HEALTH RISK ASSESSMENT OF BRACHYTHERAPY SERVICE ENGNEERS AT THE SELECTED NUCLEAR MEDICINE CENTRES

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KUALA LUMPUR

2018

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RESEARCH REPORT SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENT FOR THE DEGREE OF MASTER OF ENGINEERING

FACULTY OF ENGINEERING
UNIVERSITY OF MALAYA
KUALA LUMPUR

2018

UNIVERSITY OF MALAYA

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ABSTRACT

Brachytherapy is gaining popularity of method to treat cancers. Moreover, a number of studies have been published on brachytherapy. However, not much research are focusing on the radiation worker on maintain the Treatment Unit (TU) which using Iridium-192 isotope with a half-life of 73.83 days. As the technology grow, from manual afterloading into remote afterloading, better safety feature and procedures introduced. What is the safety and health status of a service engineer from the technology and facility improvement? Therefore, the study was done to identify and assess the health risk of engineers from maintenance activity of TU and to study the perceptions of the engineer towards the existing safety in selected nuclear medicine centres. Apart from that, the study aim is to recommend risk control for best measures on safety and protection against unwanted exposure. This research use the method of data collections which is quantitative and qualitative methodologies. In qualitative method, interview and observation at selected oncology department were used during planned maintenance and servicing. In quantitative data, questionnaire were given to the service engineers. Risk calculation were calculated using risk matrix. The study successfully assess and identify the health risk of the service engineers and recommendation had been given to improve the safety of the service engineer during PPM activity. The study also include the perception of the engineers toward the safety feature of the selected hospitals. The study also identified that both low and high risk have the same percentage which is 31% meanwhile medium risk is 38%. The hazards identified consist of 11 physical hazards, 1 biological hazard, 3 ergonomic hazards, and 1 electrical hazard. Based on the risk assessment result, it is also found that tasks posed with high risk value are during exchange source with dummy cable and source check position. There were no injury nor fatality and also nor genetic mutation effect recorded in the study even the activity is involving high risk hazards.

Keywords: brachytherapy, service, engineer, safety, Iridium-192

ABSTRAK

Brakiterapi semakin mendapat populariti sebagai cara untuk merawat kanser. Lebih-lebih lagi, beberapa kajian mengenai brakiterapi telah diterbitkan. Walaubagaimanapun, adalah kurang kajian mengenai pekerja radiasi yang berkaitan dengan Unit Rawatan yang menggunakan isotop Iridium-192 yang mempunyai separuh hayat 73.83 hari. Berkembangnya teknologi, daripada manual 'afterloading' kepada 'afterloading' kawalan jauh, malah keselamatan serta prosedur yang lebih bagus telah diperkenalkan. Apakah status keselamatan dan kesihatan seorang jurutera servis hasil daripada penambahbaikan teknologi? Oleh itu, kajian ini telah dijalankan bagi mengenal pasti and menilai risiko kesihatan terhadap jurutera daripada aktiviti penyelenggaraan ke atas Unit Rawatan dan untuk mengkaji persepsi jurutera terhadap keselamatan yang sedia ada di pusat perubatan nuclear yang terpilih. Selain daripada itu, kajian ini bertujuan untuk mencadangkan kawalan risiko sebagai langkah terbaik dalam keselamatan dan perlindungan daripada pendedahan radiasi yang tidak diingini. Kajian ini menggunakan cara mengumpul maklumat dengan cara kuantitatif serta kualitatif. Dalam cara qualitative, temu ramah dan pemerhatian di jabatan onkologi yang terpilih digunakan semasa penyelenggaraan berjadual dan activiti servis. Bagi data kuantitatif, borang soal jawab diedarkan kepada jurutera-jurutera. Pengiraan risiko dikira menggunakan matrik risiko. Kajian ini berjaya menilai dan mengenalpasti risiko kesihatan jurutera-jurutera servis dan cadangan telah diberikan bagi memperbaiki keselamatan jurutera servis semasa aktiviti penyelenggaraan berjadual. Kajian ini juga mengambil kira persepsi jurutera terhadap ciri keselamatan yang ada di hospital-hospital. Kajian ini juga mendapati kedua-dua risiko rendah dan tinggi mempunyai peratusan yang sama iaitu 31%, sementara itu risiko sederhana adalah 38%. Risiko yang dikenal pasti mengandungi 11 bahaya fizikal, 1 bahaya biologi, 3 bahaya ergonomic, dan 1 bahaya elektrik. Berdasarkan kepada hasil penilaian risiko, adalah dikenal pasti bahawa tugasan yang menjurus ke arah risiko tinggi adalah semasa pertukaran sumber radiasi dengan kabel palsu dan semasa cek kedudukan sumber. Tiada rekod kecederaan, atau kematian dan juga kesan mutasi genetik semasa kajian dijalankan walaupun aktiviti tersebut melibatkan bahaya risiko tinggi

Kata kunci: brakiterapi, servis, jurutera, keselamatan, Iridium-192

ACKNOWLEDGEMENTS

In the name of Allah, The Most Gracious and The Most Merciful

Alhamdulillah, all praises to Allah for the strengths and His blessing in completing this research report. A large number of people have made this research possible. I would like to express my gratitude to all of them.

First of all, I would like to offer my best thanks to my supervisor, Dr. Hanee Farzana binti Hizaddin, for her invaluable assistance and constant support throughout the study. . I also would like to thank both engineers from AAA Company. My sincere thanks goes to the Radiation Protection Officer (RPO) from AAA Company for all the cooperation and willingness to share knowledge.

Last but not least, my sincere gratitude goes to my beloved parents, Hj Rosli bin Mohd Nor and Aminah binti Umar and my siblings for their endless love, prayers and encouragement. To those who indirectly contributed to this study, your kindness means a lot to me. Thank you very much.

TABLE OF CONTENTS

Abstract iii

Abstrak iv

Acknowledgements vi

Table of Contents vii

List of Figures x

List of Tables..........xi

List of Symbols and Abbreviations..........xii

List of Appendices xiii

CHAPTER 1: INTRODUCTION..........14

1.1 Background..........14

1.2 Problem Statements 14

1.3 Objectives 15

1.4 Scope of Study..........15

1.5 Description of Brachytherapy Service Engineer 16

1.6 Description of Selected Nuclear Medicine Centres..........16

CHAPTER 2: LITERATURE REVIEW..........17

2.1 Ionizing Radiation 17

2.2 Biological Effect of Radiation..........18

2.3 Brachytherapy Treatment Unit 19

2.4 Brachytherapy Important Features 20

CHAPTER 3: METHODOLOGY..........22

3.1 Qualitative Data..........23

3.1.1 Interview 23

3.1.2 Observation 24

3.2 Quantitative Data 24

3.2.1 Questionnaire to Engineers 24

3.2.2 Risk Evaluation 24

CHAPTER 4: RESULTS 25

4.1 On Site Observation 25

4.1.1 Activity Work Process 25

4.1.2 Safety Features 31

4.2 Questionnaire analysis 32

4.3 Perception of Service Engineers 34

4.4 Risk Assessment 35

CHAPTER 5: DISCUSSION 41

5.1 Hazard Control Measure 41

5.1.1 Elimination and Substitution 41

5.1.2 Engineering Control 41

5.1.3 Administrative Control 43

5.1.4 Personal Protection Equipment 44

5.2 Perception of Service Engineer 45

CHAPTER 6: CONCLUSION 47

6.1 Conclusion 47

6.2 Recommendation and Future Study 48

References 49

Appendix A 52

Appendix B 55

Appendix C 56

Appendix D 57

Appendix E 58

Appendix F 59

LIST OF FIGURES

Figure 1: Research Flow Chart Process 22

Figure 2: microSelectron Brachytherapy 23

Figure 3: Work process of planned preventive maintenance. 26

Figure 4: Check cable wipe test. 27

Figure 5: Engineer remotely control the source exchange from treatment control room28

Figure 6: Top head survey............ 30

Figure 7: Emergency container with long pair of forceps............ 31

Figure 8: Risk Assessment Result............ 39

Figure 9: Hazard classification............ 40

Figure 10: Source inside an emergency container. 42

Figure 11: Emergency placed away from working area. 43

LIST OF TABLES

Table 1: Questionnaire Result from Service Engineer..32

Table 2: Perception of Service Engineers 34

Table 3: Risk Assessment using Risk Matrix 36

LIST OF SYMBOLS AND ABBREVIATIONS

ALARA	:	As Low As Reasonably Achievable
CCTV	:	Closed Circuit Television
CO-60	:	Cobalt-60
DNA	:	Deoxyribonucleic acid
IR-192	:	Irradium-192
MMCH	:	Mount Miriam Cancer Hospital
PPE	:	Personal Protective Equipment
PPM	:	Planned Preventive Maintenance
QA	:	Quality Assurance
RPO	:	Radiation Protection Officer
SIH	:	Sultan Ismail Hospital
TCP	:	Treatment Control Panel
TCS	:	Treatment Control Station
TU	:	Treatment Unit

LIST OF APPENDICES

Appendix A: Questionnaire………………………………………………………... 49

CHAPTER 1: INTRODUCTION

1.1 Background

Brachytherapy was discovered in 1901, a numerous study had been made to develop a technique to treat cancer, thus make it popular (Gasinska, A., 2016). However, in early 20th century, there was a problem arise where clinicians were exposed greatly with the radiation (Lim, G., 2006). Even though, the use of brachytherapy had reduce, a big changes was made on the introduction of new radioactive sources, techniques and machines (Hannoun-Levi, J.-M., 2017). The technology developed reduce drastically the radiation exposure to patients and healthcare specialist during treatment.

Apart from that, the technology keep growth and successfully found a way to change the manual afterloading with remote afterloading which contribute greatly on the safety of healthcare specialists from unwanted radiation exposure. Nowadays, brachytherapy is gaining back the popularity of method to treat cancel in healthcare facility. Moreover, a number of studies have been published on brachytherapy (M. Coursey, B., 2017). However, research on radiation worker on maintenance activity is still in novelty.

1.2 Problem Statements

Years by years, amount of cancer health problem is increasing in Malaysia. As oncology department in nuclear medicine center actively fight against cancer, the demand of radiotherapy also arise with the technology. In service engineer perspective, the total hours of a service engineer handling Treatment Unit (TU) will also arise. As this scenario happens, a possibility of overexposure might happen. Therefore, research should be done to assess health risk and recommend risk control for best measure.

1.3 Objectives

The aim of this study is to identify and assess the health risk from maintenance activity to the brachytherapy service engineer from AAA Company. By this, the engineer get to know if it safe to handle and service brachytherapy unit, thus take further measures to keep themselves safe from unwanted exposure.

Objectives for this research are:

I. To identify and assess the health risk of engineers from maintenance activity of TU.
II. To study the perceptions of the engineer towards the existing safety in selected nuclear medicine centres.
III. To recommend risk control for best measures on safety and protection against unwanted exposure.

1.4 Scope of Study

In these research project, there are few scopes that we need to give attention. Firstly, the service engineers involved in the study are from AAA Company. Second, the brachytherapy model that are chosen is microSelectron from Elekta which previously was manufactured by Nucletron. The TU is using Iridium-192 with a half-life of 73.83 days (Lukasz, K., 2016). Third, the nuclear medicine centres chosen are Mount Miriam Cancer Hospital (MMCH), Penang and Sultan Ismail Hospital (SIH), Johor Bahru. The assessment will show the health risk of service engineer towards radiation during Planned Preventive Maintenance (PPM) activity.

1.5 Description of Brachytherapy Service Engineer

Service engineer chosen is radiation workers from AAA Company. The engineers are Elekta certified service engineer who completed a designated training and got positive assessment.

As a service engineer, they are responsible to install brachytherapy system into nuclear medicine center, do planned maintenance, and also do source exchange upon request. A part from that, the service engineers are also required to do corrective maintenance and emergency procedure during emergency and reporting. However, the assessment for this study was done only for PPM activity. Upon handling the brachytherapy unit, an environment of safe from unwanted exposure is needed as the service process will take hours.

1.6 Description of Selected Nuclear Medicine Centres

This study will focus on Oncology Department in two Nuclear Medicine Centres. They are Mount Miriam Cancer Hospital, Penang and Sultan Ismail Hospital, Johor Bahru which is private hospital and general hospital respectively.

Both hospitals have brachytherapy treatment room called bunker which functions to avoid from unwanted gamma ray exposure. Both hospital are equipped with the same Treatment Unit (TU) which is microSelectron.

CHAPTER 2: LITERATURE REVIEW

2.1 Ionizing Radiation

Ionizing radiation may be divided into two groups which is electromagnetic radiations and corpuscular radiation. Electromagnetic radiations consist of X-ray and gamma rays. X-ray and gamma ray are distinguished from how they were produced. X-ray is produced from electron hit a tungsten target while gamma ray are produced from radioactive atomic nuclei (Piron, F., 2016). However, both of them are part of electromagnetic spectrum. They are waveforms and able to travel through vacuum (Gonc-alves et al., 2007). In medical field, X-ray is used for medical imaging while gamma is used to treat cancer. Current technology are able to use X-ray to treat cancer by accelerate them using radiofrequency produced by magnetron. High energy ionizing radiation can cause helix bond in Deoxyribonucleic Acid (DNA) to break down (M.I. , S. et al., 2017). It is know that the breakdown will be easily repaired by normal cell than a cancer cell (Candela-Juan et al., 2015).

Corpuscular radiations consist of alpha particle, beta particle and protons. Alpha particle also known as, Helium ion, He+2. Alpha particle consist of 2 protons, 2 neutrons with missing 2 electrons compared to Helium gas, which have 2 protons, 2 neutrons and 2 electrons. Beta particle is basically is a high moving electron, e- produced during beta-decay. Beta have higher energy than alpha but since beta is an ion it can be stopped by few millimeters of aluminum.

2.2 Biological Effect of Radiation

Some study are also trying to relate radiation with human health. A study by Symonds et al. (2016) the adverse effect of human health from radiation can be divided into two which are deterministic effect and stochastic effect. Deterministic effect can be seen from a very high dose in short term effects. The effect is immediately as the person exposed to high dose are seen to get skin burns, cell damage and radiation sickness. There are other effects that is immediate which are nausea, fatigue and hard to breath. Stochastic effects are effect that can be seen from low dose but in long term. This effect is more concern on cancer. Some effect are long enough that can only be detected from offspring.

Some study relate radiation as induce cancer. The frequency of radiation-induced cancer in human tissues, after total body exposures with low doses of ionizing radiation, has been determined in different epidemiological studies (Preston et al., 2007). However, many of adverse effect on health especially cancer are not produce exclusively by radiation and not all type of cancer have been shown came from exposure to ionizing radiation (Grover et al., 2017).

Many studies had been done to study the cause of cancers. It was well established that ultraviolet light can cause tumors of the skin. (Rusch et al., 1939). Then a study found that a lung cancer is caused by tobacco (Pleasance et al., 2010). A study from B. Alexandrov et al.,(2013) also stated that most known are skin cancer which relate to the ultraviolet of sunlight and lung cancer with relation to the smoking habits. Therefore, it is difficult to separate the amount of cancers that caused by the radiation alone or from other source.

2.3 Brachytherapy Treatment Unit

Brachytherapy, also known as internal radiotherapy, is the delivery of radiotherapy with the use of sealed radioactive sources. The capsule are used to prevent from alpha and beta radiation to the patient, therefore only gamma ray is emitted. The sealed capsule also provide rigidity to the source and prevent from the source leaking or left inside a patient body.

Brachytherapy can be applied as mono-therapy or in combination with external beam radiotherapy, surgery, or chemotherapy. Brachytherapy are used with applicators suitable with cases and modalities used during planning. There are two types of marker which is X-rays marker and another one is CT/MR marker suit with modalities used. The use of brachytherapy is highly localized, means the source delivered are closely adjacent to target cell. The source position determines the positive outcome of a treatment, which also known as fraction. The source also can be permanently implant. Thus, it is a conformal radiotherapy and dependent on the operator's skill and experience. Conformal radiotherapy describes the attempt to conform the treatment volume as closely as possible to the actual target volume thereby sparing the surrounding normal tissue as much as possible. In general, the normal radiation safety consideration also apply to conformal radiotherapy.

Nowadays, the brachytherapy had become more advance with remote afterloading where the source travel through sealed safe, into catheters and retracted back into the safe using computer control (Tanderup et al. 2017).

2.4 Brachytherapy Important Features

There are limitation from external radiotherapy such as Linear Accelerator. The internal organ are not static and need to reposition in each fraction. Some organ might deform from day to day and also inaccuracies in daily setup may happen during repositioning. Therefore brachytherapy is chosen to solve these problems (Jeffrey et al, 2014).

The important features of brachytherapy is the catheters, which is plastic tube specially design for brachytherapy use are inserted to target area adjacent to cancer cells are relatively easy to see using ultrasound and can be safely implanted. Apart from that, the patient will not become radioactive after the fraction which shows that the brachytherapy has a good radiation safety. They wouldn't have restriction to have contact in certain distance with other people or family members. Moreover, there were no issues in handling the source by radiotherapist or medical personal. The TU are equip with real-time dose module planning software which gives quick feedback to gain optimal implant catheter distributions.

An encapsulated source may able to be used for many fractions and varies disease sites which made it cost effective machine. The TU is also is built with wheel which makes it portable. The fractions courses are short and have brief recovery from side effects. Last but not least, the versatility of intra target dose modulation inherent to brachytherapy can be controlled.

However there are few disadvantage of brachytherapy, the result is only good with for small lesion and very labor intense. The treatment will involve group of specialist such as medical officers during health screening, surgeons & oncologist during catheter insertion, radiologist during imaging using Computed Tomography scan or Magnetic Resonance Imaging, physicist during treatment planning, and radiotherapist during treatment execution.

CHAPTER 3: METHODOLOGY

This research use the method of data collections which is quantitative and qualitative methodologies. In qualitative method, interview and observation at selected oncology department were used during planned maintenance and servicing. In quantitative data, questionnaire were given to the service engineers. Risk calculation were calculated using risk matrix. The flow chart process is shown in Figure1.

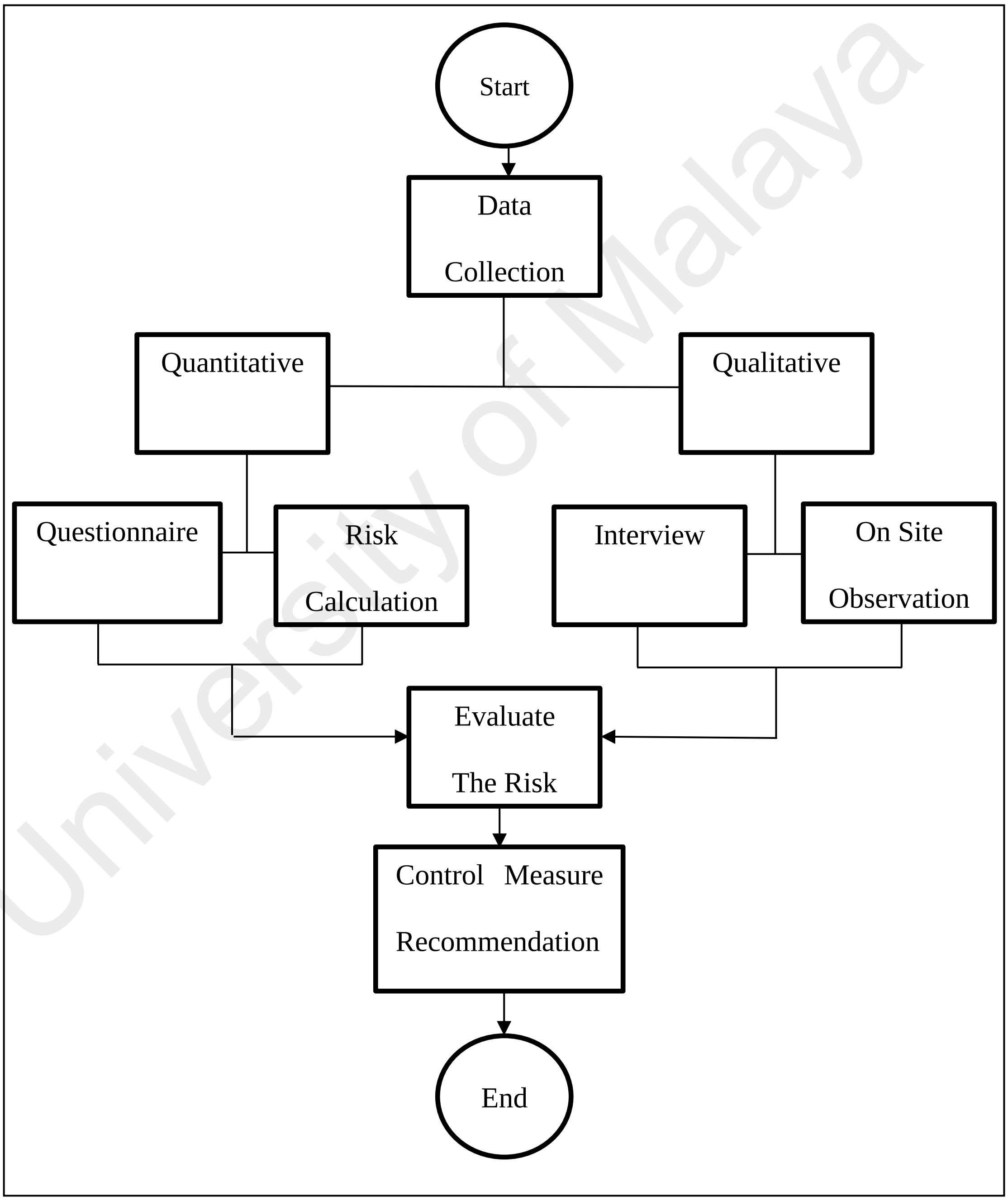

Figure 1: Research Flow Chart Process

3.1 Qualitative Data

3.1.1 Interview

Interview is part of data collection. The interviews were conducted with 2 engineers from AAA Company regarding the work process and service details of PPM.

Figure 2: microSelectron Brachytherapy

This is to understand the function of parts in microSelectron Brachytherapy as shown in Figure 2 and PPM procedure before started. Apart from that, the interview also used to determine hazards and issue faced by the engineers, so that the improvement can be done for the engineer's safety and health.

3.1.2 Observation

Observation was made during engineers servicing in both hospitals. Workflow, procedures, and safety precaution took were observed and recorded. Apart from that, the observation was made to identify potential hazards during PPM activity. Information gathered will help to improve the safety and health of the engineers.

3.2 Quantitative Data

3.2.1 Questionnaire to Engineers

Questionnaire given consist of 3 parts. First section is general information, include age, gender, no. of children, present of children genetic abnormalities, and engineers smoking habits as smoking also known as the cause of cancer. The information is needed to distinguish the other cause of cancer.

Second section is work and experience include years of experience, training attend, and good standard of practice. Third section is engineer perception towards both selected hospital. These information could help to identify the potential hazard and improvement for the engineer's safety and health.

3.2.2 Risk Evaluation

The information gathered from interview, on site observation, and questionnaire were used to identify the potential hazards. Then, risk assessment is the possibility of injury or harm at scales of likelihood and severity. Risk control will be advised as to eliminate or reduce the risk of engineers being exposed to a hazard.

CHAPTER 4: RESULTS

4.1 On Site Observation

Before activity started, a quick brief on planned preventive maintenance work process and safety reminder was given. The activity will be based on Preventive Maintenance Service Checklist for Nucletron Brachytherapy System HDR v2/v3. The briefing was made to ensure that no step skipped and to ensure the safety of engineers from unwanted exposure. Apart from that, the safety feature present in the treatment room or bunker was observed and checked.

4.1.1 Activity Work Process

Elekta recommends the complete preventive maintenance procedure must be performed at least once a year. It is noted that, PPM must be performed by qualified, factory trained service engineers only.

Firstly, the engineer is required to fill up information on customer and service details, system configuration consist of model serial number, Treatment Control Station (TCS), Treatment Control Panel (TCP) & Treatment Unit (TU) version and also survey instrument serial number and calibration date.

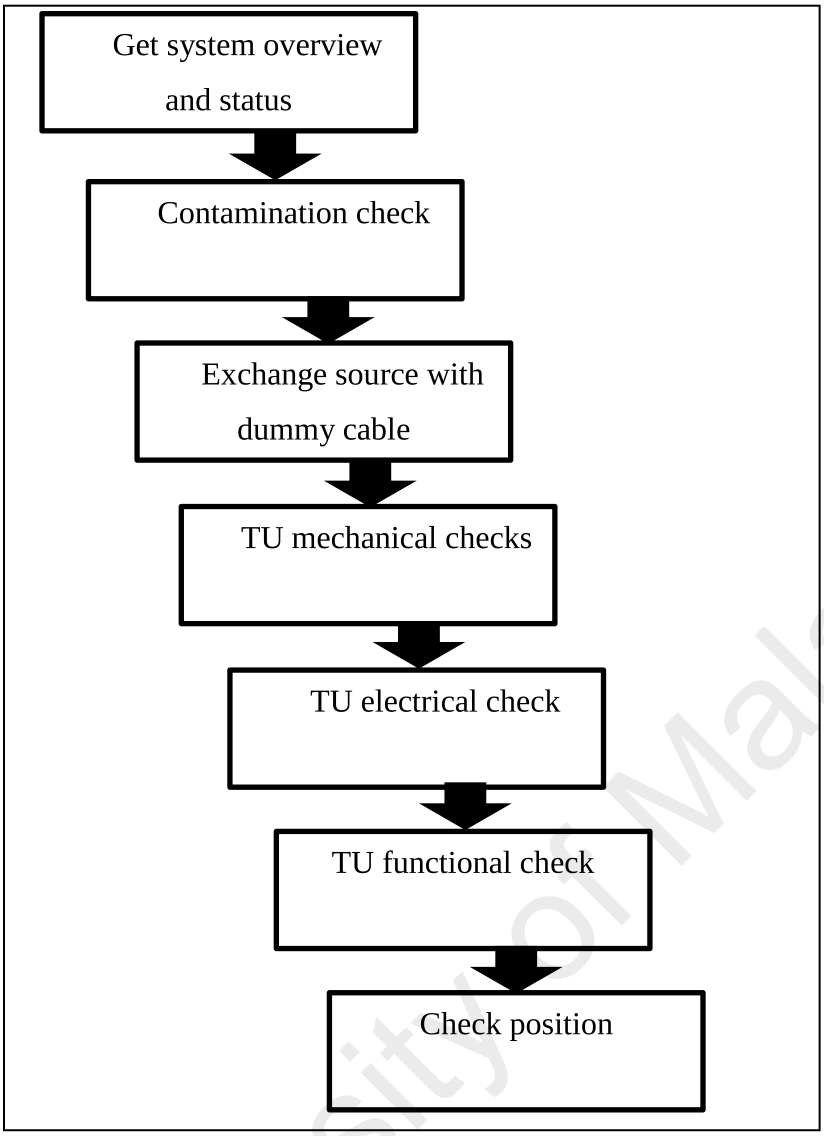

Figure 3: Work process of planned preventive maintenance.

Then, system overview need to be checked. The work process of PPM is shown in Figure 3. Refer to system overview, number of source cable and check cable run must be less than 25 000 and 5000 runs respectively. The cable must be replaced with new cable if exceed limit runs or in case of damage or excessive wear. Check cable is used to detect obstruction along the path of tubes and catheters before encapsulated radiation source cable drawn out for treatment.

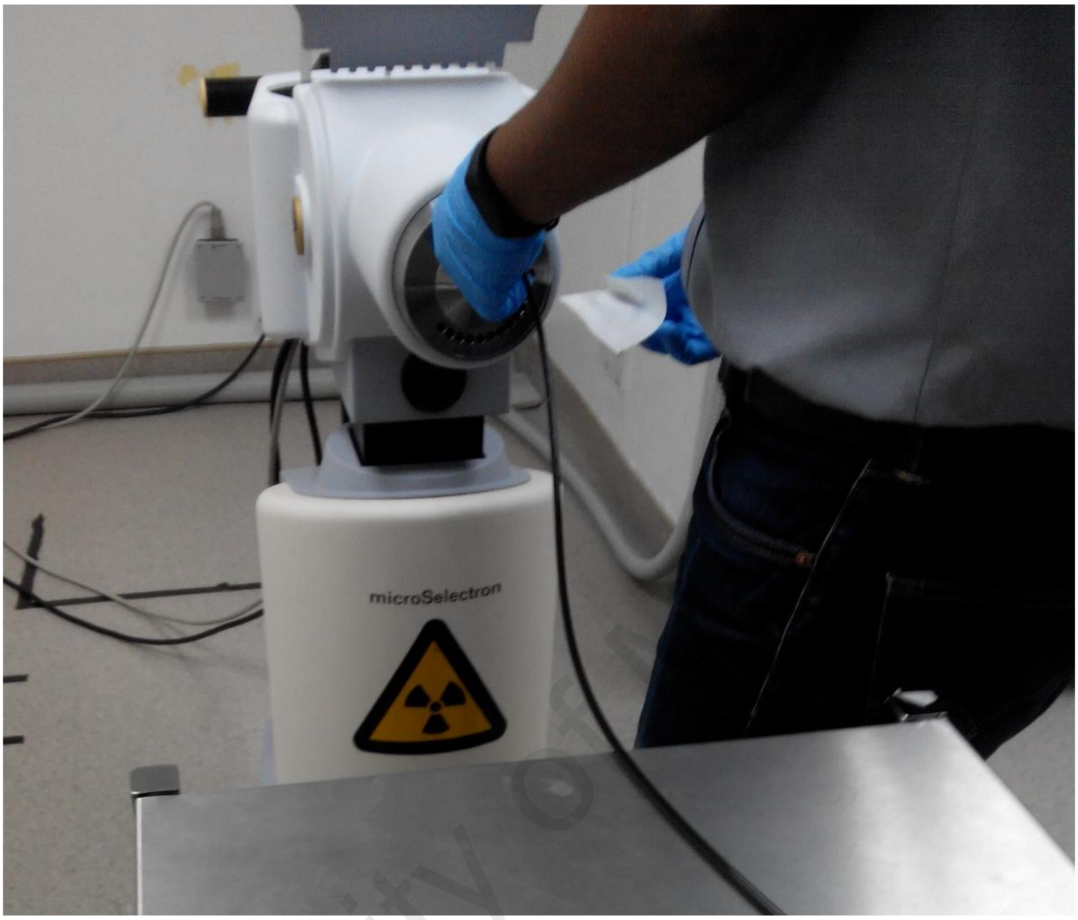

Figure 4: Check cable wipe test.

Based on Figure 4, contamination check need to be done before handling the TU. The engineer is also required to wear glove during the whole maintenance activity. Wipe test for check cable is done to detect contamination. The difference between check cable and background count must be not more than double the background count. Background count is the number of counts recorded by radiation detector from background radiation.

In order for the engineer to work in safe condition, radiation source need to be transferred to emergency container. Therefore, the source cable need to be changed with dummy cable. The system need a source cable or dummy cable for it to continue working properly and prevent from error appear. First, the engineer checked that the emergency container is empty, then placed emergency container in front of TU. Transfer tube is connected between indexer and service channel. The engineer took the survey meter and went out of the room after make sure that all connectors are well placed and the service channel is unlocked.

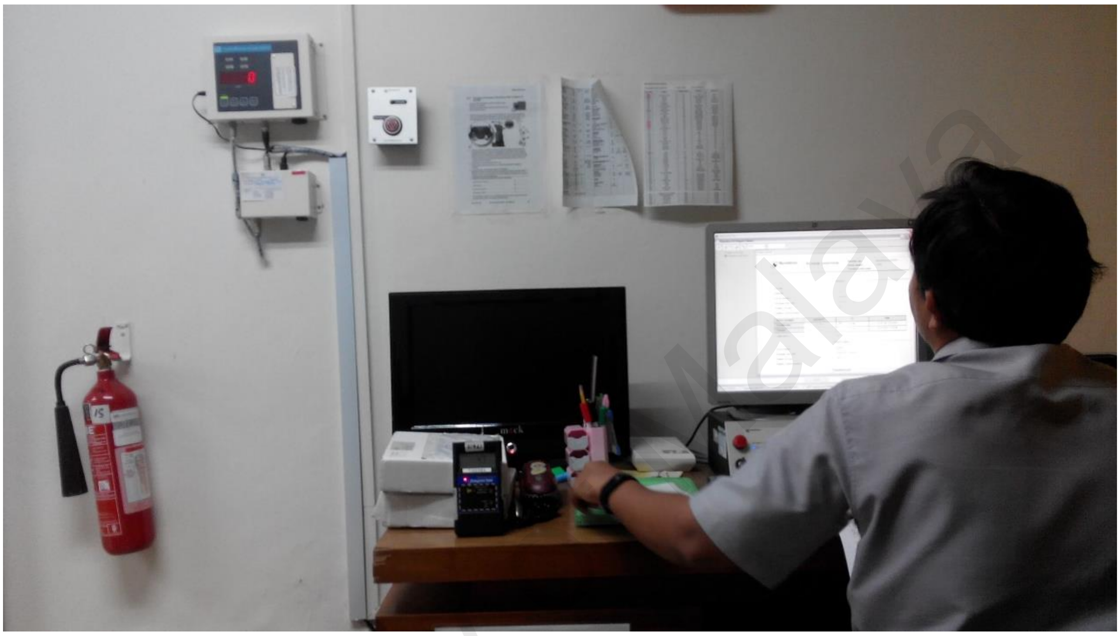

Figure 5: Engineer remotely control the source exchange from treatment control room

It is important to keep door close during the exchange since the source is out of safe and it is unsafe for engineer to stay inside the treatment room. The engineer can do the exchange remotely at treatment control room as shown in Figure 5. Before entering the treatment room, the radiation indicator which indicates that the source is in the service container was observed. The engineer checked if the encapsulated radiation source is inside the container, from indexer to the service container by using survey meter. Once source is inside the emergency container, the engineer locked the service channel and put the emergency container within the bunker compound but away from working area.

Next, the engineer did a mechanical checking. The engineer checked the wheel and lock conditions before remove the TU covers. Mechanical parts of TU need to be checked thoroughly to avoid from source stuck inside patient body or errors during treatment. A smooth mechanical run is also needed to ensure that dose given to patient is the same as in planning. The TU is able to retract and draw out cables with the rotation of cable drum and drive belt, apart from stepper motors. Therefore, cable drum was checked by the engineer and the drive belt for both source and check cable tensions were measured using Vernier caliper. Then, lock mechanism checked for both source and check cables. Engineer is also required to check wire-in-switch closing using feeler gauge. This wire-in-switch is important during retract cables. One of the importance of wire-in-switch is to make sure that source cable is in center of safe, thus prevent radiation leakage from happen. The engineer also checked the center of safe using source loading adapter. He also checked dive lock mechanism using key. Then, slip and retract function for both hand crank were checked. Last but not least in TU mechanical check, indexer, v-block and reference opto-pair condition were checked and fibre optic pathway was observed using torchlight. Next, TU electrical check was done according to PPM checklist. The voltage measurement gives the idea of the condition of the electronics part of TU.

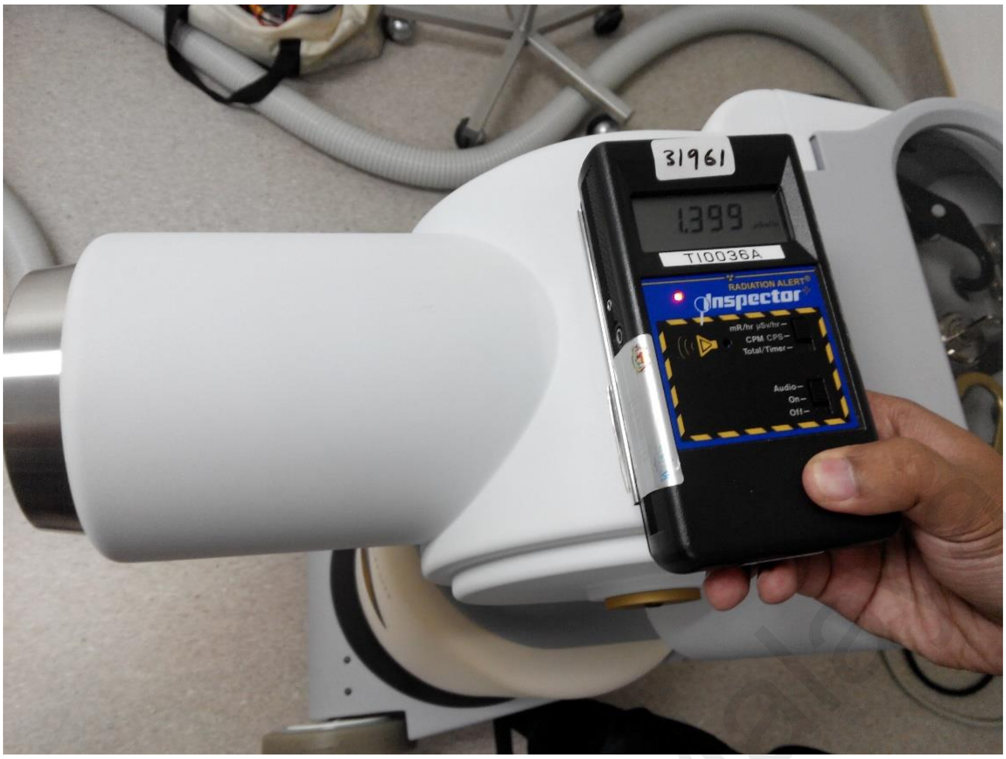

Figure 6: Top head survey

During TU functional check, the functions for all function for all buttons and controls were made sure in good condition. Apart from that, all sensors function were checked by creating 'false error' to trigger error codes. After done with observation on error codes, the dummy cable was exchanged back to original source cable. It is a compulsory for the engineer to do head survey. With the active source in the TU, he need to verify that the measurements do not exceed 2.5 µSV at any point as example shown in Figure 6.

Next, position check was done to ensure that the position of the tip of the cable are in position during withdrawal. Position check is a short QA test. The source tip position is very crucial as the radiation deliver need to be as close as to the cancer cell and to avoid from overexpose to normal cells apart from follow the treatment planning. Finally, radiation detectors function were checked and workstation condition left in clean condition.

4.1.2 Safety Features

During the visit to both hospital, a number of safety feature was installed inside and outside of the bunker. Firstly, an emergency button and alarm are present. These features is compulsory install inside the bunker. Pressing an emergency button triggers the emergency system, which then withdraws the source into the safe, independent of the normal source drive system. The microSelectron system has visual and audio alarms to inform the user about system alarm conditions.

Figure 7: Emergency container with long pair of forceps

Apart from that, an emergency container as shown in Figure 7 is present. Emergency container has two purpose which is used in case of emergency and also act as a temporary container during servicing. However, the emergency container cannot be considered as a storage container.

Next, the integrated radiation detector indicates that the source is out of the safe. One radiation indicator is located on top of the treatment unit, the second radiation indicator is located on the treatment control panel. An error code is generated if radiation is detecting when there is supposed to be nothing, or if radiation is not detecting while it is expected to be there.

4.2 Questionnaire analysis

Questionnaire were given to the service engineers. First section is general information, include age, gender, no. of children, present of children genetic abnormalities, and smoking habits. Second section is work and experience include years of experience, training attend, and good standard of practice. The questionnaire results shown in Table 1.

Table 1: Questionnaire Result from Service Engineer

	Engineer 1	Engineer 2
General Information		
Age	20-30	31-40
Gender	Male	Male
No of children	0-1	2-3
Children with genetic abnormalities	Absent	Absent
Smoking	No	No
Work and experience		
Past personal dosimeter	Below allowable limit	Below allowable limit
Annual exposure	Below allowable limit	Below allowable limit
Years of experience	3-4	5 or more
Training attend	Technical afterloading training	Technical afterloading training
How many times handling TU in a month	6 or more	4-5
Health problem after handling TU	None	None
Manuals and safety procedure provided	Yes	Yes

Do you do revision on manuals and safety procedure before PPM	Yes	Yes
Do you practice short briefing before PPM	Yes	Yes
Do you use calibrated survey meter during PPM	Yes	Yes
Do you wear PPE during PPM	Yes	Yes
Do you do contamination check before PPM	Yes	Yes

Engineer 1 is age in between 20-30 and Engineer 2 is age in between 31-40. Both engineers are male and non-smoking. Engineer 1 have 0-1 children with absent genetic abnormalities and Engineer 2 have 2-3 children also with absent genetic abnormalities.

Firstly, to assess the health of the engineers, their past personal dosimeter and annual exposure was make sure that are below allowable limit. Both of them are an experience engineers since both of them already handling the brachytherapy machine for more than 3 years. They are also certified by Elekta and done attending Technical Afterloading Training. They have quite a large number of TU handling in a month which is more than 3 times. After the handling, they didn't experience any health problem.

The questionnaire also consist of preparation and procedures which cover the safety step before or during handling the TU. Both agree that manuals and safety procedures were provided and revision were made before execute maintenance. Both of them also practice short briefing before the PPM. Apart from that, the survey meter was made sure that it is calibrated and aware of the next calibration date. They also wear PPE during PPM and also do contamination check before PPM to ensure that there are no biological contamination or radiation contamination.

Overall questionnaire shows that both of them practice good standard of procedure and well prepared before doing the PPM.

4.3 Perception of Service Engineers

The perception of service engineers toward existing safety in both hospitals shows less different. The result shown in Table 2 .

Table 2: Perception of Service Engineers

Engineer	1		2	
Hospital	Sultan Ismail, JB	Mount Miriam, Penang	Sultan Ismail, JB	Mount Miriam, Penang
Bunker is in good condition	Yes	Yes	Yes	Yes
Door interlock is in good condition	Yes	Yes	Yes	Yes
Head safe is in good condition	Yes	Yes	Yes	Yes
Emergency container is in good condition	Yes	Yes	Yes	Yes
Leakage in TCS	No	No	No	No
Internal radiation monitoring present	No	Yes	No	Yes
CCTV present	Yes	Yes	Yes	Yes
Floor surface is clean & non-slippery	Yes	Yes	Yes	Yes

4.4 Risk Assessment

Risk is being evaluated by the product between severity and likelihood. There is no record of accident and injury from the maintenance activity being recorded. Therefore the evaluation of risk was done with the engineers. The results of risk evaluation are presented in Table 3 evaluated from risk matrix by hazard identification. Management of the company and the hospital plays a vital role to ensure safety and health of the engineers and the safety of whole process in every aspect related to the working environment. The machine is considered as high risk as it will cause fatal for immediate effect or gene mutation in a long term effect if the radiation is exposed. The severity is rated low as the safety featured from TU prevents an incident to prevent, however, incident can happened due to human error.

Table 3: Risk Assessment using Risk Matrix

Task	Types of Hazard	Hazard Classification	Hazard	Risks	Risk Value (priority)			Current Risk Controls	Proposed Risk Controls
					Likelihood	Severity	Risk Level		
Get system overview and status	Health	Physical	Unintentional draw out source from safe	Radiation overexpose	2	5	10 Medium	Observe radiation indicator	Always bring along working survey meter.
Contamination checks	Health	Biological	Biohazard infectious from TU	Transmission of disease	2	4	8 Medium	Use rubber glove	Use face mask, rubber glove and apron.
	Health	Physical	Unintentional draw out source from safe	Radiation overexpose	2	5	10 Medium	Setting to draw out check cable only	Always bring along working survey meter.
Exchange source with dummy cable	Health	Physical	Source is not fully insert into the emergency container	Radiation overexpose	4	5	20 High	Lock the service channel	Use survey meter to measure current value.

Table 3, continued

	Health	Physical	Drum rotation stuck when source is out of safe	Radiation overexpose	3	5	15 High	Perform short QA check before doing PPM	Always bring along working survey meter.
TU mechanical checks	Safety	Physical	Falling of head safe	Bodily injured	1	2	3 Low	No rapid movement of TU	Reinforced rubber type glove.
	Safety	Physical	Finger pinched from belt transport roller	Finger injury	3	1	3 Low	NIL	Use reinforced rubber type glove.
	Safety	Physical	Slip on wear and tear cable	Finger injury	1	1	1 Low	NIL	Use reinforced rubber type glove.
	Health	Ergonomic	Unnatural finger push movement	Finger injury	5	1	5 Medium	NIL	Have a short rest after a time of finger pushes
	Health	Ergonomic	Unnatural wrist rotation	Wrist injury	4	1	4 Low	NIL	NIL
TU electrical checks	Safety	Electrical	Touch electrical parts with hand	Electric shock	2	4	8 Medium	Use rubber soled shoes and non-conductive gloves	Operate electrical equipment in accordance with manufacturers' instructions.

Table 3, continued

	Health	Physical	Source is totally pulled out of grip.	Radiation overexpose	3	5	15 High	Observe radiation indicator	Always bring along working survey meter.
TU functional checks	Health	Ergonomic	Unnatural wrist rotation	Wrist injury	4	1	4 Low	NIL	NIL
	Health	Physical	Source is totally pulled out of grip.	Radiation overexpose	2	5	10 Medium	Observe radiation indicator	Always bring along working survey meter.
Source check position	Health	Physical	Source is totally pulled out of grip.	Radiation overexpose	4	5	20 High	Observe radiation indicator	Always bring along working survey meter.
	Health	Physical	Drum rotation stuck when source is out of safe	Radiation overexpose	3	5	15 High	Observe radiation indicator	Always bring along working survey meter.

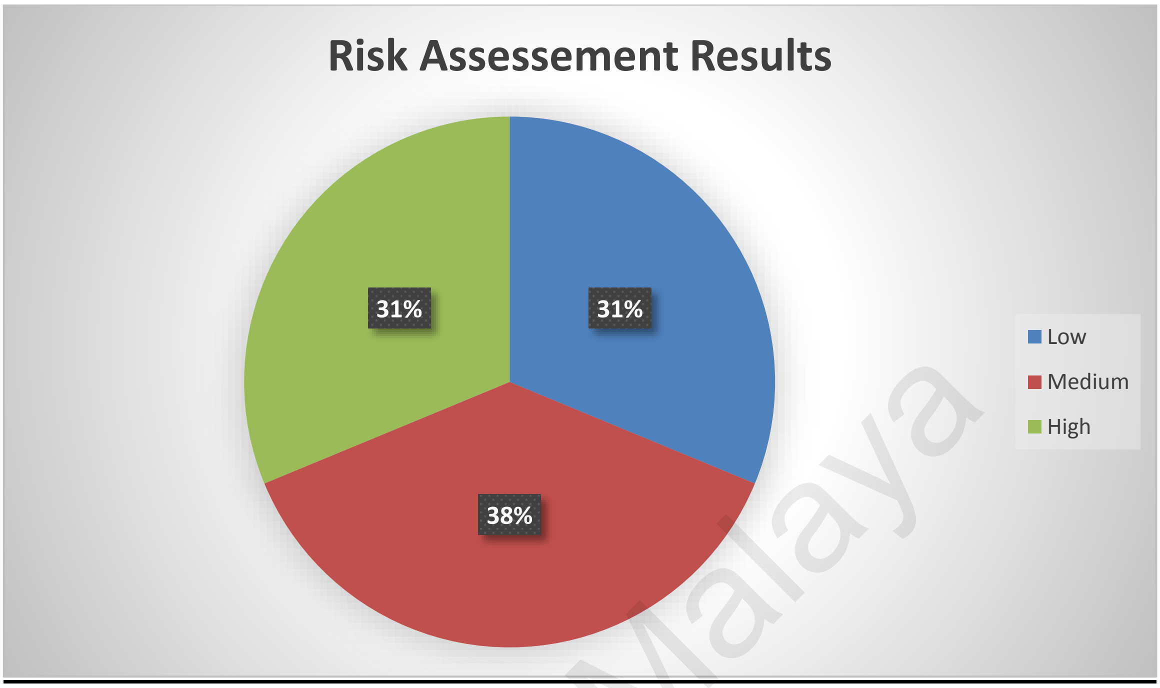

Figure 8: Risk Assessment Result

Both hospital have the same brachytherapy model and the same bunker setup. This study found that the engineers also have the same PPM workflow, procedures, and safety precaution thus having the same hazards. The result for the risk assessment result were shown as in Figure 8.

A total of 16 hazards were identified during PPM of brachytherapy. The hazards were divided into three categories, which are low, medium and high risk. Both low and high risk have the same percentage which is 31% meanwhile medium risk is 38%.

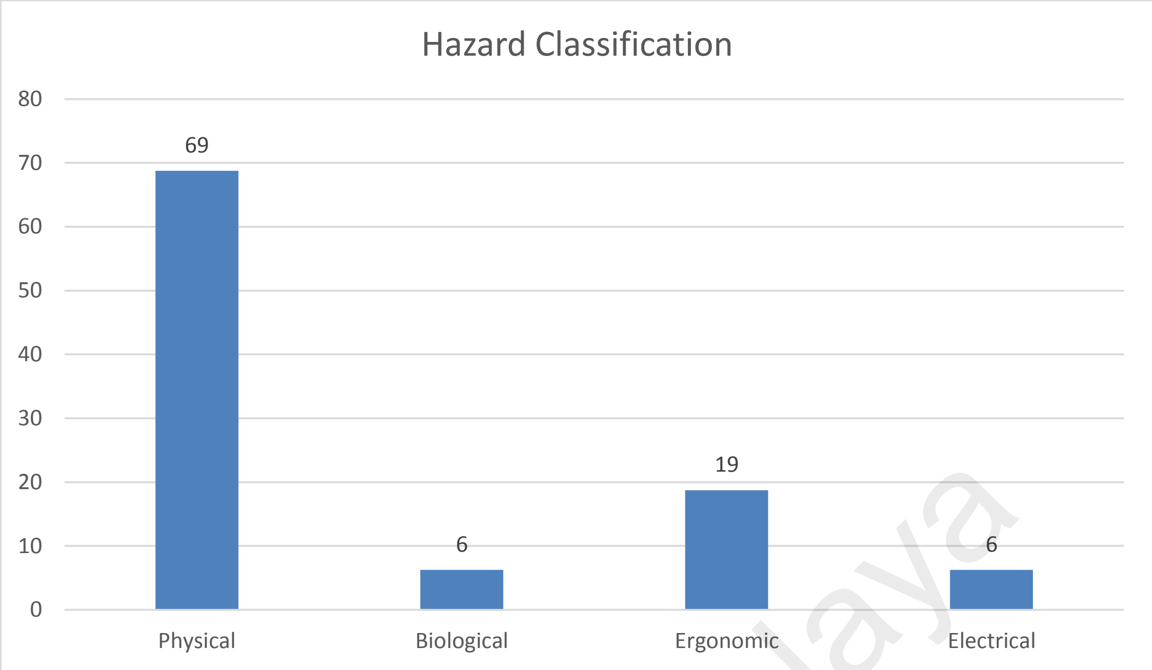

Figure 9: Hazard classification.

The hazards identified consist of 11 physical hazards, 1 biological hazard, 3 ergonomic hazards, and 1 electrical hazard. The hazard classification are shown as in Figure 9 in percentage of number items. Based on the risk assessment result, it is also found that tasks posed with high risk value are during exchange source with dummy cable and source check position.

CHAPTER 5: DISCUSSION

Hazard could happened for many reasons during the PPM, either from human error or machine system malfunction. Identification of hazards for this study were based on the interview, observation, and questionnaire. All of the information details gathered through these methods make it easier to analysis data. Finally, two main type of hazards found were safety and health hazards and none from environment hazard. Then the hazards were divided into four categories. The categories are physical, biological, ergonomic and electrical. Physical hazard contribute the highest hazards from this study followed by ergonomics, biological and electrical. The level of risks was calculated based on risk matrix as high, medium and low.

5.1 Hazard Control Measure

5.1.1 Elimination and Substitution

The TU is built with wheels that makes it possible to move. Moreover, the machine head section can be adjusted up and down. In addition, the heaviest part in the machine is at the head section. It is possible for the head safe to fall down if there is rapid movement. As a control, the engineer should lower the head as low as possible to lower the center of gravity. Then lock the wheel to prevent any unwanted movement during maintenance.

5.1.2 Engineering Control

Throughout the whole process, the engineers were aware of the radiation threat. One of the crucial procedure before doing the PPM is to exchange the source cable with dummy cable. During this exchange process, the machine will alert the engineer if the source is out of safe or inside the container safe. The radiation was detected by the build-in radiation detectors on the machine. However, as the best control, it is recommended for a facility to install internal radiation monitoring system. This system will show real time measurement, and act as an additional radiation detector to avoid from radiation worker from overexposed. Apart from that, it is known that the emergency container act as a shielding to the radiation since no PPE can block the penetration energy of gamma ray. However, there were some reading measured when the source is inside the emergency container as shown in the Figure 10. A control measure could be done by putting glass lead in between the emergency container and the engineers.

Figure 10: Source inside an emergency container.

5.1.3 Administrative Control

Based on the details gathered, the engineers were given adequate continuous training throughout their job. The job scope also were clearly understood by the engineers in order for them to complete the task successfully and safely. Apart from that, the engineers were supplied with various information on the machines, manuals, procedure and safety information.

The additional procedure that have to be done by the engineers are to put the emergency container away from working area but within the bunker room as the radiation can be reduce inversely proportional to the distance with the principle of As Low As Reasonably Achievable (ALARA) as shown in Figure 11.

Figure 11: Emergency placed away from working area.

The company also have to monitor the frequency of the engineers handling the brachytherapy machine and do job rotation or roster to reduce the time of exposure of an engineer with the radiation.

It is advisable for the engineers to do the job with a partner. Apart from reduce the exposure time with radiation, it is also to prevent human error from happening during the PPM activity.

5.1.4 Personal Protection Equipment

During handling TU, the service engineer will do contaminations check. These check is divided into two types which is biological contamination and radiation contamination which is alpha particle. Alpha particle is the byproduct of decay of the isotope. These alpha particle can be blocked just by a piece of paper, however, the alpha particle can be harmful to human if it is consumed unintentionally and stay inside the body. A biological contamination can happens since the TU are operated closely to patients. Even though transfer tube and applicators are used during fractions, safety measure once again needed to avoid from disease transmission.

Thus, the service engineers are obligate to wear gloves throughout the TU handling.
Apart from that, a procedure is required for an engineer to do contamination check before proceed with other task. This procedure is known as wipe test with the check cable. Wipe test can only be done by using special wipes from Elekta. After wiping the check cable, the special wipes then placed at the back of survey meter for background count.

5.2 Perception of Service Engineer

The engineers have been working in this field for more than 3 years and were trained and certified by Elekta, the manufacturer. Apart from neat and safe procedure, they have to make sure that working environment is safe from radiation. They also have to be aware of any changes happened either inside of the bunker or outside of the bunker as part of their indirect responsibility. The perception of these engineers towards the safety of the working area can be take into account on this study.

A questionnaire was given to the engineers regarding to the conditions and present of safety feature inside the treatment room. Even some of the feature is optional part listed by Elekta, they are good feature needed for more safe working condition. Based on the results, both engineers have similarity on the perception towards both hospital.

First, both of the engineer response that the bunker is in good condition. A good condition bunker is a compulsory to avoid from gamma radiation leakage especially when the isotope is out of safe. A good bunker does not only to avoid radiologist from exposed to the radiation but also for the members of the public and the whole radiation worker involved.

Next, the door interlock working in good condition during maintenance. Door interlock consist of door switch which are used to verify if the door of the treatment room are closed while a treatment is being given. If a door is inadvertently opened during this period, treatment is interrupted and the source returned to the safe.

Next, the engineers verify that head safe and emergency container present in both hospitals are in good condition. These features are a must since both prevent is where the radiation source is either during rest or servicing. As a result, there is no leakage in TCS.

Internal radiation monitoring and CCTV are present in MMCH but not in SIH. Mainly these features used during treatment. However, the internal radiation monitoring is a continuous detector, if survey meter is not present or broken, the internal radiation monitoring can be the backup to survey meter. An improvement can be made on SIH radiation monitoring to provide more safety environment. Note that gamma radiation cannot be seen by naked eye. Last but not least is the condition of working area. Both engineers responded that both hospital keep the area clean and the floor were non-slippery.

Overall results shows no negative perception towards the conditions and present of safety feature inside the treatment room. Even though the engineer can do the maintenance alone, it is recommended for them to do the work with a partner in order for them to be in-checked of the environment safety since some of the maintenance task required an engineer to go back and forth to TCS from treatment room.

CHAPTER 6: CONCLUSION

6.1 Conclusion

The health risk assessment of the service engineers had been identified and recommendation had been given to improve the safety of the service engineer during PPM activity. The study gathered information and details from interview, observation, and questionnaire among the engineers. Thus, risk control for best measure could be recommended on the safety and protection against unwanted exposure. The study also include the perception of the engineers toward the safety feature of the selected hospitals. The perception of the engineers can be taken into account to show the environment conditions of the working area.

The study also identified that both low and high risk have the same percentage which is 31% meanwhile medium risk is 38%. The hazards identified consist of 11 physical hazards, 1 biological hazard, 3 ergonomic hazards, and 1 electrical hazard. Based on the risk assessment result, it is also found that tasks posed with high risk value are during exchange source with dummy cable and source check position.

The engineers should keep the head of the TU as low as possible to lower the center of gravity. It is also recommended to install internal radiation monitoring and ensure a glass lead is present in the bunker as an extra shielding (A. Waly et al., 2015). Apart from that, ALARA principle can be practiced to reduce radiation. Last but not least, the engineers should always wear PPE to prevent from biological contamination and radiation contamination in the form of alpha particles.

There were no injury nor fatality and also nor genetic mutation effect recorded in the study even the activity is involving high risk hazards. A study by Yahaya et al. (2015) also found that the level of occupational radiation exposure in Malaysia hospital is at acceptable risk. However, recommendation had been made to improve the safety as a whole. Overall finding from engineer's perception shows that, facility is equipped and installed with sufficient safety features. Thus, achieved the objective of this study.

The limitations of this study are the engineers also responsible to maintain other modalities such as Linear Accelerator and Gamma Knife. Both modalities are also dealing with gamma radiation, and the frequency of the engineers handling the modalities are unknown. Apart from that, the service engineers are also responsible to do maintenance on other nuclear medicine centres which count more than 10 centres.

6.2 Recommendation and Future Study

Few improvement for future study can be made to improve an existing procedure and to reduce human errors during handling the brachytherapy machine. Apart from that a study of a late effect of radiation on engineers could be done. This study could be used to improve the existing safety feature of a machine. Moreover, a study for other activity such as exchange new source or returning depleted source could be made as the demand of these activities are increasing every years.

REFERENCES

A. Waly, E.-S., & Bourham, M. (2015). Comparative study of different concrete composition as gamma-ray shielding materials. *Annals of Nuclear Energy, 85*, 306–310.

B. Alexandrov, L., & Nik-Zainal, S. (2013). Signatures of mutational processes in human cancer. *Nature*, *500*, 415–421.

Lim, G. (2006). Clinical oncology in Malaysia: 1914 to present. *Biomedical Imaging and Intervention Journal, 2*(1), 18-28.

Lukasz, K. (2016). COMPARISON OF THE PHYSICAL PROPERTIES OF CO-60 AND IR-192 SOURCES – RETURN OF COBALT? *Phisica Medica*, 284–339.

Candela-Juan, C., Gimeno-Olmos, J., & Pujades, M. (2015). Fetal dose measurements and shielding efficiency assessment in a custom setup of Ir-192 brachytherapy for a pregnant woman with breast cancer. *Physica Medica, 31*, 286-292.

F.Guedea, & M. Ventura. (2008). Patterns of Care for Brachytherapy in Europe: facility and resources in brachytherapy in the European area. *Brachytherapy, 7*, 223-230.

Gasinska, A. (2016). The contribution of women to radiobiology:Marie Curie and beyond. *Reports of practical oncology and radiotherapy, 21*, 250–258.

Gonc-alves, J., Botelho, S., & Pascholati, P. (2007). Activity measurements of 192-Ir solid sources using a well-type ionization chamber. *Nuclear Instruments and Methods in Physics Research, 580*, 222–225.

Grover, S., Xu, M., & Jhingran, A. (2017). Clinical trials in low and middle-income countries — Successes and challenges. *Gynecologic Oncology Reports, 19*, 5-9.

Hannoun-Levi, J.-M. (2017). Brachytherapy for prostate cancer : Present and future. *Cancer/Radiotherapie, 21*, 469-472.

Jeffrey Demanes, D., & I. Ghilezan, M. (2014). High-dose-rate brachytherapy as monotherapy for prostate cancer. *Brachytherapy, 12*, 529-541.

M. Coursey, B. (2017). A reflection on the 150 anniversary of the birth of Marie Curie. *Applied Radiation and Isotopes, 130*, 280–284.

M.I. , S., AlZaatreh, M., & Dong, M. (2017). A comprehensive study of the energy absorption and exposure buildup factors of different bricks for gamma-rays shielding. *Results in Physics, 7*, 2528–2533.

Piron, F. (2016). Gamma-ray bursts at high and very high energies. *Comptes Rendus Physique*(17), 617–631.

Pleasance, E., Stephens, P., & O'Meara, S. (2010). A small-cell lung cancer genome with complex signatures of tobacco exposure. *Nature, 463*(7278), 184-190.

Preston, D., Ron, E., & Tokuoka, S. (2007). Solid cancer incidence in atomic bomb survivors: 1958-1998. *Radiation Research*, *168*(1), 1-64.

Rusch, H.P., & Baumann, C.A. (1939). Tumor production in mice with ultraviolet irradiation. *American Journal of Cancer, 35*(11).

Singh Mann, K., Rani, A., & Singh Heer, M. (2015). Shielding behaviors of some polymer and plastic materials. *Radiation Physics and Chemistry, 106*, 247–254.

Symonds, G., & Thomas. P. (2016). Radiation Exposure and Health Effects - is it Time to Reassess the Real Consequences? *Clinical Oncology, 28,* 231-236.

Tanderup, K., Ménard, C., & Polgar, C. (2017). Advancements in brachytherapy. *Advanced Drug Delivery Reviews*, *109*, 15-25.

Yahaya, S., & H. Hassim, M. (2015). Radiation risk estimation from occupational medical imaging exposure in Malaysia. *Journal Teknologi*, *75*, 6.