, the electron will exit at a high angle to the incident beam; when Ex is closer to this value, the electron will exit at close to parallel with the beam.

When the photoelectron is ejected, it has the capability, depending on its energy, to interact with subsequent electrons in other molecules or atoms in a chain reaction until all its energy is lost. If that interaction results in the ejection of an outer orbital electron, this is known as the Auger (au-jay) effect, and the electron called an Auger electron. The probability of producing a secondary photoelectron vs. an Auger electron is directly proportional to the KE of the photoelectron.

The production of photoelectric and Auger electrons is shown diagrammatically in the following figure from Jenkins and Snyder (1996). In the diagram (a) shows the incident X-ray photon, (b) shows the production of a high-energy primary photoelectron. In (c) a lower energy electron moves into the vacated K-shell resulting in the production of an X-ray photon that leaves the atom, and in (d) the X-ray photon is absorbed by an outer shell electron resulting in the emission of an Auger electron.

It is easy to see how the photoelectric (and Auger) effect can significantly damage the molecular structure of soft tissues encountered by an X-ray beam.[6]

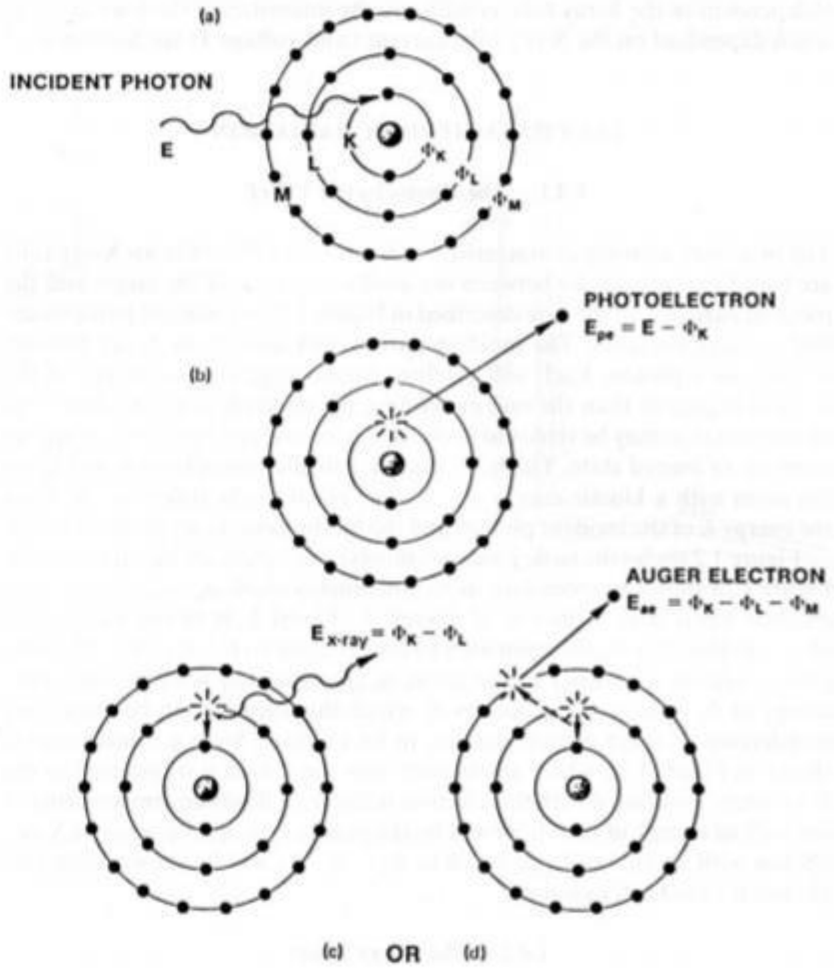

Figure (2.7): Photoelectric effect.[6]

2.3.10 the Compton Effect

The Compton Effect or Compton scattering (C), also known a incoherent scattering, occurs when the incident x-ray photon ejects a electron from an atom and an x-ray photon of lower energy is scattered from the atom. Relativistic energy and momentum are conserved in this process1 and the scattered x-ray photon has less energy and therefore greater wavelength than the incident photon. Compton Scattering is important for low atomic number specimens. At energies of 100 keV -- 10 MeV the absorption of radiation is mainly due to the Compton effect.

The Compton Effect will occur with very low atomic weight targets even at relatively low X-ray energies. The effect may be thought of as a scattering of the photons by atomic electrons. In the process, also called Compton scattering, the incident X-ray changes direction and loses energy, imparting that energy to the electron (now called a Compton electron). The Compton electron will typically interact with other atoms producing secondary ionizations. Since they possess relatively low energy, the x-rays produced will generally be low energy also.

The maximum possible energy, E, of a Compton electron (the "Compton edge") is equal to:

$$E=\frac{EX}{1+4\ EX} \qquad (2.12)$$

Where Ex is the energy of the incident photon qualitatively, it is easy to see that the Compton electrons will be significantly less energetic than photoelectrons for an equal value of.

In x-ray diffraction, Compton scatter will contribute to the overall background in the x-ray data produced, but because of the relatively low energies of the incident x-rays and the higher mass of the specimens and specimen holders, the contribution will usually be very small.[6]

2.3.11 Pair Production

Pair Production (PP) can occur when the x-ray photon energy is greater than 1.02 MeV, when an electron and positron are created with the annihilation of the x-ray photon. Positrons are very short lived and disappear (positron annihilation) with the formation of two photons of 0.51 MeV energy. Pair production is of particular importance when high energy photons pass through materials of a high atomic number.

Pair production is a rare process and only occurs at high X-ray photon energies with high atomic weight targets. It is virtually nonexistent at the low-energies involved in X-ray diffraction work. Pair production is impossible unless the incident X-rays exceed 1.02 MeV and does not become important until this exceeds about 2 MeV.

Pair production is not a significant process at the X-ray energies involved in X-ray diffraction. [6]

2.4 Previous studies

2.4.1 New basic empirical expression for computing tables of X-ray mass attenuation coefficient by Tran pouch ,Jean leprous, view issue Toc, voiume8, issue 2, April 1979, page 85-91.

This paper describes a new approach for deriving a simple relation between mass attenuation coefficient and X-ray energy or wavelength. Parameters of the latter have been adjusted to fit all up-to-date experimental, interpolated and extrapolated data thus providing means for computing a set of tables covering all values of coefficient usually encountered in applied X-ray spectroscopy. The accuracy is generally much better than±5% with respect to the average of well-established data.

2.4.2 specific gamma-ray constant and exposure rate constant of 192Ir by Glenn P.Glasgow,L.T.Dillman, View issue TOC ,Volume 6, Issue 1,January 1979 ,Pages 49-52.

2.4.3 Investigating the attenuation coefficient for different material using X-ray and gamma-ray by Ammar Adam Mohammed May 2017. It was also found attenuation coefficient of X-ray for Cu is equals 11.7, Fe is equals 6.82 and Al is equals 1.2. The attenuation coefficient of Gamma-ray for Cu is equals 0.103, Fe is equals 0.687 and Al is equals 0.0235.

2.5 Linear and mass attenuation coefficient

2.5.1introduction

The linear and mass attenuation coefficient is an important parameter, which is widely used in industry, agriculture, science, and technology, etc. [1].

With wide spread utilization of radiation and radioisotopes in medicine, industry and basic sciences, the problem of radiation protection has become important aspect while handling radiation sources and radiation generating equipments [2].

However the ill effects and hazards of radiation, especially the high energy gamma radiation, are well known. Hence the person using the radiation technology, the workers and the public around must be protected or shielded from these radiations [3].

The interaction of gamma radiations with the materials of common and industrial use, as well as of biological and commercial importance has become major area of interest in the field of radiation science The linear and mass attenuation coefficient is an important parameter, which is widely used in industry, agriculture, science, and technology, etc. [1].

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2.5.2 Linear attenuation coefficients

The attenuation of x-rays radiation can be then described by the following equation.

$$\mathbf{I=I_0.e^{-\mu x}} \qquad (2.13)$$

Since the factors that affect the linear attenuation coefficients are beam energy and materials thickness, therefore the total attenuation is a function of x. then it can be expressed as follows:

$$\ln\frac{I0}{I} = \int \mu(x)dx \qquad (2.14)$$

$\mu(x)$ is the linear attenuation coefficient as a function of position. Assuming that the sample is uniform in the beam path then, $\mu(x)$ should be a constant. So the equation (3.2) can be written as:

$$\mu x = \ln\frac{I0}{I} \qquad (2.15)$$

By plotting the values of $\ln(\frac{IO}{I})$ against the thickness x, the linear attenuation coefficient μ can be calculated using the linear regression method.

Where I is intensity after attenuation, I_o is incident intensity, μ is the linear attenuation coefficient (cm^{-1}), and physical thickness of absorber (cm).

The materials listed in the table beside are air, water and a different elements from carbon (Z=6) through to lead (Z=82) and their linear attenuation coefficients are given for three x-rays energies. There are two main features of the linear attenuation coefficient:

- The linear attenuation coefficient increases as the atomic number of the absorber increases.
- The linear attenuation coefficient for all materials decreases with the energy of the x-rays

The linear attenuation coefficient (μ) describes the fraction of a beam of x-rays or gamma rays that is absorbed or scattered per unit thickness of the absorber. This value basically accounts for the number of atoms in a cubic cm volume of material and the probability of a photon being scattered or absorbed from the nucleus or an electron of one of these atoms.

Using the transmitted intensity equation above, linear attenuation coefficients can be used to make a number of calculations. These include:

- the intensity of the energy transmitted through a material when the incident x-ray intensity, the material and the material thickness
- The intensity of the incident x-ray energy when the transmitted x-ray intensity, material, and material thickness are known.
- The thickness of the material when the incident and transmitted intensity, and the material are known.
- The material can be determined from the value of μ when the incident and transmitted intensity, and the material thickness are known.

Linear attenuation coefficients can sometimes be found in the literature. However, it is often easier to locate attenuation data in terms of the **mass attenuation coefficient.** Tables and graphs of the mass attenuation coefficients for all of the elements $Z = 1$ to 92, and for compounds and mixtures of radiological interest are available at the National Institute for Standards and Technology website. The tables on the NIST website cover energies of photons (x-ray, gamma ray, and bremsstrahlung) from 1 keV to 20 MeV. A mass attenuation coefficient can easily be converted to a linear attenuation coefficient.[7]

2.5.3 Use of Linear Attenuation Coefficients

One use of linear attenuation coefficients is for selecting a radiation energy that will produce the most contrast between particular materials in a radiograph. Say, for example, that it is necessary to detect tungsten inclusions in iron. It can be seen from the graphs of linear attenuation coefficients versus radiation energy that the maximum separation between the tungsten and iron curves occurs at around 100keV. At this energy the difference in attenuation between the two materials is the greatest so the radiographic contrast will be maximized.

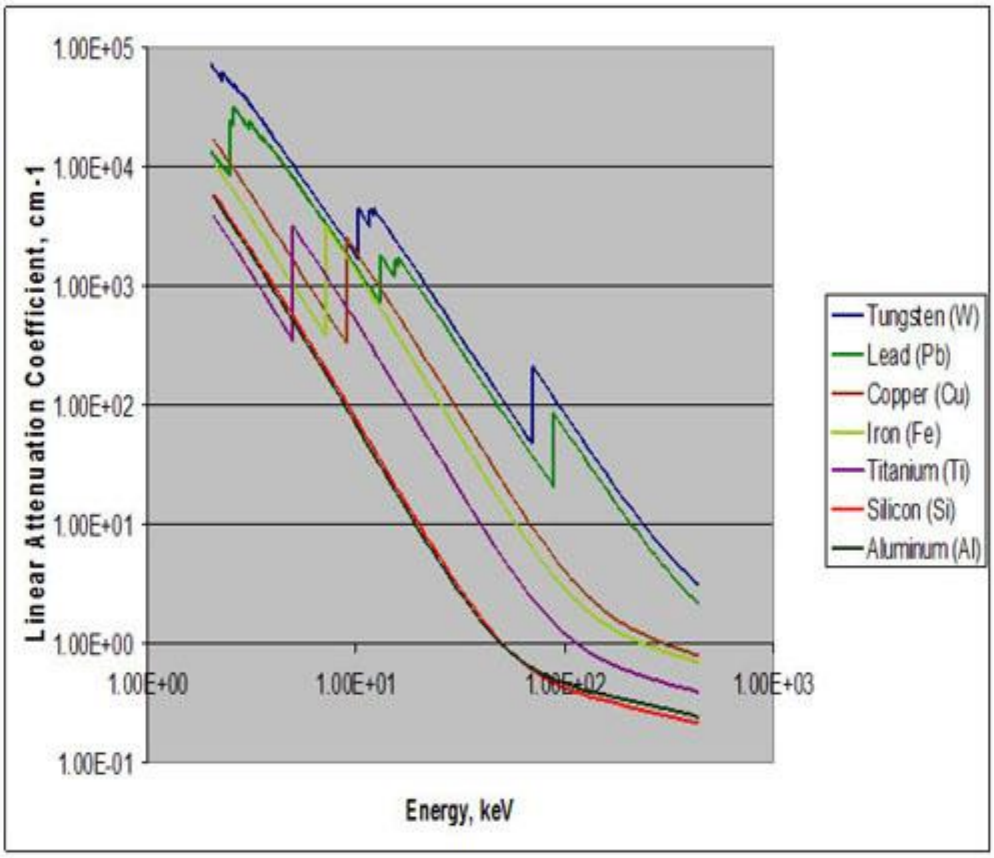

Figure (2.8): Graphic to relation between energy and linear attenuation coefficient for different material.[8]

2.5.4 Sources of Attenuation

The attenuation that results due to the interaction between penetrating radiation and matter is not a simple process. A single interaction event between a primary x-ray photon and a particle of matter does not usually result in the photon changing to some other form of energy and effectively disappearing. Several interaction events are usually involved and the total attenuation is the sum of the attenuation due to different types of interactions. These interactions include the photoelectric effect, scattering, and pair production. The figure below shows an approximation of the total absorption coefficient, (μ), in red, for iron plotted as a function of radiation energy. The four radiation-matter interactions that contribute to the total absorption are shown in black. The four types of interactions are: photoelectric (PE), Compton scattering (C), pair production (PP), and Thomson or Rayleigh scattering (R). Since most industrial radiography is done in the 0.1 to 1.5 MeV range, it can be seen from the plot that photoelectric and Compton scattering account for the majority of attenuation encountered. [8]

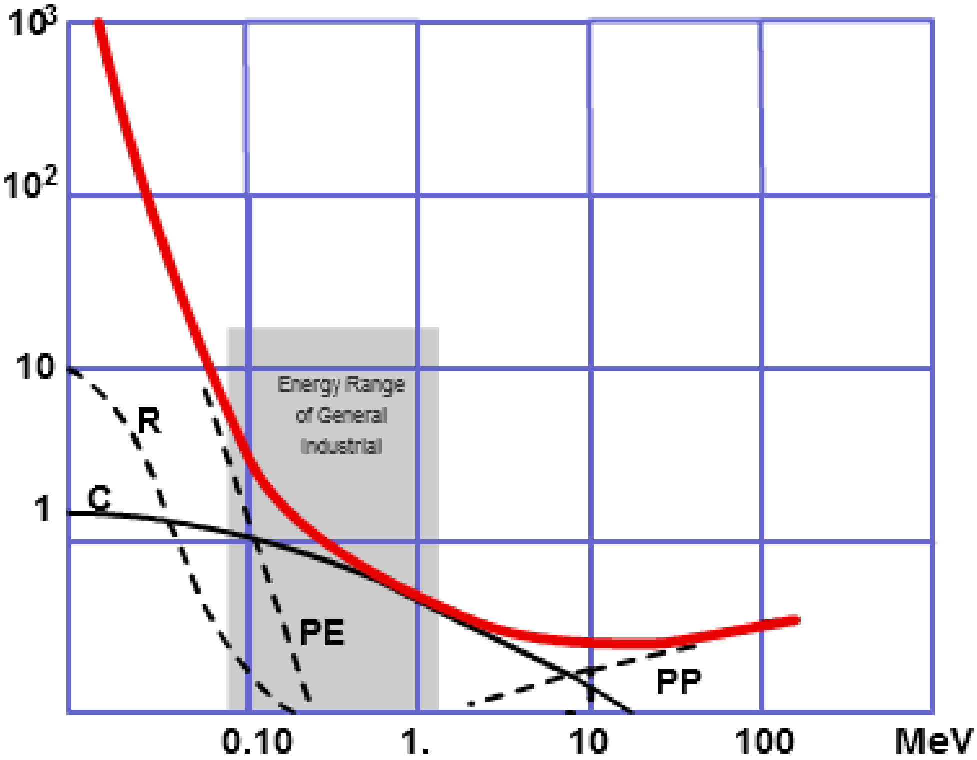

Figure (2.9): Sources of Attenuation.[8]

2.5.5 Mass attenuation coefficient

The linear attenuation coefficient is the simplest absorption coefficient to measure experimentally, but it is not usually tabulated because of its dependence on the density of the absorbing material. For example, at a given energy, the linear attenuation coefficients of water, ice, and steam are all different, even though the same material is involved. Gamma rays interact primarily with atomic electrons; therefore, the attenuation coefficient must be proportional to the electron density P, which is proportional to the bulk density of the absorbing material. However, for a given material the ratio of the electron density to the bulk density is a constant, Z/A, independent of bulk density. The ratio Z/A is nearly constant for all except the heaviest elements and hydrogen.

$$\boldsymbol{P} = \frac{\boldsymbol{Z\rho}}{\boldsymbol{A}} \qquad (2.16)$$

Where:

P = electron density

Z = atomic number

p = mass density

A = atomic mass.

The ratio of the linear attenuation coefficient to the density ($\mu\ell\ \rho$) is called the mass attenuation coefficient μ and has the dimensions of area per unit mass (cm2 g). The units of this coefficient hint that one may think of it as the effective cross-sectional area of electrons per unit mass of absorber. The mass attenuation coefficient can be written in terms of a reaction cross section, σ(cm2):

$$\mu = \frac{\boldsymbol{N0\sigma}}{\boldsymbol{A}} \qquad (2.17)$$

Where $N_0$is Avogadro's number (602×1023) and A is the atomic weight of the absorber. The cross section is the probability of x-ray interacting with a single atom. Using the mass attenuation coefficient, Equation (2.17) can be rewritten as

$$I = I_0 e^{-\mu\rho L} = I_0 e^{-\mu x} \quad (2.18)$$

where $x = \rho L$.

The mass attenuation coefficient is independent of density for the example mentioned above; water, ice, and steam all have the same value of μ. This coefficient is more commonly tabulated than the linear attenuation coefficient because it quantifies the gamma-ray interaction probability of an individual element. Equation (2.18) is used to calculate the mass attenuation coefficient for compound materials:

$$\mu = \sum \mu_i W_i \quad (2.19)$$

where :

μ_i= mass attenuation coefficient of i^{th} element. .

W_i= weight fraction of i^{th} element. [9]

The mass attenuation coefficient can be rewritten:

$$\mu_m=\mu/\rho \quad (2.20)$$

Where:

μ_m: mass attenuation coefficient

μ: linear attenuation coefficient

ρ: is the density of matter.

Note: the mass attenuation coefficient is depends to linear attenuation coefficient.

Chapter Three

Material and Method

3.1 Introduction

This chapter contains the material, method and instruments of the research

3.2 Material

Each of the materials: cork, wood, glass and plastic were used as absorbent bodies. They were cut with different thicknesses, each material according to its nature as follows:

3.2.1cork

Cork was cut into thicknesses of 1-2-3-4-5-6-7-8 cm.

3.2.2 Wood

Wood was cut into thicknesses of 0.8-1.4-2.2-2.4-2.8-3.2-3.8 cm.

3.2.3 Glass

Glass was cut into thicknesses of 2.6-4.5-7.2-9.4 mm.

3.2.4 Plastic

Plastic was cut into thicknesses of 1.5-3-4.5-6 mm.

3.3The Method

The practical method for this research is based on the use of materials with high X-ray protection and at the same time less expensive. In this research, materials were used: cork, wood, glass and plastic. Then, using an X-ray generating device, and then placing each material separately with different thicknesses. and then reading the intensity of the x-rays before and after penetrating the material by a computer connected to the generating device, then changing the current or voltage, then recording the results in tables and then analyzing the results.

3.4 Instruments

X-ray apparatus connected with computer –different material

Figure (3.1): Instruments of X-ray

Chapter four

Results Analysis and Discussion

4.1intrduction

In this part of the research, the results are recorded in tables, and then these results are analyzed to obtain the values of the linear attenuation and mass attenuation coefficient for all materials. The high attenuation factor means that this material has a high protection from X-ray radiation and therefore can be used in shielding systems.

Orange program was used to draw relationships and calculate the linear attenuation coefficient and mass attenuation coefficient

4.2 Results

Table (4.1): The relationship between the thickness of cork plates and the rate of x-ray radiation

Thickness(cm)	I (intensity)
0	9814.80
1	9538.57
2	9546.83
3	9486.57
4	9420.30
5	9395.97
6	9309.43
7	9296.57
8	9263.73

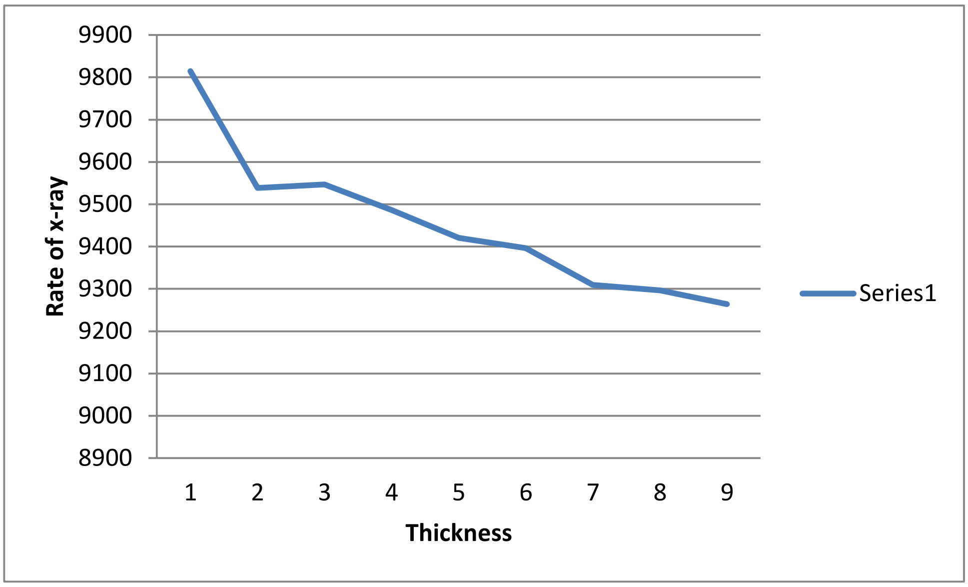

Figure (4.1): Relation between thickness of cork and rate of x-ray

Table (4.2): The relationship between the thickness of wood plates and the rate of x-ray radiation

Thickness (cm)	Rate of I at u=35kv And current I=0.8mA	Rate of I at u=35kv And current I=1mA	Rate of I at u=25kv And current I=0.8mA	Rate of I at u=25kv And current I=1mA
0	9814.80	10183.13	3880.07	4858.50
0.8	8351.43	9776.70	2816.97	3259.30
1.4	7880.80	9229.63	2575.60	3016.33
2.2	5749.23	7570.90	1858.77	2174.60
2.4	5447.67	7402.60	1789.70	2115.03
2.8	5289.97	6480.93	1718.17	2048.20
3.2	4527.97	5965.80	1409.80	1673.80
3.8	4130	4868.77	1243.40	1465.70

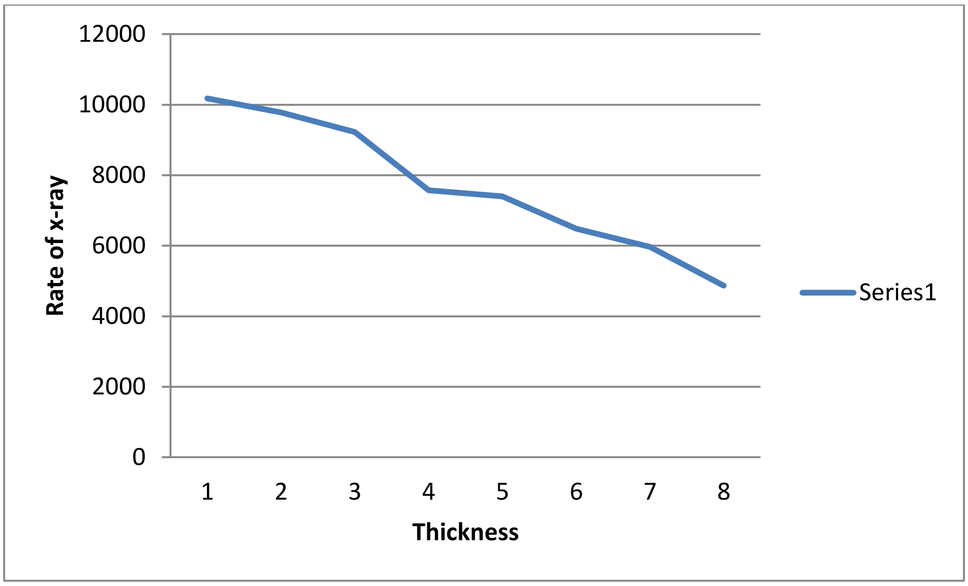

Figure (4.2): Relation between thickness of wood and rate of x-ray

Table (4.3): The relationship between the thickness of glass plates and the rate of x-ray radiation

Thickness (mm)	**Rate of I at u=25kv And current I=1mA**	**Rate of I at u=25kv And current I=0.8mA**	**Rate of I at u=30kv And current I=0.8mA**	**Rate of I at u=30kv And current I=1mA**	**Rate of I at u=35kv And current I=0.8mA**	**Rate of I at u=35kv And current I=1mA**
0	8801.60	7669.17	10233.60	9866.53	8806.87	8286.30
2.6	1487.93	1242,43	3098.87	3566.97	5333.87	6602.30
4.5	315.20	258.43	1119.93	1347.97	2444.67	2854.40
7.2	60.50	48.70	374.57	462.07	1152.77	1392.17
9.4	14.87	11.93	141.93	179.17	596.10	729.60

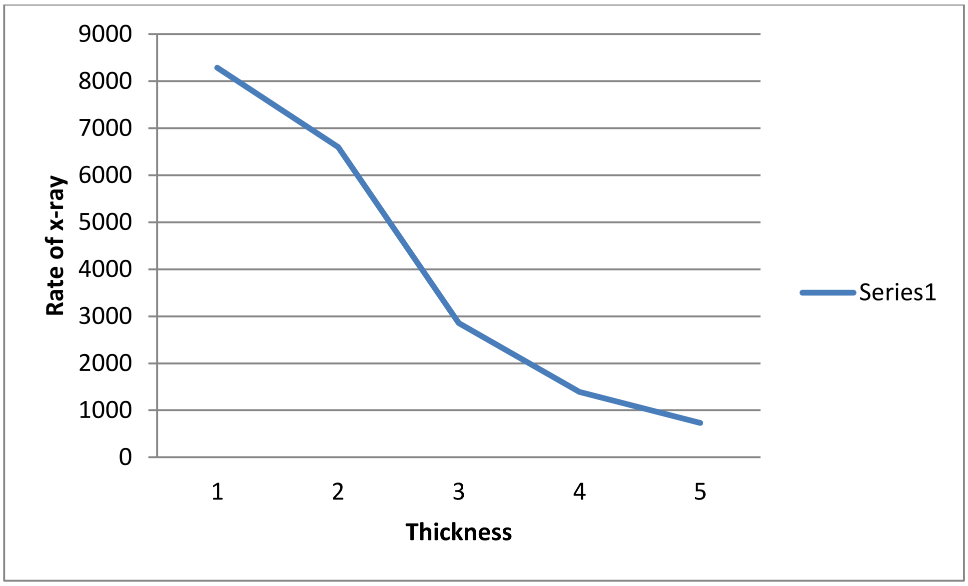

Figure (4.3): Relation between thickness of glass and rate of x-ray

Table (4.4): The relationship between the thickness of plastic plates and the rate of x-ray radiation

Thickness (mm)	Rate of I at u=25kv And current I=1mA	Rate of I at u=25kv And current I=0.8mA	Rate of I at u=30kv And current I=1mA	Rate of I at u=30kv And current I=0.8mA	Rate of I at u=35kv And current I=1mA	Rate of I at u=35kv And current I=0.8mA
0	8647.07	7553.10	9891.93	10212.93	8312.57	8887.30
1.5	8251.53	7041.90	10074.03	10196.03	8490.03	9151.53
3	7592.53	6323.50	10182.57	10066.20	8710.23	9438.90
4.5	7132.43	5878.67	10204.87	9888.60	8933.93	9625.63
6	6574.53	5349.43	10130.37	9634.47	9205.10	9894.53

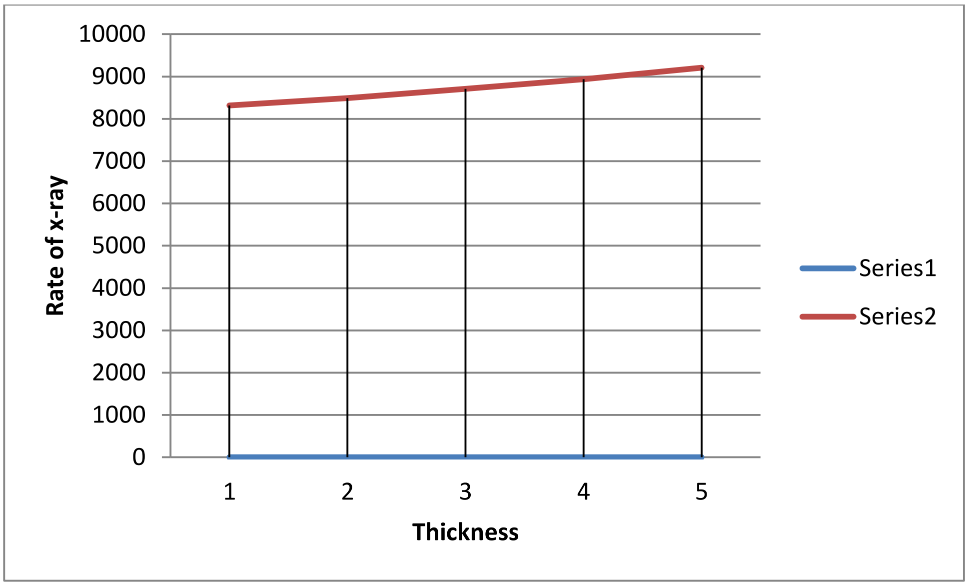

Figure (4.4): Relation between thickness of plastic and rate of x-ray

Table (4.5): The relationship between the thickness of cork and transmission of x-ray

Thickness(cm)	I (intensity)	$T=I_0/I$	LnT
0	9814.80	1	0
1	9538.57	1.289	0.02854
2	9546.83	1.280	0.02768
3	9486.57	1.0345	0.03401
4	9420.30	1.0418	0.04102
5	9395.97	1.0445	0.04361
6	9309.43	1.0542	0.05286
7	9296.57	1.0557	0.05424
8	9263.73	1.0594	0.05778

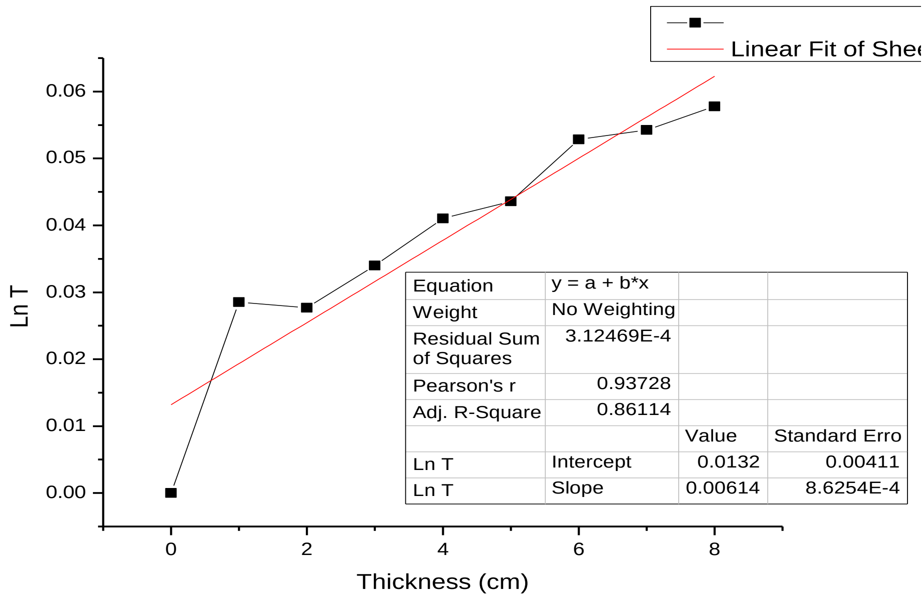

Figure (4.5): The relationship between the thickness of cork and the transmission of x-ray.

μ_L=slope=LnT/d=0.00614 (d is Thickness of cork)

$\mu_m = \mu_L / \rho$=0.00614/240 = 0.0000256 (ρ is density of cork)

Table (4.6): The relationship between the thicknesses of wood and transmission of x-ray at u=35kv and current 1mA

Thickness(cm)	Rate of I at u=35kv And current I=1mA	т=I0/I	Lnт
0	10183.13	1	0
0.8	9776.70	1.0415	0.04073
1.4	9229.63	1.1033	0.09831
2.2	7570.90	1.345	0.29642
2.4	7402.60	1.3756	0.3189
2.8	6480.93	1.5712	0.45186
3.2	5965.80	1.7069	0.53468
3.8	4868.77	2.0915	0.73789

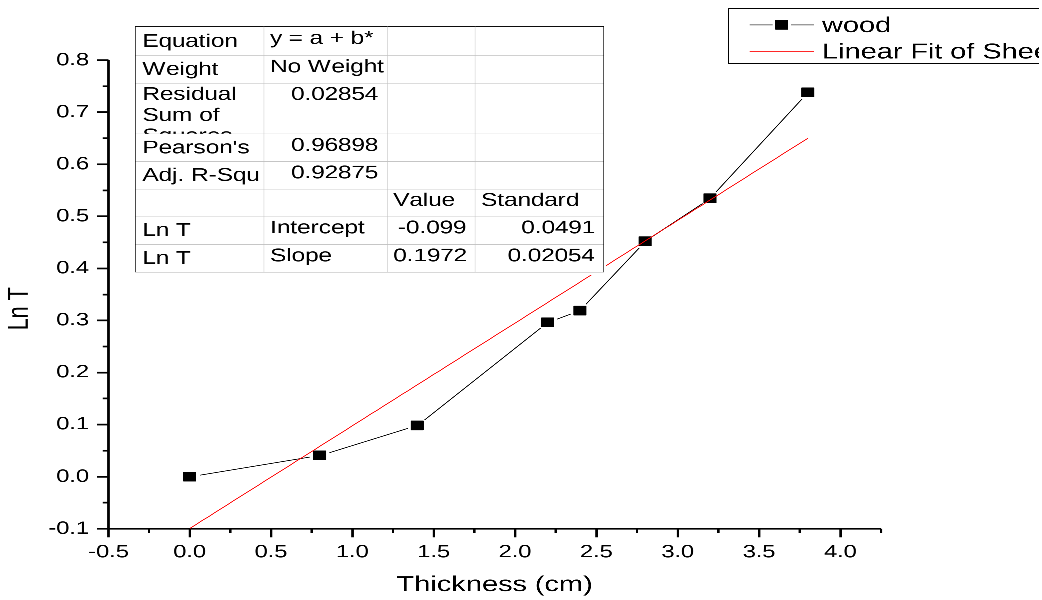

Figure (4.6): The relationship between the thickness of wood and the transmission of x-ray at u=35kv and current 1mA.

Table (4.7): The relationship between the thickness of wood and transmission of x-ray at u=25kv and current 1mA

Thickness(cm)	Rate of I at u=25kv And current I=1mA	т=I0/I	Lnт
0	4858.50	1	0
0.8	3259.30	1.4906	0.39921
1.4	3016.33	1.6107	0.47668
2.2	2174.60	2.2342	0.80388
2.4	2115.03	2.2971	0.83166
2.8	2048.20	2.37208	0.86376
3.2	1673.8	2.90267	1.06563
3.8	1465.70	3.31479	1.19839

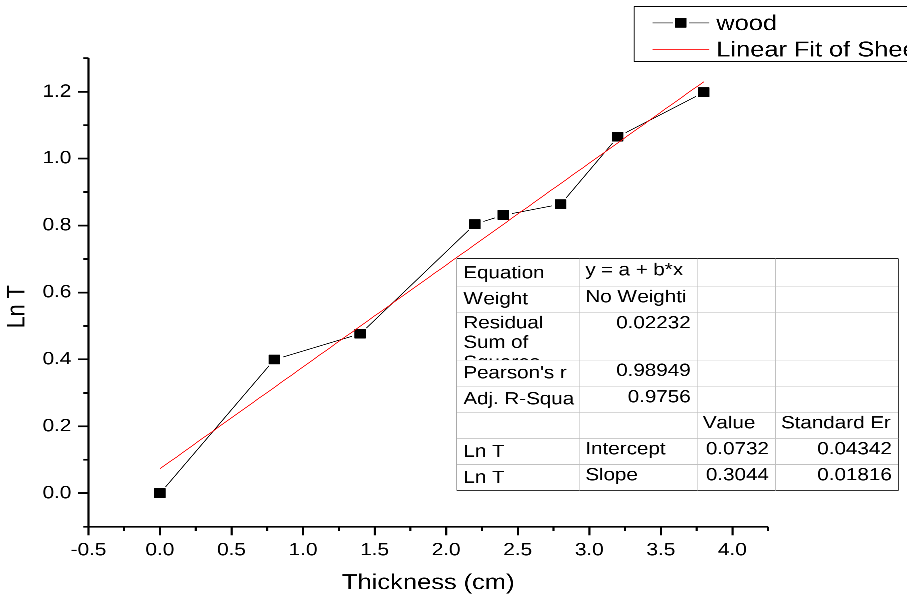

Figure (4.7): The relationship between the thickness of wood and the transmission of x-ray at u=25kv and current 1mA.

μ_L=slope=LnT/d=0.3044 (d is Thickness of wood)

$\mu_m = \mu_L / \rho$=0.3044/700=0.000435 (ρ is density of wood)

Table (4.8): The relationship between the thickness of glass and transmission of x-ray at u=25kv and current 1mA

Thickness (mm)	**Rate of I at u=25kv And current I=1mA**	**τ=I0/I**	**Lnτ**
0	8801.60	1	0
2.6	1487.93	5.9153	1.7775
4.5	315.20	27.9238	3.3294
7.2	60.50	145.481	4.980
9.4	14.87	591.903	6.3833

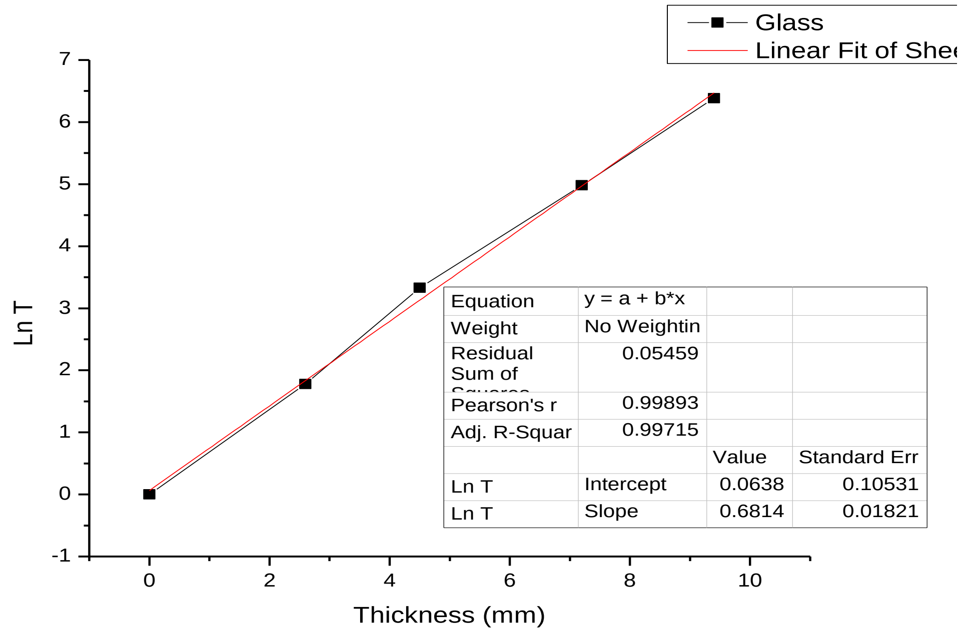

Figure (4.8): The relationship between the thickness of glass and the transmission of x-ray at u=25kv and current 1mA.

μ_L=slope=LnT/d=0.6814 (d is Thickness of glass)

μ_m= μ_L/ ρ=0.6814/2500=0.000272 (ρ is density of glass)

Table (4.9): The relationship between the thickness of glass and transmission of x-ray at u=30kv and current 1mA

Thickness (mm)	Rate of I at u=30kv And current I=1mA	T=I0/I	LnT
0	9866.53	1	0
2.6	3566.97	2.76608	1.01743
4.5	1347.97	7.3195	1.99054
7.2	462.7	21.3238	3.0598
9.4	179.17	55.0679	4.0085

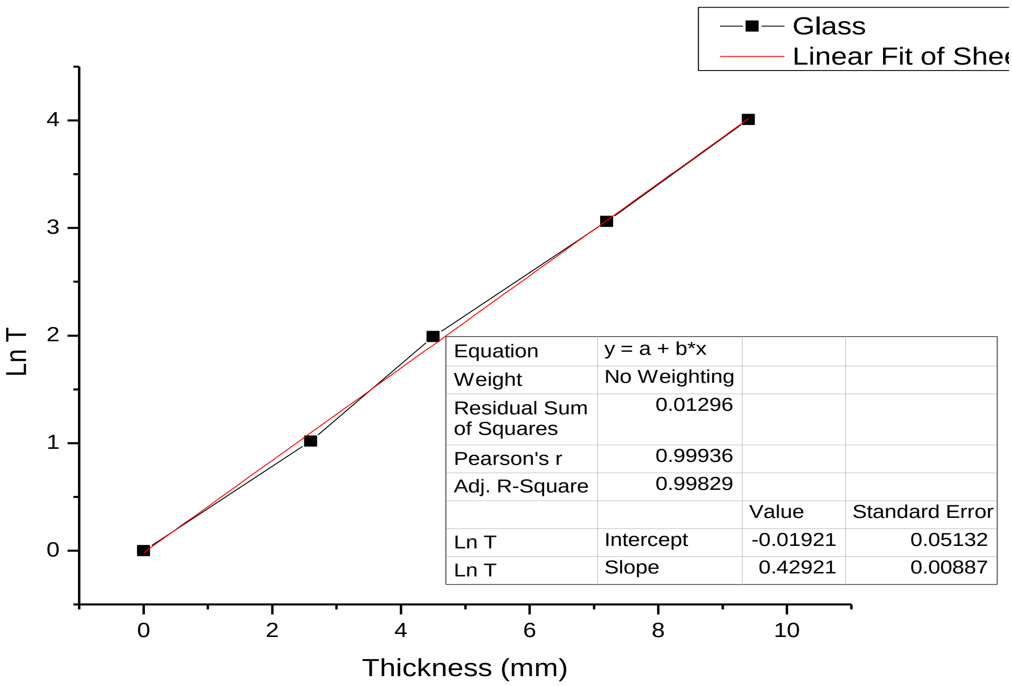

Figure (4.9): The relationship between the thickness of glass and the transmission of x-ray at u=30kv and current 1mA**.**

Table (4.10): The relationship between the thickness of glass and transmission of x-ray at u=35kv and current 1mA

Thickness (mm)	Rate of I at u=35kv And current I=1mA	T=I0/I	LnT
0	8286.30	1	0
2.6	6602.30	1.2556	0.22718
4.5	2854.40	2.90299	1.06574
7.2	1392.17	5.9527	1.78373
9.4	729.60	11.3573	2.4298

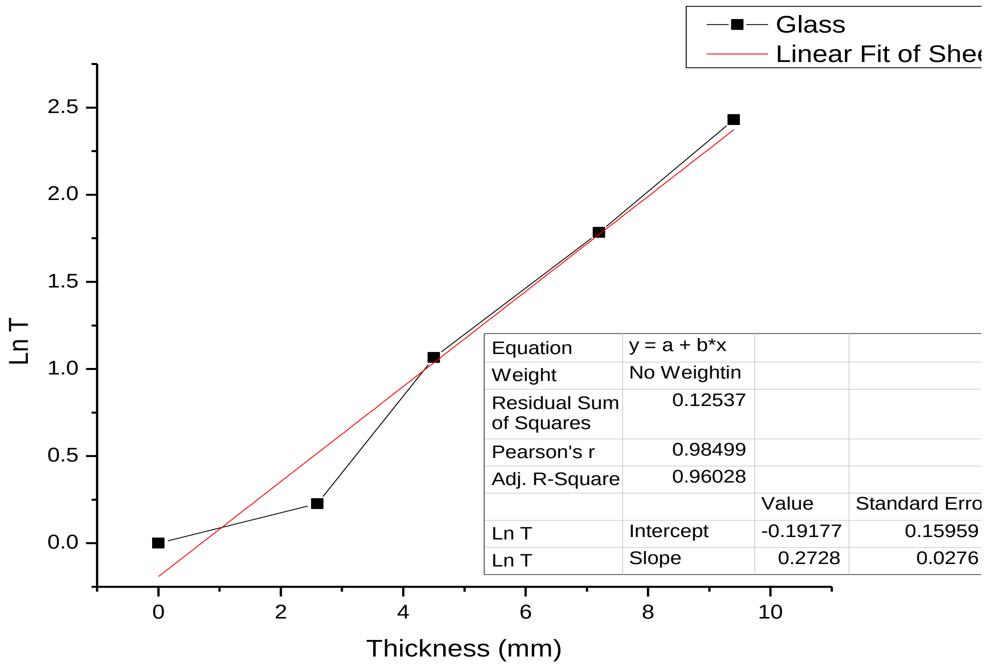

Figure (4.10): The relationship between the thickness of glass and the transmission of x-ray at u=35kv and current 1mA.

Table (4.11): The relationship between the thicknesses of plastic and transmission of x-ray at u=25kv and current 1mA

Thickness (mm)	Rate of I at u=25kv And current I=1mA	τ=I0/I	Lnτ
0	8647.07	1	0
1.5	8251.53	1.04793	0.04682
3	7592.53	1.13889	0.13005
4.5	7132.43	1.21236	0.19256
6	6574.53	1.31523	0.27401

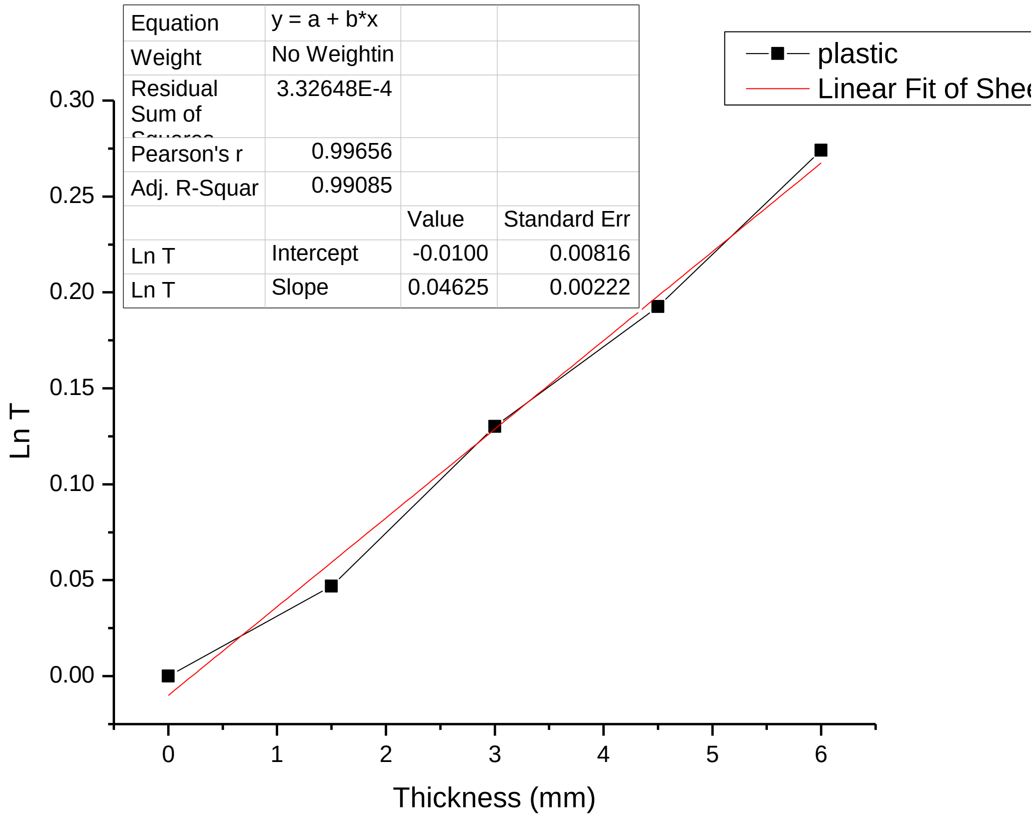

Figure (4.11): The relationship between the thickness of plastic and the transmission of x-ray at u=25kv and current 1mA.

μL =slope=LnT/d=0.04625 (d is Thickness of plastic)

$\mu_m = \mu_L / \rho$=0.04625/940=0.0000492 (ρ is density of plastic)

Table (4.12): The relationship between the thicknesses of plastic and transmission of x-ray at u=30kVand current 0.8mA

Thickness (mm)	Rate of I at u=30kv And current I=0.8mA	τ=I0/I	Lnτ
0	10212.93	1	0
1.5	10196.03	1.00165	0.001656
3	10066.20	1.01457	0.014471
4.5	9888.60	1.03279	0.032272
6	9634.47	1.06004	0.058307

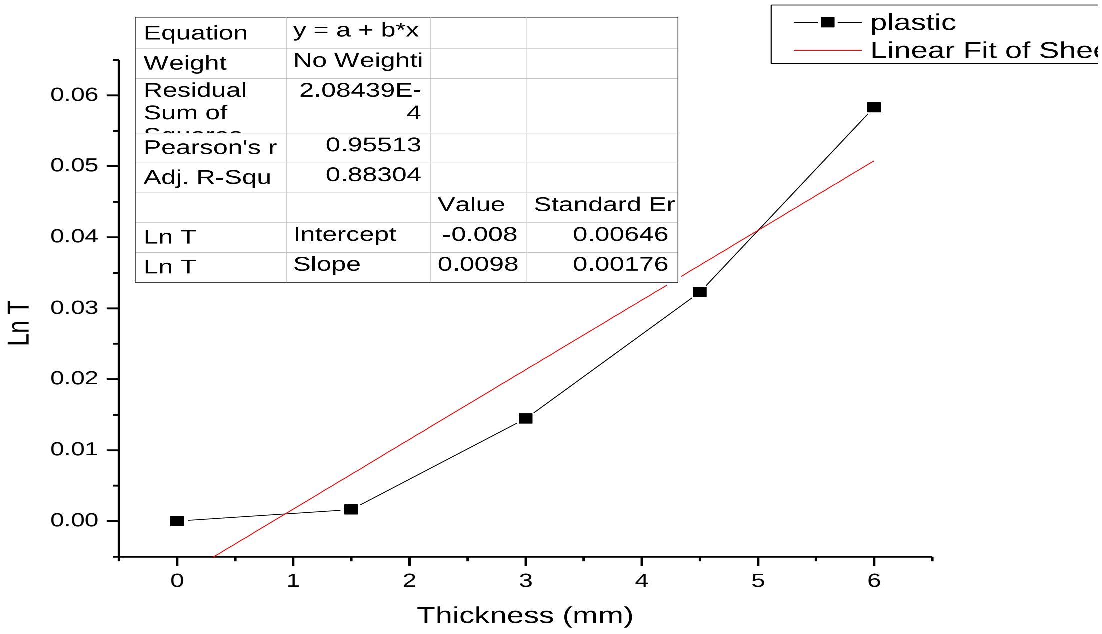

Figure (4.12): The relationship between the thickness of plastic and the transmission of x-ray at u=30kv and current 0.8mA.

Table (4.13): Value of linear and mass attenuation coefficients of all materials against kv

Material	kv	µL	µm
Cork	25	0.0614	0.0256
Wood	25	0.3044	0.435
	35	0.1972	0.281
Glass	25	0.6814	0.272
	30	0.42921	0.171
	35	0.2728	0.109
Plastic	25	0.04625	0.0492
	30	0.0098	0.0104

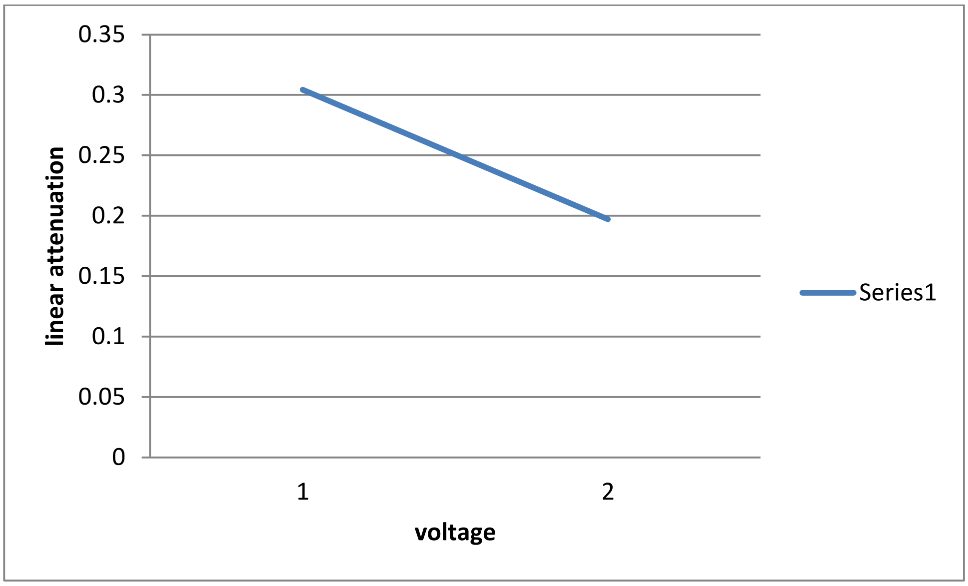

Figure (4.13): The relationship between linear attenuation coefficients against voltage (wood)

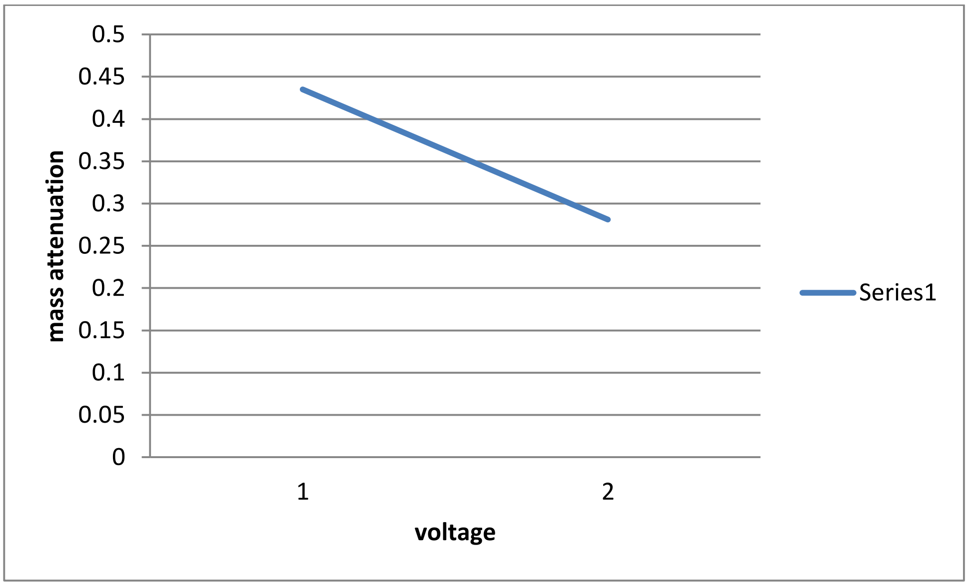

Figure (4.14): The relationship between mass attenuation coefficients against voltage (wood)

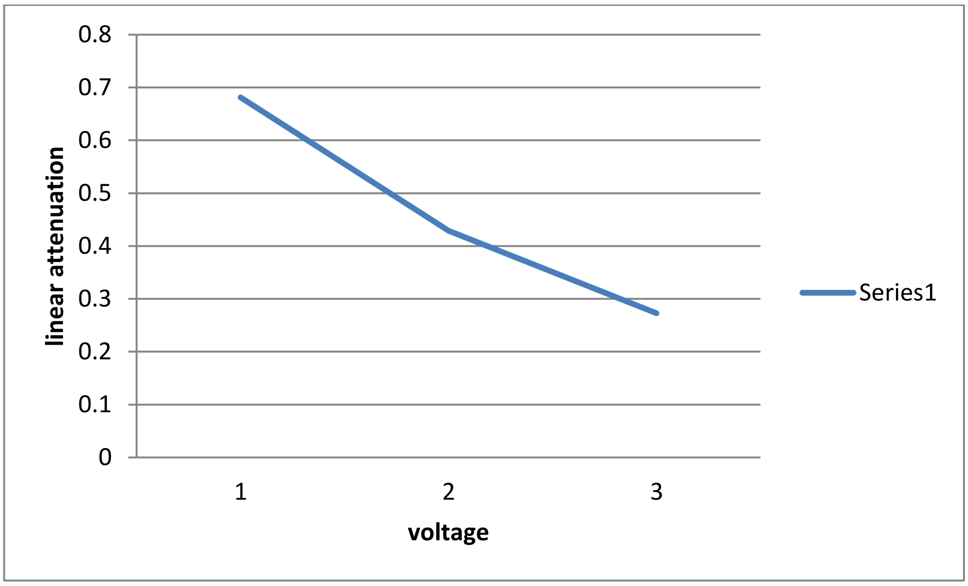

Figure (4.15): The relationship between linear attenuation coefficients against voltage (glass)

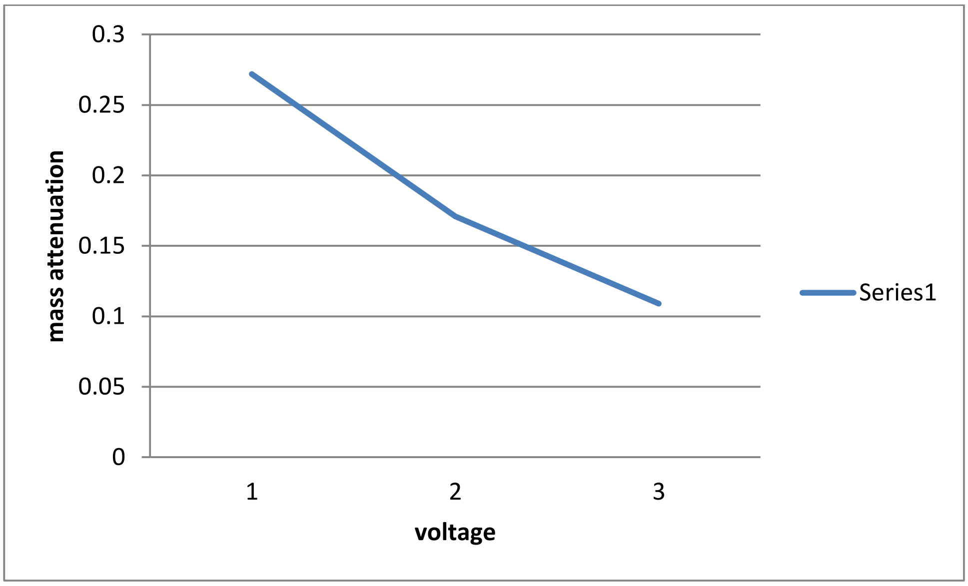

Figure (4.16): The relationship between mass attenuation coefficients against voltage (glass)

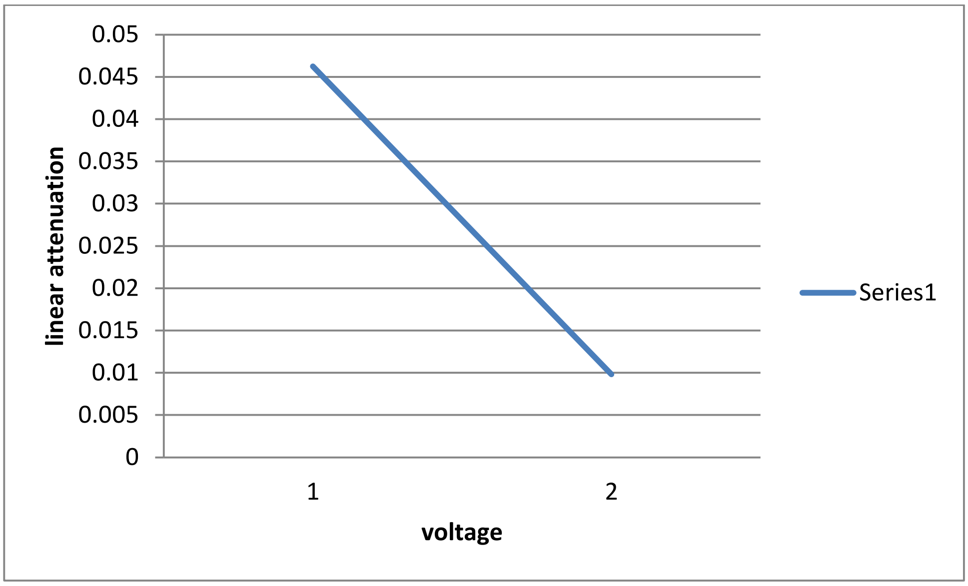

Figure (4.17): The relationship between linear attenuation coefficients against voltage (plastic)

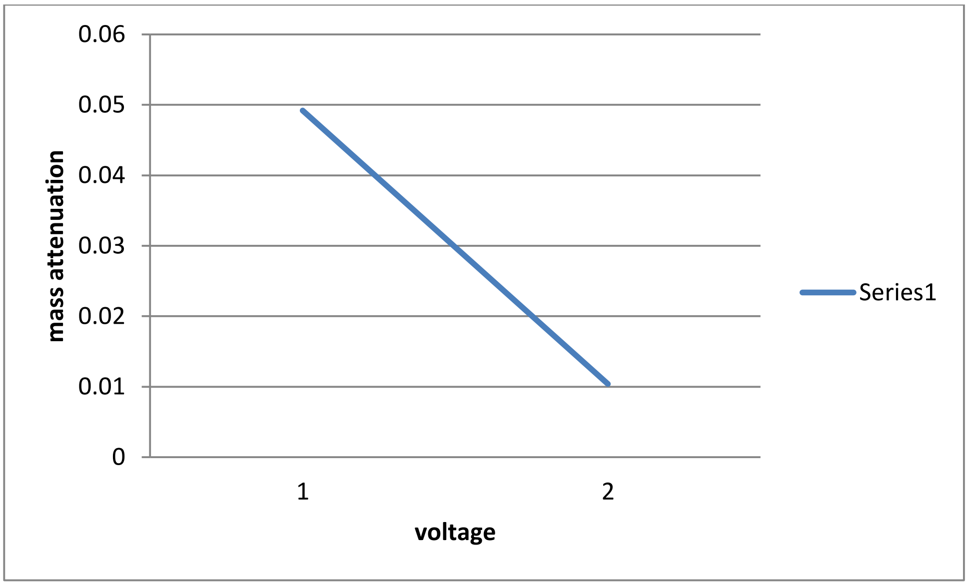

Figure (4.18): The relationship between mass attenuation coefficients against voltage (plastic)

4.3 Discussion

From figures [(4.5), (4.7), (4.8) and (4.11)] it clear that the relation between thickness and transmission of x-ray The transmission of x-ray decrease exponentially and the liner attenuation coefficient for glass is equals 0.6814 and wood is equals 0.3044 and plastic is equals 0.04625 and cork is equals 0.00614 and the mass attenuation coefficient for glass is equals 0.272 and wood is equals 0.435 and plastic is equals 0.0492 and cork is equals 0.0256.

Note from the figures [(4.6), (4.9), (4.10) and (4.12)] attenuation coefficient decrease with increase the voltage in x-ray Source

Also from the figures (4.13),(4.14),(4.15),(4.16),(4.17) and (4.18) we note that as the voltage increases, the attenuation decreases in general.

By comparing the results of previous studies on this topic, we find that there is a difference and a variation in the results, as a result of the difference in the intensity of rays in terms of voltage and current, or a difference in the thickness of the materials used.

4.4 conclusions

The maximum value of attenuation obtained for glass which will be the best shield in our study.

4.5 Recommendation

- Other materials should be used with uniform thicknesses and compare the results.
- Different sample must use to study the attenuation either with X-ray or Gamma ray
- Simulation must be hold and carried out in order to compare the result of different methods used.

References

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