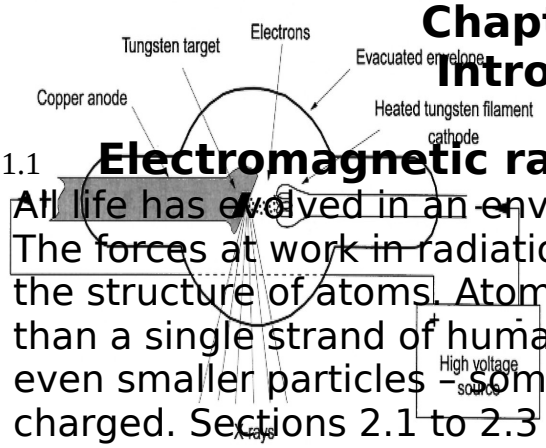
Chapter one: Introduction



1.1 Electromagnetic radiation

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. Sections 2.1 to 2.3 discuss atoms in more detail, along with basic radiation-related principles. (CNSC, 2012)

1.1.1 Ionizing radiation

Ionizing (or ionising) radiation is radiation that carries enough energy to liberate electrons from atoms or molecules, thereby ionizing them. Ionizing radiation comprises subatomic particles, ions or atoms moving at relativistic speeds, and electromagnetic waves on the short wavelength end of the electromagnetic spectrum. Gamma rays, X-rays, and the upper vacuum ultraviolet part of the ultraviolet spectrum are ionizing, whereas the lower ultraviolet, visible light (including laser light), infrared, microwaves, and radio waves are considered non-ionizing radiation. The boundary is not sharply defined, since different molecules and atoms ionize at different energies. (james.2006)

Typical particles include alpha particles, beta particles and neutrons, as well as mesons that constitute cosmic rays. (Stallcup,2006)
Ionizing radiation arises from a variety of sources, such as bombardment of the Earth by cosmic rays, the decay of radioactive materials, matter at extremely high temperatures (e.g. plasma discharge or the corona of the Sun), or acceleration of charged particles by electromagnetic fields (e.g. lightning or supernova explosions). Ionizing radiation can also be generated by the production of high energy particles in X-ray tubes and particle accelerators. (james.2006)

Ionizing radiation is invisible and not directly detectable by human senses, so radiation detection instruments such as Geiger counters are required. However, in some cases ionizing radiation may lead to secondary emission of visible light upon interaction with matter, such as in Cherenkov radiation and radio luminescence.It is applied in a wide variety of fields such as medicine, research, manufacturing, construction, and many other areas, but presents a health hazard if proper measures against undesired exposure aren't followed. (Stallcup.2006)
Exposure to ionizing radiation causes damage to living tissue, and can result in mutation, radiation sickness, cancer, and death.

1.1.2 X-ray production

X-radiation (composed of X-rays) is a form of electromagnetic radiation. Most X-rays have a wavelength in the range of 0.01 to 10 nanometers, corresponding to frequencies in the range 30 petahertz to 30 exahertz (3×10^{16} Hz to 3×10^{19} Hz) and energies in the range 100 eV to 100 keV. X-ray wavelengths are shorter than those of UV rays and typically longer than those of gamma rays. In many languages, X-radiation is referred to with terms meaning Röntgen radiation, after Wilhelm Röntgen, who is usually credited as its discoverer, and who had named it X-radiation to signify an unknown type of radiation. Spelling of X-ray(s) in the English language includes the variants x-ray(s), xray(s) and X ray(s). (Oxford University,2005).

X-rays with photon energies above 5–10 keV (below 0.2–0.1 nm wavelength) are called hard X-rays, while those with lower energy are called soft X-rays. Due to their penetrating ability, hard X-rays are widely used to image the inside of objects, e.g., in medical radiography and airport security. As a result, the term X-ray is metonymically used to refer to a radiographic image produced using this method, in addition to the method itself.

Since the wavelengths of hard X-rays are similar to the size of atoms they are also useful for determining crystal

structures by X-ray crystallography. By contrast, soft X-rays are easily absorbed in air and the attenuation length of 600 eV (~2 nm) X-rays in water is less than 1 micrometer. There is no universal consensus for a definition distinguishing between X-rays and gamma rays. One common practice is to distinguish between the two types of radiation based on their source: X-rays are emitted by electrons, while gamma rays are emitted by the atomic nucleus. This definition has several problems; other processes also can generate these high energy photons, or sometimes the method of generation is not known. One common alternative is to distinguish X- and gamma radiation on the basis of wavelength (or equivalently, frequency or photon energy), with radiation shorter than some arbitrary wavelength, such as 10^{-11} m (0.1 Å), defined as gamma radiation. This criterion assigns a photon to an unambiguous category, but is only possible if wavelength is known. (Some measurement techniques do not distinguish between detected wavelengths.) However, these two definitions often coincide since the electromagnetic radiation emitted by X-ray tubes generally has a longer wavelength and lower photon energy than the radiation emitted by radioactive nuclei. Occasionally, one term or the other is used in specific contexts due to historical precedent, based on measurement (detection) technique, or based on their intended use rather than their wavelength or source. Thus, gamma-rays generated for medical and industrial uses, for example radiotherapy, in the ranges of 6–20 MeV, can in this context also be referred to as X-rays.

1.2 Problem of study

Pediatric patients in general are more sensitive to the effects of ionizing radiation due to the nature of their rapidly dividing cells and with radiological exams on the rise it is important to understand that the effects of ionizing radiation are cumulative. In order to help reduce the effects of ionizing radiation within the pediatric population we need to utilize manual techniques.

1.3 Objectives

1.3.1 General:

The general objective is to Assess Radiation Dose for pediatric in Brain CT.

1.3.2 Specific:

To Measure Effective Dose (ED) for pediatric patient undergoing brain CT, To Estimate the radiation risks.

1.4 Important of study

To optimize dose to patient without sacrificed the image quality

1.5 Overview of study

This study falls into five chapters, Chapter one, which is an introduction , objectives of the study, Chapter two Literature review and theoretical background, Chapter three material and method , Chapter fours results and Chapter five discussions, conclusion , recommendations, then references, appendix.

Chapter two
Literature review

2.1 Theoretical backgrounds

2.1.1 Electromagnetic radiation

In physics, radiation is a process in which electromagnetic waves (EMR) travel through a vacuum or through matter-containing media; the existence of a medium to propagate the waves is not required. A different but related definition says radiation is a subset of these electromagnetic waves combined with a class of energetic subatomic particles with very high kinetic energies; these are called ionizing radiation, and the particles are termed particle radiation. Other sorts of waves, such as acoustic, seismic, hydraulic and so on are not usually considered to be forms of "radiation" in either sense. We will consider the first definition, and return to the second later. (CNSC,2012)
The word arises from the phenomenon of waves radiating (i.e., travel outward in all directions) from a source. This aspect leads to a system of measurements and physical units that are applicable to all types of radiation. Because such radiation expands as it passes through space, and as its energy is conserved (in vacuum), the power of all types of radiation radiating from a point source follows an inverse-square law in relation to the distance from its source. While it is most common that radiation may be emitted radically from a point source, such as a light-bulb filament or a microwave antenna, there are other modes of radiation. Some examples are radiation from a phosphorescent panel (chaotic), a laser beam (coherent), and emitted from a parabolic mirror (parallel), in which cases adherence to the inverse-square law is violated. (CNSC,2012)

EMR is energy transferred by waves of combined electric charge and magnetic monopole, capable of traveling through a vacuum and traveling at the universal speed of light in whatever media it is passing through; the speed is dependent on the media, and is fastest in vacuum. In

quantum mechanics these waves have been shown to have particle structure as well as wave structure; these particles are called photons. EMR includes radio and microwave signals, infrared (radiant heat), visible light and ultraviolet, and x-rays and gamma rays. These are differentiated from one another by the frequency of the waves, which directly correlates with the energy carried in each type's photons. This is the first definition of radiation stated in the opening paragraph. (james.2006)

Notice that the differentiation of radiation into the classes above is somewhat arbitrary. The classes overlap at the meeting points, and the distinctions are strictly man-made, not directly apparent in the physics of the waves under study. There is, for example, no difference between an X-ray and a gamma ray except a relative difference in frequency, and thus energy. (Gayle.1997)

This spectrum of radiant energy can be divided into ionizing and non-ionizing, according to whether it ionizes or does not ionize the atoms in ordinary chemical matter. Ionization is the removing of electrons from atoms, and it may be partial, in which the weaker held outer electrons are removed, grading upwards to removal of all electrons from an atom. The energy required to do this varies with the kinds of atoms and their physical state, such as temperature, chemical binding and so on. Some overlap of ionizing and non-ionizing radiation exists in the domain of ultraviolet where materials experience first simple thermal heating in the infrared and visible light, then excitation of electrons in "softer" UV, and then partial-to-total ionization as the energy increases with frequency. The second definition of radiation in the opening paragraph is used in reference to ionizing radiation in hard UV, x-rays, and gamma rays. (Gayle.1997)

Both ionizing and non-ionizing radiation can be harmful to organisms and can result in changes to the natural environment. In general, however, ionizing radiation is far more harmful to living organisms per unit of energy deposited than non-ionizing radiation, since the ions that are produced, even at low radiation powers, leave behind atoms which, due to charge imbalance, are eager to combine in semi-random ways with other atoms in the environment; these are called free radicals. Such random chemical action in a cell may result in anything from harmless reactions, to degradation of important structures in the cell, to killing it outright or triggering suicide, or modifying the DNA in harmful, but yet temporarily viable ways. By contrast, most non-ionizing radiation is harmful to organisms only in proportion to the thermal energy deposited (a prime example is microwaves generated in a microwave oven), and is conventionally considered harmless at low powers that do not produce a significant temperature rise. Ultraviolet radiation in some aspects occupies the overlap in a middle ground, as it has some features of both ionizing and non-ionizing radiation. Although nearly all of the ultraviolet spectrum that penetrates the Earth's atmosphere is non-ionizing, this radiation does far more damage to many molecules in biological systems than can be accounted for by heating effects, such as sunburn). These properties derive from ultraviolet's power to alter chemical bonds, even without having quite enough energy to ionize atoms. (Gayle.1997)

The question of harm to biological systems due to low-power ionizing and non-ionizing radiation is not settled. Controversy continues about possible non-heating effects of low-power non-ionizing radiation, such as non-heating microwave and radio wave exposure. Non-ionizing radiation is usually considered to have a safe lower limit, especially as thermal

radiation is unavoidable and ubiquitous. By contrast, ionizing radiation is currently conservatively considered to have no completely safe lower limit, although at some energy levels, new exposures do not add appreciably to background radiation. The evidence that small amounts of some types of ionizing radiation might confer a net health benefit in some situations is called radiation hormesis. (Gayle.1997)

2.1.1.1 Discovery

Electromagnetic radiations of wavelengths other than light were discovered in the early 19th century. The discovery of infrared radiation is ascribed to William Herschel, the astronomer. Herschel published his results in 1800 before the Royal Society of London. Herschel, like Ritter, used a prism to refract light from the Sun and detected the infrared (beyond the red part of the spectrum), through an increase in the temperature recorded by a thermometer. (Gayle.1997)

In 1801, the German physicist Johann Wilhelm Ritter made the discovery of ultraviolet by noting that the rays from a prism darkened silver chloride preparations more quickly than violet light. Ritter's experiments were an early precursor to what would become photography. Ritter noted that the UV rays were capable of causing chemical reactions. (Kwan, 2003)

The first radio waves detected were not from a natural source, but were produced deliberately and artificially by the German scientist Heinrich Hertz in 1887, using electrical circuits calculated to produce oscillations in the radio frequency range, following formulas suggested by the equations of James Clerk Maxwell. (Kwan. 2003)

Wilhelm Röntgen discovered and named X-rays. While experimenting with high voltages applied to an evacuated tube on 8 November 1895, he noticed fluorescence on a

nearby plate of coated glass. Within a month, he discovered the main properties of X-rays that we understand to this day.

In 1896, Henri Becquerel found that rays emanating from certain minerals penetrated black paper and caused fogging of an unexposed photographic plate. His doctoral student Marie Curie discovered that only certain chemical elements gave off these rays of energy. She named this behavior radioactivity. (Kwan. 2003)

Alpha rays (alpha particles) and beta rays (beta particles) were differentiated by Ernest Rutherford through simple experimentation in 1899. Rutherford used a generic pitchblende radioactive source and determined that the rays produced by the source had differing penetrations in materials. One type had short penetration (it was stopped by paper) and a positive charge, which Rutherford named alpha rays. The other was more penetrating (able to expose film through paper but not metal) and had a negative charge, and this type Rutherford named beta. This was the radiation that had been first detected by Becquerel from uranium salts. In 1900, the French scientist Paul Villard discovered a third neutrally charged and especially penetrating type of radiation from radium, and after he described it, Rutherford realized it must be yet a third type of radiation, which in 1903 Rutherford named gamma rays. (Kwan. 2003)

Henri Becquerel himself proved that beta rays are fast electrons, while Rutherford and Thomas Royds proved in 1909 that alpha particles are ionized helium. Rutherford and Edward Andrade proved in 1914 that gamma rays are like X-rays, but with shorter wavelengths. (Kwan, 2003)

Cosmic ray radiations striking the Earth from outer space were finally definitively recognized and proven to exist in 1912, as the scientist Victor Hess carried an electrometer to various altitudes in a free balloon flight. The nature of these

radiations was only gradually understood in later years. (Kwan. 2003)

Neutron radiation was discovered with the neutron by Chadwick, in 1932. A number of other high energy particulate radiations such as positrons, muons, and pions were discovered by cloud chamber examination of cosmic ray reactions shortly thereafter, and others types of particle radiation were produced artificially in particle accelerators, through the last half of the twentieth century.(Kwan. 2003)

2.1.1.2 Radiation Doses

For the purpose of radiation protection RP, dose quantities are expressed in three ways: absorbed, equivalent, and effective. Sections. Figure 2.1 presents an overview of the relationship between effective, equivalent and absorbed doses.

Fig (2.1) : Relationship between effective, equivalent and absorbed doses adopted from (Shelton,2011)

2.1.1.2.1 Absorbed dose

When ionizing radiation penetrates the human body or an object, it deposits energy. The energy absorbed from exposure to radiation is called an absorbed dose. The absorbed dose is measured in a unit called the gray (Gy). A dose of one gray is equivalent to a unit of energy (joule) deposited in a kilogram of a substance. (Shelton,2011)

2.1.1.2.2 Equivalent dose

When radiation is absorbed in living matter, a biological effect may be observed. However, equal absorbed doses will not necessarily produce equal biological effects. The effect depends on the type of radiation (e.g., alpha, beta or gamma). For example, 1 Gy of alpha radiation is more harmful to a given tissue than 1 Gy of beta radiation. To obtain the equivalent dose, the absorbed dose is multiplied by a specified radiation weighting factor (wR). A radiation weighting factor (wR) is used to equate different types of radiation with different biological effectiveness. (Shelton,2011)
The equivalent dose is expressed in a measure called the sievert (Sv). This means that 1 Sv of alpha radiation will have the same biological effect as 1 Sv of beta radiation. In other words, the equivalent dose provides a single unit that accounts for the degree of harm that different types of radiation would cause to the same tissue. (Shelton,2011)

2.1.1.2.3 Effective dose

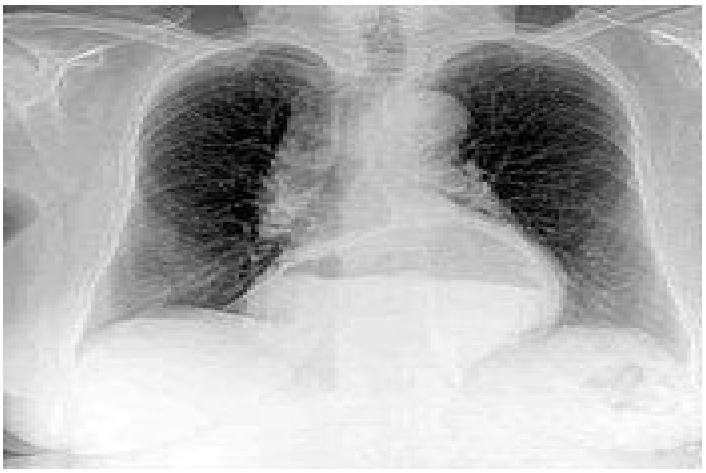
Different tissues and organs have different radiation. For example, bone marrow is much more radiosensitive than muscle or nerve tissue. To obtain an indication of how exposure can affect overall health, the equivalent dose is multiplied by a tissue weighting factor (wT) related to the risk for a particular tissue or organ. This multiplication provides the effective dose absorbed by the body. (Shelton,2011)
The unit used for effective dose is also the Sievert.

2.1.1.3 Uses of radiation

2.1.1.3.1 In medicine

Radiation and radioactive substances are used for diagnosis, treatment, and research. X-rays, for example, pass through muscles and other soft tissue but are stopped by dense materials. This property of X-rays enables doctors to find broken bones and to locate cancers that might be growing in the body Doctors also find certain diseases by injecting a radioactive substance and monitoring the radiation given off

as the substance moves through the body. Radiation used for cancer treatment is called ionizing radiation because it forms ions in the cells of the tissues it passes through as it dislodges electrons from atoms. This can kill cells or change genes so the cells cannot grow. Other forms of radiation such as radio waves, microwaves, and light waves are called non-ionizing. They don't have as much energy and are not able to ionize cells. (james.2006)



Fig(2.2) a chest radiograph of a female, demonstrating a hiatus hernia adopted from (james.2006)

Since Röntgen's discovery that X-rays can identify bone structures, X-rays have been used for medical imaging. The first medical use was less than a month after his paper on the subject, and up until 2010 5 billion medical imaging studies had been conducted worldwide. Radiation exposure from medical imaging in 2006 made up about 50% of total ionizing radiation exposure in the United States.

Figure (2.3) an arm radiograph, demonstrating broken ulna and radius with implanted internal fixation. Adopted from (james.2006)

A radiograph is an X-ray image obtained by placing a part of the patient in front of an X-ray detector and then illuminating it with a short X-ray pulse. Bones contain much calcium, which due to its relatively high atomic number absorbs x-rays efficiently. This reduces the amount of X-rays reaching the detector in the shadow of the bones, making them clearly visible on the radiograph. The lungs and trapped gas also show up clearly because of lower absorption compared to tissue, while differences between tissue types are harder to see. (james.2006)

Radiographs are useful in the detection of pathology of the skeletal system as well as for detecting some disease processes in soft tissue. Some notable examples are the very common chest X-ray, which can be used to identify lung diseases such as pneumonia, lung cancer or pulmonary edema, and the abdominal x-ray, which can detect bowel (or intestinal) obstruction, free air (from visceral perforations) and free fluid (in ascites). X-rays may also be used to detect pathology such as gallstones (which are rarely radiopaque)

or kidney stones which are often (but not always) visible. Traditional plain X-rays are less useful in the imaging of soft tissues such as the brain or muscle.

Dental radiography is commonly used in the diagnoses of common oral problems, such as cavities. (james.2006)

In medical diagnostic applications, the low energy (soft) X-rays are unwanted, since they are totally absorbed by the body, increasing the radiation dose without contributing to the image. Hence, a thin metal sheet, often of aluminum, called an X-ray filter, is usually placed over the window of the X-ray tube, absorbing the low energy part in the spectrum. This is called hardening the beam since it shifts the center of the spectrum towards higher energy (or harder) x-rays. (james.2006)

To generate an image of the cardiovascular system, including the arteries and veins (angiography) an initial image is taken of the anatomical region of interest. A second image is then taken of the same region after an iodinated contrast agent has been injected into the blood vessels within this area. These two images are then digitally subtracted, leaving an image of only the iodinated contrast outlining the blood vessels. The radiologist or surgeon then compares the image obtained to normal anatomical images to determine if there is any damage or blockage of the vessel. (james.2006)

Figure (2.4): brain image in CT scan Adopted from (james.2006)

Computed tomography (CT scanning) is a medical imaging modality where tomographic images or slices of specific areas of the body are obtained from a large series of two-dimensional X-ray images taken in different directions. These cross-sectional images can be combined into a three-dimensional image of the inside of the body and used for diagnostic and therapeutic purposes in various medical disciplines. (Gayle.1997)

Fluoroscopy is an imaging technique commonly used by physicians or radiation therapists to obtain real-time moving images of the internal structures of a patient through the use of a fluoroscope. In its simplest form, a fluoroscope consists of an X-ray source and fluorescent screen between which a patient is placed. However, modern fluoroscopes couple the screen to an X-ray image intensifier and CCD video camera allowing the images to be recorded and played on a monitor. This method may use a contrast material. Examples include cardiac catheterization (to examine for coronary artery

blockages) and barium swallow (to examine for esophageal disorders). (Gayle.1997)

for the management (including palliation) of cancer; it requires higher radiation energies than for imaging alone. (Gayle.1997)

2.1.1.4 Type of radiation

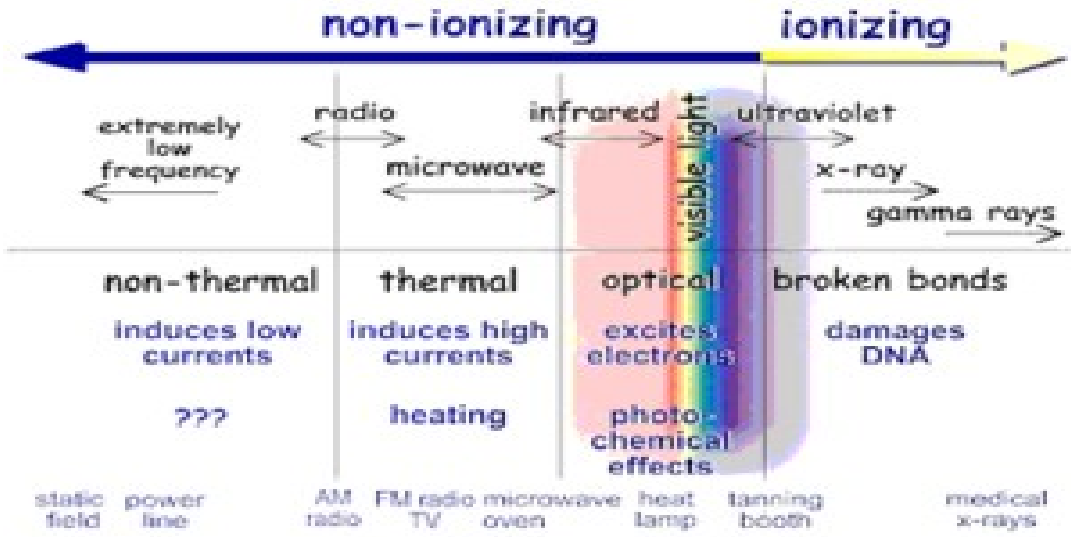


Figure (2.5); Different types of electromagnetic radiation adopted from (Gayle,1997)

2.1.1.4.1 Ionizing radiation

It is radiation that carries enough energy to liberate electrons from atoms or molecules, thereby ionizing them. Ionizing radiation comprises subatomic particles, ions or atoms moving at relativistic speeds, and electromagnetic waves on the short wavelength end of the electromagnetic spectrum. Gamma rays, X-rays, and the upper vacuum ultraviolet part of the ultraviolet spectrum are ionizing, whereas the lower ultraviolet, visible light (including laser light), infrared, microwaves, and radio waves are considered non-ionizing radiation. The boundary is not sharply defined, since different molecules and atoms ionize at different energies. (Gayle.1997)

Typical particles include alpha particles, beta particles and neutrons, as well as mesons that constitute cosmic rays. (Gayle,1997)

2.1.1.4.2 Non-ionizing radiation

The kinetic energy of particles of non-ionizing radiation is too small to produce charged ions when passing through matter. For non-ionizing electromagnetic radiation (see types below), the associated particles (photons) have only sufficient energy to change the rotational, vibration or electronic valence configurations of molecules and atoms. The effect of non-ionizing forms of radiation on living tissue has only recently been studied. Nevertheless, different biological effects are observed for different types of non-ionizing radiation. (Kwan, 2003)

Even "non-ionizing" radiation is capable of causing thermal-ionization if it deposits enough heat to raise temperatures to ionization energies. These reactions occur at far higher energies than with ionization radiation, which requires only single particles to cause ionization. A familiar example of thermal ionization is the flame-ionization of a common fire, and the browning reactions in common food items induced by infrared radiation, during broiling-type cooking. (Woodside,1997)

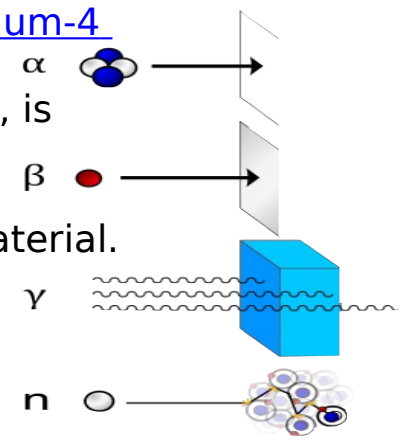
2.1.2 Ionizing radiation

Ionizing radiation arises from a variety of sources, such as bombardment of the Earth by cosmic rays, the decay of radioactive materials, matter at extremely high temperatures (e.g. plasma discharge or the corona of the Sun), or acceleration of charged particles by electromagnetic fields (e.g. lightning or supernova explosions). Ionizing radiation can also be generated by the production of high energy particles in X-ray tubes and particle accelerators. (Baradei.2003)

Ionizing radiation is invisible and not directly detectable by human senses, so radiation detection instruments such as Geiger counters are required. However, in some cases ionizing radiation may lead to secondary emission of visible light upon interaction with matter, such as in Cherenkov radiation and radio luminescence. (Baradei.2003)

It is applied in a wide variety of fields such as medicine, research, manufacturing, construction, and many other areas, but presents a health hazard if proper measures against undesired exposure aren't followed. (Baradei.2003) Exposure to ionizing radiation causes damage to living tissue, and can result in mutation, radiation sickness, cancer, and death.

2.1.2.1 Types of ionizing radiation



Alpha (**α**) radiation consists of a fast-moving helium-4 (4He) nucleus and is stopped by a sheet of paper. Beta (**β**) radiation, consisting of electrons, is halted by an aluminum plate. Gamma (**γ**) radiation, consisting of energetic photons, is eventually absorbed as it penetrates a dense material. Neutron (**n**) radiation consists of free neutrons that are blocked using light elements, like hydrogen, which slow and/or capture them. Not shown: galactic cosmic rays that consist of energetic charged nuclei like protons, helium nuclei, and high-charged nuclei called HZE ions. (Stallcup,2006)

Ionizing radiation is categorized by the nature of the particles or electromagnetic waves creating the ionizing effect. These have different ionization mechanisms, and may be grouped as directly or indirectly ionizing. (Baradei.2003)

2.1.2.1.1 Directly ionizing

Any charged massive particle can ionize atoms directly by fundamental interaction through the Coulomb force if it carries sufficient kinetic energy. This includes atomic nuclei, electrons, muons, charged pions, protons, and energetic charged nuclei stripped of their electrons, all of which must be moving at relativistic speeds to reach the required kinetic energy. The first two to be recognized were given special

names, which are used today: Helium nuclei at relativistic speeds are called alpha particles, and electrons at relativistic speeds are called beta particles. Natural cosmic rays are made up primarily of relativistic protons but also include heavier atomic nuclei like helium ions and HZE ions and muons. Charged pions are very short-lived and seen only in large amounts in particle accelerators. (James,2006)

Alpha particles consist of two protons and two neutrons bound together into a particle identical to a helium nucleus. They are generally produced in the process of alpha decay, but may also be produced in other ways. Alpha particles are named after the first letter in the Greek alphabet, α. The symbol for the alpha particle is α or α2+. Because they are identical to helium nuclei, they are also sometimes written as He2+ or 4 2He2+ indicating a Helium ion with a +2 charge (missing its two electrons). If the ion gains electrons from its environment, the alpha particle can be written as a normal (electrically neutral) Helium atom He42. (James ,2006)

They are a highly ionizing form of particle radiation, and when resulting from radioactive alpha decay have low penetration depth. They can be stopped by a few centimeters of air, or by the skin. However, so-called long range alpha particles from ternary fission are three times as energetic, and penetrate three times as far. The helium nuclei that form 10-12% of cosmic rays are also usually of much higher energy than those produced by nuclear decay processes, and are thus capable of being highly penetrating and able to traverse the human body and dense shielding, depending on their energy. (Baradei.2003)

Beta particles are high-energy, high-speed electrons or positrons emitted by certain types of radioactive nuclei, such as potassium-40. The production of beta particles is termed beta decay. They are designated by the Greek letter beta (β). There are two forms of beta decay, β− and β+, which respectively give rise to the electron and the positron. (Baradei.2003)

High-energy beta particles may produce X-rays known as Bremsstrahlung ("braking radiation") or secondary electrons

(delta ray)as they pass through matter. Both of these can subsequently ionize as an indirect ionization effect.

Bremsstrahlung is of concern when shielding beta emitters, because interaction of beta particles with the shielding material produces Bremsstrahlung radiation. This effect is greater with material of high atomic numbers, so material with low atomic numbers is used for beta source shielding. (Baradei.2003)

The positron or antielectron is the antiparticle or the antimatter counterpart of the electron. The positron has an electric charge of +1e, a spin of ½, and has the same mass as an electron. When a low-energy positron collides with a low-energy electron, annihilation occurs, resulting in the production of two or more gamma ray photons . (Baradei.2003)

Positrons may be generated by positron emission radioactive decay (through weak interactions), or by pair production from a sufficiently energetic photon. Positrons are common artificial sources of ionizing radiation in medical PET scans. (james,2006)

As positrons are positively charged particles they can also directly ionize an atom through Coulomb interactions. (james,2006)

2.1.2.1.2 Indirectly ionizing

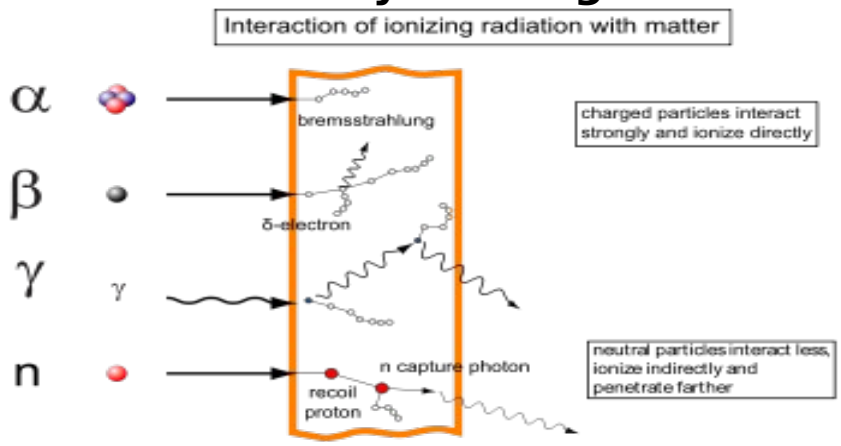


Fig (2.6) interaction of ionizing radiation with matter adopted from (james,2006)

Radiation interaction - gamma rays are represented by wavy lines, charged particles and neutrons by straight lines. The small circles show where ionization occurs. (james,2006)

Indirect ionizing radiation is electrically neutral and therefore does not interact strongly with matter. The bulk of the ionization effects are due to secondary ionizations. (Michael et al,2003)

The total absorption coefficient of lead (atomic number 82) for gamma rays, plotted versus gamma energy, and the contributions by the three effects. Here, the photoelectric effect dominates at low energy. Above 5 MeV, pair production starts to dominate. (L'Annunziata et al,2003)

Even though photons are electrically neutral, they can ionize atoms directly through the photoelectric effect and the Compton Effect. Either of those interactions will eject an electron at relativistic speeds, turning it into a beta particle that will ionize many more atoms. Since most of the affected atoms are ionized indirectly by the secondary beta particles, photons are considered to be indirectly ionizing. (Paterson , 2001)

Photon radiation is called gamma rays if produced by a nuclear reaction, subatomic particle decay, or radioactive decay within the nucleus. It is otherwise called x-rays if produced outside the nucleus. The generic term photon is therefore used describe both. (L'Annunziata, et al ,2003)

X-rays normally have a lower energy than gamma rays, and an older convention was to define the boundary as a wavelength of 10−11 m or a photon energy of 100 keV.[29] That threshold was driven by limitations of older X-ray tubes and low awareness of isomeric transitions. Modern technologies and discoveries have resulted in an overlap between X-ray and gamma energies. In many fields they are functionally identical, differing for terrestrial studies only in origin of the radiation. In astronomy, however, where radiation origin often cannot be reliably determined, the old energy division has been preserved, with X-rays defined as being between about 120 eV and 120 keV, and gamma rays as being of any energy above 100 to 120 keV, regardless of

source. Most astronomical "gamma-ray astronomy" are known not to originate in nuclear radioactive processes but, rather, result from processes like those that produce astronomical X-rays, except driven by much more energetic electrons. (Paterson A,2001)

Photoelectric absorption is the dominant mechanism in organic materials for photon energies below 100 keV, typical of classical X-ray tube originated X-rays. At energies beyond 100 keV, photons ionize matter increasingly through the Compton effect, and then indirectly through pair production at energies beyond 5 MeV. The accompanying interaction diagram shows two Compton scatterings happening sequentially. In every scattering event, the gamma ray transfers energy to an electron, and it continues on its path in a different direction and with reduced energy. (Paterson,2001)

2.1.2.2 Sources of ionizing radiation

Ionizing radiation is generated through nuclear reactions, nuclear decay, by very high temperature, or via acceleration of charged particles in electromagnetic fields. Natural sources include the sun, lightning and supernova explosions. Artificial sources include nuclear reactors, particle accelerators, and x-ray tubes. The United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) itemized types of human exposures. (Paterson A,2001)

Type of radiation exposures
Public exposure

Natural Sources	Normal occurrences	Cosmic radiation Terrestrial radiation
	Enhanced sources	Metal mining and smelting Phosphate industry Coal mining and power production from coal Oil and gas drilling Rare earth and titanium dioxide industries Zirconium and ceramics industries Application of radium and thorium Other exposure situations
Man-made sources	Peaceful purposes	Nuclear power production Transport of nuclear and radioactive material Application other than nuclear power
	Military purposes	Nuclear tests Residues in the environment. Nuclear fallout
Historical situations Exposure from accidents		

Occupational radiation exposure

Natural Sources		Cosmic ray exposures of aircrew and space crew Exposures in extractive and processing industries Gas and oil extraction industries Radon exposure in workplaces other than mines
Man-made sources	Peaceful purposes	Nuclear power industries Medical uses of radiation Industrial uses of radiation Miscellaneous uses
	Military purposes	Other exposed workers

Source UNSCEAR 2008 Annex B retrieved 2011-7-4

Table (2:1) :International System of Radiological Protection, adopted from (ICRP publication 103)

2.1.2.3 Health effects

In general, ionizing radiation is harmful and potentially lethal to living beings but can have health benefits in radiation therapy for the treatment of cancer and thyrotoxicosis.

Most adverse health effects of radiation exposure may be grouped in two general categories:

2.1.2.3.1 **deterministic effects** (harmful tissue reactions) due in large part to the killing/ malfunction of cells following high doses; and

2.1.2.3.2 **Stochastic effects,** i.e., cancer and heritable effects involving either cancer development in exposed individuals owing to mutation of somatic cells or heritable disease in their offspring owing to mutation of reproductive (germ) cells. (ICRP publication 103)

Its most common impact is the stochastic induction of cancer with a latent period of years or decades after exposure. The mechanism by which this occurs is well understood, but quantitative models predicting the level of risk remain controversial. The most widely accepted model posits that the incidence of cancers due to ionizing radiation increases linearly with effective radiation dose at a rate of 5.5% per Sievert. If this linear model is correct, then natural background radiation is the most hazardous source of radiation to general public health, followed by medical imaging as a close second. Other stochastic effects of ionizing radiation are teratogenesis, cognitive decline, and heart disease. High radiation dose gives rise to Deterministic effects which reliably occur above a threshold, and their severity increases with dose. Deterministic effects are not necessarily more or less serious than stochastic effects; either can ultimately lead to a temporary nuisance or a fatality. Examples are: radiation burns, and/or rapid fatality through acute radiation syndrome, chronic radiation syndrome, and radiation-induced thyroiditis. (james,2006)

Beneficially, controlled doses are used for medical imaging and radiotherapy, and some scientists suspect that low

doses may have a mild hormetic effect that can improve health, but the US National Academy of Sciences Biological Effects of Ionizing Radiation Committee "has concluded that there is no compelling evidence to indicate a dose threshold below which the risk of tumor induction is zero.(Beir,2006)

When alpha particle emitting isotopes are ingested, they are far more dangerous than their half-life or decay rate would suggest. This is due to the high relative biological effectiveness of alpha radiation to cause biological damage after alpha-emitting radioisotopes enter living cells. Ingested alpha emitter radioisotopes such as transuranics or actinides are an average of about 20 times more dangerous, and in some experiments up to 1000 times more dangerous than an equivalent activity of beta emitting or gamma emitting radioisotopes. (james,2006)

The human body cannot sense ionizing radiation except in very high doses, but the effects of ionization can be used to characterize the radiation. Parameters of interest include disintegration rate, particle flux, particle type, beam energy, kerma, dose rate, and radiation dose.

If the radiation type is not known then it can be determined by differential measurements in the presence of electrical fields, magnetic fields, or varying amounts of shielding. (james,2006)

The International Commission *IC* on Radiological Protection manages the International System of Radiological Protection, which sets recommended limits for dose uptake. Dose values may represent absorbed, equivalent, effective, or committed dose. The monitoring and calculation of doses to safeguard human health is called Dosimetry and is undertaken within the science of health physics. Key measurement tools are the use of dosimeters to give the external effective dose uptake and the use of bio-assay for ingested dose. The article on the sievert summarises the recommendations of the ICRU and ICRP on the use of dose quantities and includes a guide to the effects of ionizing radiation as measured in sieverts, and gives examples of approximate figures of dose uptake in certain situations. (Gayle,1997)

The committed dose is a measure of the stochastic health risk due to an intake of radioactive material into the human body. The ICRP states "For internal exposure, committed effective doses are generally determined from an assessment of the intakes of radionuclides from bioassay measurements or other quantities. The radiation dose is determined from the intake using recommended dose coefficients".(David,1999)

2.1.3 X-ray

X-radiation (composed of X-rays) is a form of electromagnetic radiation. Most X-rays have a wavelength in the range of 0.01 to 10 nanometers, corresponding to frequencies in the range 30 petahertz to 30 exahertz (3×1016 Hz to 3×1019 Hz) and energies in the range 100 eV to 100 keV. X-ray wavelengths are shorter than those of UV rays and typically longer than those of gamma rays. In many languages, X-radiation is referred to with terms meaning Rontgen radiation, after Wilhelm Röntgen, who is usually credited as its discoverer, and who had named it X-radiation to signify an unknown type of radiation. Spelling of X-ray(s) in the English language includes the variants x-ray(s), xray(s) and X ray(s). (Oxford University,2005).

X-rays with photon energies above 5–10 keV (below 0.2–0.1 nm wavelength) are called hard X-rays, while those with lower energy are called soft X-rays. Due to their penetrating ability, hard X-rays are widely used to image the inside of objects, e.g., in medical radiography and airport security. As a result, the term X-ray is metonymically used to refer to a radiographic image produced using this method, in addition to the method itself. Since the wavelengths of hard X-rays are similar to the size of atoms they are also useful for determining crystal structures by X-ray crystallography. By contrast, soft X-rays are easily absorbed in air and the attenuation length of 600 eV (~2 nm) X-rays in water is less than 1 micrometer.

There is no universal consensus for a definition distinguishing between X-rays and gamma rays. One common practice is to distinguish between the two types of radiation based on their source: X-rays are emitted by electrons, while gamma rays are emitted by the atomic nucleus. This definition has several problems; other processes also can generate these high energy photons, or sometimes the method of generation is not known. One common alternative is to distinguish X- and gamma radiation on the basis of wavelength (or equivalently, frequency or photon energy), with radiation shorter than some arbitrary wavelength, such as 10−11 m (0.1 Å), defined as gamma radiation. This criterion assigns a photon to an unambiguous category, but is only possible if wavelength is known. (Some measurement techniques do not distinguish between detected wavelengths.) However, these two definitions often coincide since the electromagnetic radiation emitted by X-ray tubes generally has a longer wavelength and lower photon energy than the radiation emitted by radioactive nuclei. Occasionally, one term or the other is used in specific contexts due to historical precedent, based on measurement (detection) technique, or based on their intended use rather than their wavelength or source. Thus, gamma-rays generated for medical and industrial uses, for example radiotherapy, in the ranges of 6–20 MeV, can in this context also be referred to as X-rays. (Gayle,1997)

2.1.3.1 Properties of x-ray

X-ray photons carry enough energy to ionize atoms and disrupt molecular bonds. This makes it a type of ionizing radiation, and therefore harmful to living tissue. A very high radiation dose over a short amount of time causes radiation sickness, while lower doses can give an increased risk of radiation-induced cancer. In medical imaging this increased cancer risk is generally greatly outweighed by the benefits of

the examination. The ionizing capability of X-rays can be utilized in cancer treatment to kill malignant cells using radiation therapy. It is also used for material characterization using X-ray spectroscopy. (Gayle,1997)

Attenuation length of X-rays in water showing the oxygen absorption edge at 540 eV, the energy−3 dependence of Photo absorption, as well as a leveling off at higher photon energies due to Compton scattering. The attenuation length is about four orders of magnitude longer for hard X-rays (right half) compared to soft X-rays (left half). (Gayle,1997)

Hard X-rays can traverse relatively thick objects without being much absorbed or scattered. For this reason, X-rays are widely used to image the inside of visually opaque objects. The most often seen applications are in medical radiography and airport security scanners, but similar techniques are also important in industry (e.g. industrial radiography and industrial CT scanning) and research (e.g. small animal CT). The penetration depth varies with several orders of magnitude over the X-ray spectrum. This allows the photon energy to be adjusted for the application so as to give sufficient transmission through the object and at the same time good contrast in the image. (Gayle,1997)

X-rays have much shorter wavelength than visible light, which makes it possible to probe structures much smaller than what can be seen using a normal microscope. This can be used in X-ray microscopy to acquire high resolution images, but also in X-ray crystallography to determine the positions of atoms in crystals. (Gayle,1997)

2.1.3.2 Interaction of x-ray with matter

X-rays interact with matter in three main ways, through Photoabsorption, Compton scattering, and Rayleigh scattering. The strength of these interactions depend on the energy of the X-rays and the elemental composition of the

material, but not much on chemical properties since the X-ray photon energy is much higher than chemical binding energies. Photo absorption or photoelectric absorption is the dominant interaction mechanism in the soft X-ray regime and for the lower hard X-ray energies. At higher energies, Compton scattering dominates. (Gayle,1997)

2.1.3.2.1 Photoelectric absorption

The probability of a photoelectric absorption per unit mass is approximately proportional to Z3/E3, where Z is the atomic number and E is the energy of the incident photon. This rule is not valid close to inner shell electron binding energies where there are abrupt changes in interaction probability, so called absorption edges. However, the general trend of high absorption coefficients and thus short penetration depths for low photon energies and high atomic numbers is very strong. For soft tissue photo absorption dominates up to about 26 keV photon energy where Compton scattering takes over. For higher atomic number substances this limit is higher. The high amount of calcium (Z=20) in bones together with their high density is what makes them show up so clearly on medical radiographs. (Gayle,1997)

A photo absorbed photon transfers all its energy to the electron with which it interacts, thus ionizing the atom to which the electron was bound and producing a photoelectron that is likely to ionize more atoms in its path. An outer electron will fill the vacant electron position and the produce either a characteristic photon or an Auger electron. These effects can be used for elemental detection through X-ray spectroscopy or Auger electron spectroscopy. (Gayle,1997)

2.1.3.2.2 Compton scattering

Compton scattering is the predominant interaction between X-rays and soft tissue in medical imaging. Compton scattering is an inelastic scattering of the X-ray photon by an

outer shell electron. Part of the energy of the photon is transferred to the scattering electron, thereby ionizing the atom and increasing the wavelength of the X-ray. The scattered photon can go in any direction, but a direction similar to the original direction is a bit more likely, especially for high-energy X-rays. The probabilities for different scattering angles are described by the Klein–Nishina formula. The transferred energy can be directly obtained from the scattering angle from the conservation of energy and momentum. (Baradei,2003)

2.1.3.2.3 Bremsstrahlung

Production Process

The interaction that produces the most photons is the Bremsstrahlung process. Bremsstrahlung is a German word for "braking radiation" and is a good description of the process. Electrons that penetrate the anode material and pass close to a nucleus are deflected and slowed down by the attractive force from the nucleus. The energy lost by the electron during this encounter appears in the form of an x-ray photon. All electrons do not produce photons of the same energy. (Baradei,2003)

2.1.3.2.4 Characristic radiation

The type of interaction that produces characteristic radiation, also illustrated above (in the "Kinetic" paragraph), involves a collision between the high-speed electrons and the orbital electrons in the atom. The interaction can occur only if the incoming electron has a kinetic energy greater than the binding energy of the electron within the atom. When this condition exists, and the collision occurs, the electron is dislodged from the atom. When the orbital electron is removed, it leaves a vacancy that is filled by an electron from a higher energy level. As the filling electron moves down to fill the vacancy, it gives up energy emitted in the form of an x-ray photon. This is known as characteristic

radiation because the energy of the photon is characteristic of the chemical element that serves as the anode material. In the example shown, the electron dislodges a tungsten K-shell electron, which has a binding energy of 69.5 keV. The vacancy is filled by an electron from the L shell, which has a binding energy of 10.2 keV. The characteristic x-ray photon, therefore, has energy equal to the energy difference between these two levels, or 59.3 keV. (Baradei,2003)

Actually, a given anode material gives rise to several characteristic x-ray energies. This is because electrons at different energy levels (K, L, etc.) can be dislodged by the bombarding electrons, and the vacancies can be filled from different energy levels. The electronic energy levels in tungsten are shown below, along with some of the energy changes that give rise to characteristic photons. Although filling L-shell vacancies generates photons, their energies are too low for use in diagnostic imaging. Each characteristic energy is given a designation, which indicates the shell in which the vacancy occurred, with a subscript, which shows the origin of the filling electron. A subscript alpha (a) denotes filling with an L-shell electron, and beta ((3) indicates filling from either the M or N shell. (Lee CI,2004)

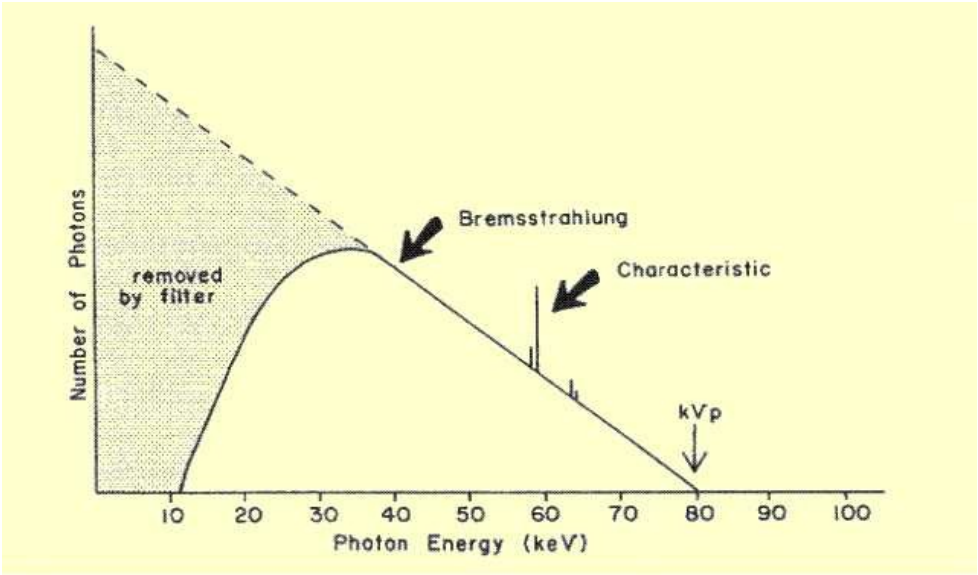


Figure (2,7) :Typical Photon Energy Spectrum from a Machine Operating at KV = 80 adopted from (Lee CI,2004)

2.1.3.3 X-ray production

B D C

A

E

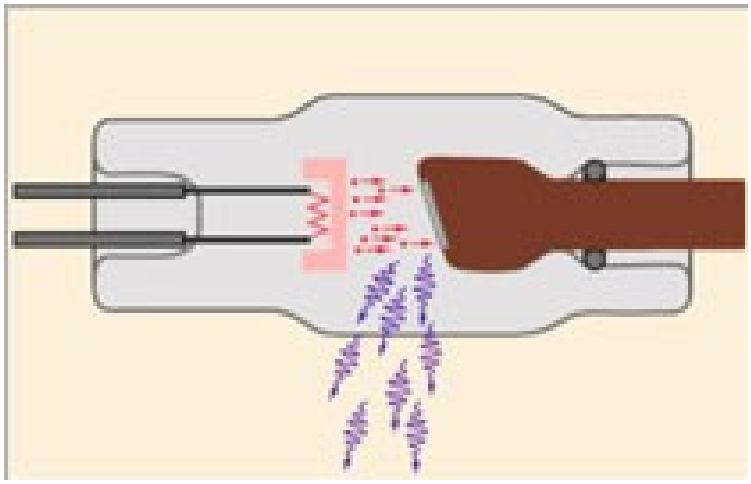


Figure. (2. 8)**.** X-ray tube. The vacuum tube (**A**) houses cathode (**B**) and anode (**C**). A current heats up the filament, releasing electrons (**D**), which are accelerated towards the anode. Interacting with either the nucleus or the shell of the target material, Bremsstrahlung and characteristic radiation are released (**E**), respectively adopted from (Thomas,2004)

X-radiation is created by taking energy from electrons and converting it into photons with appropriate energies. This energy conversion takes place within the x-ray tube. The quantity (exposure) and quality (spectrum) of the x-radiation produced can be controlled by adjusting the electrical quantities (KV, MA) and exposure time, S, applied to the tube. In this chapter we first become familiar with the design and construction of x-ray tubes, then look at the x-ray production process, and conclude by reviewing the quantitative aspects of x-ray production. (Thomas,2004)

The x-ray efficacy of the x-ray tube is defined as the amount of exposure, in mill roentgens, delivered to a point in the center of the useful x-ray beam at a distance of 1 m from the

focal spot for 1 mAs of electrons passing through the tube. (Thomas,2004)

2.1.3.4 X-ray tube

The x ray tube consists of an evacuated glass envelope with in which is the anode at one end and the cathode at the other. Appositive potential on the anode with respect to the cathode allows electrons to travel from the cathode to the anode at high energy. When they are stopped x rays are produced .The filament is raised incandescence by a high filament current so as to produce a space charge of electrons around the filament by thermionic emission. A dual –focus tube has two filaments attached to the cathode. (Baradei,2003)

The filament is made of tungsten the compound anode of stationery anode tube is constructed of copper with a tungsten insert. The main mechanism of heat loss from stationary anode tube is conduction whilst that from a rotating anode is radiation. (Baradei,2003)

A line focus is produced on the anode which is smaller than the size of the filament because of the focusing effect of the focusing cup on the electron beam an electrical induction motor is used to rotate the anode by means of rotating magnetic field which induces currents in the rotor. Electrical safety is insured by ear thing all metal parts and radiation safety to the operators is insured by lead lining on the inside of the shield .Radiation dosage to the patient is reduced by the use of the smallest practicable field size and aluminum filters (W.R.Hendee,2002)

X-Rays

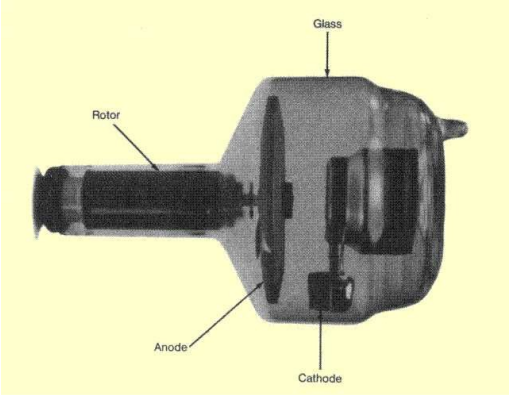


Figure **(2.9) :** X ray tube adopted from (Hendee,2002)

2.1.3.4.1 Anode

The anode is the component in which the x-radiation is produced. It is a relatively large piece of metal that connects to the positive side of the electrical circuit. The anode has two primary functions: to convert electronic energy into x-radiation, and to dissipate the heat created in the process. The material for the anode is selected to enhance these functions. (Thomas,2004)

The ideal situation would be if most of the electrons created x-ray photons rather than heat. The fraction of the total electronic energy that is converted into x-radiation (efficiency) depends on two factors: the atomic number (Z) of the anode material and the energy of the electrons. Most x-ray tubes use tungsten, which has an atomic number of 74, as the anode material. In addition to a high atomic number, tungsten has several other characteristics that make it suited for this purpose. Tungsten is almost unique in its ability to maintain its strength at high temperatures, and it has a high melting point and a relatively low rate of evaporation. For many years, pure tungsten was used as the anode material. In recent years an alloy of tungsten and rhenium has been used as the target material but only for the surface of some anodes. The anode body under the tungsten-rhenium surface on many tubes is manufactured from a material that is relatively light and has good heat

storage capability. Two such materials are molybdenum and graphite. The use of molybdenum as an anode base material should not be confused with its use as an anode surface material. Most x-ray tubes used for mammography have molybdenum-surface anodes. This material has an intermediate atomic number (Z = 42), which produces characteristic x-ray photons with energies well suited to this particular application. Some mammography tubes also have a second anode made of rhodium, which has an atomic number of 45. This produces a higher energy and more penetrating radiation, which can be used to image dense breast. (Thomas ,2004)

The use of a rhenium-tungsten alloy improves the long-term radiation output of tubes. With x-ray tubes with pure tungsten anodes, radiation output is reduced with usage because of thermal damage to the surface. (Thomas,2004)

2.1.3.4.2 Focal Spot

Not all of the anode is involved in x-ray production. The radiation is produced in a very small area on the surface of the anode known as the focal spot. The dimensions of the focal spot are determined by the dimensions of the electron beam arriving from the cathode. In most x-ray tubes, the focal spot is approximately rectangular. The dimensions of focal spots usually range from 0.1 mm to 2 mm. X-ray tubes are designed to have specific focal spot sizes; small focal spots produce less blurring and better visibility of detail, and large focal spots have a greater heat-dissipating capacity. (Thomas,2004)

Focal spot size is one factor that must be considered when selecting an x-ray tube for a specific application. Tubes with small focal spots are used when high image visibility of detail is essential and the amount of radiation needed is relatively low because of small and thin body regions as in

mammography. Most x-ray tubes have two focal spot sizes (small and large), which can be selected by the operator according to the imaging procedure. (Thomas,2004)

2.1.3.4 .3 Cathode

The basic function of the cathode is to expel the electrons from the electrical circuit and focus them into a well-defined beam aimed at the anode. The typical cathode consists of a small coil of wire (a filament) recessed within a cup-shaped region, as shown below. (Thomas,2004)

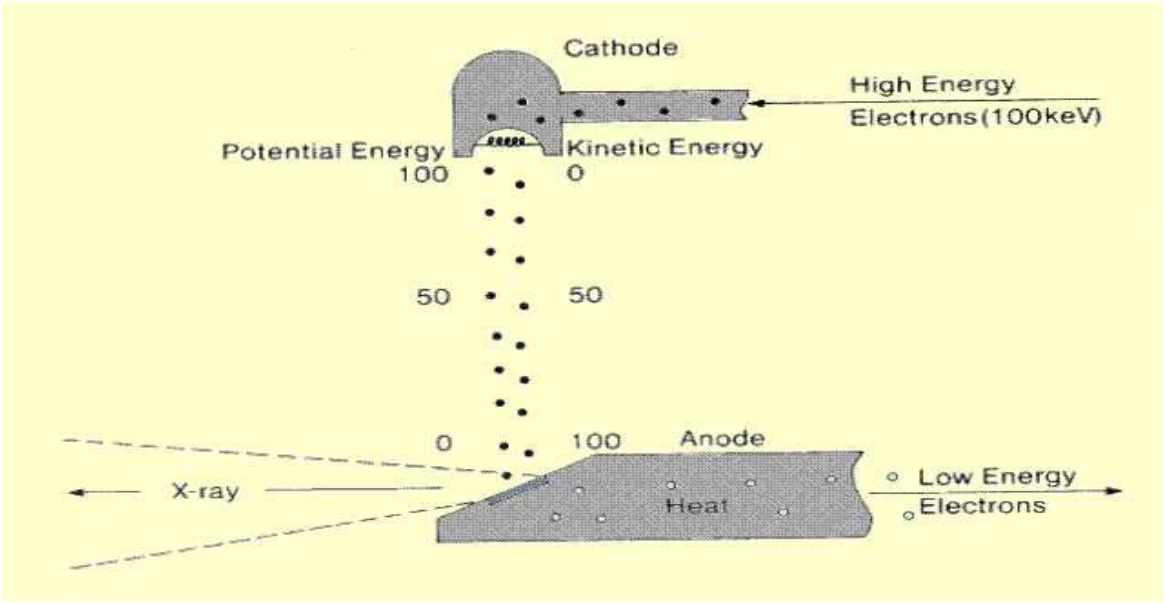


Figure (2.10) Energy Exchange within an X-Ray Tube adopted from (Thomas,2004)

The x-ray circuit 2.1.3.5

The energy used by the x-ray tube to produce x-radiation is supplied by an electrical circuit as illustrated below. The circuit connects the tube to the source of electrical energy,

that in the x-ray room is often referred to as the generator. As described in another chapter, the generator receives the electrical energy from the electrical power system and converts it into the appropriate form (DC, direct current) to apply to the x-ray tube. The generator also provides the ability to adjust certain electrical quantities that control the x-ray production process. (Thomas,2004)

The three principle electrical quantities that can be adjusted are the:KV (the voltage or electrical potential applied to the tube) , MA (the electrical current that flows through the tube) , S (duration of the exposure or exposure time, generally a fraction of a second). The circuit is actually a circulatory system for electrons. They pickup energy as the pass through the generator and transfer their energy to the x-ray tube anode as described above. (Thomas,2004)

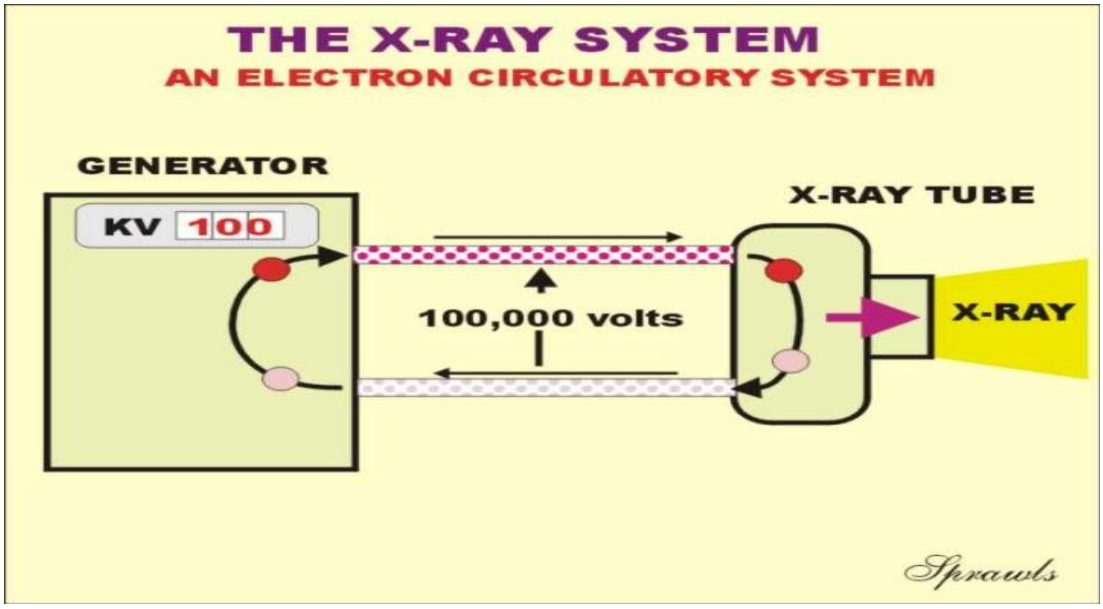


fig (2.11) : system of production x-ray adopted from (Thomas,2004)

Electron energy 2.1.3.6

The energy that will be converted into x-radiation (and heat) is carried to the x-ray tube by a current of flowing electrons as shown above. As the electrons pass through the x-ray

tube, they undergo two energy conversions, as illustrated previously: The electrical potential energy is converted into kinetic (motion) energy that is, in turn, converted into x-radiation and heat. (Thomas,2004)

Potential energy 2.1.3.6.1

When the electrons arrive at the x-ray tube, they carry electrical potential energy. The amount of energy carried by each electron is determined by the voltage or KV, between the anode and cathode. For each kV of voltage, each electron has 1 keV of energy. By adjusting the KV, the x-ray machine operator actually assigns a specific amount of energy to each electron. (Thomas,2004)

2.1.3.6.2 Kinetic energy

After the electrons are emitted from the cathode, they come under the influence of an electrical force pulling them toward the anode. This force accelerates them, causing an increase in velocity and kinetic energy. This increase in kinetic energy continues as the electrons travel from the cathode to the anode. As the electron moves from cathode to anode, however, its electrical potential energy decreases as it is converted into kinetic energy all along the way. Just as the electron arrives at the surface of the anode its potential energy is lost, and all its energy is kinetic. At this point the electron is traveling with a relatively high velocity determined by its actual energy content. A 100-keV electron reaches the anode surface traveling at more than one half the velocity of light. When the electrons strike the surface of the anode, they are slowed very quickly and lose their kinetic energy; the kinetic energy is converted into either x-radiation or heat. The electrons interact with individual atoms of the anode material, as shown below. Two types of interactions produce radiation. An interaction with electron

shells produces characteristic x-ray photons; interactions with the atomic nucleus produce Bremsstrahlung x-ray photons.(Thomas,2004)

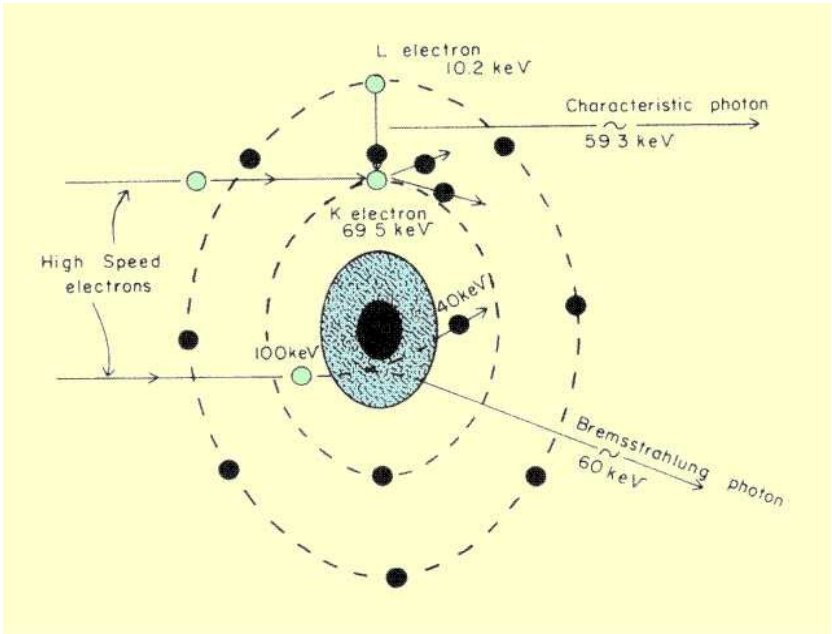


Figure (2.12): Electron-Atom Interactions That Produce X-Ray Photons adopted from (Thomas,2004)

2.1.3.6.3 Binding Energy

The electrons within an atom each have a specific amount of binding energy that depends on the size (atomic number, Z) of the atom and the shell in which the electron is located. As described in a previous chapter the binding energy is the energy that would be required to remove the electron from the atom. It is actually an energy deficit rather than an amount of available energy. The binding energy of electrons within an atom plays a major role in the production of characteristic x-radiation as described later. (Thomas,2004)

2.1.3.7 Units of measure and exposure

The measure of X-rays ionizing ability is called the exposure:

The coulomb per kilogram (C/kg) is the SI unit of ionizing radiation exposure, and it is the amount of radiation required to create one coulomb of charge of each polarity in one

kilogram of matter. The roentgen (R) is an obsolete traditional unit of exposure, which represented the amount of radiation required to create one electrostatic unit of charge of each polarity in one cubic centimeter of dry air. 1 roentgen = 2.58×10−4 C/kg.However, the effect of ionizing radiation on matter (especially living tissue) is more closely related to the amount of energy deposited into them rather than the charge generated. This measure of energy absorbed is called the absorbed dose:

The gray (Gy), which has units of (joules/kilogram), is the SI unit of absorbed dose, and it is the amount of radiation required to deposit one joule of energy in one kilogram of any kind of matter. The rad is the (obsolete) corresponding traditional unit, equal to 10 mill joules of energy deposited per kilogram. 100 rad = 1 gray.

The equivalent dose is the measure of the biological effect of radiation on human tissue. For X-rays it is equal to the dose. The Roentgen equivalent man (rem) is the traditional unit of equivalent dose. For X-rays it is equal to the rad, or, in other words, 10 mill joules of energy deposited per kilogram. 100 rem = 1 Sv.

The sievert (Sv) is the SI unit of equivalent dose, and also of effective dose. For X-rays the "equivalent dose" is numerically equal to a Gray (Gy). 1 Sv = 1 Gy. For the "effective dose" of X-rays, it is usually not equal to the Gray (Gy).

2.1.4 Computed Tomography

2.1.4.1 An Overview of CT History

Wilhelm Roentgen first discovered ionizing radiation in the form of x-rays in 1895, while performing experiments with cathode rays. Shortly after his discovery, the possible applications of x-rays for medical purposes began to

be explored in several countries, including the USA, England and France . (Flohr,2009).

In the 1970s, CT was introduced as an innovative x-ray imaging tool. This technology was invented by electrical engineer Godfrey N. Hounsfield of Central Research Laboratories (London) in 1972, along with physicist Allan M. Cormack of Tufts University (Massachusetts), who was simultaneously working on image reconstruction theory . Also in 1972, the first CT head scanner was developed, and the first commercial unit of this prototype was installed in the USA, in 1973 . Between 1974 and 1976, CT scanners began to be installed and used in medical institutions. By 1977, several manufacturing companies were marketing more than 30 models of CT scanners , and by May 1980, there were more than 1,000 operational CT homographs in the USA (Hendee,2002).

Spiral CT scanners entered the market in 1989 , and the first step towards multi-slice acquisition was the Elscint TWIN two-slice CT scanner, introduced in 1993. By 1998, all major CT manufacturers had a multi-slice SCT scanner model and, in 2004, the next-generation versions of those multi-slice CT systems – with 32, 40, and 64 simultaneously acquired slices – were available on the market. 64-slice CT systems are now operational in numerous medical institutions, and yet new tomographs, with more slices acquired simultaneously, are being developed. In 2007, Phillips introduced a scanner capable of measuring 256 slices simultaneously, using a RX cone-beam, and Toshiba announced a new 320-slice scanner (Flohr,2009).

Year	Milestone
1895	Rontgen discovers a new kind of radiation, which he named X-ray
1901	Rontgen receives the Nobel Prize for physics
1906	Bock winkel employs the Lorentz's solution in the reconstruction of three-dimensional functions from two-dimensional area integrals
1917	Radon publishes his epochal work on the solution of the inverse problem of reconstruction
1925	Ehrenfest extends the solution of Lorentz to n dimensions using the Fourier Transform
1936	Cramer and Wold solve the reconstruction problem in statistics in which the probability distribution is obtained from a complete set of marginal probability distributions
1936	Eddington solves the reconstruction problem in the field of astrophysics to calculate the distribution of star velocities from the distribution of their measured radial components
1956	Brace well applies Fourier techniques for the solution of the inverse problem in radio astronomy
1958	The Ukrainian scientist Kor enblyum develops an X-ray scanner and tries to measure thin slices through the patient with analogue reconstruction principles
1963	Cormack contributes the first mathematical implementations for tomographic reconstruction in South Africa
1969	Hounsfield shows proof of the principle with the first CT scanner based on a radioactive source at the EMI research laboratories
1972	Hounsfield and Ambrose publish the first clinical scans with an EMI head scanner
1975	Set-up of the first whole body scanner with a fan-beam system
1979	

1983	Hounsfield and Cormack receive the Nobel Prize for Medicine
1989	Demonstration of electron beam CT (EBCT)
1991	Kalender publishes the first clinical spiral-CT
	Demonstration of multi-slice CT (MSCT)

Table (2:2). Summary of historical CT milestones adopted from (FDA. 2010)

2.1.4.2 Applications of CT Imaging

CT is a radiologic, anatomical imaging technique that provides valuable clinical information for the detection and differentiation of several diseases. In fact, CT is the primary diagnostic tool for a wide range of clinical indications, being also used as a complement for other imaging modalities . A CT system produces cross-sectional images of selected regions of the body, which can be used for different diagnostic and therapeutic purposes. The images obtained can help diagnose or rule out different diseases and abnormalities, also being often used as a reference for therapy planning and monitoring (FDA. 2010).

For instance, one of the fields where CT is most widely used is Neuroradiology. It is highly useful in the examination of the brain, being frequently indicated for neurologic examinations such as the evaluation of acute head trauma, suspected intracranial hemorrhage, and vascular lesions. Also in Neurology, CT might be a suitable alternative when MRI is deemed contraindicated. Other advanced applications of CT imaging include the visualization of specific anatomical structures and tissues using CT perfusion, volumetry, angiography, and venography (FDA. 2010).

2.1.4.3 Basic Principles of CT Imaging

In CT imaging, anatomic cross-sectional (or “slice”) images of body tissues and organs are produced. These images represent the x-ray attenuation properties of the different tissues: the x-ray photons, generated within an x-ray tube, are attenuated in the patient’s tissues and organs . The interaction between x-ray and matter depends on the x -ray photons energy, and matter’s thickness and electron density. Thicker and denser materials, such as bone, attenuate more X-rays photons than less dense, thinner tissues like muscle or fat, and these differences in attenuation will result in correspondent contrast variations, in the final image(Suetens,2009).

Thin x-ray beams scan the desired anatomical region, and this process is repeated for different angle directions . The actual attenuation at each particular location inside the body is then reconstructed from all those attenuation measurements, through sophisticated mathematical algorithms, which reconstruct data information of the x-ray attenuation coefficients determined for the different anatomical structures (Suetens,2009).

The intensity of the x-ray beam before it reaches the body is measured by an x-ray detector, as well as its final intensity, in order to compute the μ values of the different tissues the x-ray beam interacts with . The x-ray detector area is constituted by a radiation-sensitive material (such as cadmium tungstate or gadolinium-oxide), which converts x-rays into visible light. This light interacts with a silicon photodiode and is converted into an electrical current, which is later amplified and converted into a digital signal . The data from the detector array is then reconstructed to obtain images of the internal structures of the body region scanned (Suetens,2009).

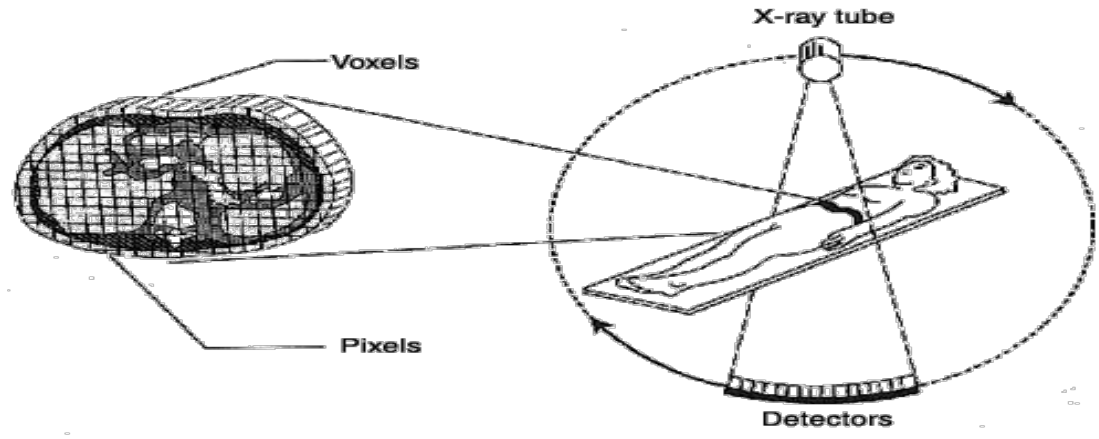


Figure (2.13) – Anatomical structures within the patient's body is reconstructed from the x-ray transmission data. Adopted from (Lima,2010)

2.1.4.4 The CT scanner Components

The general structure of a CT equipment can be divided in four principal elements:

The Data Acquisition and Transfer System, which encompasses the gantry, the patient's table, the PDU and a data transfer unit: The gantry is a central opening where the patient is moved into during the examination, in which are assembled the x-ray tube source, where electrons are generated in a cathode and accelerated towards an anode (the target) producing x-ray photons; the detector area, diametrically opposed to the x-ray source in the gantry; a collimation system, which determines the slice width; a filtering system to remove the low energy component of the x-ray beam; a refrigerating system and a power source for the x-ray tube and detectors rotation (Lima,2010).

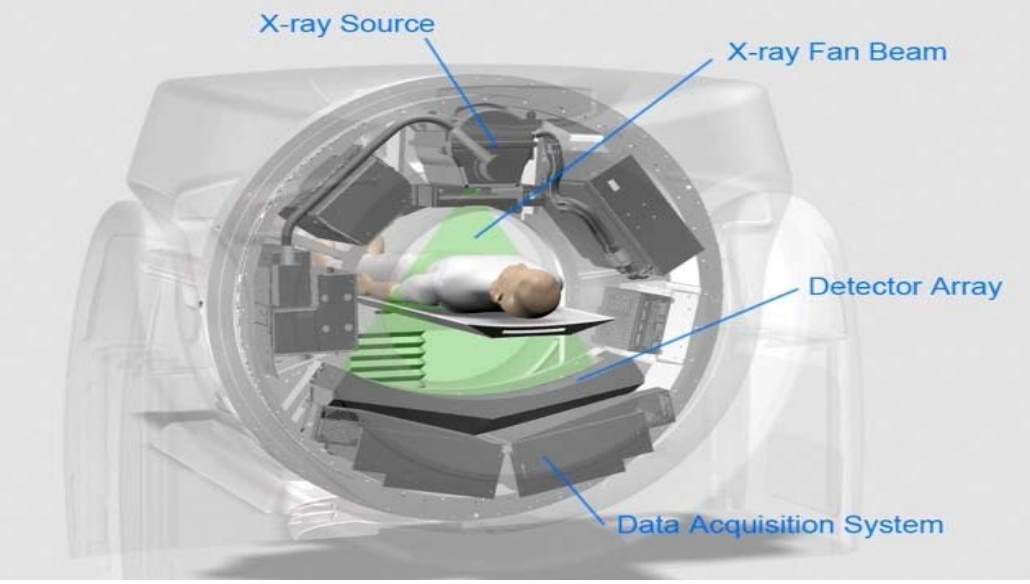


Figure (2.14) – The x-ray tube and the detector array are oppositely placed, inside the gantry. Adopted (Thorsten,1965)

The table is where the patient is positioned (lied down), and it moves through the gantry. The patient's table and the gantry constitute CT scanner itself. The Power Distribution Unit (PDU) supplies power to the gantry, the patient's table and the computers of the Computing System, which is localized in a separate room, as will be explained next. The PDU is a separate, independent unit, generally in the same room as the gantry and table. (Thorsten,1965)

In the data transfer unit, ADCs (Analog-to-Digital Converters) convert the electrical signal from the detectors in the gantry into a digital signal .(Reddinger.1997)

The computing system (or operator's console) is installed in separate room, making it possible for the operator (technician) to control the acquisition process, introducing patient. (Thorste.1965)

The image reconstruction system receives the x-ray transmission data information from the data transfer unit, in a digital format . This gathered data is then corrected using reconstruction algorithms, and later registered in a CD or a

DVD. Generally, all exam data is additionally recorded in the medical institution's PACS (Thorsten.1965)

A second operator's console, for independent image editing and post-processing is also necessary , so it is possible to analyze and review previous exam data, without interfering with the current examinations taking place(Reddinge,1997).

2.1.4.5 Types of machines

Spinning tube, commonly called spiral CT, or helical CT in which an entire X-ray tube is spun around the central axis of the area being scanned. These are the dominant type of scanners on the market because they have been manufactured longer and offer lower cost of production and purchase. The main limitation of this type is the bulk and inertia of the equipment (X-ray tube assembly and detector array on the opposite side of the circle) which limits the speed at which the equipment can spin. Some designs use two X-ray sources and detector arrays offset by an angle, as technique to improve temporal resolution. (Herman,2009)

Electron beam tomography (EBT) is a specific form of CT in which a large enough X-ray tube is constructed so that only the path of the electrons, travelling between the cathode and anode of the X-ray tube, are spun using deflection coils. This type had a major advantage since sweep speeds can be much faster, allowing for less blurry imaging of moving structures, such as the heart and arteries. Fewer scanners of this design have been produced when compared with spinning tube types, mainly due to the higher cost associated with building a much larger X-ray tube and detector array and limited anatomical coverage. Only one manufacturer (I matron, later acquired by General electric) ever produced scanners of this design. Production ceased in early 2006.In multislice computed tomography (MSCT), a higher number of tomographic slices allow for higher-resolution imaging.

Examination	Typical effective	Typical absorbed

	dose (mSv) to the whole body	dose (mGy) to the organ in question
Annual background radiation	2.4	2.4
Chest X-ray	0.02	0.01–0.15
Head CT	1–2	NA
Screening mammography	0.4	3
Abdomen CT	8	14
Chest CT	5–7	13
CT colonography	6–11	
Chest, abdomen and pelvis CT	9.9	12
Cardiac CT angiogram	9–12	40–100
Barium enema	15	15
Neonatal abdominal CT	20	20

Table(2:3) reports average radiation exposures Adopted from (www.wikipedia.com\radiationdose. enter site in October 2014)

2.1.4.6 CT Scan Room

When you enter the CT scan room, you will be asked to lie on the CT table. If you need an IV, the technologist will start one at this time. The technologist will explain the procedure to you, instruct you on holding still, breathing, and any sensations you may experience. Once you are correctly positioned you will be asked to relax and not move. Positioning straps may be placed to ensure proper position is maintained through the scan. The technologist will leave the room and begin the scanning procedure from the computer console. The technologist can see and hear you at all time--each of you can communicate with each other via an intercom system. (Paterson A,2001)

Depending upon the type of scan, the table may move in increments or one continuous movement. The total examination time is usually less than 15 minutes. The

technologist will check on you after the scan is completed, and remove the intravenous if one was started. You may leave the scan room at this time and return to normal activities unless otherwise instructed. The technologist will give you easy to follow instructions if required. (Paterson A,2001)

2.1.4.7 Advantages

There are several advantages that CT has over traditional 2D medical radiography. First, CT completely eliminates the superimposition of images of structures outside the area of interest. Second, because of the inherent high-contrast resolution of CT, differences between tissues that differ in physical density by less than 1% can be distinguished. Finally, data from a single CT imaging procedure consisting of either multiple contiguous or one helical scan can be viewed as images in the axial, coronal, or sagittal planes, depending on the diagnostic task. This is referred to as multiplanar reformatted imaging. (herman,2009)

CT is regarded as a moderate- to high-radiation diagnostic technique. The improved resolution of CT has permitted the development of new investigations, which may have advantages; compared to conventional radiography, for example, CT angiography avoids the invasive insertion of a catheter. CT colonography (also known as virtual colonoscopy or VC for short) may be as useful as a barium enema for detection of tumors, but may use a lower radiation dose. CT VC is increasingly being used in the UK as a diagnostic test for bowel cancer and can negate the need for a colonoscopy. (herman,2009)

The radiation dose for a particular study depends on multiple factors: volume scanned, patient build, number and type of scan sequences, and desired resolution and image quality. In addition, two helical CT scanning parameters that can be adjusted easily and that have a profound effect on radiation

dose are tube current and pitch. Computed tomography (CT) scan has been shown to be more accurate than radiographs in evaluating anterior inter body fusion but May still over-read the extent of fusion. (ASRT,2013)

2.1.4.8 Adverse effects

2.1.4.8.1 Cancer

The radiation used in CT scans can damage body cells, including DNA molecules, which can lead to cancer. According to the National Council on Radiation Protection RP and Measurements, between the 1980s and 2006, the use of CT scans has increased six fold (600%). The radiation doses received from CT scans are 100 to 1,000 times higher than conventional X-rays. A study by a New York hospital found that nearly a third of its patients who underwent multiple scans received the equivalent of 5,000 chest X-rays. (Redberg,2003)

Some experts note that CT scans are known to be "overused," and "there is distressingly little evidence of better health outcomes associated with the current high rate of scans." (Redberg,2003)

Early estimates of harm from CT are partly based on similar radiation exposures experienced by those present during the atomic bomb explosions in Japan during the Second World War and those of nuclear industry workers. A more recent study by the National Cancer Institute in 2009, based on scans made in 2007, estimated that 29,000 excess cancer cases and 14,500 excess deaths would be caused over the lifetime of the patients. Some experts project that in the future, between three and five percent of all cancers would result from medical imaging. (Redberg,2003)

An Australian study of 10.9 million people reported that the increased incidence of cancer after CT scan exposure in this cohort was mostly due to irradiation. In this group one in every 1800 CT scans was followed by an excess cancer. If

the lifetime risk of developing cancer is 40% then the absolute risk rises to 40.05% after a CT. (Redberg,2003)

A person's age plays a significant role in the subsequent risk of cancer. Estimated lifetime cancer mortality risks from an abdominal CT of a 1-year-old is 0.1% or 1:1000 scans. The risk for someone who is 40 years old is half that of someone who is 20 years old with substantially less risk in the elderly. The International Commission on Radiological Protection estimates that the risk to a fetus being exposed to 10 mGy (a unit of radiation exposure, see Gray (unit)) increases the rate of cancer before 20 years of age from 0.03% to 0.04% (for reference a CT pulmonary angiogram exposes a fetus to 4 mGy). A 2012 review did not find an association between medical radiation and cancer risk in children noting however the existence of limitations in the evidences over which the review is based. (Shelton, J,2011)

CT scans can be performed with different settings for lower exposure in children with most manufacturers of CT scans as of 2007 having this function built in. Furthermore, certain conditions can require children to be exposed to multiple CT scans. Studies support informing parents of the risks of pediatric CT scanning. (Baysson H,2012)

2.1.4.8.2 Contrast

In the United States half of CT scans involve intravenously injected radio contrast agents. The most common reactions from these agents are mild, including nausea, vomiting and an itching rash; however, more severe reactions may occur. Overall reactions occur in 1 to 3% with nonionic contrast and 4 to 12% of people with ionic contrast. Skin rashes may appear within a week to 3% of people. (Larson DB,2007)

The old radio contrast agents caused anaphylaxis in 1% of cases while the newer, lower-osmolar agents cause reactions in 0.01–0.04% of cases. Death occurs in about two to 30

people per 1,000,000 administrations with newer agents being safer. When deaths do occur it is more typically in those who are female, elderly or in poor health and is secondary to either anaphylaxis or acute renal failure. (james,2005)

The contrast agent may induce contrast-induced nephropathy. This occurs in 2 to 7% of people who receive these agents, with greater risk in those who have preexisting renal insufficiency, preexisting diabetes, or reduced intravascular volume. People with mild kidney impairment are usually advised to ensure full hydration for several hours before and after the injection. For moderate kidney failure, the use of iodinated contrast should be avoided; this may mean using an alternative technique instead of CT. Those with severe renal failure requiring dialysis require less strict precautions, as their kidneys have so little function remaining that any further damage would not be noticeable and the dialysis will remove the contrast agent; it is normally recommended, however, to arrange dialysis as soon as possible following contrast administration to minimize any adverse effects of the contrast. (Thorsten,1965)

In addition to the use of intravenous contrast, orally administered contrast agents are frequently used when examining the abdomen. These are frequently the same as the intravenous contrast agents, merely diluted to approximately 10% of the concentration. However, oral alternatives to iodinated contrast exist, such as very dilute (0.5–1% w/v) barium sulfate suspensions. Dilute barium sulfate has the advantage that it does not cause allergic-type reactions or kidney failure, but cannot be used in patients with suspected bowel perforation or suspected bowel injury, as leakage of barium sulfate from damaged bowel can cause fatal peritonitis. (Thorsten,1965)

2.1.4.9 Radiation safety in CT

Radiation doses in CT are relatively high. For example, the effective dose of a head scan is 2 mSv, of the thorax 10 mSv and of the abdomen 15 mSv. This is a factor 10 to 100 higher than radiographic images of the same region, but the diagnostic content of the CT images is typically much higher. Some scanners use a lower tube current and a higher voltage to reduce the dose. However, there is still some risk to a developing fetus. CT scans are therefore not recommended during pregnancy. (Thorsten,1965)

2.1.4.10 Diagnostic use

Since its introduction in the 1970s, CT has become an important tool in medical imaging to supplement x-rays and medical ultrasonography. It has more recently been used for preventive medicine or screening for disease, for example CT colonography for patients with a high risk of colon cancer, or full-motion heart scans for patients with high risk of heart disease. A number of institutions offer full-body scans for the general population although this practice goes against the advice and official position of many professional organizations in the field. (Thorsten,1965)

2.1.4.11 Specific Dose unit for CT

The currently accepted appropriate descriptor for CT dose is the Computed Tomography Dose Index (CTDI). This is a local dose descriptor of dose output for scanners measured in air at the centre of rotation The CTDI is defined as the radiation dose, normalized to beam width, measured from 100 mm length of a pencil ionization chamber. (Thorsten,1965)

Specific imaging protocols also include the pitch as a factor, thus in consideration of that factor, another descriptor has been created. The unit is CTDIvol or CTDIw,. It is defined as

$$CTDI\ vol = CTDI\ w.\ NT/I \qquad mGy$$

Where N and T are defined and represent the total collimated width of the X-ray beam and I am the table increment per rotation for helical scan or spacing between

acquisitions for axial scans. Pitch is one of the parameters in spiral CT. Pitch is defined as table distance travelled in one 360° rotation over total collimated width of the X-ray beam, while in conventional CT it is defined as table increment over slice thickness. Pitch can be calculated by the equation .
Pitch = I/NT

In describing the exposure distribution along the z axis another descriptor known as Dose Length Product (DLP) (European Commission 1998) is used as an integral dose quantity. This DLP is created as estimated effective dose value without taking account of tissue weighting factor. The DLP is expressed in units of Gy.cm and given in the equation below, (European Commission 1998)

DLP = CTDI vol. L (Scan length) mGy. cm

2.1.4.12 Diagnostic Reference Levels

In optimization of radiation in medical exposure, the ICRP publication 60 recommended as noted:-“Consideration should be given to the use of dose constraints, or investigation levels, selected by appropriate professional or regulatory agency, for application in some common diagnostic procedures. They should be applied with flexibility to allow higher doses where indicated by sound clinical judgment”. Then, the ICRP publication 73 introduced the first “diagnostic reference level” (DRL). It explained the concept of reference levels and expanded in more detail the concept of DRL . Thus in the context of optimization of radiation protection of patient in diagnostic radiology including CT, the introduction of DRL is appropriate. The DRL is defined as a dose level set for standard procedures and for groups of standard-size patients or a standard phantom for broadly defined types of equipment (CEU 1997; European Commission 1999; ICRP 1996).

The selection of DRL is decided by professional medical bodies, using third quartile dose values on the observed distribution for patients, and specifically for a country or region (ICRP 2002).The purpose of DRL is to advise local authorities as a quality assurance tool in identifying individual centers that are consistently unusually high in their dose values levels against clinical doses that need to be reviewed (IAEA 2002; ICRP 2002).

The DRL quantities should be easily measured on a simple standard phantom or representative patient for diagnostic radiology. The dose quantities suggested for CT examinations are: (1) CTDIW per slice (mGy) and (2) DLP per exam (mGy.cm) (European Commission 1998). These two quantities provide a useful indication of the relative scanner X-ray output in CT reflecting both the technique factors selected for each examination and overall scope of an examination for a given type of procedure and patient group. (Thorstern,1965)

2.1.5 Pediatric CT

Pediatric health care professionals have an important role in the use of CT on children. The health care professional ultimately decides whether a CT examination is necessary. With this important role comes a responsibility to recognize both the value of CT and its risks, which, as described previously, it is reasonable to assume are very small but real. (Frush DP,2004)
The health care professional should also be able to discuss these risks in a manner that is informative and understandable to patients and families. One must recognize that the decision regarding a CT examination will often depend on the combination of the interaction with consultants, such as radiologists, and the family. There is a

vast pool of information available on the Internet, much of which may be confusing with respect to CT, radiation, and cancer. (Frush DP,2004)
The pediatric health care professional should be in a position to be able to answer questions and address concerns. (Frush DP,2004)
The pediatric health care professional is usually the first, and often the only, source of direct communication with the child and the family. This relationship carries with it an opportunity to inform and educate the family. (Jacob K,2004)

Recent reviews that covered CT technology and its role in the imaging armamentarium. Are salient for pediatric health care professionals. CT has an increasingly recognized role as the first, if not only, imaging examination for a wide variety of disorders that affect infants and children. What is most important to realize is that the use of CT is not infrequent in children and that the frequency of CT examinations is increasing. A recent review summarized investigations indicating that CT use has increased substantially over the last 1 to 2 decades, including estimates of at least 10% growth per year. (Paterson A,2001)
Currently, approximately 11% of CT examinations are performed on children,4 which could account for more than 7 million pediatric CT examinations per year in the United States. The use of CT for common problems such as trauma (closed head injury, skeletal evaluation including cervical spine assessment, and blunt abdominal trauma), appendicitis, and renal calculi has increased the frequency of CT examinations in adult and pediatric populations. Most clinicians believe that CT studies on children prevent hospitalization for head injuries and that negative findings in patients with acute onset of abdominal pain can obviate surgical explorations. These studies provide information that leads to earlier and more definitive diagnosis. . (Jacob.2004)

This increased use, however, must be based on a firm understanding that the CT study is the best study for the clinical situation being evaluated and that the possibility of a

very small risk of cancer is considered when making the decision to order the study. The possible cancer risk is not clearly understood by many health care professionals, as concluded by 2 recent investigations. In the first investigation, Lee ET al15 surveyed emergency department patients, physicians, and radiologists. The results indicated that only 7% of patients indicated that there was any discussion outlining the radiation risks and benefits from an abdominal CT examination. In addition, only 9% of emergency department physicians believed that the lifetime risk of cancer was potentially increased by CT scanning. Moreover, 75% of physicians surveyed underestimated the accurate range for the equivalent number of chest radiographs for a CT examination in another recent investigation, Jacob et al surveyed physicians in the United Kingdom and found that only 12.5% were aware of the potential association of CT radiation and cancer. Less than 20% correctly identified the relative radiation dose of CT examinations. These studies support a continued and compelling need for radiation safety education for health care professionals and the public. (Jacob,2004)

The pediatric health care professional should also be able to provide summary information to families on local practice patterns of radiology colleagues. It is reasonable to have information immediately available from the radiology practice in addition to that stated above. This information should include:

Additional expertise of the practice (pediatric radiology fellowship training, American Board of Radiology Certificate of Added Qualification, and current Maintenance of Certification in pediatric radiology);

Appropriate pediatric head and body CT protocols consisting of size- or age-based adjustments in scanner settings; and American College of Radiology accreditation of the CT scanners and the radiologists who interpret those studies in the practice.An important role of the pediatric health care professional is to communicate with the radiologist to decide whether CT is the best study to perform. This consultation will vary from practice to practice, but it should be the goal

of both parties to facilitate discussions on imaging strategies. (Paterson,2001)
These discussions provide an opportunity to share information, such as the number of studies using ionizing radiation to which the patient has been exposed. In addition to the pediatric health care professionals and radiologists, the integration of other care providers, such as surgical consultants or emergency department physicians, in decisions regarding pediatric CT policy or practice should also be fostered. Other imaging techniques such as ultrasonography or MRI may be suitable alternatives to CT examination, and they do not use ionizing radiation. If the CT examination is indicated and the radiology department uses a low-dose technique, another way to reduce CT dose is to limit the number of times (or phases) the child is scanned for the individual examination. It is very common for adult CT protocols to involve multiple scans through the same body part, which can double or triple the radiation dose to the patient. For most indications for pediatric CT scans, a single pass through the body part of interest is usually sufficient for diagnostic purposes. (Donnelly LF,2003)

2.2 Previous studies

B Bednarz, in (The development, validation and application of a multi detector CT (MDCT) scanner model for assessing organ doses to the pregnant patient and the fetus using Monte Carlo simulations) developed and validated an MDCT scanner using the Monte Carlo method, and meanwhile the pregnant patient phantoms were integrated into the MDCT scanner model for assessment of the dose to the fetus as well as doses to the organs or tissues of the pregnant patient phantom. The scanner model was validated by comparing simulated results against measured CTDI values and dose profiles reported in the literature. The source movement along the helical trajectory was simulated using the pitch of

0.9375 and 1.375, respectively. The validated scanner model was then integrated with phantoms of a pregnant patient in three different gestational periods to calculate organ doses. It was found that the dose to the fetus of the 3 month pregnant patient phantom was 0.13 mGy/100 mAs and 0.57 mGy/100 mAs from the chest and kidney scan, respectively. For the chest scan of the 6 month patient phantom and the 9 month patient phantom, the fetal doses were 0.21 mGy/100 mAs and 0.26 mGy/100 mAs, respectively. The paper also discusses how these fetal dose values can be used to evaluate imaging procedures and to assess risk using recommendations of the report from AAPM Task Group 36. This work demonstrates the ability of modeling and validating an MDCT scanner by the Monte Carlo method, as well as assessing fetal and organ doses by combining the MDCT scanner model and the pregnant patient phantom.

Walter Huda, etal 2006 (Patient Radiation Doses from Adult and Pediatric CT) determined typical organ doses, and the corresponding effective doses, to adult and pediatric patients undergoing a single CT examination. The organs were heads, chests, and abdomens of patients ranging from neonates to oversized adults (120 kg) were modeled as uniform cylinders of water. Monte Carlo dosimetry data were used to obtain average doses in the directly irradiated region. Dosimetry data were used to compute the total energy imparted, which was converted into the corresponding effective dose using patient-size-dependent effective-dose-per-unit-energy imparted coefficients. Representative patient doses were obtained for scanning protocols that take into account the size of the patient being scanned by typical MDCT scanners.. Relative to CT scanners from the early 1990s, present-day MDCT scanners result in doses that are 1.5 and 1.7 higher per unit mAs in head and body phantoms, respectively. Organ absorbed doses in head CT scans increase from 30 mGy in newborns to 40 mGy in adults. Patients weighing less than 20 kg receive body organ absorbed doses of 7 mGy, which is a factor of 2 less than for normal-sized (70-kg) adults. Adult head CT effective doses

are 0.9 mSv, four times less than those for the neonate. Effective doses for neonates undergoing body CT are 2.5 mSv, whereas those for normal-sized adults are 3.5 mSv. Representative organ absorbed doses in CT are substantially lower than threshold doses for the induction of deterministic effects, and effective doses are comparable to annual doses from natural background radiation.

Jolanta Hansen & Anne Grethe Jurik in their study (Survival and radiation risk in patients obtaining more than six CT examinations during one year) observed 300 patients with more than six CT examinations during one year.They comprised 8% of the patients and accounted for 27% of all examinations. These patients needed further analysis.The 300 patients were analyzed concerning age, type of diseases indicating multiple CTs and the CT protocols used. The effective dose and risk of low dose radiation was estimated and survival of the patients after 1.5 year was analyzed. A total of 289 patients had malignancies, the most frequent being lung cancer, bladder cancer and colon cancer. A total of 4.3% of the patients with malignancies were 54 year old, 13.3% were 41_50 years old and 62.7% 5170 years old. The highest average number of CT examinations was observed in patients with sarcomas (11.2 examinations per patient). Eleven patients (aged 15_77 years) had traumatic lesions. Their number of examinations varied from 7 to 20. The total radiation dose for all 300 patients was 21.42 Sv, which may imply induction of a fatal cancer in one of the patients. However, only 102 patients survived their disease. A total of 198 patients had serious disease and were not alive 1.5 years after the examinations. The multiple CT examinations were necessary to monitor their treatment. For the surviving 102 patients the use of CT contributed to an optimal therapy, but the examinations implied a risk for radiation induced malignancies.

Sawsan Abdelmoneim Suliman 2011,(Measurement of adult and pediatric Patient doses during head CT scan) the aim of this research was to study the trend of CT dose from brain

examinations in Khartoum State, and its relationship to patient weight. The result of the research could be used to establish a Diagnostic Reference Level (DRL) to assist in optimizing radiation dose for CT brain examination in Sudan. The use of NRPB software dose calculator for this study has also been used by other researchers therefore the results from this study are comparable to related previous studies. Finally, an evaluation in the relationship between image quality, exposure factor selection and dose is also useful for professional benchmarking in maintaining lower dose level.

Huda .etal (2008) in (Comparison of head and body organ doses in CT) compare head and body organ doses received by adult patients undergoing whole body scans operated using the same technique factors. Dosimetry data were obtained for six CT scanners (16 and 64 slice) from four vendors. Organ doses were obtained using the Impact CT dose software package for an adult male, together with the corresponding head and body CTDIw. The data provide a link between the CTDI doses generated on most commercial scanners for each clinical CT examination and doses to organs and tissues within the directly irradiated region of an adult patient. The average numerical ratio of the brain dose to the head phantom CTDIw is 0.84 ± 0.05, the average ratio of the lung dose and liver dose to the body phantom CTDIw is 1.65 ± 0.05 and 1.48 ± 0.05, respectively. When scanned under identical conditions, lung doses are similar to brain doses, and liver doses are only -10% lower. By comparison, the average body to head CTDIw ratio was 0.49 ± 0.06, which erroneously implies that doses to organs in the head are twice those of doses to organs in the body at the same techniques. Two CT dosimetry phantom sizes are therefore not required, and our findings support the need to reassess the role, if any, of current cylindrical acrylic dosimetry phantoms.

Chapter three

Material and Method

3.1 Materials

3.1.1 Study sample

The data used in this study was collected from three hospitals in the Khartoum state: the data collected from December 2014 to January 2015.IT was Conducted on 30 pediatric during CT examinations

Hospital	Brain
Alnelein	11
Royal care	8
Royal scan	21
Total	30

3.1.2 Machine used

There were two machine used in this study , in three centers inside Khartoum state.

Hospital	Manufacture	Type of slice
Alnileen	Siemens	Dual slice
Royal care & Royal scan	Toshiba	64 slice

3.2 methods

The data were collected for patient during the routine CT imaging protocols in these departments. No modifications were made for dose optimization in this stage of the research. In general the imaging protocols were based on the following steps:

The technologist asked the patient before the exam to confirm that symptoms match the indications for the CT exam. Choose a specific exam protocol which addresses the clinical question while minimizing dose. Set up the patient carefully. Asymmetric positioning can result in decreased image quality and an increase in patient dose.

3.2.1 Techniques used

Data were collected using a sheet for all patients in order to maintain consistency of the information from display. A data collection sheet was designed to evaluate the patient doses and the radiation related factor. The collected data included patient sex, age, tube voltage and tube current–time product settings; section thickness. Clinical indications are important factor in patient dose during CT. In addition, we also recorded all scanning parameters, as well as the CT dose descriptors CT dose index volume (in milligrays) and dose-length product (in milligray-centimeters). All these factors that have a direct influence on radiation dose. The entire hospitals were passed successfully the extensive quality control tests performed by Sudan atomic energy commission and met the criteria of this study.

3.2.2 data analysis

We used excel Microsoft office to analysis the data .

Three CT machines were used to collect data during this study. These machines are installed in three radiological departments. In this study, CTDI was obtained from a measurement of dose, D(z), along the z-axis made in air using a special pencil-shaped ionization chamber connected to an electrometer. The calibration of the ion chamber is traceable to the standards of the German National Laboratory and was calibrated according to the International Electrical Commission standards. The overall accuracy of ionization chamber measurements was estimated to be ±5%. Measurements of CTDI in air ($CTDI_{100}$, air) were made as recommended by the EUR 16262EN based on each combination of typical scanning parameters obtained from the machine. The required organ doses for this study were

estimated using normalized CTDI values published by the Impact group, calculate $CTDI_{vol}$ and DLP .
Found the effective dose by the equation:

ED= DLP * coefficient K

K coefficient of pediatric brain CT show in table (3.2)

TABLE 2: Published DLP to E "*k*" Conversion Coefficients[a]

Anatomic Region	DLP to E "*k*" Conversion Coefficients [mSv / (mGy × cm)]				Phantom (cm)
	Jessen et al., [11] (1999)	EC [12] (2000)	EC Appendix B [10] (2004)	EC Appendix C [13] (2004) and NRPB-W67 [14] (2005)	
Head	0.0021	0.0023	0.0023	0.0021	16
Head and neck				0.0031	16
Neck	0.0048	0.0054		0.0059	32
Chest	0.014	0.017	0.018	0.014	32
Abdomen	0.012	0.015	0.017	0.015	32
Pelvis	0.019	0.019	0.017	0.015	32
Chest, abdomen, and pelvis				0.015	32

Note—EC = European Commission, NRPB = National Radiological Protection Board.
[a] $E = k \times DLP$, where DLP = dose–length product. The phantom size is specified for the volume CT dose index measurements on which DLP is based.

Table (3:2) k conversion coefficient adopted from (ICRP.2007)

Chapter Four
Results

Figure 4.1: correlation between ED of gender of patients

Figure 4.2: correlation between ED and slice thikness

Figure 4.3: correlation between ED and group of Age of patients

Figure 4.4: Explain between ED and two defferent machine

Figure (4.5) Explain effective dose with age and slice for each result

Chapter Five

Discussion, Conclusions and recommendation

5.1 Discussion

From figure (4,1) showed that the average effective dose was higher in female than male ,the reason came from that the mean age of female is higher (5.9year) than male (4.5year).From figure (4,2) showed that the Effective dose had inversely proportional to the slice thickness , in 5.5 mm slice have bigger effective dose then all other slices because here the result collected from machine with 64 slice. From figure (4,3) showed that the effective dose was directly proportional with age ,result of increased physical

configuration of the child and increase the proportion of bone to water in older age ,causing more effective dose to them. From figure (4,4) showed that the dose increase when we used the CT machine with 64 slice and decrease with dual slice ,because the designs of single slice and dual-slice scanners are similar in most aspects that affect radiation dose, but multi-slice scanning can potentially result in higher radiation risk to the patient due to increased capabilities allowing long scan lengths at high tube currents. From figure (4,5) showed that the age is the most factor affected into the effective dose and the minimum factor is slice thickness. The amount of radiation dose a patient receives from a CT scan depends upon two key factors, the design of the scanner and also on the way that the scanner is used. It is well known fact that CT imaging is the largest source of medical exposure now days. As the growth in CT utilization increased, particularly in pediatric patients, and as concern about the population dose from CT began to be expressed in the scientific literature and lay press, it became clear that the responsible use of CT required an adjustment of technique factors on the basis of patient size. In response to these concerns, the radiology community implemented CT dose management procedures that correspond to the principle of ALARA (as low as reasonably achievable). In this study, a total of 30 patients were examined in three Hospitals in Khartoum over 2 months and the average dose found 1.44473 mSv it’s accepted.

5. 2 Conclusions

In this study the radiation dose is higher in Royal scan hospital than the other hospitals while the radiation dose in alnelein the lowest. MSCT scanners espoused patients to a higher dose than dual scanners. Radiation dose from CT procedures varies from patient to patient. A particular radiation dose will depend on the size of the body part examined, the type of procedure, the weight of patient and the type of CT equipment and its operation. Typical values cited for radiation dose should be considered as estimates that cannot be precisely associated with any individual

patient, examination, or type of CT system. The main dose variations in the same CT unit could be attributed to the different techniques, which justify the important of use radiation dose optimization technique and technologists training. Dose reduction strategies must be well understood and properly used.

5.3 Recommendations:

Continuous education is highly recommended for the technologists working in CT machines. Dual and four CT scanners should be recommended for pediatric patients and young females in order to reduce patient doses.
Further studies should be done in order to optimize the radiation dose to establish national diagnostic reference level in Sudan.
An increase focusing on that there should be a medical physicist staff within each department of radioactivity in hospitals and diagnostics centre coached at high levels.

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Appendix :

NUM	GEN	AGE	AGE (month)	KV	slice (mm)	DLP (mGy*cm)	$CTDI_{VOL}$ mGy	ED (mSv)	Slice(mm)
1	M	2 y	24	110	5	371	24.79	0.8533	Dual
2	M	14 d	0.5	110	5	330	20.43	0.759	Dual
3	F	18 M	18	110	5	441	26.62	1.0143	Dual
4	F	6	72	110	5	546	35.11	1.2558	Dual
5	M	4	48	110	5	513	29.12	1.1799	Dual
6	M	3	36	110	8	434	34.5	0.9982	Dual
7	M	7 M	7	110	5	353	27.08	0.8119	Dual
8	M	11	11	110	5	354	25.93	0.8142	Dual

		M							
9	F	4 W	1	110	5	329	20.66	0.7567	dual
10	M	8	96	110	8	504	29.71	1.1592	dual
11	M	8	96	110	7	502	31.4	1.1546	dual
12	M	14	168	120	5.5	1149.3	62.3	2.64339	64
13	F	4	48	120	5.5	759.2	32.9	1.74616	64
14	F	1 M	1	120	5.5	560.3	31.8	1.28869	64
15	F	2	24	120	5.5	677.3	32.9	1.55779	64
16	M	8	96	120	5.5	808.01	38.65	1.858423	64
17	F	2 m	2	120	5.5	560	31.5	1.288	64
18	F	12	144	120	5.5	832	38.21	1.9136	64
19	M	1 m	1	120	5.5	449.2	25.1	1.03316	64
20	F	13	156	120	5.5	893.7	38.1	2.05551	64
21	F	12	144	120	5.5	857.2	38.7	1.97156	64
22	M	4	48	120	5.5	758.3	31.7	1.74409	64
23	M	11	132	120	5.5	806.35	38.4	1.854605	64
24	M	3	36	120	5.5	718.2	32.9	1.65186	64
25	F	8	96	120	5.5	732.1	36.9	1.68383	64
26	M	6	72	120	5.5	783.605	35.77	1.802292	64
27	F	14	168	120	5.5	1021.7	58.2	2.34991	64
28	F	10	120	120	5.5	790.51	38.2	1.818173	64
29	F	1	12	120	5.5	518.4	24	1.19232	65
30	M	7 d	0.5	120	5.5	491.9	25.1	1.13137	66