การพัฒนาระบบเฝ้าระวังรังสีแบบประหยัดสำหรับตรวจบุคคลเดินผ่าน

นายเทด ไว ตุน

วิทยานิพนธ์นี้เป็นส่วนหนึ่งของการศึกษาตามหลักสูตรปริญญาวิทยาศาสตรมหาบัณฑิต
สาขาวิชาเทคโนโลยีนิวเคลียร์ ภาควิชาวิศวกรรมนิวเคลียร์
คณะวิศวกรรมศาสตร์ จุฬาลงกรณ์มหาวิทยาลัย
ปีการศึกษา 2558

Development of An Economical Walk-through Radiation Monitoring System

Mr. Thet Wai Tun

A Thesis Submitted in Partial Fulfillment of the Requirements
for the Degree of Master of Science Program in Nuclear Technology
Department of Nuclear Engineering
Faculty of Engineering
Chulalongkorn University
Academic Year 2015

Thesis Title	Development of An Economical Walk-through Radiation Monitoring System
By	Mr. Thet Wai Tun
Field of Study	Nuclear Technology
Thesis Advisor	Mr. Decho Thong-aram
Thesis Co-Advisor	Assistant Professor Suvit Punnachaiya

Accepted by the Faculty of Engineering, Chulalongkorn University in Partial Fulfillment of the Requirements for the Master's Degree

....Dean of the Faculty of Engineering

(Professor Bundhit Eua-arporn, Ph.D.)

THESIS COMMITTEE

....Chairman

(Associate Professor Nares Chankow)

....Thesis Advisor

(Mr. Decho Thong-aram)

....Thesis Co-Advisor

(Assistant Professor Suvit Punnachaiya)

....Examiner

(Associate Professor Somyot Srisatit)

....External Examiner

(Assistant Professor Attaporn Pattarasumunt)

เทด ไว ตุน : การพัฒนาระบบเฝ้าระวังรังสีแบบประหยัดสำหรับตรวจบุคคลเดินผ่าน (Development of An Economical Walk-through Radiation Monitoring System) อ.ที่ปรึกษาวิทยานิพนธ์หลัก: เดโช ทองอร่าม, อ.ที่ปรึกษาวิทยานิพนธ์ร่วม: สุวิทย์ ปุณณชัยยะ, 85 หน้า.

งานวิจัยนี้มีวัตถุประสงค์ในการพัฒนาระบบเฝ้าระวังรังสีแบบประหยัดสำหรับตรวจบุคคลเดินผ่านเพื่อใช้ในงานป้องกันการเคลื่อนย้ายต้นกำเนิดรังสีออกจากห้องปฏิบัติการวิจัยทางนิวเคลียร์โดยไม่ได้รับอนุญาตและการลักลอบไปใช้ในทางผิดกฎหมายระบบเฝ้าระวังรังสีที่พัฒนาขึ้นออกแบบให้ใช้วัสดุและอุปกรณ์ซึ่งหาได้ง่ายและมีราคาไม่แพงเป็นหลัก โดยเลือกใช้หัววัดเรืองรังสี NaI(Tl) ขนาด 3”x 3” จำนวน 2 หัวสำหรับการวัดรังสีแกมมาติดตั้งในโครงเสาประตูสำหรับเดินผ่านที่ทำด้วยท่อ พีวีซีขนาด กรอบ 90 x 200 ซ.ม. โครงสร้างของระบบเฝ้าตรวจประกอบด้วยระบบนับรังสีแบบรวมสัญญาณสองหัววัดเรทมิเตอร์ ระบบตรวจการเข้า/ออกแบบสองทิศทาง ระบบส่งสัญญาณเสียงเตือนและระบบบันทึกการเข้า/ออก ด้วยกล้องโทรทัศน์วงจรปิด ผลการทดสอบการทำงานของระบบด้วยการถือกล่องต้นกำเนิดรังสี Cs-137 ความแรงรังสี 1 ไมโครคูรี เดินผ่านประตูของระบบที่ความเร็วประมาณ 1.4 เมตร/นาทีพบว่าระบบสามารถตรวจพบและทำงานอย่างถูกต้องแสดงให้เห็นว่าระบบที่ พัฒนาขึ้นสามารถใช้ในงานความมั่นคงปลอดภัยต้นกำเนิดรังสีที่แผ่รังสีระดับต่ำ อีกทั้งยังช่วยเพิ่มประสิทธิภาพในการดูแลความปลอดภัยของเจ้าหน้าที่ความ ปลอดภัยทางรังสีของห้องปฏิบัติการรังสีด้วย

ภาควิชา วิศวกรรมนิวเคลียร์	ลายมือชื่อนิสิต ....
สาขาวิชา เทคโนโลยีนิวเคลียร์	ลายมือชื่อ อ.ที่ปรึกษาหลัก ....
ปีการศึกษา 2558	ลายมือชื่อ อ.ที่ปรึกษาร่วม ....

5670566321 : MAJOR NUCLEAR TECHNOLOGY
KEYWORDS: RADIATION MONITOR / WALK THROUGH RPM / RADIOACTIVE SOURCE SECURITY / RATEMETER / SIGNAL SUMMING

THET WAI TUN: Development of An Economical Walk-through Radiation Monitoring System. ADVISOR: MR. DECHO THONG-ARAM, CO-ADVISOR: ASST. PROF. SUVIT PUNNACHAIYA, 85 pp.

This research aimed to develop an economical Walk-through Radiation Monitoring System (WRMS) for preventing the radioactive materials from unauthorized movement and also illegal trafficking. The developed monitoring system was constructed by mainly using of local materials and inexpensive devices. Two 3”x3” NaI(Tl) scintillation detectors were employed for gamma detection and installed in a pair of PVC pillar gate with 90cm x 200cm frame size. The system structure composed of: dual detector pulse summing counter, ratemeter, bi-directional occupancy sensor, radiation alarm warning circuit, and video surveillance recording from CCTV system. The developed system was tested by a person carry a 1 μCi of Cs-137 source walk-through the gate with approximately walking speed of 1.4 m/s. It was found that the system could detect the source and worked properly. With this level of sensitivity, it could be applied for low radiation level source security and also increasing safety control efficiency of the radiation safety officer in laboratory.

Department:	Nuclear Engineering	Student's Signature	....
Field of Study:	Nuclear Technology	Advisor's Signature	....
Academic Year:	2015	Co-Advisor's Signature	....

ACKNOWLEDGEMENTS

First of all, I would like to show my deepest gratitude to my respected thesis advisor Mr. Decho Thong-Aram and co-advisor Assistant Professor Suvit Punnachaiya for their kind academic guidance, support, very helpful discussion, suggestion and motivation on fulfilling my thesis research.

I would also like to thank other committee members of my thesis, Associate Professor Nares Chankow, Associate Professor Somyot Srisatit and Assistant Professor Attaporn Pattarasumunt for their constructive criticisms and suggestion that really helped me to polish this work. Not forgetting Dr. Kamontip Ploykrachang for her teaching on the programming of PIC microcontroller.

Furthermore, I would like to thank the CBRN Centre of Excellence, European Union for providing me the scholarship. I also thank all of the professor in the Department of Nuclear Engineering, Chulalongkorn University for their support and teaching.

Last but not least, I would like to thank all of my friends in Nuclear Security and Safeguards Program.

CONTENTS

Page

Page

Page

Page

LIST OF TABLE

LIST OF FIGURE

CHAPTER 1

INTRODUCTION

1.1 Background

Radioactive sources are used extensively throughout the country for various applications including medical, industrial, agricultural and research. All radioactive materials need to be properly secured and accounted to prevent their unauthorized movement and also illegal trafficking. It's necessary to do monitoring of these materials even in very small quantities not only at the entry/exit gates of the nuclear facilities but also at entry and exit ports of the country [1]. Different places would have their unique requirements on the radioactive source monitoring system. For example, the one that used in the port should be able to withstand with temperature change since they are used at outdoor.

Recently, securing of radioactive source at the facility has become the concern for preventing the development of dirty bomb. Nuclear security focuses on the prevention of, detection of, and response to, criminal or intentional unauthorized acts involving or directed at nuclear material, other radioactive material, associated facilities, or associated activities (IAEA) [2]. All laboratories where sources of radiation are used or stored are designated as restricted areas. Surveillance and locking unoccupied rooms where radiation sources are in use or in storage are the primary means of limiting access and securing radiation sources. The radiation sources must be protected from unauthorized removal through the use of locked containers and placed under area surveillance. The walk-through radiation portal monitor (WRPM) is one of most important tool for radiation monitoring of sources carrying in/out of the room without permission or some contamination by the use of unseal-source from the laboratory experiment.

This study aims to develop an economical walk-through radiation portal monitor system which plays an important role in detecting the movement of radioactive source. This RPM is design to be used at the laboratories using radioactive materials. From the past, laboratories are normally lack of physical protection system such as access control and radiation monitoring system. People can get in and out easily at these facilities. Therefore, a RPM is required to install in these facilities to prevent any unauthorized movement of the radioactive source. There are many type of commercial walk-through RPM and different features. Some security functions which we need may not be included in a single unit. Moreover the commercial system is very expensive and need a budget for supporting to maintain in future. By above reasons, the development of an economical walk-through RPM is interested.

1.2 Objective

The objective of this study was to develop an economical walk-through radiation monitoring system for nuclear laboratory security.

1.3 Scopes

a) Develop a bi-directional walk-through radiation monitoring system with closed-circuit television (CCTV), and a computer record system.
b) Develop the gamma detection, alarm and interfacing system.
c) Develop the software for controlling the system operation.
d) Test the system such as sensitivity, data communication and data record.

1.4 Expected Benefits

This low cost RMS can fulfill both the nuclear security and safety needs for the laboratories.

1.5 Literature Review

Several researches related with the development of pedestrian radiation portal monitor and walk-through radiation portal monitor system were done and published by the researchers. The following were the summaries for some of them.

In 2005, Detection of Unauthorized Movement of Radioactive Sources in the Public Domain for Regaining Control on Orphan Sources-Systems and Feasibility was published by Harikumar M et. al. [1]. This paper describes the systems were developed by using the plastic scintillators and their applications in monitoring in the public domain in India. The developed systems were a portal monitor for pedestrian and a camouflaged Limb/Pole monitor with sensitivity of few hundred mg of Pu and detect a low level (order of kBq) of Cs-137 or Co-60. The false alarm rate of the system is less than 2%. Figure 1.1 shows the schematic diagram of their design while Figure 1.2 shows the block diagram of the developed system.

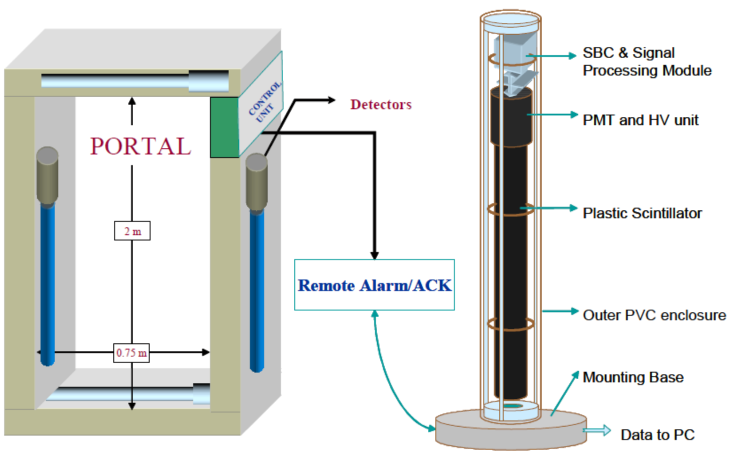


Figure 1.1 Schematic sketch of Portal Monitor and Limb Monitor developed by Harikumar M et. al. [1]

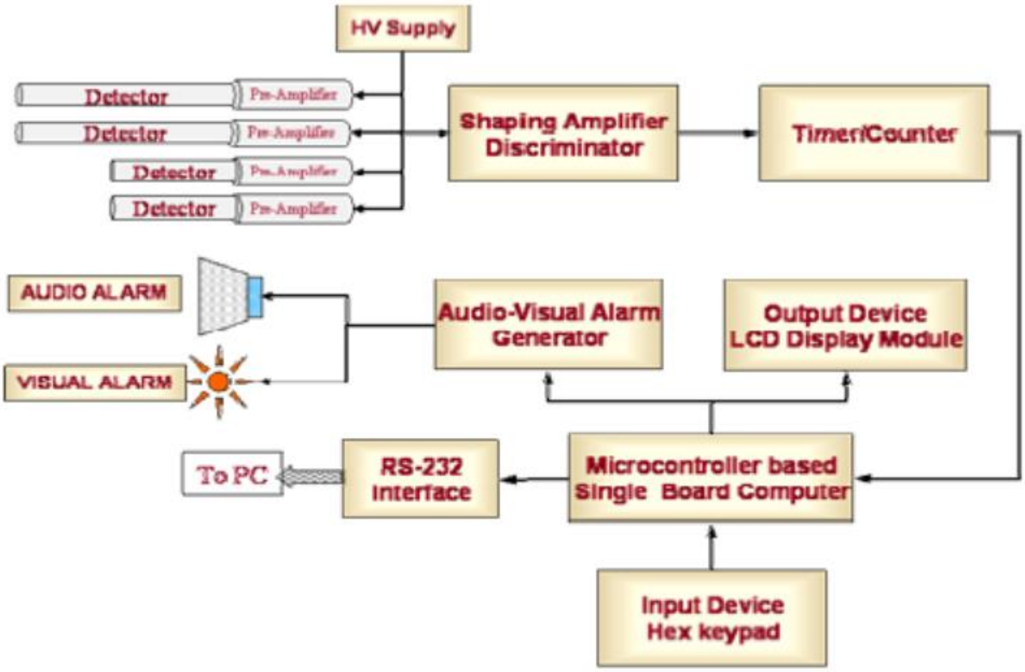


Figure 1.2 Block Diagram of Portal Monitor and Limb Monitor developed by Harikumar M et. al. [1]

In 2009, Indigenous pedestrian portal monitor radiation detector design for safeguard applications in Brazilian fuel cycle facilities was published by Miesher L. Rodrigues et. al. [3]. They performed the preliminary studies on their indigenous design of radiation pedestrian portal monitor detector (RPPMD) to estimate initial geometries, materials and performance of the initial design according to criteria suggested by ANSI N42.38-2006 standard [3]. They conducted numerical simulations using GEANT4 code, an open source Monte Carlo toolkit simulation package, to track particle interactions in matter. At the end of the study, they suggested some changes on the initial design of the RPPMD. They also suggested that the need of considering the background radiation effect to statistically address their problems.

In 2013, a multiple-detector Radioactive Material Detection Spectroscopic (RMDS) portal was published by Ilan Yaar and Ilya Peysakhov [4]. This paper described an optimization process for a Radioactive Material Detection Spectroscopic (RMDS) portal, designed to detect and identify radioactive materials concealed inside cargo containers [4]. A combination of conventional 3”x 3” NaI(Tl) gamma detectors and ^{3}He neutron detectors were used in the system. The developed system was placed in several locations in Israel to perform field tests. The developed RMDS was able to fulfill the demands of the ANSI Standard 42.38. Figure 1.3 shows the block diagram of their system.

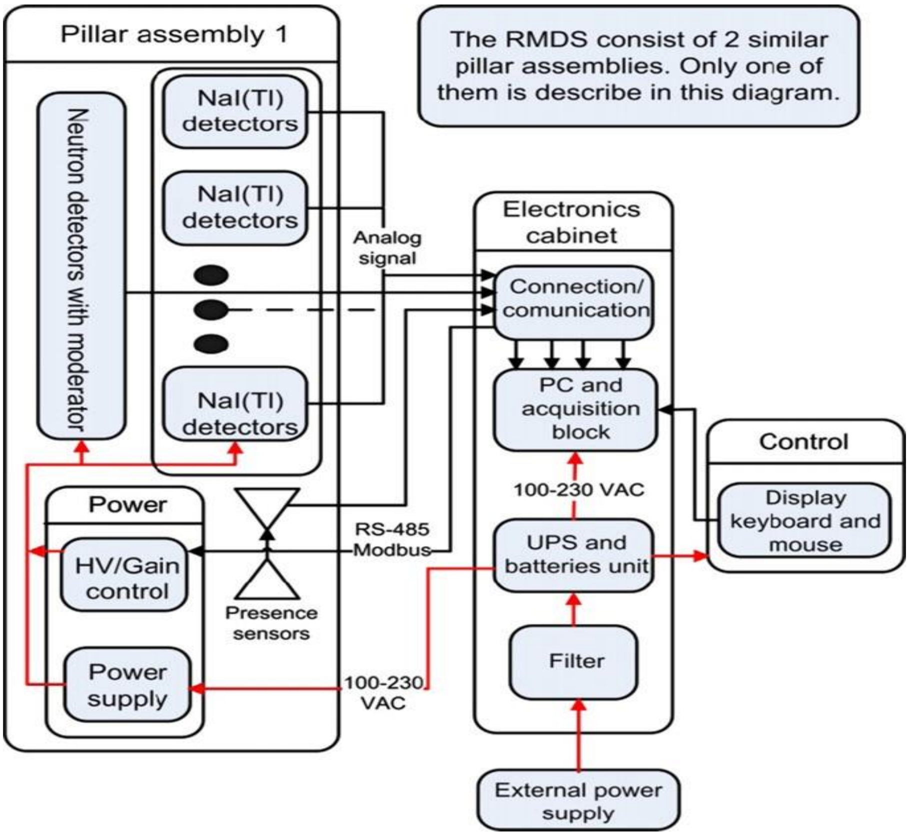


Figure 1.3 Principal block diagram of the RMDS system developed by Ilan Yaar and Ilya Peysakhov [4].

In 2014, Identification of radionuclides for the spectroscopic radiation portal monitor for pedestrian screening under a low signal-to-noise ratio condition, carried out by E. Min et. al. [5]. They developed the radionuclide identification method for the spectroscopic portal monitor (SPM) for pedestrian screening using a signal NaI(Tl) detector that is small in size (2”) [5]. The proposed algorithm is competitive with the commercial method our radionuclide identification method can be successfully applied to the SPM for pedestrian monitoring with a small detector size and a short scan time. Figure 1.4 shows the block diagram of their design.

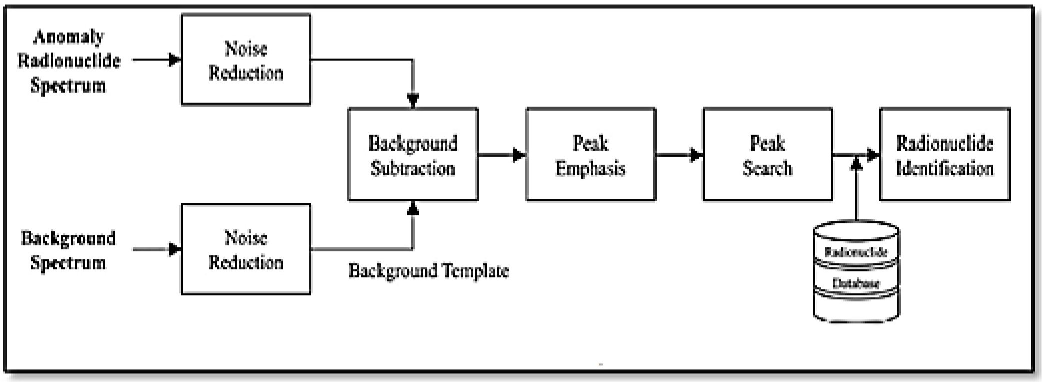


Figure 1.4 The block diagram of the spectroscopic radiation portal monitor developed by E. Min et. al. [5]

CHAPTER 2

THEORY AND PRINCIPLE

2.1 Nuclear Security

The basic definition for nuclear security is the prevention of, detection of, and response to, criminal or intentional unauthorized acts involving or directed at nuclear material, other radioactive material, associated facilities, or associated activities [2]. Whereas the associated facility is referring to a facility (including associated buildings and equipment) in which nuclear material or other radioactive material is produced, processed, used, handled, stored or disposed of and for which an authorization is required.

2.1.1 Nuclear Security in State Level

In state level, state implements the nuclear security plan by establishing a comprehensive nuclear security regime within the State. The regime is literally defined as a system of components to achieve a set of desired objectives. The objective of a State's nuclear security regime is to protect persons, property, society, and the environment from harmful consequences of a nuclear security event. The effectiveness of the nuclear security regime in one State depends on the following;

(a) The rules and regulations developed by the state,

(b) The effective implementation within the state, and

(c) The effectiveness of the nuclear security regimes in other States.

There are twelve essential elements that should to be taken in account to the national nuclear security regime [6];

(a) State responsibility

(b) Identification and definition of nuclear security responsibilities

(c) Legislative and regulatory framework

(d) International transport of nuclear material and other radioactive material

(e) Offences and penalties including criminalization

(f) International cooperation and assistance

(g) Identification and assessment of nuclear security threats

(h) Identification and assessment of targets and potential consequences

(i) Use of risk informed approaches

(j) Detection of nuclear security events

(k) Planning for, preparedness for, and response to a nuclear security event

(l) Sustaining a nuclear security regime

2.1.2 Nuclear Security in Facility Level

Prevention, detection and response are three basic elements for nuclear security which should be implemented in both state level and facility level. In the facility level, prevention includes all such security measures that may serve either as deterrence or prevent any unauthorized access to a protected nuclear facility and associated facilities. In the other hand, detection includes all such security measures that help in detection of any unauthorized access to a protected nuclear facility. While the last element, response is the security strategy used to defeat an adversary by preventing it from accomplishing its tasks either by containment or by neutralization.

In order to overcome the both external adversary and insider threat, the security measures that implemented by the facility operators should include physical protection related measures and facility functions related measures. The physical protection measure is basically referring to the hardware that can be installed to prevent the intrusion of the adversary and detect if there is any intrusion. For example, the good preventative physical protection measure may include fence installation at the boundaries, display of warning signs and visible guards and strict access control system while installation of motion detection sensors and closed circuit television (CCTV) are the detective physical protection measures.

Some of the preventive measures related to the facility functioning are identity verification, strict background check, restriction on private vehicles and escort and surveillance of the temporary workers. There are several detection security measures related to facility functions on daily basis such as nuclear material accounting and control, two-person rule, job surveillance, vehicle security system and uses of radiation detectors.

2.2 Security of Radioactive Sources

In comparison with radioactive materials, the nuclear material which is one of the key components in developing nuclear weapons remains as the main concern in nuclear security. Thus, the works in securing the nuclear materials stockpile are one of the global missions among the international committees. However, as mentioned in earlier part of the discussion, the security of radioactive sources is also very important to against nuclear terrorism. This is also recognized by the nation leaders who attended the Nuclear Security Summit [7]. All the radioactive sources should be secured in a way consistent with the international guidance provided by IAEA such as Nuclear Security Series and the Code of Conduct on Safety and Security of Radioactive Sources.

2.2.1 Responsibilities of the State and Operator

IAEA provides the guidance and standard for the security of radioactive source. Nevertheless, the security of radioactive sources remains as the responsibility of the state and the operator. The responsibility of the state is establishment, implementation and maintenance of a nuclear security regime (stated in 2.1.1) including the setup of the legislative framework (law and regulation) related with protecting the nuclear materials and the establishment of the regulatory body to do enforcement of the law. The import and export of radioactive sources should also be considered from the safety and security aspect [8]. It is very important for the state to provide the guideline on implementing security measures so that the operators are able to comply all the necessarily requirements. Besides that, the monitoring of all the border crossings should be implemented at all entry and exit points in a country to prevent the illicit trafficking of radioactive materials. All detected events should be reported to the Incident and Trafficking Database which established by the IAEA since 1995 [9].

According to the Nuclear Safety Glossary published by the IAEA, the operator is referred to any organization or person applying for authorization or authorized and/or responsible for nuclear, radiation, radioactive waste or transport safety when undertaking activities or in relation to any nuclear facilities or sources of ionizing radiation [10]. The operator can be come from various organizations, such as governmental bodies, private individuals, consignors or carriers, hospitals, self-employed persons, etc. The operators have the primary responsibility for implementing and maintaining security measures for radioactive sources in accordance with national requirements [11]. They have to fulfill all the requirement set by the regulatory body and obey all the laws and regulations. Any absence or discrepancy should be promptly investigated and reported to the regulatory body.

A human factor is generally a contributor to all nuclear security related incidents as well as malfunctions related to activities involving radioactive material. Therefore, the state should promote the establishment of the nuclear security culture with respect radioactive source. A dynamic and effective security culture should exist at all levels of operator staff and management. The nuclear security culture is defined as the assembly of characteristics, attitudes and behavior of individuals, organizations and institutions which serves as a means to support and enhance nuclear security [12].

2.2.2 Source Security Concepts

A security system of the radioactive source should be designed to perform basic security functions: deterrence, detection, delay, response, and security management [11].

- Deterrence

Deterrence occurs by implementing measures that are perceived by potential adversaries as too difficult to defeat. Examples of deterrence are the presence of fences at the outer boundary, the presence of security guards in parking lots, adequate lighting at night around the facility and posting of warning signs.

- Detection

Detection is the discovery of an adversary action. Detection can be achieved by several means, including visual observation, video surveillance, electronic sensors, accountancy records, seals and other tamper indicating devices, process monitoring systems, and other means.

- Delay

Delay is comes after detection as a security function to slow down the adversary progress. Delay can be accomplished by personnel, barriers and locks.

- Respond

The response function consists of the actions taken by the response force to prevent adversary’s success. These actions, typically performed by security or law enforcement personnel, include interrupting an adversary while the attempted unauthorized removal or sabotage is in progress, preventing the adversary from using the radioactive source to cause harmful consequences, recovering the radioactive source, or otherwise reducing the severity of the consequences.

- Security management

The security management includes ensuring adequate resources for the security of sources. It also includes developing procedures, records, and plans for the security of sources and for a more effective security culture. This term also includes developing procedures for the proper handling of sensitive information and protecting it against unauthorized disclosure.

A well designed security system should integrate measures to perform all five security functions so as to effectively secure the target from the threat. The concepts of "balanced protection" and "defense in depth" should be used for implementing the source security system. Balanced protection is a concept of equivalent security functions that provides adequate protection against all threats along all possible pathways while the concept of defense in depth can be defined as the combination of multiple layers of systems and measures that have to be overcome or circumvented before nuclear security is compromised. The security requirements for radioactive material require a designed mixture of hardware (security devices), procedures (access control, follow-up, etc.) and facility design. Figure 2.1 shows the concept of defense in depth in the facility design for detecting the unauthorized access.

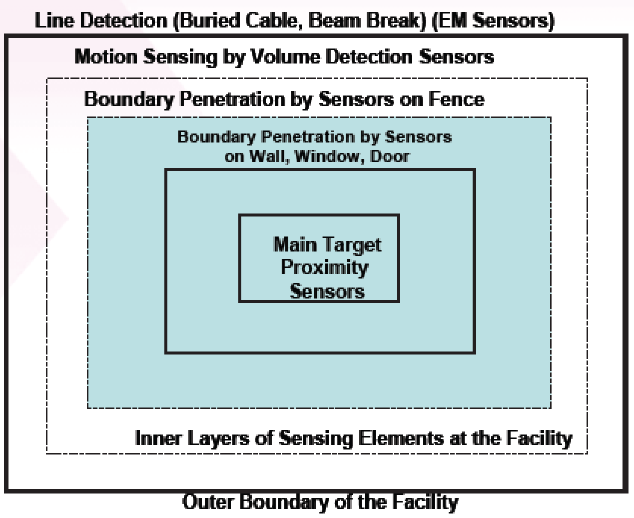


Figure 2.1 The concept of defense in depth applied in the designing of the intruder detection system

2.2.3 Categories for Commonly Used Sources

According to the recommendation of IAEA, security requirements for radioactive material should be based on a graded approach, taking into account the principles of risk management, including such considerations as the level of threat and the relative attractiveness of the material for a malicious act leading to potential unacceptable radiological consequences (based on such factors as quantity, its physical and chemical properties, its mobility, and its availability and accessibility). Security requirements should be adapted depending on whether the radioactive material concerned is sealed source, unsealed source, disused sealed source or waste, and should cover transport [2].

A categorization system should be established that implements the graded approach by associating security levels with specific types and quantities of radioactive material, thereby ensuring greater levels of protection for radioactive material for which a malicious act could result in higher consequences. The categorization system should take aggregation of radioactive material into account as appropriate [2]. The categorization of the radioactive source can be done according to the TECDOC 1344 issued from IAEA (Categorization of Radioactive Source). By using this standard, the Category 1 sources are considered to pose a high risk to human health if not managed safely and securely, and Category 5 sources a low risk. Table 1 shows the categorization of commonly used sources. The categorization system is based on the potential for sources to cause deterministic effects and uses the 'D' values as normalizing factors. The definition and other information of D-value are stated in TECDOC 1344 [13].

Table 2.1 The categorization of commonly used radioactive sources [13].

Category	Categorization of common practices[a]	Activity ratio[b] (A/D)
1	• Radioisotope thermoelectric generators (RTGs) • Irradiators • Teletherapy • Fixed, multi-beam teletherapy (gamma knife)	A/D ≥ 1000
2	• Industrial gamma radiography • High/medium dose rate brachytherapy	1000 > A/D ≥ 10
3	• Fixed industrial gauges -level gauges -dredger gauges -conveyor gauges containing high activity sources -spinning pipe gauges • Well logging gauges	10 > A/D ≥ 1
4	• Low dose rate brachytherapy (except eye plaques and permanent implant sources) • Thickness/fill-level gauges • Portable gauges (e.g. moisture/density gauges) • Bone densitometers • Static eliminators	1 > A/D ≥ 0.01
5	• Low dose rate brachytherapy eye plaques and permanent implant sources • X ray fluorescence devices • Electron capture devices • Mossbauer spectrometry • Positron Emission Tomography (PET) checking	0.01 > A/D ≥ Exempt/D

2.3 Radiation Portal Monitor System

Previously, the radiation portal monitor (RPM) was mostly installed in the nuclear facility for detecting the contamination of radiation and used for nuclear safety purpose. With the arising of nuclear security concerns, the RPMs are distributed across the globe Under Second Line of Defense which initiated by the Department of Energy’s National Nuclear Security Administration (DOE/NNSA) with the goal of “deterring, detecting, and interdicting” the illicit trafficking of nuclear material that can be used in nuclear weapons or RDDs. These RPMs are primarily located in former Soviet Union states and major international shipping ports [14]. These RPMs are the main role players in detecting the illicit trafficking of the radioactive material and the detective nuclear security measure for state level.

The RPMs are fix-installed radiation detection systems designed for automated screening of pedestrians, vehicles and trains passing through the detection zone of RPM for presence of gamma and neutron radiation. These pedestrian and vehicle radiation monitors are designed to be used at checkpoints such as those at road and rail border crossings, airports or maritime ports. The RPMs can provide high sensitivity monitoring of a continuous flow of scanning targets while minimizing interference with the flow of traffic. The sensitivity of the system depends upon the proximity of the detector and source and the speed of the vehicle [15].

2.3.1 Basic Structure of RPM

Generally, the RPM consists of two pillars which contain the subsystem modules of radiation sensitive detection assemblies and other associate system. Depends on its purpose, the neutron or gamma radiation or both can be detected by the RPMs. The RPMs generally consists of the following component;

(a) Vertical pillars

The pillars are used to control the passage of the pedestrian or vehicle through the detection zone. They are spaced enough apart to permit safe passage for pedestrian and vehicle traffic.

(b) Gamma detectors

Gamma detectors are very important to detect the presence of radioactive source. Most of the radioactive materials decay with releasing the gamma radiation. Due to its high penetration power, gamma radiation is become the detection target rather than beta and alpha particles.

(c) Lead shielding

The lead shielding is placed on the rear and sides of the gamma detectors, to reduce the background radiation and increase the ability of the system to detect radioactive material passing through the portal.

(d) Neutron detectors

The neutron detector is installed to detect neutron from self-fission in case of RPM with purpose of detecting nuclear materials.

(e) Occupancy sensor

The occupancy sensors are used to detect the presence of pedestrian or vehicle that passing through the portal gate. The use of suitable occupancy sensors that trigger the data collection process is essential for achieving the required low false alarm rate.

(f) Alarm indicator

The alarm indicator is used to inform the security office and pedestrian about the presence of radioactive or nuclear materials.

(g) Monitoring Software

All the collected information and alarm from the RPM should be recorded and stored in the computer system.

(h) Uninterruptable Power Supply (UPS)

The UPS is used for maintaining the RPM system in case of a failure of electrical power supply.

2.3.2 Type of RPMs

There are mainly two types of RPMs i.e. RPMs for pedestrian or also known as walk-through RPMs and RPMs for vehicles such as car, truck and trains. Due to the difference between human body and vehicle, the technical specifications and features are different for pedestrian and vehicle monitors. For example, the passage for pedestrian monitoring should be restricted in such a way that the person being screened remains at a distance of 1 m or less from the instrument while for vehicle monitoring, two pillar monitors are required and the distance between pillars should be not more than six meters [16]. The vehicle portal monitors always have an occupancy sensor while the pedestrian monitors may or may not have an occupancy sensor. If an occupancy sensor is used, it has to be positioned in such a way that it is triggered only when the area being screened by the instrument is occupied and not triggered by individuals walking in the vicinity of the monitor. Figure 2.2 shows the typical vehicle and pedestrian radiation monitors.

(a) Vehicle monitors installed at a border crossing. (b) Typical pedestrian monitor installed at an airport.

Figure 2.2 The typical vehicle and pedestrians radiation monitors [16].

2.3.3 Gamma Alarm Setting

There are three types of gamma alarms i.e. false alarm, nuisance alarm and real alarm. The radiation alarm of monitoring instruments should be set up so the false alarm rate is minimized as much as possible. Some false alarms will occur because of the statistical fluctuations in the gamma background count rate.

The radioactive decay is a random process. In any series of measurements, such as measuring the count rate each second, the frequency of occurrence of any particular value follows some probability distribution such as normal distribution (Gaussian's). Figure 2.3 shows the statistical distribution of count rates. Supposed A represents the count of sample plus the background count and B represents the background count. Due to the statistical distribution, there might be an overlapped region between these count rates (represented by C).

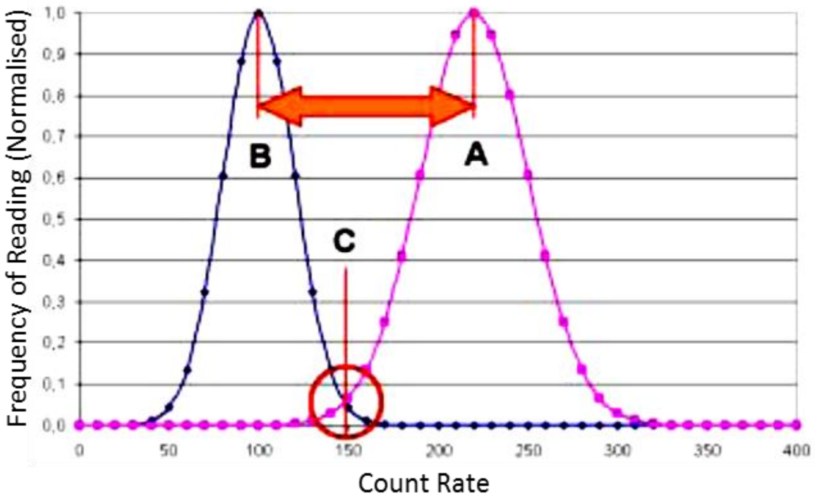


Figure 2.3 The statistical distribution of background count rate and sample count rate. (taken and modified from [17])

Due to these distributions, the selection of an alarm threshold of a monitoring instrument has to be set appropriately. The alarm threshold can be expressed in terms of multiples of background, or as a multiple of the standard deviation of the background count rates [17]. According to the guidance of IAEA

(TECDOC-1312), for monitoring of pedestrians or cars, where it is expected that innocent alarms are unlikely to be happened frequently, a lower investigation level of 1.2 times natural background can be used as the alarm threshold value. However, a higher investigation level which is 1.4 times natural background should be applied for truck monitoring.

If the alarm threshold is set in term of multiple of standard deviation of the background count rate, the threshold must be set considerably below the nominal investigation level chosen to allow for statistical variations. In order to achieve a detection probability of 99.9%, the instrument threshold has to be set at least at 3 σ below the desired level in order to catch all those events that fall statistically on the 'low side'. On the other hand, the instrument setting must stay safely away from values too close to background. For a false alarm rate of 1 in 10 000 the instrument alarm threshold must be set at least 4 σ higher than average background for systems under Gaussian assumptions (3 σ for a false alarm rate of 1 in 1000) [17].

2.4 Walk-Through Radiation Monitoring System

The vehicle and pedestrian RPMs are similar in basic structure while some technical specifications are different. In the vehicle RPMs the passing speed of vehicle is 8 km/h but the walk-through radiation monitoring system has to be suitable for screening the pedestrian with a normal walking speed of at 1.4m/s or 5km/h. The components of walk-through RMS are designed for indoor operation. The radiation measuring system is the main part of the walk-through RMS.

2.4.1 Gamma Detection Used in RMS

The detection of the gamma radiation in the RMS was based on the scintillations process of the scintillator. The detection of ionizing radiation by the scintillation light produced in certain materials is one of the oldest techniques on record. The scintillation process remains one of the most useful methods available for the detection and spectroscopy of a wide assortment of radiations [18].

Scintillation is a flash of light produced in a transparent material by the passage of a particle (an electron, an alpha particle, an ion, or a high-energy photon). The intensity of scintillated light emission is proportional to the energy of incident radiation while the amounts of scintillated light are proportional to the number of incident radiation. These scintillated lights can be converted into pulse signal and measured. The detected information is used to calculate the amount of radiation exposure.

The scintillation detector is composed of two parts i.e. scintillator coupled with photosensitive device in encapsulation.

(a) Scintillators

Scintillators are photoluminescent materials that absorb energy from radiations, high energy particles, gamma radiation and x-rays, and fluoresce with a wavelength of light that is easily detected. These materials are transparent so that the emitted light can travel through the materials. Scintillation properties can be found in both organic and inorganic materials.

a. Organic scintillator

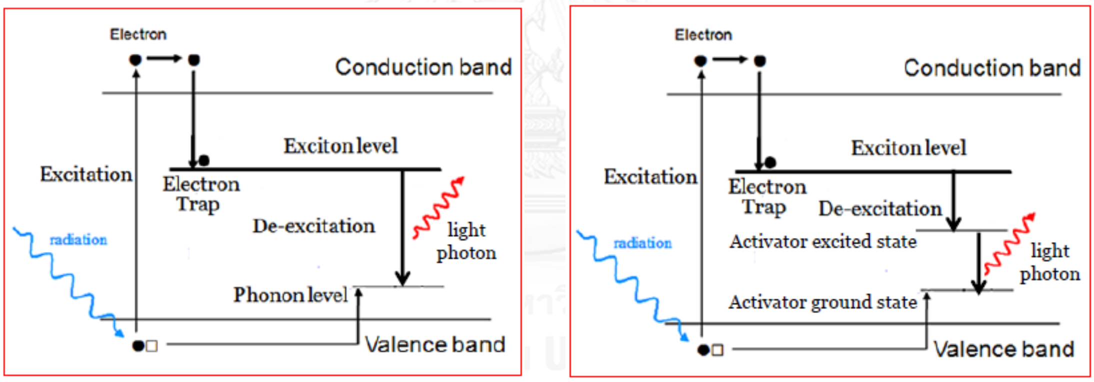
The materials that are efficient organic scintillators belong to the class of aromatic compounds. They consist of planar molecules made up of benzenoid rings. The production of light emission in organics scintillators is the result of molecule transition. The fluorescence process in organics arises from transitions in energy level structure of a single molecule and therefore can be observed from a given molecular species independent of its physical state. This behavior is contrast to the crystalline inorganic scintillators such as sodium iodide which require a regular crystalline lattice as a basis for the scintillation process.

The organic scintillators also are readily adaptable to the detection of fast neutron or photon by the addition of some suitable materials into scintillator. The organic scintillator can be divided into three categories i.e. crystal, plastic and liquid. Examples of organic scintillator are Naphthalene (crystal), trans-stilbene (crystal), Toluene PPO (liquid), and polystyrene-tetraphenyl-butadiene (plastic).

b. Inorganic scintillator

Most of the inorganic scintillators are crystals of the alkali metals, in particular alkali halide, which is activated with a small concentration of impurity. The most commonly used inorganic scintillator is Sodium iodide activated with Thallium, NaI(Tl). Other scintillators are CsI(Tl), CsI(Na), LiI(Eu) and CaF2(Eu).

The luminescence of inorganic scintillators can be generated by radiation induced exciton pair and de-excitaion of excited electron in electronic energy states of atom. Figure 2.4 shows the mechanism of inorganic scintillation process for pure and activated inorganic crystal.



a. Pure crystal b. Activated crystal

Figure 2.4 Scintillation process of inorganic crystal

(b) Photosensitive device

The photosensitive device is a device that optically coupled to the scintillation crystal for converting the extremely weak light output of a scintillation pulse into a corresponding electrical signal. Generally, there are two types of the photosensitive device for this purpose i.e. photomultiplier tube (PMT) and avalanche photodiode (APD). PMT is the most common photosensitive device used to couple with scintillator detectors. The PMT consists of a photocathode and usually a series of 10 dynodes include anode. An outer glass envelope serves as a pressure boundary to keep vacuum conditions inside the tube that are required for low energy electrons accelerated by internal electric fields. In Figure 2.5 shows the assembly diagram of NaI(Tl) scintillation detector.

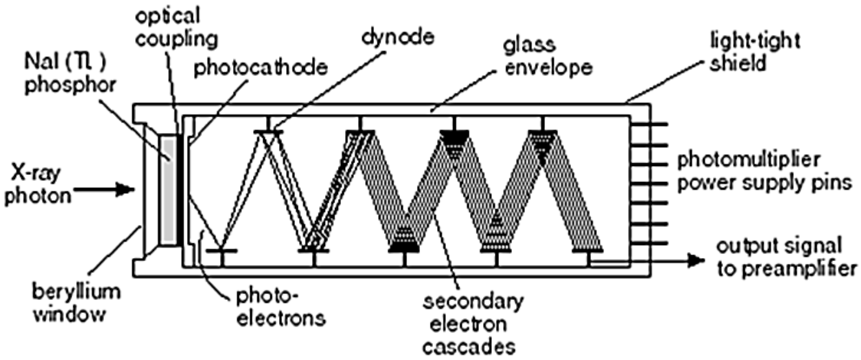


Figure 2.5 The diagram of NaI(Tl) scintillation detector.

The plastic scintillators are normally being used as the gamma detectors in the RPMs due to the durability and able to be fabricated in large volume to enhance the detection efficiency. However, the 3” X 3” NaI(Tl) scintillators are used in the work due to the limited availability of the instruments. The advantage of NaI(Tl) scintillators over the plastic scintillators is they are able to give the energy spectrum of incidence radionuclides which can help to identify the radioactive materials. However, one of the weak point which make the NaI(Tl) scintillators be the less preferably choice in the RPMs is that they are very sensitive with the temperature changes and moisture. However, this should not be the concern on the developed walk-through RMS system as the system is intended to be installed indoor.

2.4.2 Radiation Measuring System

The function of detector is to produce a signal for every nuclear radiation entering to it. These electrical signals created by principle of energy to charges conversion process through the interaction of radiation with the detector medium. The nuclear measurement is needed to quantify the amount of radiation detected either in mean of activity of the source or the energy of the radiation detected.

Nuclear instrumentation can be found in many different structures for supporting various activities. However, nuclear counting system can be divided in mainly three type’s i.e. integral counting system, differential counting system and coincidence counting system. The radiation measuring system used in this work is the integral counting system.

The integral counting system is mainly used to measuring the radioactivity or the strength of the radioactive materials. The type of nuclear instruments which utilize the integral counting system are including radiation counter, survey meter, dosimeter, contamination counter, alarm monitor, isotope calibrator and portal monitor. Figure 2.6 shows the block diagram for integral counting system and the function of each block/module in the system are discussed in Table 2.2.

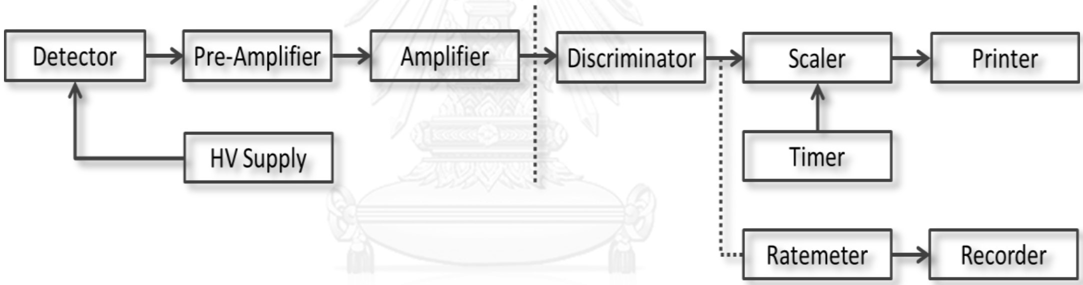


Figure 2.6 Block diagram for a particle counting system.

Table 2.2 The Nuclear Instrumentation Standard Module and Their Function.

Module	Description	Function
Pre-amplifier	The preamplifier conventionally provides no pulse shaping, and its output is a linear pulse. The decay time of the pulse is made quite large, typically 50 or 100 μs. Preamplifier usually located as close as to the detector.	- Maximize the signal to noise ratio by terminating the capacitance quickly - Provide output with low impedance that can drive through long connecting cable

Table 2.2 The Nuclear Instrumentation Standard Module and Their Function (continued)

Module	Description	Function
Amplifier	The pulse amplifier is used to gain up and shaping (CR-RC circuit) a pulse signal input into desired pulse shape i.e. semi-Gaussian.	- Pulse shaping and gaining - Pole-zero cancellation - Base-line restoration
High Voltage Supply	Almost all radiation detectors require the application of an external high voltage for their proper operations.	- Detector bias
Integral Discriminator	The simplest unit that can be used to produce the logic pulse if the input pulse amplitude exceeds a discrimination level.	- Cut off noise - Change linear pulse to logic pulse
Scaler/Counter	A simple digital register that is incremented by one count each time a logic pulse is presented to its input.	- Quantify the amount of input signal
Timer	The timer is used to start and stop the accumulation period for the counter.	- Control the period for counting
Ratemeter	The frequency to voltage converter by charge pumping. The accumulated pulses can be indicated by a display meter.	- Visual indication of count rate

2.4.3 Attached Monitoring Devices

Besides the radiation measuring system, the monitoring devices such as closed circuit television (CCTV) and occupancy sensor are also attached with the developed walk-through RMS. The CCTV, also known as video surveillance, is the use of video cameras to transmit a signal to a specific place, on a specific set of monitors. The term "CCTV" is usually applied to the cameras used for surveillance in areas that need attention such as banks, airports or convenience stores [19]. CCTV can be installed in the industrial plant to observe the process that might be harmful to human and the public area for surveillance purpose. In term of security, the CCTV can be used to deter the adversary from carrying out the task and also can be in data recording and providing evidence for crime analysis.

The occupancy sensor is used to inform the system that the presence of pedestrian or vehicles that passing through the portal gate. For the system which not collects the background data continuously, the occupancy sensor is also used to trigger the radiation measuring system. The alarm is only be triggered if there is an increase of radiation level when the portal gate is occupied, thus can reduce the problem of cross talk event.

Basically, the intrusion detection sensor can be categorized into two groups' i.e. active sensors and passive sensors. The active sensors refer to the sensor that has both transmitter and receiver while the passive sensors are the sensors measure the changes in the environment such as thermal radiation and sound. The occupancy sensors employed in the RPM is mostly the active-typed sensor for instant triggering of RPM system operation. In this work, the photoelectric sensors are used as the occupancy system in the walk-through radiation monitoring system. Photoelectric sensor is an active sensor that can be used to detect absence or presence of an object by using a light source and photoelectric receiver [20]. The set up of sensor may be in configuration of transmission or reflection detection technique.

2.5 Standard test for a radiation Portal Monitor

As mentioned in earlier part, the early uses of RPMs were mainly for the nuclear safety purpose. In 1995, the Federal Emergency Management Agency (FEMA), developed a test procedure of the contamination monitoring standard for a portal monitor used for radiological emergency response.

2.5.1 Federal Emergency Management Agency

The FEMA is an agency in United State (U.S.) which has a mission to support the citizens and first responders to ensure that as a nation is work together to build, sustain and improve our capability to prepare for, protect against, respond to, recover from and mitigate all hazards [21]. On 1st March, 2003, the FEMA became part of the U.S. Department of Homeland Security (DHS) and was given responsibility for helping to ensure that the first responders in U.S. were trained and equipped to deal with weapons of mass destruction.

2.5.2 Contamination Monitoring Standard for RPM

The standard test of the contamination monitoring standard for a portal monitor used in radiological emergency response or often known as FEMA-REP-21 was published on March 1995 [22]. The Standard set forth in this document is published as FEMA's Contamination Monitoring Standard for portal monitors used by State and local Governments in response to commercial nuclear power plant accidents. A portal monitor (stand-alone whole-body personal contamination monitor) used to monitor individuals exposed or potentially exposed to a plume of radioactive material must have the capability to detect one micro-curie (μCi) of radionuclides that emit beta and gamma radiation (radionuclides such as those that may be released following a reactor accident) in the form of surface contamination with a widespread non-uniform distribution over an individual.

In determination of compliance with the standard by the manufacturer, one or more cesium-137 source(s) with a total activity not exceeding one μCi shall be used for determining compliance with this Standard. Delectability of this amount of radioactivity shall be demonstrated with the Cs-137 source(s) located at several points along a vertical line centered between the two side columns of the portal monitor between 0.5 and 5½ feet above the base upon which the individual stands when being monitored.

CHAPTER 3

DESIGN AND CONSTRUCTION OF WALK-THROUGH RMS

3.1 System Configuration Design

The feature designed of the walk-through RMS was bidirectional occupancy sensing for incoming and outgoing security on a single portal gate unit. The system structure was consisted of two pillars which contained the gamma detection assembled in association with bidirectional occupancy sensor, front and rear closed-circuit television (CCTV) video camera, and alarm system with both audible/visual signals. The pillars was spaced enough apart to permit safe passage referred to standard door sizes [23]. The system operated by using internal battery power supply. Battery was constantly charged from the site's AC line during normal operation. A system integration of the developed walk-through RMS was shown in the block diagram of Figure 3.1.

Any person walks through the gate would be detected by the occupancy sensor. Meanwhile, the CCTV would record all the movement in the area of monitoring. If that person brought the radioactive source or contaminated with radioactive substance would be detected by the gamma radiation detectors located at both pillars. When the radiation level go higher than the threshold level setting then the alarm unit (sound and light indication) would be activated. This event would be recorded by the computer under a control function on microcontroller. For integrating all the components to become a complete walk-through radiation monitor system, a system program was developed for interfacing all the hardware into a computer system.

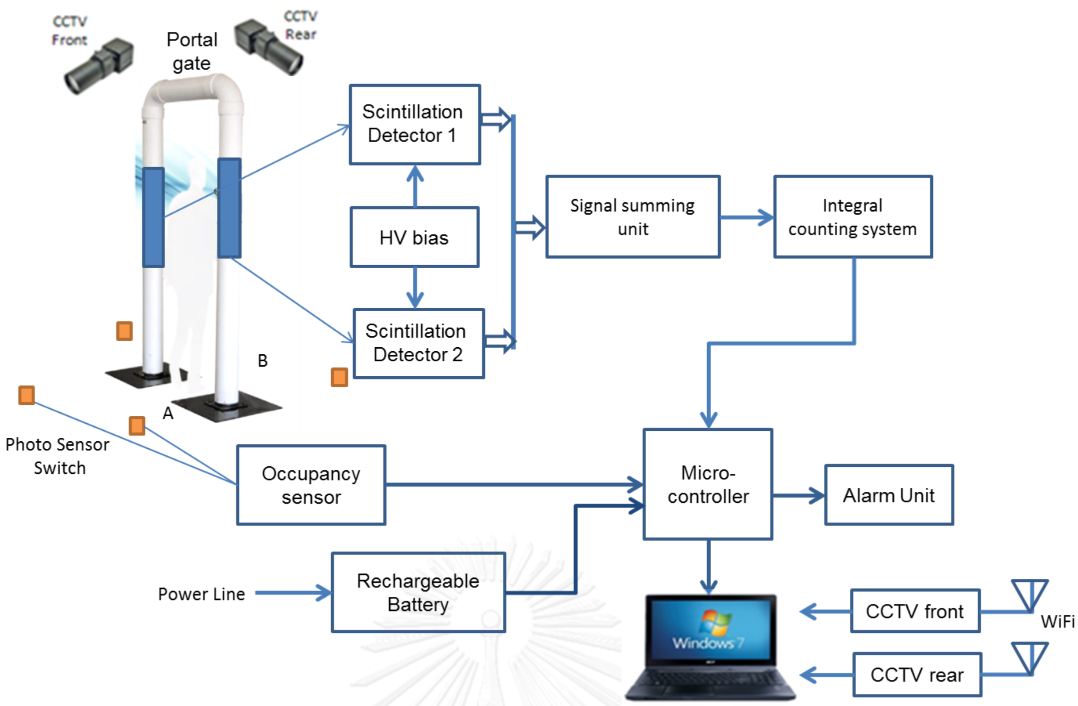


Figure 3.1 The walk-through radiation monitoring system integrated with complete security purpose.

3.1.1 Criteria for System Design

Generally, the walk-through portal radiation monitor was designed to meet the FEMA standard for Emergency Response Portal Monitoring (FEMA-REP-21). With the integration of occupancy sensors and CCTVs, the system was also able to fulfill the requirements of nuclear security. The criteria of designed walk-through RMS are stated as below;

- able to detect a Cs-137 source with activity ≥ 1μCi
- bidirectional operation
- only respond when people passes through the portal gate
- CCTV recording when movement detected in imaging area of monitoring
- alarm information i.e. data, time, and camera index are recorded in the computer
- the status of the system (occupied or ready) showed by LED indicator

- audio and light alarm indicator provided
- Uninterrupted Power System (UPS) equipped

3.1.2 System Hardware Design

There are four main parts of the system hardware i.e. the portal gate, the radiation detection system, occupational sensing system and the video recording system. The radiation detection system composed of two gamma detectors located in left and right of portal gate pillars. The 3” X 3” NaI(Tl) scintillation detectors were employed and assembled with high voltage bias power supply in each portal pillar. In order to reduce the background radiation and increase the ability of the system, for detection of low activity radioactive sources, the detectors with lead shielding of 4 mm thickness, covered at the rear and sides of the gamma detectors, were placed at 75 cm above ground which was around the upper legs position of the pedestrian.

The signal of two detectors were summed up and measured by the integral counting system. The analog summing technique was selected to sum up of the detector anode outputs and sent to the integral counting system. Two sets of IP video camera with wireless LAN interface were used for video surveillance at front and rear direction of the gate. Two sets of photo-switches were applied for bidirectional occupancy sensor (A and B sets) to trigger the system start and stop the gamma counting system. The system operated from an internal battery. The battery was constantly charged from the site’s AC line during normal operation. In the event of a power outage, the battery permits continued operation for at least 12 hours. More details on all three parts of the system will be discussed in following parts of the chapter (3.2 and 3.3).

3.1.3 System Control Program Design

The system hardware such as occupancy sensor, gamma detection and measuring system were integrated by using the microcontroller. The microcontroller was programmed for system controlling of occupancy sensing, gamma alarm detection, and alarm signal generation including alarm message sent to microcomputer for alarm event recording. The microcontroller and microcomputer were interfaced via cable RS-232. Part 3.4 will discuss more details on the system control program.

3.1.4 Inexpensive Device Selection

The occupancy sensors and the CCTVs were provided from the local electronic markets and shops. The E3F-DS30C4 photo switches which available in the electronic market were employed as the occupancy sensor. A reflector was also applied to increase the sensitivity of sensing and the effective range of the sensor. The IP cameras were used as the CCTVs in the walk-through RMS. Unlike CCTVs which require a digital video recorder (DVR), the IP cameras send the video data through WiFi or LAN cable. The IP cameras are the inexpensive devices which can be used for security surveillance purpose. As long as the protocol used are the same, different brands of the IP cameras can be monitored by the same software. The PIC 18F4553 microcontroller was selected due to the advantages for PIC microcontroller is inexpensive and easy to program.

3.2 Gamma Detection and Portal Gate Designs

Gamma detection system was the main part of system hardware in the walk-through RMS. A preliminary study on signal summing was carried out by using the standard nuclear instrumentation module (Nuclear Instrument Module, NIM) to figure out the optimum setting of the gamma detection system. The laboratory studied results led to system designed. All the nuclear measuring modules used in the walk-through RMS were developed in the Center of Excellent for Nuclear Material Analysis and Testing (NucMAT) by using local based knowledge, this including the high voltage module. The portal gate was designed according to the standard door size and the constructed by using the locally available raw materials and tools.

3.2.1 Dual Pulse Signal Summing System Study

There are two types of signal summing technique depend on the preferred signal: analog or digital. The configurations of both types of summing circuits are shown in Figure 3.2.

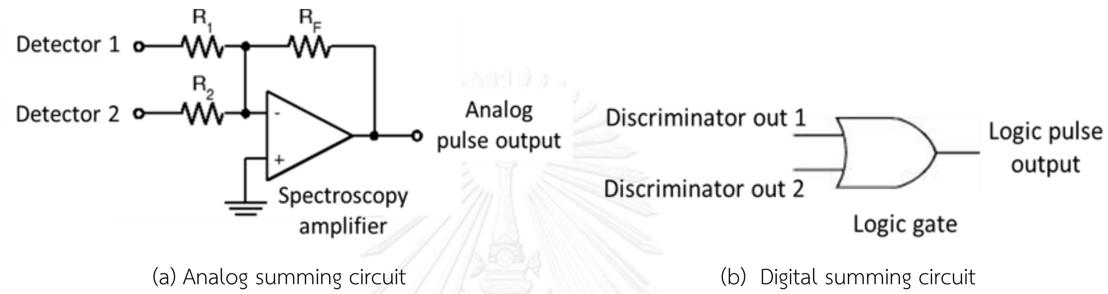
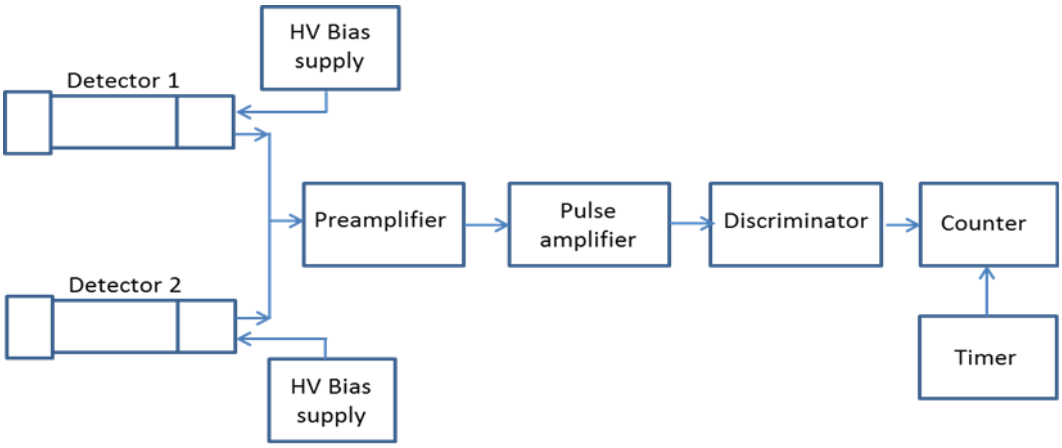
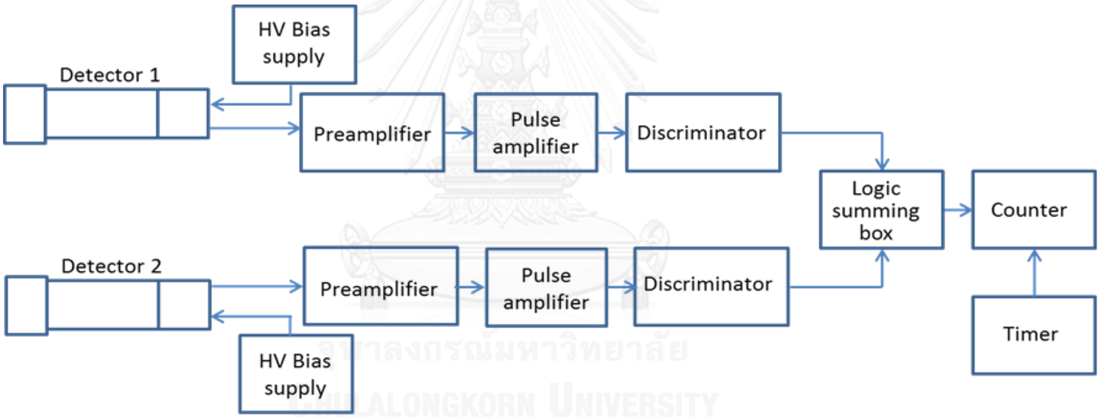


Figure 3.2 Signal summing technique

In the comparison of analog and digital signal summing technique, the two 3”x3” NaI(Tl) scintillation detector with the NIM counting system in associated with the signal summing circuits were employed. The integral counting system was applied gamma detection of the RMS. The spacing of two detectors was set at 80 cm. The schematic diagrams of both the signal summing systems are shown in Figure 3.3. Figure 3.3(a) shows analog summing signal from the both anode output of PMT tube bases directly while Figure 3.3(b) shows digital summing of logic signal from both discriminator outputs in separately. A 10 μCi Cs-137 gamma source was used to represent high count rate while a background count represent to low count rate counting for testing an effect of count loss in both summing technique. The obtained results were used to determine the efficiency of digital summing and analog summing systems.



(a) Block diagram for analog summing system.



(b) Block diagram for digital summing system.

Figure 3.3 The block diagram of the analog and the digital summing system

3.2.2 Gamma Counting System Design

As mentioned earlier, the integral counting system was used in the walk-through RMS because the system is only used to detect the change in radiation intensity but not the energy spectrum of the radionuclides. Figure 3.4 shows the block diagram of the counting system designed for the walk-through RMS.

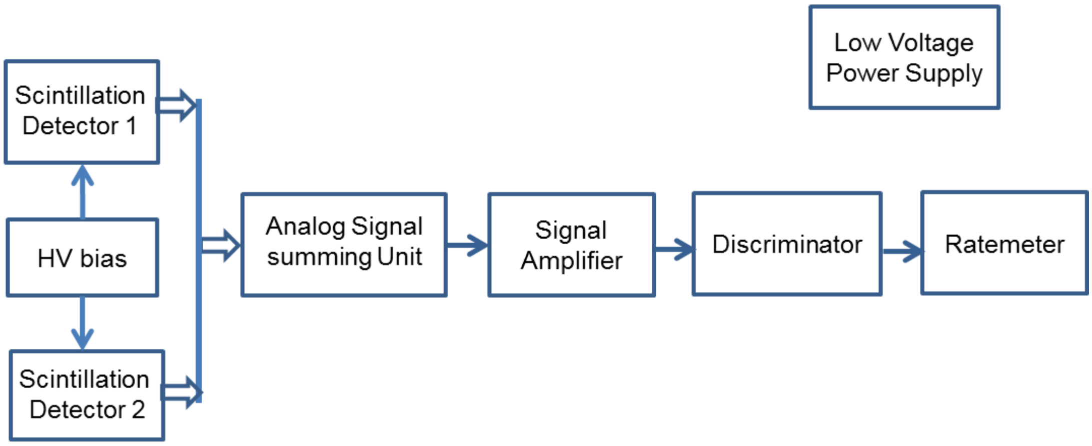


Figure 3.4 The block diagram of the integral counting system in the developed walk-through RMS.

A low voltage power supply was necessarily for all the nuclear counting modules. The low voltage power supply with various output voltages that used in the walk-through RMS. Table 3.1 shows the low voltage power output and its function.

Table 3.1 The output voltage of the low voltage power supply and its function.

Output Voltage	Nuclear Counting module
+5V and Ground	Ratemeter
+12V and Ground	High Voltage
+12V, -12V and Ground	Signal Amplifier
	Discriminator
	Voltage Amplifier

The Bicron 3” X 3” NaI(Tl) scintillation detectors from Ortec company were employed in the walk-through RMS system. In order to produce to the electrical signal, the scintillation detectors have to be biased from by the high voltage supply.

One high voltage module with two output ports was used to bias the scintillation detectors. The high voltage outputs were set at 880V.

The anode signals from the 14 pin tube base (Ortec Photomultipier base 266) were summed through the T-connectors. The summed negative anode signals were inverted to positive pulse and amplified by the amplifier. The discriminator was used to cut out an unwanted signal in the measuring system and convert the analog pulse (linear pulse) to logic pulse (0 and 5V). The discrimination level set in the system is 0.5V (500 mV). The logic pulse was then triggering the ratemeter. The ratemeter with adjustable response time which function as the frequency to voltage converter was used for counting the intensity of the radiation in term of voltage. The ratemeter could be set to two ranges i.e. 100 cps and 1000 cps.

In order to increase the efficiency of the counting system, the lead shielding with a thickness of 4 mm was applied to shield both detectors. A brass tube with outer diameter of 3.5” inches was used as the support for placing the lead shielding. The entrance window of shielding (brass and lead) was open half the area of the NaI(Tl) crystals in the position faced to the center of the portal gate. Figure 3.5 (a) shown the detector used in the walk-through RMS system and its tube base while Figure 3.5 (b) shown the lead shielding of the detectors.

Detector tube base   3” x 3” NaI(Tl) Scintillation Detector

(a) NaI(Tl) scintillation detector and tube base

(b) Lead Shielding of the detector

Figure 3.5 The gamma detector and its lead shielding design used in walk-through RMS.

3.2.3 Gamma Alarm System Design

The walk-through RMS alarm system was triggered if a person brought the radioactive sources passing through the gate in any direction. The alarm threshold value of the system was set by the microcontroller. For each alarm event, the buzzer and beacon were activated and the alarm message (text message) was sent to computer via RS-232 cable. Figure 3.6 shows the block diagram of the gamma alarm system.

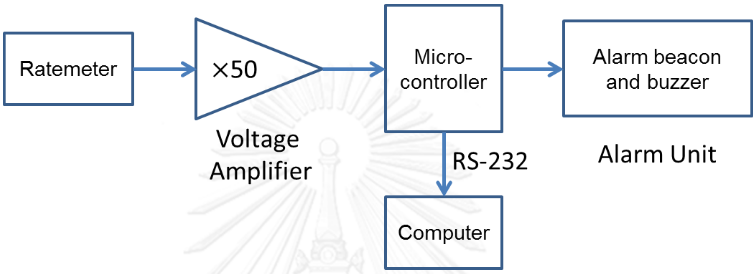


Figure 3.6 The block diagram of the gamma alarm system in the walk-through RMS.

The ratemeter converted the count rate to voltage level and compared to the alarm setting level in microcontroller. The voltage output of ratemeter was connected to the ADC converter (input port: AN0) of microcontroller. However, the ratemeter output could not be directly used as ADC input of the microcontroller because the ratemeter output was too small. The maximum voltage output was 100 mV and this voltage was approximately 50 times gained by the voltage amplifier to become 5V which is the maximum voltage for ADC converter in microcontroller.

During the system startup, the microcontroller measured the background level of the radiation and calculated the alarm threshold value. The measured voltage level needed to be back calculated to get the count rate of background radiation. The alarm threshold value was calculated according to gamma sigma function as in Equation (1) [24].

$$\text{Alarm threshold value} = N\sigma + \text{Background count} \qquad \text{............ (1)}$$

where sigma (σ) is the standard deviation of the average background (background count)$^{1/2}$ and N is the number entered. In this walk-through RMS, the number of N was set at 5.5 which allow the system to detect the 1μCi Cs-137 source. At the same time, the fault alarm rate was in the acceptable level.

3.2.4 Portal Gate Design

The portal pillar of the walk-through RMS has to be spaced enough apart to permit safe passage of pedestrian. The dimension of the portal gate was designed with referring the standard door size which is approximately 0.9 m X 2 m for an exterior doorway (Figure 3.7) [23]. The portal gate of the walk-through RMS was built by using the polyvinyl chloride (PVC) pipe with the inner diameter of 4 inches and thickness of 3 mm. Figure 3.8 shows the frame of the portal gate which built up from PVC pipe. As shown in the picture, the portal gate could not stand stably. A base was then designed to support the portal gate. Two pieces of thick PVC plates (thickness of 1cm) with the dimensions of 30 cm X 30 cm were used to support the portal gate. The supporting arms for CCTV and occupancy sensors of both directions also built up.

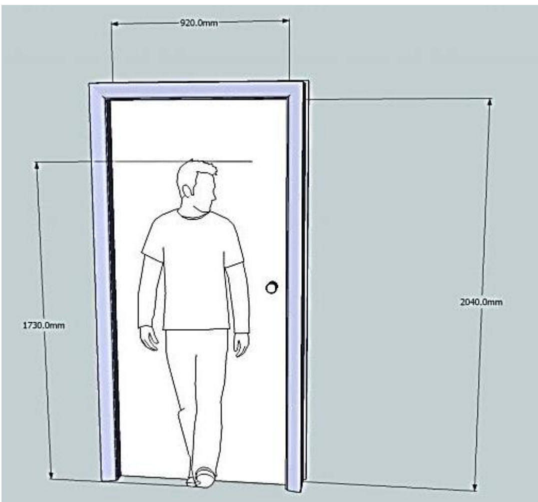


Figure 3.7 The standard door size [23].

Figure 3.8 The PVC portal gate in the walk-through RMS.

3.3 Occupational Sensing and Video Recording System

The occupational sensing system played the role to trigger the data collection of the gamma counting system while the video recording system was for video surveillances and recording purpose. This also means that the system would not alarm if no one passing through the system despite the radiation level is higher than the preset alarm threshold value. This was to reduce the false alarm rate as the short ratemeter response time was adjusted in order to promptly respond the low activity source.

3.3.1 Bidirectional Operation of System Design

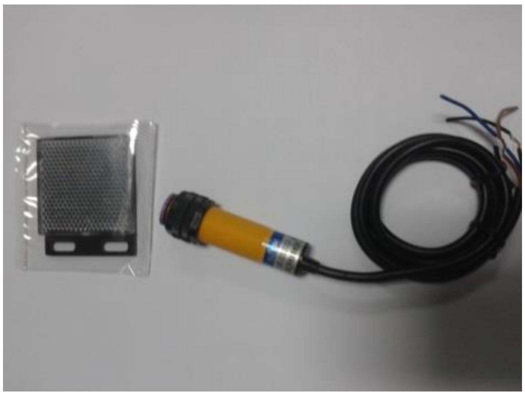
As mentioned earlier, two sets of occupancy sensors (set A and set B) and two IP cameras (front and rear sides) were installed for bidirectional operation of the walk-through RMS. The system would start operation when any person walked through the gate by the front set of occupancy sensor. The trigger signal would start gamma counting system and change the light indicator to red color. At the same time, the IP camera in the front side would do the recording. If that person carried the radioactive source or contaminated by radioactive substance, the gamma counter would sent the total summing count to ratemeter. The counting signal from ratemeter was interfaced to the microcontroller port and compared to the alarm threshold level. The alarm system (beacon and buzzer) would be activated if the detected signal higher than the alarm threshold level. This alarm event would be recorded with the CCTV index (A or B) by the microcomputer in the log file through serial communication with microcomputer. The system would stop operation when that person passed through the rear set of occupancy sensor. At the same time, the light indicator would be changed to green color to show the status of ready for next passenger. The system could operate both walk-through directions but different in recording direction index. The alarm event video searching could be done by matching of the recorded time with a CCTV direction index.

3.3.2 Occupational Sensing System Design

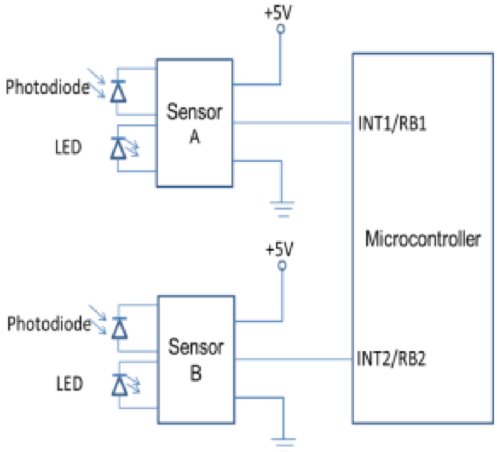
The optoelectronic sensor photo switches (E3F-DS30C4) were used as the occupancy sensors in the system. The technical specification of the E3F-DS30C4 was summarized as in Table 3.2. As shown in the table, the sensory distance of the photoelectric switch was 30 cm and this was insufficient for the walk-through RMS. Therefore, an infrared reflector was applied with the photoelectric switch to increase the sensory distance up to 2m. The sensitive sensing area was lined in between the photoelectric switch and reflector. Figure 3.9 shows the photoelectric sensor used in the walk-through RMS and its schematic diagram connect microcontroller. The photoelectric sensors were connected to the external interrupt port of the microcontroller. When the person passing though the space between sensors and reflector, the signal would change from low to high and thus the interrupt flag were raised to start the gamma counter.

Table 3.2 The specification of the E3F-DS30C4 Photoelectric Switch [25].

Sending Light	Infrared Rays
Detection Way	Diffuse Type
Output Form	3 Wires
Output State	NPN Normal Open
Voltage	DC 6-36 V
Current	200 mA
Sensory Distance	30 cm
Head Diameter	1.6 cm (0.6”)
Body Size	2.3 X 6.9 cm (0.9” X 2.7”) (max. D*L)
Material	Plastic, Alloy



(a) Photoelectric Switch E3F-DS30C4 and the reflector



(b) The diagram of sensors connection

Figure 3.9 The occupancy sensor used and the block diagram of the sensors.

3.3.3 CCTV Monitoring System Control Design

As mentioned earlier, the IP cameras which can send and receive data via a computer network and the internet were employed as the video surveillance tools for the walk-through RMS. The IP cameras used were the PnP WiFi Indoor IP Camera, the products from Shen Zhen Vstarcam Technology Co., Ltd. from China (Figure 3.10 (a)). This IP camera adopted Plug and Play (PnP) technology which is easy to install and operate. The cameras could be viewed by computer software, through internet browser or any PnP application available for mobile phone. At the same time, the pan and tilt (PT) function allowed the user to control the camera to move in both horizontal and vertical planes.

For the developed walk-through RMS, the IP cameras were interfaced by computer software called “IP Camera Super Client (PnP)” (Figure 3.10(b)) which used for multiple camera monitoring, characterized with multi-camera monitoring, PTZ control, record, alarm and access, authority management function [26]. The software was installed to monitor both front and rear side CCTV at the same time via WIFI connection.

The built-in motion detecting feature of the IP cameras was applied to detect all the motion across the monitoring area. The alarm would be triggered if there was any movement across the cursor area. The sensitivity of the motion detection could be chose from 1 (highest sensitivity) to 10 (lowest sensitivity). In case of alarm event, video image with the information of date and time of the event will be saved to the computer. The searching of the recorded evidence (video and photography) for each RMS alarm event could be done manually by matching the date, time and camera index in the alarm message.

(a) The VStarCam PnP IP Cameras (b) The main interface of IP Camera Super Client PnP

Figure 3.10 The IP cameras used in the walk-through RMS and the main interface of its software.

3.4 System Control Software Development

The system control software was used to integrate the gamma counting system, gamma alarm system and occupational sensing system for supporting the bi-directional function of the walk-through RMS.

3.4.1 System Control Program Flowchart

A flowchart of the system control program was designed to support the hardware designed function. The program code was then written based on the designed flow chart. Figure 3.11 shows the flow chart of the system control program in the walk-through RMS.

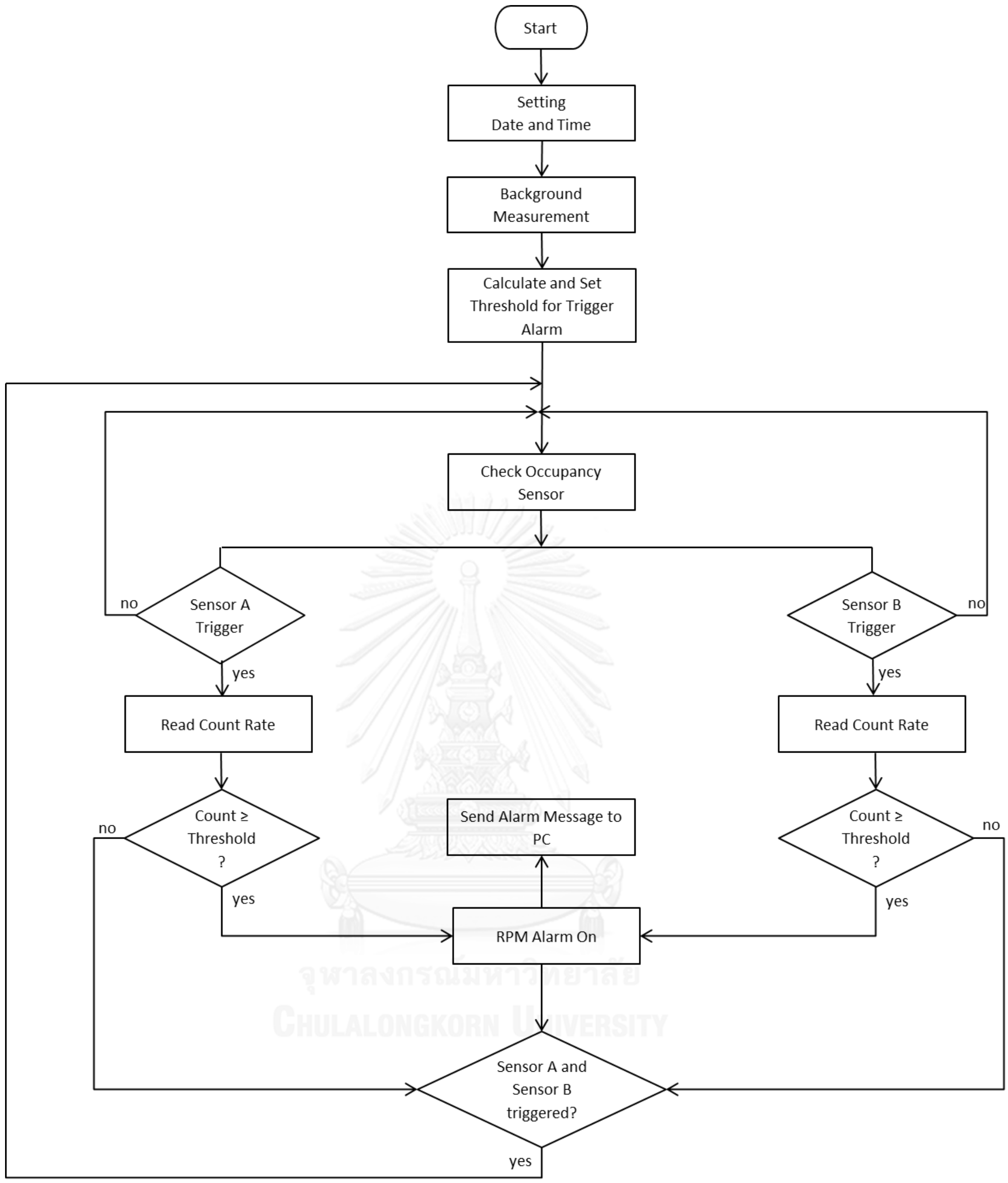


Figure 3.11 The flow chart of the system control program in the walk-through RMS.

During the startup of the system, the date and time information were required to set up the real time clock for the microcontroller. The radiation background was determined and used for the alarm threshold setting. The control program was designed for bidirectional occupancy sensing to start the gamma counter in either direction of A or B. The counting rate was compared to the alarm threshold setting, if the count rate higher than the threshold setting the alarm unit was activated and sent the massage with the information of date, time and a direction index to alarm event recording file. Once both sensors were triggered, the read out of the count rate would be stopped and in case of alarm event, both the light and audio indicator would be deactivated.

3.4.2 Programming of RMS system

The microcontroller in the walk-through RMS was programmed based on the flow chart shown in Figure 3.11. The code was written in Basic programming languages. The code was then compiled by the Proton Compiler software into hex code which can be read by the microcontroller. The microcontroller were programmed with the hex file through a programmer called PICKIT2 which also made by the Microchip Technology. Figure 3.12 shows the flow of changing basic programming language to the hex code that can read by the microcontroller [27]. Figure 3.13 shows the microcontroller board used in the walk-through RMS and the programming tools used to program the microcontroller.

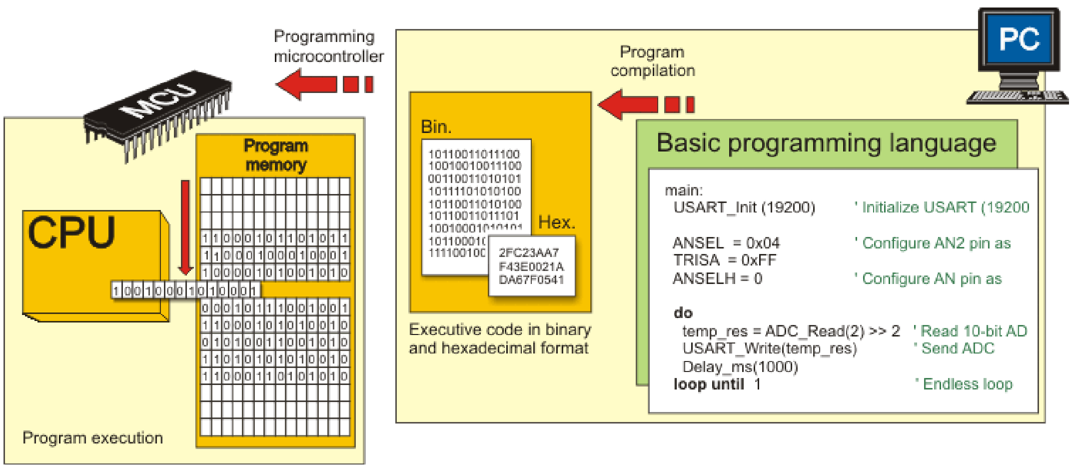
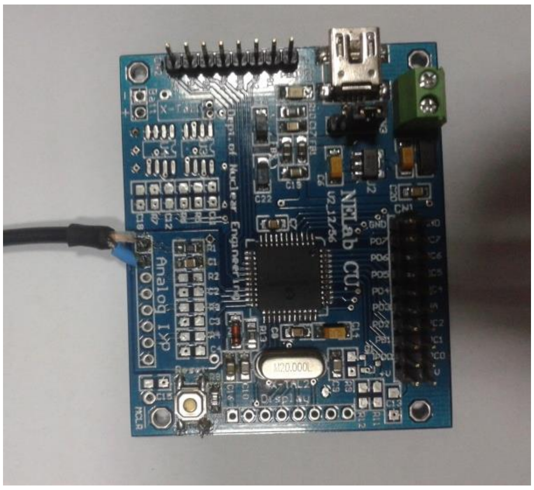


Figure 3.12 The programming of microcontroller by Basic programming language.



(a) The microcontroller board

(b) The programming tools (PICKIT 2)

Figure 3.13 The microcontroller board and its programming tools used in walk-through RMS.

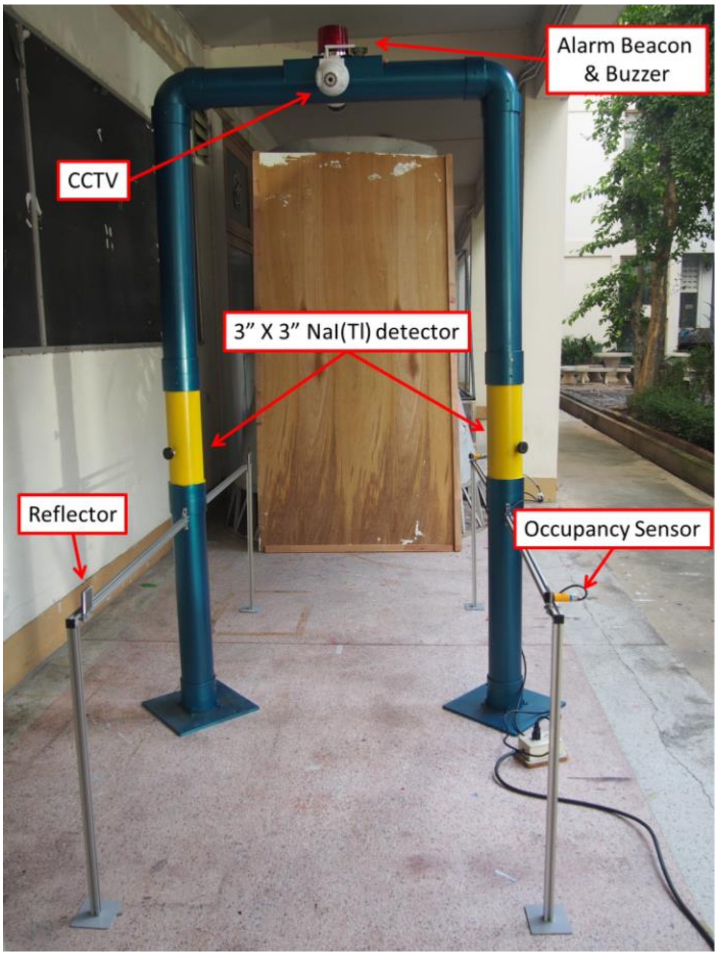
3.5 System Assembly

All the hardware including the portal gate, the occupancy sensors, the CCTV, the NaI(Tl) scintillation detectors, the gamma counting modules, the microcontroller, the power supply and the alarm unit such as beacon and buzzer were integrated and assembled in the walk-through RMS.

3.5.1 Portal Gate Assembly

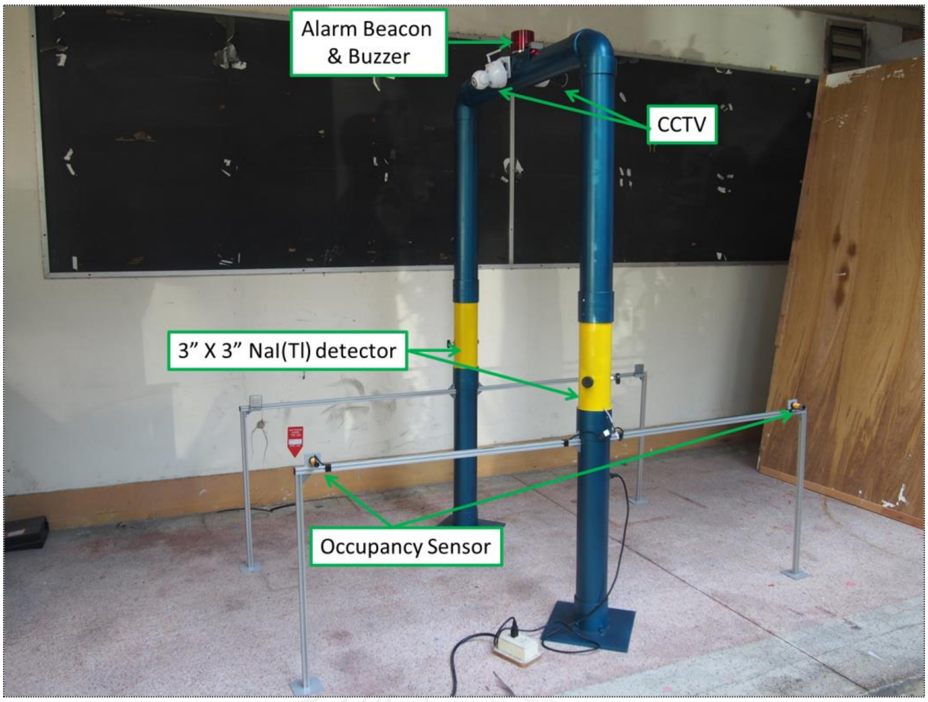
Figure 3.15 shows the assembled portal gate. Figure 3.14 (a) shows the front view of the portal gate. The yellow colored parts of the portal gates pillars show the position of the 3” X 3” NaI (Tl) scintillation detectors which was located at 75 cm above the ground. The photoelectric switch and the reflector were located at the same level which was 70 cm above the ground. The alarm beacon and buzzer were placed on the top of the portal gate. The IP camera was fixed in the center of the horizontal column of the portal gate and faced to the front side of the portal gate.

The side view of the portal gate shown in Figure 3.154 (b), illustrated two sets of occupancy sensors and two IP cameras. One IP camera was placed and faced in the front side of the portal gate while another one was faced to the rear side of the portal gate. The distance between two occupancy sensors were 2 meters. Once the person walked through the space between the photoelectric switch, the signal would trigger the interrupt program of the microcontroller. The system would stop once the person passed through the other set of photoelectric switch and reflectors.



(a) The front view of the portal gate.

Figure 3.14 The assembled portal gate of the developed walk-through RMS

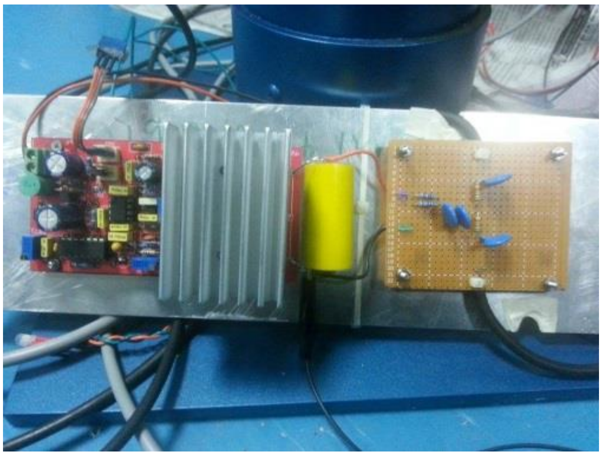


(b) The side view of the portal gate.

Figure 3.14 The assembled portal gate of the developed walk-through RMS (continued).

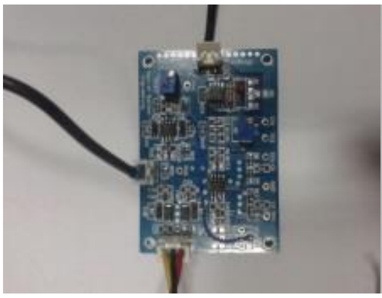
3.5.2 Radiation Monitoring System Assembly

The modules of the radiation monitoring system were assembled in the portal gate. Figure 3.15 shows the individual modules for high voltage power supply, low voltage power supply, pulse amplifier, discriminator, ratemeter and voltage amplifier. All these modules were then placed in the horizontal column of the portal gate (Figure 3.16).

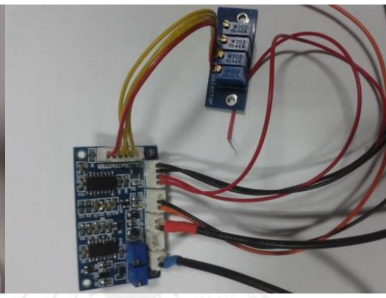


(a) High Voltage power supply

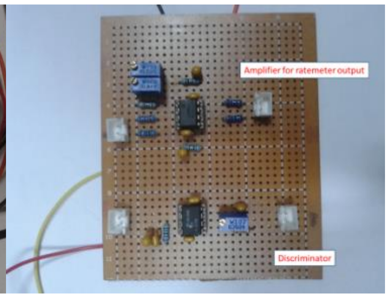
(b) Low Voltage power supply



(c) Pulse Amplifier



(d) Ratemeter



(e) Voltage amplifier and discriminator

Figure 3.15 The assembled modules of radiation monitoring system.

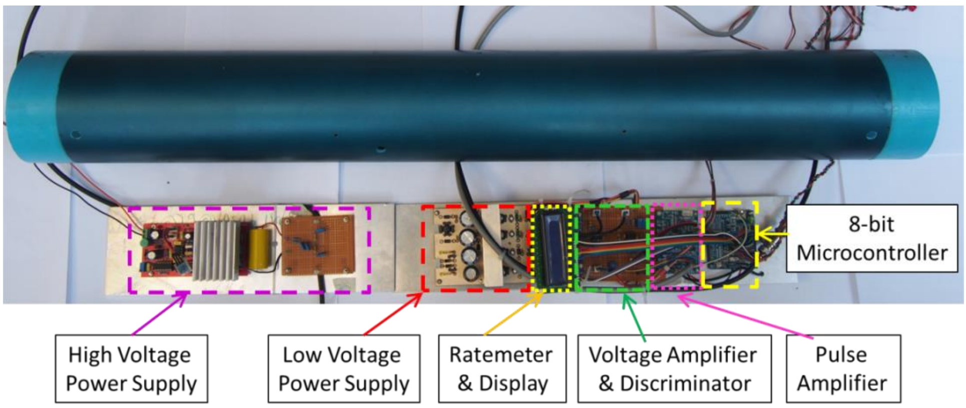


Figure 3.16 The radiation monitoring system placed in the walk-through RMS.

CHAPTER 4

EXPERIMENTAL RESULTS

4.1 Gamma Detection Testing

Prior to the designing and construction of the walk-through RMS, some preliminary studies regarding the gamma detection of the system had been carried out to determine the optimum setup of the gamma counting system. As there were two scintillation detectors employed in the system, the dual pulse signal summing system study was carried out to compare the analog and digital summing system. The sensitivity of the scintillation detectors study was also performed to test if the detectors would detect the radioactive source with a desired level of activity. These tests were carried out by using the standard NIM.

After the designing the gamma counting system of the walk-through RMS, the counting system modules like amplifier and ratemeter were assembled, tested and calibrated. All the assembled modules were then employing in the gamma counting system. At the end, the integrated gamma alarm system was then tested.

4.1.1 Dual Pulse Signal Summing System Study

As discussed in Part 3.2.1, two 3”x 3” NaI(Tl) were placed at spacing of 80 cm in connection to the NIM counting system to compare the analog and digital signal summing technique. A 10 μCi Cs-137 gamma source was used to represent high count rate for testing an effect of count loss in both summing technique while the measurement of background radiation represented the condition of low count rate. The tested results of 10 second counting time of both analog and digital summing systems were presented in Table 4.1 and Table 4.2 respectively.

Table 4.1 The counting results of analog summing system

(a) High Count Rate (10 μCi Cs-137 placed in the middle position between the two detectors)

Reading	Detector A	Detector B	Sum up (by calculation)	Sum up (counted by system)
1	20497	22040	42537	42602
2	20262	22366	42628	42498
3	20555	22282	42837	43125
4	20279	22149	42428	42578
5	20571	22143	42714	42499
Average	20432.8	22196	42628.8	42660.4

(b) Low Count Rate (background measurement)

Reading	Detector A	Detector B	Sum up (by calculation)	Sum up (counted by system)
1	4081	3700	7781	8021
2	4196	4023	8219	8190
3	4044	4039	8083	8200
4	4146	4112	8258	8242
5	4094	4031	8125	8032
Average	4112.2	3981	8093.2	8137

Table 4.2 The counting results of digital summing system

(a) High Count Rate (10 μCi Cs-137 placed in the middle position between the two detectors)

Reading	Detector A	Detector B	Sum up (by calculation)	Sum up (counted by system)
1	21419	20810	42229	42157
2	21476	20908	42384	42649
3	21345	20942	42287	42079
4	21465	21045	42510	42834
5	21768	20666	42434	42260
Average	21494.6	20874.2	42368.8	42395.8

(b) Low Count Rate (background measurement)

Reading	Detector A	Detector B	Sum up (by calculation)	Sum up (counted by system)
1	4161	3971	8132	8294
2	4015	4039	8054	8084
3	4155	3866	8021	8441
4	4206	4081	8287	8132
5	4108	4255	8363	8092
Average	4129	4042.4	8171.4	8208.6

The results found that both the analog summing system and digital summing system were able to perform in the condition of high count rate and low count rate. However, the analog summing system had the advantages over the digital summing system as the electronic component of analog summing system was less than digital summing system. Therefore, the analog summing type could be applied in the RPM counting system in order to reduce the cost of designed walk-through RMS.

4.1.2 Sensitivity of Scintillation Detectors Study

(a) Background Reduction Study

For increasing the sensitivity of detection, the counting from background must be reduced. A background reduction study was carried out to compare the sensitivity of gamma detection system with and without lead shielding. The integral counting system with analog summing technique was set up by the NIM during this experiment. Figure 4.1 shows the detecting system set up of shielded and un-shielded detector. The space between two 3” X 3” NaI(Tl) scintillation detectors was set at the 80 cm and a 10 μCi Cs-137 gamma source was placed in the middle of two detectors. Table 4.3 shows the counting results of the shielded and un-shielded detecting system.

(a) Configuration without lead-shielded.

(b) Configuration with lead-shielded.

Figure 4.1 The system configuration used in the background reduction study.

Table 4.3 The counting result of the background reduction study.

Reading	Unshielded detector		Shielded detector	
	Background	With source	Background	With source
1	35839	76202	8021	42602
2	35716	76590	8190	42498
3	36254	76109	8200	43125
4	36061	76223	8242	42578
5	36185	75634	8032	42499
Average	36011	76152	8137	42660.4

Based on the results shown in Table 4.3, the source to background count ratio of the unshielded detectors was approximately 2. With the lead shielding, the source to background counting ratio was around 5 times and thus 2.5 times higher than that of the unshielded detectors. The results showed that the source detection sensitivity of shielded detectors was better than unshielded detectors and thus a lead shielding should be used in the walk-through RMS.

The increasing of the detection sensitivity could be also determined in the statistical term. The limit of detection is the point where we can distinguish a signal from the background and it can be calculated based on Equation (2).

$$\text{Limit of detection} = 3\sigma + \text{Background count} \qquad \text{..........} (2)$$

where the 3σ value corresponds to a confidence level of about 99%.

By using Equation (2), the limit of detections of the unshielded detectors and the shielded detectors are 36580 counts and 8408 counts respectively. The calculated results showed the shielded detector was more sensitive than the unshielded detector as its limit of detection was much smaller (approximately 4.3 times) than that of the unshielded detector.

(b) RPM alarm system simulation

In an alarm system test, the Log/linear ratemeter with audible threshold adjustment (Ortec model 449) was employed in combining with the counting system. Two 3” X 3” NaI (Tl) scintillation detectors were placed at the simulated portal gate with a width of 80 cm. The analog summing technique was employed to sum up the signals from two detectors. The threshold of the alarm was set slightly above the background level (no alarm sound without any radioactive sources).

The detection of low activity gamma sources was tested by moving pass through a middle of simulated portal gate. The alarm will be activated and generate an audible sound when the count rate or dose level increasing above a setting threshold function. The result of the demonstrated alarm system found that with two 3” X 3” NaI(Tl) scintillation detectors with the spacing of 80 cm, the RPM can detect the Cs-137 source that have activity equal and more than 1 μCi.

(c) Contour Sensitivity Study

A contour sensitivity study of walk-through RMS was carried out to study the sensitivity of gamma detection at various position of the portal gate. In this experiment, the pillars of the portal gate were spaced at 90 cm and one 3” X 3” NaI(Tl) detector was placed in each pillar at the position of 75 cm from the ground level. The detectors were shielded by the lead sheet of 4 mm and the windows were opened in the direction faced to middle of portal gate. The analog summing system was applied to sum up the analog signals from the detectors and the output was connected to the integral counting system which assembled by using the NIM modules. The counting time of the system was set at 4 s. The count rates of a 10 μCi were measured at the various positions (see Figure 4.2).

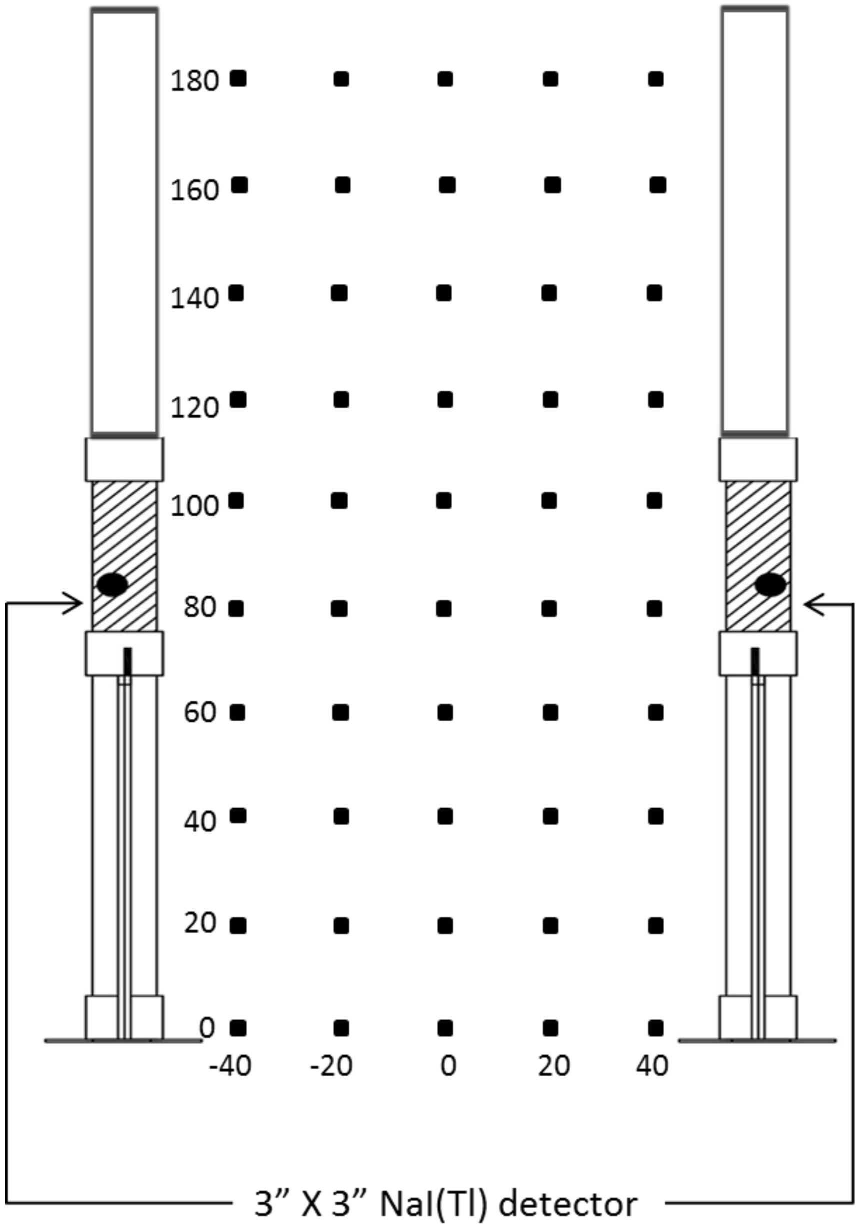


Figure 4.2 The measurement positions of the contour sensitivity study

The black dots represented the position where the measurement was taken. In this contour sensitivity study, there was a total of 45 measurement points. The results of this study are shown in Figure 4.3.

Y \ X	-40	-20	0	20	40
180	1234	1124	1181	1203	1152
160	1357	1176	1327	1457	1248
140	1565	1038	1718	1684	1469
120	1951	2486	2406	2255	1845
100	4706	4331	3076	3137	4282
80	44433	6025	3713	3976	23374
60	8568	4570	3228	3622	6573
40	3569	3029	2614	2709	2823
20	2236	1978	1950	1998	1976
0	1034	1817	1753	1706	1646

Color	Count Rate (c/4s)
	C ≤ 2,000
	2,001 ≤ C ≤ 4,000
	4,001 ≤ C ≤ 6,000
	6,001 ≤ C ≤ 8,000
	8,001 ≤ C ≤ 10,000
	C ≥ 10,001

Figure 4.3 The result of the contour sensitivity study of the walk-through RMS

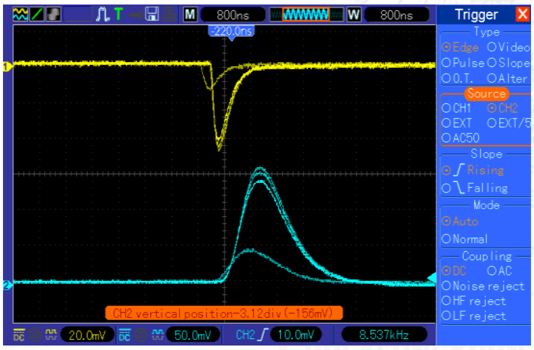
Based on the results obtained, the position near the detector could give the highest count rate of the sources, especially at (-40, 80) and (40, 80) which were very near to the detectors. Along the same position of Y-axis, as the source was moved to the center of two pillars, the detection efficiency of position detection was reduced. The count rate of the source was high at the position where was normal to the detectors (Y-axis = 40 – 120) and it decreased as the source moved to the upper part and the lower part of the portal gate.

4.1.3 Gamma Counting System Testing

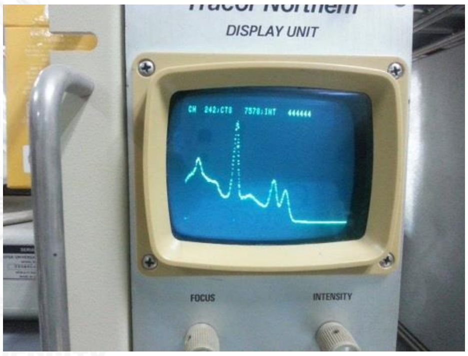
The integral counting system which consisted of the detectors, amplifier, discriminator and ratemeter were employed in the walk-through RMS. The amplifier, discriminator and the ratemeter were assembled. Each electronic circuit module was tested before assembled.

(a) Amplifier

The testing results of the amplifier are shown in Figure 4.4. Figure 4.4 (a) shows the result of assembled amplifier circuit displayed on the oscilloscope. The yellow signal (Channel 1) shows the signal output of the detectors tube while the blue signal (Channel 2) represents the output of the amplifier. The negative anode signal was shaped by the amplifier to become the semi-Gaussian signal and the pulse height of the signal was gained. The amplifier was also tested by connecting to multichannel analyzer (MCA). Figure 4.4 (b) shows the result displayed by the MCA. The result shows that the gamma spectrum of Cs-137 and Co-60 could be clearly differentiate by the MCA as the noise in the amplifier circuit was low.



(a) The input and output of amplifier



(b) The amplified peak of Cs-137 and Co-60

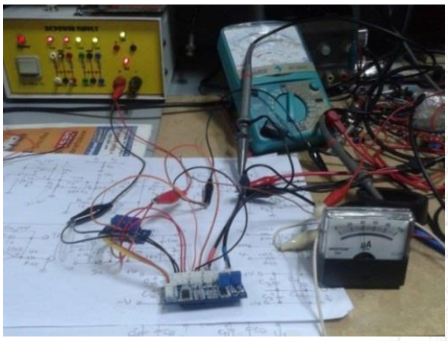
Figure 4.4 The testing result of the assembled amplifier circuit.

(b) Discriminator

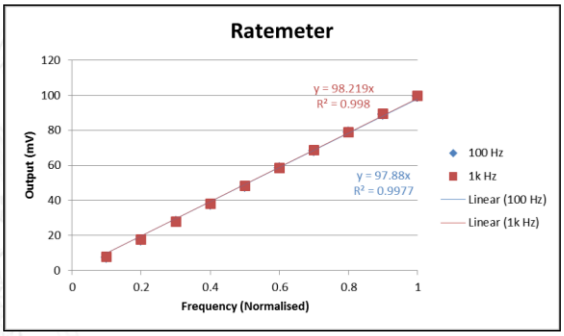
The voltage comparator was used as the discriminator and put as the front stage of the ratemeter. The discriminating level was set as 500 mV to cut out the noise. The logic output of the discriminator was 5 V which can trigger the ratemeter.

(c) Ratemeter

There are two range of the ratemeter i.e. 100 Hz and 1000 Hz. The assembled ratemeter were calibrated by using the function generator as shown the set up in Figure 4.5 (a). The calibration was conducted by using the TTL signal with frequency varying in range of 100-1000 Hz from a function generator as the input of the ratemeter. The output voltages of the ratemeter at each frequency were measured by the digital multimeter and its linearity was plotted as shown in Figure 4.5 (b).



(a) The calibration of the ratemeter



(b) The linearity of the ratemeter

Figure 4.5 The calibration of the ratemeter and its linearity after calibration.

(d) Voltage Amplifier

The relationship between radiation count rate and voltage could be derived from the calibration curve of the ratemeter with voltage amplifier. The calibration of ratemeter with voltage amplifier was carried out using the digital multimeter. Figure 4.6 shows the data and the plot of the calibration curve.

Input (Hz)	Amplifier (V)
100	0.4846
200	0.9697
300	1.4923
400	1.9850
500	2.4928
600	3.0177
700	3.5169
800	4.0290
900	4.5447
1000	5.0511

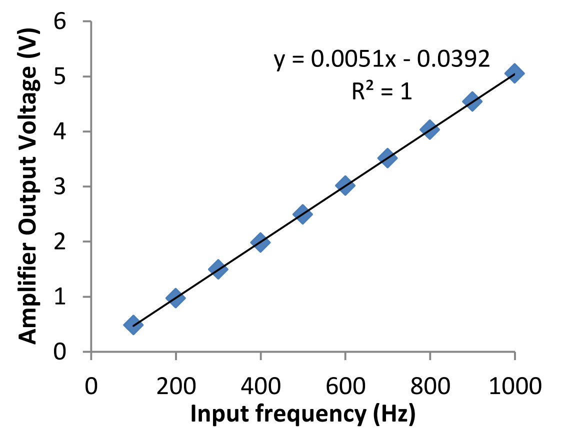


Figure 4.6 The data and the plot of calibration curve of the voltage amplifier connected to the ratemeter.

After assembled and calibrated each module, all the modules were integrated to become the gamma counting system in the walk-through RMS. The stability and precision of the gamma counting system was tested by repeating the background measurements. The results found that the background counting of the surrounding were stable.

4.1.4 Gamma Alarm System Testing

After interface of the gamma counting system and the alarm unit to the microcontroller, the gamma alarm system was tested. Figure 4.7 shows the alarm unit including beacon and buzzer installed in the walk-through RMS. When the radiation level was higher than the preset threshold value in the microcontroller, the output port that connect to the alarm unit would turn to high (5V) and thus activate the alarm units to release the light and sound signal.

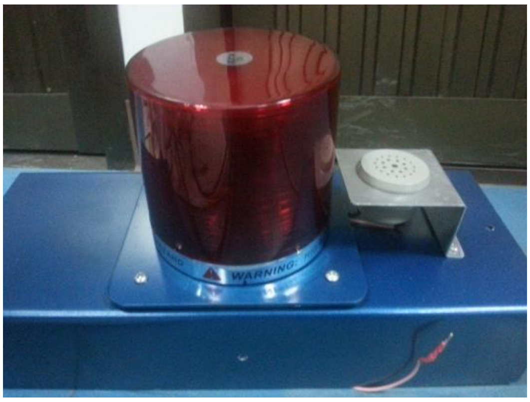


Figure 4.7 The alarm beacon and buzzer assembled in the walk-through RMS.

The data communication between the microcontroller and microcomputer was done via RS-232 of the serial communication in the Proton Compiler software. During the startup of the microcontroller, the microcontroller would do sampling for the value of background voltage and calculating of the threshold value. The background count and the calculated threshold count were sent to the micro-computer via serial communication. The threshold count was calculated based on the 5.5 times of sigma plus the background count. In case of the person bringing the radioactive materials, the alarm message would also be sent to the microcomputer. The alarm message contained the information of date, time and the camera index (A or B) of the alarm event of bidirectional detection. Figure 4.8 shows the example of the alarm message which had been saved as notepad.

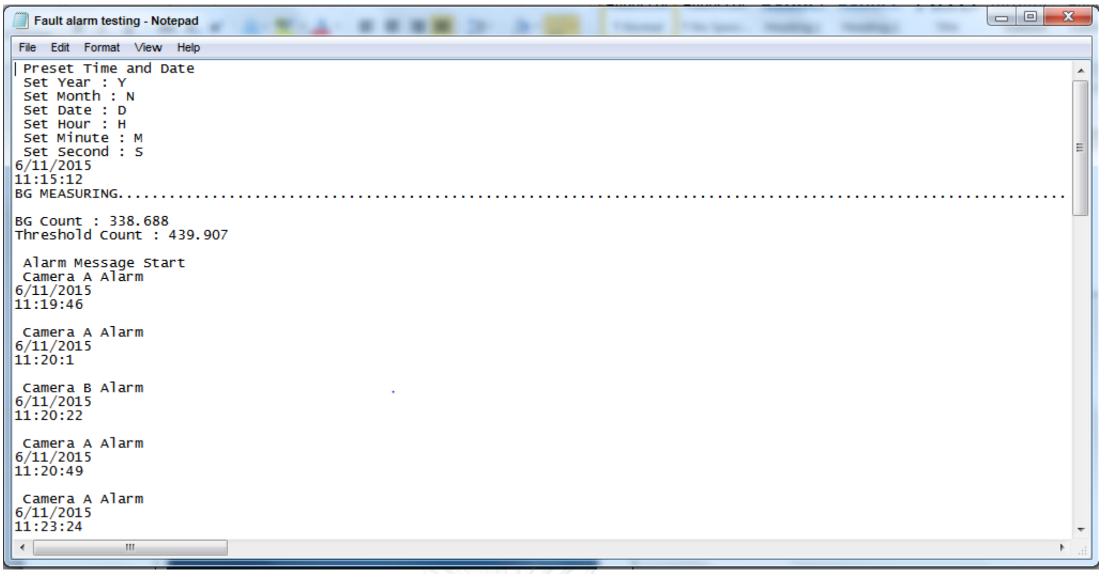


Figure 4.8 The alarm message received from the microcontroller via serial communication.

4.2 Occupational Sensing and Video Recording System Testing

As mentioned in Section 3.3, the photoelectric switch and IP camera were designed to be used as the occupancy sensor and video recording system. In order to support the bidirectional function of the system, two sets of occupancy sensor and two sets of IP cameras were installed in the system. The occupational sensing and the video recording system were developed and tested prior to be integrated with the walk-through RMS.

4.2.1 Occupational Sensing System Testing

The photoelectric switches were tested and it found that the sensor were sensitive to the human body. The sensitivity of the photoelectric switch was low and its sensing distance could not more than 30 cm. The sensitivity of the photoelectric switch was increased when it paired with the reflector. The sensing distance was laid between the photoelectric switch and the effective sensing distance to the human body could be increased up 2 m. Therefore, the pairs of the photoelectric switch and the sensor were being used in the walk-through RMS as the occupancy sensors which trigger the gamma counting system.

4.2.2 Bidirectional Operating Function Testing

Two sets of occupancy sensors were employed to trigger the bidirectional operating function of the walk-through RMS. The detection of two occupancy sensors was done by the microcontroller. A two color LED were assigned as the status indicator of the portal gate. When a person passed through the front side of the portal gate and triggered the sensor A, the LED would turn to red color to show that the walk-through RMS was occupied. The gamma alarm detection system would be activated due to the interrupt signal from the sensor A. When that pedestrian walked through the sensor B at the rear side, the gamma alarm detection system would be stop. After 1 second, the LED would turn to green color to show the system was ready for next pedestrian. This was to avoid the multiple trigger of the sensor by the human body movement of the previous pedestrian. The same condition would happen if the person passed the rear side of the portal gate. Both sensor A and sensor B were able to trigger the gamma alarm detection system of the walk-through RMS.

4.2.3 CCTV Monitoring System Control Testing

The IP cameras were employed as the CCTV in the walk-through RMS. The IP cameras were able connected to the computer via WiFi and the real time monitoring of the CCTV monitoring system was done through the IP camera Super Client (PnP) software. The motion detecting features were used to detect all the people passing through the portal gate. In case of motion detected, a video file and some snapshots were automatically captured and saved to the computer. Figure 4.9 shows that the snapshots captured by using the motion detecting features of the IP camera.

Figure 4.9 The snapshots captured by using the motion detecting features of the IP camera.

As shown in Figure 4.9, the date and time of the detected motion were shown in the snapshot. The same information also could be found the folder of the alarm. By matching the information such as date and time, the recorded video for the gamma alarm event could be manually searched.

The performance of the designed CCTV monitoring system was strongly influenced by the internet speed and the stability of the WiFi system. Both the real time monitoring and the motion detection function of the IP camera could not performed if the internet connection was not in good condition. Therefore, a stable and high speed internet connection was necessarily for the CCTV monitoring system to be effective.

4.3 Full System Integration Operation of RMS Testing

After developing, testing and calibrating all the gamma detection and counting system, gamma alarm system, occupancy system and CCTV monitoring system, all the system were integrated and assembled to become the walk-through RMS. The function of the walk-through RMS was tested by bringing the sources passing through the portal gate. The sensitivity of the walk-through RMS was checked by applying the FEMA-REP-21 standard. The fault alarm testing was also carried out to evaluate the effectiveness of the developed system.

4.3.1 Walk-Through Gamma Alarm Sensitivity Testing

The sensitivity of the walk-through RMS was tested by bringing the Cs-137 sources passing through the portal gate with a normal walking of approximately 1.4m/s. In order to test the compliance of the developed system to the FEMA-REP-21 standard, the total activity of the sources were 1 μCi. The source was brought through the portal along the center position between two portal pillars. The sources position was varied very 10 cm along the vertical axis of the portal gate from 20 cm from the ground to 160 cm from the ground. Each position was repeated for 20 times and the detection sensitivity was evaluated in term of detection probability. Figure 4.10 shows how the person performs the sensitivity testing while Table 4.4 shows the testing result. The source position in Table 4.4 refers to vertical position of the radioactive source from the ground level. The plot of sensitivity tested according to the results from Table 4.4 shown in Figure 4.11.

Figure 4.10 The person brings the radioactive source (contained in yellow box) to test the system.

Table 4.4 The results of the walk-through gamma alarm sensitivity testing.

Source Position	Testing Result																				Number of Alarm Case
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	
20cm	√	√	0	√	0	√	√	√	√	√	0	√	0	√	√	0	√	√	√	√	15
30cm	√	√	0	√	√	0	√	√	√	√	0	√	√	√	0	√	√	0	0	√	14
40cm	√	√	√	√	√	√	√	√	√	√	0	√	0	√	√	√	√	√	√	√	18
50cm	√	√	√	√	√	√	√	√	√	√	0	√	√	√	√	√	√	√	√	√	19
60cm	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	20
70cm	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	20
80cm	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	20
90cm	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	20
100cm	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	√	20
110cm	√	√	√	√	√	√	√	0	√	√	√	√	√	√	√	√	√	√	√	0	18
120cm	√	√	√	√	√	√	0	√	0	√	√	√	√	√	√	0	√	0	0	0	14
130cm	0	0	√	√	0	√	√	√	0	0	0	√	√	√	0	√	0	√	0	0	10
140cm	√	0	√	√	√	0	0	0	0	0	√	√	√	0	√	0	0	0	0	0	8
150cm	0	√	0	0	0	0	0	0	0	0	√	0	0	0	0	0	√	0	0	0	3
160cm	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Note: √ - alarm triggered 0 – no alarm triggered

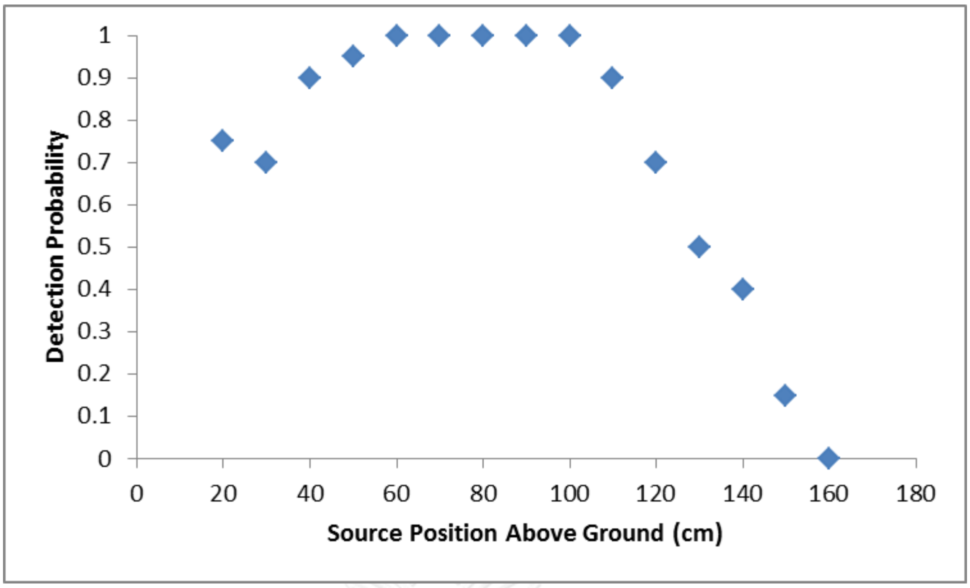


Figure 4.11 The plot of detection sensitivity

Based on the results obtained, the developed walk-through RMS could detect the 1 μCi of Cs-137 source if the source located at the position lower than 160 cm from the ground level. If beyond this level, the system could not able to detect the source. As stated in FEMA-REP-21 standard, the complied RPM with the standard must able to detect the 1 μCi of Cs-137 located at the vertical line centered between the two side columns of the portal monitor between 0.5 feet (≈ 15 cm) and 5 ½ feet (≈ 167 cm) above the base upon which the individual stands when being monitored. Based on this statement, the developed walk-through RMS could not fully meet the FEMA-REP-21 standard as the system could not detect the source more than 160 cm.

The detection probability for the source position between 60 cm and 10 cm from ground level was equal to 1. It meant the developed walk-through RMS could able to detect if the people placing the radioactive source in their pocket or carrying the source by their hands.

The results showed that the sensitivity of the system reduced as the distance between source and detectors increased. According to the inverse square law, the intensity of radiation is reduced as the source and detector distance was increased.

Therefore, the sensitivity of the system was getting lower as the source moving further from the detectors.

Besides the source to detector distance, the walking speed of the pedestrian was also one of the factors influencing the sensitivity of the system. The gamma alarm system could not respond if the moving speed of the radioactive sources was too fast. Therefore, the sensitivity test was carried out based on the average walking speed of people which is at 1.4 m/s.

4.3.2 Fault Alarm Testing

The fault alarm test was carried out to determine the false alarm rate of the developed walk-through RMS. The fault alarm testing was carried out by the people walk-through the portal gate without radiation contamination or bringing any radioactive materials. Three sets of the fault alarm testing were carried out on the developed walk-through RMS. For each set of testing, the person passed through the portal gate for 100 times. After complete one set of testing, the system was restarted and another set of testing was carried out after the background sampling of the system. The false alarm rate was calculated based on Equation (2). Table 4.5 shows the results of the false alarm testing.

Fault Alarm Rate = Number of alarm event / Total number of event .... (3)

Table 4.5 The results of the false alarm tests.

Testing Set	Background Count	Threshold Count	Total number of event	Number of alarm event	False alarm rate
1	338.688	439.907	100	8	0.08
2	349.975	452.868	100	6	0.06
3	342.086	443.812	100	7	0.07
				Average	0.07

The tested results showed that the false alarm rate of the system were not significantly different for the all three set of testing. The background counts for the gamma counting system were also stable. Based on results obtained, the average of the false alarm rates was 0.07 or 7%. The false alarm could be induced from the short response time of the ratemeter employed in the integral counting system. For the detection of a very low activity sources, the short response time was used to increase the sensitivity of the system. Therefore, the appropriate response time should be considered based on the desired sensitivity with an acceptable false alarm rate.

CHAPTER 5

CONCLUSION, DISCUSSION AND SUGGESTION

5.1 Conclusion

An economical walk-through RMS was successfully developed. The developed walk-through RMS consisted of the gamma detection and measuring system, gamma alarm detection system, occupancy system and the CCTV monitoring system. The system were designed and developed by the local based knowledge and the inexpensive device.

Based on the dual pulse summing study and the sensitivity of scintillation detection study, two 3” X 3” NaI(Tl) scintillation detectors were employed with the lead shielding in the portal gate and the analog summing system was used to sum up the anode signal from the tube base. The integral counting system was designed for the gamma measuring system and all the modules such as high voltage power supply, low voltage power supply, pulse amplifier, discriminator and ratemeter were developed. The gamma alarm system consisted of the gamma alarm detection and the responding action to the alarm event such as activating the alarm beacon and sending the alarm message to computer were developed based on the programming of microcontroller.

The occupancy sensing and the CCTV monitoring system which support the security function of the walk-through RMS were also applied. Two sets of occupancy sensors and two sets of CCTV were employed for supporting the bidirectional features of the walk-through RMS.

All these developed system was integrated by the developed system controlling software and the assembled on the PVC portal gate with the dimensions of 90 cm X 200 cm. The full system integration operation of RMS testing was carried out to test the functionality of the developed walk-through RMS. Based on the gamma alarm testing, the RMS could detect the Cs-137 source that have activity equal and more than 1 μCi. The sensitivity to other sources could be reported in further experiment. The false alarm rate of the developed system was less than 0.07 or 7 %.

There is a limitation for the developed walk-through RMS. The sensitivity of the gamma detection system was depended on the walking speed of the pedestrian. The system might not able to detect the low radioactivity sources if the pedestrian passes the system with a high speed. The source to detector position could also influent the sensitivity of the gamma detection. If the sources to detector is too far then the system could not detect the sources.

5.2 Discussion

The results of the study shown a walk-through RMS integrated with CCTV monitoring system and alarm data recording system could be developed based on the local based knowledge and inexpensive device. The design of the walk-through RMS based on the analog summing system was leading to be cost effective. The bidirectional feature of the portal gate was suitable for the small facility where the radioactive materials are being used. The developed walk-through WRMS was light-weighted and able to be relocated easily. According to the categorization of the radioactive source, the developed system could be applied for low radiation level source security. It also can be used for increasing safety control efficiency of the radiation safety officer in laboratory as the walk-through RMS was developed to meet the FEMA-REP-21 standard. As a conclusion, the developed walk-through RMS could be beneficial for the laboratories that using radioactive sources.

5.3 Suggestion

The following suggestions were given to further improve the functionality of the walk-through RMS and increase the sensitivity of the system.

1. In order to increase detector sensitivity and further reduce the cost of the system, the large volume plastic scintillators in association with multiple photomultiplier tubes can be used as the gamma detectors.
2. The width of portal gate can be reduced to shorten the distance between the gamma detectors and the radioactive sources to increase the sensitivity of the system.
3. The developed walk-through RMS is operated in a walk-through basis with a quick scan occurring while a person is positioned within the portal. The stop-and-count mode could also be integrated in the walk-through RMS for allowing for a more sensitive scan.
4. The neutron detectors could also be integrated to the system for full function of RPM alarm detection.
5. The developed system should be installed in the area which can access to high speed internet connection. In case of lack of internet connection, the IP cameras should be replaced by the conventional analog CCTV with transmitting data via cable.
6. The CCTVs can be connected to the microcontroller and triggered by the occupancy sensors to record the occupied event.

REFERENCES

[1] Harikumar, M., Vaishali, M.T., Amit, K.V., Krishnamachari, G., Sharma, D.N.. Detection of Unauthorized Movement of Radioactive Source in the Public Domain for Regaining Control on Orphan Sources – System and Feasibility in **International Conference on the Safety and Security of Radioactive Sources: Towards a Global System for the Continuous Control of Sources throughout their Life Cycle** Vienna: International Atomic Energy Agency, 2005.

[2] International Atomic Energy Agency. **Nuclear Security Recommendations on Radioactive Material and Associated Facility**. IAEA Nuclear Security Series No. 14. Vienna: International Atomic Energy Agency, 2011.

[3] Misher, L.R., Andre, D.S.S., Zhong, H.. Indigenous Pedestrian Portal Monitor Radiation Detector Design For Safeguard Applications in Brazilian Fuel Cycle Facilities in **International Nuclear Atlantic Conference**, 2009.

[4] Ilan Yaar, Ilya Peysakhov. A multiple-detector Radioactive Material Detection Spectroscopic (RMDS) portal. **Nuclear Instruments and Methods in Physics Research A** 712 2013 : 62-74.

[5] Eungi, M., Mincheol, K., Hakjae, L., Yongkwon, K., Jinhun, J., Sung-Kwan, J. Kisung, L.. Identification of Radionuclides For The Spectroscopic Radiation Portal Monitor For Pedestrian Screening Under A Low Signal-To-Noise Ratio Condition. **Nuclear Instruments and Methods in Physics Research A** 758 2014 : 62-68.

[6] International Atomic Energy Agency. **Objective and Essential Elements of a State's Nuclear Security Regime**. IAEA Nuclear Security Series No. 20. Vienna: International Atomic Energy Agency, 2013.

[7] **The Hague Nuclear Security Summit Communiqué**. The Hague : Council of The European Union, 2014. Available from: http://www.consilium.europa.eu [2015, September 3]

[8] International Atomic Energy Agency. **Code and Conduct on the Safety and Security of Radioactive Sources**. Vienna: International Atomic Energy Agency, 2004.

[9] International Atomic Energy Agency. **Incident and Trafficking Database (ITDB) 2015 Fact Sheet**. Vienna : International Atomic Energy Agency, 2015. Available from: http://www-ns.iaea.org/downloads/security/itdb-fact-sheet.pdf [2015, September 3]

[10] International Atomic Energy Agency. **IAEA Safety Glossary Terminology Used in Nuclear Safety and Radiation Protection 2007 Edition**. Vienna: International Atomic Energy Agency, 2007.

[11] International Atomic Energy Agency. **Security of Radioactive Sources**. IAEA Nuclear Security Series No. 11. Vienna: International Atomic Energy Agency, 2009.

[12] International Atomic Energy Agency. **Nuclear Security Culture**. IAEA Nuclear Security Series No. 7. Vienna: International Atomic Energy Agency, 2008.

[13] International Atomic Energy Agency. **Categorization of Radioactive Sources**. IAEA-TECDOC-1344. Vienna: International Atomic Energy Agency, 2003.

[14] Hevener, Ryne Andrew. **Investigation of Energy Windowing Algorithms to Enhance Nuclear Material Screening in Radiation Portal Monitor**. Master Degree. Nuclear Engineering, Graduate Faculty of North Carolina State University, 2011.

[15] International Atomic Energy Agency. **Monitoring for Radioactive Material in International Mail Transported by Public Postal Operators**. IAEA Nuclear Security Series No. 3. Vienna: International Atomic Energy Agency, 2006.

[16] International Atomic Energy Agency. **Combating Illicit Trafficking in Nuclear and Other Radioactive Material**. IAEA Nuclear Security Series No. 6. Vienna: International Atomic Energy Agency, 2008.

[17] International Atomic Energy Agency. **Detection of Radioactive Materials at Borders**. IAEA-TECDOC-1312. Vienna: International Atomic Energy Agency, 2002.

[18] Glenn F. Knoll. **Radiation Detection and Measurement**. Third Edition. New York: John Wiley & Sons, Inc, 1999.

[19] Word System, Inc. **Closed-Circuit Television (CCTV) System** [Online]. (n. d.). Available from: http://www.wsystems.com/news/all-information-about-cctv-systems.html [2015, September 17]

[20] Fargo Control, Inc. **Operating Principles for Photoelectric Sensors** [Online]. (n. d.). Available from: http://www.fargocontrols.com/pdf/sensors/Fargo_photo.pdf [2015, September 17]

[21] Federal Emergency Management Agency. **About the Agency** [Online]. 2015. Available from: https://www.fema.gov/about-agency [2015, September 26]

[22] Federal Emergency Management Agency. **Contamination Monitoring Standard For A Portal Monitor Used For Radiological Emergency Response**. 1995.

[23] Antenociti's Workshop Ltd. **What is "Scenery Scale" and How Big Should My Doors Be** [Online]. 2012. Available from: http://www.antenocitisworkshop.com/news/what-is-scenery-scale-and-how-big-should-my-doors-be/ [2014, April 30]

[24] Nucsafe, Inc. **Alarms and Statistics** [Online]. 2015. Available from: http://www.nucsafe.com/cms/Alarms+and+Statistics/47.html [2015, September 30]

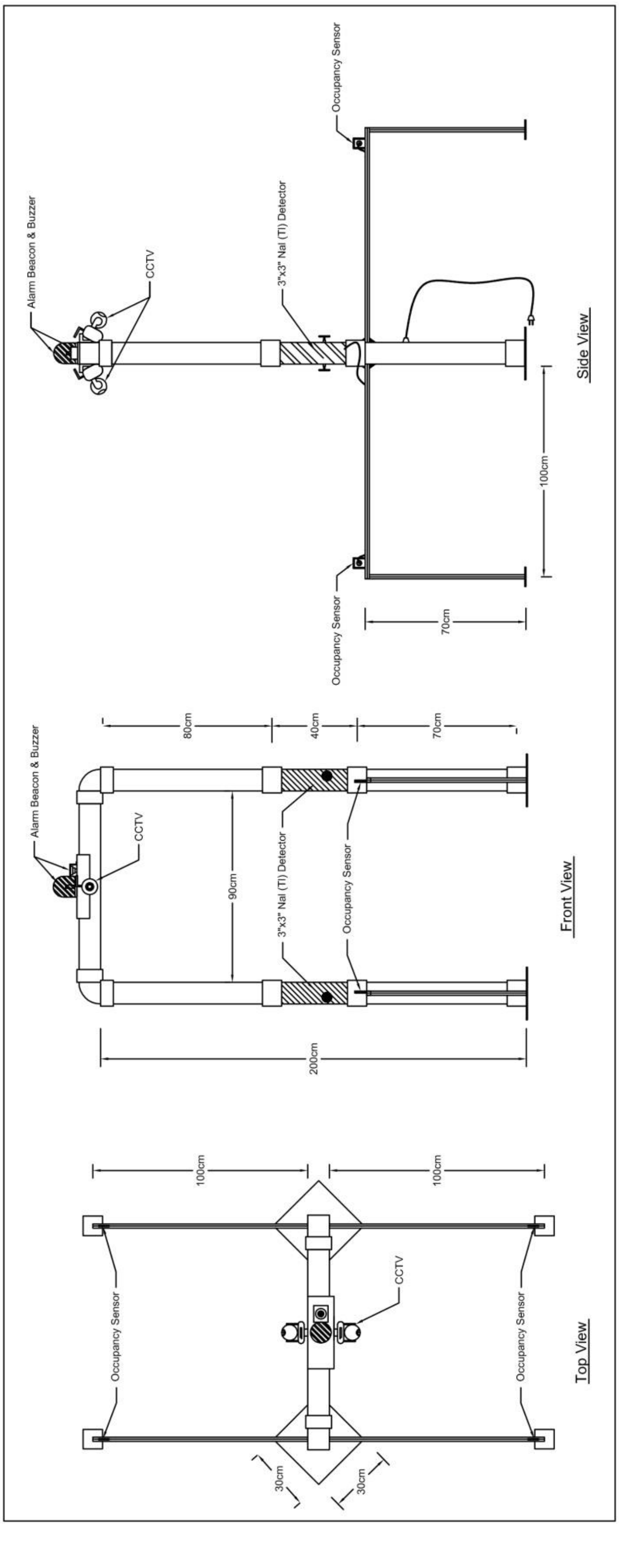
[25] Amazon. **1.2M Cable 30cm Optoelectronic Sensor Photoswitch E3F-DS30C4 NO DC 6-36V**. (n. d.). Avaible from: http://www.amazon.com/Cable-Optoelectronic-Sensor-Photoswitch-E3F-DS30C4/dp/B008S9IS1I [2015, July 17]

[26] Shenzhen Vstarcam Technology Co., Ltd.. **Manual For IP-Camera Super Client (PnP)** [Online]. (n. d.). Available from: http://download2.eye4.cn/download/doc/manual-en-HP-PC-vstarcam.pdf [2015, June 19]

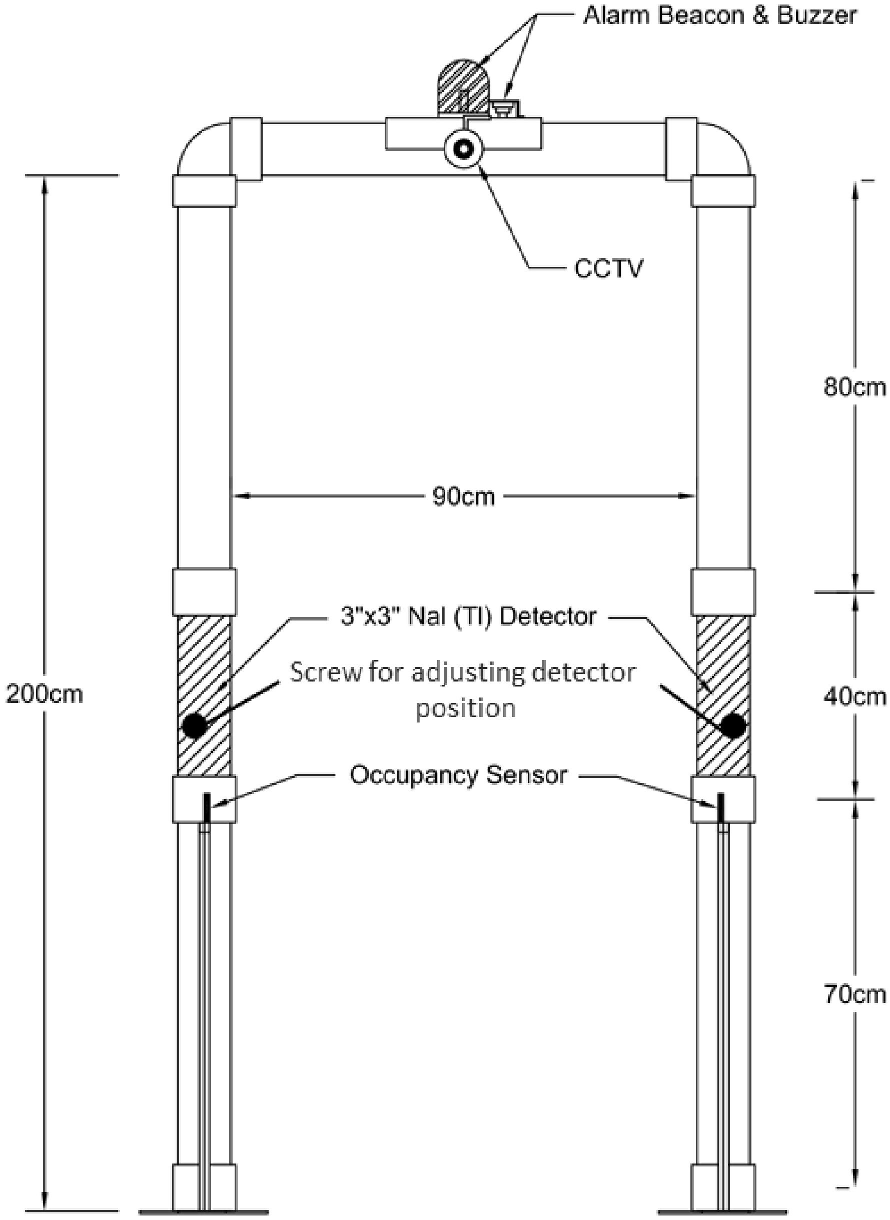
[27] Milan Verle. **PIC Microcontrollers - Programming in Basic**. 1st Edition. Belgrade: mikroElektronika, 2010.

APPENDIX

APPENDICE A – PORTAL GATE DRAWING

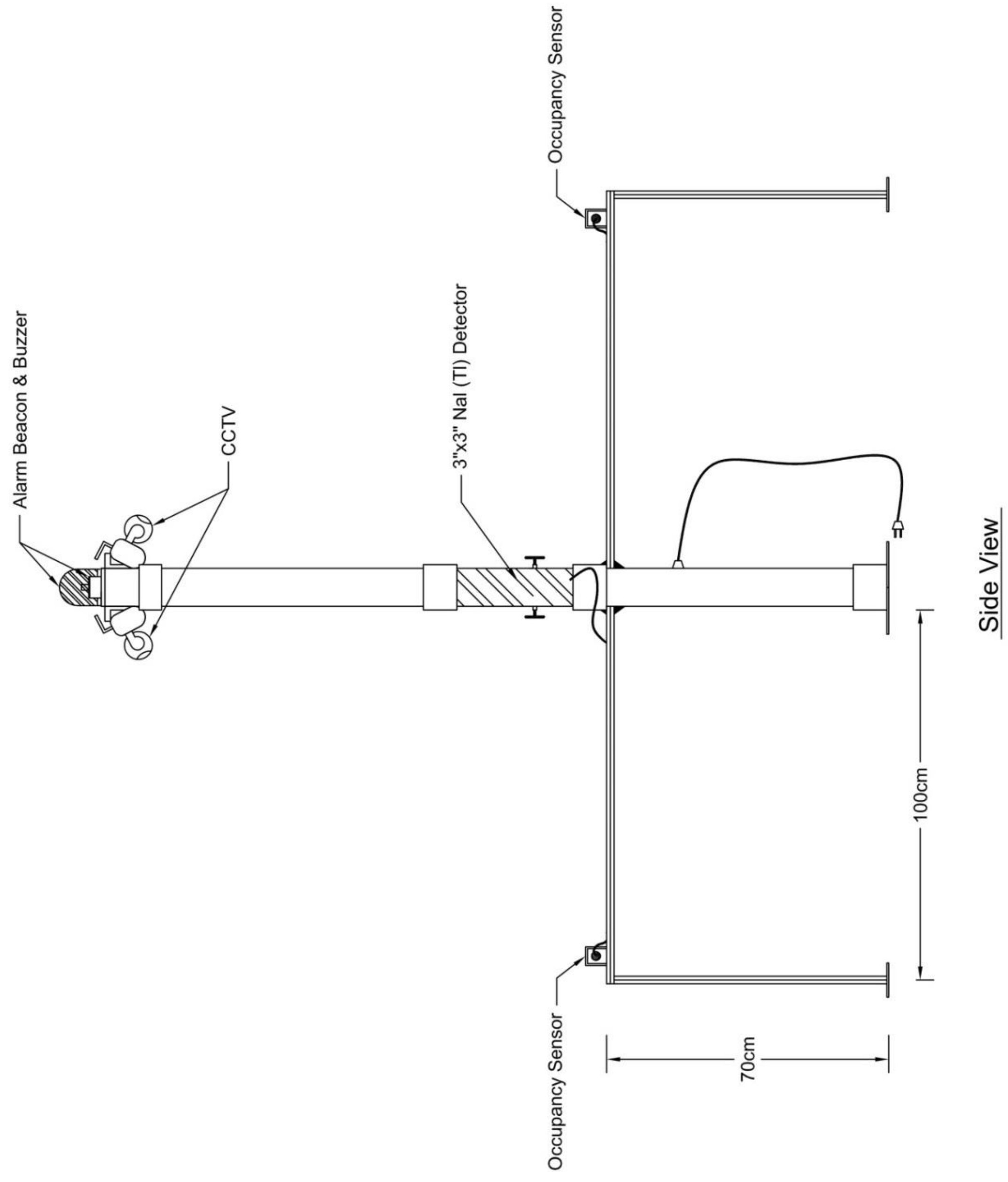


Front View

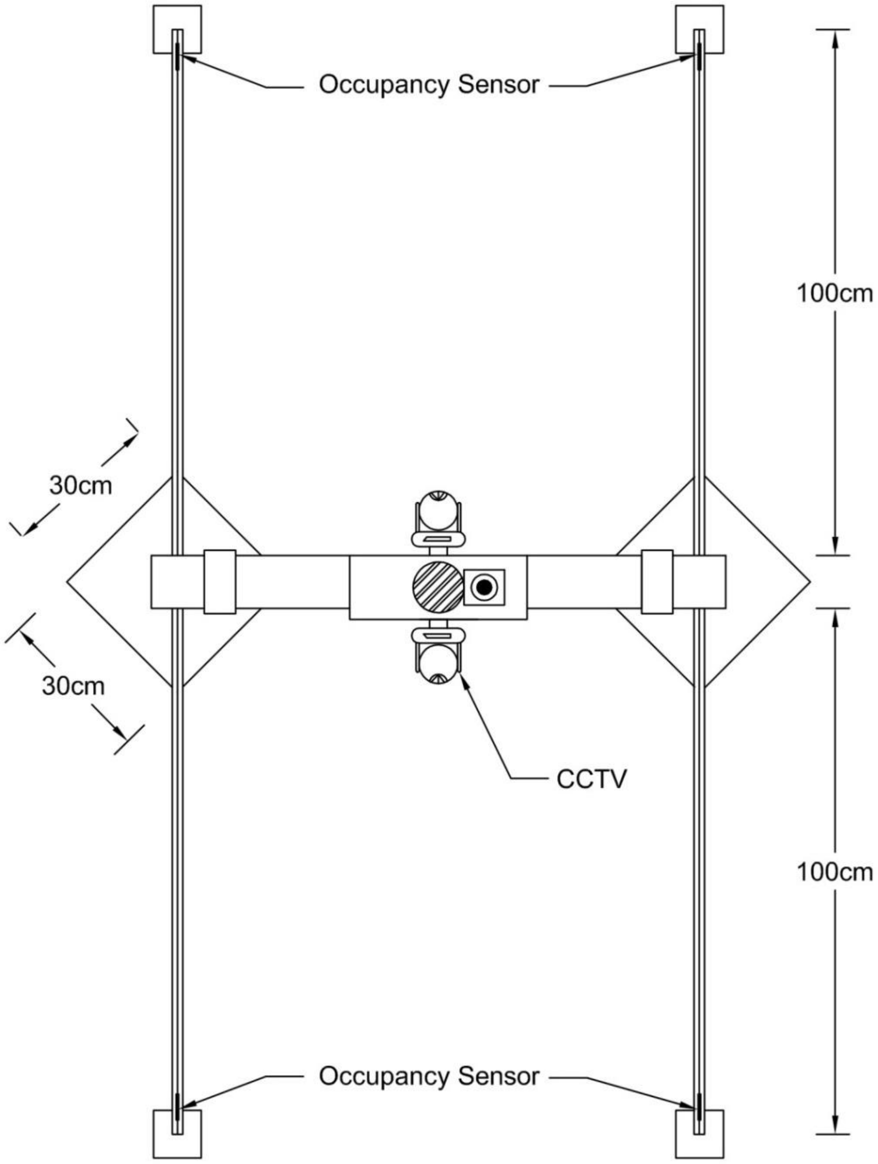


Front View

Side View


Alarm Beacon & Buzzer
CCTV
3"x3" NaI (Tl) Detector
Occupancy Sensor
Occupancy Sensor
100cm
70cm
Side View

Top View



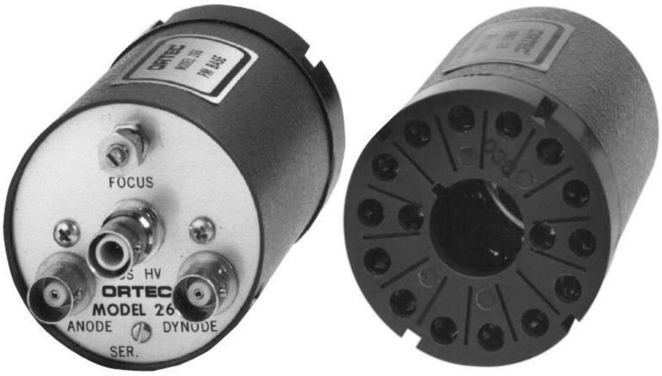
Top View

APPENDICE B – DATA SHEET OF SOME DEVICE

ORTEC®

266
Photomultiplier Base

- **For use with 10-stage PMTs that fit standard 14-pin sockets**
- **Linear output available from anode or tenth dynode**
- **Focus control for optimum peformance**



The ORTEC Model 266 Photomultiplier Base provides voltage distribution to essentially all 10-stage photomultiplier tubes (PMTs) that fit its standard 14-pin tube socket. It provides capacitively-coupled linear output signals from the anode and the tenth dynode that can be used in either timing or linear pulse height analysis systems. This arrangement allows the use of either polarity of output without an inverting amplifier. High-quality signals are maintained when these outputs are fed through 50-Ω terminated cables or directly into a linear preamplifier such as the ORTEC Model 113 Scintillation Preamplifier. The Model 113 output is fed into one of the ORTEC main amplifiers, where it can be either active-filter- or delay-line-shaped for analysis. The focus control on the Model 266 allows optimum adjustments for the best performance of the particular PMT.

The Model 266 is compatible with most standard 10-stage PMTs that fit standard 14-pin sockets, including those listed in Table 1.

Other compatible tubes may be determined by comparison with those that are listed (also see Figs. 1 and 2). Note that all photomultiplier tube specifications are given by the PMT manufacturer.

Table 1. Compatible Photomultiplier Tubes.

ADIT	Burle (formerly RCA)	Hamamatsu	Phillips	Electron
B51B01	4900	PM55	XP2202	9266K
L51B01	5819	R208	XP2203B	9272K
V51B01	6342A	R550	XP2412B	9250K
B51D01	6655A	R594		9256K
B51C01	S83006E	R877		9305K
B76B01	S83013F	R878		9265K
V76B01	S83019F	R1507		9269K
B76C01	S83020F	R1512		9273K
B89B01	S83021E	R1513		9274K
B89C01	S83022F	R1612		9306K
B89D01	S83025F	R1791		9390K
B133D01		R1836		9275K
B133C01		R1847-07		
V133B01		R1848-07 7696		

266
Photomultiplier Base

Specifications

PERFORMANCE

BLEEDER RESISTANCE 1.5 MΩ total, tapped to provide proportional bias steps to successive tube elements.

CONTROL

FOCUS The voltage to the focus electrode in the tube is available as an external trim adjustment using a screwdriver potentiometer.

INPUTS

POS HV SHV connector accepts positive bias voltage to 2.5 kV maximum.

PMT SOCKET TRW 3B14. Fits JEDEC B14-38 PMT pin base (see Fig. 2).

OUTPUTS

ANODE BNC connector provides negative linear output through Z_0 ~1.1 MΩ, capacitively-coupled.

DYNODE BNC connector provides positive linear output from the tenth dynode through 1.1 MΩ, capacitively-coupled.

ELECTRICAL AND MECHANICAL

WEIGHT
Net 0.37 kg (0.81 lb).
Shipping 0.96 kg (2.12 lb).

DIMENSIONS 5.6 cm (2.2 in.) diam x 10.2 cm (4 in.) long.

Related Equipment

Either the anode or dynode signal may be processed through an ORTEC Model 113 Scintillation Preamplifier that is connected to a main shaping amplifier such as ORTEC Models 460, 570, 572A, 575A, or 590A. These signals may also be connected through 50-Ω coaxial cables and amplified by fast amplifiers to be used in timing applications with the ORTEC Model 473A Constant-Fraction Discriminator or other fast discriminators. If one of the outputs is not used, it should be terminated with a C-27 100 Ω terminator to prevent distortion on the other outputs. The ORTEC Model 556 High-Voltage Power Supply is recommended for supplying the positive high voltage. A C-24-1 Cable is recommended for connecting the dynode output to a Model 113 Preamplifier. A C-24-12 Cable can be used between the preamplifier output and the input to the main shaping amplifier. For timing from the anode use a C-25-12 Cable. The C-36-12 Cable is recommended for the high voltage connection.

Ordering Information

To order the Model 266 Photomultiplier Base or related accessories, use the following model numbers and descriptions:

Model	Description
266	Photomultiplier Base
C-24-1	RG-62A/U 93-Ω Cable with two BNC male plugs, 1-ft length
C-24-12	Same as above, 12-ft length
C-25-12	RG-58A/U 50-Ω Cable with two BNC male plugs, 12-ft length
C-36-12	RG-59A/U 75-Ω Cable with two SHV female plugs, 12-ft length
C-27	Terminator, 100 Ω, BNC male plug

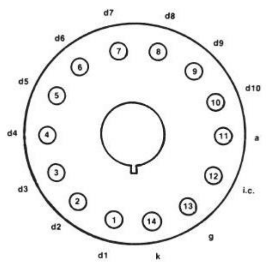


Fig. 2. JEDEC B14-38 PMT Pin Base, with Pin Assignments:

d1 – d10	dynodes 1 to 10
a	anode
i.c.	internal connection
g	grid
k	cathode

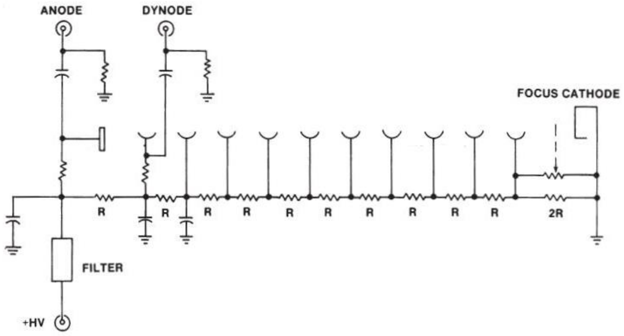


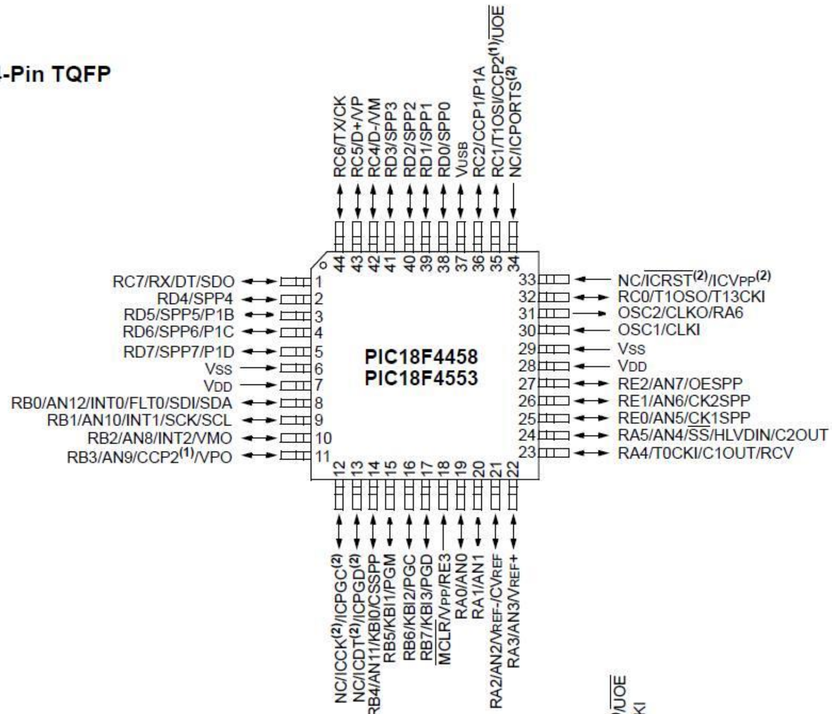
Fig. 1. Simplified Schematic Diagram of ORTEC Model 266 Photomultiplier Base.

Specifications subject to change
043008

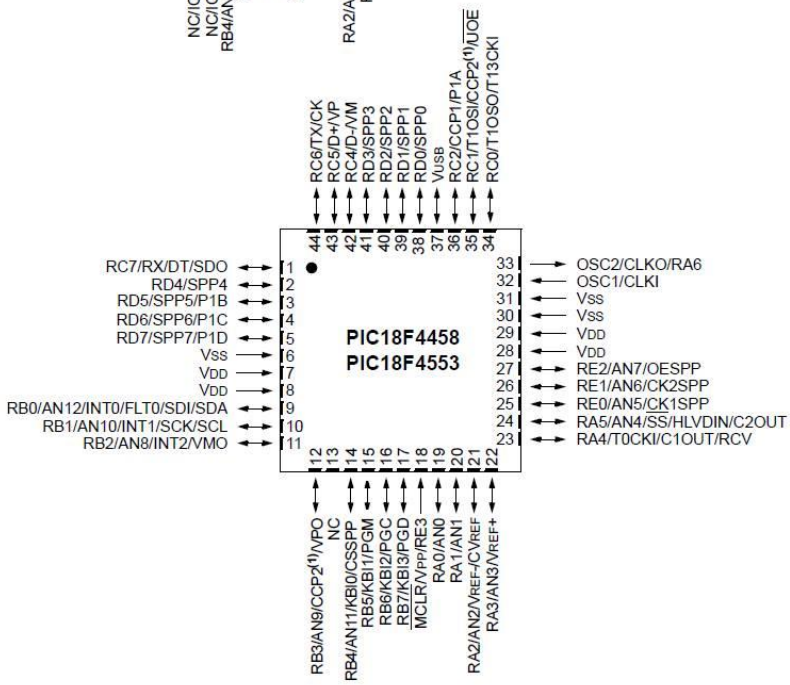
ORTEC®
www.ortec-online.com
Tel. (865) 482-4411 • Fax (865) 483-0396 • ortec.info@ametek.com
801 South Illinois Ave., Oak Ridge, TN 37831-0895 U.S.A.
For International Office Locations, Visit Our Website
AMETEK®
ADVANCED MEASUREMENT TECHNOLOGY

Pin Diagram of 44 Pin PIC18F4553 Microcontroller

44-Pin TQFP



44-Pin QFN



VITA

Mr. Thet Wai TUN was born on 18th February 1977, in Myanmar. From 1998 to 2000, he studied the Machine Tools and Design (Diploma Degree) in the Government Technological Institute (GTI), Myanmar. In the same year, 2000, he continued to study the bachelor of engineering in Nuclear Engineering at Yangon Technological University of Myanmar. Mr. Thet Wai has been working at Department of Atomic Energy, Ministry of Science and Technology since 2003. In 2013, he received the scholarship for studying the Master of Science in Nuclear Technology, specialized in Nuclear Security and Safeguards at Chulalongkorn University, Bangkok, Thailand.