Palestine Polytechnic University

College of Engineering

The Graduation Project

Design of a Portable X-ray Leakage Detection System

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كلمة شكر

ما الفضل إلا لأهل العلم إنهم على الهدى لمن استهدى أدلاء
وقيمة المرء ما قد كان يحسنه والجاهلون لأهل العلم أعداء
فقم بعلم ولا تطلب به بدلا فالناس موتى وأهل العلم أحياء

الإمام الشافعي

نتقدم بالشكر الجزيل الى كافة أعضاء الهيئة التدريسية في كلية الهندسة عامةً و دائرة الهندسة الكهربائية خاصةً الذين أحرقوا زهرة حياتهم ليقدموا لنا ثمرة عملهم وينيروا دربنا الطويل ويشدوا أزرنا لنكون شعلة للأجيال القادمة ، وكما نشكر معلمينا الأفاضل القائمين على قسم هندسة الأجهزة الطبية ونتوجه إليهم بخالص الامتنان ونخص بالذكر :

المهندس: علي عمرو

الذي تفضل بالإشراف على هذا العمل ولم يبخل بالعلم والمعرفة وكان خير دليل على الإخلاص والعمل الدؤوب.

ونتقدم بالشكر الجزيل إلى من قدم لنا يد العون والمساعدة لإنجاح هذا العمل الذي نتمنى أن يحقق الفائدة المرجوة منه.

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Abstract

Due to the increasing of human medical needs and requirements for radiography images, several techniques and applications have been developed to facilitate dealing with an X-ray to monitor and detect the possible leakage of X-ray in order to overcome the possible negative side effects on human beings. The medical use of ionizing X-ray, whether for diagnosis or therapy, does not affect only the patient. But it may also affect the radiologists, radiographers and other workers or people in the radiographic section. The high level of ionizing X-ray has sufficient energy to change the structure of molecules, including deoxyribonucleic acid (DNA) within the cell of the human body, such changes would be expected to result in cancer and other harmful health effects. Therefore, the basic aim of protection in X-ray photographic rooms is to ensure that the doses received are as small as possible by install the X-ray equipment in adequately shielded rooms to Guarantee that the public in the vicinity do not exposed to X-ray emissions. Sometimes, the room shielding is not good enough. So, as bioengineering students, it is our responsibility to design a leak detection system which help to detect the X-ray leakage. This system uses a device that called Geiger Counter. This system can record the room leakage which is enhancing the protection and Occupational safety.

The Geiger Counter is one of the world's best-known X-ray detecting meters. It is used for measuring the ionization effect that produces in a Geiger-Müller (GM) tube. The GM tube is the sensing element which detects the surrounding X-ray. The detected X-ray ionize the ions inside the tube which connects with High voltage Power source (HV) to operate a GM tube. The output voltage from the tube is minimized by using the appropriate circuits with a suitable voltage that used to feed the low voltage electronics circuits. The low voltage signal is a square wave pulses such that each of these pulses represents the counts of the detected X-ray at specific times. The meter includes a controlling system which used to convert the analog square pulses at its input to digital readout which is represented as a digital number on the data display system. The controller used also to compare the detected value of X-ray with the acceptable and certified standard value by International Atomic Energy Agency (IAEA). The counter provides an alarm system which operates when it detects abnormal value of X-ray leakage.

The Detection system was implemented correctly by following all designing and construction steps and the supervisor instructions, then the system was tested at the radiology department at Al-Ahli Hospital. The X-ray detection readings were collected by the detection system designed for the project and another device used for a similar purpose by the National Center for Occupational Health and Safety for conventional and Computed Tomography (CT) machines. The collected data was represented in tables and curves to compare and calculate the error ratio between them.

الملخص

نتيجة لزيادة الاحتياجات والمتطلبات الطبية البشرية للصور الإشعاعية، تم تطوير العديد من التقنيات والتطبيقات التي تهدف إلى تسهيل التعامل مع الأشعة السينية لرصد ومرقبة التسربات المحتملة للأشعة السينية من غرف التصوير الإشعاعي للتغلب على الآثار الجانبية السلبية المحتملة التي تضر بالجنس البشري.

لا يؤثر الاستخدام الطبي للأشعة السينية المؤينة ، سواء للتشخيص أو العلاج، على المريض فقط. بل أنه قد يؤثر أيضًا على فنيي وأخصائيي الأشعة، وغيرهم من العاملين في قسم التصوير الإشعاعي.

إن المستوى المرتفع للأشعة السينية المؤينة يمتلك طاقة كافية لتغيير بنية جزيئات خلايا الإنسان ، بما في ذلك الحمض النووي داخل الخلية، ومن المتوقع أن تؤدي هذه التغييرات إلى السرطان وغيره من التأثيرات الصحية الضارة.

ولذلك ، فإن الهدف الأساسي للحماية في غرف التصوير بالأشعة السينية هو التأكد من أن الجرعات المتلقاة صغيرة قدر الإمكان بما يتطلب ذلك من تثبيت معدات الأشعة السينية في غرف محمية بشكل كافٍ ومناسب لضمان عدم تعرض الجمهور في المنطقة المجاورة لانبعاثات الأشعة السينية الضارة.

في بعض الأحيان، يكون الترصيص الخاص بغرف التصوير الإشعاعي غير مستوفٍ لكامل شروط الترصيص اللازمة. لذا، و كطلاب الهندسة الحيوية، كان من الضروري تصميم نظام للكشف عن التسرب الذي من شأنه المساعدة في الكشف عن التسرب خارج الغرفة نفسها. يستخدم هذا النظام جهازًا يسمى بعداد جايجر بحيث يمكن لهذا النظام تسجيل تسربات الغرف الأمر الذي يعزز الحماية والسلامة المهنية ويدعم موثوقية نظام الحماية ويقلل من الآثار السلبية الناتجة.

يعد عداد جايجر مولر(نسبة إلى العالم المكتشف) أحد أشهر أجهزة الكشف عن الأشعة السينية في العالم فهو يمثل عنصر الاستشعار الذي يكتشف الأشعة السينية المحيطة بقياس تأثير التأين الذي ينتج عن الأنبوب بحيث تقوم الأشعة السينية المكتشفة بتأين الغازات داخل الأنبوب الذي يرتبط بمصدر طاقة عالي الجهد الذي يزود الأنبوب بالجهد اللازم لتشغيله. يتم تقليل جهد الخرج من الأنبوب باستخدام مجموعة من الدوائر الخاصة التي تنتج جهد مناسب يستخدم لتغذية الدوائر الإلكترونية ذات الجهد الكهربائي المنخفض.

إشارة الجهد المنخفض تمثل مجموعة من النبضات الموجية المربعة التي تعبر عن عدد مرات تأين الأنبوب خلال وقت محدد. يتضمن المقياس نظام تحكم يستخدم لتحويل النبضات التناظرية المربعة عند مدخلها إلى قراءات رقمية يتم تمثيلها بشكل رقمي في نظام عرض البيانات. تستخدم وحدة التحكم أيضًا لمقارنة القيمة التي تم اكتشافها مع القيمة المرجعية المعتمدة من قبل الوكالة الدولية للطاقة الذرية (IAEA).

يوفر العداد نظام إنذار يعمل عندما يكتشف قيمة أعلى من القيمة المعتمدة للتسرب. تم تنفيذ نظام الكشف بشكل صحيح من خلال اتباع جميع خطوات التصميم والبناء وتعليمات المشرف، ومن ثم تم فحص واختبار النظام في القسم الأشعة التابع للمستشفى الأهلي وتم جمع قراءات كشف الأشعة السينية بواسطة نظام الكشف المصمم في المشروع وجهاز آخر يستخدم لغرض مشابه من المركز الوطني للصحة والسلامة المهنية لأجهزة التصوير الطبقي المحوري وجهاز الأشعة العادي تحديداً. تم تمثيل البيانات التي تم جمعها في الجداول والمنحنيات لمقارنة وحساب نسبة الخطأ بينهما.

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Abbreviations	Full Word
DNA	**Deoxyribonucleic Acid**
Nal	**Sodium-Iodide**
Hz	**Hertz**
eV	**electron Volt**
KVp	**Kilo Volt Peak**
CT scan	**Computed Tomography**
GM	**Geiger-Müller**
HV	**High Voltage Power Source**
LV	**High Voltage Power Source**
CPS	**Count Per Second**
CPM	**Count Per Minute**
IAEA	**International Atomic Energy Agency**
uR/hr	**Micro Rad per hour**
ICRP	**International Commission Radiological Protection**
LED	**Light Emitting Diode**
LCD	**Liquid Crystal Display**
IC	**Integrated Circuit**
R	Roentgen
REM	Roentgen Equivalent Man
Gy	Gray
EMF	Electromotive force

Chapter One

Introduction

1.1 Project Overview

The frequent uses of the medical ionizing x-rays cause a different hazard on the all humans that work in the radiographic section in the hospital that included the people who is setting or walking at the outside of the room.

Therefore, the proposed project aims to support and contribute in developing an X-ray survey meter, which helps in detection an X-ray leakage from radiographic rooms.

A suitable and special kind of radiation sensor (GM Tube) will be used in order to determine the real value of an X-ray emission that leaks outside of the by comparing the final result of leaks with the standard range of leaking by using an appropriate programming system to announce the existence of a problem discovered in the room shielding that allow to maintain this problem before be larger and causes a harmful effect.

1.2 The Project Objectives

The main objective of the project is to:

- Design and construct a portable X-ray radiation meter that detects the high emission of X-ray.
- Compare the results of detection readings with the standard rate of leakage and other X-ray detection devices.

1.3 The Project Importance

The importance of this project is to:

- Keep the patients, doctors and nurses outside the radiography room safe from the radiation.
- Check the performance and quality of bullets walls shielding of the room without any leakage of radiation.

1.4 Literature Review

The concern over the biological effect of ionizing radiation began shortly after the discovery of X-rays in 1895. Over the years, numerous recommendations regarding occupational exposure limits have been developed by the International Commission on Radiological Protection (ICRP) and other radiation protection groups. In general, the guidelines established for radiation exposure have had two principle objectives; prevent acute exposure and to limit chronic exposure to acceptable levels. Current guidelines are based on the conservative assumption that there is no safe level of exposure. the smallest exposure has some probability of causing a stochastic effect, such as cancer. This assumption has led to the general philosophy of not only keeping exposures below recommended levels or regulation limits but also maintaining all exposure by discovered an instrument to meet the required purpose.

1.5 Economical Study

This section lists the overall cost of the project components that are considered in implementing this system.

The **Table 1.1** contains the main required hardware components of the project design and its prices.

Table 1.1: The Project Components Prices

No	Types	Price	Quantity
1	**Printed Circuit Board (PCB)**	40 $	1
2	**GM Tube**	20 $	1
3	**Atmega 328A Integrated circuit (IC)**	10 $	1
4	**LCD Display**	10 $	1
5	**Battery**	5 $	1
6	**Switches**	3 $	4
7	**Transistors**	2 $	3
8	**Capacitors**	2 $	15
9	**Resistors**	2 $	19
10	**Screw and Connectors**	2 $	(2,4)
11	**Diodes**	1.5 $	3
12	**Radial Inductor**	1.5 $	1
13	**Trimmer**	1.5 $	1
14	**LEDs**	0.5 $	2
The Total Price		**101 $**	

1.6 The Project Timeline

The **Table 1.3** and **Table 1.4** shows the activities that done in the project in both semesters and the time of each one.

Table 1.3: Activities Schedule of the First Semester

Weeks Activities	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Data collection	🟦	🟦	🟦	🟦												
Data analysis					🟦	🟦	🟦	🟦	🟦	🟦						
System design											🟦	🟦	🟦	🟦		
Documentation					🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦	🟦		
Presentation preparing															🟦	🟦

Table 1.4: Activities Schedule of the Second Semester

Weeks Activities	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Full Designing	🟦	🟦	🟦	🟦	🟦											
Purchasing components						🟦	🟦	🟦	🟦	🟦	🟦	🟦				
System Implementation													🟦	🟦		
System Analysis														🟦	🟦	
Documentation															🟦	🟦

Chapter Two

Anatomy and Functionality of the Skin

The skin is the largest organ in the body, it forms the interface between the human body and the environment. It represents about (12 – 16) % of the total body mass, it covers an area of about $1.2 - 2\ m^2$ in adults. [1] The skin tissue varies in thickness according to body location, it also differs between men and women, being Generally less thick in women.

This chapter illustrates with details the structure of the skin with its layers and their functions. Also, it shows the interaction between the skin and X-ray and the negative effects of the X-ray on the skin.

2.1 Skin Structure

The skin models are complicated by the fact that skin is irregularly shaped, inhomogeneous, multi-layered, has anisotropic physical properties. In spite of these, the skin is constructed from the three basic layers (epidermis, dermis and hypodermis), as shown in **Figure 2.1**. Also, it contains the different types of tissues like the collagen fibers that gives skin tensile strength, elastic fibers give the skin its elastic properties, mast cells as an anticoagulant, reticular fibers, oil producing glands, hair follicles and sweat glands.

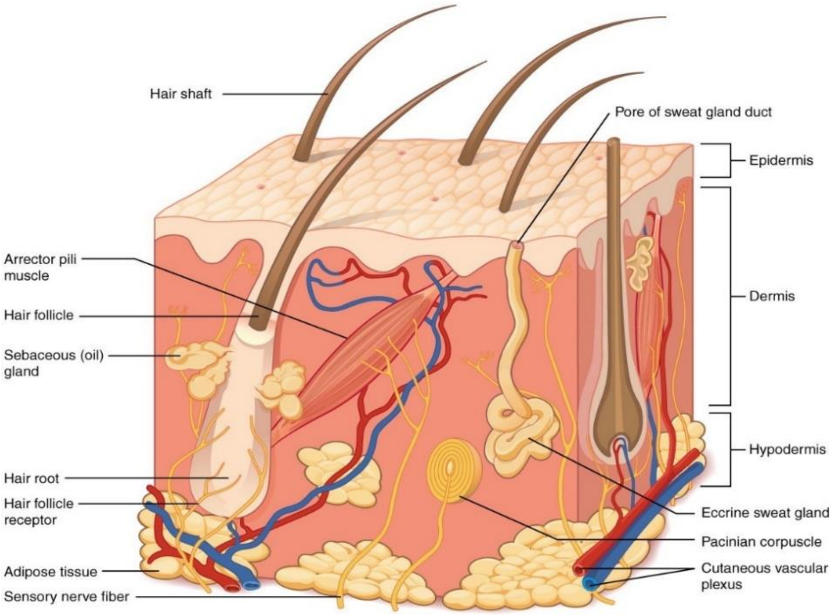


Figure 2.1: The Skin Ingredients [2]

2.2.1 Epidermis

The epidermis is the outer layer of the skin. it is made from epithelial tissue and does not have a blood supply of its own. The thickness of the epidermis varies in different types of skin. It is the thinnest on the eyelids at 0.05 mm and the thickest on the palms and soles at 1.5 mm.

The epidermis involved of five major layers, Stratum Basale, Stratum Spinosum, Stratum Granulosum, Stratum Lucidum and Stratum Corneum, as shown in **Figure 2.2.**

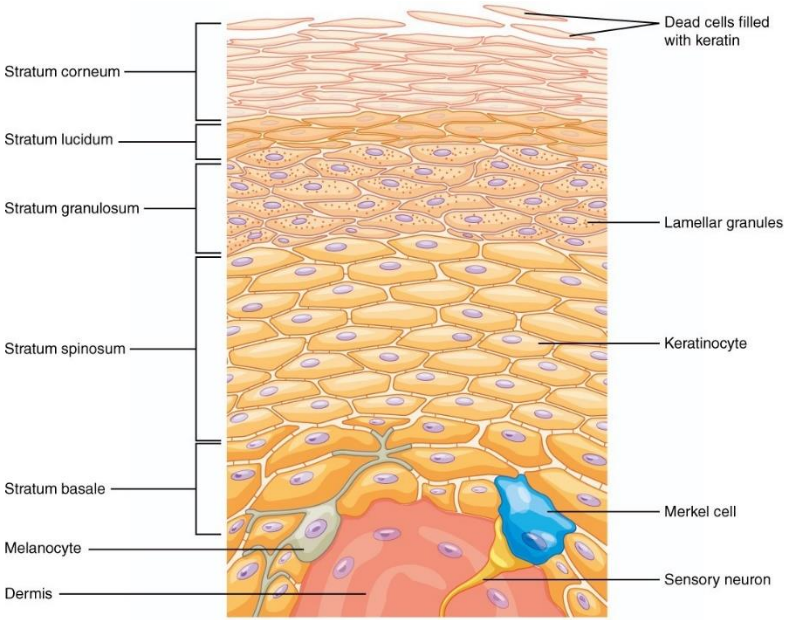


Figure 2.2: The Epidermis Layers [3]

2.2.1.1 The Stratum Basale

It is the bottom layer of keratinocytes in the epidermis that is responsible for constantly renewing epidermal cells. It has a Markel cells that used as a sensory receptor for the sense of light touch. Also, it has the melanocytes that produce a dark brown pigment known as the melanin.

This layer contains just one row of undifferentiated columnar stem cells that divide very frequently. Half of the cells differentiate and move to the next layer to begin the maturation process. The other half stay in the basal layer and divide over and over again to replenish the basal layer, as shown in **Figure 2.3.**

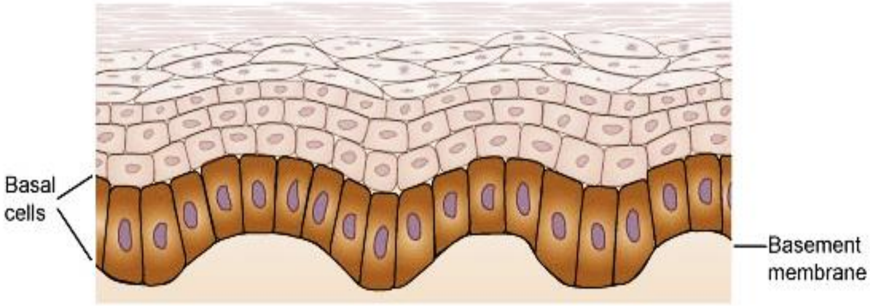


Figure 2.3: The Stratum Basale [4]

2.2.1.2 The Stratum Spinosum

The cells of this layer start to synthesize keratin because it contains Langerhan's cells, which are white blood cells that works as the immune response after They are made in the red bone marrow,

The stratum spinosum provides the strength to the epidermis layer and it changes from the columnar cells to be the polygonal cells, as shown in the **Figure 2.4.**

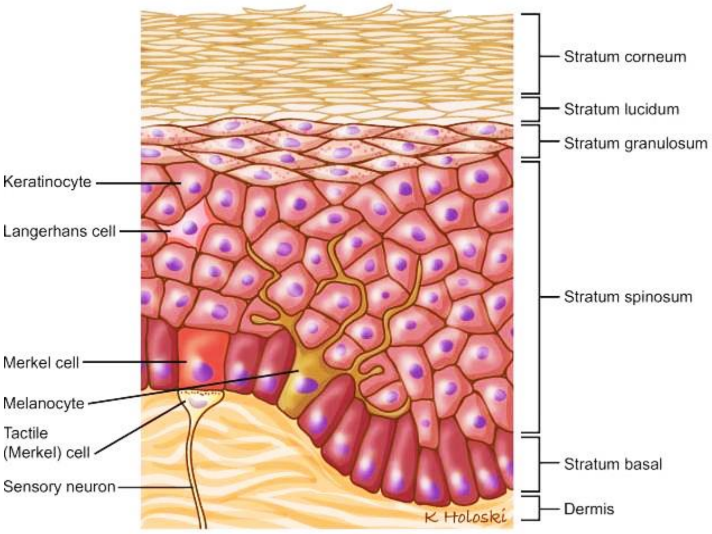


Figure 2.4: The Stratum Spinosum [5]

2.2.1.3 The Stratum Granulosum

The cells of this layer lost their nuclei and grouped as a dark clump of cytoplasmic material, this allow to have a grainy appearance, so this layer is called the stratum granulosum. There are a lot of activity in this layer as produce the keratin proteins and lipids, as shown in **Figure 2.5.**

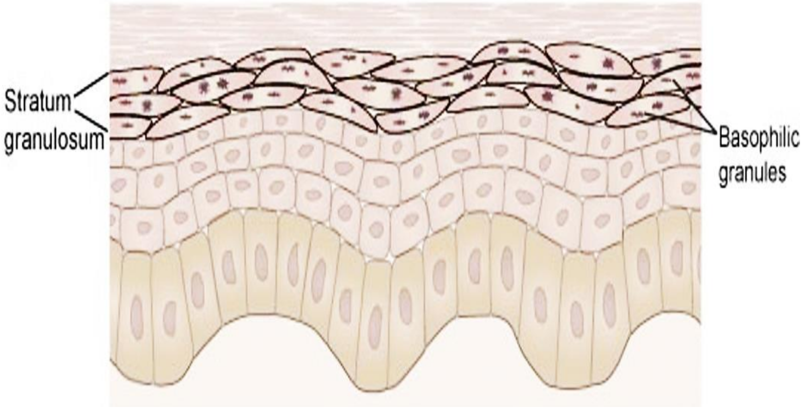


Figure 2.5: The Stratum Granulosum [6]

2.2.1.4 The Stratum Lucidum

It is a narrow and transparent layer that consists of a flat cell filled with keratin and cleared in the thickened areas of the skin, such as the soles of the feet and palms of the hands. It provides a protection from ultra-violet radiation and helps to reduce the friction and shear forces between the Stratum Corneum and the Stratum Granulosum, as shown in **Figure 2.6.**

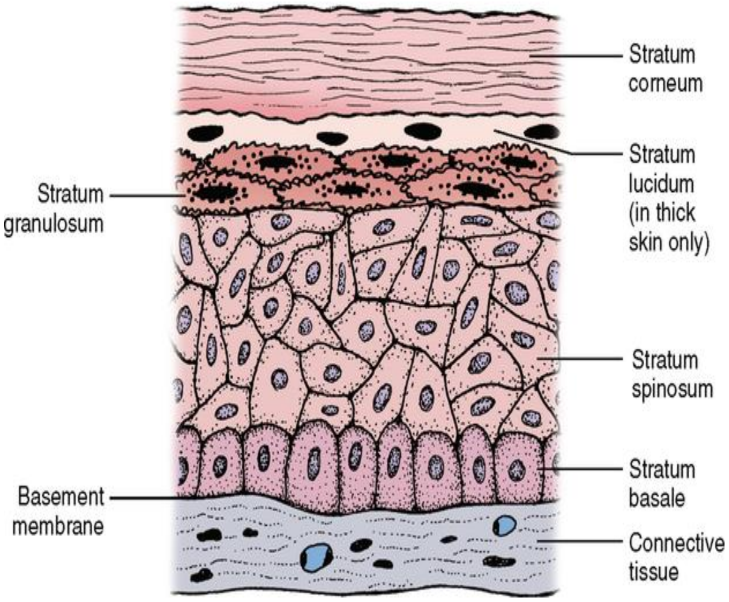


Figure 2.6: The Stratum Lucidum [7]

2.2.1.5 The Stratum Lucidum

This layer is Composed of many sublayers of flat, dead keratinocytes called corneocytes that are continuously shed and replaced by cells from deeper strata in a process that is called desquamation through 28 to 30 days in young adults, while it takes 45 to 50 days in elderly adults, as shown in **Figure 2.7.**

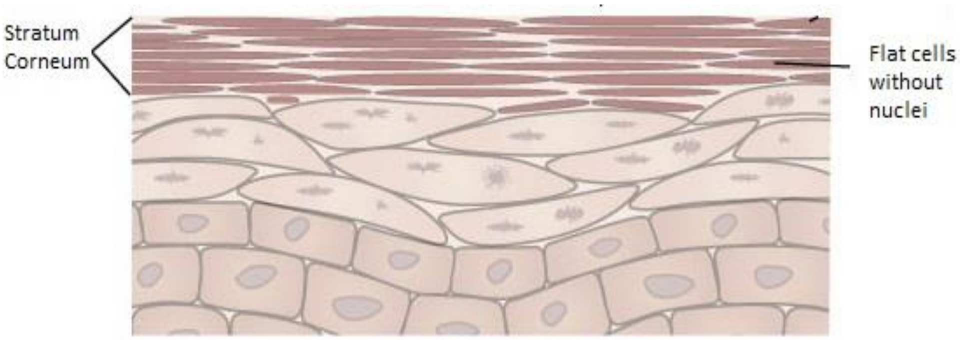


Figure 2.7: The Stratum Corneum [8]

2.2.2 Dermis

The dermis layer is often referred as the true skin as it forms the bulk of the skin. It also varies in the thickness depending on the location of the skin. for instance, it forms 0.3 mm on the eyelid and 3.0 mm on the back.

The dermis is made up of connective tissue and is divided into two layers; Papillary Layer which lies directly under the epidermis, it is quite thin and has cone like projections called papillae. It provides nutrients and oxygen to the germinating layer of the epidermis, and Reticular Layer which lies below the papillary layer and is the main section of the dermis, as shown in the **Figure 2.8.**

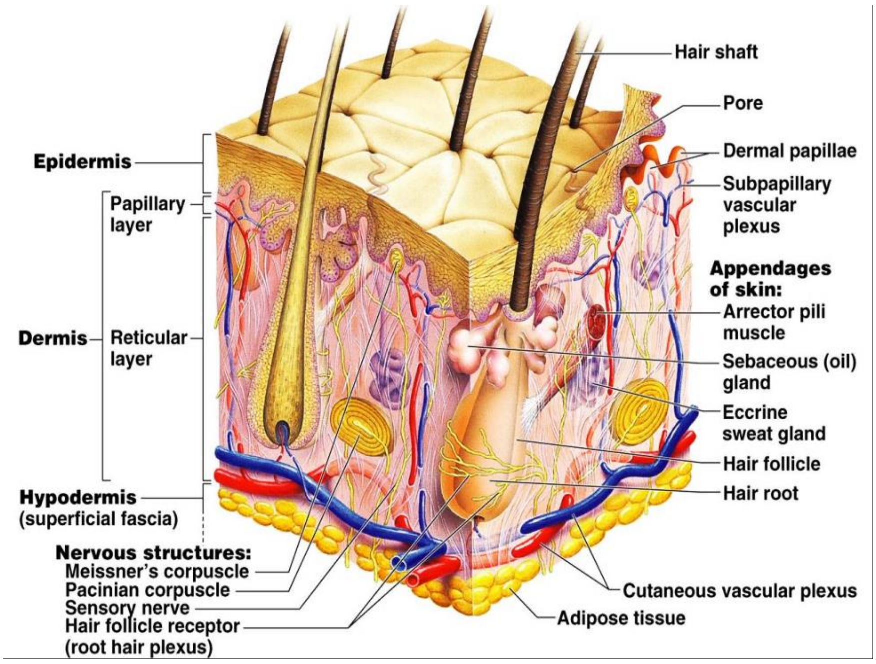


Figure 2.8: The Dermis Layer [9]

2.2.3 Hypodermis

It is also called the subcutaneous tissue. The hypodermis is the layer of fat and connective tissue that houses larger blood vessels and nerves, as shown in the **Figure 2.9.** This layer plays an important role in the body, it connects the dermis with the muscles and bones, Control the body temperature and store the fat.

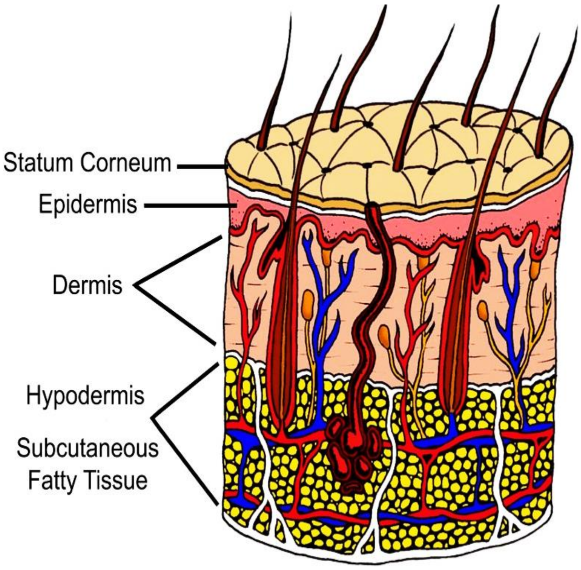


Figure 2.9: The Hypodermis Layer [10]

2.3 Skin Functions

The general skin functions are summarized in protection from water loss, injury and microorganism growth, it excretes the Uric acid in the kidney, regulate the body temperature, it detects the light touch and the factors that can damage tissues and its synthesis the Vitamin d under sunlight.

2.4 The Interaction Between the Skin and X-Ray Radiation

The water forms about (70 - 80) % of human body weight the water molecule involves two hydrogen atoms and one oxygen atom. [11] When the water molecule is struck by X-ray, it picks up the energy lost by the X-ray in the collision. If the X-rays energy that penetrated into the human body is sufficient to overcome the bonding force in the molecule, the electrons will strip from orbit by break or modify chemical bonds within critical biological molecules that make up the cells, this process can cause cell injury or cell death. The molecule will break up as shown in the following equation:

$$\mathbf{H_2O \longrightarrow H^+ + OH^- \quad .\,.\,.\,.\ (2.1)}$$

These two ions produced from the water molecule are known as “free radicals”. They are very reactive and can cause harmful chemical changes in the organic molecules in the cells of the tissue.

The most important organic molecule in the tissue that may be affected from ionizing radiation is deoxyribonucleic acid or DNA. The DNA molecule carries the blueprints for life. Most of the chemical changes in the structure of the DNA, whether these occur spontaneously or because of exposure to radiation or other agents, are actively repaired by living cells. A small fraction of the DNA damage is not completely repaired so, it results in permanent changes in the DNA structure that appears as a harmful biological effect, such as an inherited genetic defect or as a cancer. This means that repair errors are more than for the damage. At low x-ray doses, the fraction of changes with harmful biological effects is less than 0.01% of the total chemical changes produced in the DNA [12]. The **Figure 2.10** shows the X-ray penetration stages of the body tissues.

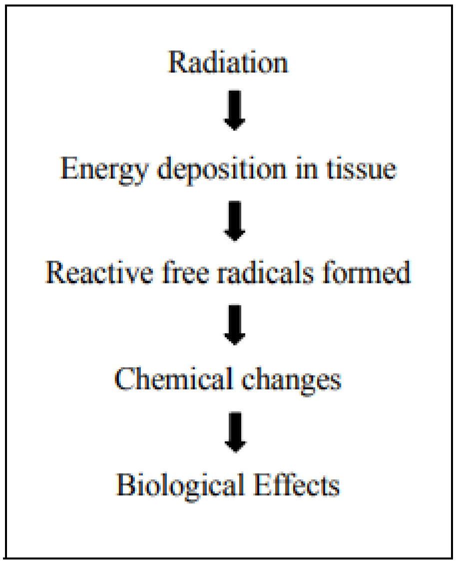


Figure 2.10: The X-ray Penetration Stages of the Body Tissues [13]

2.4.1 Factors that Determine Biological Effects

There are a Several factors contribute to the biological effects of x-ray exposure, such as, dose rate, total dose received, energy of the radiation, area of the body exposed, individual sensitivity and cell sensitivity

Depending on the period of time over which it is received, a dose is commonly categorized as acute or chronic. An acute dose is received in a short period (seconds to days); a chronic dose is received over a long period (months to years). For the same total dose, an acute dose is more damaging than a chronic dose because the cell does not have adequate time to repair all the damage between “hits,” thus resulting in residual enduring cell damage.

When the total amount of radiation received increase, the effects observed will increase. The effects of an acute dose of more than 100 rems are easily observed. [14] However, the signs and symptoms of an acute dose of amounts less than 10 to 25 rems are not easily observed.

The energy of x-rays ranges typically lies between (40 -100) KeV. [15] The higher energy of the x-ray will increase the penetration into body tissue that increase the probability of damage to internal organs, bone, or bone marrow, the site of blood-forming tissue. Lower energy x-rays are absorbed in the first few millimeters of tissue and can cause damage to the skin surface without any effect on the internal organs of the body.

The larger the area exposed, the more difficult it is for the body to repair the damage. so, the radiation dose to the whole body, which contains the vital organs and blood-forming tissue, is much more damaging than a dose delivered only to a hand.

Some individuals are more sensitive to radiation that affects on how the body responds to radiation dose.

Some cells are more sensitive to radiation. The non-specialized cells, such as sperm and hair follicle are the most radiosensitive. the mature cells or cells that are less-actively dividing, such as bone, muscle, or brain cells, are more radio resistant.

2.4.2 The Negative Biological Effects of the X-Ray on the Skin.

It is possible to list a general classification of the kind of changes that ionization radiation can produce in skin. It is useful to categorize these effects into three areas; Reversible Changes, Conditional Reversible Changes and Irreversible Changes.

The most common and earliest reversible change is the production of reddening of the skin or erythema. If the dose and energy is low enough that most of the radiation is absorbed in the superficial layers of the skin, the reddening occurs, then disappears without any future effects.

Another reversible change is the loss of hair or epilation. It is possible to give a dose of radiation that will stop cell division in the epithelial cells so that hair ceases to grow temporarily and falls out. With a low dosage, the hair will begin to grow after a period of time, with no apparent permanent ill effects. [16] A third system that shows reversible effects are the sebaceous glands (oil-producing glands in the skin) which are temporarily affected to produce less sebum (oil secretion of these glands in the skin).

Pigmentation of the skin is not a totally reversible change. If a large area of skin is irradiated, erythema and pigmentation will occur with the pigmentation eventually fading. It has been shown that the resulting skin is not normal and has some "memory of the injury." Future doses of the same area do not produce the same skin response.

The **Table 2.1** summarized the negative biological effects of the X-ray on the skin which when it absorbed the proper energy will destruct the hair or sweat glands, or whole skin, with a resulting scar. The irreversible changes are categorized in radiation dermatitis, chronic radiation dermatitis and radiation cancer.

Table 2.1: The Negative Effects of The X-Ray on The Skin.

Dose Energy	The Negative Effect
Low	Absorbed in the skin surface layers
Moderate (Short Term)	Reddening of the skin and
Moderate (Long Term)	The hair ceases to grow temporarily and falls out.
High (Short Term)	Permanent destruction of either hair or sweat glands
High (Long Term)	Chronic radiation dermatitis and radiation cancer

As a result of the pervious table that illustrates the Negative effects of the higher dosage of the X-ray on the skin, the **Table 2.2** shows the dosage limits for the workers at the hospitals and radiology centers that should not excess these values in millisievert (mSv) per year.

The **Table 2.2** The Dosage Limits for The Workers of X-Ray Per Year [17]

Application	The Dosage limits for workers in millisievert (mSv) per year
Pregnant women	10
Effective dose (full-body dose)	50
The equivalent dose of the lens of the eyes	150
Equivalent dose of reproductive organs	200
The equivalent dose for (breast, lungs, glands)	250
The equivalent dose (upper and lower limbs, skin, bones)	500

Chapter Three

Fundamentals of The X-ray Physics

An X-ray is a common imaging Diagnostic test to detect the abnormalities within the body for a several decades. It is a non-invasive and painless way that can help a doctor to view the inside of the body like, broken bones, tumors, dental decay, and the presence of strange bodies.

This chapter illustrates an X-ray definition and its features, the X-ray machine design and the construction of X-ray tubes, then look at the X-ray production process, recognize radiographic room shielding design.

3.1 The History of the X-ray

In 1870, a British engineer William Crookes invented Crookes Tube. It’s a sealed glass cylinder, empty from the air and it contained two electrodes: a negative Cathode and a positive Anode. The Tube displayed an interesting phenomenon: when a very high voltage difference was set between the anode and the cathode, a weird glow would appear inside the tube, and a greenish–yellowish spot of light appeared on the glass wall behind the anode, as shown in the **Figure 3.1**.

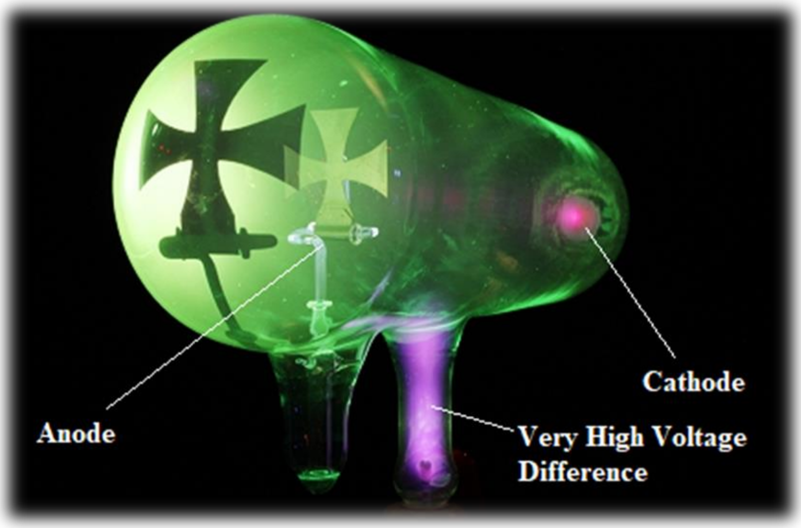


Figure 3.1: Crooke's Tube [18]

In November, 1895, after six weeks of assiduous work, Wilhelm Roentgen was Interested in the mysterious Crookes Tube. he tested its properties and noted that solid objects placed in the beam between the Crooke's tube and the fluorescent screen serving as an image receptor attenuated the beam, depending upon their density and structure.

After turning off the lights in the room, Roentgen noticed a fluorescent effect on a small paper screen painted with barium platinocyanide. This fluorescence appeared when the paper was fewer than two meters away from the tube, even when the paper was obscured by black cardboard. Roentgen concluded that the tube was producing invisible radiation of an unknown nature, which he called an X-ray, and that this was causing the fluorescence he had observed.

Roentgen also discovered that the ray could pass through the tissue of humans, but not bones. in late 1895, the Roentgen's first medical experiment was a film of the hand of his wife, as shown in the **Figure 3.2.**

Figure 3.2: The Roentgen's First Medical Film [19]

As a result, the X-rays is a form of electromagnetic radiation that travel in a straight line at the speed of light. it cannot be deflected by electric or magnetic fields; This mean that they are uncharged or neutral particles. X-rays can produce fluorescence and photoelectric emission and affects on photographic film, but it vibrates at shorter wavelengths and higher frequencies that enables them to penetrate objects, such as human tissues.

3.2 X-ray Specifications and Machine Categories

The X-rays have a wavelength ranging from (0.01 to 10) nanometers (nm), corresponding to frequencies in the range (3×10^{16} to 3×10^{19}) Hz and energies in the range between (100 to 100k) eV [20]. It can penetrate the walls and bodies, but it cannot penetrate the earth's atmosphere, as shown in the **Figure 3.3.**

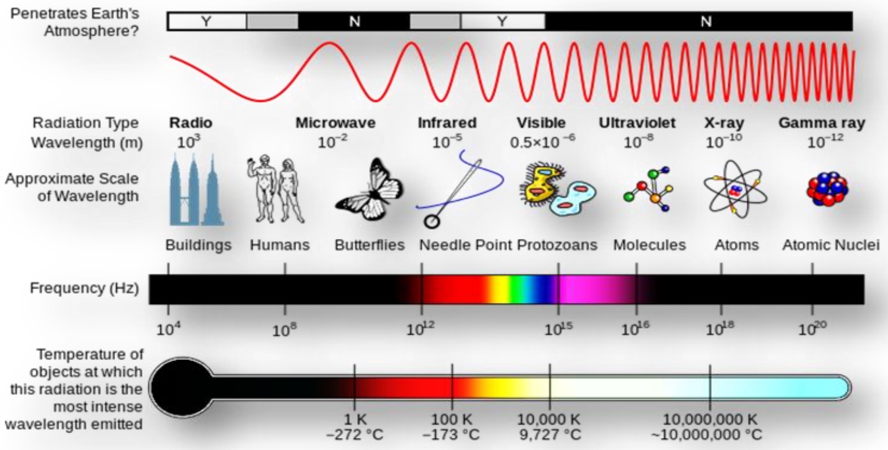


Figure 3.3: The Electromagnetic Spectrum [21]

The modern medical X-ray machines have been grouped into two categories, the soft X-ray that has a low frequency and use to photograph bones and internal organs but, it causes a little damage for the tissues. And the hard X-ray that has very high frequency rays that use to destroy the molecules within specific cells, as a treatment for cancer, CT scanning and other applications, as shown in the **Figure 3.4**.

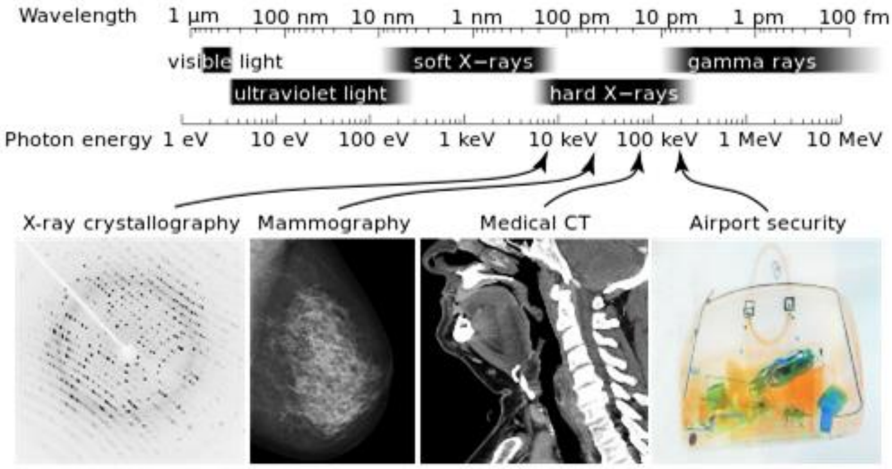


Figure 3.4: The Hard X-ray Medical Applications [22]

An X-ray machine is a device that used in medical field with the ability to penetrate the skin tissues to diagnosis the problems inside the body as the broken bones. X-ray machine includes a lot of types for many functions like, conventional X-ray, fluoroscopy X-ray, dental or panorama X-ray, mammography X-ray, mobile X-ray, C-arm X-ray and CT scan.

The conventional X-ray which shown in the **Figure 3.5.** is used for screening of the different regions at the body and the spine or chest by used the Bucky stand part [23] (invented by German radiologist Gustav Bucky).

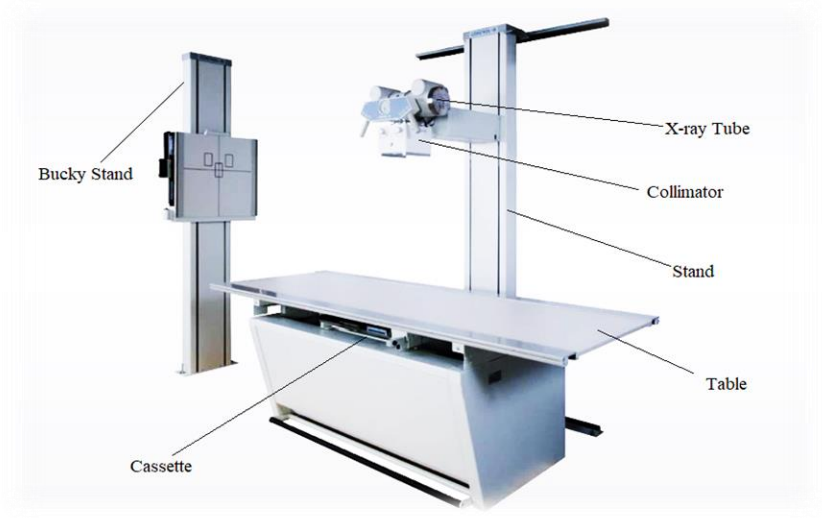


Figure 3.5: Conventional X-ray [24]

The fluoroscopy x-ray, as shown in the **Figure 3.6.** uses X-rays and a fluorescent screen to study moving or real-time structures in the body, such as viewing the heart beating, digestive processes, blood flow and cardiac angioplasty.

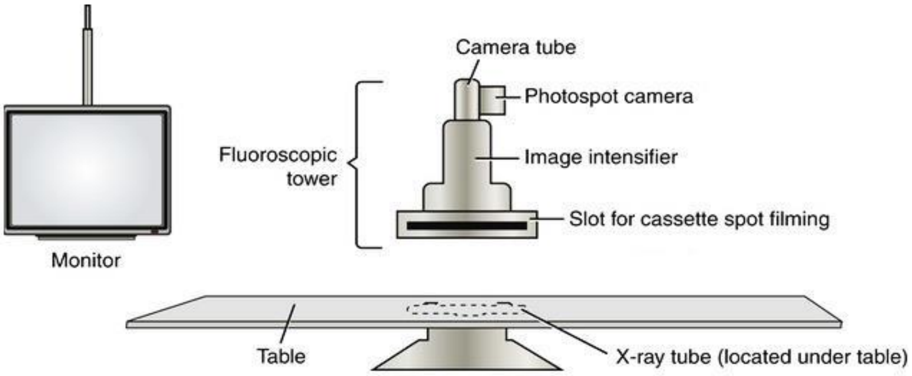


Figure 3.6: Fluoroscopy X-ray [25]

The panorama or dental x-rays machine that shown in the **Figure 3.7** gives a high level of detail about bones, teeth, and supporting tissues of the mouth. It enables the dentists to look at the tooth roots, the status of the developing tooth, and health of the bony areas.

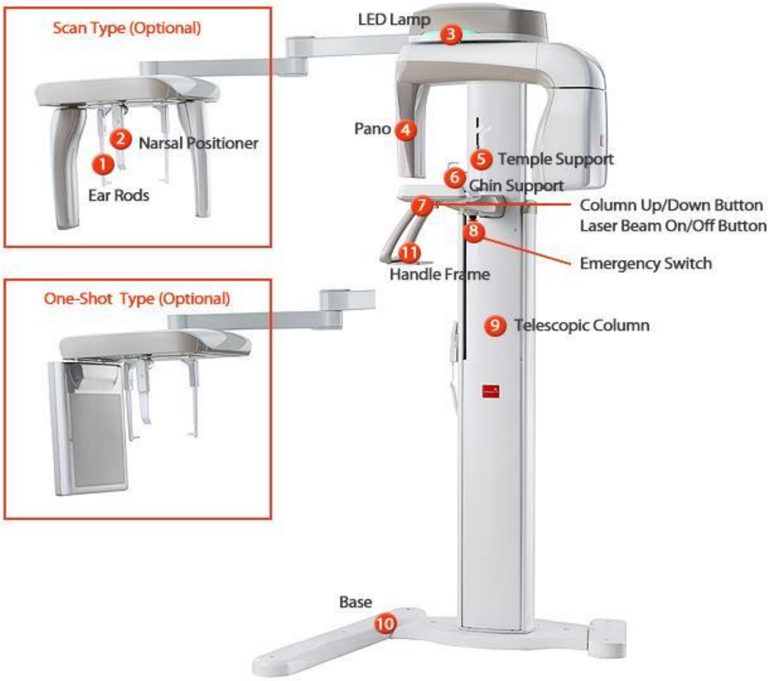


Figure 3.7: Dental or Panorama X-ray [26]

Mammography used to detect breast cancer, as shown in the **Figure 3.8.**

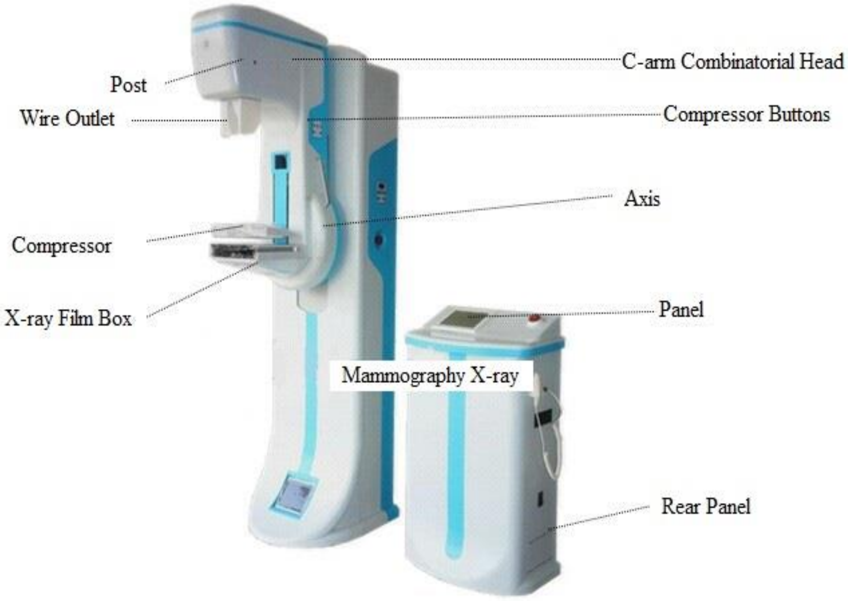


Figure 3.8: Mammography X-ray [27]

The mobile x-ray, as shown in the **Figure 3.9**. is designed to be just as a solution specifically for use when it is not safe or practical to move a patient from his or her bed to the radiology department.

Figure 3.9: Mobile X-ray [28]

C-arm X-ray used for a variety of diagnostic imaging and invasive surgical like visualizing kidney drainage, abdominal and thoracic aortic aneurysm repair, percutaneous valve replacements, cardiac surgery, gastroenterology, orthopedics, pain management and neurology procedures, orthopedic and podiatric imaging, as shown in the **Figure 3.10**.

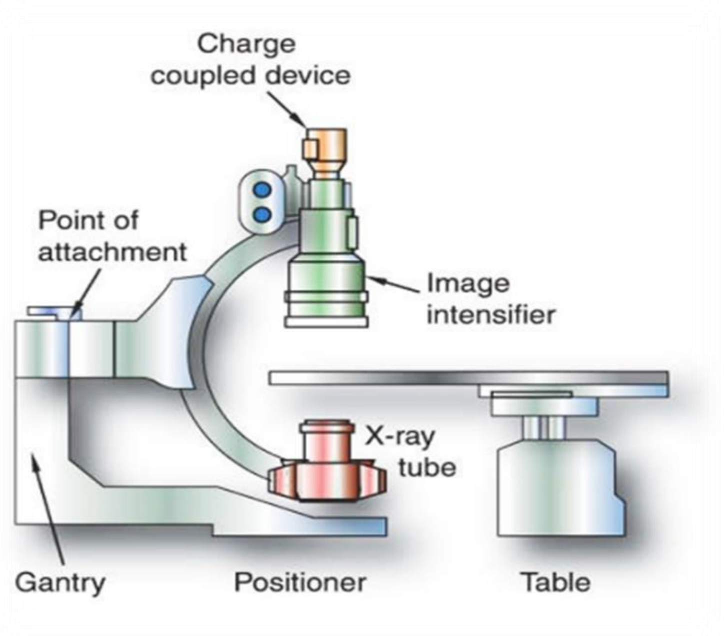


Figure 3.10: C- arm X-ray [29]

The standard computed tomography or CT scan test aids in obtaining detailed images of areas inside the body, typically for the diagnosis of circulatory system such as blood vessel aneurysms and blood clots, as shown in the **Figure 3.11**.

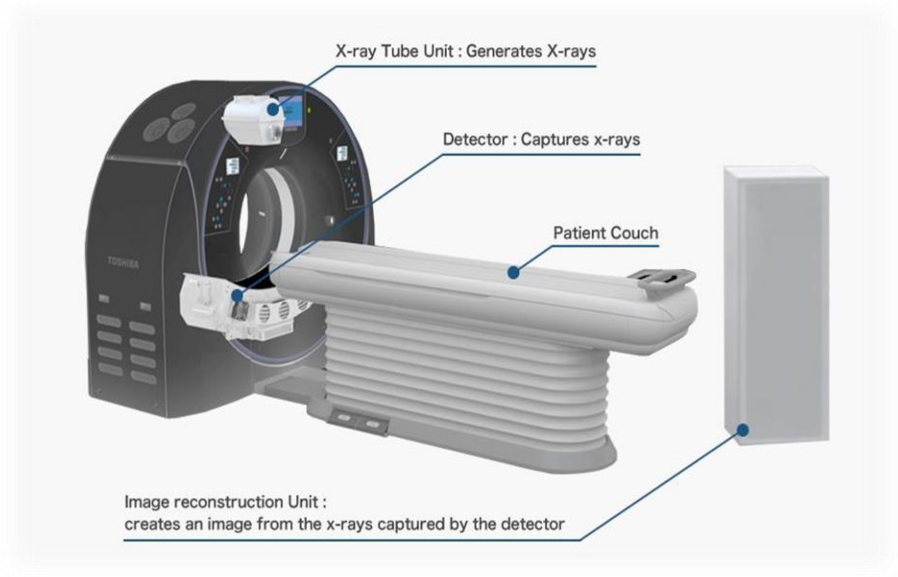


Figure 3.11: CT Scan [30]

3.3 X-ray Machine Components

X- ray machine has a lot of parts in its ingredients. But, The X-ray tube (also called as Coolidge tube) is the most important and expensive component of X-ray machine which is found in all types of X-ray machine and inaccessible since it is contained in a protective housing that made from Pyrex glass to withstand the tremendous heat. it consists of two primary parts the cathode and the anode, as shown in the **Figures 3.12**.

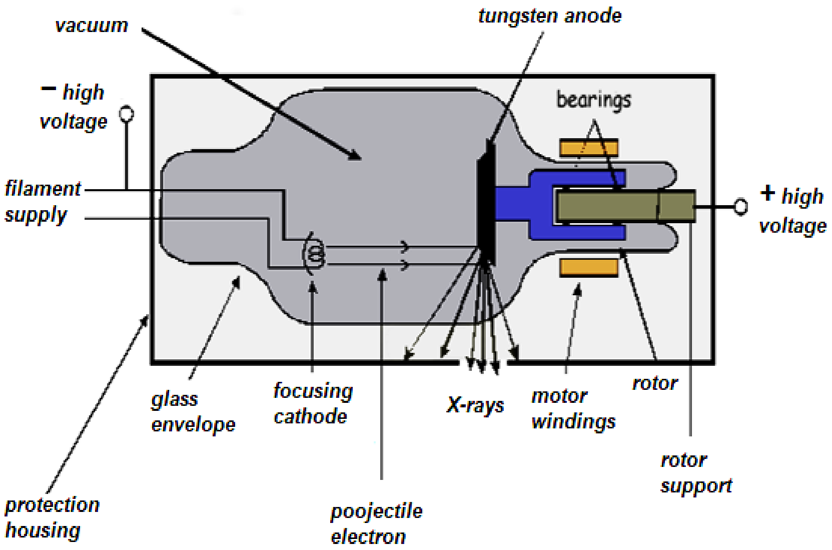


Figure 3.12: X-ray Tube Ingredients [31]

The cathode is a negative charged electrode that used to repel electrons and condense electron beam to small area on focal track. It consists of two primary parts; the focusing cup which is a metallic shroud (made usually from nickel) containing the two filaments and the filament which is a small coil of thoriated tungsten, as shown in the **Figure 3.13**.

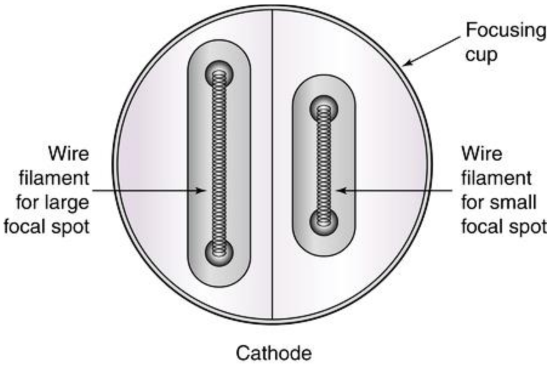


Figure 3.13: The Cathode Ingredients [32]

The anode is a positive charged electrode that usually made of tungsten. It represents the area target that was struck by the electron stream and depends on the voltage, the current, and the length of time of the struck. It consists of two primary parts; stationary or fixed anode which is limited to use in the study of small anatomic structures such as the teeth and rotating anode which is used in all applications in radiography since provides a greater target area of exposure and heat dissipation, as shown in the **Figure 3.14**.

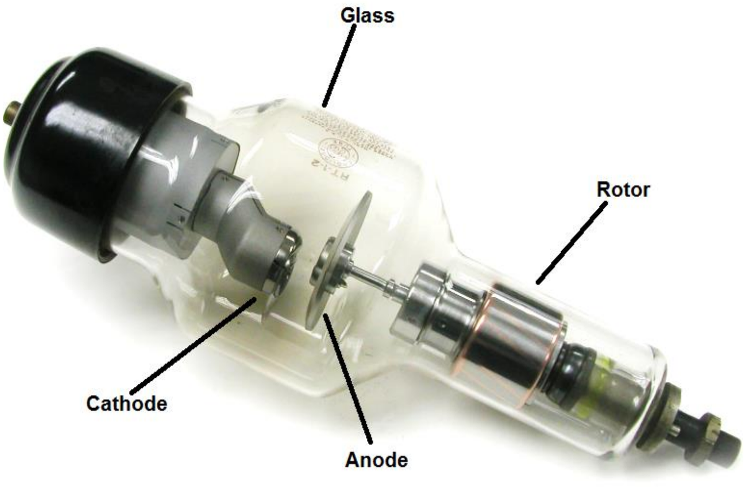


Figure 3.14: The Rotating Anode [33]

When the X-ray machine is turned on by the operating console that shown in the **Figure 3.15**, the High voltage between (20 to 150) KVp is applied between the cathode and anode [34]. A small amount of current flows through the cathode to heat filament coil. the controlling of the filament current adjusts the tube current. This causes to move the electrons towards the positive terminal of the tube at a velocity reach to half of the light velocity.

Figure 3.15: The Operating Console [35]

X-rays are produced due to sudden deceleration of fast-moving electrons when they collide and interact with the target anode. In this process, more than 99% of the electron energy is converted into heat and less than 1% of energy is converted into x-rays photons with precise energies determined by the electron energy levels [36], as shown in the **Figure 3.16.**

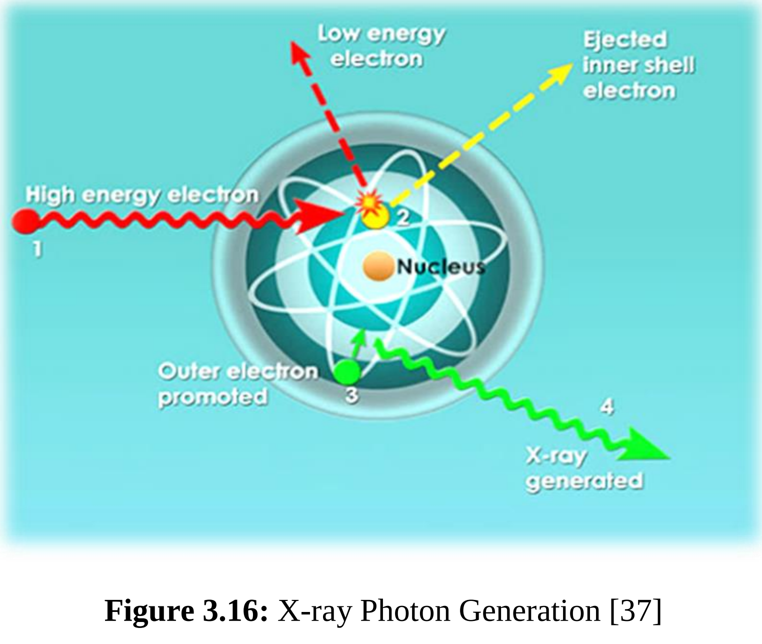


Figure 3.16: X-ray Photon Generation [37]

A collimator has two or three sets of lead shutters which Located immediately between (8 − 18) cm below the tube window to limit the X-ray beam and remove unwanted radiations, as shown in the **Figure 3.17.**

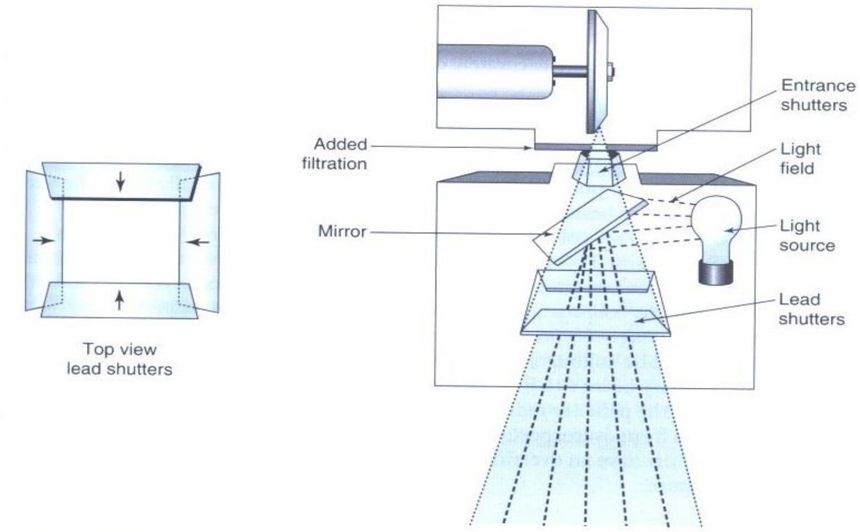


Figure 3.17: Lead Shutter [38]

When the X-ray beam hit the body, it will be absorbed by the tissues without any contribute in the X-ray image. The beam may be Scattered, and this adds the fog to the X-ray image or Transmission with penetrates through body to hit radiographic film. The transmission X-ray beam only reach to the radiographic grid which shown in the **Figure 3.18.** It is a part of the Bucky that found under the radiographic table that hold the film cassette that produce from the lead material and insert between the patient and the film to reduce the scattered radiation and improve image contrast

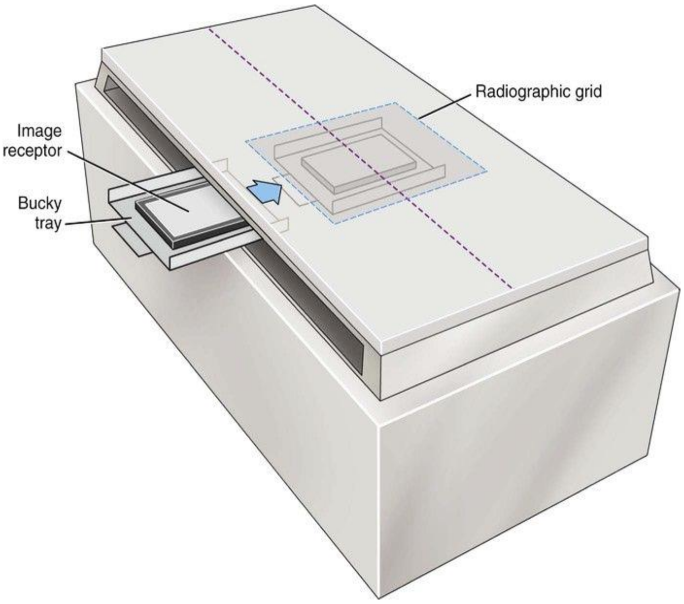


Figure 3.18: Radiographic Grid [39]

The photographic film made from silver halide and gelatin which consists super coat as a protective covering, emulsion as a radiation and light sensitive and the plastic Base for stability. The photographic film used the Developer that convert the latent image to manifest image through 22 second [40]. Then, the acetic acid used to fix the manifest image. The acetic acid is washed by the special water to remove the residual chemicals then, the blow dryer used to dry to obtain the final image that shown in the **Figure 3.19.**

Figure 3.19: Radiographic Image [41]

3.4 The Radiographic Room Shielding

The medical use of ionizing radiations, whether for diagnosis or therapy, does not affect only on the patient but may also affect on the radiologists, radiographers and other workers. Therefore, the basis aim of the Protection in the radiation photographic rooms is to ensure that the doses received are as small as possible by install the X-ray equipment in adequately shielded rooms to ensure that public in the vicinity of the X-ray installations are not unduly exposed to X-ray radiation, such that the consequent damage never constitutes a significant hazard to the health, as shown in the **Figure 3.20.**

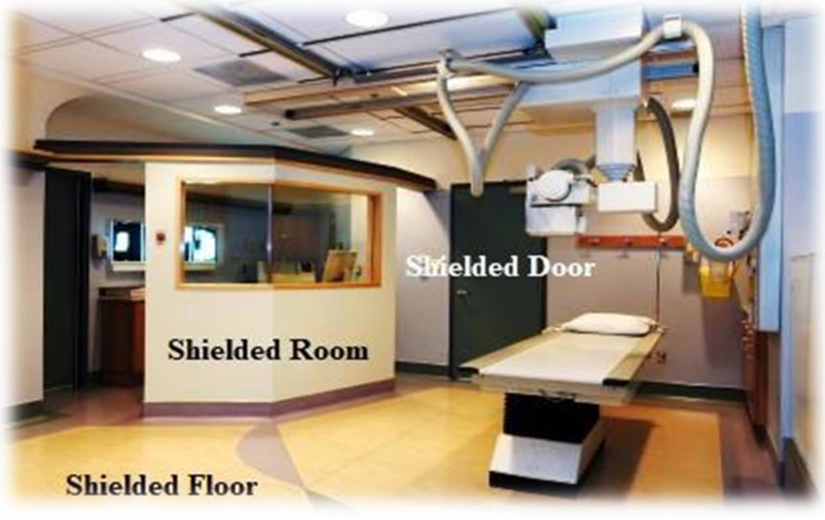


Figure 3.20: Radiographic Room Shielding [42]

For general X-ray rooms, the lead equivalence required for a room of dimensions that suitable with the X-ray machine function. in general, the radiographic room set in dimensions about 6m x 4m x 3m.

A 150 mm solid concrete provides sufficient shielding between floors of multiple storey buildings. Except for walls equivalent to at least 1.4 mm lead, an additional protective panel may be specified for use behind the vertical Bucky, depending on the occupancy of the adjoining area. This is generally 15Kg/m^{-2} sheet lead, suitably supported and overlapped. If required, the panel needs to extend from the floor (although up to 30 cm from the floor will be permitted) to a height of around 200 cm and extend 30 cm either side of the vertical Bucky. The protective panel may be attached to the wall with the vertical Bucky supports provided its presence is obvious and there is no risk of physical injury to anyone dismantling the vertical Bucky.

The adequacy of shielding depends on the material and thickness used for this purpose. However, the high-density solid concrete or brick are considered the best materials, as they are easily available, economical and have good structural strength. While the lead sheets of walls are very effective and suitable shielding option for energies encountered in diagnostic X-rays, since it has a high atomic number and high density, as shown in the **Figure 3.21.**

Figure 3.21: The Radiographic Room [43]

As an alternative to using concrete, wall shielding may be provided using panels of lead plasterboard or lead plywood as in the operator’s console. Typically,1.3 mm sheet lead or its shielding equivalent is specified. This may need to be higher if the protective screen is less than 2 m from either x-ray tube or patient, as shown in the **Figure 3.22.**

Figure 3.22: Lead Sheet of Radiographic Room [44]

In the operator's room, the sheet lead be supported on both sides such as a ply-lead-ply sandwich or similar to prevent creeping under gravity. Sheets be an overlapped to ensure continuous shielding or butt jointed with an overlapping lead strip. A permanent label must indicate the thickness of lead in the protective screen.

The screen window extend from the floor to a height of not less than 2 m and be wide enough (more than 90 cm) to protect the operator from leakage radiation from the tube housing and scattered radiation from the patient which the side protective shields may be required.

The protective window needs to contain the same lead equivalence and have dimensions more than (30 cm x 30 cm) such that the radiographer can observe the patient during an X-ray exposure. Generally, the protective window is either lead glass (nominal thickness 6 mm, 1.5 mm lead equivalence) or H-22 lead acrylic (1.0 mm lead equivalence at 100 kVp). All shielding must overlap by a minimum 5 mm. A permanent label indicating the lead equivalence of the window at a nominal kVp is required.

The screen window is to be secured to either the floor or wall so that the location of the protective screen is fixed. Although fixed in position for everyday use, the screen may be hinged for service access to controls. A small gap (less than 5 cm) between the floor and screen for castors is permitted. For mammography, protective screen needs to be at least 0.3 mm lead equivalence at 30 kVp.

The X-ray room also contain Lead glass has a high lead and barium content and is commonly used for the viewing windows in X-ray rooms, as shown in the **Figure 3.23.** Additional shielded battens may be provided in areas where items have to be fixed to the wall. Where service perforations are required in walls, i.e. electrical socket outlets, light switches, service outlets, ventilation grilles, installation of sinks, cabinets, light boxes, etc., additional lead shielding is required in place of the shielding that is displaced.

Figure 3.23: The Operator’s Room Glass [45]

For installations other than CT room, the shielding equivalent to at least 1 mm lead at 100 kVp is required. A choice of building materials is available to achieve this degree of shielding, including a single layer of solid clay brick with fully mortared joints, two thicknesses of ordinary cored brick, 15 Kg/ m^{-2} sheet lead (suitably supported and overlapped) or two layers (2 x 16 mm) of barium plaster x-ray.

For CT installations, shielding equivalent to 1.5 mm lead or more may be required. Protection needs to extend from the floor to a height of not less than 2 m and be continuous. Where recessed wall boxes such as a medical gas panels are installed, sufficient shielding must be added to maintain the level of shielding provided by the rest of the wall, as shown in the **Figure 3.24.**

Figure 3.24: CT Scan Installations [46]

Typical building materials in dental, including double gyprock walls, are generally sufficient provided all personnel maintain at least the minimum permitted distance of 2 m from the x-ray tube and the patient during exposures.

There may be several doors leading to an X-ray room including the patient door, the staff door, and doors to changing cubicles or possibly to a patient toilet. The room should be designed so that the uninterrupted X-ray beam will not normally be directed towards doors, windows, or the operator's console. Even with this provision the door and doorframe must be shielded against scatter. The shielding must be uninterrupted between double doors, between the door and frame, and between the door frame and the adjoining wall, as shown in the **Figure 3.25.**

Figure 3.25: Radiographic Room Door [47]

For doors, shielding may only be required for major medical installations. a10 kg / m^{-2} sheet lead is generally satisfactory unless the area outside the door is likely to have reasonably continuous occupancy, e.g. if the area is an office, film sorting processing area. The doors to CT rooms should generally not have less than 15 kg / m^{-2} lead. Where radiation protection is requested for doors, the frames are excluded from this requirement. It is sufficient that the steel door frame be detailed to overlap the wall structure for the necessary protection to be achieved. Warning lights at room entrances may be required for fixed general purpose, fluoroscopic or CT equipment where entry is not directly under the equipment user's control. Where required, warning lights ("Caution X-rays") should be mounted alongside the entrance and connected into the X-ray generator circuit so that they illuminate at 'prep' and for the duration of the exposure.

In general, Each X-ray installation must be assessed for shielding requirements based on the dimensions of the room, positions of the X-ray control, vertical Bucky and operator, proposed construction materials (protective screens, walls, floors, doors), areas adjacent to x-ray room (occupancy, future use) and X-ray workload.A structural protection plans must be supplied to the radiological council prior to construction or for existing buildings prior to use of the x-ray equipment in the room.

However, the lead is a weak structural material with tendency to lose uniformity and needs periodic radiation survey to ensure its continued adequacy. Also, lead poses a serious environmental hazard and the use of it is being discouraged the world over. Recently, many new materials are being developed as potential shielding materials, as an alternate to Lead.

Gaps in shielding are more likely to occur where different forms of shielding meet. there are many problems that encounter the radiographic room. For instance, there may not be sufficient overlap between walls and shielded doorframes, similarly there may not be sufficient overlap between shielded doors and doorframes or windows and window frames, the integrity of the joints between lead sheets may not be sufficient, where sockets, switches, plumbing, or ducting, etc. breach the shielding, these areas may not be adequately protected and the Joints between ceilings and walls may not be adequately shielded.

Chapter Four

Technology Background

When radiations pass through matter, they interact with molecules and transfer energy to them. The transfer of energy has an ionization effect which occurs when cause an orbital electron to be stripped away from its parent atom or molecule, thus creating an ion pair. Hence, the term ionizing radiation is used when referred to the emissions from radioactive material and involved in the detection of radiation events.

This chapter explains an X-ray detection systems definition with its types, know the features and specifications of the meter used in the project and the reason for its preference with compared to other systems used in measurement. This in addition to illustrate in details the basic principles of the conversion Circuit from low voltages to high voltages (Boost convertor Circuit) and finally identify the most important electronic pieces used in the practical part of the project.

4.1 X-ray Detection Systems models

The X-ray detection system is a radiation detection device or meter that used to check the exposure range of personnel, equipment, and facilities for radioactive contamination, or check the external ionizing radiation fields to evaluate the direct exposure hazard. The detection meters are the most important resource for the radiographer to determine the presence and intensity of radiation because of a majority of X -ray hazards occur when an X-ray technician did not use a detection meter.

There are many different models of detection meter available to measure radiation in the field. Such as, the scintillation counter and the gas proportional detector.

4.1.1 The Scintillation Counter

A scintillation counter measures ionizing radiation. The sensor that called a scintillator which consists of a transparent crystal, or organic liquid that fluoresces when struck by ionizing radiation. A photomultiplier tube used to measure the light from the crystal. it is attached to an electronic amplifier and other electronic component to count and quantify the amplitude of the signals produced by the tube. When a charged particle strikes the scintillator, a flash of light is produced. The association of a scintillator and photomultiplier with the counter circuits forms the basis of the scintillation counter apparatus. A common and useful scintillating material is sodium iodide, with traces of thallium, as shown in the **Figure 4.1.**

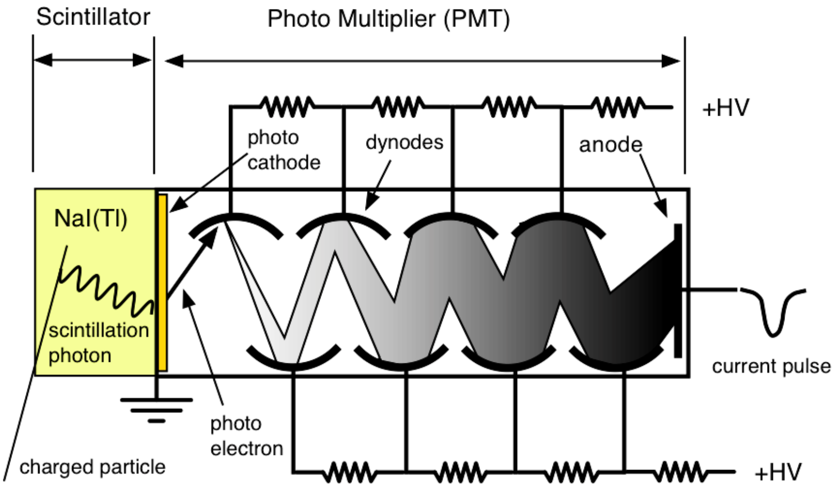


Figure 4.1: The Sodium-Iodide Scintillation Counter [48]

Sodium-Iodide (Nal) detectors are used to detect X-ray emitting radioactive materials. the Thin end-window Nal detectors have been developed to detect low energy X-ray emitted from iodine. Larger Nal detectors (up to 1-inch-thick) and energy compensated GM detectors are used to monitor for higher energy emitters such as chromium, iodine or zinc.

4.1.2 The Gas Proportional Detector

The gas proportional detector which the Gas filled detectors consists of a gas filled cylinder with two electrodes. Sometimes, the cylinder itself acts as one electrode, and a needle or thin taut wire along the axis of the cylinder acts as the other electrode. A voltage is applied to the device so that the central needle or wire become an anode (positive charge) and the other electrode or cylinder wall becomes the cathode (negative charge). The gas becomes ionized whenever the counter is brought near radioactive substances. The electric field created by the potential difference between the anode and cathode causes to move the electrons of each ion to the anode while the positively charged gas atom is drawn to the cathode. This results in an electrical signal that is amplified, correlated to exposure and displayed as a value, as shown in the **Figure 4.2.**

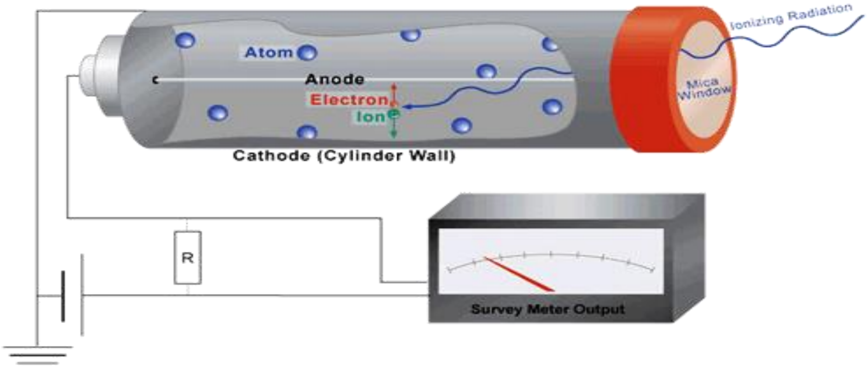


Figure 4.2: The Gas Proportional Detector [49]

Depending on the voltage applied between the anode and the cathode, the detector may be considered an ion chamber, a proportional counter, or a GM counter.

In a proportional counter the fill gas of the chamber is an inert gas which is ionized by incident radiation, and a quench gas to ensure each pulse discharge terminates; a common mixture is 90% argon, 10% methane, known as P-10. An ionizing particle entering the gas collides with an atom of the inert gas and ionizes it to produce an electron and a positively charged ion, commonly known as an "ion pair". As the charged particle travels through the chamber it leaves a trail of ion pairs along its trajectory, the number of which is proportional to the energy of the particle if it is fully stopped within the gas. Typically, a 1 MeV stopped particle will create about 30,000 ion pairs, as shown in the **Figure 4.3.** [50]

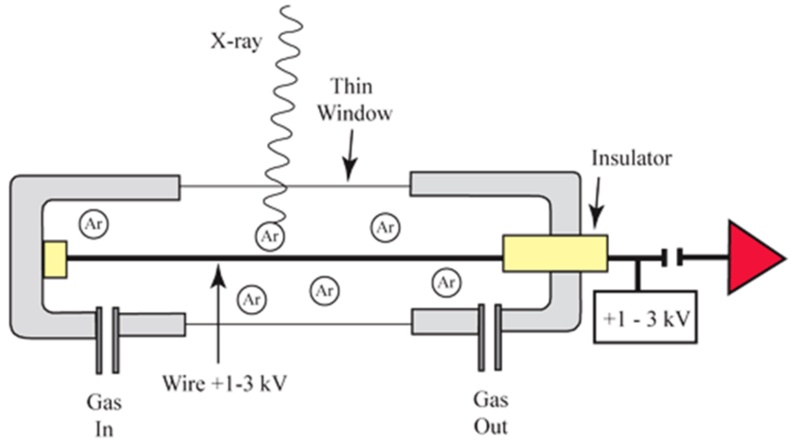


Figure 4.3: The Basic Scheme of A Proportional Counter [50]

Ionization chambers may be used to measure ionizing radiation by measuring the amount of charge generated from the interaction of radioactive particles with molecules of a certain gases. The simplest form of the chamber consists of a cylinder at ground and one charged positive center electrode. When radiation is introduced into the gas between these two electrodes it liberates electrons from the gas molecules creating gas ions, and thus allowing charge to flow from center electrode (wire) to outer electrode cylinder. The strength of the electrical field generated is directly proportional to how much radiation is present in the chamber and the amount of distance between the electrodes and the given volume of gas between them, as shown in the **Figure 4.4.**

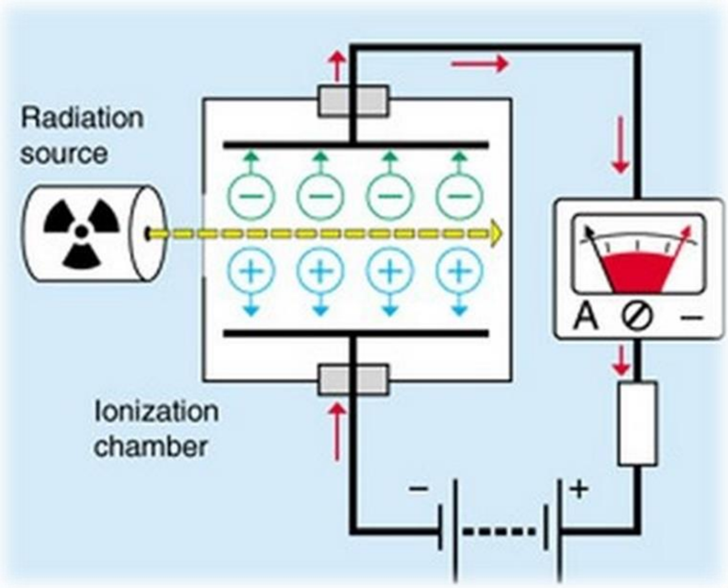


Figure 4.4: Ionization Chambers Detector [51]

In a gas-filled ionization chamber, the voltage between the electrodes is increased until all ion pairs produced by the impinging radiation are collected. However, the voltage remains below that required to produce additional ion pairs as the ion pairs produced by radiation interactions migrate to the collecting electrodes. Consequently, the electrodes receive only ion pairs that result directly from interactions of ionizing radiation with gas in the chamber.

4.2 The Geiger-Müller Tube

The original GM tubes principle was discovered in 1908, but it was not use until 1928 when the Hans Geiger and Walther Müller invent a counter for radioactive rays. The tube is a hollow cylindrical tube that is made of copper which is enclosed in a partially evacuated glass tube with a length about 15 – 50 cm, as shown in **Figure 4.5** .it contains a rarefied noble gas (generally argon or Helium) at a pressure of 10 cm of Hg, with 10% vapors of ethyl alcohol which becomes conductive of electricity when it is impacted by a high-energy particle.

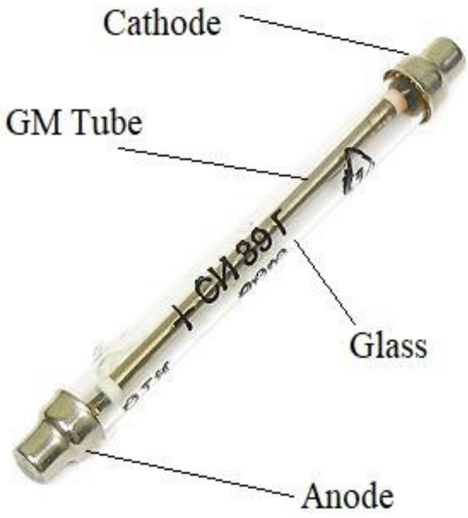


Figure 4.5: Geiger Muller Tube [52]

There are a lot of types and shapes of GM tube that differs in its lengths and thickness, the inner gas, operation voltage and anode resistor, detection particles and prices.

One of these tubes is “SBM-20 Tube” that shown in **Figure 4.6.**

Figure 4.6: “SBM-20” Tube [57]

4.2.1 Physical properties

It provides various facilities and simplicity; such as highly sensitive to radiation, a small size, cheap price, thickness wall and has a wide range of measurement as illustrated in **Appendix A.**

4.2.2 The Working Range

The tube required 400 volts that has to be applied to enable its operation with the recommended anode resistor is 4.7 megaohms. The tube working range at the operating temperature range (-60 to +70) is located between (0.014 to 144) mR/hr. This value of measurement is an appropriate one, since the normal range of room leakage is equal 1 mR/hr, as illustrated in the **Appendix B**.

4.2.3 Sources of Errors

Some possible errors may be occurred in Instrument resolution, Failure to calibrate or check zero of instrument or environmental factors.

4.2.4 Precautions

The operating voltage should correspond to the midpoint of flat plateau region. In case the continuous discharge is produced, the voltage should be lowered and the applied voltage must be relatively stabilized. Introduction of light should be prevented to avoid photo electric effect.

4.2.5 Comparison with Other Tubes

The common thread that connect between the several types of Geiger tubes are that all tubes detect the ionizing radiation. in the other meaning, they are capable of ionizing the gas atoms inside a GM tube which allows for their detection.

The inexpensive GM tubes like the SBM-20 Geiger tube only detect beta, x-ray and gamma radiation while the more expensive GM tubes, like the LND-712 Geiger tube that shown in the **Figure 4.7** have a thin mica window that allows alpha particle radiation to penetrate into the interior of the GM tube and ionize the gas for detection. Thin mica window detects alpha, beta, and gamma radiation.

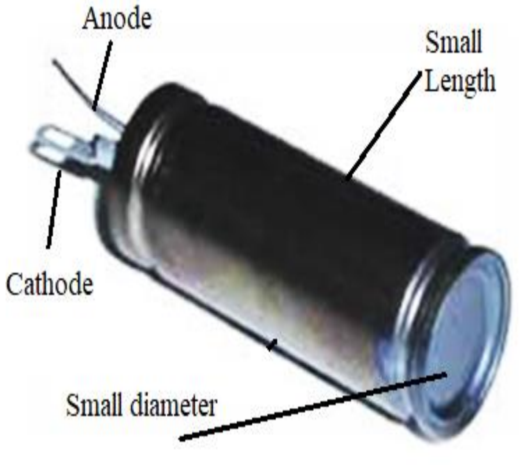


Figure 4.7: “LND-712” Tube [58]

The **Table 4.1** summarizes the comparison between "SBM-20" and "LND-712" such that the "LND-712" operating voltage ranges between 450 to 600 volts and the recommended voltage is 500 volts. The recommended anode resistor is 10 megaohms. It also has a 9.1 mm wide, 40 mm long and filled with Neon and halogen gases, as detailed in **Appendix C.**

Table 4.1: The Comparison Between Different GM Tube Characteristics

Comparison	SBM-20	LND-712
Financially	Inexpensive Tube	More Expensive
Detection Particle	Detect Beta, X-Ray and Gamma Radiation	Detects Alpha, Beta and Gamma Radiation.
Anode Resistor	5 MΩ	10 MΩ
Length	10 – 15 cm	4-5 cm

As a result of this comparison, the "SBM-20 tube" is an identical choice for usage in the project to detect the X-ray emission from the radiographic rooms than the other tubes.

4.3 The Geiger-Müller Counter

After 1928 the GM counter became a practical instrument Since it has been very popular due to its robust sensing element and relatively low cost. However, there are limitations in measuring high radiation rates and the energy of incident radiation.

Now, a practical radiation instrument could be produced relatively cheaply, and so the Geiger-Muller counter was born. As the tube output required little electronic processing, a distinct advantage in the thermionic valve era due to minimal valve count and low power consumption, the instrument achieved great popularity as a portable radiation detector. The modern versions of the Geiger counter use the halogen tube invented in 1947 by Sidney H Liebson. It superseded the earlier Geiger tube because of its much longer life and lower operating voltage.

The main working principle of GM tube is presented in the **Figure 4.8** such that a tungsten wire of about 0.5mm of diameter is fixed along the axis of GM tube (but insulated from the tube). The tungsten wire is connected to the positive terminal and metallic GM tube to the negative terminal with about 10000 Volts. A thin window (generally made of mica), is provided on one side of tube for entrance of particles to be detected [53].

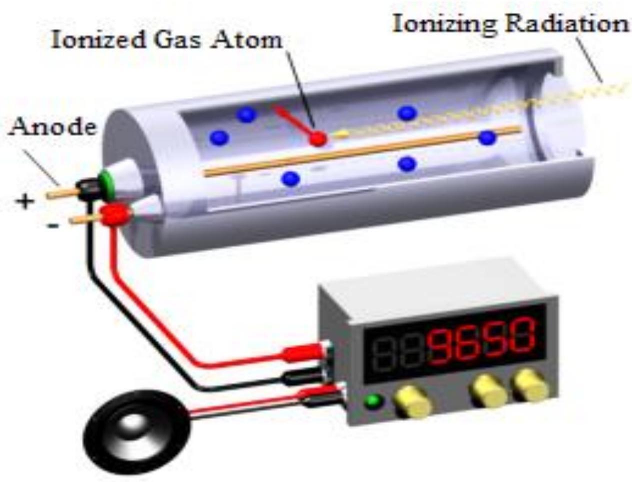


Figure 4.8: Geiger Muller Tube voltage [54]

When a Geiger counter is exposed to ionizing radiation, the particles penetrate the tube and collide with the gas, releasing more electrons. Positive ions exit the tube and the negatively charged electrons become attracted to a high-voltage middle wire. When the number of electrons that build up around the wire reaches a threshold, it creates an electric current. This causes the temporary closing of a switch and generates an electric pulse. This large pulse from the tube makes the GM Counter relatively cheap to manufacture, as the subsequent electronics is greatly simplified. The electronics also generates the high voltage, typically 400–600 volts, that has to be applied to the GM tube to enable its operation, as shown in the **Figure 4.9.**

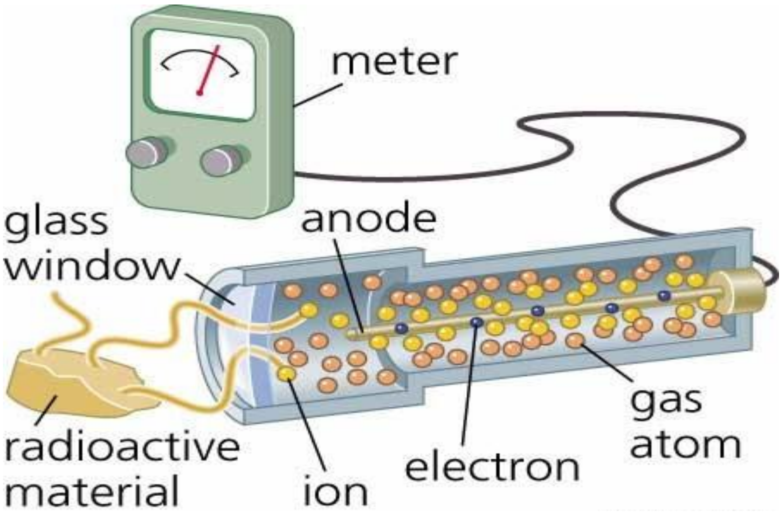


Figure 4.9: Geiger Muller counter principle [55]

The electronic circuit of a GM counter records the number of pulses (the number of ionizing events) and represents the information at the screen typically in sievert or display the dose rate as an analog signal, as shown in the **Figure 4.10.** it is also relative with a speaker and a flashing light to give a mark at the leaking region.

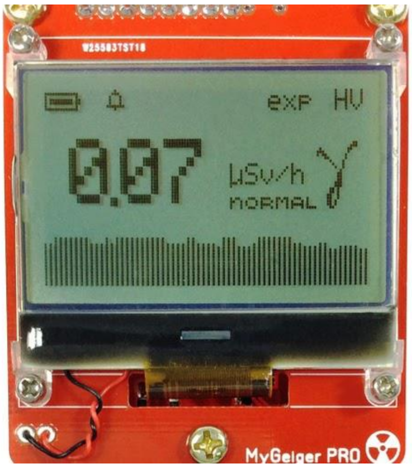


Figure 4.10: The Digital and Analog Signal of Geiger Counter [56]

The modern portable Geiger counters of Fluke company for example, are offering serial communications with a host computer or network, as shown in **Figure 4.11**. The purpose of this is to allow the user to concentrate on manipulation of the instrument whilst retaining auditory feedback on the radiation rate that is displayed in a multiple unit such as the Sievert (S) unit or Roentgen (R).

Figure 4.11: Geiger Counter Computer Connection [56]

4.4 Radiation Units

International organizations, such as the International Commission on Radiological Protection (ICRP) and the International Commission on Radiation Units and Measurements (ICRU) have been concerned with the protection of ionizing radiation; specific definitions have been developed for the physical quantities used to express exposure to ionizing radiation and the resulting radiation.

The International System (SI) is used to express radiated amounts using a several units like Roentgen, RAD, REM, gray and sievert

The Roentgen abbreviated with (R) is the measurement of energy produced by Gamma or X-Ray radiation in a cubic centimeter of air. but the RAD is Radiation Absorbed Dose. Original measuring unit for expressing the absorption of all types of ionizing radiation (alpha, beta, gamma, neutrons, etc) into any medium. One rad is equivalent to the absorption of 100 ergs of energy per gram of absorbing tissue.

Roentgen Equivalent Man abbreviated with (REM) is a measurement that correlates the dose of any radiation to the biological effect of that radiation. Since not all radiation has the same biological effect, the dosage is multiplied by a quality factor (Q) that is differ from particle to another, as shown in **Table 4.2**. For example, a person receiving a dosage of gamma radiation will suffer much less damage than a person receiving the same dosage from alpha particles. So alpha particles will cause three times more damage than gamma rays.

Table 4.2 The Quality Factor For A Few Radiation Types.

Radiation	Quality Factor (Q)
Beta, Gamma and X-rays	1
Thermal Neutrons	3
Fast neutron, electron and protons	10
Heavy and recoil nuclei	20

The difference between the rad and rem is that the rad is a measurement of the radiation absorbed by the material or tissue. The rem is a measurement of the biological effect of that absorbed radiation. For general purposes, most physicists agree that the Roentgen, Rad and Rem may be considered equivalent.

The SI units for radiation measurements are gray (Gy) and sievert (Sv) for absorbed dose and equivalent dose respectively. The **Table 4.3** shows the conversion from one system to another.

Table 4.3 The Conversion Between Radiation systems.

1 Sv = 100 R
1 Gy = 100 rad
1 Sv = 100 REM

4.5 Boost Convertor Circuit

According to the performance of the tube and since it detects the ionization X-ray that can emit a current pulse whenever an ionization event occurs inside the tube. The GM tube is connected with a high voltage power source that is called Boost Convertor Circuit, Step Up Convertor or DC to DC Convertor.

The boost converter output voltage is greater than the input voltage. Hence, the name is “boost”. The **Figure 4.12.** illustrates the basic circuit of a Boost converter with the switching transistor is a power MOSFET transistor.

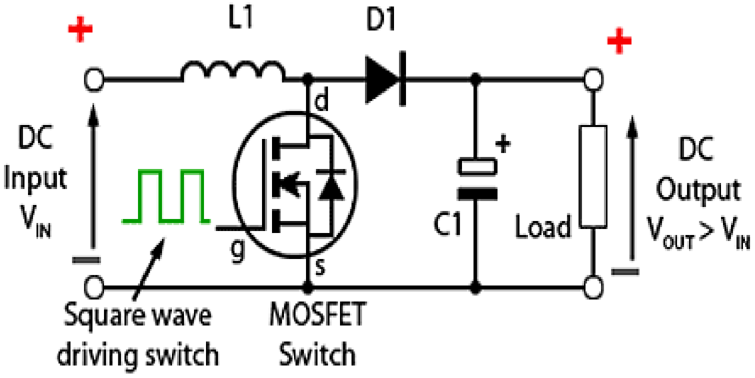


Figure 4.12: Boost Convertor Circuit

The **Figure 4.13** illustrates the circuit action during the initial high period of the high frequency square wave applied to the MOSFET gate at start up. During this time MOSFET conducts, placing a short circuit from the right-hand side of L1 to the negative input supply terminal. Therefore, a current flow between the positive and negative supply terminals through L_1, which stores energy in its magnetic field. There is virtually no current flowing in the remainder of the circuit as the combination of D_1, C_1 and the load represent a much higher impedance than the path directly through the heavily conducting MOSFET.

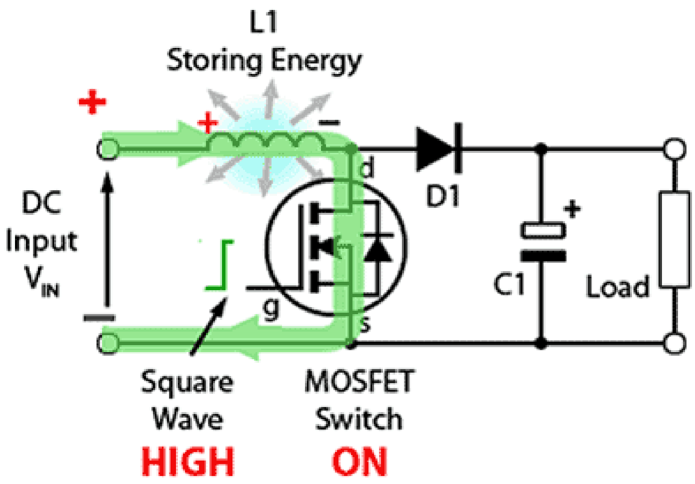


Figure 4.13: Boost Convertor Circuit Action During High Period

The **Figure 4.14** shows the current path during the low period of the switching square wave cycle. As the MOSFET is rapidly turned off the sudden drop in current causes L_1 to produce a back Electromotive force (EMF) in the opposite polarity to the voltage across L_1 during the on period, to keep current flowing. This results in two voltages, the supply voltage Vin and the back EMF (V_L) across L_1 in series with each other.

This higher voltage (Vin +V_L), now that there is no current path through the MOSFET, forward biases D_1. The resulting current through D_1 charges up C_1 to Vin +V_L minus the small forward voltage drop across D_1, and also supplies the load.

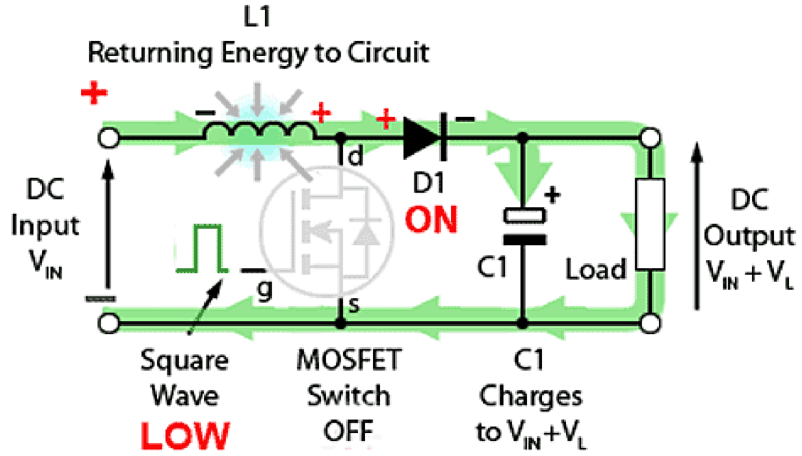


Figure 4.14: Boost Convertor Circuit Action During High Period

The Figure 4.5 shows the circuit action during MOSFET on periods after the initial startup. Each time the MOSFET conducts, the cathode of D1 is more positive than its anode, due to the charge on C1. D1 is therefore turned off so the output of the circuit is isolated from the input, however the load continues to be supplied with Vin +VL from the charge on C1. Although the charge C1 drains away through the load during this period, C1 is recharged each time the MOSFET switches off, so maintaining an almost steady output voltage across the load.

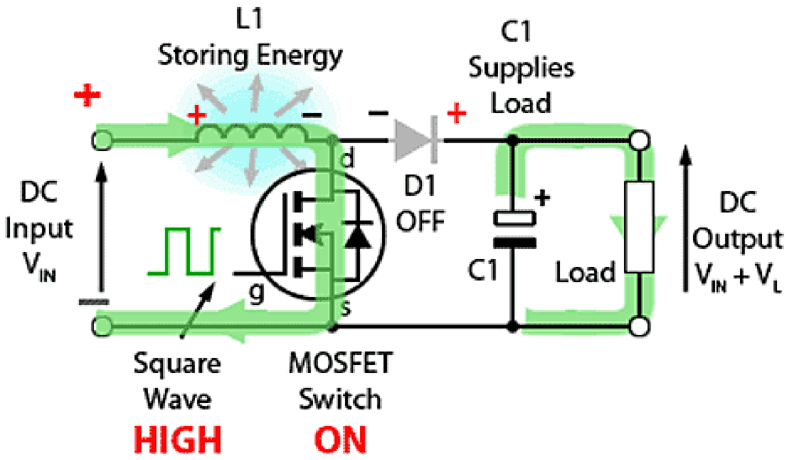
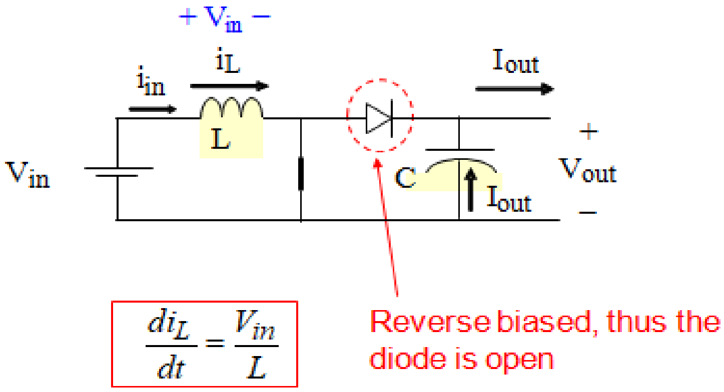


Figure 4.15: Boost Convertor Circuit Action After MOSFET Startup

4.5.1 The Boost Converter Circuit Derivation

The Figure 4.6 illustrates the boost convertor circuit at closed switch high period (DT seconds) of the high frequency square wave applied to the MOSFET transistor. During this level the diode represents the reverse bias state (open diode).



$$\boxed{\frac{di_L}{dt} = \frac{V_{in}}{L}}$$

Figure 4.16: The Boost Convertor Circuit at Closed Switch High Period

The **Figure 4.17** illustrates the boost convertor circuit at open switch low period (DT -1 seconds) of the switching square wave cycle. During this level the diode represents the foreword bias state (closed diode).

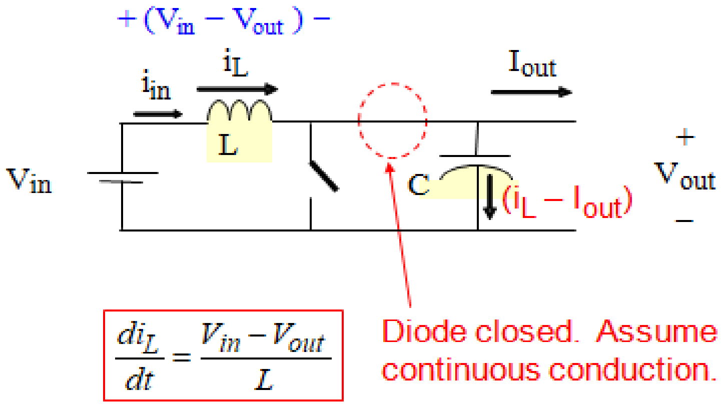


Figure 4.17: The Boost Convertor Circuit at Open Switch Low Period

Since the Average voltage across the L is Zero. So,

VL avg = D * Vin + (1-D) * (Vin-Vout) = 0

Vout * (1-D) = Vin + D * Vin – D * Vin

$$Vout = \frac{Vin}{1-D}$$

At the closed switch state, VL = Vin, $\frac{diL}{dt} = \frac{Vin}{L}$

At the closed switch state, VL = Vin – Vout, $\frac{diL}{dt} = \frac{Vin-Vout}{L}$

The **Figure 4.18** illustrates the inductor current examination such that the average current (I avg) is the half way between the maximum current (I max) and the minimum current (I min)

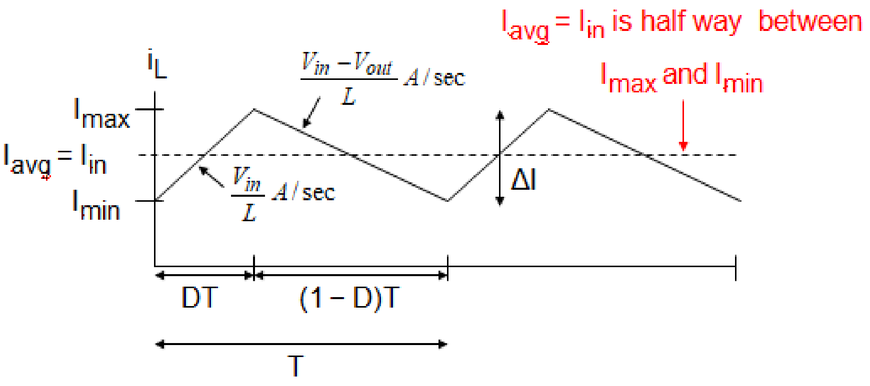


Figure 4.18: An Inductor Current Curve

$$I_{Lrms}^2 = I_{avg}^2 + \frac{1}{12} I_{pp}^2 = I_{in}^2 + \frac{1}{12}\left(\Delta I^2\right)$$

The maximum impact of the ΔI on the rms current occurs at the boundary of the continuous and discontinuous conduction, where $\Delta I = 2\ I_{in}$, that shown in the **Figure 4.19**.

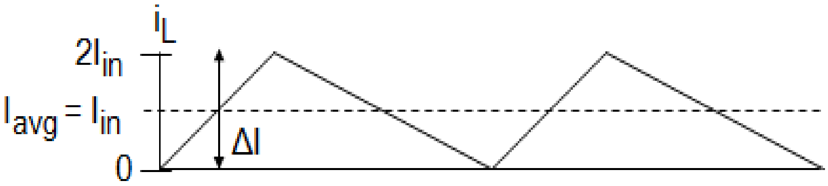


Figure 4.19: The Maximum Impact of ΔI

$$I_{Lrms}^2 = I_{in}^2 + \frac{1}{12}(2\Delta I_{in})^2 = \frac{4}{3} I_{in}^2$$

Use max

$$I_{Lrms} = \boxed{\frac{2}{\sqrt{3}} I_{in}}$$

The **Figure 4.20** illustrates the MOSFET transistor and the diode current ratings such that the diode current curve is been a block at the first but the MOSFET current is been a block at the end. Hence the worst case od D is taken for both

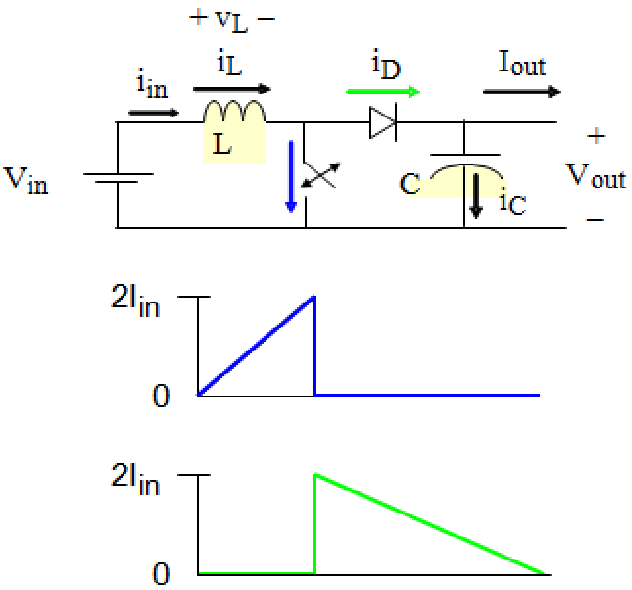


Figure 4.20: MOSFET Transistor and Diode Current Ratings

Take worst case D for each ⇒ $$\boxed{I_{rms} = \frac{2}{\sqrt{3}}\overset{\text{Use max}}{I_{in}}}$$

The **Figure 4.21** illustrates the capacitor current and current rating by it. The peak value on the curve represents the capacitor currents that taken at the maximum point

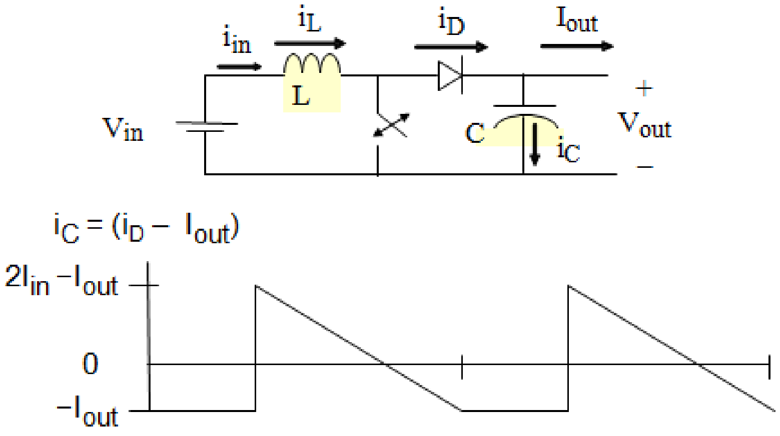


Figure 4.21: capacitor current and current rating

At the max rms current occurs at the boundary of the continuous and discontinuous conduction, where ΔI = 2 I_{out}

$$\boxed{I_{Crms} = \overset{\text{Use max}}{I_{out}}}$$

The **Figure 4.22** represents the worst-case load voltage ripple such that it is been at the period under the zero as illustrates at the shaded region on the curve

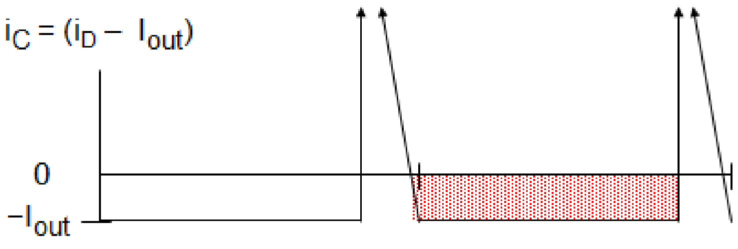


Figure 4.22: Worst-Case Load Voltage Ripple

The worst case is where C provides I_{out} for most of the period

$$\Delta v = \frac{\Delta Q}{C} = \frac{Iout * T}{C} = \frac{Iout}{Cf}$$

The **Figure 4.23** represents the voltage rating such that when MOSFET is closed the diode and capacitor sees the output voltage, but when the when MOSFET is opened the MOSFET sees the output voltage. At this case, the MOSFET and diode uses the 2 V_{out}, but the capacitor uses the (3 V_{out} / 2)

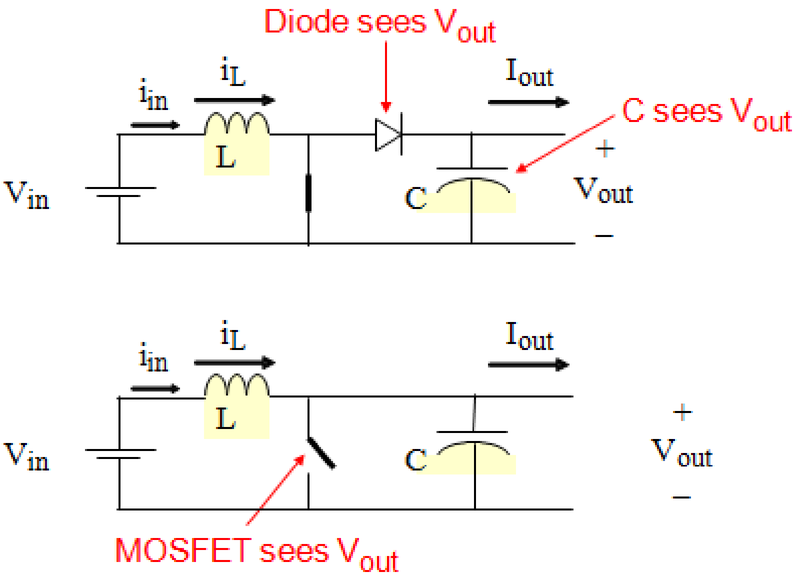


Figure 4.23: voltage rating of Diode, Capacitor and MOSFET

The **Figure 4.24** shows the curve of the inductance current while it is passes through the inductor such that the average current is equal to the input current and inductance is taken at the maximum voltage and the minimum inductor current.

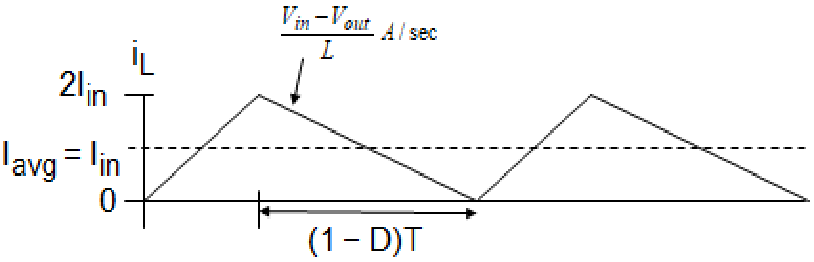


Figure 4.24: Inductance Current Curve

$$2I_{in} = \frac{V_{out} - V_{in}}{L_{boundary}} \bullet (1-D)T = \frac{\frac{V_{in}}{1-D} - V_{in}}{L_{boundary}} \bullet (1-D)T = \frac{V_{in}\left(\frac{1}{1-D} - 1\right)(1-D)}{L_{boundary}\, f}$$

$$2I_{in} = \frac{V_{in} D}{L_{boundary}\, f}, \qquad L_{boundary} = \frac{V_{in} D}{2 I_{in} f}$$

$$L > \frac{\overset{\text{use max}}{V_{in}}}{\underset{\text{use min}}{2I_{in}}f}$$

The **Figure 4.25** illustrates the basic purpose of the DC to DC convertor such that the low voltage converted to high required voltage which use to nourish the resistor with an appropriate voltage to the required application (5v to 400v to operate the GM tube).

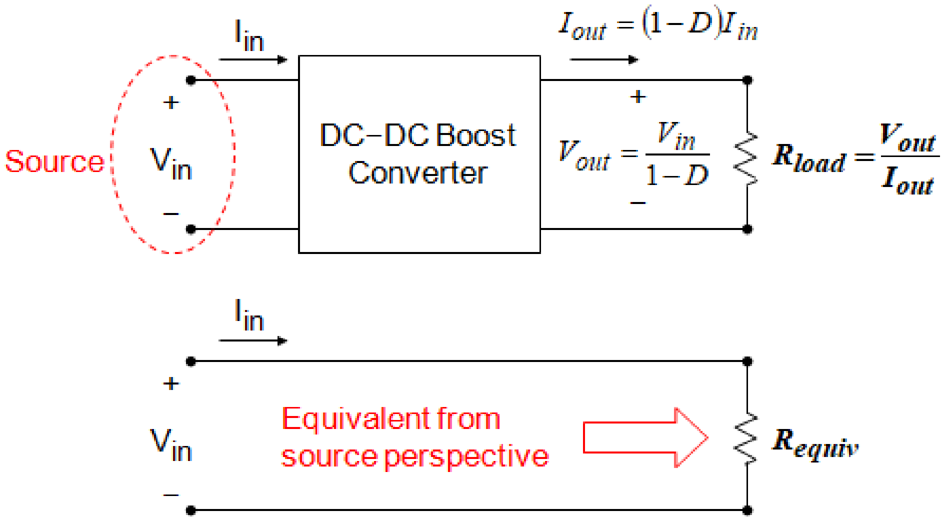


Figure 4.25: Boost Convertor Load

$$R_{equiv} = \frac{V_{in}}{I_{in}} = \frac{(1-D)V_{out}}{\frac{I_{out}}{1-D}} = (1-D)^2 \frac{V_{out}}{I_{out}} = (1-D)^2 R_{load}$$

At the boost convertor circuit, the four parameters are needed to calculate the power stage; The Input Voltage Range (Vin $_{min}$ and Vin $_{max}$), The Nominal Output Voltage (V_{out}), The Maximum Output Current (Iout $_{max}$).

4.6 Controlling System

The controller part represents the brain at any project that established to process the data information that comes from the different system components and give a suitable response upon these data. Such as reading on LCD display, audible or flashing alarm, operate a motor and etc.

The controlling system in this project is an Atmega 328A integrated circuit (IC). ATmega328 is an Advanced Virtual RISC (AVR) microcontroller chip found on Arduino

Uno boards which supports the data up to eight (8) bits and has 32 kilobyte (KB) internal built in memory.

ATmega 328 has 1 KB Electrically Erasable Programmable Read Only Memory (EEPROM). This property shows if the electric supply supplied to the micro-controller is removed, even then it can store the data and can provide results after providing it with the electric supply. Moreover, ATmega 328 has several different features which make it the most popular device in today’s market. These features consist of advanced RISC architecture, good performance, low power consumption, real timer counter having separate oscillator, 6 PWM pins, programmable Serial USART, programming lock for software security, throughput up to 20 MIPS etc.

The **Figure 4.26** shows the Arduino kit components and the Atmega328 ingredients. it totally has 28 pins and 3 Ports which are named as Port B, Port C and Port D. Port C is an analog Port which has six pins in total. Port B and Port D are digital ports and have 7 pins each. So, it has 14 digital pins in total. It also supports SPI Protocol and Serial Communications which perform serial communication via pin number 2 (RX) and pin number 3 (TX). It needs a crystal oscillator for generating the frequency at range from 4MHz to 40 MHz

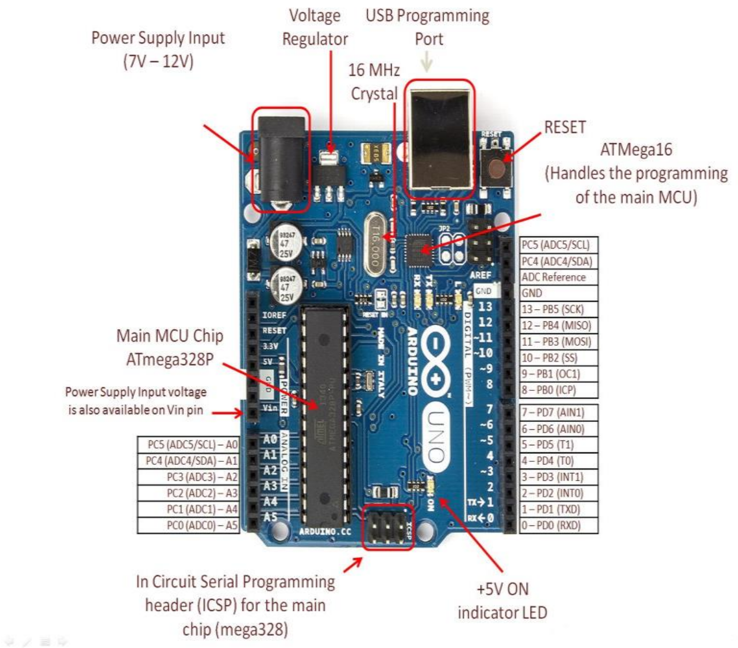


Figure 4.26: Arduino Kit [58]

4.7 Data Display (LCD display)

The LCD controller is an alphanumeric dot matrix liquid crystal display (LCD). The character set of the controller includes ASCII characters and some symbols in two 28-character lines. Using an extension driver, the device can display up to 80 characters. The LCD controller is limited to monochrome text displays and is often used in copiers, fax machines, laser printers, industrial test equipment, networking equipment, such as routers and storage devices.

The microcontroller interface to LCD modules is almost always 16 pins, as shown in **Figure 4.27**. The first three pins provide power to the LCD module. Pin 1 is GND and should be grounded to the power supply. Pin 2 is VCC and should be connected to +5V power. Pin 3 is the LCD Display Bias. By adjusting the voltage or duty cycle of pin 3, the contrast of the display can be adjusted. Most character LCDs can achieve good display contrast with a voltage between 5V and 0V on pin 3.

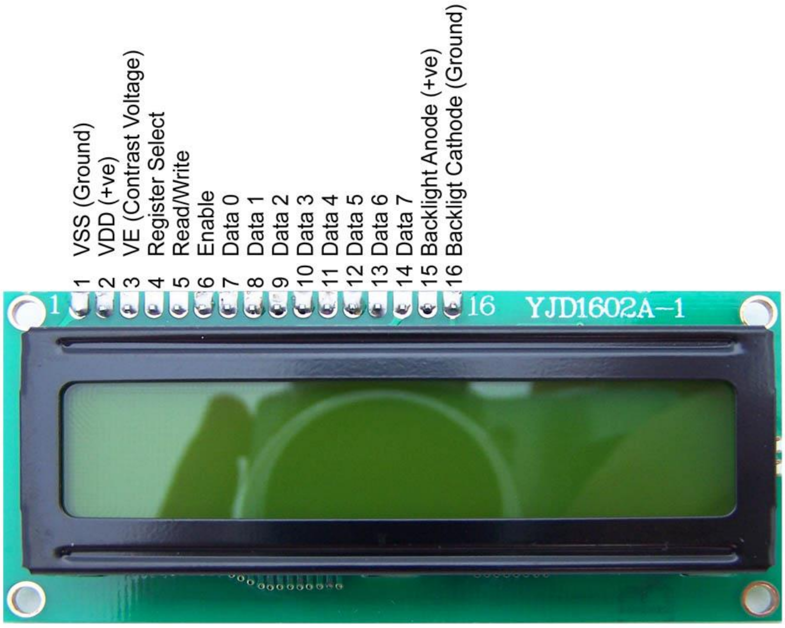


Figure 4.27: LCD Ingredients [59]

Character LCD modules are accessed through only two “registers”, the Command Register, and the Data Register. When you perform a read or write with RS low, you are accessing the Command Register and giving the module instructions. When you read or write with RS high, you are accessing the Data Register and reading or writing characters/data from or to the display, the pseudo-code can be implemented on any microcontroller and assumes that DBPORT is the port to which DB0-7 are connected.

4.8 Buzzer

A buzzer that show in the **Figure 4.28** is an audio signaling device, which may be mechanical, electromechanical, or piezoelectric. Active buzzer 5V Rated power can be directly connected to a continuous sound, can complete a simple circuit design, to "plug and play." It includes the three pins that is VCC, input and ground, it also includes a PNP transistor and a resistor.

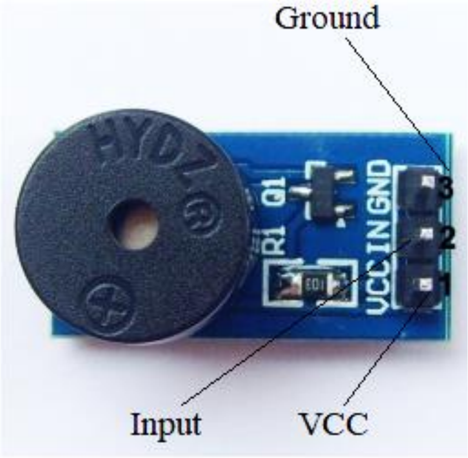


Figure 3.38: Buzzer [61]

Chapter Five

System Design

This chapter of the project aims to design and construct a complete portable device circuit which can detect the X-ray leaking from the radiographic room. The design system consists of radiation detection part and radiation measurement part. The radiation detection part includes the" SBM-20 tube" that detects the X-ray from the surrounding environment and the HV that feed the tube with the high voltage reach to 400 volts that is connected with the radiation measurement part. The radiation measurement part includes the low voltage power source (LV) that is applied to nourish the HV and the integrated circuits system to work and its ripple voltage was rectified with decoupling capacitors. It also includes the controlling system that has a reference value of X-ray leakage connected with an alarm system (LEDs and Buzzer) to give an audible and flashing alarm at abnormal value and represent the value of the leakage on LCD Display.

The general block diagram of the project that illustrated in the **Figure 5.1.** summarizes the work destination.

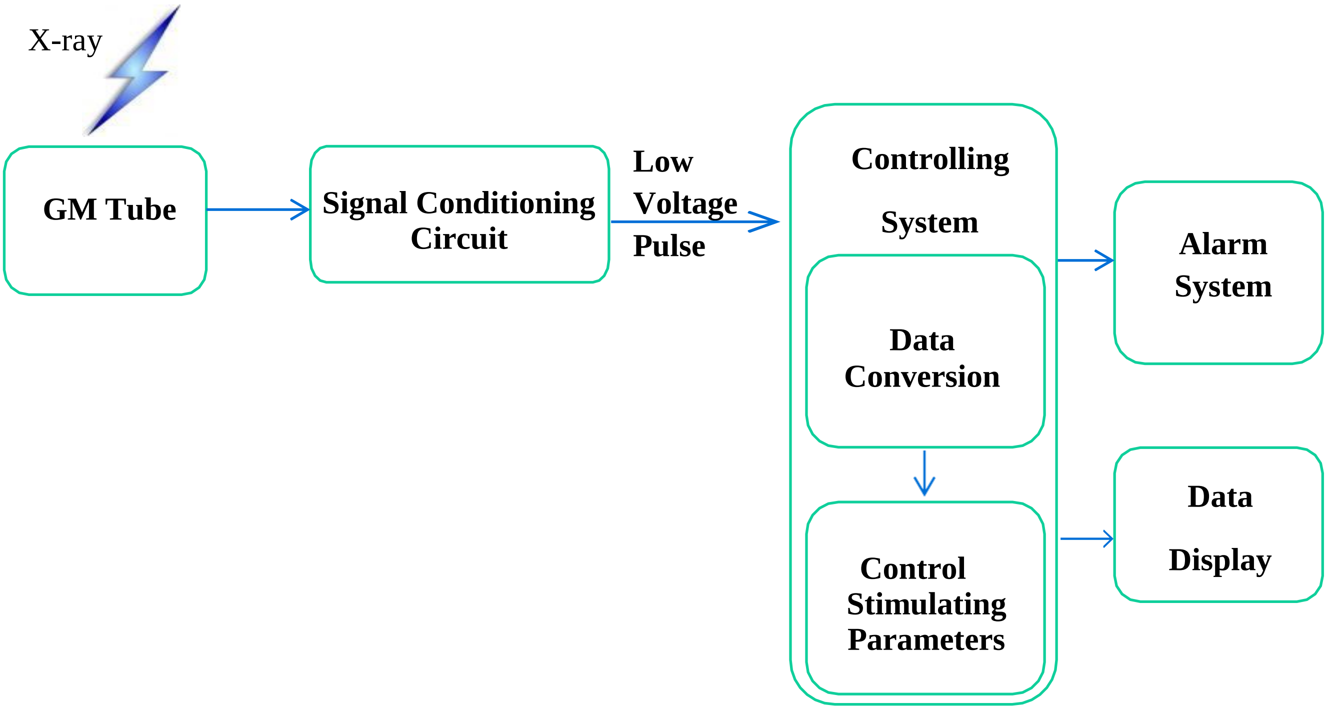


Figure 5.1: General Block Diagram

The pervious block diagram shows the main blocks of the proposed Geiger counter circuit. The circuit control unit implements all of the logic functions and analog processing of the external signals. A 9 Volt power supply must be used for the circuit that is convert to 5 volts to nourish the electronic elements with an appropriate voltage.

The following sections illustrated the system design for all the hardware components required. Each stage of the system will be explained in detail such that the hardware components of each stage are chosen carefully to achieve the desired objectives.

5.1 High Voltage Power Source

The boost converter is the first stage of the project circuit. The function of boost converter can be divided into two modes, Mode 1 and Mode 2. Mode 1 begins when the MOSFET transistor that detailed in **Appendix D** is switched on at time T=0. The input current rises and flows through inductor L1 and transistor. The Mode 2 begins when MOSFET is switched off at time(T=t_1). The input current now flows through L, C, resistor load with the 100kΩ, and diode UF4007. The inductor L1 current falls until the next cycle. The stored energy in inductor L1 that detailed in **Appendix F** flows through the resistor load.

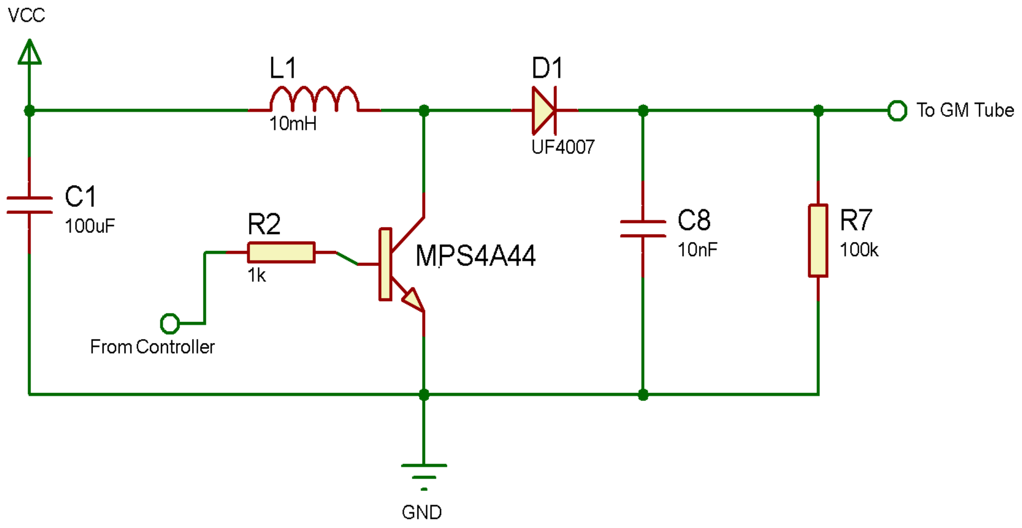


Figure 5.2: Boost Convertor Circuit

The following Subsections illustrates the calculation of each component values for the project boost converter circuit.

5.1.1 Calculating the Duty Cycle

The first step to calculate the switch current is to determine the duty cycle (D) for the minimum input voltage (5 volt). The minimum input voltage is used because this leads to the maximum switch current.

The Duty Cycle (D) =1− [Vin (min)∗η /Vout] **…. (4.1)**

Where, D is a Duty Cycle, Vin(min) is the minimum input voltage, Vout is a desired output voltage and η is the Efficiency of the converter = 90%

So, D=1− [5V∗0.9 / 400] = 0.98875

The efficiency is added to the duty cycle calculation, because the converter has to deliver also the energy dissipated. This calculation gives a more realistic duty cycle than just the equation without the efficiency factor.

5.1.2 Calculating an Inductor

This is the most crucial components in designing a DC/DC Converter. Often data sheets give a range of recommended inductor values. If this is the case, it is recommended to choose an inductor from this range. The higher the inductor value, the higher is the maximum output current because of the reduced ripple current. For parts where no inductor range is given, the following equation is a good estimation for the right inductor:

$$L=Vin*(Vout-Vin)/(\Delta IL*fs*Vout) \qquad \textbf{.... (4.2)}$$

where, L is an Inductance in Henry, Vin is typical input voltage, here is 5V, Fs is the minimum switching frequency of the converter, here is 1.5 MHz [62] and ΔIL is an estimated inductor ripple current.

$$\Delta IL=\frac{Vin*D}{Fs*L}$$

$$=\frac{5*0.9875}{1.5M*10mH}= 0.32m\ A$$

A good estimation for the inductor ripple current is 20 % to 40 % of the output current as illustrated in Appendix C. A smaller ripple reduces the magnetic hysteresis losses in the inductor, as well as output voltage ripple. But in the same way, regulation time rises at load changes. In addition, a larger inductor increases the total system costs. Inductor Ripple Current can be found out as below:

$$\Delta IL=\frac{(0.2to0.4)*Iout*Vout}{Vin} \qquad \textbf{.... (4.3)}$$

where, Iout(max) is maximum output current desired in the application, here, we would like the output current to be approximately 20uA, as detailed in Appendix A. Taking an estimate for the inductor ripple current as 30 % of the desired output current, we get,

$$I_{out}=\frac{\Delta IL*Vin}{(0.2\ to\ 0.4)*Vout} \qquad \textbf{.... (4.4)}$$

$$I_{out}=\frac{0.32m*5}{0.3*400}=13.3uA$$

Substituting in the formula for Inductance, L,

$$L= \frac{5 *(400-5)]}{0.32\text{mA}* 1.5\text{M} * 400} = 10.28\text{mH}$$

5.1.3 Calculating the Maximum Switch Current

It is a good idea to verify that can deliver the desired output current of 20 uA or not. The following equation illustrates that as:

where, ILIM-min is a minimum value of the current limit of inductor integrated switch, from datasheet, 34mA for RLB0812-103KL inductor.

Thus, I-out max = [34 m−(0.32m / 2)] *(1−.98875) = 0.3807 mA

Next, the Maximum Switch Current is:

$$I_{SW\text{-}max} = \frac{\text{Iout}-\text{max}}{(1-D)} + \Delta IL/2 \qquad \textbf{…. (4.5)}$$

By keeping our desired output current to be 20uA,

$$I_{SW\text{-}max} = (0.32\ m / 2) + \frac{0.3807\ m}{(1-0.98875)}$$

$$I_{SW\text{-}max} = 34\ mA$$

So, this switching current limit.

5.1.4 Capacitor Selection

With external compensation, the following equations can be used to adjust the output capacitor values for a desired output voltage ripple: The following formula uses to calculate the output capacitance needed

Cmin = Iout(max)*D/ (Fs*ΔV_{OUT}) **…. (4.6)**

ΔVout is a desired output voltage ripple. Here is too much small, like 2.5 %,

as shown in Appendix C.

Cmin = [0.3807 mA* 0.98875 / (1.5 M* 0.025)] = 10.03 nF

5.1.5 Resistor Calculation

The resistors are calculated as follows:

RGM =R 7 * [Vo/Vfb-1] **…. (4.7)**

10 M Ω = R 7 * [400/4-1] = 99k Ω Then,

Fb is the feedback voltage form the datasheet

5.2 Signal Conditioning Circuit

The conditioning circuit is a second stage of the project. it consists of the transistor and the different resistors and capacitor. The high voltage power supply (HV) at 400 volts through R_{11} and R_{12} was applied the voltage divider rule which [(R12 / (R11+R12)) * $V_{Tube]}$ = [(10/11) *400] = 363 volt to its anode for the maximum count rate and lifetime of the tube. The capacitor C_{12} was connected by alternating current (AC) coupling type to AC signals pass through it as shown in **Figure 5.3.**

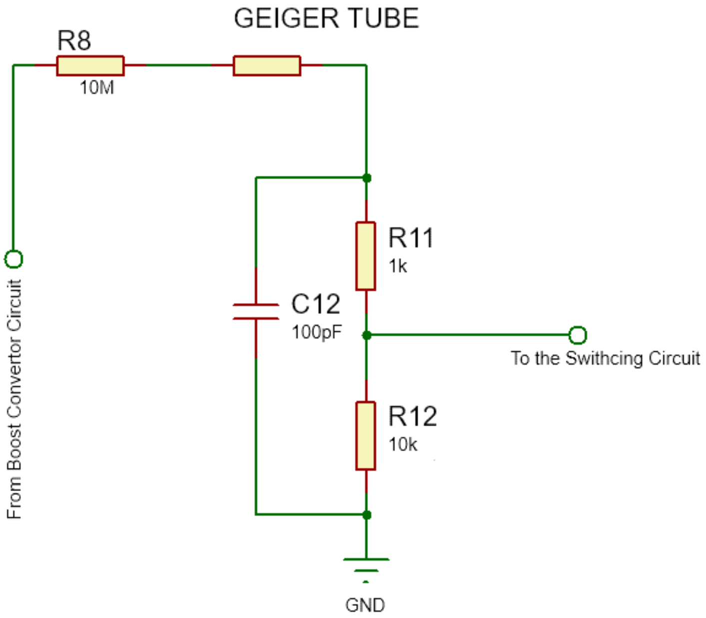


Figure 5.3: The Workable Circuit of GM Tube

The tube briefly conducts electrical charge when particles or photon of incident radiation makes the gas conductive by ionization. The output signal detected at the anode of the tube is the negative trigger pulse. The signal is sharp peak about more than 400 volts as shown in the **Figure 5.4.** This signal will send to a next part to adjust its shape for a data counting.

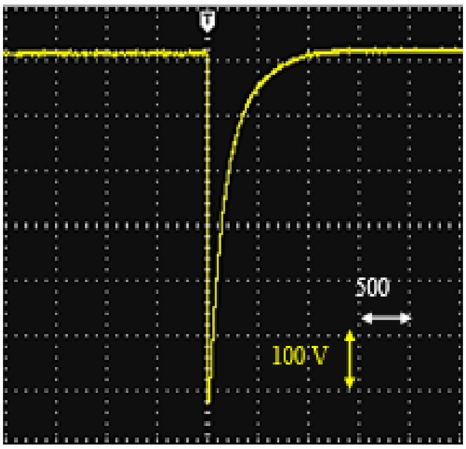


Figure 5.4: Sharp Peak Negative Trigger Pulse

The next part is the switch transistor that was designed to transform a negative trigger pulse to a positive narrow square pulse. The input signal voltage is divided by R_{11} and R_{12} to limit the input current for decreasing damage and increasing lifetime of the circuit, as shown in **Figure 5.5.**

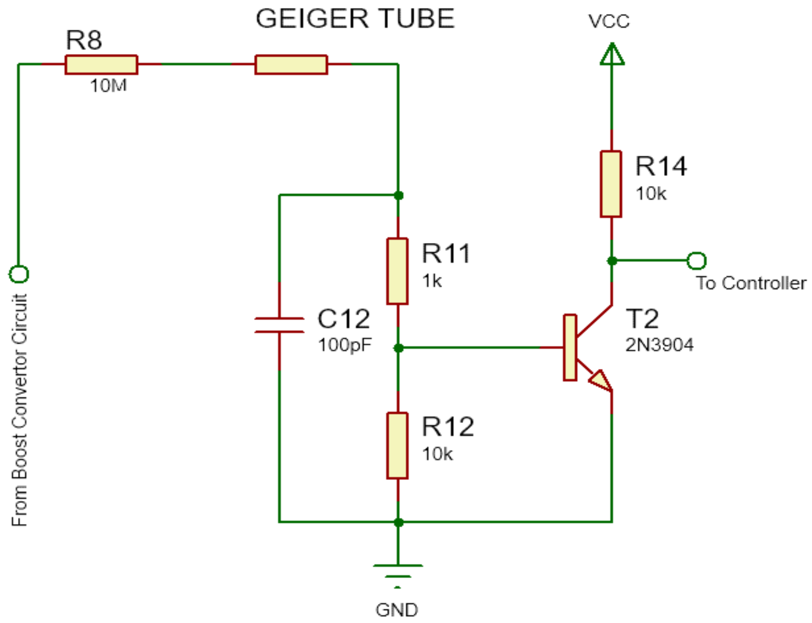


Figure 5.5: Switching Circuit

The resistor R_{14} is criterion to control voltage level of operating of 2N3904 NPN transistor that detailed at **Appendix E**. The output signal compares with the input signal as shown in the **Figure 5.6.**

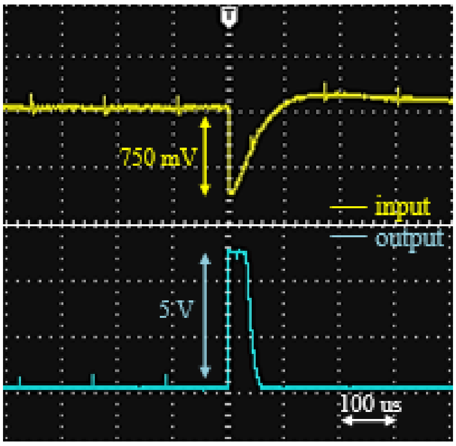


Figure 5.6: The Switching Circuit Input and Output Signal

5.3 Controlling System

The Arduino controlling system (Atmega 328P IC) that shown in the **Figure 5.7** is the third stage of the project that convert the analog square wave to digital values. This stage has a programmable code that doing the required instruments.

The Atmega 328P IC converts the square pulses to the digits and by using the specific factor conversion between this pulse and its values in micro sievert that will detail it in the Arduino code section. The leakage X-ray will appear on LCD in the micro sievert and counts per minute unit (CPM) or in the counts per second unit (CPS) as the state required. The conversion between the both units occurs by pressing on push button switch.

The IC also compare between the X-ray value and the reference value that is determined by the IAEA as at Appendix **B**, that is equal 1000 counts per hour. The controlling system coded to operate an alarm system that consists of LED and Buzzer circuit that give a flasher light on the LED and the sound from the Buzzer at abnormality value of X-ray leakage.

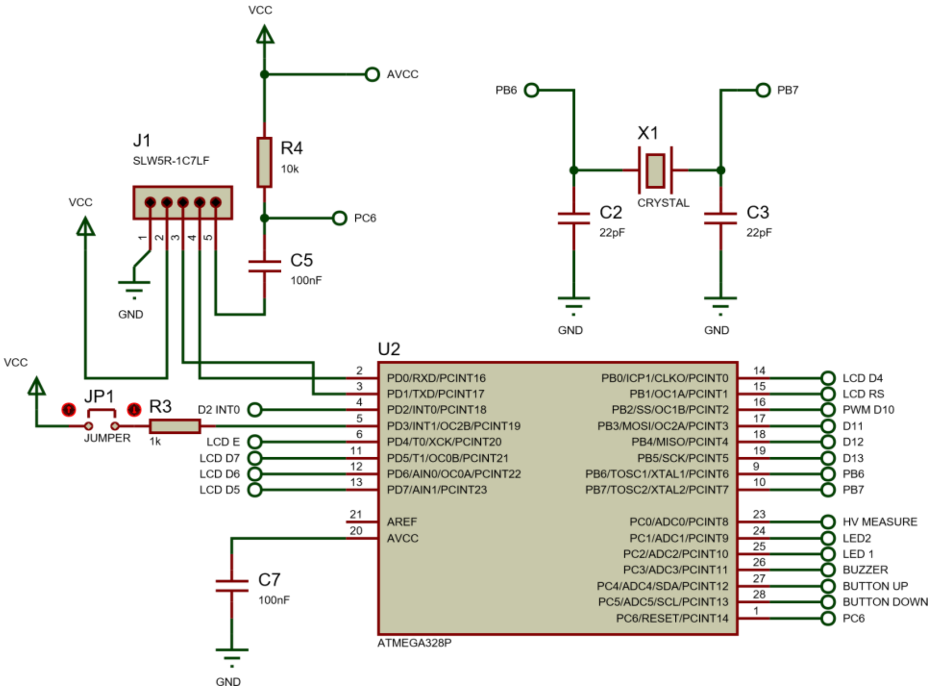


Figure 5.7: Controlling Circuit

5.4 Data Display

This stage is the final stage of the project circuit that consists from the LCD display to exhibit the value of the leakage X-ray as a CPM reading or as a micro Sievert per hour Reading. The LCD connects with a pin of IC as the **Figure 5.8.** such that all pins in the LCD connects with the specific pins of the Arduino and the 10kΩ trimmer potentiometer to adjust the brightness of the LCD and 220 Ω the resistor connected with the last pin of the LCD as a protection resistor.

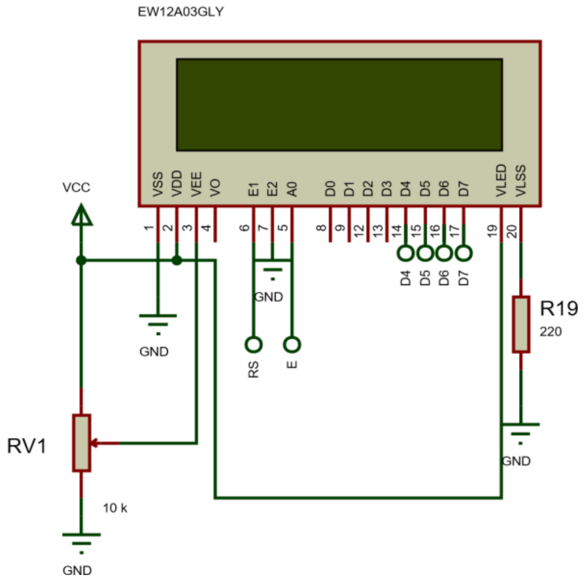


Figure 5.8: LCD Circuit

5.5 Alarm Systems

The alarm system is also the final stage of the project circuit that connected with the controlling system included two LEDs (red and green) with its small resistors values and the Buzzer circuits. The green LED is used to visualize Geiger Counter. The red LED and Buzzer work as an alert warning such that they are operated when the detected value of the X-ray more than the reference value. The Push – Button switches connected with the controller which the Push button down is used to convert between CPM Dose Rate counter and CPS display with fast bar-graph. Push button up is used to mute buzzer, as shown in the **Figure 5.9.**

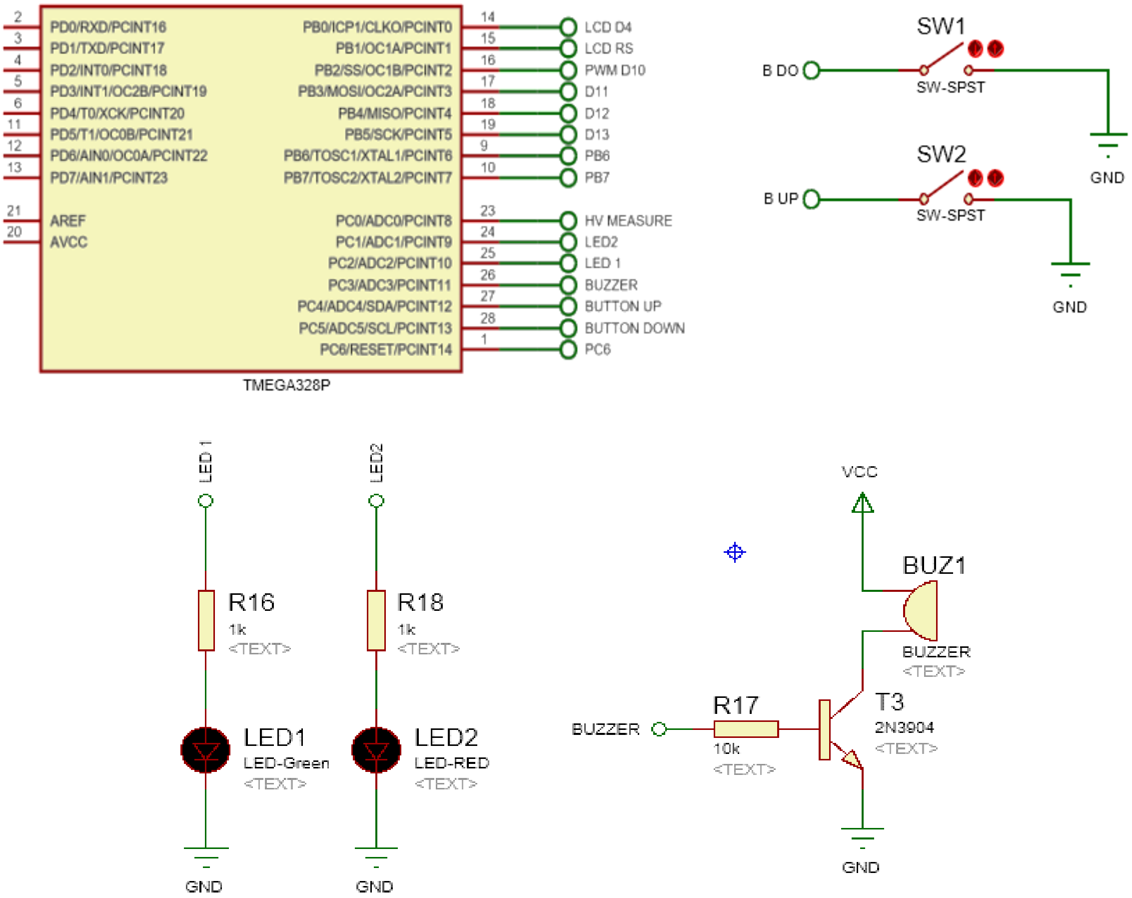


Figure 5.9: Alarm system and push buttons Circuit

5.6 The Power Supply Circuit

The hardware system needs power supply to provide its components with the required power. As the system is required to be portable, a battery that has the following characteristics is required:

1. Light weight.
2. Provide the required system power.
3. Has relatively long life.

Due to limitation of power supply in the system, choosing of system parts should fulfill the need for an optimal with minimum current consumption leading to increase the life time of the battery.

The LM78XX voltage regulators are a popular kind for regulating and outputting positive voltage, while the LM79XX are a popular series of regulators for negative voltage. The system power supply required to use a positive voltage regulator with outputs 5V (LM7805 regulator) that shown in **Figure 5.10.**

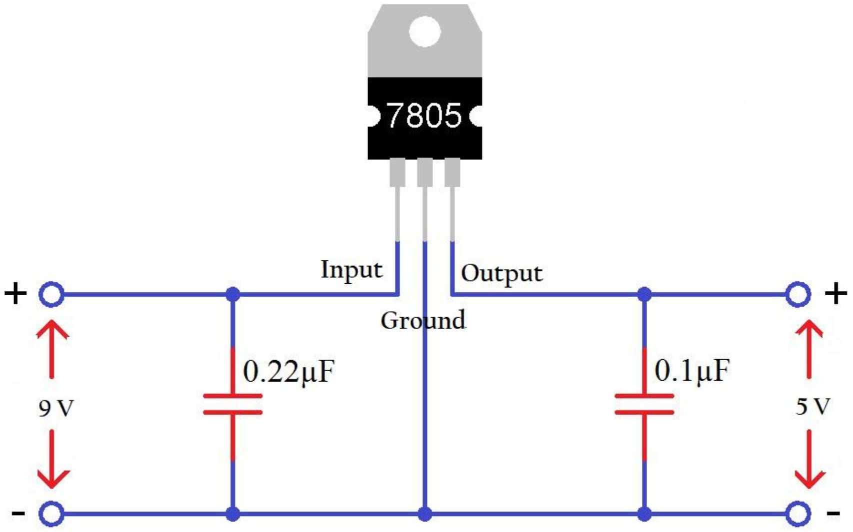


Figure 5.10: The Voltage Regulator Circuit

To obtain these voltage values from the battery keeping in mind the current consumption of all electrical parts used in the system. The Table 4.1 explain the name of the overall system current consumption relate to each one to find the overall system current and verify that the power source able to give this desired value, also calculate the expected life time for the battery

Table 4.1: Current Consumption of The Internal System Components.

Part number	**Function**	**Quantity**	**Current consumption**
ATMEGA328	Output pins	1	**0.2 mA**
HD44780	Display	4	**4*5mA= 20mA**
MPSA44	Transistor	1	**300 mA**
2N3904	Transistor	2	**2*200 = 400 mA**
RLB0812-103KL-ND	Inductor	1	**34 mA**
UF4007	Diode	3	**3*10 u= 0.03 mA**
LED	Display	2	**2*20 = 40 mA**
Total Current Consumption = 794.23 mA			

All data exist in the previous table obtained from the datasheet of each part **[Appendix -D-E-F-G].** after the estimation about the expected current values of all system components, now it is important to choose the power supply parameter to meet these requirements reaching to optimal system operation. The 9 Volts VARTA battery is used with the Capacity (550mAhr), this battery is enough to supply the portable system with its required power such that the lifetime of this battery continue to 41.5 minutes.

Lifetime = $\frac{battery\ Capacity}{current\ consumption} = \frac{550mAhr}{794.23\ mA}$ = 0.7 hour * 60 minutes = 41.5 minutes

5.7 System Flowchart

A controller is necessary in the project to acquire the data from the GM Tube, analyze these data and provide the display system with the results. The detection system is taken a value in CPM every 10 seconds.

After measuring the variables required and processes them by converted the measured in pulses to the digital values using the sieverts conversion factor that is equal 0.0057 that is detailed in **Appendix A.**

Then, the converted data transport to the LCD display to exhibit as a numeric value at CPM and uS/hr that can switch it to appear in CPS, as shown in flowchart in **Figure 5.11**

Chapter Six

System Implementation and Testing

In this chapter the hardware system design in the preceding chapter is implemented to accomplish the project as a one unit which achieves the purpose of the project such that the circuits will be implemented before the final value implementation of the system.

6.1 Project implementation

The GM tube has to be close enough to the shielded region such that the limited distance that is needed to detect an X-ray is approximately ranging between the (5-10) meter for the CT scan machine and the distance for the conventional X-ray not exceed to 5 meter as a maximum range.

6.1.1 Geiger Muller Counter Circuit

The GM counter includes the main board with the LCD. This model compatible with 400v GM Tubes and has full support of 500v GM Tubes. It is improved version of High Voltage converter and has true voltage feedback and HV regulation that fully controlled by precision microcontroller functions. HV output is set with jumper to select 400V or 500V output. HV converter is able to drive 500V into 20Mega ohm resistive load. With a good quality GM tube, it can go up to maximum CPS counting with high activity radiation source. The counter with moving average and recalculation on rapid changes and displayed the X-ray leakage value in uSv/h unit, as shown in the Figure 6.1.

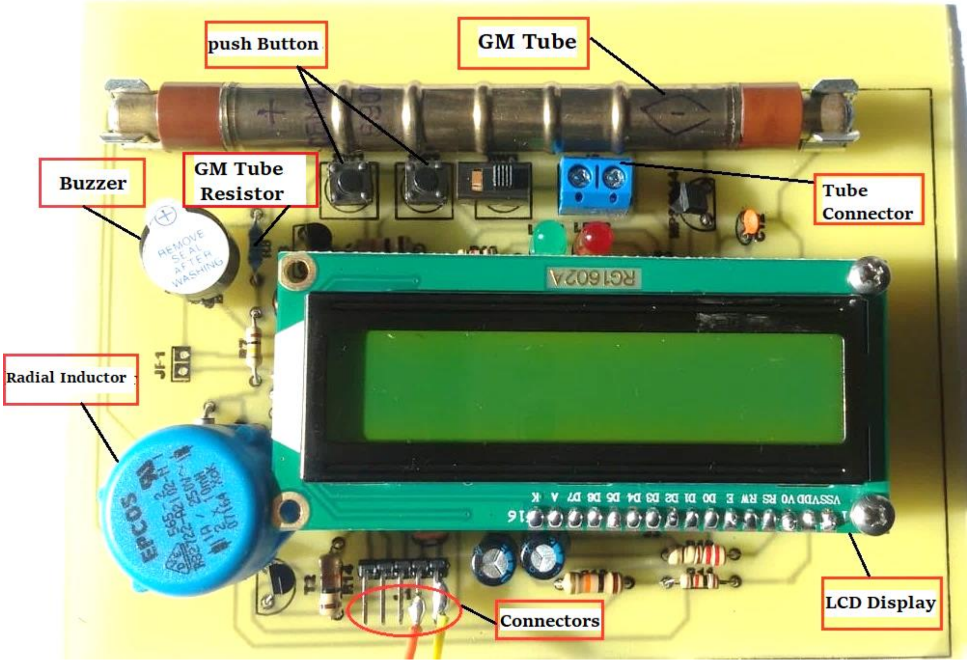


Figure 6.1: Geiger Muller Counter Circuit

6.1.2 Controller Connections

As mentioned in the previous chapters, the Atmega 328A is the brain of the project since all of the project circuits (LCD, LEDs, Switches, GM Tube and Buzzer) are connected with it. This section shows these connections, as shown in the Figure 6.2

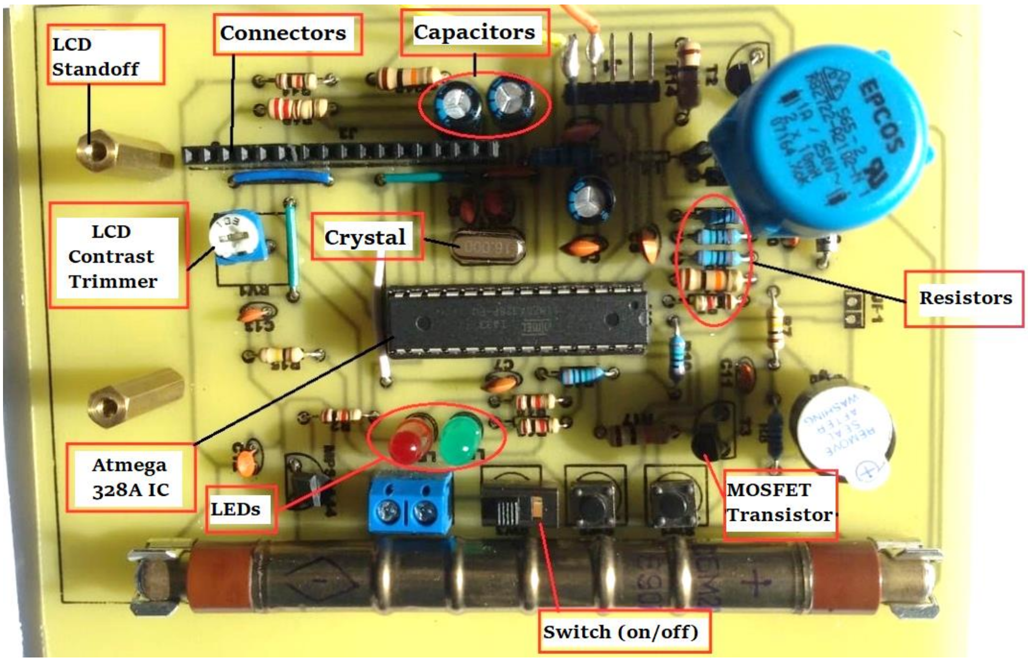


Figure 6.2: Controlling System and its Connected Components

6.1.3 Power Supply Circuit

As mentioned in the previous chapter, the power supply circuit is used to provide the required voltage (5V) to the other circuits and subsystems. The Figure 6.3 shows the power supply circuit and its components.

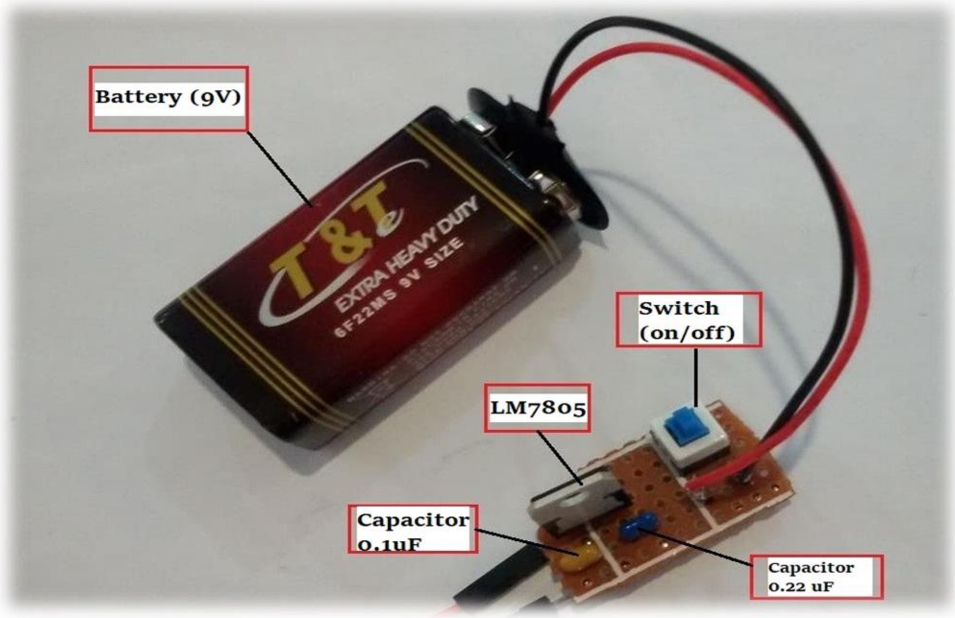


Figure 6.3: Power Supply Circuit.

6.2 The Project Testing

According to the project objectives, the system is supposed to provides the user with the X-ray leakage and display the results on the LCD screen. The **Figure 6.4** displays the normal range results of X-ray detection.

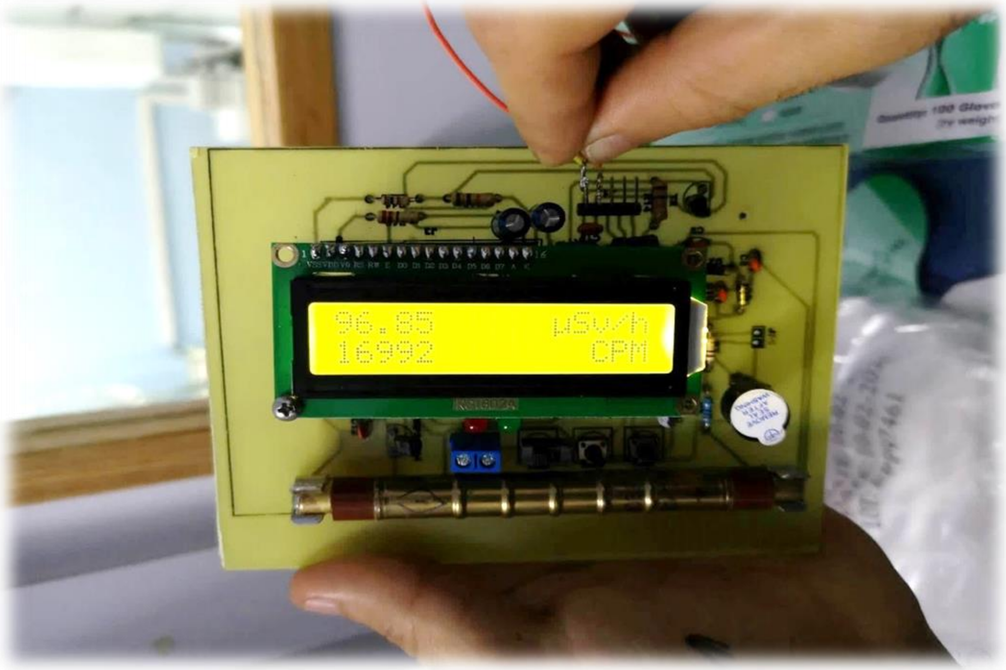


Figure 6.4: The Output Readings for Normal Range of Leakage

Chapter Seven

Result Analysis and Conclusion

This chapter of the project presents the reading of the different devices that is used to detect the X-ray leakage by the different devices from the different position at the radiographical department at al-Ahli specialist hospital in Hebron.

7.1 Results

The results of all readings that tabled at **Table 7.1, 7.2, 7.3** and **7.4** is been in the normal ranges of the X-ray leakage for the people at the waiting region in the department and for the worker inside the radiographical room.

7.1.1 The Designed Detection device

The readings of X-ray leakage are taken by the device that construct in this project for two X-ray machines; a CT Scan Machine and the conventional X-ray machine

The **Table 7.1** represents the X-ray leakage that is taken by the project detection system at different values of X-ray tube current and voltages for the CT scan machine. Then, the readings are drawn by the curve **Figure 7.1.**

Table 7.1: The X-ray Leakage Detection Readings of CT Scan Machine

Sample Number	Distance in meter (m)	mAs	KVp	Reading in (uSv)
1	2.2	400	120	3.25
2	2.2	700	120	3.63
3	2.2	740	120	3.81
4	4.73	750	120	4.18
Mean Value			**3.7175**	

The mean value is equal to the sum of readings divided by its number:

$$Mean = \frac{\sum readings}{no.of\ readings} = \mathbf{(3.25 + 3.63 + 3.81 + 4.18) / 4 = 3.7175\ uSv}$$

The **Figure 7.1** shows the relations between an X-ray tube current and the X-ray leakage reading in micro sieverts

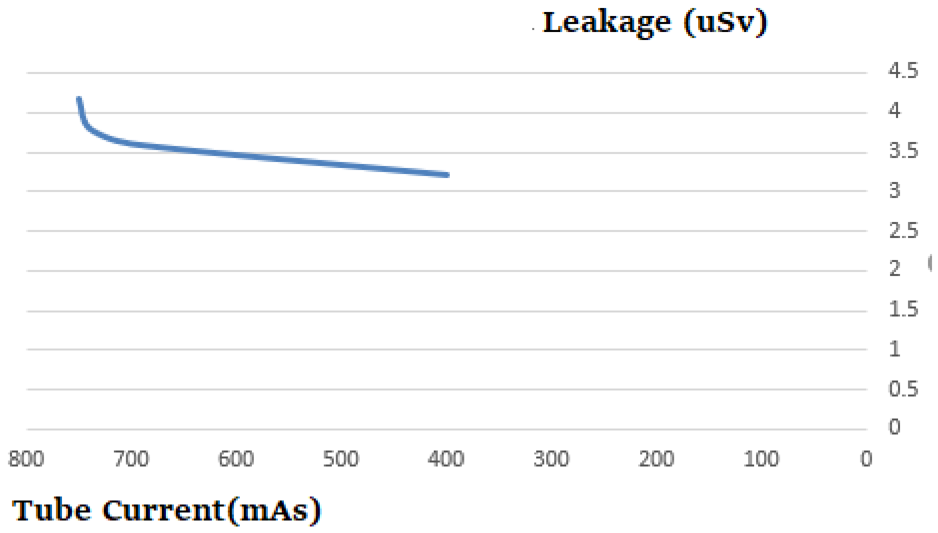


Figure 7.1: The Relations Between Current Tube and X-ray Leakage

The **Table 7.2** also represents the X-ray leakage that is taken by the project detection system at different values of X-ray tube current and voltages for conventional X-ray machine. Then, the readings are drawn by the curve **Figure 7.2.**

Table 7.2: The X-Ray Leakage Detection Readings of The Conventional X-Ray

Sample Number	Distance in meter (m)	mAs	KVp	Reading in (uSv)
1	4.5	5	56	0.14
2	4.5	125	100	41.5
3	5	125	100	10.3
4	5.5	125	100	2.96
Mean Value			**13.725**	

The mean value is equal to the sum of readings divided by its number:

$$Mean = \frac{\sum readings}{no. of\ readings} = \mathbf{(0.14 + 41.5 + 10.3 + 2.96) / 4 = 13.725\ uSv}$$

The **Figure 7.2** shows the relations between the distance in meter (m) and the X-ray leakage reading in micro siverts (uSv)

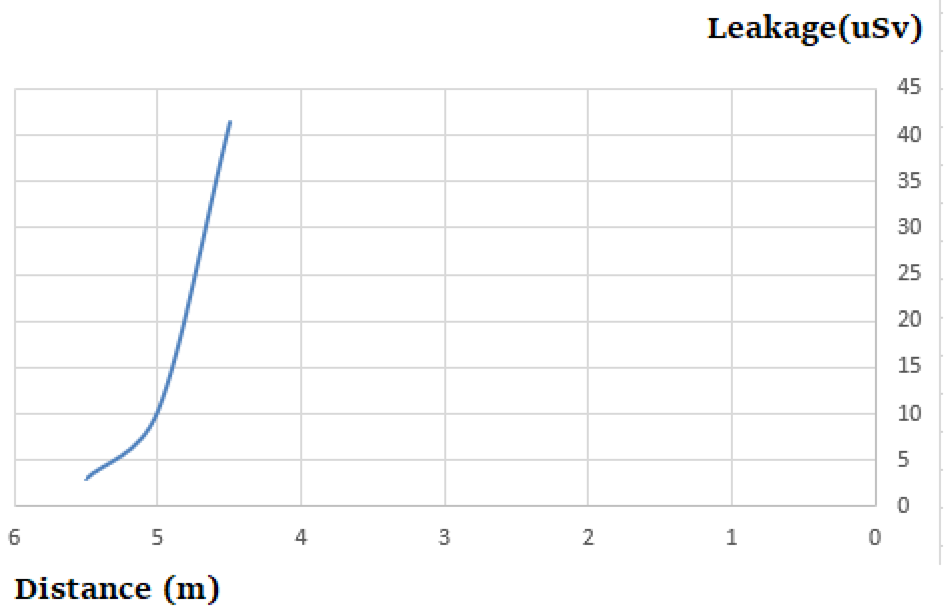


Figure 7.2: The Relations Between Distance and X-ray Leakage

7.1.2 AT6130 Radiation Monitor device

The readings of X-ray leakage are taken by the device that construct in this project for two X-ray machines; a CT Scan Machine and the conventional X-ray machine

The **Table 7.3** represents the readings of X-ray leakage are taken by the AT6130 radiation monitor device that illustrated in an **Appendix I** system at different values of X-ray tube current and voltages for the CT scan machine.

Table 7.3: The X-Ray Leakage Detection Readings for CT Scan

Sample Number	Distance in meter (m)	mAs	KVp	Reading in (uSv)
1	2.2	400	120	2.87
2	2.2	700	120	2.95
3	2.2	740	120	3.03
4	4.73	750	120	3.11
Mean Value			**2.99**	

The mean value is equal to the sum of readings divided by its number:

$$Mean = \frac{\sum readings}{no.of\ readings} = \mathbf{(2.87 + 2.95 + 3.03 + 3.11) / 4 = 2.99\ uSv}$$

The **Figure 7.3** shows the relations between an X-ray tube current and the X-ray leakage reading in micro sieverts

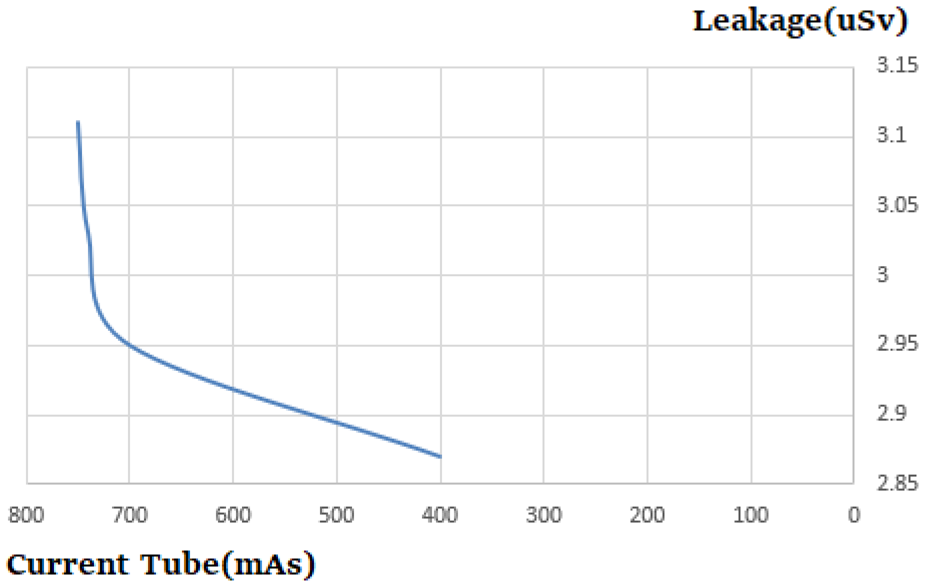


Figure 7.3: The Relations Between Current Tube and X-ray Leakage

The **Table 7.4** also represents the X-ray leakage that is taken by the project detection system at different values of X-ray tube current and voltages for conventional X-ray machine.

Table 7.4: The X-Ray Leakage Detection Readings of The Conventional X-Ray

Sample Number	Distance in meter (m)	mAs	KVp	Reading in (uSv)
1	4.5	5	56	0.11
2	4.5	125	100	34.62
3	5	125	100	16.44
4	5.5	125	100	7.08
Mean Value			**14.56**	

The mean value is equal to the sum of readings divided by its number:

$$Mean = \frac{\sum readings}{no.of\ readings} = \mathbf{(0.11 + 34.62 + 16.44 + 7.08) / 4 = 14.56}$$

The **Figure 7.4** shows the relations between the distance and the X-ray leakage reading in micro sieverts

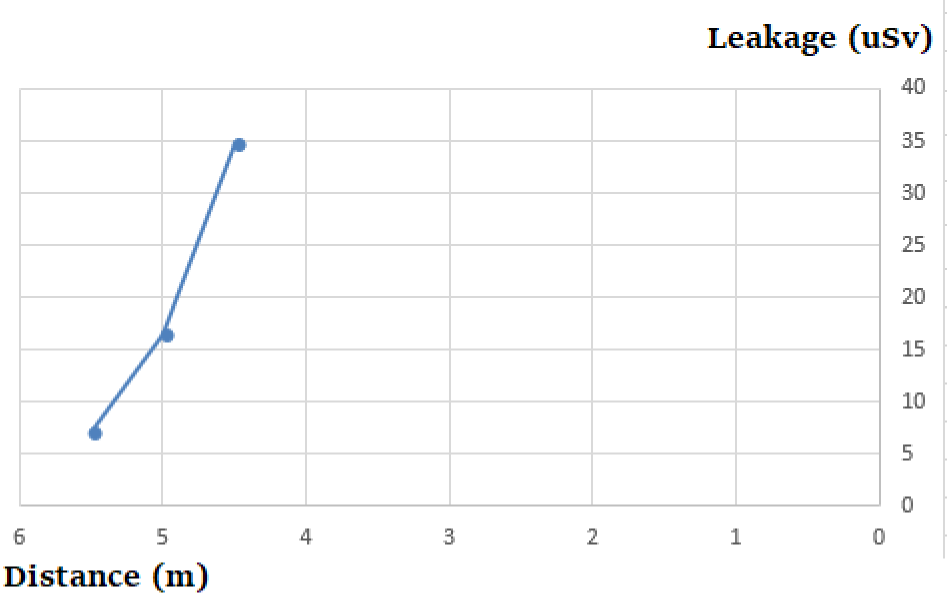


Figure 7.4: The Relations Between Distance and X-ray Leakage

By comparing between the project Detection system and the other Detection System, the readings error for the CT Scan machine is

$$E = \frac{differnece\ between\ both\ mean\ reading}{AT6130\ reading} * 100\% = \frac{3.7175-2.99}{2.99} * 100\% = 24.3\%$$

Also, the readings error for the X-ray conventional machine is

$$E = \frac{differnece\ between\ both\ mean\ reading}{AT6130\ reading} * 100\% = \frac{14.56-13.725}{14.56} * 100\% = 5.73\%$$

7.2 Challenges

While implementing the system, there are many challenges have been faced, such as:

- The critical problem in the project that caused the project delayed is GM tube detector. it is not available in Palestinian markets. Hence, it is requested from America.
- The situation was exacerbated since the political scrutiny for everything that enters to Palestine. so, the required components were delayed to reach to the Hebron until 2 month and it spends a lot of semester time.
- The costs are greater than expected because the project components were ordered from multiple sources in anticipation of any circumstance that may happen.

7.3 Conclusions

The portable X-ray detection and its Detector is useful system to do its aim that represents in detection of the high emission of X-ray and compare its result with the standard rate of leakage to provide the following purposes:

- keep the patients, doctors and nurses outside the radiography room safe from the radiation.
- The device also has light weight so it can be used easily at any time
- This system combined between effectiveness and efficiency, since it helps to know the quality of the shielding and the validity of the radiation devices

Chapter Eight

Future Work and Recommendations

The project system was designed to detect X-Ray leakage outside radiology department, but this system is not sufficient to give the exact total measurement because the doses and readings are changing by the time. Also, the charge of the battery empties very fast with using and the data collected cannot share with other. hence, it needs to improve its features that could be added laterally like continuously reading signal, usage the USB connection with the computer and battery rechargeable port. it also could be added the Wi-Fi module that allow to participate the output data with the other people via the mobile phone.