Chapter Tow

Literature Review

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 radiation 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 G.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-Hoong Ng, 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-Hoong Ng, 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-Hoong Ng, 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-Hoong Ng, 2003)

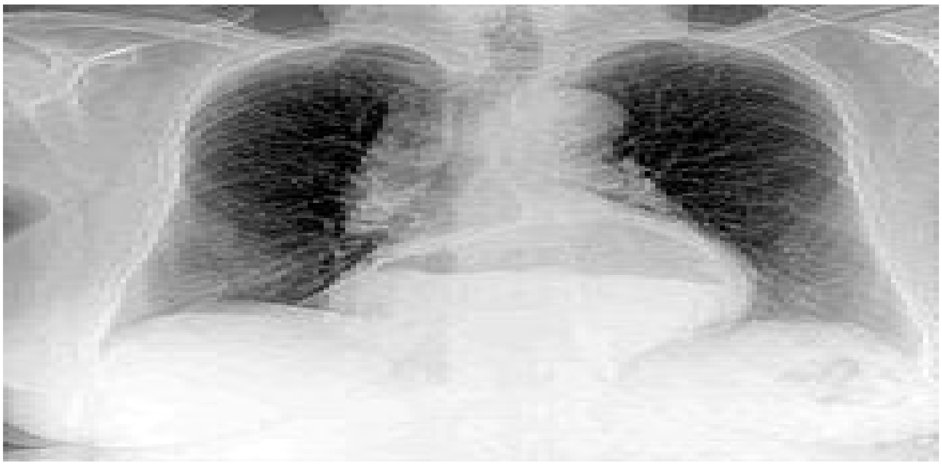
Henri Becquerel himself proved that beta rays are fast electrons, while Rutherford and Thomas Royds proved in 1909 that alpha particles are ionized helium. Rutherford and Edward Andrade proved in 1914 that gamma rays are like X-rays, but with shorter wavelengths. (Kwan-Hoong Ng, 2003)

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-Hoong Ng .etal, 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-Hoong Ng, 2003)

2.1.1.2 Uses of radiation 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 G,2006)



Fig(2.1) a chest radiograph of a female, demonstrating a hiatus hernia adopted from (james G.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 (2.2) an arm radiograph, demonstrating broken ulna and radius with implanted internal fixation. Adopted from (james G.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 G.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 G.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 G.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 G.2006)

Figure (2.3): brain image in CT scan Adopted from ((james G.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)

2.1.2 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 G.2006)

Typical particles include alpha particles, beta particles and neutrons, as well as mesons that constitute cosmic rays. (Stallcup et al,G,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 G.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. (Stallcup et al,G,2006)
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 et al,G,2006)
Exposure to ionizing radiation causes damage to living tissue, and can result in mutation, radiation sickness, cancer, and death.

2.1.2.1 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)

Table (2,1) :International System of Radiological Protection,

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		

2.1.2.2 Health effects of ionizing radiation

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:

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

2.1.2.2.2 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 not 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. (mottchildren.org)

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. (mottchildren.org)

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 G,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 G,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 Attwood,1999)

2.1.3 X- ray

X-radiation (composed of **X-rays**) is a form of electromagnetic radiation. Most X-rays have a wavelength ranging from 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). (Physics.nist.gov,2011)

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. (Physics.nist.gov,2011)

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. (Physics.nist.gov,2011)

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. Photoabsorption 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.

2.1.3.2.1 Photoelectric absorption

The probability of a photoelectric absorption per unit mass is approximately proportional to Z^3/E^3, 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 photoabsorption 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.

A photoabsorbed 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.

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 probability 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.

2.1.3.2.3 Rayleigh scattering

Rayleigh scattering is the dominant elastic scattering mechanism in the X-ray regime. The inelastic forward scattering is what gives rise to the refractive index, which for X-rays is only slightly below 1.

2.1.3.3 Production of x-rays

Whenever charged particles (electrons or ions) of sufficient energy hit a material, x-rays are produced. (Lee CI,2004)

Characteristic X-ray emission lines for some common anode materials.[15][16]					
Anode material	**Atomic number**	**Photon energy [keV]**		**Wavelength [nm]**	
		$K_{\alpha1}$	**$K_{\beta1}$**	**$K_{\alpha1}$**	**$K_{\beta1}$**
W	74	59.3	67.2	0.0209	0.0184
Mo	42	17.5	19.6	0.0709	0.0632
Cu	29	8.05	8.91	0.157	0.139
Ag	47	22.2	24.9	0.0559	0.0497
Ga	31	9.25	10.26	0.134	0.121
In	49	24.2	27.3	0.0512	0.455

2.1.3.4 Production by electrons

Spectrum of the X-rays emitted by an X-ray tube with a rhodium target, operated at 60 kV. The smooth, continuous curve is due to bremsstrahlung, and the spikes are characteristic K lines for rhodium atoms. (Lee CI,2004)

X-rays can be generated by an X-ray tube, a vacuum tube that uses a high voltage to accelerate the electrons released by a hot cathode to a high velocity. The high velocity electrons collide with a metal target, the anode, creating the X-rays. In medical X-ray tubes the target is usually tungsten or a more crack-resistant alloy of rhenium (5%) and tungsten (95%), but sometimes molybdenum for more specialized applications, such as when softer X-rays are needed as in mammography. In crystallography, a copper target is most common, with cobalt often being used when fluorescence from iron content in the sample might otherwise present a problem. (Lee CI, 2004)

The maximum energy of the produced X-ray photon is limited by the energy of the incident electron, which is equal to the voltage on the tube times the electron charge, so an 80 kV tube cannot create X-rays with an energy greater than 80 keV. When the electrons hit the target, X-rays are created by two different atomic processes:

2.1.3.4.1 Characteristic X-ray

Characteristic X-ray emission: If the electron has enough energy it can knock an orbital electron out of the inner electron shell of a metal atom, and as a result electrons from higher energy levels then fill up the vacancy and X-ray photons are emitted. This process produces an emission spectrum of X-rays at a few discrete frequencies, sometimes referred to as the spectral lines. The spectral lines generated depend on the target (anode) element used and thus are called characteristic lines. Usually these are transitions from upper shells into K shell (called K lines), into L shell (called L lines) and so on.

2.1.3.4.2 Bremsstrahlung

This is radiation given off by the electrons as they are scattered by the strong electric field near the high-Z (proton number) nuclei. These X-rays have a continuous spectrum. The intensity of the X-rays increases linearly with decreasing frequency, from zero at the energy of the incident electrons, the voltage on the X-ray tube.

So the resulting output of a tube consists of a continuous bremsstrahlung spectrum falling off to zero at the tube voltage, plus several spikes at the characteristic lines. The voltages used in diagnostic X-ray tubes range from roughly 20 to 150 kV and thus the highest energies of the X-ray photons range from roughly 20 to 150 keV.

Both of these X-ray production processes are inefficient, with a production efficiency of only about one percent, and hence, to produce a usable flux of X-rays, most of the electric power consumed by the tube is released as waste heat. The X-ray tube must be designed to dissipate this excess heat.

Short nanosecond bursts of X-rays peaking at 15-keV in energy may be reliably produced by peeling pressure-sensitive adhesive tape from its backing in a moderate vacuum. This is likely to be the result of recombination of electrical charges produced by triboelectric charging. The intensity of X-ray triboluminescence is sufficient for it to be used as a source for X-ray imaging.[19] Using sources considerably more advanced than sticky tape, at least one startup firm is exploiting tribocharging in the development of highly portable, ultra-miniaturized X-ray devices.

A specialized source of X-rays which is becoming widely used in research is synchrotron radiation, which is generated by particle accelerators. Its unique features are X-ray outputs many orders of magnitude greater than those of X-ray tubes, wide X-ray spectra, excellent collimation, and linear polarization.[21]

2.1.3.5 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. (M. 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. (M. 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)

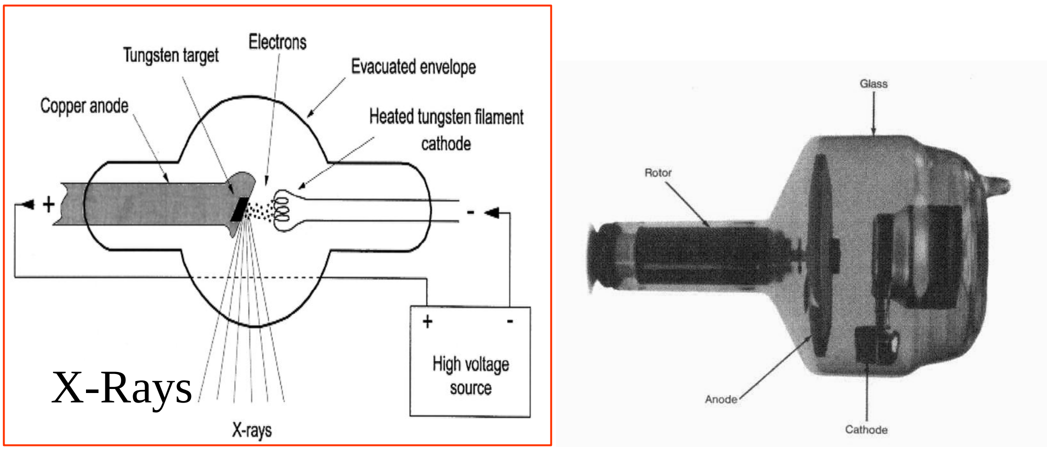


Figure (2.4) : X ray tube

2.1.3.6.1 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 M. Desern,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 M. Desern,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 M. Desern,2004)

2.1.3.6.2 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 M. Desern,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)

2.1.3.6.3 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)

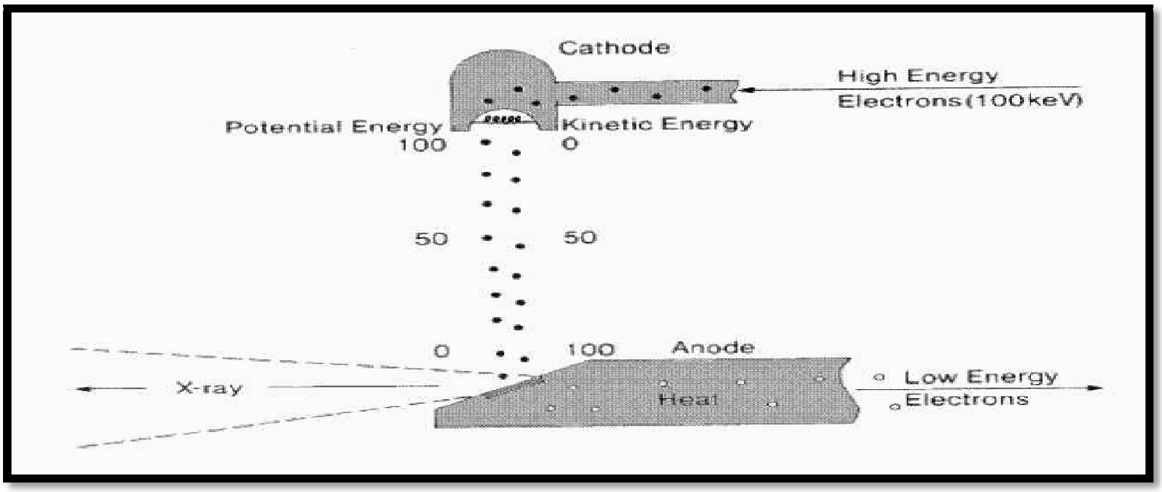


Figure (2.5) Energy Exchange within an X-Ray Tube adopted from (Thomas , 2004)

2.1.4 Quality assurance

Quality assurance program defined as an organized effort by the staff operating facility to inssure that the diagnostic image produced by the facility are of sufficiently high quality so that they consistently provide adequate diagnostic information at the lowest possible cost and whith the least possible exposure of the patient to radiation.

Quality assurance (QA) is a program used by management to maintain optimal diagnostic image quality with minimum hazard and distress to patients. The program includes periodic quality control tests, preventive maintenance procedures, administrative methods and training. It also includes continuous assessment of the efficacy of the imaging service and the means to initiate corrective action.

The primary goal of a radiology quality assurance program is to ensure the consistent provision of prompt and accurate diagnosis of patients. This goal will be adequately met by a QA program having the following three secondary objectives:

To maintain the quality of diagnostic images; To minimize the radiation exposure to patient and staff and To be cost effective.

2.1.4.1 Importance of quality assurance program

Diagnostic radiology's basic task is to provide high quality diagnostic image information about anatomic detail or ongoing physiological process within patient's body, where such information can not be provided using alternative diagnostic method which excludes the use of ionizing radiation. Ensuring adequate clinical diagnostic information together with the least possible exposure of the patient to radiation (As Low As Reasonably Achievable--ALARA principle) at the lowest costs is quality assurance (QA) program's main goal--optimization of radiological practice. Implementation of QA program does not mean just meeting legal requirements regarding quality control (QC) of X-ray and associated equipment and areas where they are installed but also implies optimum use of equipment, human and material resources inspected trough film rejection analysis and monitoring of patient doses received in particular radiological diagnostic examinations. In Sudan QA program in diagnostic radiology has not been yet systematically implemented in any medical institution. Except for legally bounded QC of X-ray equipment, other aspects of QA program are not conducted due to many reasons such as lack of educated staff and adequate measuring equipment.

2.1.4.2 Radiology Department QA Committee:

In a hospital x-ray facility, the radiology department should establish a formal Quality Assurance Committee (QAC). It will provide the structure required to plan and evaluate the program and to resolve quality assurance issues and problems. A

QAC will also provide management with recommendations for direction to those charged with the various aspects of the program.

The QAC should have an overall documented strategy with clearly defined work plans to achieve the goals and objectives of the radiology department. The committee should include representatives from all levels of the radiology staff, meet at regular intervals and report directly to the department's management. It should recommend program policies to management and outline program specifics such as the duties and responsibilities of the staff. In addition, it should formulate the standards for image quality and regularly review the effectiveness of the program. A formal QAC will promote the importance of and encourage participation in the department's QA program.

2.2 Prvious studies

In study by Marija Suri et al, (**Importance of Quality Assurance Program Implementation in Conventional Diagnostic Radiology**) concluded that

The Implementation of quality assurance is a complex and demanding process and has to be supported by legal Regulatory bodies of the country. Effective QA program in diagnostic radiology enables the achievement and maintenance of obtaining radiological information of appropriate quality for the purposes of medical diagnosis, minimizing doses received by patient and medical personnel compatible with the type of clinical examination undertaken and the optimization of costs by cutting losses of time and resources. Improvement of professional and public reputation of radiological department as a result of education and active work approach is also not negligible. Monitoring of patient doses is enables to optimize radiological practices, image quality analysis and consistent application of justification principles would significantly reduce the total collective dose of the population of exposure to medical radiation sources. QA implementation in radiological departments of Croatian medical institutions will be a long lasting process due to various problems presented earlier. Only good collaboration among legal authorities, medical institution's administration and all the staff of radiological department together with support of international agencies, such as IAEA, could enable us to proceed in the direction of improving the situation and produce useful results.