TOMSK POLYTECHNIC UNIVERSITY ТОМСКИЙ ПОЛИТЕХНИЧЕСКИЙ УНИВЕРСИТЕТ

Министерство науки и высшего образования Российской Федерации
федеральное государственное автономное
образовательное учреждение высшего образования
«Национальный исследовательский Томский политехнический университет» (ТПУ)

Инженерная школа ядерных технологий
Направление подготовки 14.04.02 Ядерные физика и технологии
Отделение ядерно-топливного цикла

МАГИСТЕРСКАЯ ДИССЕРТАЦИЯ

Тема работы
Оценка воспроизводимости параметров многолепесткового коллиматора (MLC) в лучевой терапии с модуляцией интенсивности (IMRT)

УДК1 615.849:681.777

Студент

Группа	**ФИО**	**Подпись**	**Дата**
0АМ9М	Чума Эдмунд Джозеф		

Руководитель ВКР

Должность	**ФИО**	**Ученая степень, звание**	**Подпись**	**Дата**
Доцент ОЯТЦ ИЯТШ	Сухих .Е.С	к.ф-м.н		

КОНСУЛЬТАНТЫ ПО РАЗДЕЛАМ:

По разделу «Финансовый менеджмент, ресурсоэффективность и ресурсосбережение»

Должность	**ФИО**	**Ученая степень, звание**	**Подпись**	**Дата**
Доцент ОСГН ШИП	Спицына Л. Ю.	к.ф.н.		

По разделу «Социальная ответственность»

Должность	**ФИО**	**Ученая степень, звание**	**Подпись**	**Дата**
Доцент ОЯТЦ ИЯТШ	Веригин Д.А.	к.ф-м.н		

ДОПУСТИТЬ К ЗАЩИТЕ:

Руководитель ООП	**ФИО**	**Ученая степень, звание**	**Подпись**	**Дата**
Ядерная медицина	Верхотурова В.В.	к.и.н.		

Томск – 2021 г.

TOMSK POLYTECHNIC UNIVERSITY ТОМСКИЙ ПОЛИТЕХНИЧЕСКИЙ УНИВЕРСИТЕТ

Министерство науки и высшего образования Российской Федерации
федеральное государственное автономное
образовательное учреждение высшего образования
«Национальный исследовательский Томский политехнический университет» (ТПУ)

School of Nuclear Science & Engineering
Field of training (specialty): 14.04.02 Nuclear Science and Technology
Specialization: Nuclear Medicine
Nuclear Fuel Cycle Division

MASTER THESIS

Topic of research work
Evaluation of Multi-Leaf Parameters Reproducibility of Intensity Modulated Radiotherapy (IMRT) Plans

UDC 615.849:681.777

Student

Group	**Full name**	**Signature**	**Date**
0AM9M	Chuma Edmund Joseph		

Scientific supervisor

Position	**Full name**	**Academic degree, academic rank**	**Signature**	**Date**
Associate Professor	Sukhikh .E.S	PhD		

ADVISERS:

Section “Financial Management, Resource Efficiency and Resource Saving”

Position	**Full name**	**Academic degree, academic rank**	**Signature**	**Date**
Associate Professor	Spicyna L. Y	PhD		

Section “Social Responsibility”

Position	**Full name**	**Academic degree, academic rank**	**Signature**	**Date**
Associate Professor	Verigin D.A	PhD		

ADMITTED TO DEFENSE:

Programme Director	**Full name**	**Academic degree, academic rank**	**Signature**	**Date**
Nuclear Medicine	Vera V. Verkhoturova	PhD		

Tomsk – 2021

LEARNING OUTCOMES

Competence code	Competence name
Universal competences	
UC(U)-1	Ability to make critical analysis of problem-based situations using the systems analysis approach, and generate decisions and action plans.
UC(U)-2	Ability to run a project at all life-cycle stages.
UC(U)-3	Ability to organize and lead the teamwork and generate a team strategy to achieve the target goal.
UC(U)-4	Ability to use modern communication technologies to realize academic and professional interaction.
UC(U)-5	Ability to analyze and account for cultural diversity in the process of intercultural interaction.
UC(U)-6	Ability to set and pursue individual and professional activity priorities and ways to modify professional activity based on the self-esteem.
General professional competences	
GPC(U)-1	Ability to formulate goals and objectives of the research study, select assessment criteria, identify priorities for solving problems.
GPC(U)-2	Ability to apply modern research methods, evaluate and present the results of the performed research.
GPC(U)-3	Ability to present research outcomes in the form of articles, reports, scientific reports and presentations using computer layout systems and office software packages.
Professional competences	
PC(U)-1	Ability to maintain medical and technical documentation related to medico-physical aspects of radiation therapy, interventional radiology and radionuclide diagnostics and therapy.
PC(U)-2	Ability to ensure radiation safety of personnel, public, and the environment, to carry out monitoring of radiation exposure levels of patients, personnel, public, and the environment.
PC(U)-3	Ability to operate and maintain equipment and tools applied for the medical use of radiation.
PC(U)-4	Ability to manage the quality of physical and technical aspects within radiation therapy, diagnostics, interventional radiology and radionuclide diagnostics and therapy departments in accordance with the specific equipment requirements, regulatory requirements and staffing of a medical organization.

PC(U)-5	Ability to conduct and organize dosimetry planning, clinical dosimetry, quality assurance procedures for radiotherapy, interventional radiology, and radionuclide diagnostics and therapy.
PC(U)-6	Ability to apply knowledge of natural sciences, fundamental laws in the field of nuclear physics and technology, clinical and radiation standards, hygienic measures in nuclear medicine, which is sufficient to study issues associated with medical physics using modern equipment and information technology relying on the latest Russian and international experience.
PC(U)-7	Ability to develop reference books, tables and software containing data for clinical use in dosimetric planning of radiation therapy, radionuclide diagnostics and therapy.
PC(U)-8	Ability to take part in the design and physical and technical equipment development for radiation therapy, diagnostics, interventional radiology and radionuclide diagnostics and therapy, and radiation safety divisions.
PC(U)-9	Ability to conduct training sessions and develop instructional materials for the training courses within the cycle of professional training programs (bachelor degree programs).

TOMSK POLYTECHNIC UNIVERSITY ТОМСКИЙ ПОЛИТЕХНИЧЕСКИЙ УНИВЕРСИТЕТ

Министерство науки и высшего образования Российской Федерации
федеральное государственное автономное
образовательное учреждение высшего образования
«Национальный исследовательский Томский политехнический университет» (ТПУ)

School of Nuclear Science & Engineering
Field of training (specialty): 14.04.02 Nuclear Science and Technology
Specialization: Nuclear Medicine
Nuclear Fuel Cycle Division

APPROVED BY:
Program Director
_____ Verkhoturova V.V.
«____» _____ 2021

ASSIGNMENT
for the Graduation Thesis completion

In the form:

Master Thesis

For a student:

Group	**Full name**
0AM9M	Chuma Edmund Joseph

Topic of research work:

Evaluation of Multi-Leaf Parameters Reproducibility Intensity Modulated Radiotherapy (IMRT) Plans	
Approved by the order of the Director of School of Nuclear Science & Engineering (date, number):	№ 29-49/c dated January 29, 2021

Deadline for completion of Master Thesis:	05.06.2021

TERMS OF REFERENCE:

Initial data for research work: *(the name of the object of research or design; performance or load; mode of operation (continuous, periodic, cyclic, etc.); type of raw material or material of the product; requirements for the product, product or process; special requirements to the features of the operation of the object or product in terms of operational safety, environmental impact, energy costs; economic analysis, etc.)*	- Reproducibility of IMRT Plans; - Treatment Planning and quality assurance; - Elekta Synergy Linear Accelerator, EPID-Panel,TG244, -
List of the issues to be investigated, designed and developed	- A review of literary sources on the subject under study; creation and verification of dosimetric plans; analysis of the results; section "Financial management, resource efficiency and resource saving" (Calculation of the cost of research and development); section "Social Responsibility
List of graphic material *(with an exact indication of mandatory drawings)*	- Presentation;

Advisors to the sections of the Master Thesis *(with indication of sections)*

Section	Advisor
Literature Review of the research, Creation and verification of dose metric plan and analysis of results	Sukhikh E.S.
Financial management, resource efficiency and resource saving	Spicyna L. Y
Social responsibility	Verigin. D.A

Date of issuance of the assignment for Master Thesis completion according to the schedule	

Assignment issued by a scientific supervisor / advisor (if any):

Position	Full name	Academic degree, academic status	Signature	Date
Associate Professor	Sukhikh. E.S.	PhD		
Medical Physicits	Vertinsky Andrey	PhD-Student		

Assignment accepted for execution by a student:

Group	Full name	Signature	Date
0AM9M	Chuma Edmund Joseph		

TASK FOR SECTION
«FINANCIAL MANAGEMENT, RESOURCE EFFICIENCY AND RESOURCE SAVING»

To the student:

Group	Full name
0AM9M	Chuma Edmund Joseph

School	**Nuclear Science and Engineering**	**Division**	Nuclear fuel cycle
Degree	Master programme	**Educational Program**	14.04.02 Nuclear Physics and Technology/Nuclear Medicine

Input data to the section «Financial management, resource efficiency and resource saving»:	
1. *Resource cost of scientific and technical research (STR): material and technical, energetic, financial and human*	- Equipment deprecation 20014340 - Material costs 38650 - Basic salary 212506 - Additional salary 21250.6 - Labor tax 65884.1 - Overhead 163628.72 - Other direct cost 5 220
2. *Expenditure rates and expenditure standards for resources*	- Power rates 5.8 rubles per 1 kWh - Regional rate 1.15
3. *Current tax system, tax rates, charges rates, discounting rates and interest rates*	- Coefficient of deductions 30% – Scientific activities have rate – 10%
The list of subjects to study, design and develop:	
1. *Development of charter for scientific-research project*	– SWOT-analysis;
2. *Scheduling of STR management process: structure and timeline, budget, risk management*	– calculation of working hours for project; – creation of the time schedule of the project; – calculation of scientific and technical research budget;
A list of graphic material *(with list of mandatory blueprints):*	
1. *SWOT- analysis* 2. *Gantt chart and budget of scientific research* 3. *Assessment of resource, financial and economic efficiency of STR* 4. *Potential risks*	

Date of issue of the task for the section according to the schedule	

Task issued by adviser:

Position	Full name	Scientific degree, rank	Signature	Date
Associate professor	Spicyna L. Y	PhD		

The task was accepted by the student:

Group	Full name	Signature	Date
0AM9M	Chuma Edmund Joseph		

«Social Responsibility»

To student:

group	Full name
0AM9M	Chuma Edmund Joseph

School	Nuclear Science and Engineering	Department	Nuclear fuel cycle
Degree	Master programme	**Specialization**	Nuclear Medicine

Title of graduation thesis:

Evaluation of Multi-Leaf Parameters Reproducibility of Intensity Modulated Radiotherapy (IMRT) Plans	
Initial data for section «Social Responsibility»:	
1. Information about object of investigation (matter, material, device, algorithm, procedure, workplace) and area of its application	IMRT/VMAT plans: Application area: Treatment Planning and Quality Assurance in Radiotherapy department
List of items to be investigated and to be developed:	
1. Legal and organizational issues to provide safety: – Special (specific for operation of objects of investigation, designed workplace) legal rules of labor legislation; – Organizational activities for layout of workplace.	– Labor code of Russian Federation #197 from 30/12/2001 GOST 12.2.032-78 SSBT – Sanitary Rules 2.2.2/2.4.1340-03. – Hygienic requirements for PC and work with it
2. Work Safety: 2.1. Analysis of identified harmful and dangerous factors 2.2. Justification of measures to reduce probability of harmful and dangerous factors	– Enhanced electromagnetic radiation level – Insufficient illumination of workplace – Excessive noise – Deviation of microclimate indicators – Electric shock
3. Ecological safety:	– Indicate impact of Linear accelerator on hydrosphere, atmosphere and lithosphere.
4. Safety in emergency situations:	– Fire safety;

Assignment date for section according to schedule	

The task was issued by consultant:

Position	Full name	Scientific degree, rank	Signature	date
Associate Professor	Verigin D.A.	PhD		

The task was accepted by the student:

Group	Full name	Signature	date
0AM9M	Chuma Edmund Joseph		

TOMSK POLYTECHNIC UNIVERSITY ТОМСКИЙ ПОЛИТЕХНИЧЕСКИЙ УНИВЕРСИТЕТ

Министерство науки и высшего образования Российской Федерации
федеральное государственное автономное
образовательное учреждение высшего образования
«Национальный исследовательский Томский политехнический университет» (ТПУ)

School of Nuclear Science & Engineering
Field of training (specialty): 14.04.02 Nuclear Science and Technology
Specialization: Nuclear Medicine
Level of education: Master degree program
Nuclear Fuel Cycle Division
Period of completion: spring semester 2020/2021 academic year

Form of presenting the work:

Master Thesis

SCHEDULED ASSESSMENT CALENDAR
for the Master Thesis completion

Deadline for completion of Master's Graduation Thesis:	05.06.2021

Assessment date	Title of section (module) / type of work (research)	Maximum score for the section (module)
1.02.2021	Creation and approving technical specification	...
7.02.2021	Finding and studying Literature Review	...
21.02.2021	Experiment and measurements	
29.03.2021	Developing of methodology	
09.04.20121	Analysis, description of the results and writing thesis	
10.05.2021	Compilation of the master's thesis	
5.06.2021	Submission	

COMPILED BY:
Scientific supervisor:

Position	Full name	Academic degree, academic status	Signature	Date
Associate Professor	Sukhikh. E.S.	PhD		

APPROVED BY:

Program Director	Full name	Academic degree, academic status	Signature	Date
Nuclear Medicine	Vera V. Verkhoturova	PhD		

ACKNOWLEDGEMENT

This research report would not have been possible without the assistance and corperation of certain individuals and institutions. I would like to say that it was a pleasure to spend 2 years at School of Nuclear science and technology at national Tomsk polytechnic University, surrounded by amazing people and I would like to express my sincere gratitude to those who have supported me and contribute to this work. First and foremost would like to show my appreciation to my supervisor Dr. Sukhikh Evgeniya, for assisting me in choosing this topic, making the opportunity available to me and assisting me whenever and however I needed throughout the process. A special thanks to my assistant supervisor Andrey Vertinsky PHD student at Tomsk polytechnic University. I would like to express my gratitude to DR. Vera Viktarovina and Tatiyana stipnovina for helping me to come at TPU for further study. Also I am to say thanks to the staffs of our school of Nuclear science and Technology, including DR.Yulia, DR Semenov, DR Vergina, and Prof. Yakovleba, Professor Sukhikh L, Evgeniya Sukhikh, and other for supporting and giving me the knowledge about nuclear medicine. Also I take another opportunity to say just thanks to my class met including my Sister Marina, Islam, Nangoma, Veronica, Todor, Nikita, Denis and for interacting and cooperating with me.

Finally, I would like to express my truly and deeply gratitude to Russian Government for giving me scholarship to study in Russia. Finally, I would like to express my truly and deeply gratitude to my family supported me. Anything of this would have been possible without your support and motivation.

ABSTRACT

Today cancer treatment using Intensity Modulated Radiotherapy (IMRT) and Volumetric Modulated Arc Therapy (VMAT) is still increasing and spreading in uses arround the world. IMRT and VMAT use the MLC to delivery more conformal, highly precise and accuracy dose to the tumor. The planning of these modalities is very complex, because of that the specific QA programs need to ensure the errors or deviations which will affect the dose delivery will be detected and eliminated in order to maximize the dose delivered to the tumor and minimize the dose delivered to the OARs, the low dose to the OARs reducing tissues complications or damage of the organs.

The purpose of this research was to evaluate the MLC parameters reproducibility of IMRT/VMAT plans using Electronic Portal Imaging Devices (EPIDs) together with its software based on PerFRACTION. According to the definition of the goal of my research, the research based on the pretreatment dose verification.

In this study agility MLC from Elekta Synergy linear accelerator installed at Tomsk used to delivery 6MV and 10MV photons. Only segment width of the agility MLC was considered in this study reproducibility of IMRT and VMAT plans. The plans planned by using TPS-Monaco software version 5.11.03 and 3D-CT-images from the TG244-Lung patient, TG244-Prostate and TG244-Thorax patient. The total of 12- plans were planned in order to get the good results. 4-Plans Planned in each structure (Lung, Prostate and Thorax). In this research 2D and 3D-dose analysis also were used for all plans and the measurements were carried out with the Electronic Portal Imaging Device (EPID) to measure the dose distribution. The EPID is the device that has been demonstrating accurate dosimetric capabilities and is currently used in many radiotherapy for dosimetric verification including Tomsk Region Oncology Clinic. The analysis was made using Per-Fraction software, which analyzed EPID results in 2D and 3D-dose analysis in order to detect the errors of the system. Thus, the reference and the

measured dose distributions were compared using both gamma analysis and DVH analysis.

The measurements showed that 3D-dose analysis had been better results than 2D-dose analysis and the lower point passing rate associated with large value of error. All segment width with higher gamma passing that 95% for (2%, 2cGy, TH=10%) criteria were good for planning treatment. However the results showed that there was no correlation between the gamma analysis and DVHs. In case of 2D and 3D-dose analysis some segment width 2D and 3D-dose analysis are correlated, for example for the lung at 1cm segment width both 2D and 3D-dose analysis had lower point passing rates than other segment width. In case of the MLC errors, the segment width of the MLC can affect the dose delivered because the results proved that there were some deviation or errors in the segment width of MLC and the results also proved that some segment width of MLC associated with the random errors and some segment width of MLC associated systematic errors.

ABBREVIATION AND SYMBOLS

- AC-Attenuation correction
- A-Si EPID - Amorphous silicon EPID
- AAPM- American association of physics in medicine
- ADD- Absolute dose difference
- BM- Beam modulated CT
- CAX- Central axis
- Cm -Centimeter
- CD- Calculated dose
- cGy- Centi-gray
- CT- Computed Tomography
- CTV-Clinical target volume
- DD-Dose difference
- DLG- dosimetric leaf gap
- DICOM Digital Imaging and Communication in Medicine
- DMLC-Dynamic Multi-leaf collimator
- DRR Digitally Reconstructed Radiograph
- DTA-Distance to agreement
- DVH-Dose volume histogram
- 1D-One dimensional
- 2D-Two dimension
- 3D-Three-dimendional
- 3D-CRT- three-dimensional conformal radiotherapy
- EPIDs- Electronic portal Imaging Devices
- FF-Flattening filter
- G.A – Gantry angle
- C.A-Couch angle
- Gy-Gray
- Col. A – Collimator angle
- GPR- Gamma passing rate
- GTV-Growth Tumor Volume

- Γ-Gama passing rate
- IC-Ionization chamber
- IMBs -Intensity modulated beams
- IMRT-Intensity modulated radiotherapy
- keV-kilo electron volt
- LINAC- Linear Particle Accelerator
- MD-Measured dose
- MLC-Multi-leaf collimator
- mm_ Millimeters
- MU-Monitor Unit
- MV-Megavoltage
- MeV - Megaelectron Volt
- MCS -Modulation complexity
- OAR - Organs at risk
- PTV - Planning target volume
- PD- Planned dose
- Pixels- Surface element
- QA-Quality assurance
- QC-Quality control
- RDD-Relative dose difference
- ROI-Region of interest
- RTP-Radiotherapy treatment planning
- SD-Standard deviation
- SNC-Sun Nuclear corporation
- SSD- Source to surface distance
- SW-Segment width
- TTF-Thin transistor film
- TG-Task group
- TPS-Treatment Planning system
- VMAT- Volumetric Modulated Arc Therapy
- Voxel-Volume elements

Contents

INTRODUCTION

Cancer is characterized by the uncontrolled growth and spread of abnormal cells. If this spread is not controlled, it can result in serious illness and death. In 2020 17 million new cases of cancer were recorded in the world: 8.8 million (52%) in males and 8.2 million (48%) in females, giving a male: female ratio of 10:9.3. The World age-standardized (AS) incidence rate item shows that there are 204.7 new cancer cases for every 100,000 men in the world, and 175.6 for every 100,000 females. According to the World Health Organization (WHO), in twenty years from 2020 the number of new cases of cancer will increase by 70% to more than 22 million cases [1]. The four most common types of cancer worldwide are lung, female breast, bowel (including anus) and prostate cancers, and account for more than four in ten (43%) of all new cases [2]. Figure (1) below represented percentage of New Cancer Cases and the percentage of death of cancer patients for both male and female between the age of the 5+ and 85+ years according WHO in each continent

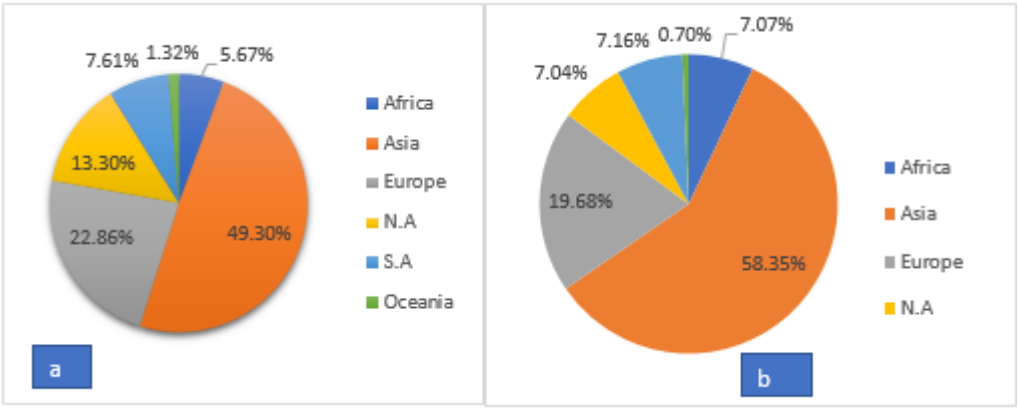

Fig 1. (a) Represented % of New Cancer Cases and (b) represented the percentage of death of cancer patients for both male and female according WHO in each Continent

Surgery, Chemotherapy and Radiotherapy among of the modalities used for cancer treatment. Surgery is usually done when the tumor is accessible or when organ

preservation is not an essential requirement. Chemotherapy uses systemic agents (drugs) to kill the abnormal cells which are dividing rapidly. In this way, in several cases chemotherapy is used together with surgery and radiation therapy. Radiation therapy (radiotherapy) uses ionizing radiation to destroy the cancer cells. Photons, Electron, Protons and Heavy ions (e.g.: carbon) are ionizing radiation used in radiotherapy.

Currently, treatment of cancer by using modern radiotherapy reducing or decreasing dose delivery to the (OARs) and also it increases the dose delivery to the cancer cell tissues. Brachytherapy and External Beam radiotherapy are the most common types of Radiotherapy which are used for cancer treatment. Large number of cancer patients treated by EBRT which including Intensity Modulated Radiotherapy (IMRT) and Volumetric Modulated Arc Therapy (VMAT) and Three dimensional conformal Radiotherapy to maximize tumor's dose and minimize dose to organ at risk(OARs) . .

Technological developments allowed not only conformal methods, such as IMRT and VMAT, but also higher prescribed doses, has increased the need for accurate procedures during the patient's treatment to ensure treatment quality or to prevent accidents during the treatment. The Quality assurance procedures is very crucial for the conformal techniques like IMRT and VMAT, fractioned techniques and single shot schemes, machine and patient-specific Quality in order to avoid major accidents as those that have been reported. For example, in 2000, at the National Institute of Panama an error related with the data introduced into Treatment Plan System (TPS) resulted in continued through a time in treatment. As consequence 28-patients were exposed to prolonged irradiation which resulted in 11-deaths due overdose toxicity [3]. In France, between 2004 and 2005, 23-prostate cancer patients received an overdose correspondent to 7-34% of the realized dose due to an error in dose intensity calculation in TPS. As result 5-patients died and the remaining developed serious complications. During one year in United Kingdom, 5-patients were exposed to an overdose due to a change in

operational procedures and 1-patient died [4]. Among the patients involved in the accident, four died and 19 developed serious late complications, including rectal inflammation [5].

It is not easy to handle QA in IMRT and VMAT plans than for the conventional static radiation delivery techniques. Several verification devices such as Arc-CHECK, Matri-XX and Octavius (PTW, Freiburg, Germany) [6], have been used for performing IMRT or VMAT-QA. Instead of the verification devices mentioned above, Electronic Portal Imaging Devices (EPIDs) introduced in many research for dose checking. The EPID performed dose verification in 2D and 3D- dose analysis with or without patient of phantom [7-9]. The main goal of pre-treatment patient-specific QA is to verify whether the dose distribution produced by the Electron linear accelerator does not deviate significantly from the planned. Many EPID -methods used for dose verification [6].

My research worked on pre-treatment QA which focused on detection of Reproducibility of IMRT and VMAT plans by using segmental width of MLC for sliding window techniques of dose delivering by using EPID together with its software based on zero-PerFRACTION Software. In order to identify reproducibility of IMRT and VMAT plans, EPID used in this work to perform dose verification for MLC parameters in 2D and 3D dose analysis without the actual patient. The gamma index analysis and DVH analysis are used to make comparison between the planned and EPID measured dose. Different Segment widths of MLC between 0.5 and 2 cm were planned for Lung, Prostate and Thorax plans and dose distributions were measured. MLC reproducibility due to segment width of the MLC were introduced in the plans in order to check the accuracy of the leaf position.

Although the work based on pretreatment of specific QA by using EPID panel together with its software for IMRT and VMAT plans, also it can be used or applied to

check the QA of other delivering techniques which are not involved MLC parameters such as 3D-CRT.

This research divided in six chapters, Chapter is a theoretical part which include background, Purpose of the research, Research questions, Statement of the research problem, Limitations and delimitations of the research. Chapter 2 included Equipment and materials, chapter 3 is Practical part which included Experiment and procedures, Results and discussion of the results, Chapter 4 described Literature Review of the Research. Chapter 5 contained the information of the financial management and chapter 6 included social responsibility. Also this research includes Conclusion, Reference and Appendix

CHAPTER 1 : THEORETICAL PART

1.1 Background

1.1.1 Modern Radiotherapy

Modern Radiotherapy uses conformal techniques such as IMRT and VMAT to achieve the goal of Radiotherapy for maximizing tumor dose and minimizing the dose to the OARs in order to avoid tissues damages and other tissues complications by radiation. Modern radiotherapy also using fractionation method to deliver the total dose in multiple treatments to allow the normal tissues and nearby OAR to recover between fractions. In this way, an entire radiotherapy treatment typically consists of 30-40 fractions, 5 times per week, which takes approximately 6 or 7 weeks to deliver the total dose prescribed [11]. Radiotherapy using EBRT and Brachytherapy to treat tumor. EBRT using high energy beams of ionization radiation such as photons, electrons or protons to destroy the tumor cells inside the human body and the dose is delivered by a linear accelerator. Photon therapy is used in deep tumors, being able to penetrate deep into the body while sparing the skin; electron therapy is used for superficial treatments, providing a high dose to a few centimeters depth from the skin surface avoiding dose delivery beyond that; and Proton therapy delivers energy with extreme precision, therefore limiting unwanted dose. In brachytherapy a sealed radioactive source is introduced into or next to the area requiring treatment.

1.1.1.1 Clinical Procedure in Radiotherapy

The main procedures of EBRT including: clinical evaluation of the patient, definition of the patient immobilization system, image acquisition, definition and delineation of volumes of interest, treatment planning, pre-treatment patient-specific quality assurance, radio-therapeutic treatment and clinical follow-up [21].

The first step consists at collecting the patient's clinical history and evaluation of the extent of pathology, defining accordingly the objective of treatment, curative or palliative. After the initial assessment the immobilization system used to verify the position of the patient by finding tumor's position. Subsequently anatomical images of the patient are acquired to plan the radiotherapy treatment. CT is the primary image modality used to acquire anatomical images; however, it can be supplemented with MRI and/or PET as shown on the figure (1.2) below

The Second step is Contouring of anatomical structure. The aim to separate the target Volume and OARs after obtaining anatomical images. The International Commission on Radiation Units and Measurements (ICRU) protocol still using for volume separation and sets the total dose to administer as well as the dose per fraction. The volumes originally defined in the ICRU 50 report [22] as described by figure (1.3) below. Delineation of the tumor, OAR, and other anatomical structures are an essential for optimization and selection of the beams and other requirements for planning. This will in turn ensure that tumor's volume received 95% of the dose delivered in it.

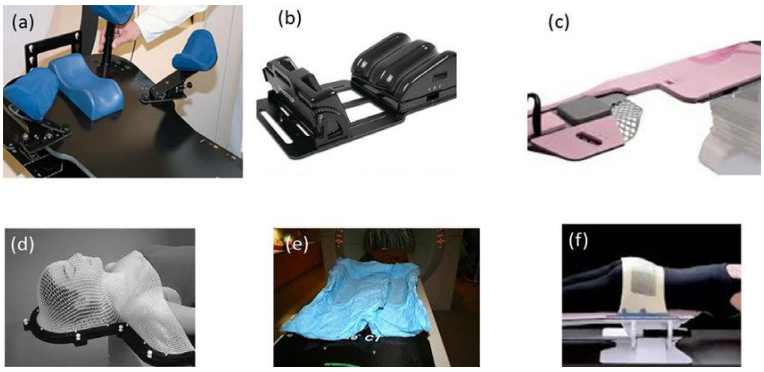

Fig 1.1.Some of immobilization devices used in Radiotherapy department

Fig 1.2.Siemens CT-Simulator used fo acquization of anatomical images

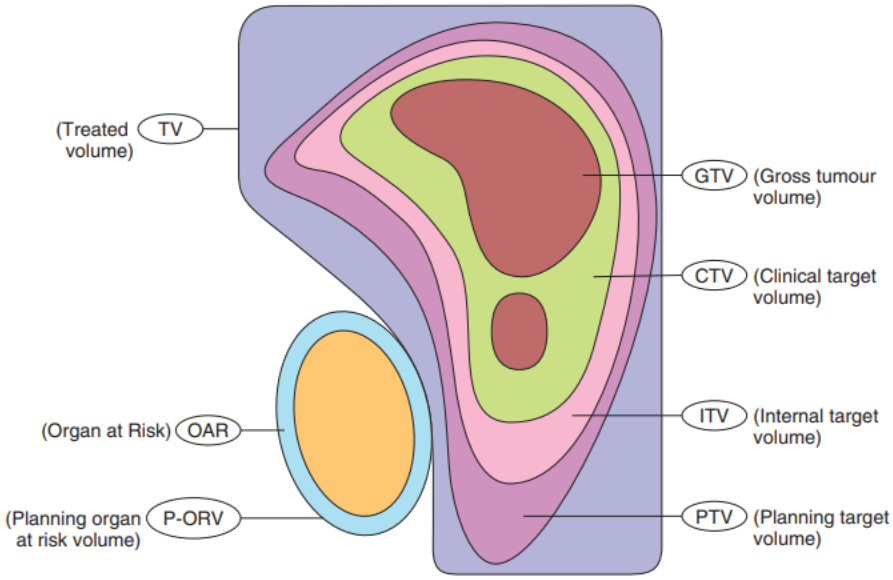

Fig 1.3. Schematic representation of the volumes defined in ICRU Report 50 [15]

The GTV corresponds to the palpable or visible tumor extension, where the location of tumor cells is considerably higher. In turn, the CTV corresponds to a volume of tissue that contains the GTV and an additional margin associated with sub-clinical tumor extent, which includes microscopic tumor spread in the GTV limit. This volume considers, in addition to internal variations driven by mobility and anatomical changes of internal organs, the external variations that specifically correspond to uncertainties related to patient positioning, tumor's position and alignment of the radiation beam. The

treated volume (TV) is the volume of tissue enclosed by an iso-dose surface selected and specified by the clinician as being appropriate to achieve the aim of treatment, i.e., cure or palliation. The TV should not be significantly larger than the PTV. OARs these are organs or structures which are closer to tumor. Any movements OAR or uncertainties of set-up may be accounted for with a margin similar to the principles for PTV. The irradiated volume (IV) is the tissue volume receiving a radiation absorbed dose that is considered significant in relation to normal tissue tolerance. This concept is not often considered in practice but may be useful when comparing one or more competing treatment plans. Clearly, it would be preferable to accept the plan with the smallest IV, all else being equal [22].

1.1.1.2 **Treatment planning system (TPS)**

TPS is a computer software that receives patient information to generate planning according to the dose constraints that each tissue could have. It is also capable of making plan evaluations through DVHs and transferring the plan to the treatment machine. Dose calculations have evolved from 2D models to 3D models and from there to 3D Monte-Carlo simulations.

The patient information is then stored in a medical imaging standard format, namely DICOM. DICOM-RT is specific for radiotherapy and incorporates different types of information such as: RT Structure, which contains the delineation of the relevant structures; RT Plan, with all the dosimetric and geometric information of the treatment plan; RT dose, for distributed dose are obtained through TPS [23].

It is important to mention that the RTP is a file format also used in radiotherapy for exporting and importing information about treatment planning data. This file may not contain as much information as the DICOM-RT Plan, but it is used by the LINAC to deliver the treatment. Due to the different technique, the TPS uses different methods to

calculate dose. The 3D-CRT technique uses forward treatment planning that requires a previous choice of specific parameters such as beam selection, energies, and MLC configuration, before dose calculation. IMRT technique is the "inverse" treatment planning, which introduced to predefine the number of dose restrictions corresponding to each type of tissue and the prescription dose. The software then automatically calculates the optimal beam modulation for the aim to match the chosen thresholds or criteria [24]. There are many TPS software such as eclipse TPS, Pinnacle TPS and e.t.c but this work focused on Monaco-TPS software for treatment planning for planning and dose calculation.

1.1.1.3 **Radiotherapy Delivery Techniques**

There are many delivery techniques used in radiotherapy departments to execute the dose delivering including 2D-convetional therapy, 3D-CRT. In case of having irregular PTV, 3D-CRT is not capable of separating PTV dose from the healthy tissues [14-17]. This work dealing with IMRT and VMAT modality due to the sliding window mode of dose delivery. IMRT and VMAT using MLC to deliver the accuracy and maximum dose to PTV and lower dose to the OAR [17]. The MLC is controlled automatically by computer, and allows for achieving the desired conformation/field geometry and modulation of the beam intensity.

In dynamic MLC mode, dose through IMRT delivered by continuously the leaves movement of the MLC at a constant or fixed gantry angle. The fluence distributions are adapted to the treatment constraints of the patient and each radiation beam is modulated. With these dynamically shaped fields, the distributed dose can be more conformal to the tumor.

The VMAT technique was introduced in 2007 by Karl Otto [18] and uses sliding window(dynamic MLC) mode, to deliver dose by continuous rotation of the gantry

around the patient and dose is distributed simultaneously region of the interest (ROI). The VMAT technique allows the irradiation from all angles in one or more rotations of 360◦ around the patient. During that beam shaping is defined by leaves of the MLC while the intensity modulated is obtained through multiple rotational arcs. In this way, the gantry is making a complete or a partial arc. VMAT can deliver more conformal distributed dose by continuously and simultaneously varying gantry angle, field shape and dose rate during treatment [19]. The major advantage of VMAT over IMRT fixed angle is increasing of delivering efficiency due to large efficient of time used and reduction of number of MU. The reduction in treatment delivery time is an extremely important factor since it reduces the occurrence of potential motion and discomfort of the patient, minimizing set-up variations. Analyzing of three distributed dose from the 3D-CRT, IMRT and VMAT techniques as shown on the figure (1.5)

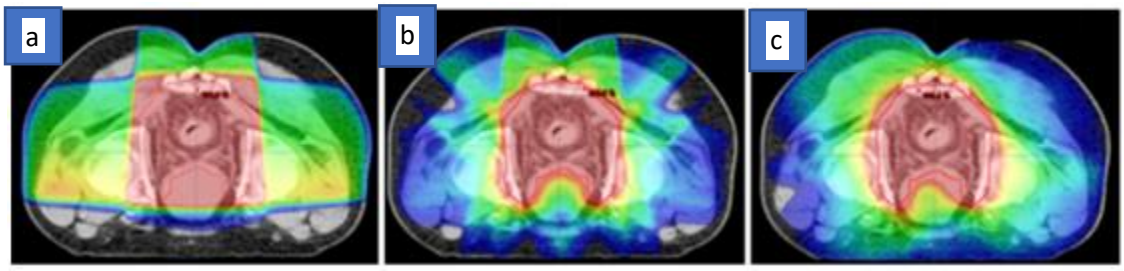

Fig 1.4.Dose distributions: (a) 3D-CRT, (b) IMRT and (c) VMAT techniques

1.1.1.4 **Depth dose**

It is important to define the SI unit responsible for describing the amount of energy deposited in tissues. This quantity is denoted by Gray (Gy), and is equivalent to 1 Joule per kilogram (1 Gy = 1 J/Kg). Therefore, the absorbed dose ii expressed by the quotient of the average energy transmitted by ionizing radiation (dE) and the corresponding mass (dm):

$$D = \frac{d\bar{E}}{dm} \qquad (1)$$

The basic principle inherent to external radiotherapy is the use of an ionization source that is located from the patient at some distance. It is essential to understand the way the radiation is absorbed to the patient.

The inverse square law used to express the propagation of the megavoltage photon beam through air or vacuum, between the energy per unit area and distance. The law stated that the intensity of radiation (I) at a specific point is inversely proportional to the square of the distance from the source (d) and is given

$$I \propto \frac{1}{d^2} \qquad (2)$$

In a patient or a phantom used to simulate the effect of dose distributed, besides the inverse square law, there are other factors, such as the attenuation and photon scattering which are responsible for the curve's shape of the dose deposition along the depth (Figure 1.4).

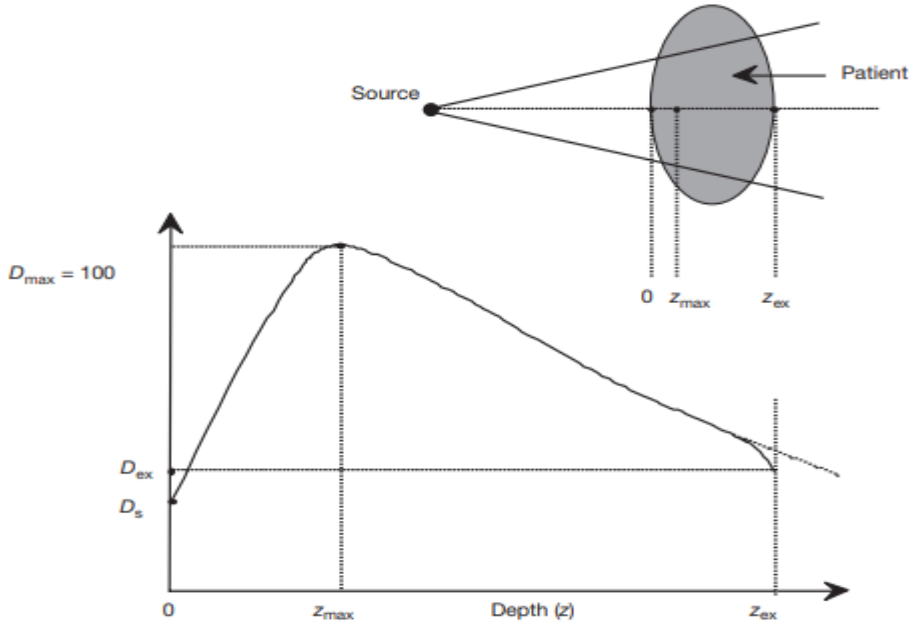

Fig 1.5. Deposited dose in a patient. $\boldsymbol{D_s}$is the surface patient's dose, at- $\boldsymbol{z_{max}}$ depth, the dose reaches its maximum value $\boldsymbol{D_{max}}$ and $\boldsymbol{D_{ex}}$ is the dose at the exit patient point [13].

The photon beam enters at the patient surface and delivers an amount of dose D_s . As the beam penetrates the deposited dose increases until a certain depth z_{max} . From that depth the dose decreases almost exponentially until it reaches a value D_{ex} at the patient exit point. The maximum absorbed dose depends mainly on beam energy and absorbent material, but also on the field size.

1.1.1.5 **Quality Assurance**

With the increasing complexity of Radiotherapy techniques, it becomes more important to ensure the delivery of the prescribed doses within accepted criteria since an incorrect delivery of megavoltage energy beams may lead to serious damage to healthy tissues. Therefore, dedicated Quality Assurance (QA) programs are required to ensure that treatments is more quality and the safety of the patients. Machine-specific QA and patient-specific QA are kinds of QA involved in radiotherapy department. Machine-specific QA allows checking whether the machine characteristic do not deviate significantly from their base line values of commissioning. Depending on each specific machine functionality (such as output, MLC position, couch, gantry rotation, and jaws motion and beam quality) these QA programs are performed at different frequencies (daily, weekly, monthly and annually). Patient-specific QA ensure the quality of each individual patient plan, specifically for conformal techniques (IMRT, VMAT and SBRT). These QA programs can be performed priori or during the treatment session and due to that it is better to differentiate vivo patient-specific QA from pretreatment QA.

The main purpose of pre-treatment patient-specific QA is to verify whether the delivered the distributed dose does not deviate significantly from the dose planned of the LINAC, before the treatment session to be started. If the deviations occurred due to the distributed dose is beyond the defined acceptance criteria, the recalculation of the dose distributed is required. In vivo patient-specific QA allows the comparison between the measured and planned dose when patient is used.

In Radiotherapy Departments, pre-treatment patient-specific QA is more common than in vivo and it is usually performed by applying the plan to 2D or 3D phantom distributed dose. These measurements may be performed using ionization chambers, thermo-luminescent detectors or diodes at a single or multiple point. Although the 2D devices such as diode or ionization chamber arrays contain more measurement points, a resolution higher than 1 cm is rarely achieved. In turn, film measurements provide high resolution but require digitization of the measured data which is time consuming. In addition to high resolution of the digital data, the electronic portal imaging device (EPID) allows speed-up of acquisition of the data, reason why their potential to perform pre-treatment dosimetric verification has been explored.

1.1.2 Electronic Imaging Devices (EPIDs) and EPID dosimetry

Electronic portal imaging devices were originally developed for verification of patient positioning during treatment and to replace film that was previously used. The portal images of the megavoltage treatment beam acquired by the EPID used to indicate uncertainties in the patient set-up or errors of the radiation field placement prior or during field delivery. In clinical practice EPID as a tool for set-up verification measurements of the patient position, it was realized that EPID images also contained dose information [25]. Consequently, it has become more advantageous than other dosimetric device used for dose verification.

Several types of EPIDs designed and classified for dose verification. First EPID being commercially available was the liquid-filled ionization chamber EPID (Li-Fi EPID), followed by the camera-based EPID (CC-based EPID) and, more recently, the amorphous-silicon EPID (a-Si EPID) which currently is the most used [10].

The EPID is a device attached to the LINAC and placed at 160cm from the head of the LINAC, as shown on figure 1.2. EPID measures the intensity of the radiation delivered to the patient during treatment by acquiring portal images [26]. During the

irradiation a frame (signal from one readout of the entire panel) is taken every two seconds, approximately. The EPID signal is calculated by multiplying the average pixel value and number of frames acquired. Before obtaining the total EPID signal, each individual frame is corrected for individual pixel sensitivity and offset. The corrected image I_{proc} is giving by [27]:

$$I_{proc} = \frac{I_{raw} - I_{dar\_dyn}}{I_{flat} - I_{dark}}$$

Where the I_{raw} is the average of all frames or each frame individually, I_{dar_dyn} is a dynamic dark image acquired every 30 seconds when the EPID is not being irradiated. The $I_{flat}$is an open field image delivered to the entire sensitive area that accounts for individual pixel sensitivities (response) and corrects their differences. The I_{flat} and I_{dark} are acquired when EPID is installed or when some changes in the set-up are made. Variations in the dark field current introduce an offset to the pixel signal. This procedure was developed to optimize image quality [27, 28]

1.1.2.1 **A-Si EPID**

The a-Si EPID is new model form of EPID using for dose verification centers and first described by Antonuk et al. in 1996. A-Si-EPID is the two-dimensional matrix of image pixels device that convert X-ray to digital image [10, 29]. A-Si EPID-iView-GT is an example of an A-Si EPID used from Elekta. It is a flat panel imager with a sensitive surface of 40 cm x 40 cm of amorphous silicon-photodiode detector. The EPID-iView-GT has in total 1024 x 1024 pixels; each pixel (picture element) of the active-matrix consists of a light sensitive photodiode and a field-effect transistor (a-Si-FET). The photodiode is responsible for the detection of the visible light emitted by the phosphor screen in the form of electric current while the FET acts as a switch to control the readout of the generated charge [29]. The surface elements collect the dose that falling on EPID

panel and X-ray converter converting the dose transmitted from the patient into the corresponding number of electrons and is a copper plate attached to a phosphor screen is also responsible for absorbing the radiation that is diffused from the patient. For the further process, the electrons are change into electrical signals by using imaging tools finally portal image is acquired.

1.1.2.2 **EPID Dosimetry**

Besides their application as imaging detectors, the EPIDs also used planar dose detectors. In EPID dosimetry (portal dosimetry), there are different EPID dosimetry methods based on whether the radiation beams passing or not transmitted through an attenuating medium (a phantom or patient. These methods used to verify the dose distributed to the patient or phantom. Non-transit images are a valuable tool for performing quality control of treatment parameters included LINAC's dosimetry characteristics, such as symmetry of the beam, the absolute output of LINAC or MLC leaf positions or trajectory.

EPID dosimetry can be arranged in different forms of verification, as represented on the figure (1.6) [10]. At the EPID level the acquired portal image, which can be in grayscale values or converted to fluence or dose values depending on the approach used defined the 2D-dose analysis and predicted EPID response or distributed dose can be calculated at the EPID by a specific algorithm. Another verification is done by EPID is reconstructing dose distributed inside the body or phantom (volume elements) and portal image obtained by EPID through CT-image, and then compared to TPS [10]

EPID measurements can be performed with minimum set-up requirements and a 2D delivered dose conversion can be done immediately using the digital images acquired. Although an EPID image contains 2D and not 3D information, it is still possible to produce 3D dose analysis inside a patient or more recently, time-resolved or 4D dose

distributions [10]. In this way, EPID dosimetry allows dose verification in: 1D, 2D, 3D, and 4D or time-resolved. The portal dose dosimetry involved several steps in to obtain the portal dose. Step one is to acquire the planned dose and data from the TPS (e.g. planning CT) which will be compared with EPID measured dose. The planned dose and TPS data, point dose, planar dose (2D) or the 3D or 4D planned dose distributions are calculated with a prediction model. Step two, when the treatment is being delivered the EPID images acquired need to be converted into portal dose images [7, 12, 31]. Then, the 2D portal dose images recombined to produce 3D or 4D dose distributions.

Finally, it is necessary to do a quantitative comparison between the measured dose distributed and the planned (predicted) dose distributed using a dose comparison method. The most commonly used quantitative dose comparison method is the gamma evaluation [32, 33, and 34].

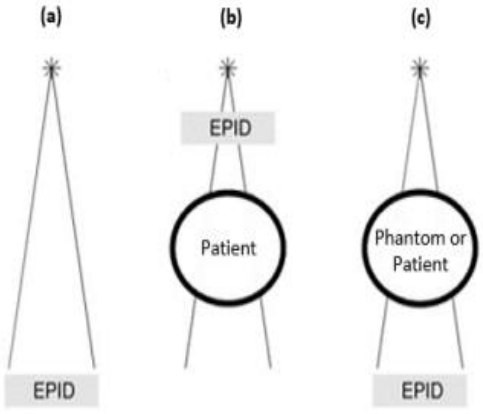

Fig 1.6.Methods of arrangements of EPID dosimetry [10]

1.1.3 Advantages and disadvantage of the Dosimetric system

The EPID provides more sensitivity method of determining radiation field placement accuracy. It is capable of capturing images at every treatment and even

multiple images during each treatment with little effort. Portal Dosimetry as a pre-treatment verification tool is that the fields are measured separately.

The disadvantages of the EPID. MLC position, dose rate (D R) and GS (gantry speed) as a function of time cannot obtained directly from the EPID. It cannot provide the acquire images of step-and-shoot fields easily than you expected. Furthermore, it would be desirable to use Portal Dosimetry for in vivo dosimetry. It does not give a verification that the TPS has correctly calculated the dose distribution, it does not give much information about the total dose distribution.

1.2 The purpose of the study

1.2.1.1 Main objective of the study

The main objective of this research was to evaluate MLC parameters reproducibility of IMRT and VAMT plans using EPID together with its software based on PerFRACTION software.

1.2.1.2 Specific objectives of the research

- To understand the relationship between the gamma passing rate and reproducibility
- To find the suitable segment width in each localization
- To investigate the correlation between 2D and 3D dose analysis
- To investigate the correlation between gamma index analysis and DVH analysis.
- To study the relationship between the MLC parameters and EPID

1.3 Research Questions or problems of the research

- What the impact to the dose delivered if the MLC parameters either would be increased or increased?

- How you can estimate or measure the MLC parameters reproducibility of IMRT or VMAT plans?
- What is the directly correlation between the MLC parameters and electronic portal imaging detector?
- What is comparison and correlation between the 2D and 3D-dose distribution?
- Which structure produce large reproducibility than other and why?

1.4 Problem statement of the Research

The purpose is to evaluate the MLC parameters reproducibility of IMRT/VMAT plans. The problem is that there are possibilities of MLC parameters reproducibility affect the dose delivery to the patient using IMRT/VMAT plans during the treatment planning.

The problem was solved by using the segment width of MLC to verify the distributed dose on PTV and detected it by EPID detector. The data from EPID analyzed into dose by using PerFRACTION software which display the results quantitatively and distributed dose analyzed by gamma evaluation method for comparing the dose delivered and expected dose in each segment width through 2D- gamma index analysis and 3D-gamma analysis (DVHs) in order to provide timely and efficient interventions for the correction of under-dose and overdose.

1.5 Significance of the study

- The study of the evaluation of the MLC parameters reproducibility of IMRT and VMAT plans helps us to find the better way of achieving more conformal, precise and accuracy dose to the PTV if planning associated with large value of reproducibility.
- It can solve the problem of quality assurance by using other MLC parameters

- It can help the radiotherapy department to understand the procedures of using EPID for quality assurance in order to save the time.
- It can help the radiotherapy department how to plan and performing the quality assurance of other modalities of dose delivery such as static –IMRT and e.t.c

CHAPTER 2 : MATERIALS AND METHODS

2.1 Equipment and Materials

2.1.1 Elekta Synergy Linear Accelerator Machine

Elekta Synergy accelerator is produced by Elekta Company and can provide electron and Photon beams. Accelerator may be used to irradiate a very complex targets in Three-dimensional conformal and Intensity Modulated plan. Elekta Synergy is a digital linear accelerator that has capable of delivering 4 MV, 6 MV and 10 MV, 15 V and 18 MV photons.

In research, Elekta Synergy linear accelerator installed at Tomsk Regional Oncology Clinic, use as source of Mega Voltage X-ray photons which produced 6mv and 10MV photon. All the procedures and plans in this study done by using Elekta Synergy Linear accelerator Installed at. It is equipped with agility Multi-leaf collimator which shapes and modulates beam and EPID imaging detectors (XVI and a-Si- EPID-iView-GT) for image capturing and storing.

Elekta MLC containing a 160 inter-digitating leaves and single focused MLC leaf pairs have a minimum separation of 5mm each at iso-cenetr and 95% of the leaves made up by tungsten materials and have average transmission $< 0.5\%$ and have maximal interleaf leakage$< 2\%$. Each MLC leaf can travel with a maximal leaf speed of 3cm/s and maximum carriage leaf speed of 3.5cm/s and it can travel beyond the central axis by -15cm up 20cm to a total distance of 35 cm to produce a maximum open field with area of (40 x 40)cm^2. Dosimetry leaf gap as the function of MLC, so the maximum Dynamic leaf gap is 1mm and leaves can shape the beam up to end leaf radius 170mm.

Elekta synergy interacting with two EPID imaging detectors (XVI and a-Si-EPID-iView-GT). EPID-XVI is 2D, 3D and 4D kV-CBCT X-ray volume imaging detector which used in the planning and treating in 2D and 3D verification. The 3D

imaging capability of XVI enables clinicians to handle complex cases without using markers to visualize soft tissues structures, target volume and position of critical structure. XVI provides low dose volumetric 3D data sets with sub-millimeter isotropic resolution, obtained from patient in the treatment side. The system can acquire a complete 3D volume in a partial or complete gantry revolution with reconstruction taking place simultaneously. The XVI software offers the flexibility to vary the dose necessary to acquire a volume view image by considering the level of contrast required.

A-Si-EPID is a flat panel imager composed, active detector surface of 40cm x 40cm covered by amorphous-Silicon photodiode and positioned at a source-Detector surface distance (SDD) of 160cm form the treatment head for the treatment as shown on the figure 2.1 below. Each frame is a scan of the detector elements and this EPID has a total of 1024 x 1024 pixels; each pixel (picture element) consisting of a light sensitive photodiode and a thin film transistor to enable readout [34]. The surface elements collect transmitted beam that reached on them and convert that it into the electron density. The electron density are then changed into electrical signals which are continuing processed by the imaging tools to the portal image. Elekta a-Si EPID used IView-GT software to capture or acquire, to store and convert portal images and portal dose image. The portal obtained by delivering a photon beam from an Elekta Synergy LINAC to the Elekta iView-GT a-Si EPID and then delivered images compared expected portal images. In my research portal images obtained by varying the source to EPID detector distance for any flood field and dark field.

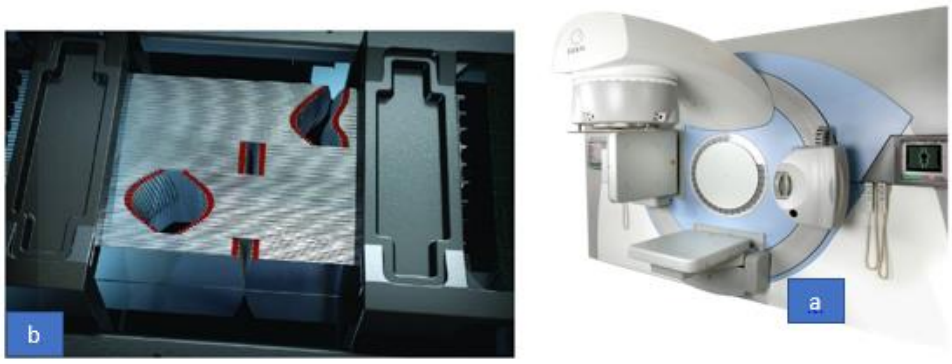

Fig 2.1. (a) Elekta Synergy Machine together with its EPID and (b) Elekta Agility MLC

2.1.2 TG244-Patients

Because no actual patient used in the work, so all plans done by using TG244_patient folder which contains the 3D-DICOM-CT scan images and RTP localization sets of various parts of the body associated with its total dose, dose fractionations used for treatment planning. My research used TG244-Lung cancer Patient, PTG244-Prostate cancer Patient and TG244_Thorax Cancer Patient planning. These TG244- patients contained CT-images of the lung patient, prostate patient and Thorax patient corresponding to its dose description for each structure and for each patient which used for planning IMRT and VMAT at a dose threshold of 10% and threshold gamma passing rate of 95% for (2%, 2mm) criterion as represented as shown on the table 3.1 below

Table 2.1– TG244-Lung, TG244-Prostate and TG244-Thorax Patient

TG244-Patient	Total dose (Gy)	Fraction's number	Dose/Fraction	Global Passing rate
Lung-PTV63	63	35	1.8	95%
ProstatePTV60	60	30	2	95%
Thorax PTV68	68	34	2	95%

2.1.3 TPS-Monaco software version 5.11.03

This work used the TPS- Monaco software version 5.11.03 for planning, delivering and data collection treatment planning, dose delivering and data collection. The TPS – Monaco software is among of the Elekta software that uses Monte Carlo for photon beams algorithms, the accuracy dose mode calculation available. This software uses physical and biological cost functions that allow the modeling of tissues to dose response. It uses a multi-criteria optimization that automatically to get low dose to the health tissues without compromising PTV coverage. In relation to IMRT/VMAT plans, the dose deposition is made from several oblique radiation fields, called anterior right and left and oblique posterior right and left along the beam's direction. After performing dose calculation, Monaco is capable of creating DVHs and percentage passing rate for OARs and tumor volumes. Monaco is connected to Elekta-TPS, which is a patient oncology information management system. The connected TPS – Monaco software with the treatment machine by allowing the transference of patient information such as the treatment plan.

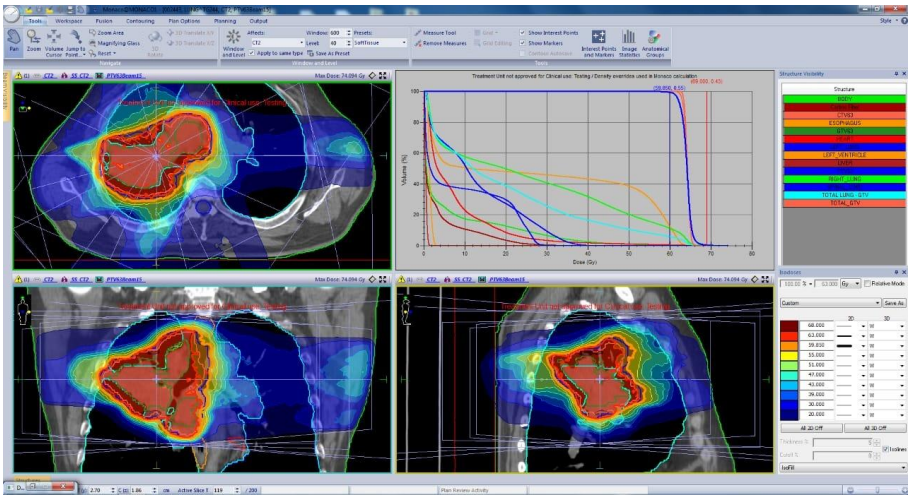

Fig 2.3. Monaco Treatment planning system of lung

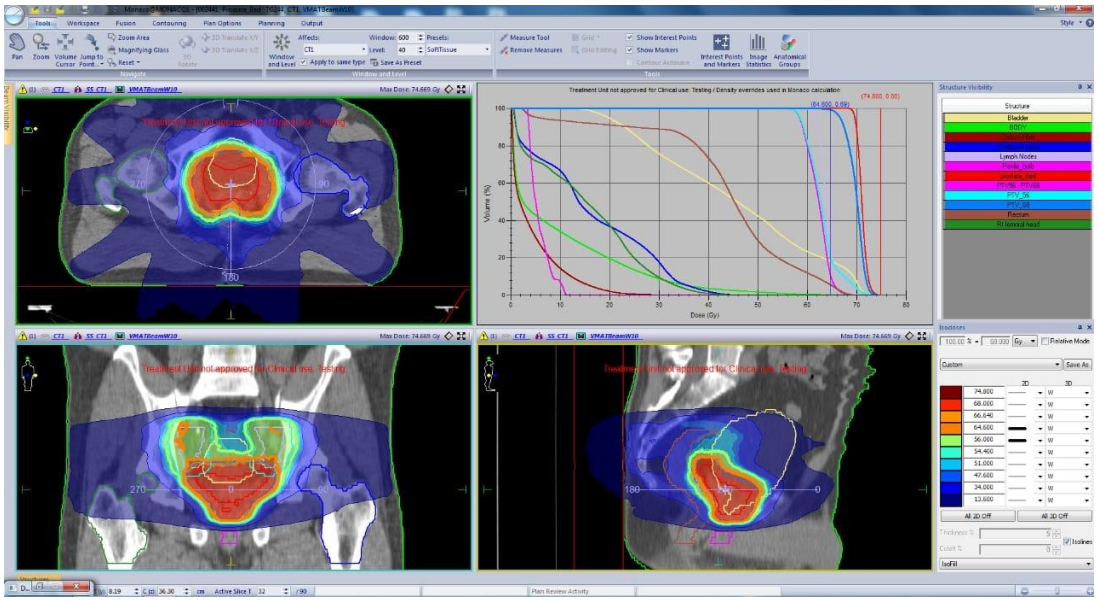

Fig 2.4.Monaco Treatment planning system of prostate

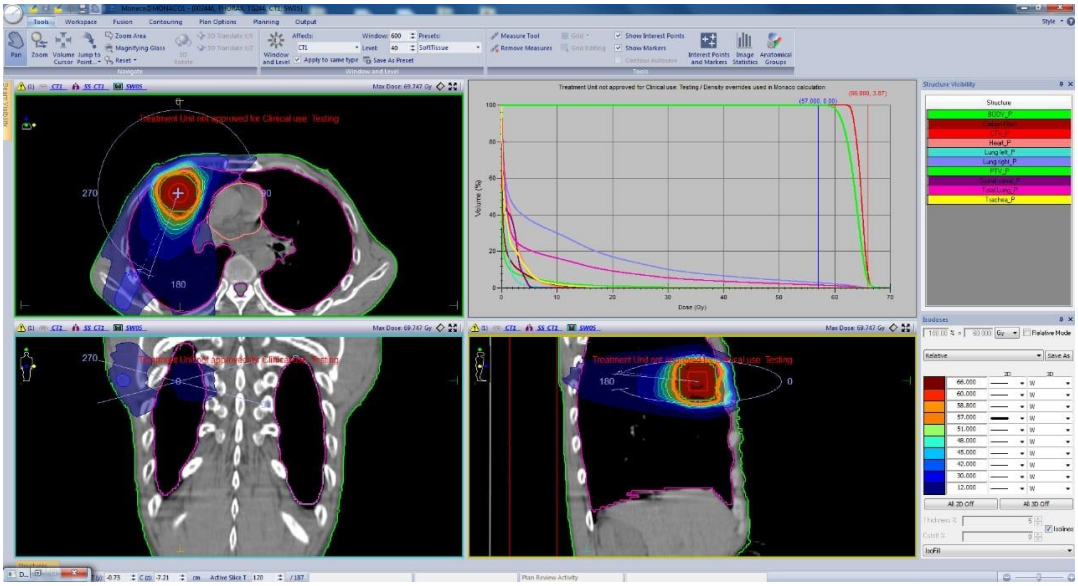

Fig 2.5. Monaco Treatment planning system of thorax

2.2 Methods

2.2.1 Segment width of the Dynamic MLC

The aim was to evaluate the MLC parameters reproducibility of IMRT and VMAT plans by EPID together with its software. The work's goal can be achieved by the segment width of sliding window of MLC mode used to perform dose delivering. The segment width was achieved by leaves position of MLC and then dose to the target obtained when leaves are "ON". In this work, the varying segment width from 0.5cm to 2cm were used to shaped and modulated beams according to PTV. Finally dose was delivered through these segment widths of Dynamic MLC and hence the MLC parameters reproducibility will be assed.

2.2.2 2D and 3D-EPID Dosimetry based on PerFRACTION Method

The experiment worked on 2D and 3D-dose analysis by EPID without patient. In 2D-dose analysis, image portal dose determined when the dose distributed at the surface area (pixels) EPID panel. In this method the Expected image portal dose from EPID and delivered dose image compared by using gamma analysis method.

In 3D-dose distribution dose was measured by combining the 2D information due to the back-projection reconstruction of the point dose, the aim of 3D here to reconstruct dose volume from volume element and EPID dose is compared to TPS-dose [36-41]. This reconstruction method used EPID images without the patient placed in the beam and algorithm of calculating dose does not dependent a Monte Carlo dose engine. The method involved four steps until the final dose calculation as shown on the **Figure 2.6.** First step, a portal image is captured in the same procedures as real treatment and is converted into a portal dose image using a-Si EPID-iView-GT [23]. Second step is to extract from this portal dose image the energy fluency exiting the LINAC. As a third step, a phase space distribution is sampled from the energy fluence. In the final step, the

reconstructed phase space distribution is the starting point for the dose calculation. The 3D dose calculation is performed inside the patient planning CT.

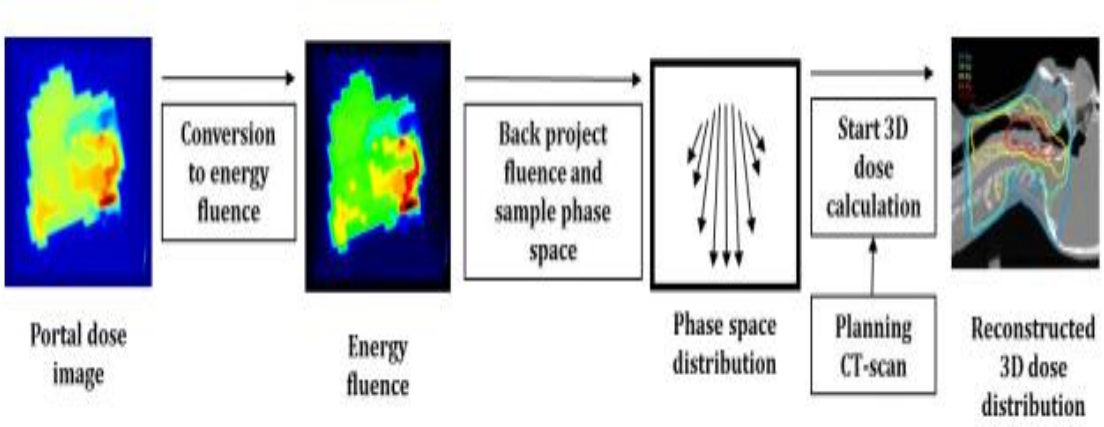

Fig 2.6. Schematic representation of the several steps involved in the model used for 3D in vivo dosimetry. In a first step the 2D open-field portal dose images acquired by the EPID from all beam directions are converted to energy Fluence.

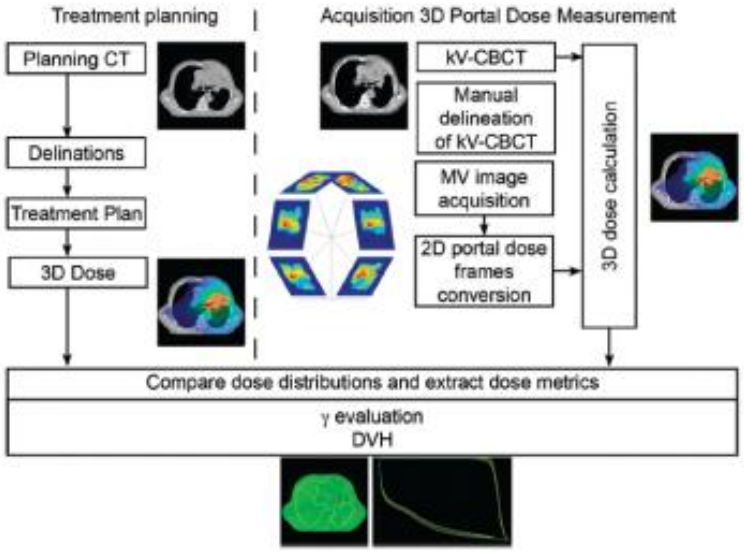

Fig 2.7. Workflow of the 3D portal dose measurement acquisition and extraction of dose metrics from the DVH and gamma evaluations.

The work used PerFRACTION software to analyze the EPID measurements quantitatively. In 2D-EPID dosimetry the results analyzed in gamma index analysis (2D

gamma analysis) and in 3D-EPID, the results analyzed in DVH analysis (3D gamma analysis) as shown on the figure (2.7)

The PerFRACTION (PF) system is an automatic complex part of SunCHECK platform for monitoring the irradiation quality of each fraction delivered to a particular patient. It reconstructed dose, and the dose predictions of the planning where compared The system has the following features, log files of the linear accelerator, CBCT images, and portal imaging of the EPID panel. Due to the information above, the built-in Sun Nuclear Dose Calculator, graphics processing unit, accelerated Collapse Cone Convolution/Superposition (CCC) algorithm – performs an independent calculation of distributed dose. This algorithm uses a beam model created by Sun Nuclear Corporation.

The dosimetric plan developed by the TPS in the DICOM format was transferred to the Per-fraction server. The data includes a set of CT images, a set of structures and individual dose characteristics of the beams. After receiving incoming data, the DoseCHECK module a part of the SunCHECK platform that was used for pretreatment verification automatically provides independent quality assessment of the planning system by recalculating beam doses using CCC-algorithm. The results are presented as a comparison of Planned by TPS and Calculated (QA) doses by point dose and 3D-point distributed in structure. The pre-treatment QA is made without the presence of a patient (zero-fraction). The treatment plan is fully reproduced with the collection of EPID-images. The obtained images are analyzed by the gamma index method compared to the "expected" ones and are used to form a 3D dose distribution. In vivo dosimetry of each fraction uses daily CBCT and EPID images of the patient in combination with the accelerator log files. All EPID images obtained at the first fraction are selected as a base (baseline). All subsequent images are automatically compared to the baseline. EPID results due to the distributed dose on the structures of the patient analyzed by 2D-and 3D- gamma analysis method.

2.2.3 Gamma evaluation method

The gamma evaluation method is a method by which the planned dose and dosed measured can be compared in a quantitative manner in the dose and spatial domains [2, 24].The method uses two criteria simultaneously, a distance to agreement (DTA) and difference of dose (DD) which are complementary with overdose and under-dose area, to find the gamma value for each surface element and volume element as shown on figure 3.4. Therefore, in clinical practice a number of different evaluation ways applied to compare distributed dose such as profile comparisons, gamma evaluation method and e.t.c.

Dose difference (DD). DD is the most intuitive and straightforward quantitative evaluation method in which the dose difference between two points of distributed dose can be calculated as a dose domain. In this way, considering a point in the reference dose distribution ($\vec{r}_m$) and the corresponding point in estimated dose distribution ($\vec{r}_c$) the DD is given by expression below

$$\Delta D = DD = D_c(\vec{r}_c) - D_m(\vec{r}_m), \quad (3)$$

Or

$$\Delta D = \left(\frac{D_c(\vec{r}_c) - D_m(\vec{r}_m)}{D_m(\vec{r}_m}\right) x\ 100\%, \quad (4)$$

DD criterion (ΔD) is set such that the points with a dose difference value higher than fail the criterion and the points with a dose difference value lower than ΔD pass the criterion. In clinical practice normally ΔD% of the maximum dose. Although this method is considered clinically significant for low-dose slope areas, it is inadequate to evaluate high-dose surface areas since a small spatial shift in the alignment can translate into a large difference in dose.

Distance-to-Agreement (DTA). DTA is the distance between a points in a calculated distribution $\overrightarrow{r_c}$and the closest point in the measured distribution $\overrightarrow{r_m}$ that indicates the same dose. The DTA is given by the expression 1.

$$DTA(\vec{r}_c) = min|\vec{r}_c - \vec{r}_m|, \quad (5)$$

In order for a part of the image to pass it would have to have a DTA lower than the chosen criteria (Δd mm). The DTA method is suitable in high gradient surface whereas the dose-difference method is suitable in low gradient surface as shown in the figure. A DTA criterion (Δd mm) is also set, and the points with a DTA value at higher than Δd fail the criterion and the points with a DTA value lower than Δd pass the criterion. Unlike the DD, the DTA method is sensitive in high-dose gradient regions. However, for the low-dose surface the DTA method can display area of disagreement large than the DTA criterion, defined as clinically acceptable criterion, for relatively small dose differences. The gamma evaluation method combines the features of dose difference and DTA methods, which complement each other.

An ellipsoid on **figure 2.8** is used as the surface representing the acceptance criteria for gamma evaluation as represented by **equation** 7. Knowing that r represents the spatial location and δ the difference in dose between the evaluated and reference distributions at the point r_m and r_c respectively.

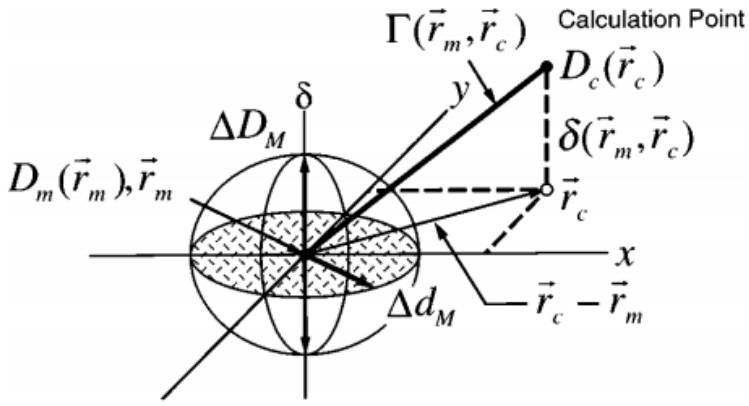

Fig 2.8. Geometric representation of Gamma evaluation method using the combined ellipsoidal absolute dose difference and DTA. The x and y axes show the dircteion of distributed points in the evaluated distribution ($\vec{r}_c$) relative to the the reference point distributed ($\vec{r}_m$)

$$\mathrm{r}(\vec{r}_c,\vec{r}_m)=\sqrt{\frac{r^{2(\vec{r}_c,\vec{r}_m)}}{DTA^2}+\frac{\delta^{2(\vec{r}_c,\vec{r}_m)}}{\Delta D^2}}, \quad (6)$$

$$\gamma(\vec{r}_c)=\min\{\mathrm{r}(\vec{r}_c,\vec{r}_m)\}\,\forall\{\vec{r}_m\}. \quad (7)$$

Were ΔD is the dose difference, DTA- distance to agreement.

$$\%\gamma\,(\%\Delta D,\Delta d(mm))\leq 1, \text{ calculation passes} \quad (8)$$

$$\%\gamma(\%\Delta D,\Delta d(mm))> 1, \text{ calculation fails} \quad (9)$$

The surface of the image that fulfil either criteria would then pass and parts of the image that would not fulfil this criterion will not pass and hence through either expression 8 or expression 9 above the two dose distributions would be compared.

The work used gamma evaluation method of passing rate of %γ (2%, 2mm) ≥ 95% criterion at dose Threshold of 10% and %γ (3%, 3mm) ≥ 95% criterion at dose Threshold of 20% and the dose analyzed by 2D-gamma analysis and 3D-gamma analysis using PerFRACTION Software.

CHAPTER 3 : PRACTICAL PART

3.1 Procedures and Experiment of IMRT/VMAT plans Verifications

Research based on experiment of the IMRT and VMAT verifications. The plans created by TPS by including gantry angle, MLC setting and number of monitor and the plans were done in accordance with Elekta synergy specifications including 6MV and 10MV photon beam and all plans planned by using TPS-Monaco software version 5.11.03. After plans delivered to the imager in air without phantom or patient or any attenuating medium between the source of the radiations and EPID after created as shown in **figure 3.1**. The actual patient not involved in the process. Instead of that, the tested plans were done by emulated patient plans in 3D-CTimages from a TG244_Lung patient, TG244_Thorax patient and TG244_Prostate patient plans and Portal dose image of each segment width between 0.5 cm and 2cm in each structure was measured by converting portal image captured into portal dose image by using EPID associated with its software.

The portal dose images of both plans were measured at different SDD less than 100cm and the evaluation was performed in the portal dosimetry review workspace with a (2%, 2mm) gamma analysis at a dose threshold of 10% for a threshold gamma passing rate was set at 95%. And at this condition the acquired portal dose image and predicted dose image was compared. A total of 12-plans were planned .4-Plans planned in each structure as. All lung and Prostate plans planed with zero degree (0°) of couch angle and zero degree (0°) of and all thorax plans planned with 345° of collimator angle and 345° of couch angle as shown on table and the final results analyzed by per-fraction software in 2gamma analysis and DVHs analysis.

Table 3.1– Plans created for Lung, Prostate and Thorax patients

N_0	Structure, Energy	Modality	SW (cm)	Beam	Tot. Dose (Gy)	Fraction Number	Dose/ Fraction	γ(2%,2mm)<1 TH=10%
1	Lung 6MV	IMRT	0.5	5	63	35	1.8	95
		IMRT	1	5				
		IMRT	1.5	5				
		IMRT	2	5				
2	Prostate 10MV	VMAT	0.5	2	68	30	2	95
		VMAT	1	2				
		IMRT	1.5	2				
		VMAT	2	2				
3	Thorax 6MV	VMAT	0.5	2	63	34	2	95
		VMAT	1	2				
		VMAT	1.5	2				
		VMAT	2	2				

Table 3.2–Plan Parameters applied for Lung plans measurements

Structure, Energy	Modality	SW (cm)	Beam	SSD (mm)	G.A (deg)	Col. A, C.A (deg)	N_0 MU	Plan. Dose (Gy)
Lung 6MV	IMRT	0.5	05 x 11	856.7	208.6	0	145.9	0.471
			05 x12	846.3	265.7	0	129.3	0.616
			05 x13	879.6	318.6	0	120.1	0.397
			05 x14	862.3	0	0	151.8	0.300
			05 x 15	837.3	142.7	0	120.1	0.053
	IMRT	1	10 x 11	856.7	208.6	0	127.5	0.476
			10 x 12	846.3	265.7	0	102.7	0.606
			10 x13	879.6	318.6	0	126.1	0.485
			10 x 14	862.3	0	0	64.4	0.237
			10 x15	837.3	142.7	0	121.4	0.065
	IMRT	1.5	15 x 11	856.7	208.6	0	96.9	0.469
			15 x 12	846.3	265.7	0	95.3	0.538
			15 x 13	879.6	318.6	0	113.9	0.429
			15 x 14	862.3	0	0	70.1	0.283
			15 x 15	837.3	142.7	0	96.1	0.107
	IMRT	2	20 x 11	856.7	208.6	0	95.9	0.467
			20 x 12	846.3	265.7	0	86.3	0.503
			20 x 13	879.6	318	0	125.5	0.465
			20 x 14	862.3	0	0	68	0.307
			20 x15	837.3	142.7	0	79	0.09

Table 3.3– Plan Parameters applied for Prostate plan measurement

Structure Energy	Modality	SW (cm)	Beam	SSD (mm)	G.A (deg)	Col.A C.A (deg)	$\frac{N_0}{MU}$	Plan. Dose (Gy)
Prostate 10MV	VMAT	0.5	1a005	895.7	180	0	333.5	1.114
			2a005	883.6	5	0	415	0.957
	VMAT	1	1B010	895.7	180	0	301	0.961
			1B010	883.6	5	0	378.9	1.105
	IMRT	1.5	1C015	895.7	180	0	267.6	0.925
			1C015	883.6	5	0	375.5	1.172
	VMAT	2	1D020	895.7	180	0	270	1.007
			1D020	883.6	5	0	298.6	1.084

Table 3.4– Plan Parameters applied for Thorax patient measurements

Structure Energy	Modality	SW (cm)	Beam	SSD (mm)	G.A (deg)	Col.A C.A (deg)	$\frac{N_0}{MU}$	Plan. Dose (Gy)
Thorax 6MV	VMAT	0.5	SWA05	855	200	345	333.5	1.114
			SWB05	915.5	65	345	415	0.957
	VMAT	1	SWA10	855	200	345	301	0.961
			SWA10	915.5	65	345	378.9	1.105
	VMAT	1.5	SWA15	855	200	345	267.6	0.925
			SWA15	915.5	65	345	375.5	1.172
	VMAT	2	SWA20	855	200	345	270	1.007
			SWA20	915.5	65	345	298.6	1.084

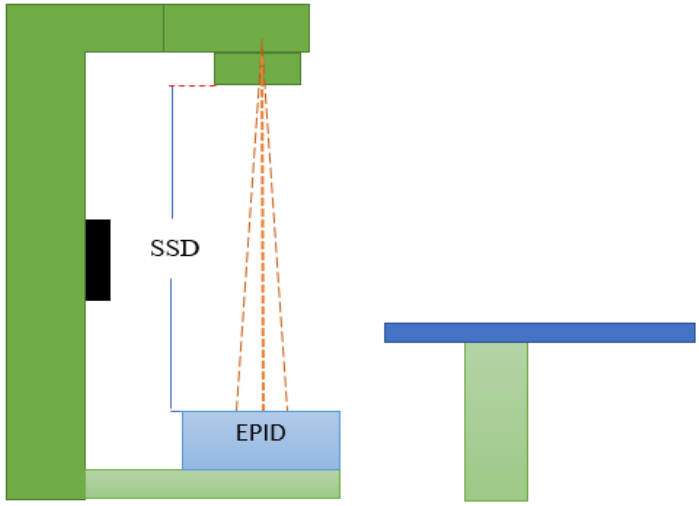

Fig 3.1. Scheme set up virtual patient EPID measurement configuration allowing for pre-treatment

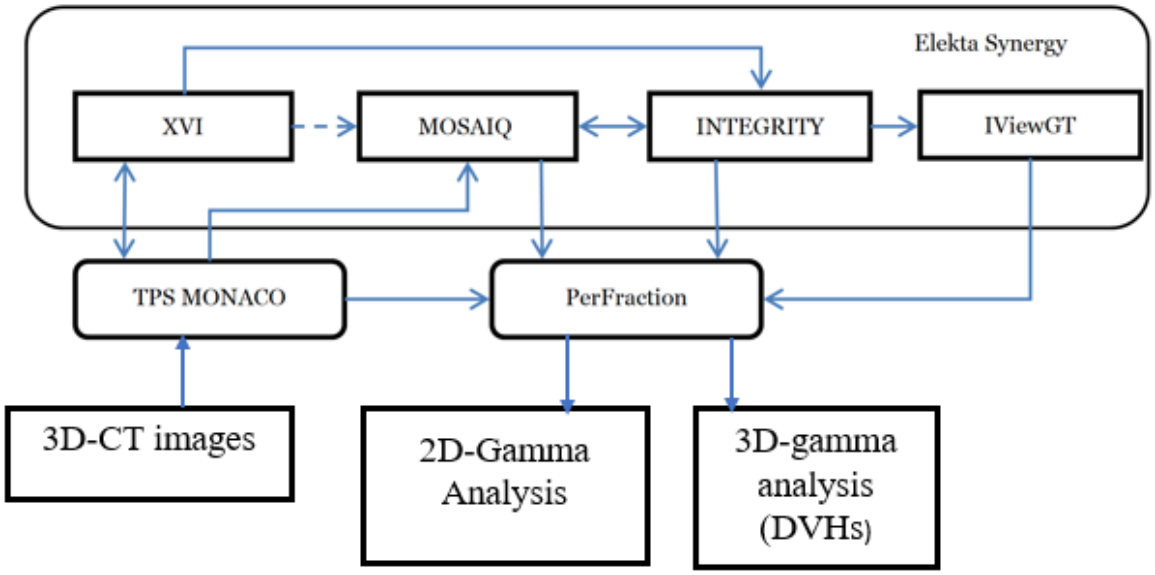

Fig 3.2. The scheme of interaction between TPS, accelerator elements and Per-Fraction server

3.2 Results and Discussion

The procedures under section (3.1) done by using specifications of LINAC Elekta Synergy Installed at Tomsk Regional Oncology Clinic and the results analyzed and discussed using gamma index analysis and DVH analysis for ($\%\gamma(2\%,\ 2\text{mm}, \text{TH} = 10\%) \geq 95\%$ gamma criterion and recalculated under gamma analysis for ($\%\gamma(3\%,\ 3\text{mm}, \text{TH} = 20\%) \geq 95\%$ were set for both 2D and 3D-Dose analysis for segment widths of 0.5 cm up 2cm for each structure. Through the measurements some differences were observed which related to the dose distribution in each segment width for each structure or Localization. The results explained as follows.

3.2.1 Results for the first Experiment

The first experiment done under ($\%\gamma(2\%,\ 2\text{mm}, \text{TH} = 10\%) \geq 95\%$ gamma criterion. Observed that all plans planned in 2D- dose analysis, each localization had lower gamma passing rate than threshold gamma passing rate of 95% was set for both 6MV and 10MV photon beams on both structures as shown on the tables (4.1, 4.2 and 4.3) below.

The table 3.1 represented the EPID measured and calculated results of the lung plans at ($\%\gamma(2\%,\ 2\text{mm}, \text{TH} = 10\%) \geq 95\%$ gamma criterion when 6MV photon beam and IMRT modality of dose delivery were used. For 05 x 12, 05 x 14, 10 x 11, 10 x 14, 15 x 12 15 x 14, 20 x11, 20 x 12 and 20 x14 beam names, had gamma passing rate lower than mean calculated gamma passing rate of 60.57%, although their dose difference detected by EPID were smaller than the mean measured dose difference of 1.74%.

Table 3.1−Lung plan Results in 2D-dose distribution

Structure, Energy Modality	SW (cm)	Beam	Passed Points	Plan Dose (Gy)	Meas. Dose (Gy)	Rel. Dose Diff (%)	Abs Dose Diff (cGy)
Lung 6MV IMRT	0.5	05 x11	67.79	0.471	0.468	-0.6	-0.3
		05 x12	60.95	0.616	0.626	1.6	1
		05 x13	67.12	0.397	0.390	-1.7	-0.7
		05 x 14	38.01	0.300	0.300	1.6	0.5
		05 x 15	79.51	0.053	0.055	3.7	0.2
		Mean $\pm SD$	62.68 24.47			0.92 2.11	0.14 0.67
	1	10 x 11	57.85	0.476	0.524	10	4.8
		10 x 12	60.12	0.606	0.611	0.8	0.5
		10 x13	71.79	0.485	0.501	3.5	1.7
		10 x 14	43.01	0.237	0.233	-1.6	-0.4
		10 x15	73.21	0.065	0.068	6.2	0.4
		Mean ±SD	61.196 19.54			3.78 4.54	1.4 2.04
	1.5	15 x 11	67.26	0.469	0.481	2.5	1.2
		15 x 12	57.41	0.538	0.548	1.8	1
		15 x 13	69.11	0.429	0.428	-0.2	-0.1
		15 x 14	49.65	0.283	0.272	-3.8	-1.1
		15 x 15	67.58	0.107	0.119	11.2	1.2
		Mean ±SD	62.202 13.41			2.3 4.96	0.44 1.02
	2	20 x 11	48.7	0.467	0.497	6.4	3.0
		20 x 12	48.49	0.503	0.508	0.9	0.5
		20 x 13	64.5	0.465	0.461	-0.8	-0.4
		20 x 14	45	0.307	0.303	-1.3	-0.4
		20 x15	74.36	0.09	0.085	-5.5	-0.5
		Mean ±SD	56.21 20.18			-0.06 4.31	0.44 1.49
	Tot. mean ±Tot.SD		60.57 19.3			1.74 4.23	0.605 1.38

For 05 x 12, 05 x 14, 10 x 12, 10 x 14, 15 x 14, 20 x 12 and 20 x14 beams, had lower EPID dose difference than the mean dose difference but still had lower gamma passing rates than 60.57% and hence associated with under dose. Figure 3.1 showed the comparison the between the delivered dose and expected EPID portal dose image for the 05 x 14 beams in 2D-dose distributions. The red color indicted the higher dose and blue color indicated the lower dose and green color indicated the gamma index. The EPID measured portal dose imaged had large red spots than delivered image dose Expected.

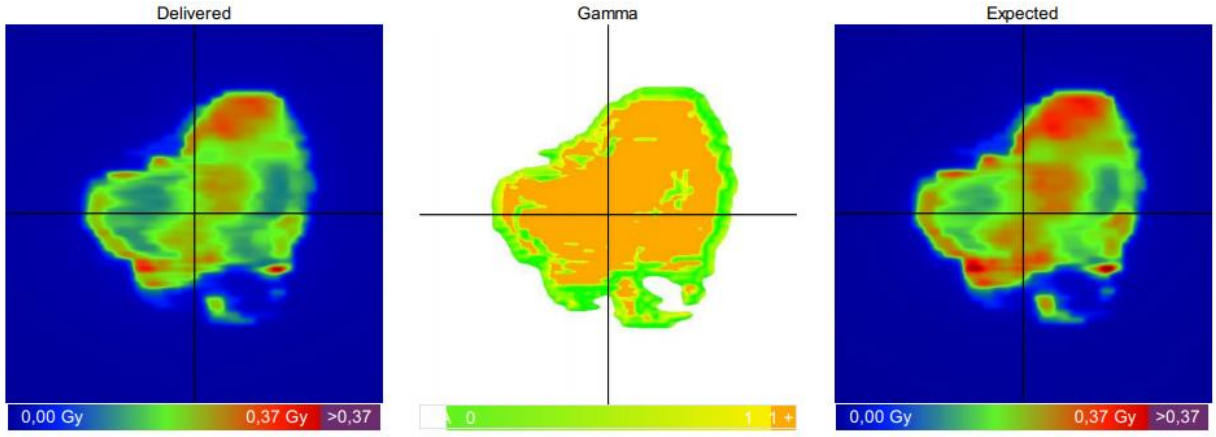

Fig 3.1.Comparison between the delivered dose and Expected portal dose image for 2B010 beam for the Lung for plans (2%, 2mm, TH=10%) gamma criterion

The table 4.2 Represented the EPID measured and calculated results for the Prostate plans at $(\%\gamma(2\%,\ 2\text{mm}, \text{TH} = 10\%) \geq 95\%$ gamma criterion. All plans planned by IMRT and VMAT dose delivery technique, using 10MV photon beam. 0.5, 1 and 2cm planned by VMAT and 1.5 cm planned by IMRT.

The results showed all beams had higher gamma passing rates than the mean gamma passing rate of 75.33 % except 2B010 and 2D020 beams had lower gamma passing rate than 75.33% and hence they associated slightly with under-dose. This was explained by the smaller value of EPID measured dose difference (-1% and 2.6%) than the mean calculated dose difference (-0.8%). So the higher negative values means that

the lower dose and thus why their passing rate were lower. The figure 3.2 showed the comparison the between the delivered dose and expected EPID portal dose image for 2B010 beam in 2D-dose distributions. The EPID (expected) portal dose image associated with lower dose than the delivered dose image this indicated by large area to be covered with blue spots. So if this beam will be used, tumor will be received lower dose than expected.

Table 3.2−Prostate plans results in 2D-dose distributions.

Structure, Beam Energy	SW (cm)	Beam	Passed Points (%)	Plan. Dose (Gy)	Meas. Dose (Gy)	Rel. Dose Diff (%)	Abs. Dose diff (cGy)
Prostate 10MV	0.5	1a005	87.76	1.114	1.109	0.4	0.5
		2a005	86.71	0.957	0.951	-0.6	-0.6
		Mean ±SD	87.24 0.85			-0.1 0.71	-0.05 0.78
	1	1B010	90.30	0.961	0.950	1.1	1.1
		2B010	14.55	1.105	1.094	-1	-1.1
		Mean ±SD	52.43 61.4			0.05 1.48	0 1.56
	1.5	1C015	90.32	0.925	0.934	0.9	0.9
		2C015	76.99	1.172	1.152	-1.6	-1.9
		Mean ±SD	83.66 10.81			-0.35 1.77	-0.5 2
	2	1D020	83.71	1.007	0.976	-3.0	-3.1
		2D020	72.32	1.084	1.055	-2.6	-2.9
		Mean ±SD	78.015 9.23			-2.8 0.28	-3 0.14
	Tot. mean ±%Tot.SD		75.33 33.69			-0.8 1.55	-0.89 1.65

.

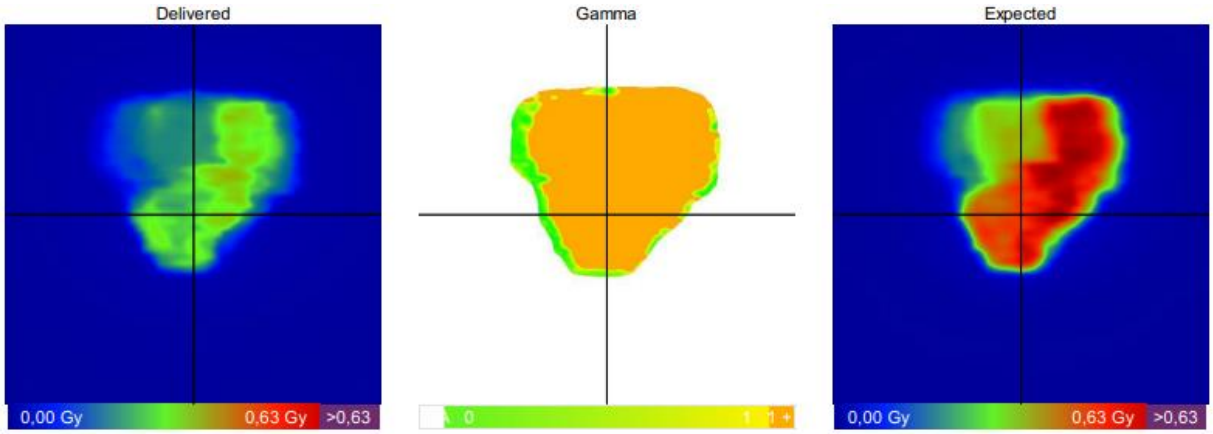

Fig 3.2.Comparison between the delivered dose and Expected portal dose image for 2B010 beam for the prostate for plan (2%, 2mm, TH=10%) gamma criterion.

The table 4.3 represented the EPID measured and calculated results for the Thorax plans planned at $(\%\gamma(2\%,\ 2\text{mm}, \text{TH} = 10\%) \geq 95\%$ gamma criterion. All plans planned by VMAT dose delivery techniques using 6MV photon beam. The results indicated that all beams had higher passing rate than mean calculated passing rate (75.68%) expect 1a005 beam which had lower gamma passing rate of 14.17%. This explained by lower dose difference of 0.1% than mean calculated dose difference of 3.14%.

Figure 4.3 showed the comparison the between the delivered dose and expected EPID portal dose image for 1a00 beam in 2D-dose analysis. The EPID (expected) portal dose image associated with lower dose than the delivered dose image this indicated by large area to be covered with blue spots. So if this beam will be used, tumor will be received lower dose than expected.

Table 3.3−Thorax plan results in 2D-dose analysis

Structure, Beam Energy	SW (cm)	Beam Name	Passed Points (%)	Plan. Dose (Gy)	Meas. Dose (Gy)	Rel. Dose Diff (%)	Abs. Dose diff (cGy)
Thorax 6MV VMAT	0.5	1a005	14.17	0.979	0.980	0.1	0.1
		2a005	94.73	1.150	1.175	2.1	2.5
		Mean ±SD	54.45 56.96			1.1 1.4	1.3 1.7
	1	1B010	78.49	1.019	1.066	4.6	4.7
		1B010	86.79	1.144	1.139	-0.4	-0.5
		Mean ±SD	82.64 5.87			2.1 3.5	2.1 3.7
	1.5	1C015	78.85	1.019	1.030	1.0	1.1
		1C015	85.48	1.144	1.135	-0.7	-0.9
		Mean ±SD	82.17 4.69			0.15 1.2	0.1 1.4
	2	1D020	76.51	0.951	1.058	11.2	10.7
		1D020	90.38	1.215	1.303	7.2	8.8
		Mean ±SD	83.45 9.81			9.2 2.8	9.8 1.3
	Tot. Mean ±Tot. SD		75.68 25.64			3.14 4.24	3.31 4.39

.

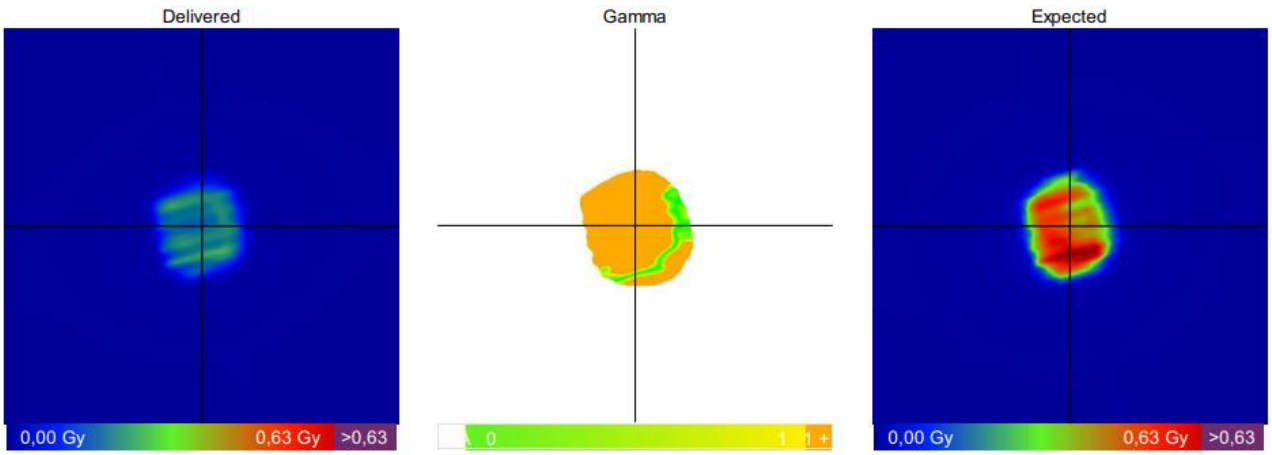

Fig 3.3. Comparison between the delivered dose and Expected portal dose image for 1a005 beam for the thorax for plan (2%, 2mm, TH=10%) gamma criterion

DVHs analysis used to analyze the measured by EPID through PerFRACTION software of 3D-dose distributions by combining all the plan fields planned in 2D-dose distributions under (2%, 2mm, TH=10%) gamma criterion when threshold gamma passing rate of 95% was set for both segment widths in each structure (localizations). The results showed that in some segment width in 3D- dose distributions satisfied and some segment widths were not satisfied the (2%, 2mm, TH=10%) gamma criterion for threshold gamma passing rate of 95% as shown on the table 3.4. below.

For lung, all plans planned using IMRT dose delivery technique using 6MV photon beam. The mean gamma point passing rate for the lungs plans was 95.4% which was higher than threshold gamma passing rate of 95%. 0.5 cm and 1.5 cm segment widths had higher gamma point passing rate than 95.4%, the higher gamma point passing rate explained by lower iso-center composite dos difference of 0.4% and 1.2 % respectively measured by EPID which were less than the mean calculated dose difference of 1.65%. 1 cm and 2 cm segment widths had lower gamma passing rates of 90.33% and 93.83% respectively which were lower than mean gamma passing rate of 95.4%. The lower gamma passing rate for 1cm segment width explained by large value of dose difference

of 3.8% which was higher than the mean dose difference and hence these segment associated with slight overdose to the OARs and slightly under-dose to the PTV. The lower gamma passing rate on 2 cm segment widths was explained by lower dose difference of 1.2% than 1.65% and hence this segment width associated with under-dose to the PTV.

Table 3.5−Isocenter Composite point dose results under (2%, 2mm, TH=10%) gamma criterion when threshold gamma passing rate of 95% was set.

$N_{\underline{0}}$	Structure Beam energy	SW (cm)	Plan. Dose (Gy)	Meas. Dose (Gy)	Rel. Dose Diff. (%)	Abs. Dose Diff. (cGy)	Passed Points (%)
1	Lung, 6MV	0.5	1.837	1.845	0.4	0.8	99.39
		1	1.868	1.938	3.8	7	90.33
		1.5	1.827	1.849	1.2	2.2	98.06
		2	1.833	1.854	1.2	2.1	93.83
		Mean ±SD			**1.65 1.48**	**3.03 2.73**	**95.4 4.33**
2	Prostate 10MV VMAT/ IMRT	0.5	2.071	2.06	-0.5	-1.1	88.42
		1	2.065	2.045	-1.0	-2.0	93.29
		1.5	2.098	2.041	-2.7	-5.7	94.36
		2	2.093	2.032	-2.9	-6	96.42
		Mean ±SD			**1.2 1.29**	**2.5 2.69**	**93.12 3.64**
3	Thorax, 6MV VMAT	0.5	2.19	2.155	1.2	2.6	92.45
		1	2.163	2.204	1.9	4.1	85.5
		1.5	2.163	2.165	0.1	0.2	84.47
		2	2.167	2.36	8.9	19.3	68.13
		Mean ±SD			**3.02 4**	**6.55 8.65**	**82.64 12.46**

Table 3.6- Results of the gamma passing rate for TPS and DVH analysis at (2%, 2mm, TH=10%) gamma criteria at D_{mean},D_{95} and D_{90} for lung (PTV)

Structure (Target)	SW (cm)	TPS					EPID-DVH
		Reference Dose	D.TPS	D.QA	ΔD%	%GPR	%GPR
PTV63	0.5	D_{mean} D_{90} D_{95}	1.8 1.8 1.8	1.8 1.8 1.7	-0.00 -0.1 -0.2	98	98.21
	1	D_{mean} D_{90} D_{95}	1.8 1.8 1.8	1.8 1.8 1.8	1 -0.1 -0.8	77	77.21
	1.5	D_{mean} D_{90} D_{95}	1.8 1.8 1.8	1.8 1.8 1.8	0.2 0.1 0.0	91	94.10
	2	D_{mean} D_{90} D_{95}	1.8 1.8 1.7	1.8 1.8 1.7	0.1 0.7 1.2	91	91.36
	Mean ±SD				0.175 0.55	89.25 8.8	90.22 10.11

The quantitatively results of PTV and OARs are represented and analyzed as shown on the table 3.5 and table 3.6. According to the results from the table 3.5, there slight difference between the TPS gamma passing rate and per-fraction gamma passing rate, TPS gamma passing rate showed that only 1cm segment width had lower gamma passing rate than 89.25% and per-fraction showed that only 1cm segment width had lower gamma passing rate than 90.22%, so the results showed that at 1cm segment width PTV was irradiated with lower dose than other segment width and hence associated with large effect of reproducibility values. So at (2%, 2mm, TH=10%) gamma criterion only 0.5 cm segment width satisfied because the PVT irradiated with large dose than other segment width

Table 3.6−Results of OARs for each segment width between 0.5cm and 2cm for lung plans

OARs	S.W (cm)	TPS. Maximum dose				PER-FRACTION
		D.TPS (Gy)	D.QA (Gy)	%Δ*D*	%GPR	%GPR
Spinal cord	0.5	0.8	0.8	-1.3	100	99.92
	1	0.8	0.9	6.5	83	83.27
	1.5	0.8	0.9	3.1	91	90.64
	2	0.8	0.8	-1.4	97	96.76
	Mean ±SD			1.73 3.8	92.75 8	92.65 7.9
Tot. Lung-GTV	0.5	2	2	-0.3	99	99.47
	1	2	2	1.4	93	92.53
	1.5	2	2	0.9	99	98.96
	2	1.9	1.9	0.2	95	94.70
	Mean ±SD			0.55 0.75	96.5 3	96.42 3.48
Heart	0.5	1.8	1.8	0.2	100	99.59
	1	1.8	1.8	-0.1	92	91.67
	1.5	1.8	1.8	-0.7	99	99.47
	2	1.8	1.8	0.1	88	88.25
	Mean ±SD			-0.13 0.4	94.75 6.06	94.75 6.015
Esophagus	0.5	1.8	1.8	-0.3	99	99.48
	1	1.8	1.8	1.9	78	77.81
	1.5	1.8	1.8	0.6	92	91.77
	2	1.8	1.8	-0.5	85	85.44
	Mean ±SD			0.43 1.09	88.5 10.2	88.63 10.4

Table 3.6 showed the results of the OARs, when PTV63 (lung) was irradiated with 6MV by using IMRT modality, the results showed that spinal cord at 1cm and 1.5 cm segment had lower gamma passing rates than mean calculated gamma passing rate and hence associated with higher dose, the lower gamma passing rate in 1cm and 1.5 segment width explained by large dose difference of 6.5% and 3.1% than the maximum tolerance dose difference of 2% used. For Total Lung GTV, 1cm segment width had

lower passing rate than other this means, it has associated with large reproducibility effect.

Tables 3.7 and 3.8 represented the results of the PTV and OARs when the prostate irradiated with 10MV. Table 3.7 showed that all segment width had lower gamma passing rate than 95% used as reference this indicated that PTV received (irradiated with) lower dose, this proved by TPS and Per-fraction Gamma passing rates. The large reproducibility the lower gamma passing rate. Table 3.8 showed that for rectum there are slightly difference between the TPS and Per-fraction gamma passing rates of (93.65±3)% and (96.5±1.73)%. For bladder had (93.75±2.9) % and (96.6±1.62) % gamma passing rates.

Table 3.7– TPS Gamma passing rate and DVH analysis at (2%, 2mm, TH=10%) gamma criteria at D_{mean},D_{95} and D_{90} for Prostate (PTV)

Structure	SW	TPS					EPID-DVH
		Referenc Dose	D.TPS	D.QA	ΔD%	%GPR	%GPR
PTV68	0.5	D_{mean}	2	2.1	-0.9		
		D_{90}	2	2	-1.9	77	77.40
		D_{95}	2	1.9	-2		
	1	D_{mean}	2.1	2	-1.4		
		D_{90}	2	2	-1.5	88	87.91
		D_{95}	2	1.9	-1.6		
	1.5	D_{mean}	2	2	-1.1		
		D_{90}	2	2	-0.7	94	94.48
		D_{95}	2	1.9	-0.7		
	2	D_{mean}	2	2	-1.5		
		D_{90}	2	1.9	-1.4	87	86.86
		D_{95}	2	1.9	-1.4		

Table 3.8– Results of OARs for each segment width between 0.5cm and 2cm

OARs	S.W (cm)	TPS. Maximum dose				EPID-DVH
		D.TPS (Gy)	D.QA (Gy)	% ΔD	%GPR	%GPR
Rectum	0.5 1 1.5 2	2 2 2 2	2 2 2 1.9	0.1 0.6 0.4 1.4	94 97 90 94	93.62 97.11 89.66 94.22
	Mean ±SD				93.65 3	96.5 1.73
Bladder	0.5 1 1.5 2	2.1 2.1 2.1 2.1	2.1 2.1 2.1 2.1	0.8 2 1.2 1.7	94 97 98 97	94.35 97.13 98.21 96.74
	Mean ±SD				93.75 2.9	96.6 1.62

Table 3.7 above showed the results of the thorax (PTV) when the Thorax irradiated with 6MV. From the results observed that the PTV was irradiated with lower dose, thus is why the gamma passing rates in each segment width were lower, the lower gamma passing rate indicated the effect of reproducibility, the large effect of reproducibility the smaller passing rate than the lower value of reproducibility . At 2cm segment width the PTV was irradiated by very low dose than other segment width. Although PTV irradiated with lower dose but there slightly difference between the TPS and Per-fraction gamma passing rates of (59.5±40.32) % and (59.41± 40) %.

Table 3.8 showed the results of OARs for each segment width when thorax irradiated with 6MV photon beam using VMAT, the results showed that the Total lung-P at 0.5, 1 and 1.5 cm segment widths had large gamma passing rate than 79.25% but at 2cm segment width , the Total Lung-P had lower gamma passing rate than 79.25%, this explained by large dose difference of 11.1% than 4.1%, but generally all segment associated with higher dose because they had lower gamma passing rate than 95%

Table 3.9−Results of the GPR for TPS and DVH analysis at (2%, 2mm, TH=10%) gamma criteria at D_{mean},D_{95} and D_{90} for Thorax target (PTV)

Structure (Target)	SW (cm)	TPS					EPID-DVH
		Reference Dose	D.TPS	D.QA	ΔD%	%GPR	%GPR
PTV60	0.5	D_{mean} D_{90} D_{95}	2.1 2.1 2	2.1 2.1 2	0.8 0.3 0.2	87	86.86
	1	D_{mean} D_{90} D_{95}	2.1 2 2	2.1 2 2	-1.4 -1.5 -1.6	61	60.77
	1.5	D_{mean} D_{90} D_{95}	2.1 2 2	2.1 2 2	0.8 0.0 -0.6	88	87.66
	2	D_{mean} D_{90} D_{95}	2.1 2 2	2.3 2.1 2.1	8.3 6.8 6.4	2	2.36
	Mean ±SD					59.5 40.32	59.41 40

Table 3.10−Measurements of OARs for each segment width between 0.5cm and 2cm

OARs	S.W (cm)	TPS. Maximum dose				EPID-DVH
		D.TPS (Gy)	D.QA (Gy)	%ΔD	%GPR	%GPR
Tot. Lung-P	0.5 1 1.5 2	2.2 2.2 2.2 2.2	2.2 2.3 2.2 2.5	1.4 2.5 1.4 11.1	93 80 82 62	93.01 80.36 82.30 62.49
	Mean ±SD			4.1 4.7	79.25 12.84	79.54 12.65

3.2.2 Results of the Second Experiment

The $(\%\gamma(3\%,\ 3\text{mm}, \text{TH} = 20\%) \geq 95\%$ gamma criterion was performed in the experiment in order to recalculate or to check the results of the first experiment done by $(\%\gamma(2\%,\ 2\text{mm}, \text{TH} = 20\%) \geq 95\%$ gamma criterion for the same EPID and per-fraction software under the same procedures for 2D-dose analysis. The results as shown on the table below 3.11. The results indicated that, 2D-dose analysis due to $(\%\gamma(3\%, 3\text{mm}, \text{TH} = 20\%) \geq 95\%$ gamma criterion had good results for all plans in each structure compared to the $(\%\gamma(2\%,\ 2\text{mm}, \text{TH} = 20\%) \geq 95\%$ gamma criterion when it is used. For the 3D-dose analysis both gamma criterion produced the same results in each segment for each structure or localization.

For the Lung plans, the gamma passing rate was improved from $60.57\% \pm 19.3$ in $(\%\gamma(2\%,\ 2\text{mm}, \text{TH} = 10\%)) \geq 95\%$ gamma criterion to gamma passing rate $92.58\% \pm 6.41\%$ in $(\%\gamma(3\%,\ 3\text{mm}, \text{TH} = 20\%)) \geq 95\%$ in 2D-dose analysis.

For the prostate plans. The gamma passing rate was improved from $75.33\% \pm 33.69\%$ in $(\%\gamma(2\%,\ 2\text{mm}, \text{TH} = 10\%)) \geq 95\%$ gamma criterion to gamma passing rate $91.69\% \pm 3.7\%$ in $(\%\gamma(3\%,\ 3\text{mm}, \text{TH} = 20\%)) \geq 95\%$ in 2D-dose analysis but for the 3D-dose analysis both gamma criterion produced the same results in each segment width for each structure or localization. For the thorax plans the gamma passing rate was improved from $75.64\% \pm 25.64\%$ in $(\%\gamma(2\%,\ 2\text{mm}, \text{TH} = 10\%)) \geq 95\%$ gamma criterion to gamma passing rate $81.63\% \pm 12.52\%$ in $(\%\gamma(3\%,\ 3\text{mm}, \text{TH} = 20\%)) \geq 95\%$ in 2D-dose analysis.

Table 3.11− Results Lung, Prostate and Thorax plans for 6MV and 10MV for (%γ(2%, 2mm, TH = 10%))and (%γ(3%, 3mm, TH = 20%)) ≥ 95%

N_0	Structure Energy Modality	SW	%GP (2%, 2mm, TH=10% at 95%)		%GP (3%, 3mm, TH=20%, at 95%	
			2D-dose analysis	3D-dose Analysis	2D-dose analysis	3D-dose analysis
1	Lung, 6MV IMRT	0.5	62.68	99.39	98.6	99.39
		1	61.2	90.33	85.4	90.33
		1.5	62.2	98.06	96.1	98.06
		2	56.21	93.83	90.21	93.83
		Mean ±SD	60.57 19.3	95.4 4.33	92.58 6.41	95.4 4.33
2	Prostate 10MV IMRT VMAT	0.5	87.24	88.42	87.76	88.42
		1	52.42	93.29	90.30	93.29
		1.5	83.66	94.36	93.1	94.36
		2	78.01	96.42	95.6	96.42
		Mean ±SD	75.33 33.69	93.12 3.4	91.69 3.7	93.12 3.4
3	Thorax 6MV VAMT	0.5	54.45	92.45	91.3	92.45
		1	82.64	85.5	84.4	85.5
		1.5	82.17	84.47	83.6	84.47
		2	83.45	68.13	67.2	68.13
		Mean ±SD	75.64 25.64	82.64 12.46	81.63 12.52	82.64 12.46

CHAPTER 4 : LITERATURE REVIEW

According to WHO (2020) the major causes of death in worldwide is cancer and it is characterized by uncontrolled growth and spread of abnormal cells and expected that the number of new cancer cases will be increased by 70% to more than 22million cases in twenty years from now. According to international Agency of research on cancer (IARC-2018), large than 43% of all new cases in the worldwide come from the following group of cancer: Lung, Female breast, intestines plus anus and Prostate cancers.

Due to the source of radiation, Internal and External Radiotherapy can be distinguished. Internal Radiotherapy uses radioactive sources placed on the surface or inside of the patient in a very close location of the tumor. High-energy photons (X-ray and γ-ray) and electrons, produced by a linear accelerator (LINAC) are among of ionizing radiation used in EBRT according to Podgorsak. E. (2005). According to Nijsten. S (2009). The beam high energy x-ray photons modulated and shaped before moving outside the treatment head of the LINAC. Beam may be shaped either by moulded blocks or MLC or jaws that are installed in the machine. The MLC typically consists of a series of 80 to 160 movable metallic leaves arranged in pairs. By changing their individual position, these leaves can block some part of the intensity of the beam thereby shaping the gape due to the tumor shape.

Tumor volumes, OARs and other atomic structure are the essential part in the radiotherapy treatment planning process for optimal treatment' ICU reports 50, (1993,). These contain clear definitions to enable centers to use the same criteria for delineating tumors for radiation so that their treatment results can be compared.

According to Jordan and Williams (1994) multi-leaf collimators have many functions in radiation therapy. MLC defines the exchange of conventional radiotherapy blocks which decreeing the duration needed by removing the block production and also decrease he duration of sequential field setting but at the same time in associated with

challenges. LoSasso, Chui, and Ling (2001) improving the technology allows the using of IMRT techniques which leaves of MLC can be either used in manner out than expected and QA is required to verify the accurate leaf location and leaf function.

Yu. C (1955) and Otto.K (2008) MLC deliver more conformal distributed dose in 3D when beam dynamically modulated either by continuous shaping of the dose rate and changing of the gantry velocity compared conformal 3D-distributed dose generated under fixed gantry. VMAT needs small number of monitor unit and generally used shorter duration to obtained distrusted dose according to Otto. K(2008, 2010) and to Goyal and Kataria (2014) and Van Herk (2004) in radiotherapy terms a treatment error can be defined as any deviation in treatment delivery from what as planned or intended to be delivered.

Incorrect leaves positions can destroy distributed dose at any point in the surface which differentiated conventional blocking from MLC. In sliding window of MLC, an uncertainties in position of the leaf can be taken through entire field, causing the red spots when leaves closed and blue spots when the leaves opened, Chui, Spirou, and LoSasso (1996). Red and blue also can be appeared during the step and shoot deliveries to regions of many sub-field structures. Red and Blue spots indicated the significance of function of the leaf position assurance of MLC during the clinical dose delivering by static or dynamic IMRT mode

TG142 divides MLC-equipped Linacs into three types; these are non-IMRT, IMRT and those capable of MLC or micro-MLC-based Stereotactic radiosurgery/Stereotactic body radiation therapy, with each type requiring different procedures and tolerances on these procedures. The Canadian Partnership for Quality Radiotherapy (CPQR) replaced CAPCA to generate, maintain and inform the QC and QA systems. In 2013, CPQR released ‘Technical Quality Control Guidelines for Canadian Radiation Treatment Centres: Medical Linear Accelerators and Multileaf

Collimators' which summarized and combined the 2005 and 2006 CAPCA documents. The TG142 and CPQR documents includes Linac and MLC QC and specifies that it is for non-patient specific IMRT QA.

According to Ping X., Joseph Y. T, Colin G. O (2007). Dynamic multi-leaf collimation where the collimator leaves are moving while beam is ON and hence the velocity of the leaves of the leaves is virtually important. This makes DMLC more complicated to plan and deliver than MLC. According to LoSasso, Chui, Ling (1998), leaf gap separation defines the broadening of the radiation field than narrow field of the grooved MLC leaf edges. The dosimetric leaf gap can be estimated the dose method using sweeping gaps of various widths. A tolerance of 0.1 mm is advised.

According to McDermott, L. N (2007), Electronic portal imaging devices were originally developed for verification of patient positioning during treatment and to replace film that was previously used. The images of the megavoltage treatment beam acquired by the EPID, also called portal images, used to estimate the discrepancies in the patient set-up or errors of the radiation field placement prior or during field delivery. Set-up verification measurements of the patient position, it was realized that EPID images also contained dose information. According to Van Elmpt et al. (2008) EPIDs used as devices for transmission (transit), or non-transmission (non-transit) dosimetry, i.e., with or without an attenuation object. Pre-treatment verification can detect a large number of errors in the radiotherapy chain before starting treatment, but if there is any unexpected change during the treatment time, it will be missed. It is not easy to translate the influence of pre-treatment discrepancies on the real dose distribution delivered at the day of occurrence. Possible sources of errors could be changes in the linac output, incorrect accessory, MLC failure, patient changes (tumor shrinkage, weight loss, organ motion, anatomical changes in patient since planning CT) or even changes in patient setup, including obstruction from immobilization devices (van Elmpt et al., 2008; Chytyk-

Praznik et al., 2013). Many of these errors could be detected if all parameters would be checked during the patient treatment via patient transmitted dose.

According (Low et al., 2011; Mijnheer et al., 2013) in vivo dosimetry (IVD), as part of a QA program, could detect major errors and indicate the relevance between treatment's planned and treatment's delivered. Comprehensive overviews of techniques of IMRT/VMAT testing by using point detectors, two-dimension arrays, films, and also EPIDs. The EPID is an excellent in vivo dosimetry system since performed dose verification in all dimensions (0, 1, 2, 3 and 4D). Both methods can be categorized into a forward and back-projection or dose reconstruction approach. In the forward approach, the verification of fluence or dose is done at the position of the imager, while in the second approach measurements are made outside the attenuating medium, and the verification is performed inside the patient or phantom (Wendling et al., 2006; Wendling et al., 2009). There are different possible approaches to using portal dose information for verification. McCurdy and Pistorius (2000) comparison of the measured portal dose image (PDI) to a predicted image. This in turn could be done either in vivo with a PDI of the patient in position compared to a predicted image calculated using CT data of the patient, or with a PDI of the radiation field without patient compared to a predicted image calculated without patient (Van Esch et al., 2004).

According to Kasper. L. Pasma (1999) a method of pre-treatment verification used to ascertain that the radiation fluence is delivered from the accelerator in accordance with the plan. This method would reveal errors in the movement and positioning of the MLC leaves, the correct transfer of the treatment plan and the mechanical and dosimetric performance of the accelerator. Pre-treatment testing of this kind mainly occurs in intensity modulated radiotherapy (IMRT) where the high complexity, with changing leaf patterns and non-homogenous dose distributions, increases the risk of errors as well as making the errors more difficult to detect.

According to Zhuang A. and Olch A. (2015) per-fraction from Sun Nuclear (www.sunnuclear.com) compares EPID images from each field of each fraction n (>1) behind a patient with a reference portal image using 2D gamma analysis. In a sensitivity study of this software, it was demonstrated that per-fraction, using integrated EPID images, is sensitive enough to identify positional, angular, and dosimetric errors. The EPID image applied to evaluate MLC leaf positions of that fraction that applied as input for a 3D dose calculation on planning CT data using the linac log-file. Such an approach should be considered as a pseudo-3D dose verification tool but not as an in vivo dosimetry method. The per-fraction Fraction 0 software from Sun Nuclear (www.sunnuclear.com) is also able to perform a 2D dose determination at EPID surface, and then compared to the distributed dose in that plane calculated with the TPS for independent 2D planar analysis. The EPID image also applied to evaluate MLC leaf position applied as input for a 3D dose calculation on planning CT data using the linac log-file.

According to Low D. A. et.al (1998) gamma evaluation technique used quantitatively method to compare distributed dose, including superimposed isodoses, dose-difference, and distance-to-agreement (DTA) distributions. The criterion for acceptable calculation performance is generally defined as a tolerance of the dose and DTA in regions of low and high dose gradients, respectively. The dose difference and DTA distributions complement each other in their useful regions. A composite distribution has recently been developed that presents the dose difference in regions that fail both dose-difference and DTA comparison criteria. By approaches developed by Podesta. M, Persoon L. C. G. G, Verhaegen. F. A (2014), the acceptance criteria are applied. The pixels or voxels for which $|\gamma| \leq 1$ meet the acceptance criteria and are considered to pass the gamma analysis. The pixels or voxels for which $|\gamma| \geq 1$ are not satisfy the acceptance criteria and are considered to fail the gamma analysis.

CHAPTER 5 : FINANCIAL MANAGEMENT, RESOURCE EFFICIENCY AND RESOURCE SAVING

5.1 Pre-Research Analysis

The research evaluates the Multi-leaf Collimator (MLC) Parameters Reproducibility of Intensity Modulated Radiotherapy (IMRT) and Volumetric modulated arc Therapy (VMAT). This master's thesis performed on clinical base in Tomsk Regional Oncology Clinic. This research was done by special equipment, Elekta Synergy Linear accelerator with equipped a-Si-EPID panel (iView-GT and XVI) system for Portal dose image calculation and Reproducibility detection.

Financial management, Resource efficiency and Resource saving are an important aspect in fulfil a project, because they help to measure the prospects and success of a Research Project plan for managing and acquiring special support for implementation. It involves assessing the commercial potential, attractiveness to the target audience. This section discusses the issues of Competitiveness, Resource Efficiency and Resource saving, SWOT analysis as well as financial costs regarding the object of study of Master's thesis.

Competitiveness analysis is carried out for this purpose. SWOT analysis helps to identify strengths, weaknesses, opportunities and threats associated with the project, and gives an idea of working with them in each particular case. In-order to achieve the goals of my thesis, fund was required to pay as the salaries for participants or assistant of my project and also fund required for necessary equipment, a complete list is given in the relevant section. The calculation of the resource efficiency indicator helps to make a final assessment of the technical decision on individual criteria and in general.

Nowadays, nuclear medicine has a wide range of technologies and has sophisticated equipment for diagnosis and treatment of cancer. Radiotherapy is the most effective method for a cancer treatment, compared with surgery or chemotherapy. Modern

radiotherapy allows to escalate the dose to the tumor and minimize the dose to the healthy tissues. The realization of such state-of-the-art technologies requires high accuracy in performing. In this study the effectiveness of IMRT and VMAT quality assurance of MLC parameters and their impact Reproducibility on treatment planning has been evaluated. The study used in medicine but based treatment planning and quality assurance of radiotherapy in treatment of malignant tumor. The final consumer is radiotherapy departments. Studies have shown advantage of the treatment planning of IMRT and VMAT for Lung, Prostate and Thorax cancer.

5.1.1 Competitiveness Analysis of Technical Solutions

The evaluation of the commercial value of work, helping to find the source of financing of the project. Analysis of competitive technical solutions in terms of resource efficiency and resource saving allows to evaluate the comparative effectiveness of scientific development. The evaluation card was used to carry out of this analysis.

First of all, it is necessary to analyze possible technical solutions and to select the best one based on the consideration of technical and economic criteria.

Evaluation map analysis presented in Table 5.1. As the competitive methods are chosen IMRT (C_1), VMAT (C_2) and Non-Usable (C_3) modality for MLC parameters. These modalities are evaluated with the five-point scale for each chosen criterion, where 1 is the weakest position and 5 is the strongest. The weights of indicators in the amount should be 1. Analysis of competitive technical solutions is determined by the formula 10:

$$C = \sum_{i=1}^{m} W_i * P_i \quad (10)$$

C - the competitiveness of research or a competitor;

Wi– criterion weight;

Pi – point of i-th criteria.

Table 5.1 – Evaluation Card for Comparison of Competitive Technical Solutions

Evaluation criteria	Criterion weight	Points			Competitiveness		
		P1	P2	P3	C_1	C_2	C_3
1	2	3	4	5	6	7	8
Technical criteria for evaluating resource efficiency							
Planning efficiency	0.1	5	4	3	0.5	0.3	0.4
Energy efficiency	0.1.5	3	4	5	0.75	1.25	0.2
3. Delivery dose	0.05	4	3	2	0.2	0.1	0.1
4. Delivery time	0.05	5	4	4	0.5	0.6	0.05
5. Dose conformity	0.1	4	3	3	0.4	0.5	0.3
5. Reliability of results	0.05	4	3	4	0.3	0.4	0.3
4. Functional Capacity	0.1	3	4	5	0.3	0.5	0.4
5. Labor Intensity	0.1	5	4	3	0.8	0.9	0.8
6. Ease of use	0.1	5	3	4	0.5	0.4	0.3
Economic criteria for performance evaluation							
1. Competitive ability	0.05	4	4	5	0.4	0.25	0.15
2. Wide accepted method	0.05	2	2	4	0.15	0.25	0.15
3. Expected life cycle	0.1	5	5	5	0.5	0.5	0.5
Total	1				5.4	5.95	3.65

The results showed, VMAT had good score because of the reliability of the results, is the most competitive, due to the dose delivery, dose conformity and time delivery, is very similar to IMRT, but Non-useable modality had bad results and has less dose conformity than IMRT modality.

5.1.2 SWOT Analysis

Complex analysis solution with the greatest competitiveness is carried out with the method of the SWOT analysis: Strengths, Weaknesses, Opportunities and Threats. The analysis has several steps. The first step consists the strengths and weaknesses of the project, identifying opportunities and threats to the project that have emerged or may appear in its external environment. The second stage consists of identifying the compatibility of the strengths and weaknesses of the project with the external environmental conditions. This compatibility or incompatibility should help to identify what strategic changes are needed. SWOT analysis of this study as shown on the table 5.2

Table 5.2 – SWOT analysis

	Strengths: S1. Increasing of dose distribution accuracy S2. Development of single approach based on clinical reality and aims	**Weaknesses:** W1. Lack of equipment W2. Lack of staff expertise
Opportunities: O1. Time management planning O2. Reduction of dose delivered to the healthy tissues or organ at risk	Strategy which based on strengths and opportunities: 1) Ability to improve the quality of treatment Decreasing tumor under-dose risk	Strategy which based on weaknesses and opportunities: 1)Employee advanced trainings allow to improve the accuracy of treatment and by finding errors

Continuation of table 5.2 – SWOT analysis.

		2)Competent approach would allow to use equipment according to aims
Threats: T1. Threat of MV injury T2. Lack of commercial interest to these methods	Strategy which based on strengths and threats: 1) Writing science papers which show the benefits of using such methods of geometric verification, that would show the necessity of using this equipment and enough financing 2) High rate of treatment quality would influence on enough financing of overhead expenses	Strategy which based on strengths and threats: 1) Regular courses of medical staff increase the level of education, which potentially raise interest to new technologies 2) Getting research grants

5.2 Project Initiation

The initiation process group includes the processes that are performed to define a new project or a new phase of an existing one. In the initiation processes, the initial purpose and content are determined and the initial financial resources are fixed. The

internal and external stakeholders of the project who will interact and influence the overall result of the research project are determined (table 5.3 and 5.4).

Table 5.3 – Stakeholders of the Project

Project stakeholders	Stakeholder expectations
Clinical departments	Research of advantages comparison of using IMRT/VMAT of patient treatment planning
Research center	

Table 5.4 – Purpose and results of the project

Purpose of project:	- To evaluate the multi-leaf parameters Reproducibility of IMRT/VAMT plans.
Expected results of the project:	- Comparison of reproducibility in each MLC parameters for a group of patients. - Evaluation of under-dose in PTV and overdose in OARs. - Finding the best segment width which we can be used for treatment planning. - Finding the relationship between the MLC parameters and dosimetric system.
Criteria for acceptance of the project result:	- Increasing of effectiveness of treatment up to 95% of patient receiving 95% of prescribed dose in PTV.
Requirements for the project results	- The project should be finished to the 1st of June
	- The results of the project should be meet the criteria for acceptance
	- The results of this research must be demonstrated at Russian conference
	- In case of unacceptable results it is important to repeat the experiment or to change the treatment planning.

5.2.1 The organizational structure of the project

It is necessary to solve some questions: who will be part of the working group of this project, determine the role of each participant in this project, and prescribe the functions of the participants and their number of labor hours in the project. This information is collected in table 5.5.

Table 5.5 – The working group of the project

№	Participant	Role in the project	Functions	Labor time, hours.
1	E.S. Sukhikh, PhD, Chief Medical Physicist of Tomsk Regional Oncology Center	Research Supervisor	Control of the project	150
2	A.V.Vertinsky	Assistant advisor , Medical Physics, PHD student	Preformed measurements, data	50
3	E.J .Chuma	Master student	Analyzing , evaluating the results and research writing	550
Total				750

5.2.2 Project Limitations

Project limitation are all factors that can be as a restriction on the degree of freedom of the project team members. Project limitations are illustrated in the table 5.6

Table 5.6 – Project limitations.

Factors	Limitations / Assumptions
Project's budget	20650000 of rubles
Source of financing	Government budget
Project timeline:	October 2020-June 2021
Date of approval of plan of project	01.02.2021
Completion date	01.06.2021

5.2.3 Project Schedule

Also as a part of planning a science project, it is necessary to build a project timeline and a Gantt chart (tab5.7 and 5.8).

Table 5.7 – Project timeline.

	Job title	working days	Start date	Date of completion	Participants
1	Creation and Approving Technical Specification	5	01.20.2021	05.02.2021	Research Supervisor
2	Finding and Studying of Literature Review	15	07.02.2021	15.02.2021	Master's student
3	Selection study way	2	18.02. 2021	19.02 .2021	Research supervisor
4	Experiment and measurements performing	35	21.02 .2021	27.03 2021	Master's student
5	Development of general methodology of the research	7	29.03 2021	04.04. 2021	Research advisor, Master's student
6	Calendar planning of research activities	2	05. 04. 2021	06.04 2021	Research advisor
7	Analysis, description of the Results and writing of thesis	33	07.04.2021	09.05.3021	Research Supervisor Master's student
8	Compilation of the master's thesis	20	10. 05.2021	01.05.2021	Master's Student

A Gantt chart, or harmono-gram, is a type of bar chart that illustrates a project schedule table5.7. This chart lists the tasks to be performed on the vertical axis, and time intervals on the horizontal axis. The width of the horizontal bars in the graph shows the duration of each activity.

Table 5.7 – Calendar schedule of master's thesis performing

№	Activities	Participants	T_c, days	Duration of the project											
				February			March			April			May		
				1	2	3	1	2	3	1	2	3	1	2	3
1	Creation and approving of technical specification	RS	5												
2	Finding and Studying of Literature Review	MS	15												
3	Creation of dosimetric test or plans(different MLC parameters) in TPS	RS	2												
4	Irradiating dosimetry test and Measurements performing	MS	35												
5	Development of general methodology of the research	RS, MS	7												
6	Calendar planning of research activities	RS	2												

Continuation of table 5.7. Calendar schedule of master's thesis performing

7	Analysis, description of the Results and writing of thesis	RS,MS	33												
8	Compilation of the master's thesis	MS	20												

Icons show participations activity, -master's student, - Research Supervisor.

5.3 Scientific and Technical Research budget

The amount of costs associated with the implementation of this work is the basis for the formation of the project budget. This budget will be presented as the lower limit of project costs when forming a contract with the customer.

To form the final cost value, all calculated costs for individual items related to the manager and the student are summed.

In the process of budgeting, the following grouping of costs by items is used:

- Material costs of scientific and technical research;
- Costs of special equipment for scientific work (Depreciation of equipment used for design);
- Basic salary;
- Additional salary;
- Labor tax;
- Overhead.

The budget for scientific and technical research is shown in table 5.8.

Table 5.8 – The budget for scientific and technical research.

Name	Material costs	Costs of special equipment	Basic salary	Addi-tional salary	labor tax	Over-head	Total cost
Cost, rub.		20104000	71070	7107	56899	140463	20360740

5.3.1 Calculation of material costs

The calculation of material costs is carried out according to the formula:

$$C_{nT} = (1 + k_i) \times \sum_{i=1}^{n} P \times N_{const} \quad (11)$$

Where n – the number of types of material resources consumed in the performance of scientific research; N_{consi} – the amount of material resources of the i-th species planned to be used when performing scientific research (units, kg, m, m^2, etc.); P_i – the acquisition price of a unit of the i-th type of material resources consumed (rub. /units, rub. /kg, rub. /m, rub. /m^2, etc.); k_T – coefficient taking into account transportation costs.

Prices for material resources can be set according to data posted on relevant websites on the Internet by manufacturers (or supplier organizations).

Table 5.9 – Material costs.

№	Name	Units	Amount	Price per unit, rub.	Material costs, rub.
1	Internet	GB	20	5000	5000
2	Paper	Bundle	1	350	350
3	Electrical cables	20A	2	800	800
4	Pen	Black/Blue	50	50	2500
5	Computer	Lenovo	1	30000	30000
Total					38650

For this kind of work some equipment have been already bought. So we need to calculate deprecation of such equipment per year. It is calculated by the formula:

$$D = \frac{C_{primary} \times N_d}{100} \quad (12)$$

, where D – annual deprecation; $C_{primary}$ – primary cost of equipment; $N_d=100/T_{life}$ – norms of depreciation deductions, T_{life} – service life of equipment. It is supposed, that service life of all equipment is 10 years.

Table 5.10 – Special equipment.

№	Name	Manufacturer	Amount	Price per unit rubles.	Material deprecation costs, thousands rubles
1	Linac Elekta Synergy	Elekta	1	20000000	20000
2	Monaco Software	Elekta	1	14340	14.340
Total					20014.34

5.3.2 Basic salary

This point includes the basic salary of participants directly involved in the implementation of work on this research, research advisor am master's student. The value of salary costs is determined based on the labor intensity of the work performed and the current salary system.

The basic salary (S_b) is calculated according to the following formula:

$$S_b = S_a \times T_w \quad (13)$$

Where Sb – basic salary per participant; T_w – the duration of the work performed by the scientific and technical worker, working days;

The average daily salary is calculated by the formula:

$$S_d = \frac{S_m \times M}{F_v} \quad (14)$$

Where S_m – monthly salary of an participant, rub; *M* – the number of months of work without leave during the year: at holiday in 49 days, M = 10.4months, 5 days per week; F_v– valid annual fund of working time of scientific and technical personnel (251 days).

Table 5.11 – The valid annual fund of working time

Working time indicators	Participants
Calendar number of days	365
The number of non-working days - weekend - holidays	 60 14
Loss of working time - vacation - sick absence	 49 0
The valid annual fund of working ti	242

Monthly salary is calculated by formula:

$$S_{month} = S_{base} \times (k_{premium} + k_{bonus}) \times k_{reg} \quad (15)$$

Where

S_{base} – base salary, rubles;

$k_{premium}$ – premium rate;

k_{bonus} – bonus rate;

k_{reg} – regional rate.

Table 5.12 – Calculation of the base salaries

Performers	S_{base}, rubles	$k_{premium}$	k_{bonus}	k_{reg}	S_{month}, rub.	W_d, rub.	T_w, work days	W_{base}, rub.
Research supervisor	22500	1.1	1.1	1.3	64350	2369	30	71070
Master's student	20000				57200	1861	76	141436

5.3.3 Additional salary.

This point includes the amount of payments stipulated by the legislation on labor, for example, payment of regular and additional holidays; payment of time associated with state and public duties; payment for work experience, etc.

Additional salaries are calculated on the basis of 10-15% of the base salary of workers:

$$W_{add} = k_{extra} \times W_{base} \quad (16)$$

Where W_{add} – additional salary, rubles;

k_{extra} – additional salary coefficient (10%);

W_{base} – base salary, rubles.

Table 5.13_Additional salary for 10% of the basic salary

Performers	Research supervisor	Master's student	Total amount
Base salary, rubles	71070	141436	212506
Additional salary, rubles	7107	14143.6	21250.6

5.3.4 Labor tax

Tax to extra-budgetary funds is compulsory according to the norms established by the legislation of the Russian Federation to the state social insurance (SIF), pension fund (PF) and medical insurance (FCMIF) from the costs of workers.

Payment to extra-budgetary funds is determined of the formula:

$$P_{social} = k_b(W_{base} + W_{add}) \quad (17)$$

Where k_b – coefficient of deductions for labor tax.

In accordance with the Federal law of July 24, 2009 No. 212-FL, the amount of insurance contributions is set at 30%. Institutions conducting educational and scientific activities have rate - 27.1%.

Table 5.14 – Labor tax for deduction of 30%

Performer	**Research supervisor**	**Master's student**	**Total**
Base Salary, rubles	71070	141436	
Labor tax, rubles	23453.1	42431	65884.1

5.3.5 Overhead costs.

Overhead costs include other management and maintenance costs that can be allocated directly to the project. In addition, this includes expenses for the maintenance, operation and repair of equipment, production tools and equipment, buildings, structures, etc.

Overhead costs account from 30% to 90% of the amount of base and additional salary of employees.

Overhead is calculated according to the formula:

$$C_{ov} = k_{ov} \times (W_{base} + W_{add}) \quad (18)$$

Where k_{ov} – overhead rate.

Table 5.14 – Overhead costs

	Research supervisor	Master's student	Total
Overhead rate	70%		
Salary, rubles	71070	141436	
Overhead, rubles	54723	108905.72	163628.72

5.3.6 Other direct cost

PC work duration for this research is about 800 hours, linac measurement duration is 6 hours. Energy costs which include equipment and computer work are calculated by the formula:

$$C = P_{el} \times P \times F_{eq} = 5.8 \times (50\text{kW} \times 6\text{hours} + 0.75\text{kW} \times 800\text{hours}) = 5220 \quad (19)$$

Where P_{el}– power rates (5.8 rubles per 1 kWh); P – power of equipment, kW;

F_{eq}– equipment usage time, hours.

5.3.7 Formation of budget costs

The calculated cost of research is the basis for budgeting project costs. Determining the budget for the scientific research is given in the table 5.15.

Table 5.15 – Items expenses grouping

Name	Cost, rubles
1. Equipment deprecation	20014340
2. Material costs	38650
3. Basic salary	212506
4. Additional salary	21250.6
5. Labor tax	65884.1
6. Overhead	163628.72
7. Other direct cost	5 220
Total planned cost	20360740

5.4 Evaluation of the comparative effectiveness of the project

Determination of efficiency is based on the calculation of the integral indicator of the efficiency of scientific research. Its finding is associated with the determination of two weighted averages: financial efficiency and resource efficiency.

An integral indicator of the financial efficiency of a scientific research is obtained in assessing the budget of costs of three (or more) variants of the implementation of a scientific research as shown on Table 5. For this, the largest integral indicator of the implementation of a technical problem is taken as the basis of the calculation (as the denominator), with which the financial values for all execution options are correlated.

Integral financial indicator is determined in the formula:

$$I_f^p = \frac{F_{pi}}{F_{max}} \qquad (20)$$

Where

- I_f^p – Integral financial indicator of current project;
- F_{pi} – Price for *i*-th variant of execution;
- F_{max} – Maximum cost of execution of a research project (including analogs).

The resulting value of the integral financial indicator of development reflects the corresponding numerical increase in the budget of development costs in times (a value greater than one), or the corresponding numerical reduction in the cost of development in times (a value less than one, but higher than zero).

The integral indicator of the resource efficiency of the variants of the object of research can be defined as follows:

$$I_m^a = \sum_{i=1}^{n} a_i b_i^a \quad , \quad I_m^p = \sum_{i=1}^{n} a_i b_i^p \qquad (21)$$

Where

- I_m^a −is an integral indicator of resource efficiency of options;
- a_i -the weight coefficient of the i-th parameter;
- b_i^a, b_i^p - the score of the i-th parameter for the analog and development, set by an expert method on the selected rating scale;
- n - the number of comparison parameters.

Table 5.16−Comparative evaluation of the characteristics of the project execution options

Criteria	Parameter Weighting Factor(PWF)	Scientific Research Project (SRP)	Analog 1	Analog 2
Growth in User' productivity	0.2	5	3	4
Convenience in operation	0.15	4	2	3
Noise level	0.15	5	3	2
Energy efficiency	0.1	4	3	3
Reliability	0.1	4	4	3
Material consumption	0.15	4	3	3
Safety	0.15	5	2	2
Total	1			1

I_{SRP} = 0.2 *5 + 0.15 * 4 + 5 *0.15 +0.1*4 +0.1*4 +0.15*4 + 0.15 *5=4.5

Analog1 = 3*0.2+2*0.15+3*0.15+3*0.1+4*0.1+3*0.15+2*0.1= 2.8

Analog 2 = 4*0.2+0.15*3+0.15*2+3*0.1+3*0.15+3*+2*0.15= 2.9

An integral efficiency indicator of the scientific research project (I_{fin}^P) and of the analog (I_{fin}^a) are found according to the formula of the integral basis of the financial integral resource efficiency:

$$I_{fin}^{P} = \frac{I_m^p}{I_f^p}, I_{fin}^{a} = \frac{I_m^a}{I_f^a} \quad (21)$$

The comparative efficiency the project will be determined by comparison of the integral indicator of the efficiency of the current project and analogs. Comparative project efficiency:

$$E_{av} = \frac{I_{fin}^{P}}{I_{fin}^{a}} \quad (23)$$

Where

- E_{av} is the comparative project efficiency;
- I_{fin}^{P} - Integral indicator of project;
- I_{fin}^{a} −Iintegral indicator of the analog.

Table 5.17 −comperative Project efficiency

№	Indicator	Project	Analog	comparative project efficiency
1	Integral financial indicator	1	1	1
2	Integral resource efficiency indicator	4.5	5.7	0.79
3	Integral efficiency indicator	4.5	5.7	0.79

Comparison of the values of integral performance indicators allows us to understand and choose a more effective solution to the technical problem from the standpoint of financial and resource efficiency

CHAPTER 6 : SOCIAL RESPONSIBILITY

6.1 Introduction

Intensity Modulated Radiotherapy (IMRT) and Volumetric Modulated Arc Therapy (VMAT) among of the Conformal Techniques used to deliver more conformal and high precise and accuracy dose to the tumor and minimizing the dose to the Organ at risk (OARs) or other health tissues. The evaluation of MLC parameters Reproducibility of IMRT/VMAT plans was estimated according to International protocols. Such procedures help to increase the maximum dose delivering to the target or Tumor (PTV) and to minimize the dose delivering to Organ at risks or healthy tissues. Experimental calculations have been performed to compare the Planned and Measured Measurements. These measurements allow to find the best segment width which we can use to provide optimal treatment planning. The research was performed by using Elekta Synergy Linear accelerator Installed at Tomsk Regional Oncology Clinic.

This work can be applied in radiotherapy department in area of Treatment planning and quality assurance in order to assure the dose delivered to the Target is optimal dose.

6.2 Legal and organizational items in providing safety

Nowadays one of the main way to radical improvement of all prophylactic work referred to reduce Total Incidents Rate and occupational morbidity is the widespread implementation of an integrated Occupational Safety and Health management system. That means combining isolated activities into a single system of targeted actions at all levels and stages of the production process.

Occupational safety is a system of legislative, socio-economic, organizational, technological, hygienic and therapeutic and prophylactic measures and tools that ensure the safety, preservation of health and human performance in the work process [49]. According to the Labor Code of the Russian Federation, every employee has the right:

- to have a workplace that meets Occupational safety requirements;
- to have a compulsory social insurance against accidents at manufacturing and occupational diseases;
- to receive reliable information from the employer, relevant government bodies and public organizations on conditions and Occupational safety at the workplace, about the existing risk of damage to health, as well as measures to protect against harmful and (or) hazardous factors; to refuse carrying out work in case of danger to his life and health due to violation of Occupational safety requirements;
- be provided with personal and collective protective equipment in compliance with Occupational safety requirements at the expense of the employer;
- for training in safe work methods and techniques at the expense of the employer;
- for personal participation or participation through their representatives in consideration of issues related to ensuring safe working conditions in his workplace, and in the investigation of the accident with him at work or occupational disease;
- for extraordinary medical examination in accordance with medical recommendations with preservation of his place of work (position) and secondary earnings during the passage of the specified medical examination;
- for warranties and compensation established in accordance with this Code, collective agreement, agreement, local regulatory an act, an employment contract, if he is engaged in work with harmful and (or) hazardous working conditions.

The labor code of the Russian Federation states that normal working hours may not exceed 40 hours per week, the employer must keep track of the time worked by each

employee. Rules for labor protection and safety measures are introduced in order to prevent accidents, ensure safe working conditions for workers and are mandatory for workers, managers, engineers and technicians.

6.3 Basic ergonomic requirements for the correct location and arrangement of researcher's workplace

The workplace when working with a PC should be at least 6 square meters. The legroom should correspond to the following parameters: the legroom height is at least 600 mm, the seat distance to the lower edge of the working surface is at least 150 mm, and the seat height is 420 mm. It is worth noting that the height of the table should depend on the growth of the operator.

The following requirements are also provided for the organization of the workplace of the PC user: The design of the working chair should ensure the maintenance of a rational working posture while working on the PC and allow the posture to be changed in order to reduce the static tension of the neck and shoulder muscles and back to prevent the development of fatigue.

The type of working chair should be selected taking into account the growth of the user, the nature and duration of work with the PC. The working chair should be lifting and swivel, adjustable in height and angle of inclination of the seat and back, as well as the distance of the back from the front edge of the seat, while the adjustment of each parameter should be independent, easy to carry out and have a secure fit.

6.4 Occupational safety

A dangerous factor or industrial hazard is a factor whose impact under certain conditions leads to trauma or other sudden, severe deterioration of health of the worker [49]. A harmful factor or industrial health hazard is a factor, the effect of which on a worker under certain conditions leads to a disease or a decrease in working capacity.

6.4.1 Analysis of harmful and dangerous factors that can create object of investigation

The object of investigation is Intensity modulated radiotherapy (IMRT) and volumetric modulated arc therapy (VMAT) plans to carry out the evaluation of reproducibility of multi-leaf collimator parameters. Therefore, object of investigation can cause the harmful factor due to external irradiation of high-energy X-ray beam up to 10 MeV, which can potentially causes acute radiation syndrome to the patients and radiation workers as well as stochastic effect of radiation workers due to prolonged exposure during work.

6.4.2 Analysis of harmful and dangerous factors that can arise at workplace during investigation

The working conditions in the workplace are characterized by the presence of hazardous and harmful factors, which are classified by groups of elements: physical, chemical, biological, psychophysiological. The main elements of the production process that form dangerous and harmful factors are presented in Table 6.1.

Table 6.1 - Possible hazardous and harmful factors

Factors (GOST 12.0.003-2015)	Work stages			
	Develop-ment	Manu-facture	Exploi-tation	
2. Excessive noise		+	+	Legal documents
3.Increased level of electromagnetic radiation	+	+	+	
4.Insufficient illumination of the working area		+	+	

Continuation of the Table 6.1 – Possible hazardous and harmful factors

				of residential and public buildings. Sanitary rules 2.2.4 / 2.1.8.562–96. Noise at workplaces, in premises of residential, public buildings and in the construction area. Sanitary rules 2.2.4.548–96. Hygienic requirements for the microclimate of industrial premises.
5. Abnormally high voltage value in the circuit, the closure which may occur through the human body	+	+	+	Sanitary rules GOST 12.1.038-82 SSBT. Electrical safety. Maximum permissible levels of touch voltages and currents.
6. Increased levels of ionizing radiation	+	+	+	Sanitary Rules 2.6.1. 2523 -0 9. Radiation Safety Standards (NRB-99/2009).

The following factors effect on person working on a computer:

- Physical factors :
  - Temperature and humidity;
  - Noise;
  - Static electricity;
  - Electromagnetic field of low purity;
  - Illumination;
  - Presence of radiation;

- Psychophysiological factors:

Psychophysiological dangerous and harmful factors are divided into:

- Physical overload (static, dynamic)

- Mental stress (mental overstrain, monotony of work, emotional overload)

6.4.2.1 **Deviation of microclimate indicators**

The air of the working area (microclimate) is determined by the following parameters: temperature, relative humidity, air speed. The optimum and permissible values of the microclimate characteristics are established in accordance with [34] and shown on Table 6.2

Table 6.2 - Optimal and permissible parameters of the microclimate

Period of the year	Temperature, C	Relative humidity,%	Speed of movement, m/s
Cold and changing seasons	23-25	40-60	0.1
Warm	23-25	40	0.1

6.4.2.2 **Excessive noise**

Noise and vibration worsen working conditions, have a harmful effect on the human body, namely, the organs of hearing and the whole body through the central nervous system. It results in weakened attention, deteriorated memory, decreased response, and increased number of errors in work. Noise can be generated by operating equipment, air conditioning units, daylight illuminating devices, as well as spread from the outside. When working on a PC, the noise level in the workplace should not exceed 50 dB.

6.4.2.3 **Increased level of electromagnetic radiation**

The screen and system blocks produce electromagnetic radiation. Its main part comes from the system unit and the video cable. According to [34], the intensity of the

electromagnetic field at a distance of 50 cm around the screen along the electrical component should be no more than:

- in the frequency range 5 Hz - 2 kHz - 25 V / m;
- in the frequency range 2 kHz - 400 kHz - 2.5 V / m.

The magnetic flux density should be no more than:

- in the frequency range 5 Hz - 2 kHz - 250 nT;
- in the frequency range 2 kHz - 400 kHz - 25 nT.

6.4.2.4 **Abnormally high voltage value in the circuit**

Depending on the conditions in the room, the risk of electric shock to a person increases or decreases. Do not operate the electronic device in conditions of high humidity (relative air humidity exceeds 75% for a long time), high temperature (more than 35 ° C), the presence of conductive dust, conductive floors and the possibility of simultaneous contact with metal components connected to the ground and the metal casing of electrical equipment. The operator works with electrical devices: a computer (display, system unit, etc.) and peripheral devices. There is a risk of electric shock in the following cases:

- with direct contact with current-carrying parts during computer repair;
- when touched by non-live parts that are under voltage (in case of violation of insulation of current-carrying parts of the computer);
- when touched with the floor, walls that are under voltage;
- Short-circuited in high-voltage units: power supply and display unit.

Upper limits for values of contact current and voltage as represented on Table 6.3.

Table 6.3 – Upper limits for values of contact current and voltage

	Voltage, V	Current, mA
Alternate, 50 Hz	2	0.3
Alternate, 400 Hz	3	0.4
Direct	8	1.0

6.4.2.5 **Insufficient illumination of the working area**

Light sources can be both natural and artificial. The natural source of the light in the room is the sun, artificial light are lamps. With long work in low illumination conditions and in violation of other parameters of the illumination, visual perception decreases, myopia, eye disease develops, and headaches appear.

According to the standard, the illumination on the table surface in the area of the working document should be 300-500 lux. Lighting should not create glare on the surface of the monitor. Illumination of the monitor surface should not be more than 300 lux.

The brightness of the lamps of common light in the area with radiation angles from 50 to 90° should be no more than 200 cd/m, the protective angle of the lamps should be at least 40°. The safety factor for lamps of common light should be assumed to be 1.4. The ripple coefficient should not exceed 5%.

6.4.2.6 **Increased levels of ionizing radiation**

Ionizing radiation is radiation that could ionize molecules and atoms. This effect is widely used in energetics and industry. However, there is health hazard. In living tissue, this radiation could damage cells that result in two types of effects. Deterministic effects (harmful tissue reactions) due to exposure with high doses and stochastic effects due to DNA destruction and mutations (for example, induction of cancer).

To provide radiation safety with using sources of ionizing radiation one must use next principles:

- keep individual radiation doses from all radiation sources not higher than permissible exposure;
- forbid all activity with using radiation sources if profit is low than risk of possible hazard;

Keep individual radiation doses from all radiation sources as low as possible.

There are two groups of people related to work with radiation: personnel, who works with ionizing radiation, and population (see Table 6.4).

Table 6.4 – Dose limits for groups of people related to work with radiation

Quantity	Dose limits	
	personnel	population
Effective dose	20 mSv per year in average during 5 years, but not higher than 50 mSv per year	1 mSv per year in average during 5 years, but not higher than 5 mSv per year
Equivalent dose per year in eye's lens	150 mSv	15 mSv
skin	500 mSv	50 mSv
Hands and feet	500 mSv	50 mSv

Effective dose for personnel must not exceed 1000 mSv for 50 years of working activity, and for population must not exceed 70 mSv for 70 years of life.

In addition, for women from personnel of age below 45 years there is limit of 1 mSv per month of equivalent dose on lower abdomen. During gestation and breast feeding women must not work with radiation sources.

For students older than 16, who uses radiation sources in study process or who is in rooms with increased level of ionizing radiation, dose limits are quarter part of dose limits of personnel.

6.4.3 Justification of measures to reduce the levels of exposure to hazardous and harmful factors on the researcher

6.4.3.1 **Deviation of microclimate indicators**

The measures for improving the air environment in the production room include: the correct organization of ventilation and air conditioning, heating of room. Ventilation can be realized naturally and mechanically. In the room, the following volumes of outside air must be delivered:

- at least 30 m^3 per hour per person for the volume of the room up to 20m^3 per person;
- natural ventilation is allowed for the volume of the room more than 40 m^3 per person and if there is no emission of harmful substances.

The heating system must provide sufficient, constant and uniform heating of the air. Water heating should be used in rooms with increased requirements for clean air.

The parameters of the microclimate in the laboratory regulated by the central heating system, have the following values: humidity 40%, air speed 0.1 m / s, summer temperature 20-25 ° C, in winter 13-15 ° C. Natural ventilation is provided in the laboratory. Air enters and leaves through the cracks, windows, doors. The main disadvantage of such ventilation is that the fresh air enters the room without preliminary cleaning and heating.

6.4.3.2 **Excessive noise**

In research audiences, there are various kinds of noises that are generated by both internal and external noise sources. The internal sources of noise are working equipment, personal computer, printer, ventilation system, as well as computer equipment of other engineers in the audience. If the maximum permissible conditions are exceeded, it is sufficient to use sound-absorbing materials in the room (sound-absorbing wall and

ceiling cladding, window curtains). To reduce the noise penetrating outside the premises, install seals around the perimeter of the doors and windows.

6.4.3.3 **Increased level of electromagnetic radiation**

There are the following ways to protect against EMF:

- increase the distance from the source (the screen should be at least 50 cm from the user);

- the use of pre-screen filters, special screens and other personal protective equipment.

When working with a computer, the ionizing radiation source is a display. Under the influence of ionizing radiation in the body, there may be a violation of normal blood coagulability, an increase in the fragility of blood vessels, a decrease in immunity, etc. The dose of irradiation at a distance of 20 cm to the display is 50 μrem / hr. According to the norms [28], the design of the computer should provide the power of the exposure dose of x-rays at any point at a distance of 0.05 m from the screen no more than 100 μR / h.

Fatigue of the organs of vision can be associated with both insufficient illumination and excessive illumination, as well as with the wrong direction of light.

6.4.3.4 **Increased levels of ionizing radiation**

In case of radiation accident, responsible personnel must take all measures to restore control of radiation sources and reduce to minimum radiation doses, number of irradiated persons, radioactive pollution of the environment, economic and social losses caused with radioactive pollution.

Radiation control is a main part of radiation safety and radiation protection. It is aimed at not exceeding the established basic dose limits and permissible levels of radiation, obtaining the necessary information to optimize protection and making

decisions about interference in the case of radiation accidents, contamination of the environment and buildings with radionuclides.

The radiation control is control of:

- Radiation characteristics of radiation sources, pollution in air, liquid and solid wastes.
- Radiation factors developed with technological processes in working places and environment.
- Radiation factors of contaminated environment.
- Irradiation dose levels of personnel and population.

The main controlled parameters are:

- Annual effective and equivalent doses
- intake and body content of radionuclides
- volume or specific activity of radionuclides in air, water, food products, building materials and etc.
- radioactive contamination of skin, clothes, footwear, working places and etc.
- dose and power of external irradiation.
- particles and photons flux density.

Radiation protection office establish control levels of all controlled parameters in according to not exceed dose limits and keep dose levels as low as possible. In case of exceeding control levels radiation protection officers start investigation of exceed causes and take actions to eliminate this exceeding.

During planning and implementation of radiation safety precautions, taking any actions about radiation safety and analysis of effectiveness of mentioned action and precautions one must value radiation safety with next factors:

- characteristics of radioactive contamination of the environment;
- probability of radiation accidents and scale of accidents;

• degree of readiness to effective elimination of radiation accidents and its aftermathches;

• number of persons irradiated with doses higher than controlled limits of doses;

• analysis of actions for providing radiation safety, meeting requirements, rules, standards of radiation safety;

• analysis of irradiation doses obtained by groups of population from all ionizing radiation sources.

6.4.3.5 **Abnormally high voltage value in the circuit**

Measures to ensure the electrical safety of electrical installations:

- disconnection of voltage from live parts, on which or near to which work will be carried out, and taking measures to ensure the impossibility of applying voltage to the workplace;
- posting of posters indicating the place of work;
- electrical grounding of the housings of all installations through a neutral wire;
- coating of metal surfaces of tools with reliable insulation;
- inaccessibility of current-carrying parts of equipment (the conclusion in the case of electroporating elements, the conclusion in the body of current-carrying parts) [49].

6.4.3.6 **Insufficient illumination of the working area**

Desktops should be placed in such a way that the monitors are oriented sideways to the light openings, so that natural light falls mainly on the left.

Also, as a means of protection to minimize the impact of the factor, local lighting should be installed due to insufficient lighting, window openings should be equipped with adjustable devices such as blinds, curtains, external visors, etc.

6.5 Ecological safety

6.5.1 Analysis of the impact of the research object on the environment

Sources of ionizing radiation used in medicine could be divided into two groups: radioactive substances and radiation generators. The difference is that radiation generators like accelerators and x-ray tubes emit ionizing radiation only when they are turned on. In ordinary work with necessary safety precautions, there are insignificant impact of using sources of ionizing radiation on environment. The immediate effect of ionizing radiation is ionization of air in room, but after a specified time the ionization disappears.

The danger of using radioactive materials could occur only in accidents with stealing and loosing these materials due to high toxicity.

6.5.2 Analysis of the environmental impact of the research process

Process of investigation itself in the thesis do not have essential effect on environment. One of hazardous waste is fluorescent lamps. Mercury in fluorescent lamps is a hazardous substance and its improper disposal greatly poisons the environment.

Outdated devices go to an enterprise that has the right to process wastes. It is possible to isolate precious metals with a purity in the range of 99.95–99.99% from computer components. A closed production cycle consists of the following stages: primary sorting of equipment; the allocation of precious, ferrous and non-ferrous metals and other materials; melting; refining and processing of metals. Thus, there is an effective disposal of computer devices.

6.5.3 Justification of environmental protection measures

Pollution reduction is possible due to the improvement of devices that produces electricity, the use of more economical and efficient technologies, the use of new methods for generating electricity and the introduction of modern methods and methods

for cleaning and neutralizing industrial waste. In addition, this problem should be solved by efficient and economical use of electricity by consumers themselves. This is the use of more economical devices, as well as efficient regimes of these devices. This also includes compliance with production discipline in the framework of the proper use of electricity [51]. Simple conclusion is that it is necessary to strive to reduce energy consumption, to develop and implement systems with low energy consumption. In modern computers, modes with reduced power consumption during long-term idle are widely used.

6.6 Safety in emergency

6.6.1 Analysis of probable emergencies that may occur at the workplace during research.

The fire is the most probable emergency in our life. Possible causes of fire:

- malfunction of current-carrying parts of installations;
- work with open electrical equipment;
- short circuits in the power supply;
- non-compliance with fire safety regulations;
- presence of combustible components: documents, doors, tables, cable insulation,

Activities on fire prevention are divided into: organizational, technical, operational and regime.

6.6.2 Substantiation of measures for the prevention of emergencies and the development of procedures in case of emergencies

Organizational measures provide for correct operation of equipment, proper maintenance of buildings and territories, fire instruction for workers and employees, training of production personnel for fire safety rules, issuing instructions, posters, and the existence of an evacuation plan.

The technical measures include compliance with fire regulations, norms for the design of buildings, the installation of electrical wires and equipment, heating, ventilation, lighting, the correct placement of equipment. The regime measures include the establishment of rules for the organization of work, and compliance with fire-fighting measures. To prevent fire from short circuits, overloads, etc., the following fire safety rules must be observed:

- elimination of the formation of a flammable environment (sealing equipment, control of the air, working and emergency ventilation);
- use in the construction and decoration of buildings of non-combustible or difficultly combustible materials;
- the correct operation of the equipment (proper inclusion of equipment in the electrical supply network, monitoring of heating equipment);
- correct maintenance of buildings and territories (exclusion of the source of ignition
- prevention of spontaneous combustion of substances, restriction of fireworks);
- training of production personnel in fire safety rules;
- the publication of instructions, posters, the existence of an evacuation plan;
- compliance with fire regulations, norms in the design of buildings, in the organization of electrical wires and equipment, heating, ventilation, lighting;
- the correct placement of equipment;
- Well-time preventive inspection, repair and testing of equipment.

In the case of an emergency, it is necessary to:

- inform the management (duty officer);
- call the Emergency Service or the Ministry of Emergency Situations - tel. 112;
- Take measures to eliminate the accident in accordance with the instructions.

CONCLUSION

The aim of the this research was to evaluate the MLC parameters reproducibility of IMRT and VMAT plans, so according to the results that obtained, analyzed and discussed on the chapter 4, proved that research was succeed 99%, because the results answered the goal or objective of the research. The results proved that the MLC parameters reproducibility of IMRT and VMAT plans would affect the dose delivered to the patient. If so the measures must be taken to avoid the damage of the OARs and to maximize the tumor dose. The effect of reproducibility would be large when the segment width of the MLC increased.

Results were evaluated in 2D and 3D-dose analysis through EPID panel based on the PerFRACTION software, through that the 3D-dose analysis showed good results than 2D-dose analysis, due to that 3D-dose analysis is better method for treatment than 2D dose analysis when IMRT and VMAT were used, this is because had small reproducibility effect than 2D-dose analysis. The most conclusive results were obtained using the EPID device in which statistically significant correlation was identified in some segment widths. The large effect of the reproducibility in this research was observed on the thorax than in lung and prostate.

The results from EPID analyzed through the gamma index analysis and DVHs analysis, but through these analysis, observed that the gamma index analysis lacks specificity because it didn't indicate the amount of volume where was covered by dose delivered. The research indicated that there was no directly relationship between the MLC parameters and electronic portal imaging device. EPID used to captures, to store and convert images into Portal images dose, although this occurred done by 100% but the experiment showed that EPID images associated with many artifacts.

Despite the few MLC parameters used, it can be concluded that the more complex the beam is, the greater the possibility that the delivered dose differs from the desired

one. However, this information is not yet sufficient to identify plans to be rejected in pre-treatment QA tests. For any case where the reproducibility affect would be large for example in 2D-dose analysis, in order assure the more conformal dose we need to redo again the planning and if after repetition you will get the same results we need to change criteria or the system used is more complex

REFERENCE

1. World Health Organization. Cancer, (2015, 2016).at http://www.who.int/mediacentre/factsheets/fs297/en/.
2. International Agency for Research on Cancer, GLOBOCAN 2018 accessed via Global Cancer Observatory(link is external). Accessed September 2018.
3. International Atomic Energy Agency. Investigation of an Accidental Exposure of Radiotherapy Patients in Panama: Technical Report of a Team of Experts.
4. Gantchew .M, "Radiotherapy Risk Profile," Rentgenologiya i Radiologiya, vol. 49, no. 4. World Cancer Report Press, pp. 14–21, 2010.
5. Ash .D, Lessons from Epinal. Clinical oncology (Royal College of Radiologists (Great Britain)), 19(8):614–5, oct 2007.
6. Lang, S. et al. Pretreatment quality assurance of flattening filter free beams on 224 patients for intensity modulated plans: A multicentric study. Medical Physics 39, 1351–1356 (2012).
7. Podesta, M. et al. Time dependent pre-treatment EPID dosimetry for standard and FFF VMAT. Physics in Medicine and Biology 59, 4749–4768 (2014).
8. Woodruff, H. C., Fuangrod, T., Rowshanfarzad, P., McCurdy, B. M. C. & Greer, P. B. Gantry-angle resolved VMAT pretreatment verification using EPID image prediction. Medical Physics 40, 081715 (2013).
9. Vazquez Quino, L. A. et al. Patient specific pre-treatment QA verification using an EPID approach. Technology in Cancer Research & Treatment 13, 1–10 (2014).
10. Van Elmpt, W. et al. A literature review of electronic portal imaging for Radiotherapy dosimetry. Radiotherapy and Oncology 88, 289–309 (2008).
11. Van Elmpt, W. 3D dose verification for advanced radiotherapy. PhD Thesis, Maastricht University (2009).
12. Nijsten, S. Portal dosimetry in radiotherapy. PhD Thesis, Maastricht University (2009).

13. Podgorsak E.B and Kristofer K. Radiation Oncology Physics: A Handbook for Teachers and Students. Medical Physics, 33(6):1920, 2006.

14. Maria Jo˜ao Dias Cardoso. Estudo dosim´etrico para implementa¸c˜ao da t´ecnica radioterapˆeutica Volumetric Modulated Arc Therapy (VMAT), 2011.

15. Xia P, Ting JY, Orton CG. Segmental MLC is superior to dynamic MLC for IMRT delivery. Med Phys. 2007;34: 2673.

16. Persoon, L. C. G. G., Podesta, M. et al. Is integrated transit planar portal dosimetry able to detect geometric changes in lung cancer patients treated with volumetric modulated arc therapy? Acta Oncologica 54, 1501–1507 (2015).

17. Deluca P. M. ICRU Report 83, Prescribing, Recording and Reporting PhotonBeam Intesity-Modulated Radiation Therapy (IMRT), volume 10. Journal of the ICRU, 2010.

18. Otto, K. Volumetric modulated arc therapy: IMRT in a single gantry arc. Medical Physics 35, 310–317 (2008). Teoh, M., Clark, C. H., Wood, K., Whitaker, S. & Nisbet, A. Volumetric modulated arc therapy: a review of current literature and clinical use in practice. The British Journal of Radiology 84, 967– 996 (2011).

19. AAPM Report No 85; Task Group No. 85; Tissue inhomogeneity corrections for megavoltage photon beams.

20. Podgorsak.E: Review of Radiation Oncology Physics: A Handbook for Teachers and Students. International Atomic Energy Agency, Vienna, AT, 2005.

21. International Commission on Radiation Units and Measurements (ICRU), Prescribing, Recording, and Reporting Photon-Beam, Report 50, (199).

22. Maria.L and Brent L. DICOM-RT and Its Utilization in Radiation Therapy1. Radiographics, 29(3):655–667, 2009.

23. IAEA. IAEA Technical Reports Series No. 430: Commissioning and Quality Assurance Of Computerized Planning Systems For Radiation Treatment Of Cancer. Technical report, 2006.

24. Louwe R .J. W, McDermott L. N, Sonke J.J, Tielenburg .R, Wendling M, Van H. M.B, and Mijnheer B.J. The long-term stability of amorphous silicon flat panel imaging devices for dosimetry purposes. Medical physics, 31(11):2989– 2995, 2004.

25. Markus W, Robert J W Louwe R.J.W, McDermott L N, Sonke J.J, Van H.M. B, and Mijnheer B.J. Accurate two-dimensional IMRT verification using a back-projection EPID dosimetry method. Medical physics, 33:259–273, 2006.

26. McDermott L.N, Louwe R.J.W, Sonke J.J, van Herk M.B, and Mijnheer B.J. Dose-response and ghosting effects of an amorphous silicon electronic portal imaging device. Medical physics, 31(2):285–295, 2004.

27. Wahlin E. Dosimetric pre-treatment verification with an electronic portal imaging device. PhD thesis, 2006.

28. Antonuk L.E, Yorkston J, Huang W, Sandler H, Jeffrey H. S, and Mohri Y. E. Megavoltage imaging with a large-area, flat panel, amorphous silicon imager. International Journal of Radiation Oncology Biology Physics, 36(3):661–672, 1996.

29. ELEKTA. Corrective Maintenance Manual - IviewGT, 2006.

30. Nijsten, S. et al. A global calibration model for a-Si EPIDs used for transit dosimetry. Medical Physics 34, 3872–3884 (2007).

31. Mans .A, Wendling M, McDermott L.N, Sonke J. J, Tielenburg R, Vijlbrief R, Mijnheer B, Van Herk M, and Stroom C. J, Catching errors with in vivo EPID dosimetry. Medical physics, 37:2638–2644, 2010.

32. Low .D.A and Dempsey J.F. Evaluation of the gamma dose distribution comparison method. Medical physics, 30(9):2455–2464, 2003.

33. Low .D.A, Harms. W.B, Mutic S, and Purdy. J.A. A technique for the quantitative evaluation of dose distributions. Medical physics, 25(5):656–661, 1998.

34. International Commission on Radiation Units and Measurements (ICRU), Prescribing, Recording, and Reporting Photon-Beam Intensity-Modulated Radiation Therapy (IMRT), Report 83, 2010.

35. Kasper L Pasma, Maarten L P Dirkx, Marco Kroonwijk, Andres G Visser and Ben J M Heijmen, Dosimetric verification of intensity modulated beams produced with dynamic multileaf collimation using an electronic portal imaging device, Medical Physics 26(11):2371–2378, 1999.

36. Low, D. A., Harms, W. B., Mutic, S. & Purdy, J. A. A technique for the quantitative evaluation of dose distributions. Medical Physics 25, 656–661 (1998).

37. Podesta, M., Persoon, L. C. G. G. & Verhaegen, F. A novel time dependent gamma evaluation function for dynamic 2D and 3D dose distributions. Physics in Medicine and Biology 59, 5973–5985 (2014).

38. Olch A, Zhuang A. Sensitivity study of an automated system to acquire and analyze EPID exit dose image. 57th AAPM Annual Meeting & Exhibition, Anaheim, CA, July. Med Phys. 2015; 42:3193.

39. Mijnheer BJ, Gonzalez P, Olaciregui-Ruiz I, Rozendaal RA, van Herk M, Mans A. Overview of 3-year experience with large-scale electronic portal imaging device-based 3-dimensional transit dosimetry. Pract Rad Oncol. 2015; 5:e679–e687

40. LoSasso, Chui, Ling. Physical and dosimetric aspects of a multileaf collimation system used in the dynamic mode for implementing intensity modulated radiotherapy. Medical physics. 1998; 1919–27.

41. Vial, Oliver, Greer, Baldock. An experimental investigation into the radiation field offset of a dynamic multileaf collimator. Physics in medicine and biology. 2006; 5517–38.

42. Wasbø, Valen. Dosimetric discrepancies caused by differing MLC parameters for dynamic IMRT. Physics in medicine and biology. 2008; 405–15.

43. Vieira, Dirkx, Pasma, Heijmen. Fast and accurate leaf verification for dynamic multileaf collimation using an electronic portal imaging device. Medical physics. 2002; 2034–40.

44. Yu C, "Intensity-modulated arc therapy with dynamic multileaf collimation: An alternative to tomotherapy," Physics in Medicine and Biology 40, 1435-1449 (1995).

45. Palma D.A, W.F. Verbakel, K. Otto, S. Senan, "New developments in arc radiation therapy: a review," Cancer treatment reviews 36, 393-399 (2010).

46. Xia P, Verhey L .J, "Multileaf collimator leaf sequencing algorithm for intensity modulated beams with multiple static segments," Med Phys 25, 1424-1434 (1998).

47. Federal Law "On the Fundamentals of Labor Protection in the Russian Federation" of 17.07.99 № 181 – FZ.

48. San PiN 2.2.2 / 2.4.1340-03. Sanitary-epidemiological rules and standards "Hygienic requirements for PC and work organization".

49. GOST 12.1.038-82 Occupational safety standards system. Electrical safety.

50. Fire and explosion safety of industrial facilities. GOST R12.1.004-85 Occupational safety standards system. Fire safety

APPENDIX I: Results for 2D-Dos analysis

Table 3.0−Lung, Prostate and Thorax plans results in 2D- Dose analysis

Localization. Beam Energy	SW (cm)	Beam Name	G.A (deg)	Col.A (deg)	C.A. (deg)	N_0 MU	Plan. Dose (Gy)	Meas. Dose (Gy)	Rel. Dose Diff (%)	Abs. Dose Diff (cGy)
Lung 6MV IMRT	0.5	05 x 11	208.6	0	0	145.9	0.471	0.468	-0.6	-0.3
		05 x12	265.7	0	0	129.3	0.616	0.626	1.6	1
		05 x13	318.6	0	0	120.1	0.397	0.390	-1.7	-0.7
		05 x14	0	0	0	151.8	0.300	0.300	1.6	0.5
		05 x 15	142.7	0	0	120.1	0.053	0.055	3.7	0.2
	1	10 x 11	208.6	0	0	127.5	0.476	0.524	10	4.8
		10 x 12	265.7	0	0	102.7	0.606	0.611	0.8	0.5
		10 x13	318.6	0	0	126.1	0.485	0.501	3.5	1.7
		10 x 14	0	0	0	64.4	0.237	0.233	-1.6	-0.4
		10 x15	142.7	0	0	121.4	0.065	0.068	6.2	0.4
	1.5	15 x 11	208.6	0	0	96.9	0.469	0.481	2.5	1.2
		15 x 12	265.7	0	0	95.3	0.538	0.548	1.8	1
		15 x 13	318.6	0	0	113.9	0.429	0.428	-0.2	-0.1
		15 x 14	0	0	0	70.1	0.283	0.272	-3.8	-1.1
		15 x 15	142.7	0	0	96.1	0.107	0.119	11.2	1.2
	2	20 x 11	208.6	0	0	95.9	0.467	0.497	6.4	3.0
		20 x 12	265.7	0	0	86.3	0.503	0.508	0.9	0.5
		20 x 13	318	0	0	125.5	0.465	0.461	-0.8	-0.4
		20 x 14	0	0	0	68	0.307	0.303	-1.3	-0.4
		20 x15	142.7	0	0	79	0.09	0.085	-5.5	-0.5
Prostate 10MV IMRT VMAT	0.5	1a005	180	0	0	333.5	1.114	1.109	0.4	0.5
		2a005	5	0	0	415	0.957	0.951	-0.6	-0.6
	1	1B010	180	0	0	301	0.961	0.950	1.1	1.1
		2B010	5	0	0	378.9	1.105	1.094	-1	-1.1
	1.5	1C015	180	0	0	267.6	0.925	0.934	0.9	0.9
		2C015	5	0	0	375.5	1.172	1.152	-1.6	-1.9
	2	1D020	180	0	0	270	1.007	0.976	-3.0	-3.1
		2D020	5	0	0	298.6	1.084	1.055	-2.6	-2.9
Thorax 6MV VMAT	0.5	SWA05	200	345	345	186	0.979	0.980	0.1	0.1
		SWB05	65	345	345	199.2	1.150	1.175	2.1	2.5
	1	SWA10	200	345	345	158.9	1.019	1.066	4.6	4.7
		SWA10	65	345	345	173	1.144	1.139	-0.4	-0.5
	1.5	SWA15	200	345	345	158.9	1.019	1.030	1.0	1.1
		SWA15	65	345	345	173	1.144	1.135	-0.7	-0.9
	2	SWA20	200	345	345	203.9	0.951	1.058	11.2	10.7
		SWA20	65	345	345	220.9	1.215	1.303	7.2	8.8

Structure, Beam Energy Modality	SW (cm)	Beam Name	Passed		Failed		Total Points
			Points	%	Points	(%)	
Lung 6MV IMRT	0.5	05 x11	41750	67.79	19834	32.21	61584
		05 x12	34590	60.95	22158	39.05	56748
		05 x13	47765	67.12	23402	32.88	71167
		05 x 14	2182	38.01	44337	61.99	71519
		05 x 15	47937	79.51	12364	20.49	57610
	1	10 x 11	35827	57.85	26098	42.14	61926
		10 x 12	34635	60.12	22975	39.88	57610
		10 x13	52571	71.79	20658	28.21	73229
		10 x 14	30781	43.01	40749	56.94	71568
		10 x15	48596	73.21	17782	26.79	66378
	1.5	15 x 11	42997	67.26	20927	32.74	63924
		15 x 12	32586	57.41	24175	42.59	56761
		15 x 13	51730	69.11	23126	30.89	74856
		15 x 14	36335	49.65	36847	50.35	73182
		15 x 15	48022	67.58	23038	32.42	71060
	2	20 x 11	29652	48.7	31233	51.30	31233
		20 x 12	27523	48.49	29237	51.51	56760
		20 x 13	47408	64.5	26096	35.5	73504
		20 x 14	32932	45	40251	55	73183
		20 x15	51405	74.36	17725	25.64	69130
Prostate 10MV IMRT/VMAT	0.5	1a005	4182	87.76	5833	12.24	47654
		2a005	47394	86.71	7264	13.29	54658
	1	1B010	47328	90.30	5086	9.7	52414
		2B010	8063	14.55	47336	85.45	55399
	1.5	1C015	47552	90.32	5096	9.68	52648
		2C015	43986	76.99	13148	23.01	57134
	2	1D020	43286	83.71	8422	16.28	51708
		2D020	41750	72.32	15979	27.68	57729
Thorax 6MV VMAT	0.5	SWA05	2374	14.17	14378	85.83	16752
		SWB05	13591	94.73	756	5.27	14347
	1	SWA10	12381	78.49	3392	21.27	15773
		SWB10	13642	86.79	2077	13.21	15719
	1.5	SWA15	12430	78.85	3335	21.15	15765
		SWB15	13439	85.48	2282	14.52	15721
	2	SWA20	11946	76.51	3667	23.49	15613
		SWB20	12863	90.38	1369	9.62	14232

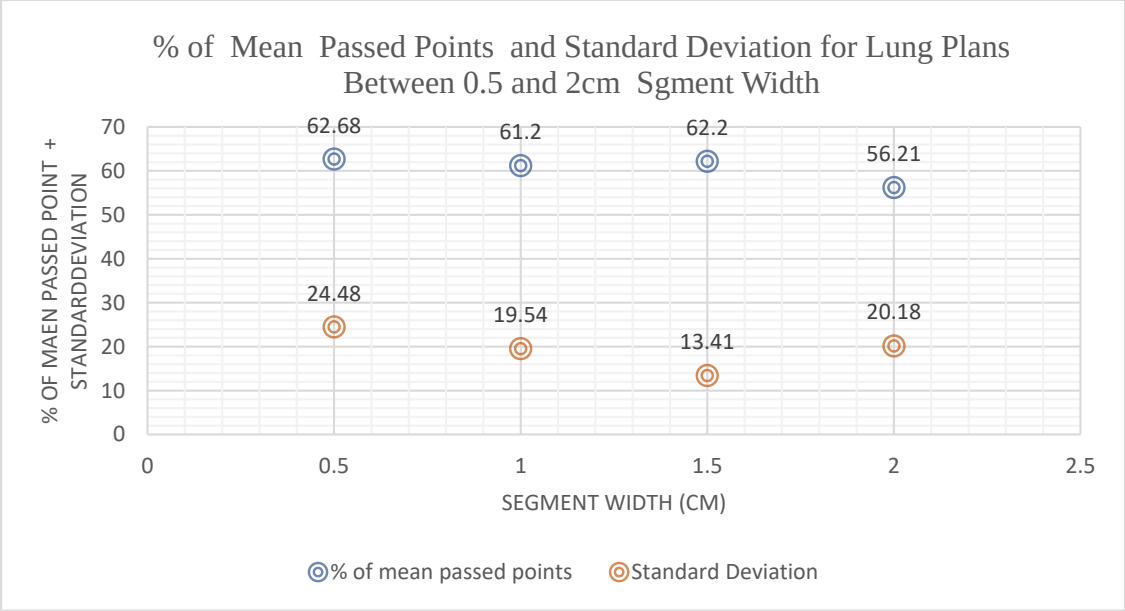

Fig 3.4. Points passed and standardization for lung plans in 2D-Dose analysis

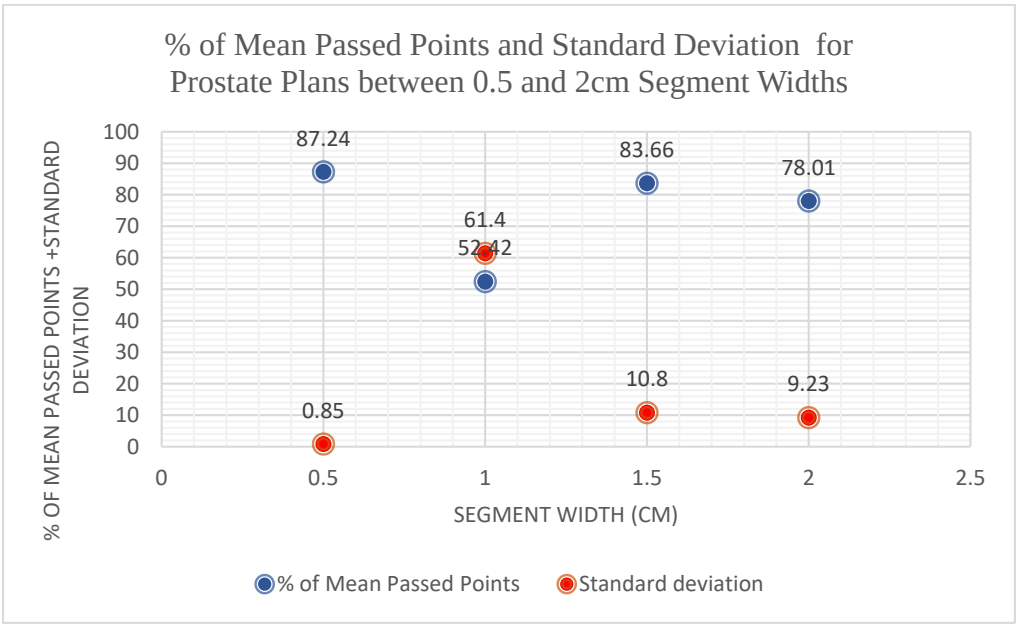

Fig 3.5. Points passed and standardization for Prostate plans in 2D-Dose analysis

APPENDXI II: Results of 3D-dose analysis

Table 3.4−Passed and failed points in 3D-Dose analysis

N_0	Structure, Beam Energy Modality	SW .cm	Passed Points		Failed Points		Total Points
			Points	(%)	Points	(%)	
1	Lung 6MV IMRT	0.5	154962	99.39	947	0.61	155909
		1	141934	90.33	15197	9.87	157181
		1.5	152051	98.06	3003	1.94	155054
		2	144729	93.83	9512	6.17	154241
2	Prostate 10MV IMRT/VMAT	0.5	23498	88.42	3076	11.58	26574
		1	24793	93.29	1782	6.7	26575
		1.5	25065	94.36	1499	5.65	26564
		2	12844	96.42	477	3.58	13321
3	Thorax 6MV VMAT	0.5	174586	92.45	14265	7.55	188851
		1	162870	85.5	27612	14.49	190482
		1.5	160591	84.47	29533	15.53	190124
		2	39818	68.13	18624	31.87	58442

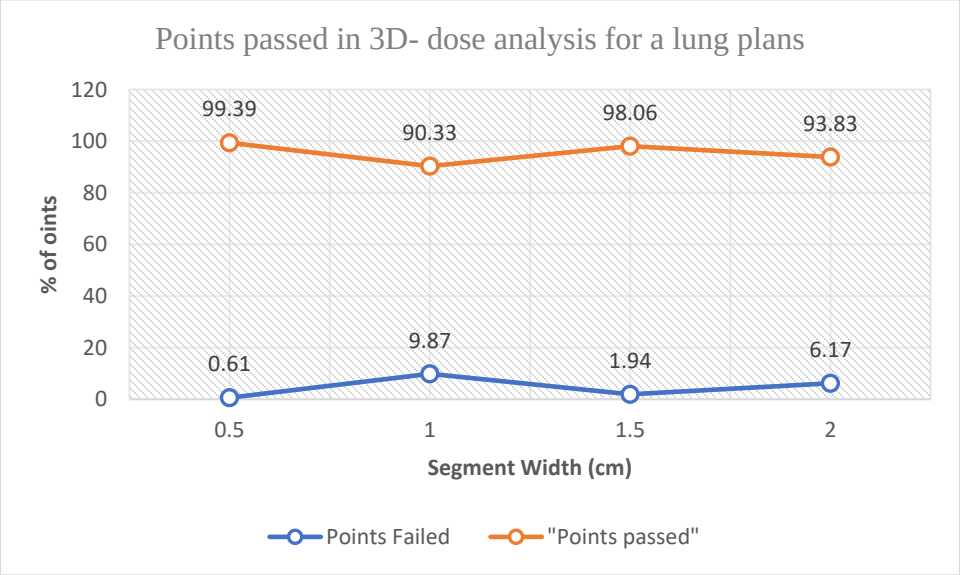

Fig 3.5. % of Passed and Failed points for Lung plans in 3D-Dose analysis

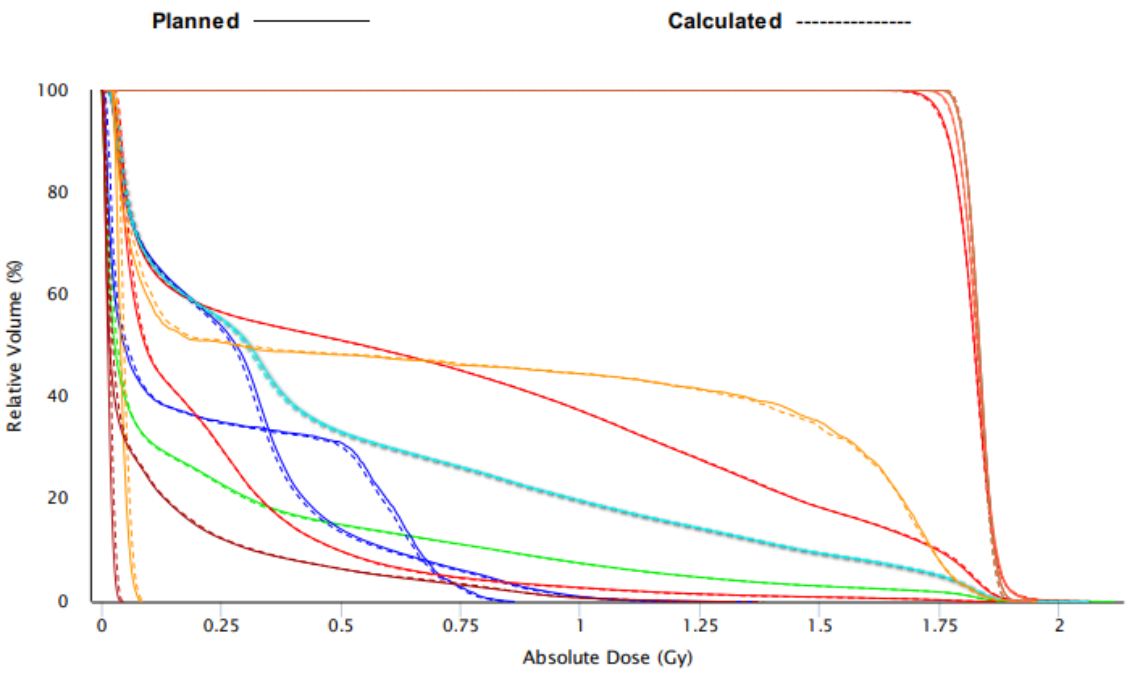

Fig 3.6. Dose Volume Histogram for Lung Plans of 0.5 cm segment width

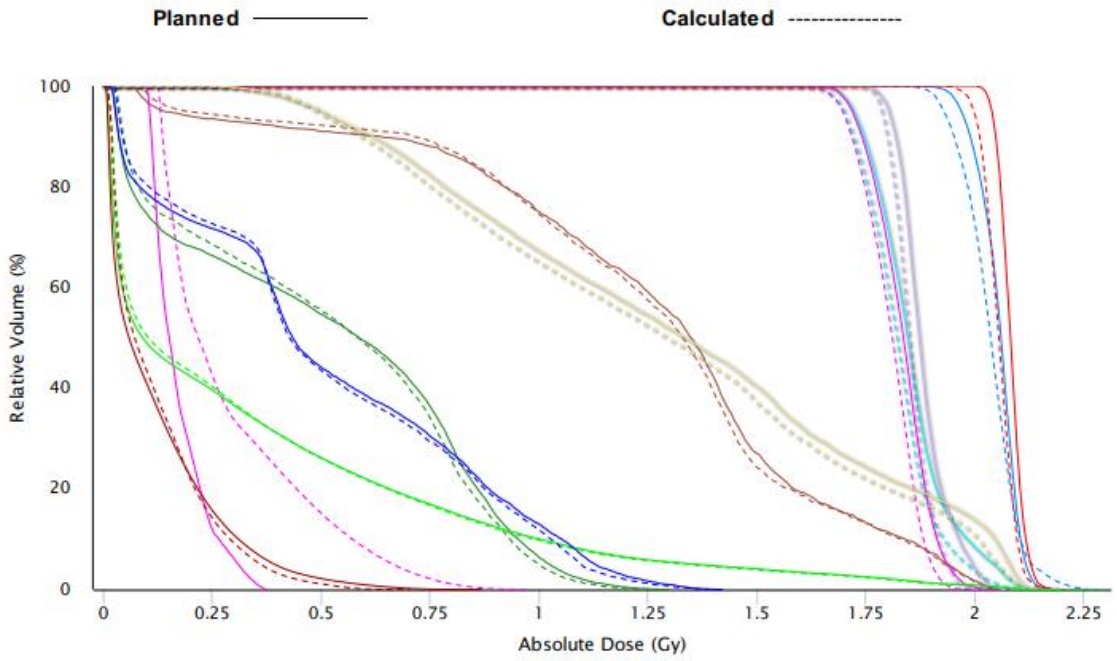

Fig 3.7. Dose Volume Histogram for Prostate Plans of 0.5 cm segment width

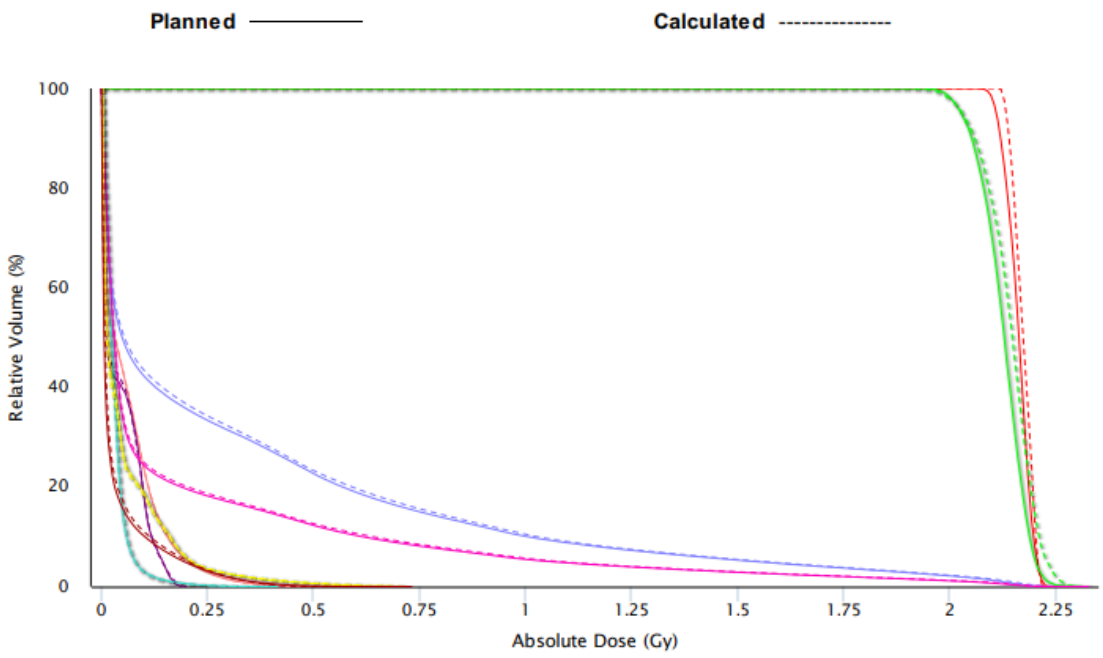

Fig 3.8. Dose Volume Histogram for Thorax Plans of 0.5 cm segment width

APPENDIXIII: Recalculating Results

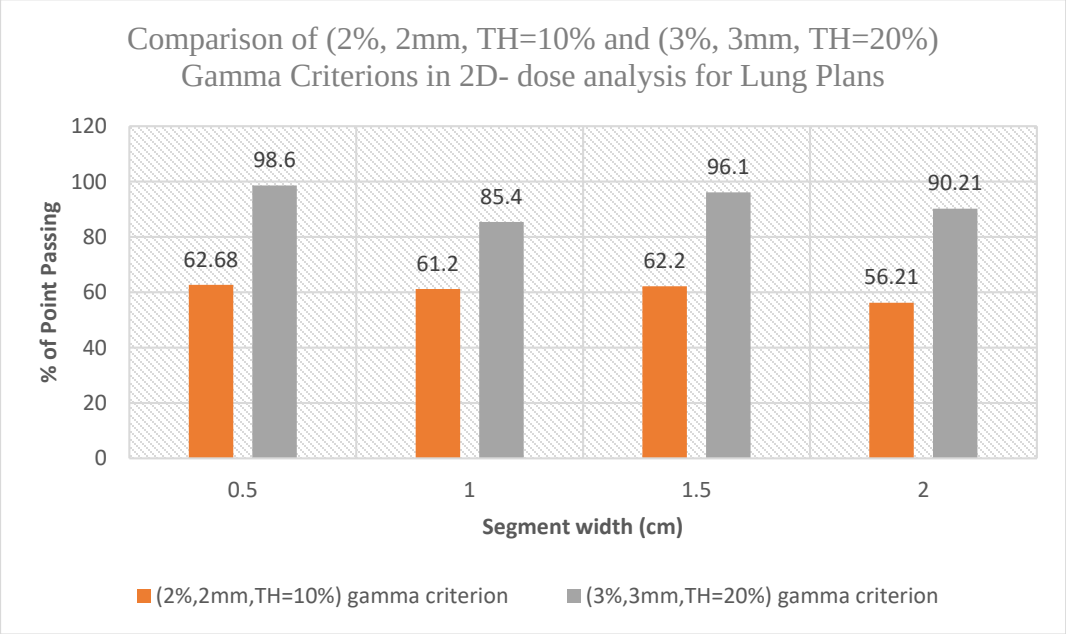

Fig 3.6 comparison of (2%, 2mm, TH=10%) and (3%, 3mm, TH=20%) gamma criterion in 2D-dose analysis for lung plans

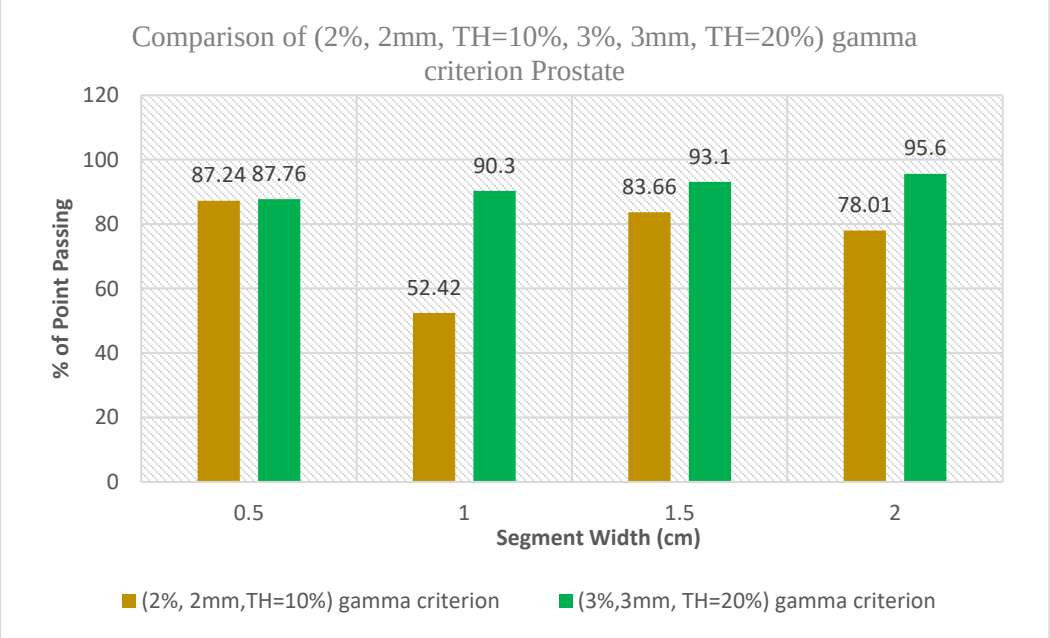

Fig 3.7 comparison of (2%, 2mm, TH=10%) and (3%, 3mm, TH=20%) gamma criterion in 2D-dose analysis for Prostate plans

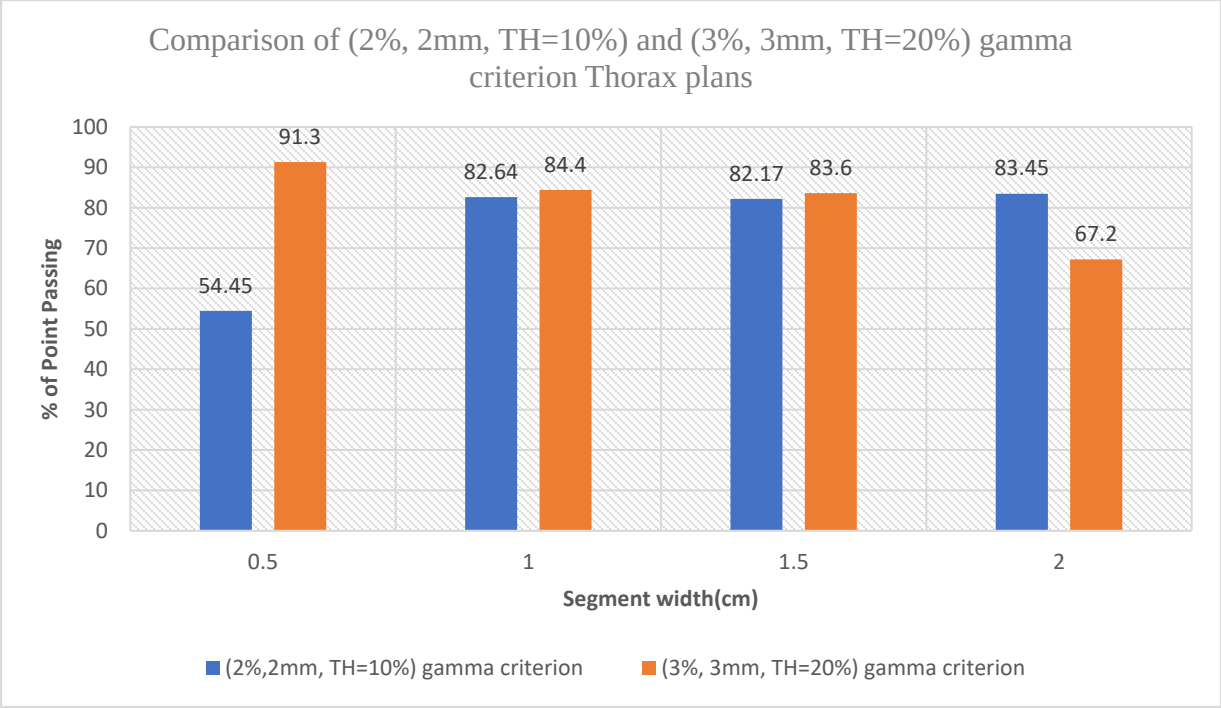

Fig 3.8 comparison of (2%, 2mm, TH=10%) and (3%, 3mm, TH=20%) gamma criterion in 2D-dose analysis for Thorax plans