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
Влияние ширины сегмента интенсивно-модулированных планов облучения в рамках процедур Гарантии Качества

УДК 539.1.074: 615.849

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Томск – 2021 г.

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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
Influence of segment width of intensity modulated radiotherapy plan based on quality assurance (QA) plans

UDC 539.1.074: 615.849
Student

Group	Full name	Signature	Date
OAM9M	Nangoma Hampuwo		

Scientific supervisor

Position	Full name	Academic degree, academic rank	Signature	Date
Associate professor	Sukhikh Evgeniya Sergeevna	PhD		

ADVISERS:

Section “Financial Management, Resource Efficiency and Resource Saving”

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

Section “Social Responsibility”

Position	Full name	Academic degree, academic rank	Signature	Date
Associate Professor	Verigin Dan Alexandrovich	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

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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	Nangoma Hampuwo

Topic of research work:

Influence of segment width of intensity modulated radiotherapy plan based on quality assurance (QA) 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 date 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.)*	IMRT and VMAT plans of radiation therapy, Monaco treatment planning system, dosimetric verification with ArcCHECK-SNC and 3DVH software package, delivery of treatment with Elekta synergy linac, determining optimum segment width for lung cancer, thorax cancer and prostate cancer at Tomsk Regional Oncology Center. Application area: Radiation treatment planning

List of the issues to be investigated, designed and developed *(analytical review of literary sources with the purpose to study global scientific and technological achievements in the target field, formulation of the research purpose, design, construction, determination of the procedure for research, design, and construction, discussion of the research work results, formulation of additional sections to be developed; conclusions).*	-Reviewing literature sources on the subject of study -Formulating objectives and goals, -Creating and verifying dosimetric plans. -Analysis of results -Financial management, resource efficiency and resource saving -Social responsibility -Conclusion

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

Section	Advisor
One: Literature Review	Associate Professor Sukhikh Evgeniya Sergeevna
Two: Materials and Methods	Associate Professor Sukhikh Evgeniya Sergeevna
Three: Results and Discussion	Associate Professor Sukhikh Evgeniya Sergeevna
Four: Financial management, Resource efficiency and conservation	Associate Professor Spicyna Luibov Yurievna
Five: Social Responsibilities	Associate Professor Verigin Dan Alexandrovich

Date of issuance of the assignment for Master Thesis completion according to the schedule	05.06.2021

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

Position	Full name	Academic degree, academic status	Signature	Date
Associate Professor	Sukhikh Evgeniya Sergeevna	PhD		
Medical physicist	Vertinsky Andrew	PhD Student		

Assignment accepted for execution by a student:

Group	Full name	Signature	Date
0AM9M	Nangoma Hampuwo		

TOMSK POLYTECHNIC UNIVERSITY ТОМСКИЙ ПОЛИТЕХНИЧЕСКИЙ УНИВЕРСИТЕТ

Министерство науки и высшего образования Российской Федерации
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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	Development of technical specifications and selection of research area	
18.02.2021	Selection and study of scientific literature	...
9.04.2020	Performing measurements	
15.04.2021	Analysis of the obtained experimental data	
27.04.2021	Compilation of results and report submission	
10.05.2021	Defense preparation	

COMPILED BY:
Scientific supervisor:

Position	**Full name**	**Academic degree, academic status**	**Signature**	**Date**
Associate professor	Sukhikh Evgeniya Sergeevna	PhD		

APPROVED BY:

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

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

Student:

Group	Name
0AM9M	Nangoma Hampuwo

School	School of Nuclear Science & Engineering	**Department**	Division for Nuclear-Fuel Cycle
Educational level	Master	**Specialization**	14.04.02 Nuclear Science and Technology

Initial data for the section "Financial Management, Resource Efficiency and Resource Saving":	
1. *The cost of scientific research resources: material, technical, energy, financial, informational and human*	*-Planned budget -**306661.63** rubles* *-basic salary -**154125.1** rubles*
2. *Norms and standards for spending resources*	*-Supervisor' salary –35120 rubles per month* *-Master's student' salary –17310 rubles per month.* *-Electricity cost 5.8 rubles per 1kW*
3. *The system of taxation used, tax rates, volumes of payments, discounts and loans*	*-coefficient of incentives-**10%*** *-Labor tax-**27%*** *-Overhead -**50%***
Problems to research, calculate and describe:	
1. *Assessment of the commercial potential of engineering solutions*	*Competitiveness analysis of technical solutions*
2. *Planning of research and constructing process and making schedule for all periods of the project*	*calendar plan of the project and hierarchical structure of work*
3. *Requirement for investments*	*Costs calculations*
4. *Budgeting an engineering project*	*Creation of the project budget*
5. *Calculation of resource, financial, social, budgetary efficiency of an engineering project and potential risks*	*-Competitiveness analysis of technical solutions. -SWOT analysis -Calendar schedule of master's thesis -integral indicator of resource efficiency for the developed project -A Gantt chart.*
Graphic materials	
1. *«Portrait» of the consumer* 2. *Competitive power of the project* 3. *SWOT matrix* 4. *Assessment of the prospects of a new product* 5. *Plan of investments. The budget for scientific and technical research* 6. *Project Efficiency indicators* 7. *Project risks*	

Assignment date	

Consultant:

Position	Name	Academic degree	Signature	Date
Associate Professor Division for Social Sciences and Humanities School of Core Engineering Education	Spicyna Luibov Yurievna	PhD		

Student:

Group	Name	Signature	Date
OAM9M	Nangoma Hampuwo		

Task for section
«Social responsibility»

To student:

group	Full name
0AM9M	Nangoma Hampuwo

School	Nuclear Science and Engineering	Department	Nuclear fuel cycle
Degree	Master degree program	Specialization	Nuclear medicine

Topic of research work:

Investigation of the influence of minimum segment width of intensity modulated radiotherapy (IMRT) plan based on quality assurance (QA).	
Initial data for section «Social Responsibility»:	
1. Information about object of investigation (matter, material, device, algorithm, procedure, workplace) and area of its application	Intensity modulated radiotherapy and volumetric modulated arc therapy plans. Application area: Radiation treatment planning
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 Dan Alexandrovich	PhD		

The task was accepted by the student:

Group	Full name	Signature	date
0AM9M	Nangoma Hampuwo		

Abstract

The master's dissertation consists of (100) pages; figures 16; tables 44; references 54.

Keywords: optimization of dose distribution, segment width, intensity modulated radiotherapy, volumetric modulated arc therapy, thorax cancer, prostate cancer, lung cancer.

The objective of this study is to optimize dose distribution and to determine universal minimum segment width for IMRT and VMAT plans based on 3D dosimetric phantom for thorax cancer, prostate cancer and lung cancer treatment.

The dissertation presents results obtained from investigating influence of segment width of intensity modulated radiotherapy and volumetric modulated arc therapy plans based on quality assurance plans. The study was conducted at Tomsk oncology region clinic, Russia. Plans were designed using Monaco v.5.11.03 treatment planning system (TPS) by incorporating penalties of minimum segment width of 0.5cm, 1.0cm, 1.5cm and 2.0 cm for thorax localization, lung localization and prostate localization. photon beams of 6MV and 10MV were delivered using Elekta synergy linear accelerator. For dosimetric verification a cylindrical phantom ArcCHECK (Sun nuclear corp.) together with SNC -software package patient for 2D analysis and 3DVH-software package for 3D analysis were used. The results indicated optimum segment width for lung cancer to be 0.5cm and 1.5cm, while thorax and prostate at 1.0cm and 1.5cm were optimum and can be considered for clinical practice.

Application areas: radiation treatment planning.

List of Acronyms and Abbreviations

3D-CRT-Three-dimension conformal radiotherapy

CT- Computed tomography

CTV-Clinical target volume

DVH- Dose Volume Histogram

GPR- Gamma pass rate

IAEA -International Atomic Energy Agency

IMRT- Intensity modulated radiotherapy

LINAC- Linear accelerator

MLC-Multi-leaf collimators

MSWs- minimum segment widths

MU-Monitor unit

OAR- Organs at risk

PDP-Planned dose perturbation

PTV-Planning target volume

QA -Quality assurance

ROI -Region of interest

TPS-Treatment planning system

VMAT-Volumetric modulated arc therapy

Table of content

Introduction

Cancer is a major global health problem that affects people all over the world regardless of their age, gender or social class and has been established as major leading cause of death. According[1] lung cancer, thorax cancer and prostate cancer are among the common oncological diseases in Russia giving the country a high mortality rate of 26%, among Russian men for instance the cancer mortality is at 212 per 100,000 population when compared to other European countries. Thorax cancer occurs in the chest cavity while lung cancer begins in the lung tissues and prostate cancer is concentrated in the prostate gland. The treatment of cancer largely depends on three modalities that is surgery, radiotherapy and chemotherapy. These modalities can be used as a combination or separately. Currently radiotherapy emerges as one of major and widely used modality, however its success depends on accurately delivering a radiation beam to the area of interest. In radiotherapy the goal is to deliver a high precise amount of radiation dose to the tumor while sparing surrounding vital organs. The need to continuously achieve this goal has led to development of more advanced and complex treatment techniques which make use of multi-leaf collimator. Among complex technique is Intensity modulated radiation therapy (IMRT) and volumetric modulated arc therapy, they are widely used as the conform more precisely dose to the target and spare much more better organs at risk compared to conventional. IMRT/VMAT uses small segment to generate very complex dose distribution that shapes the tumor, hence require high multi-leaf accuracy positioning to reduce dose delivery errors with minimum segment width the minimum separating distance between opposing leaves can be obtained. The plans must be optimized and verified to insure patient specific quality assurance, verification can done by applying the treatment plan to a dosimetric phantom and compare measured dose to calculated dose, this process allows to detect any existing mismatches between planned and delivered doses [2]. By verify the quality complex plan as IMRT/VMAT we can be confident that the patient will receive the prescribed treatment correctly.

Statement of the problem

One important aspect in radiation therapy is the accuracy of radiation dose being administered to the patient, in this case radiation therapy is faced some challenges that must be overcome for a successful treatment. One of the challenges is assuring quality dose delivery of the plan, providing dose consistence between planned dose and measured doses. IMRT/VMAT uses small segments to create complex dose distribution that will shape the tumor and require high multi-leaf collimator position accuracy to reduce dose delivery errors, MLC inaccuracies can have a direct impact on the dose distribution.

One parameter that is used to determine the minimum leaf separation between opposing leaves is segment width. By changing parameters such as minimum segment width (MSWs) we simply change the complexity of the plan and the linear accelerator (LINAC) may not be able to deliver dose to the patient as it was calculated in the treatment planning system (TPS) therefore there must be correlation between the measured dose and TPS calculated dose. IMRT and VMAT QA, requires good reproducibility of the measured dose. There are some Published studies that investigated the reproducibility of individual measurements for instance Mancuso GM[3] investigated the reproducibility of the ion chamber, film and 2D diode array measurements in patient specific IMRT QA the work was based on the structure set geometry and not actual clinical plans. Fraser too [4] investigated the reproducibility of various ion chambers for IMRT QA and McKenzie[5] investigated the reproducibility of IMRT QA across a wide array device. However, no known study that has explored IMRT and VMAT optimization of dose distribution and determine universal minimum segment width (MSW) for IMRT and VMAT plans based on 3D dosimetric phantom for thorax cancer, prostate cancer and lung cancer treatmentObjectives

To investigate the influence of segment width of intensity modulated radiotherapy and volumetric modulated arc therapy plans based on QA plans.

Specific Objectives

To compare results of 2D and 3D dose verification at different segment width.

To determine an optimal and acceptable minimum segment width criterion for thorax cancer, lung cancer and prostate cancer plans.

Research Questions

Are there correlations between results of 2D and 3D dose verification process?

What is the optimal value of minimum segment width determined to be used for the case of thorax, lung and prostate cancer for best reproducibility of the plans?

Chapter 1 Literature review

1.1 Radiotherapy in cancer treatment

As described by [6] Cancer remains a major cause of death at global level. According to [7] the international research agency for research on cancer announced in 2008 that most accurate assessment of global cancer burden show that 7.6 million deaths and over 12.7 million new case occurred in developing countries. In addition from [8] world health organization (WHO) on top ten commonly diagnosed incidence of cancer in the year 2020 showed prostate cancer as the second leading cancer disease and cause of death while lung cancer recorded at third position, with a highest mortality rate recorded for lung among all the ten common cancer incidences worldwide. This just shows the important and need for accurate radiotherapy treatments. In 2012 there were over 8.2 million deaths, prostate cancer was estimated at 307,000 deaths representing 6.6% of the total male cancer mortality, as evident from these records of these researchers [8], [9]and 1.1 million cases worldwide were recoded with almost 70% of them occurring in more developed region, the commonly diagnosed cancer was lung cancer at 1.82 million and it recorded the most cause of death at 1.6 million deaths, liver cancer at 745,000 deaths and stomach at 723,000 million deaths. With such past and recent records and estimate, specialist from various disciplines all around the world work to effectively and efficiently provide patients with optimal radiotherapy treatment and care.

From [11] At least half of all cancer patients will require radiotherapy at some stage during their treatment. [10]radiotherapy has continued to grow and evolve for the last years such as the invention of high energy radiotherapy delivered by a cobalt 60 machine (CO^{60}) or a linear accelerator (LINAC), scientific advances and improved care hence improving therapeutical outcomes and reduced side effects. Among advances include the technologies that maximizes and increase conformity of prescription dose to the tumor at the same time minimizing exposure to normal surrounding organs and tissues including intensity modulated radiotherapy and [11]Volumetric modulated arc therapy among others.

Radiotherapy is now widely used to treat all cancer case including lung, prostate, thorax, breast, liver commonly diagnosed cancer worldwide. [12] it can be used preoperatively to shrink cancer cell and improve respectability or used in postoperative to remove tumor residues deposited in surrounding tissues and resected regions.

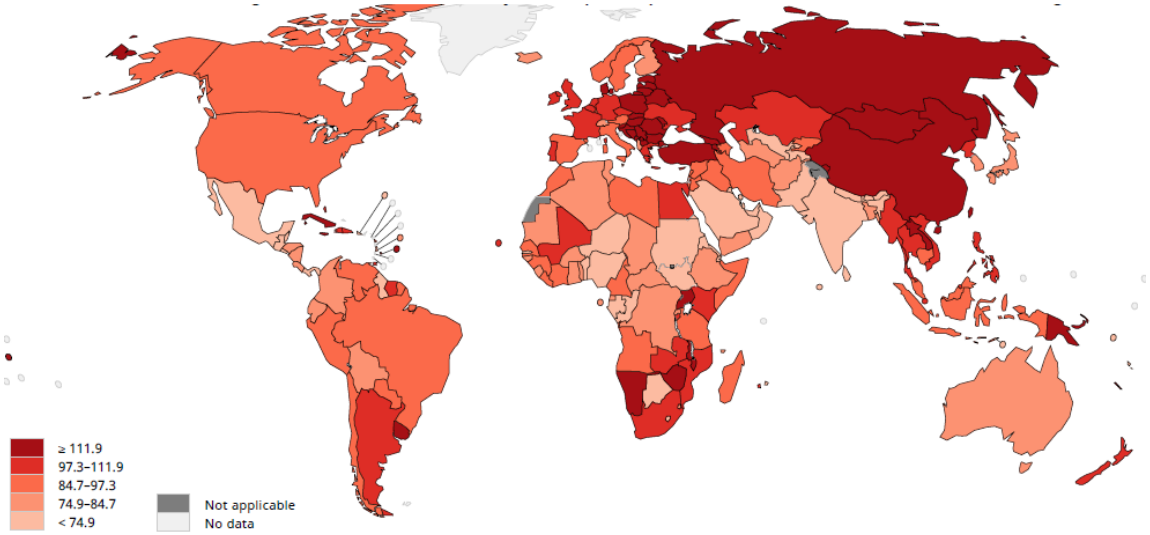

Figure 1.2.1-1_mortality rate estimation 2020 worldwide

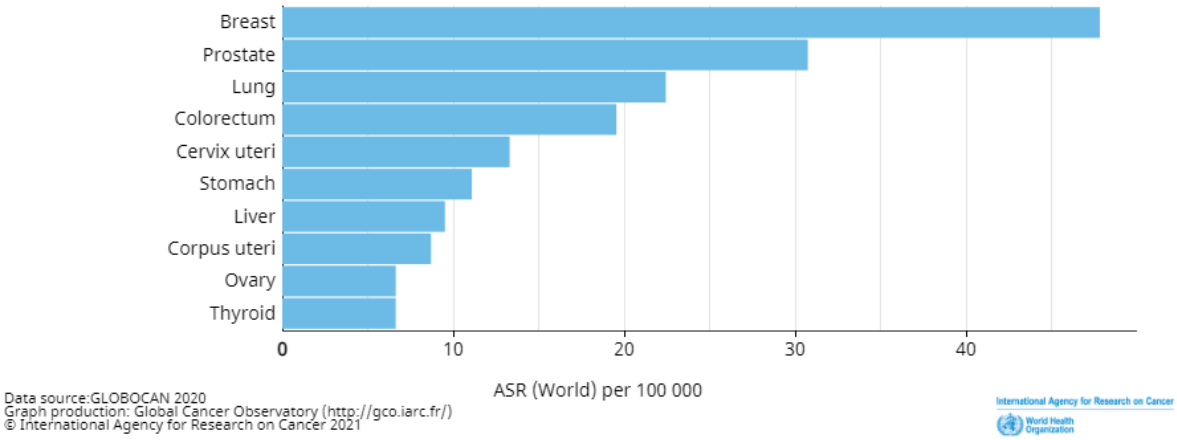

Figure 1.2.1-2_ cancer incidence rates worldwide

1.2 Intensity modulated radiotherapy

Thorax cancer, lung cancer and prostate cancer are among the common diagnosed cases. Radiotherapy has proved to be an effective mode of treatment for in

the past years especially for these cases, however planning treatment can be a challenge because there is need to maximize dose to the target and spare the healthy tissue. Fortunately advances in external beam radiation therapy techniques have provided techniques that help achieve maximum dose like intensity modulated radiation therapy (IMRT). IMRT is a successful accepted technology in radiation therapy since the origin of inverse planning and computed tomography (CT) in 1982, since then it has gained popularity and is now used as a default option on most recent linear accelerator and treatment planning system (TPS). According to rim et al [13] in a survey to determine the rate use of IMRT in Korea, they found that there was a steady increase usage in 2016 and they estimated that the rate is likely to be over 50% by 2017. Also the radiation oncology respondent of a 2002 and 2004 US survey on the use of IMRT indicated an increase from 32% to73% users [14] It can be predictable that every center performs IMRT for patient that benefits from it. [15]defines IMRT as a radiation treatment technique with several beams having beams that are intensity modulated and intentionally delivering a non-uniform intensity on to the tumor, in this case the desired dose distribution in the target can be achieved. intensity modulated radiotherapy enables the escalation of dose to the target for instance to the prostate while reducing the toxicities to the rectum and the bladder leading to an improved local control and decrease complications as compared to conventional, three-dimensional conformal therapy(3D-CRT)[14].

1.2.1 Intensity modulated radiotherapy planning treatment

The acknowledgment that dose distribution could effectively be achieved by IMRT provides the physicians a sense of relieve that a problem in radiation treatment plan can finally be handled. This technique has proved to be more different than older treatment techniques as 3D conformal radiation therapy(3D-CRT) whose fields conform to the beams eye view (BEV) outline of the target volume[16]. IMRT planning as a dose delivered by treatment plans that are optimized. IMRT uses multi-leaf collimators (MLC)shaping by using mode like step and shoot, sliding window and volumetric modulated arc therapy (VMAT). It is important that when planning IMRT

target volume and critical structures are shown so as to assist in providing a correct prescribed dose, to this regard an optimization plan must be generated that will achieve the target volume dose requirement and the dose constraints, thereby restricting dose exposure to vital structures[17]

Optimization of the plan is vital in IMRT, it is a process of exchange between target coverage and dose strains to critical organs finding an optimal plan to use, it is done using various methods and algorithms, there is setting of physical dose objectives and constraints then analyzing dose volume histograms (DVH) and biological planning objectives until the prescription objective is achieved. Every patient's anatomy predicts a special or different kind of beam orientation, by utilizing computer and human optimization better plans can be obtained for better patient treatment outcome.

1.2.2 IMRT treatment delivery

Intensity modulation radiotherapy treatment is effectively administered using multi-leaf collimator (MLC), MLC consists of many separate leaves designed to shape radiation fields and deliver designed dose, these leaves can move separately in and out of the radiation beam blocking unwanted areas. Every separate leaf can be managed independent of the others thereby generating a field opening pattern designed to conform to the target volume [17]. In around 1984 first commercial MLC was devised and used by scanditronics, later on other linac vendors employed it in their equipment's due to the beneficial results that were seen and now linac companies have even improved radiality of MLC and have designed even small leaf width. With smaller leaf widths we can enable the treatment planning system to apply even finer beamlet size that irradiate at different times during the optimizing stage and achieve a good plan quality [18]. IMRT treatments are delivered by using static beam angles or circulating beams, all these forms have existed since the invention of IMRT technology. [19]the field segment can be delivered dynamically for instance MLC changing through the field segment dynamically while the beam is on and delivery can be through one segment at a time in that the MLC is static during irradiation.

1.3 Volumetric modulated arc therapy (VMAT)

Over the past years there has been technological advance in radiation therapy techniques and deliveries, these are attributed to acquiring a greater conformal dose distribution and improving treatment results. VMAT was made known in 2007, it defines a technique that allows modulation of multi-leaf collimator ,gantry rotation speed and dose rate simultaneously during treatment [20]. VMAT is different from fixed beam IMRT in that radiation is delivered while the gantry rotates around the patient, continuously reshaping and changing the intensity of the radiation beam as it moves around the patient increasing accuracy delivery. Clinical application of VMAT is increasing significantly as it can be used to treat very complex tumor sites including thoracic, lung, prostate, brain, head and neck cancers among others [21]. Many studies have been reported on VMAT technique for example a report by [22] concluded that the techniques is safe modality for all cancer types. [23] published an earliest VMAT planning study in 2008 indicating advantages of VMAT such as dose distribution and short time treatment. VMAT techniques allows treating of the target volume with one or more arcs depending on how the complex the plan is. VMAT systems are available in various brands like rapid Arc, smart Arc, Elekta VMAT [21].

1.4 Dosimetric tools used for IMRT/VMAT QA

In order to ensure an effective and efficient implementation of IMRT there are several tools that have been put in place so that day to day clinical practice can yield better results. Researchers have reviewed and compared different dosimetry tools that can be used especially for IMRT/VMAT. The widely used tools include detectors, scanners, phantoms and dosimetric analysis tools. [24] describes these tools in details putting out how they are to be used and cases where they cannot be applied.

Detectors have evolved from 1-D through 2-D and 3-D even 4D detector systems are now available, for 1-D we have examples such as ion chambers TLDs and MOSFET, they have their own weakness and strength for instance ion chamber are easy to calibrate, they are capable of measuring absolute dose and they come in different shapes and sizes, however they can only make one measurement point for

each irradiation providing less information to evaluate dose through the entire target volume. Examples of 2-D detector arrays are films like radiographic and radio chromic, 2-D detectors such as Mapcheck and ion chamber linear array. Taking for instance radiographic films that are very sensitive to storage condition, in spite this they are readily available, not as expensive as other 2-D detectors, and can give excellent resolution. Now many dosimetry tools exist, for example a study that analyzed and compared the dose distribution of different IMRT and VMAT plans with intentions to provide pretreatment QA using different tools, they considered Delta4 phantom, ion chamber and used gamma evaluation. [25] In another study to compare the quality assurance results of IMRT researchers used four different dosimetric tools that is they irradiated radio chromic film, a diode array, an ion chamber and an electron portal imaging device for patients specific quality assurance [26].

Due to increase in the use of complex treatment plan such as IMRT/VMAT there is need to study efficient and most reliable techniques for performing QA for such plans. [27] this study used three systems of ion chamber with film, 2-D diode array and 2D ion chamber array, the study concludes that these systems can be used for VMAT QA provided the user understands and is attentive to the strength and limitations of the QA devices. In another study that used 2D planar diode arrays and 3-D cylindrical diode arrays in IMRT and VMAT found that both detectors have excellent performance for IMRT and VMAT verification[28] . All these reports encourages that all users should be aware of each tool they intend to use. Knowledge of dosimetric tools and technique will allow user to be able to perform QA with appropriate tools for even complex treatment techniques giving them a wide range of choices.

Table 2.1.2.1-1_ specifications of different common dosimetry systems designed for IMRT QA purposes

	MapCHECK (Sun Nuclear)	***MatriXX Evolution (IBA Dosimetry)***	***OCTAVIUS 1500 /OCTAVIUS 4D (PTW)***	***ArcCHECK (Sun Nuclear)***	***Delta4 (ScandiDos)***
Phantom shape	2D array	2D array	2D array/cylinder	cylinder	cylinder
Detector	Diode	Ion chamber	Ion chamber	Diode	Diode

Detector area(mm^2)	0.64	15.9	19.4	0.64	0.78
Detector volume(cm^3)	0.000019	0.08	0.06	0.000019	0.000039
Detector distance(mm)	1.01	7.62	7.1	10	5/10
Number of detectors	1527	1020	1405	1386	1069
Detector pattern	Plane	Plane	Plane	cylinder	2ortho-planes
Max field size	32 x 26	24.4 x24.4	27 x 27	27	20
Weight	7.1	-	6/29	16	27

1.5 The need for pretreatment verification

The main objective of pretreatment QA is to verify that the treatment plan will deliver the planned dose distribution within the specified tolerance [29]. Therefore, for complex treatment plan such as IMRT which utilizes linear accelerator with dynamic multi-leaf collimators there is need to perform specific patient quality assurance for the so reason that the predicted dose by the treatment planning system is actually the actual dose being delivered to the patient during treatment[30].

Treatment plans that indicate differences between the measured and calculated dose distribution and exceed the specified tolerance requires that the plan be reconsider. We can only determine these differences by performing pretreatment verification QA using phantoms and dose measuring device. Furthermore [28]agrees that QA is necessary for ensuring that the intensity map pattern matches with the TPS and the MU specified by the TPS will deliver an intended dose. [31], [32]both reports recommend verification measurements for patient specific QA for IMRT and VMAT, users must create time for dosimetric verification and investigate problems if any.

The verification process for specific patient verification quality assurance (QA) can be summarized as firstly verifying the patient planning parameters and MLC, it is then required that dose measurement equipment is scanned and transfer data to planning computer creating verification plan, then move treatment information to record and verification system and finally results are then compared. There are a wide range of commercial dosimetry systems devices designed for dose measurement for

IMRT QA, this research considered ArcCHECK cylindrical detector array designed for rotational dosimetry and a software system known as 3DVH from Sun Nuclear corporation.

1.6 ArcCHECK for IMRT/VMAT treatment verification QA

ArcCHECK dosimetry system is one of the newly three-dimension detector design especially for rotational radiation deliveries QA verification process, it is suitable system for IMRT and VMAT treatment plans and has been recommended by AAPM task group 218 for 3D measurement requirements. The system was developed by Sun Nuclear Corporation in order to aid rotational therapy QA [33], [34]. It is cylindrical in shape and is used for measurement of radiation dose. ArcCHECK can take measurement at any angle this enables identifying even small gantry angle miss outs that can be missed when using 2D detectors, a good spatial resolution even for very small leaf width of 3mm is observed [33]. ArcCHECK provides so many features that enable complex treatment QA easier according to ArcCHECK user guide,2009, reports describe the phantom as designed to look like a patient simulating geometry so as to match reality. The specification of the phantom is shown in figure 3, it consists of 1386 diodes detectors arranged in a cylindrical style, detectors are spaced at 1.0 cm. with diameter and length of 21.0cm while the cavity diameter is 15cm designed to incorporate accessories.

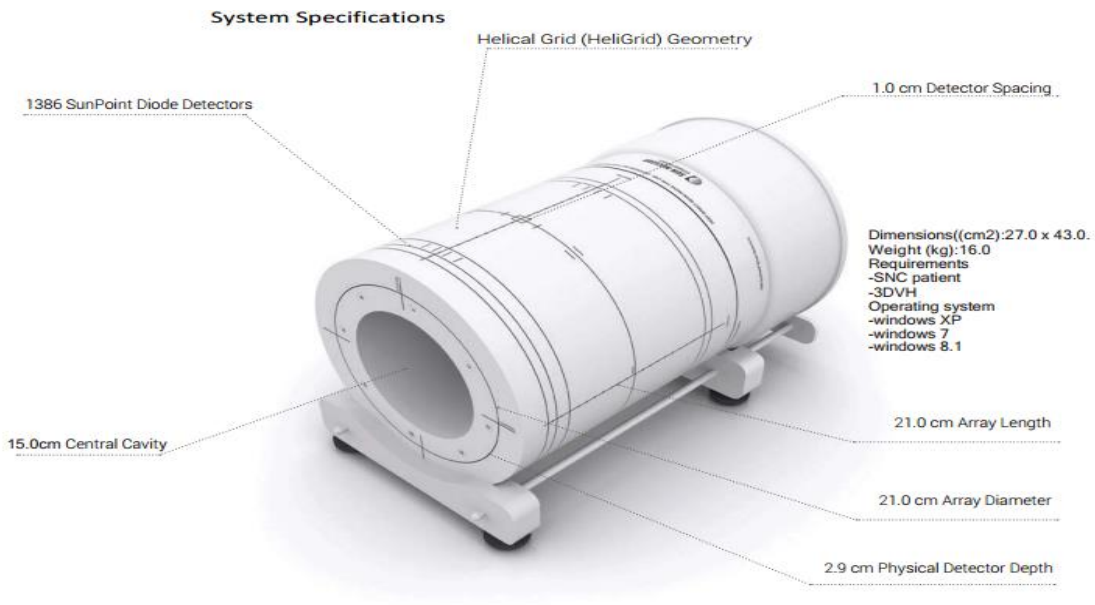

Figure 1.2.2-1_shows specifications of ArcCHECK-Diode dosimetric system

Since the invention of the phantom, its applicability and reliability of the data continue to be reported and reviewed by several researchers. [35] evaluate the dosimetric accuracy of new treatment modality using ArcCHECK, it was reported that the plans gave a good agreement and the system can provide good measurement. [35] furthermore ArcCHECK can give substantial information through simple and easy procedure. [28]reported that the system is excellent for IMRT and VMAT verification, form these reports we can deduce already that ArcCHECK system is ideal for complex QA verification and that it can be used in everyday clinical practice

Table 2.1.2.1-1_Advantages and disadvantages of ArcCHECK-Diode

Advantages (ArcCHECK)	Disadvantages (ArcCHECK)
-Can perform both relative and absolute dose measurements	-Sometime may take a lot of time
- Reduces and simplifies IMRT QA workload	-Because QA using ArcCHECK involves a linac it may only be done after working hours' time
-Consistent and highly sensitive measurements at all gantry angles	-Sometimes it is difficult to replicate the geometry of the patient
-Provides immediate readout	-Requires connection of large visible cables and voltage source
-Ideal geometric characteristics close to that of a patient's body	-Involves correction factors for temperature dose rate, energy angular dependency
-Easy to install less than 5 minutes and no need of a higher voltage	- We cannot pin point where the error is exactly

1.7 3-DVH software for IMRT/VMAT treatment verification QA

Due to the increased use of complex treatment plans in clinical practice the desire for dosimetry verification and QA is increasing too. Three-dimensional dose volume histogram is a software package designed by sun nuclear to assist further analysis of measurement dose especially to specific region of interest. The system takes into account all possible measurement errors encountered during delivery and any if errors exist between measured dose and calculated TPS dose, the system back projects theses errors into the original treatment plan. This process allows obtaining of 3D perturbed distribution of dose which reflects errors detected and gives actual measurements. 3DVH allows analysis of target volume and risk organ separately so we can visualize and understand where exactly the error is or rather discrepancies in measurement. [36]the 3-D gamma metric that is obtained and the DVH of ROIs can be used to compare and transform the QA process to a more patient centered than phantom centered. The accuracy of the system has widely been studied in many studies, [36],

[37]evaluated the effectiveness of 3DVH software with ArcCHECK 3-D diode array detector and the writer recommended the use of the software for IMRT QA.

The advantages of 3DVH software system may include:

- Provision of fast results with automated tools
- No need of commissioning
- Allowing the user to further analyze the result in terms of 3D gamma index and DVH regions of interest
- Allows errors to be traced back to the actual treatment plan

The known drawbacks on the software may include:

- It is only compatible to specific dosimetry systems
- It requires already existing measurements from device to be able to compare with treatment plan.

1.8 linear accelerator Elekta synergy

Intensity modulated radiation therapy (IMRT) and volumetric modulated arc therapy (VMAT) are linear based modalities meaning that they use linear accelerator equipped with multi leaf collimators (MLC). One of the earliest linear accelerators designed to meet the needful criterial of IMRT and VMAT is Elekta Synergy linear accelerator invented by Elekta corporation. The linac is equipped with MLC which, allows the beam to be shaped according to the shape of the tumor. Elekta synergy accelerator uses agility multi-leaf collimator with 160 leaves Interdigitating tungsten alloy leaves with a width projected to the isocenter of 5mm and a maximum filed size at the isocenter of 40 x 40 cm^2 , each leaf bank is joined to a dynamic leaf guide and combined speed of these two components can reach 6.5cm per second closely twice as fast as conventional MLCs [38]. The position of all leaves is monitored and controlled by optical camera located in the collimator of the linac, the leaf movement is done by high torque electric motors stopping the leaf from assuming incorrect positioning. The ability of the collimator to provide exceptional 45cm distance from the patient is important for IMRT/VMAT. IMRT /VMAT requires all these features for excellent and successful operation

The invention of Elekta Synergy linac achieves one important feature that is required for complex techniques that is the ability to visualize internal structure. It was the first linac to sort out 3D image guidance into treatment set up process, with imaging tools such as 3D and 4D volumetric cone beam for soft tissue delineation these features are incorporated along with Elekta Synergy linac. Elekta Synergy provides personalized, safe, effective and high-quality radiation enhanced dose conformity according to tumor size, shape and pathology, this technology has improved tumor control probability, reduction of secondary tumors and minimized side effects[39].

Elekta Synergy is consisting of a couch for supporting and positioning the patient, electronic portal imaging device (EPID), gantry, kV imaging system and a stand as external components. The internal components comprise of the accelerating wave, bending magnets, circulator, a cooling system, electron gun, energy selector klystron/ magnetron, wave guide and the treatment head, the treatment head contains components required for beam production and shaping, target, beam shaping collimators and optical distance indicator[40].

Table 2.1.2.1-1_ specifications of Elekta Synergy

Elekta Synergy	Specifications/features
Photon energy (MV)	6,10 and18
Electron energy (MV)	4,6, 8, 10, 12, 15, 18 and 20
Gantry angle (left and right)	0…180º
Multi-leaf collimator (MLC)	Agility 160 40 x 40
Treatment delivery	IMRT, VMAT, SRS/SBRT, 3D-CRT
Maximum dose rate	600MU/min
Weight (kg)	5500
SSD	100cm

Elekta Synergy has many advantages: that fully integration of multi-leaf collimator, digital treatment center to personalize imaging and treatment workflows, offering real time patient position verification. The large diameter around the isocenter allows patients set -up easier and offers a large field of view.

1.9 Monaco treatment planning system (TPS)

The wide use of Radiotherapy in clinical practice requires physicians to be more accurate than ever as this modality has greatly improved in many areas such as delivery techniques leading to very fast and more complex treatment with higher dosage delivery to targeted site and shorter fractionation schemes. Therefore, treatment planning systems ought to be fast accurate, automated sensitive and incorporated to treatment machines. In order to alleviate challenges faced with treatment planning system of complex treatment modalities and provide efficient and effective features, Monaco treatment planning system was designed.

It is one of the commonly used planning systems all around, its increased application is due to several beneficial features that improve plan quality. [41] The treatment planning system puts together monte Carlo dose calculation with powerful optimizing tools to give high quality radiation treatment plans. Monte Carlo (MC) algorithms are the gold standard for dose computing dose in radiotherapy[41], MC dose engines simulate particles, tracking individual interactions and secondary generated particles and then tally dose deposition in a medium[41]. Monaco is designed to generate plans that spare as much healthy tissues as possible while maximizing the dose to the target volume utilizing multicriterial optimization (MCO). It is well suited and provides solution for 3-D, IMRT, VMAT, SBRT and SRS.

Monaco technology allows quick calculations allowing physicians and patients benefits from the accuracy of monte Carlo algorithm while reducing overall planning time. collection of biological and physical dose-based planning tools and templates makes the planning process easy [42]. [43]Monaco templates improves efficiency by allowing users to import and export treatment plan using DICOM services. It provides user to design treatment plan and visualize the final planned dose results. It is possible also to come up with multiple prescriptions continuously this can decrease treatment Elekta Synergy linear accelerator together with Monaco treatment planning system combine unrivalled dose delivery and intelligent dose planning.

Advantages are many these include offering comprehensive contouring, plan review tools to support modern treatment modalities. Ability to define organ response

rates with constrained optimization. There is accuracy that does not interfere with MC algorithm leading to precise accuracy for different tissue densities. It is said to be a trend toward improved target dose conformity, resulting in fewer segments leading to the reduction in estimated fractional delivery time[44].

Chapter 2 Materials and Methods

2.1 Elekta Synergy linear accelerator(linac)

For delivery quality assurance of the plans, an Elekta Synergy (Elekta, ltd) linear accelerator was used to deliver photon beam of 6MV and 10MV.The linac is installed at Tomsk Regional Oncology Clinic in Tomsk, Russia where the study was conducted. It is equipped with 160 agility mulileaf collimator with a field size of 40 x 40 cm^2 external component include couch for supporting and positioning the patient, electronic portal imaging device (EPID), gantry, kV imaging system and a stand. Two strategies of IMRT with multi-leaf collimator were used in the study one is dynamic technique (DMLC), were the MLC leaves move continuously while the radiation beam is on but the gantry is fixed in one position, the second is volumetric modulated arc therapy (VMAT) the MLC leaves move continuously and gantry rotates around the patient while the radiation beam is on. Both of these techniques work to produce a dose that conforms to the shape of the target volume in the chosen field trajectory with minimal exposure to normal organs.

Table 2.1.2.1-1_characteristics of Elekta synergy MLC

Features	**Agility MLC**
Maximum field size (cm)	40 x 40
Leaf pitch(cm)	0.5
X collimator range with respect to central axis(cm)	Not applicable
Leaf guide range with respect to central axis(cm)	5 to 20
MLC leaf range with respect to guide (cm)	-20 to 0
MLC range with respect to central axis (cm)	-15 to 20
Y collimator range with respect to central axis(cm)	-12 to 20
Focus -MLC distance(cm)	31.8
MLC thickness (cm)	9.0
Maximum MLC leaf speed(cms^{-1})	3.5
Maximum X-collimator/leaf guide speed(cms^{-1})	3.0
Maximum Y-collimator speed (cms^{-1})	3cm/sec

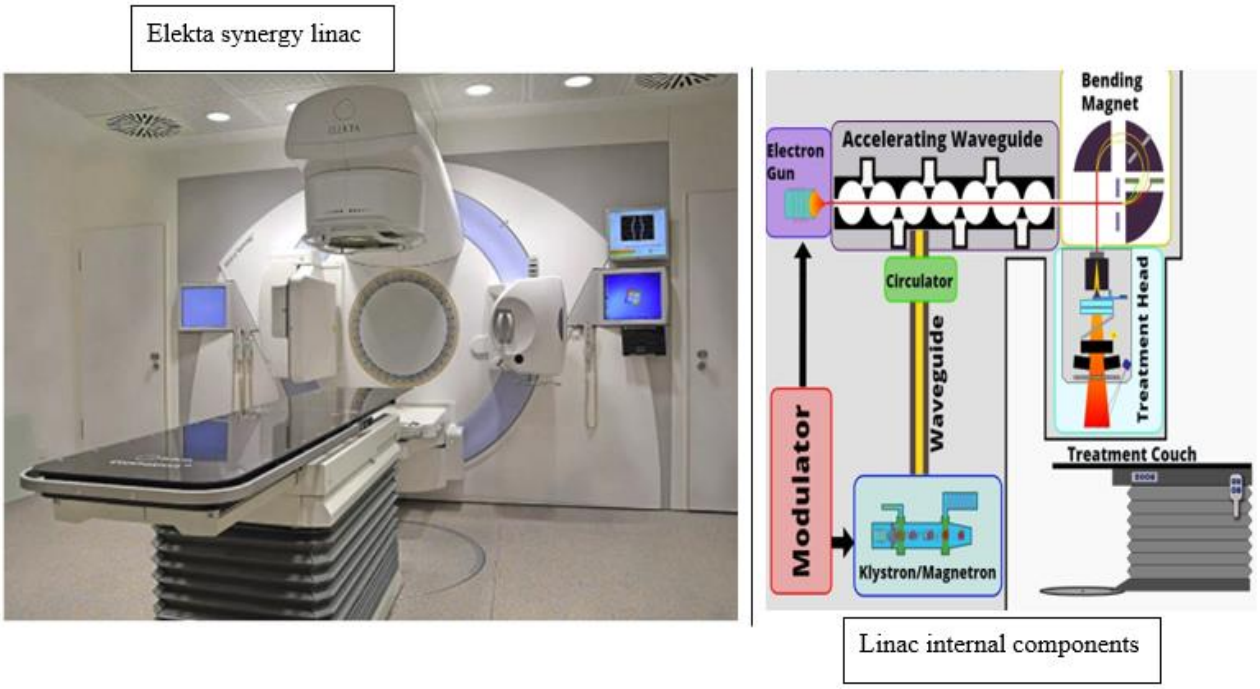

Figure 1.2.2-1_Elekta synergy linac

The combination of benefits from Monaco TPS with IMRT/VMAT into Elekta Synergy significantly reduces treatment times, meaning more patients can receive modulated treatment per day. Elekta synergy is used exclusively for modulated treatment allowing the clinic to treat many patients with modulated radiation therapy every day.

2.1.1 Patients' cases

Statistics indicate high levels of thoracic cancer including lung cancer and prostate cancer among men and women regardless of the age and gender. Henceforth, three localizations of patients with thorax, lung and prostate cancer were selected from the clinical database. Patients were treated with external IMRT and VMAT. four plans were generated for each case and planned following test case plans from AAPM TG-244 report. All plans were obtained by incorporating minimum segment width of 0.5cm, 1.0cm, 1.5cm and 2.0cm with 0.5cm increment.

All patients were scanned using computed tomography imaging scanner in rotational mode and the reconstructed CT images were transferred to Monaco 5.11 TPS, contouring of CT images was done in Monaco software to avoid variation in

system regarding to contour interpolation. From the CT image the target volume and vital structures were defined. Dose prescription was at 68Gy in 2Gy/fraction. For thorax cancer case the dose prescribed was at 60Gy in 2Gy/fraction and for lung prescribed dose was at 63Gy in 1.8Gy/fraction.

2.1.2 Monaco treatment planning system (TPS)

This study was conducted using Monaco treatment planning system a widely accepted treatment planning system (TPS) with optimization scheme. Monaco TPS is a complete IMRT treatment planning system which supports several delivery modes including step and shoot IMRT, VMAT and many other. This study used Monaco version 5.11 TPS for contouring, planning dose, optimization of plan and evaluating the plan for delivery quality assurance quality,

Table 2.1.2.1-1_ Total dose and Fractionations and dose per fraction

Localization	Plan dose (Gy)	Fraction dose (Gy)	Number of fractions	Photon Beam	Technique	Collimator and couch angles (0^0)
Lung	63	1.8	35	6.0 MV	IMRT	0
Thorax	60	2.0	30	6.0MV	VMAT	0
Prostate	68	2.0	34	10MV	VMAT	0

2.1.2.1 Minimum segment width

Optimizing IMRT and VMAT plans involves two step processes, the first step process allows creating and optimizing ideal fluence to suit prescription, this is done using optimizing algorithms. The second step process allows the ideal fluence obtained in the first step to be translated into a deliverable form set of MLC segments delivery. It is at this stage that setting of constraints for generating MLC segments is obtained such as settings for minimum segment width was placed at this step. After obtaining deliverable fluence dose was optimized and calculated for each plan.

Minimum segment width is a parameter of Monaco that is used to correct the minimum width of the segments, like minimum separation of a leaf pair. It allows lessening effects of bad MLC calibration and leaf positioning accuracy.

The range of values allowed in the optimizer is starting from0.5cm to 2.0cm maximum. For this study four plans were devised with different penalties on minimum segment width (MSW) of 0.5cm, 1.0cm, 1.5cm and 2.0cm for each case of the study.

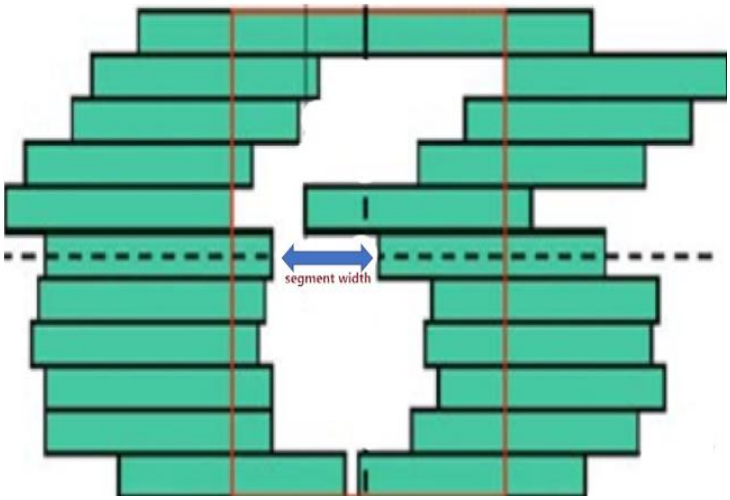

Figure 2.1.2-1_ showing MLC pattern.

2.2 AAPM TG-244 REPORT

In year 2014, AAPM task group 244(TG-244) published an important report that aims at providing commissioning and quality assurance of treatment planning dose calculations for photon and electron beams. The practice guidelines recommended ways of validating the dose for intensity modulated radiotherapy (IMRT), volumetric modulated arc therapy (VMAT)and helical delivery plans by simply comparing individual beams or composite measurements with the treatment planning system calculations. In addition to this, the group set out ways establishing a routine quality assurance program that does not only improve but helps to validate dose consistency through recalculation of reference plans for both megavoltage photon and electron beams, the task group established six sample datasets these datasets of respective tumor cases are widely accepted and applied for routine quality assurance.

Therefore, this study followed the recommendations so as to be able to provide high quality plans. Three case type were selected for the study, that is TG-244-Thorax patient, TG-244-Lung patient and TG-244-Prostate patient.

2.2.1 IMRT/VMAT dosimetric verification

It is necessary to verify the accuracy of radiation delivered by carrying out tests such as delivery quality assurance (QA) prior to patient treatment especially for high precision and complex treatments such as IMRT/VMAT.

2.2.2 ArcCHECK 2-D Dosimetric verification

Dosimetric verification of IMRT/VMAT QA plan was performed using ArcCHECK diode detector, it is a 3D detector that measured the 2D %GPR for differences between measured dose by the dosimeter and TPS calculated dose. Comparison of unfolded 2D profile from the dosimeter surface. Below is shown the obtained sample results of ArcCHECK-SNC. [36] defines ArcCHECK as a cylindrical, and water equivalent phantom specifically designed for rotational beam delivery verification (QA) with 1,386 3D spiral positioned detectors , a diode interval of 1cm just within the cylinder, an active size of about 0.8cm x0.8cm and a diameter of 21cm, its length is 21cm and detector depth is of 2,89cm [45].

A software program SNC patient was utilized to measure the 2D pass rate for differences between delivered dose and dose calculated dose in TPS. A gamma criterion of 3%/2mm with a threshold of 20% was applied. The plan passes if greater than 95% of its points meet the 3%/2mm criterion.

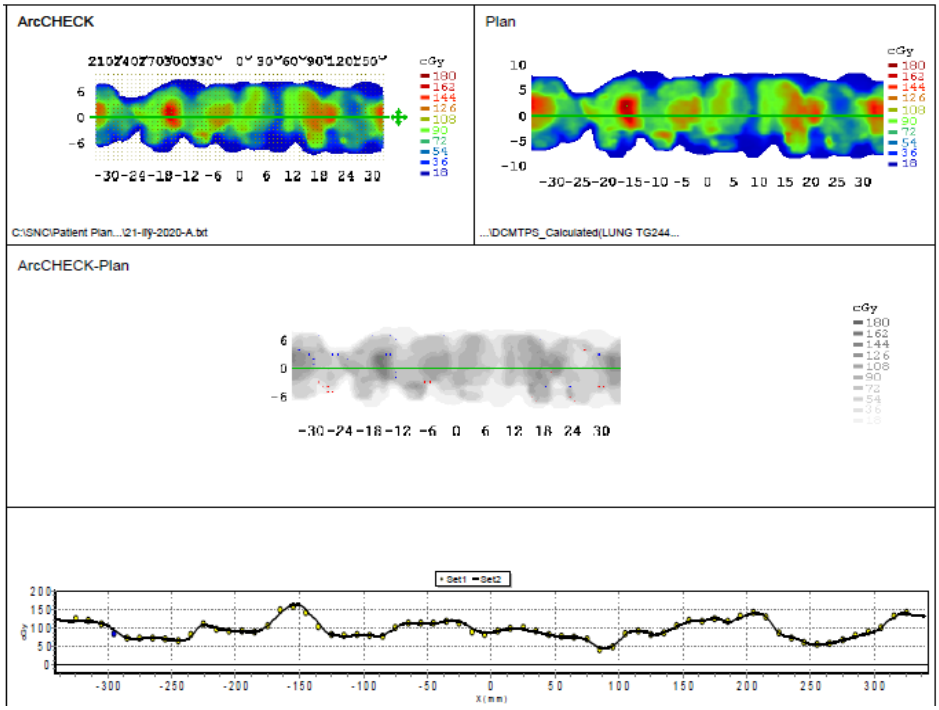

Figure 2.2.2-1_ ArcCHECK plan verification

2.2.3 3-DVH Software -3D Dosimetric verification

3DVH-software was used further analysis of measured dose thereby comparing the refence dose to comparison dose. Sets of data were transferred to 3-DVH Software, these include, TPS-optimized patient plan, dose distribution, contoured structures and CT images, corresponding TPS- calculated dose measured results and ArcCHECK measured data were then changed to 3-D dosimetric data using PDP algorithm and compared against the original treatment plan that was transferred from TPS using 3-D gamma analysis (3mm DTA,2%DD global), And the dose difference found for each beam were projected back into TPS 3D dose calculation, to get actual delivered 3D dose distribution.

The results from the software were displayed as DVH of the reference (TPS) and compared dose distributions, with this software I was able to analyze the gamma passing rate of each corresponding region of interest (ROI).

The % deviation (DE) between DVH values from 3DVH and TPS were calculated using equation 1

$$DE = \left| \frac{D_{3-DVH} - D_{TPS}}{D_{TPS}} \right| \times 100 \qquad \text{……..1}$$

Here D_{3-DVH} is the dose value calculated from 3-DVH software

D_{TPS} is the dose value extracted from TPS, calculated from for each plan the region of interest (ROI).

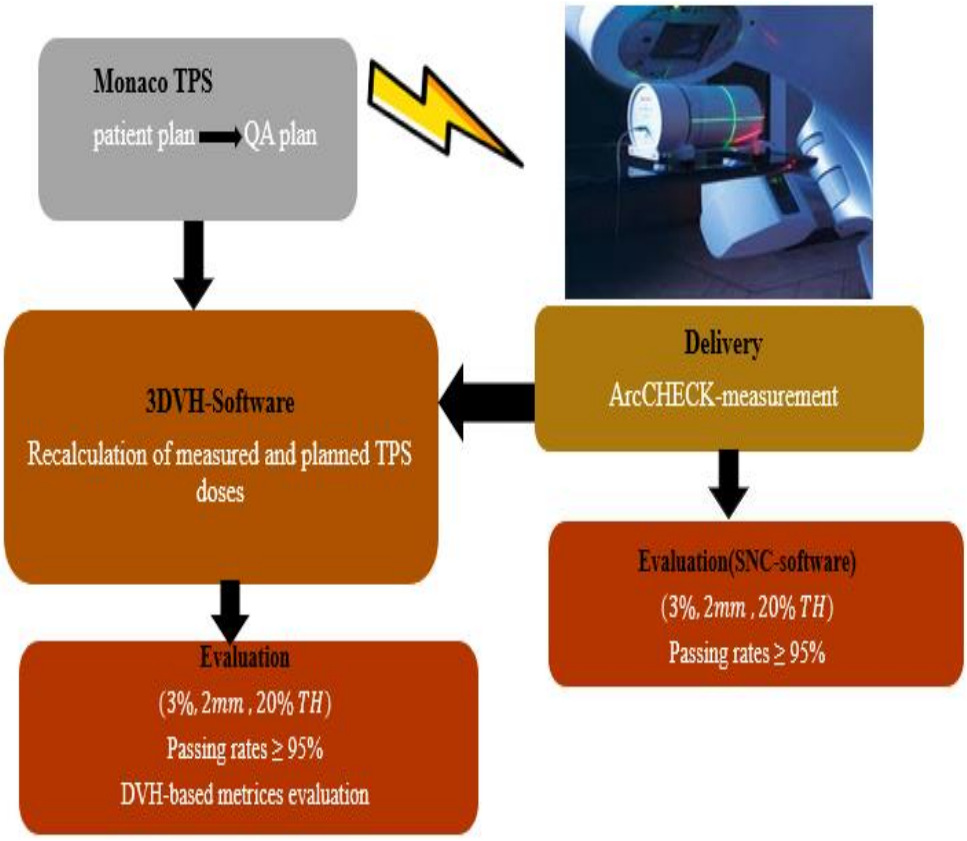

Figure 2.2.3-1_ A schematic design of the study. Patient specific QA methods using ArcCHECK-SNC and 3DVH software package

2.2.4 Gamma analysis evaluation

The gamma analysis method gives gamma index values to each individual point where a gamma index value of ≤1 means a passed and a greater value will represent a failed. So, the results of passing points in the gamma distribution expressed in percentage is collective known as gamma pass rate(%GPR). For this study a value of ≥95%(%GPR) was set as a pass percentage with a dose difference (ΔD) and distance to agreement (DTA) criteria of 3%/2mm.

Chapter 3 Results and Discussion

Verification of delivery quality is vital process of quality assurance. In this study, IMRT-VMAT dose calculated in Monaco TPS were verified by using a water equivalent cylindrical phantom ArcCHECK together with SNC-patient and 3DVH software package. Planned dose was compared to measured dose distributions. For all optimized treatment plan 90% to 99% of prescribed dose encompassed 95% of tumor volume. The plan efficiency and delivery accuracy were evaluated and the results from the study evaluated the total number of segments, total number of monitor units and dosimetric measurement verification results using a global normalized gamma index criterion with ArcCHECK -SNC patient (2-D gamma pass rate), 3DVH for 3-D gamma pass rate and DVH-based metric of target volume and region of interest (ROI).

3.1 Planning quality evaluation

Lung localization

3.1.1 Total monitor units and number of segment width at different segment width

Table 3-3.1 _ monitor units and number of segments per segments width

Lung location		
MS	Total number of segments	Total monitor unit
0.5	194	667.22
1.0	189	542.18
1.5	192	472.34
2.0	176	454.70

From the table it is seen that as the minimum segment width increases total number of monitor units decreases, it is at the highest segment width that we find the lowest number of segment and decreases monitor units indicating shorter treatment time. For case of lung cancer where intra and inter fraction can be possible the segment is 2.0cm provides a way of avoiding this effect and can give comfortability to patients during treatment.

3.1.2 Dose distribution and target coverage per segment width

The results evaluated how dose conforms to the planning target as segment width was changing.

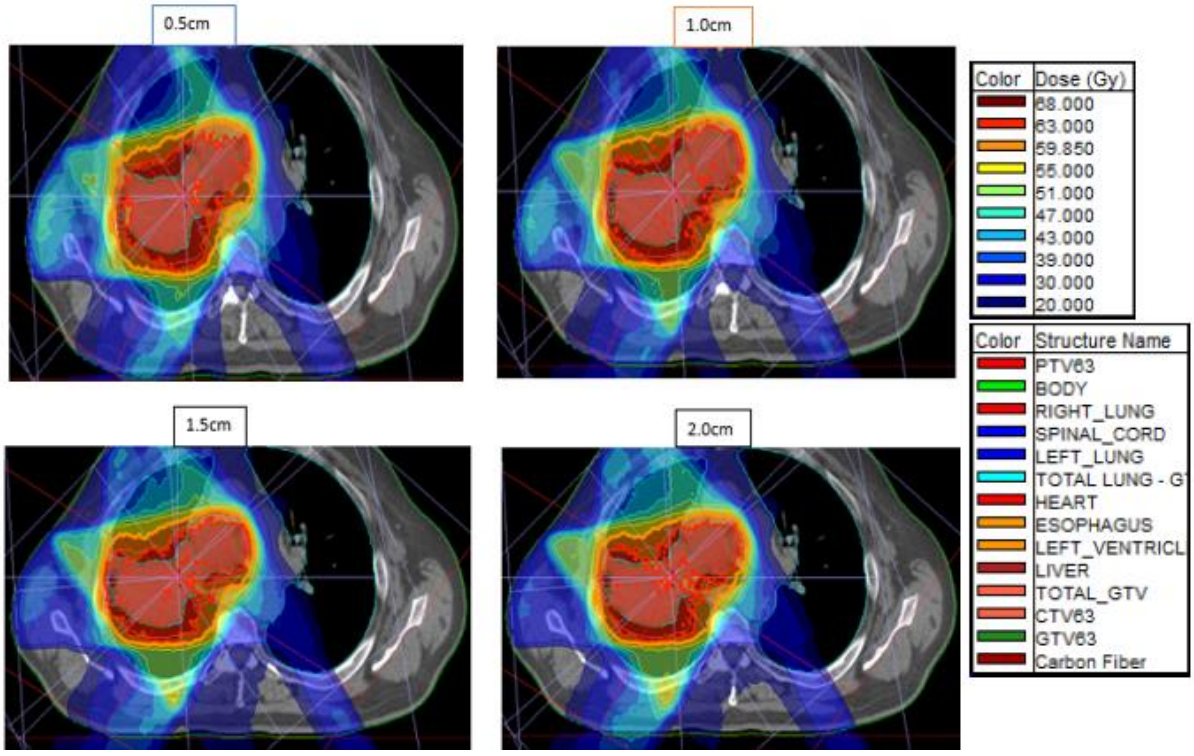

Figure 3.1.2-1_ dose distribution of lung cancer

Very conformal dose distributed in the target volume reducing dose to surrounding structures was seen to have improved more at segment width of 0.5cm and 1.5cm when compared to 2.0cm. looking at the dose distributed and target dose coverage in all the plans the prescribed dose covered 95% target volume. There were was not very much differences in minimum doses to vital regions however, plans at 0.5cm and 1.5cm showed decreased exposure of organs at risk. All in all, the plans were of good quality and ready to be delivered.

3.1.3 Statistical dose volume histogram per segment width

To make a through plan evaluation dose distribution and dose histogram (DVH) of Monaco TPS were generated, this helps to precise evaluate the extent of dose to surrounding structures and to determine that a sufficient treatment dose is attributed to the tumor volume without exceeding the dose threshold for normal tissues, it is

important that the plan objectives are meet. In this analysis was done using statistical DVH so critically see where differences may occur.

Table 2.1.2.1-1_ planning target DVH

MSW (cm)	ROI	Min-dose (Gy)	Max- dose (Gy)	%Vol<Cold ref (cm^3)	%Vol>Hot ref (cm^3)
0.5	**PTV-63**	50.524	73.880	0.92	0.21
1.0		49.796	75.364	0.97	0.32
1.5		51.300	77.710	0.81	0.65
2.0		36.760	73.671	2.64	0.34
0.5	**GTV-63**	60.687	67.817	8.79	-
1.0		61.349	69.008	1.53	-
1.5		59.978	69.546	1.40	0.004
2.0		59.211	68.416	5.07	-
0.5	**CTV-63**	57.036	73.880	3.09	0.20
1.0		56.969	75.364	1.24	0.30
1.5		57.424	77.697	1.36	0.55
2.0		46.815	73.671	4.50	0.33

Table 2.1.2.1-2_ organs at risk DVH

MSW (cm)	OARs	Dose (Gy)	%Vol<Cold ref (cm^3)	%Vol>Hot ref (cm^3)
0.5	**Heart (min)**	0.697	-	1.03
1.0		0.703	-	1.03
1.5		0.710	-	1.03
2.0		0.656	-	1.02
0.5	**Esophagus (min)**	0.640	-	48.78
1.0		0.671	-	48.95
1.5		0.644	-	49.10
2.0		0.640	-	46.40
0.5	**Spinal cord (max)**	30.057	-	-
1.0		31.496	-	-
1.5		30.887	-	-
2.0		31.192	-	-

From these results is shown doses to planning target, some existing differences are indicated in the mean and maximum doses with presence of some cold regions with the highest record at 2.0cm. Some percent areas of hot spots are also observed with varying segment width the highest percent is seen at 1.5cm, however 0.5cm and 1.5cm

indicate that the minimum dose receive to the planning target was of good quality compared to the minimum dose delivered at segment with 2.0cm very small amount is seen which may not help treat the target volume as indicated in the prescription.

Looking at vital surrounding structures there was no observed much differences in the minimum dose and maximum dose.

Thorax localization

3.1.4 Total monitor units and number of segment width at different segment width.

Table 2.1.2.1-1_ monitor units and number of segments per segments width

Thorax location		
Parameter	Total number of segments	Total monitor unit
0.5	70	385.81
1.0	72	331.83
1.5	72	331.83
2.0	69	424.83

Thorax case shows a lower number of monitor units at segment width of 1.0cm and 1.5cm however the lowest number of segments is observed at 2.0cm. the decrease in monitor units and number of segments can indicate a shorter treatment time for patient and can be beneficial in avoiding motion effect.

3.1.5 Dose distribution and target coverage per segment width

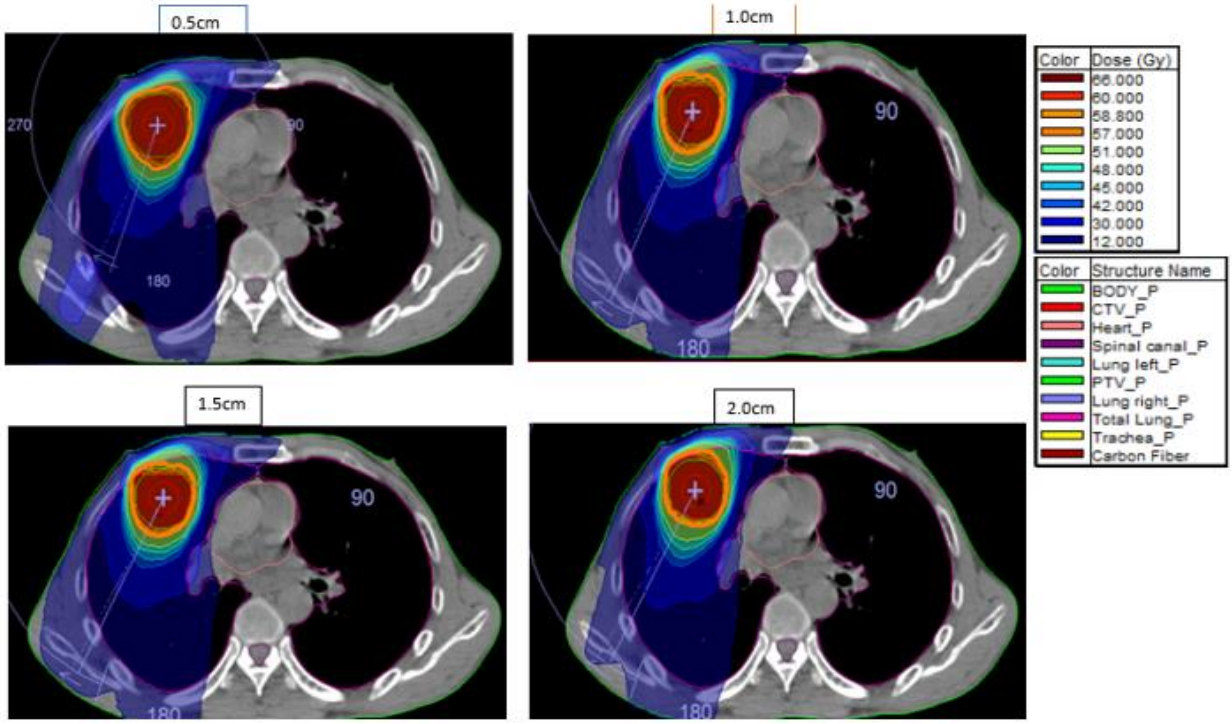

Figure 3.1.5-1_ dose distribution for thorax cancer

The figure shows dose in grays delivered to planning structures with respect to the color. All the plans indicated a 95% dose coverage with little insignificant variations per segment width. Organs at risk received negligible small doses. Hence the plans were successful.

Table 2.1.2.1-1_ planning target DVH

MSW (cm)	ROI	Min-dose (Gy)	Max-dose (Gy)	%Vol<Cold ref (cm^3)	%Vol>Hot ref (cm^3)
0.5	**PTV_P**	57.535	69.747	-	3.87
1.0		56.316	68.255	0.04	1.04
1.5		56.316	68.255	0.04	1.04
2.0		55.410	68.670	0.11	6.00
0.5	**CTV_P**	61.917	67.340		7.97
1.0		61.656	67.312		1.89
1.5		61.656	67.312		1.89
2.0		62.553	67.155		4.72

It is clear from the table that there were no significant variations in all the plans in the mean dose and maximum dose, however small percent cold spots are seen with

increase in segment width. For planning quality efficiency all plans were good and successful.

Table 2.1.2.1-2_organs at risk

MSW (cm)	ROI	Reference	Comparison	Diff (Abs/%)	GPR%
0.5	**Heart (min)**	0.05	0.05	0	100
1.0		0.04	0.05	0	100
1.5		0.04	0.04	0	100
2.0		0.03	0.03	0	100
0.5	**Trachea (min)**	0.05	0.05	0	100
1.0		0.04	0.04	0	100
1.5		0.04	0.04	0	100
2.0		0.05	0.05	0	-

Looking at organs at risk like the heart the plans spared high doses to these regions indicating quality plans readiness for delivery.0.5cm ,1.0cm and 1.5cm seemed better than 2.0cm which showed high percent of cold regions.

Prostate localization

3.1.6 Total monitor units and number of segment width at different segment width

Table 2.1.2.1-1_ number of segments and total monitor units per segment width

Prostate location		
Parameter	Total number of segments	Total monitor unit
0.5	136	748.56
1.0	141	679.95
1.5	132	643.15
2.0	126	569.15

With increasing the minimum segment width, the total monitor unit increases and decreases with decreasing the segment width, hence at 2.0cm the lowest monitor

unit is calculated and it is at this segment that the lowest number of segments is observed.

3.1.7 Dose distribution and target coverage per segment width

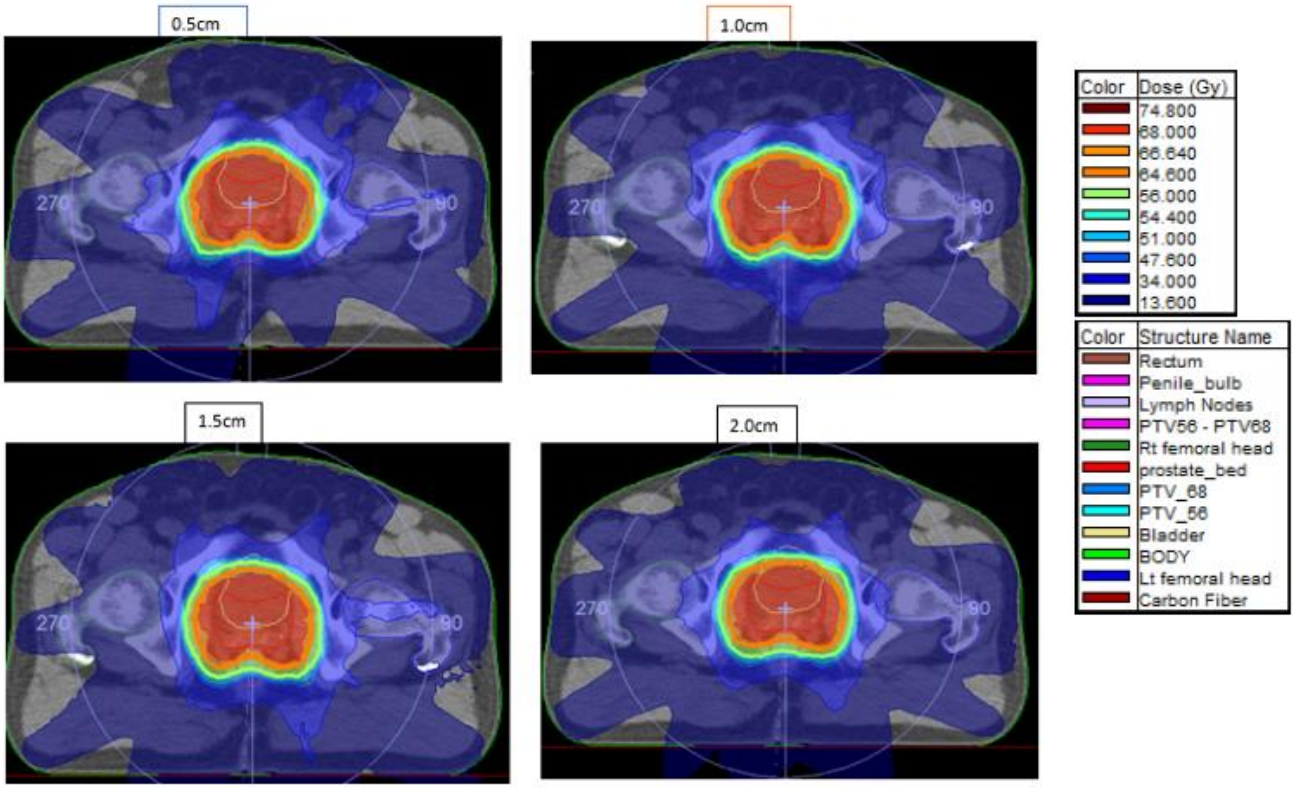

Figure 3.1.7-1_ dose distribution of prostate cancer

Evaluating the dose distributed to planning volume and surrounding vital organs, there is significantly no notable differences as the segment width changes. All the plans indicated a 95% dose coverage with little insignificant variations per segment width. Organs at risk received negligible small doses. Hence the plans were successful.

Table 2.1.2.1-1_ planning target DVH

MSW (cm)	ROI	Max-dose (Gy)	Min-dose (Gy)	%Vol<Cold ref (cm^3)	%Vol>Hot ref (cm^3)
0.5	**PTV-68**	74.551	60.726	0.40	
1.0		74.669	60.770	0.69	
1.5		74.680	59.373	0.86	
2.0		75.063	58.461	1.04	

The dose maximum and minimum dose to PTV in all the plans were similar as shown in the table relatively very little insignificant difference are seen. Although segment width 2.0cm shows the highest percent volume of cold spot with the lowest seen at 0.5cm, the maximum dose is best achieved at 1.0cm and 1.5cm.

Table 2.1.2.1-2_ organs at risk

MSW (cm)	OARs	Min -dose (Gy)	%Vol<Cold ref (cm^3)	%Vol>Hot ref (cm^3)
0.5	**Bladder**	7.609	82.15	-
1.0		9.845	82.03	-
1.5		11.555	81.98	-
2.0		12.085	82.13	-
0.5	**Rectum**	2.126	87.52	
1.0		2.183	88.04	
1.5		2.091	87.29	
2.0		2.277	87.55	

The minimum doses to OARs changed with change in segment width. Looking at the bladder it increased with increasing segment width otherwise the other risk structures showed no differences as shown in the table.

3.2 Dosimetric verification (QA results)

3.2.1 ArcCHECK-SNC(2D) and ArcCHECK-3DVH(3D) gamma pass rates at different segment width.

In this section the results present comparison of dosimeter measured dose and planned TPS at different segment width for thorax cancer, prostate cancer and lung cancer.

Gamma passing rate was calculated at 3% dose difference and 2mm distance to agreement and a threshold of 20% with a pass rate of ≥95% was used to obtain optimum segment width for IMRT and VMAT plans. The results were established for 2D pass rate and 3D pass rate as shown in table 13. For all cases at different minimum segment width.

Table 2.1.2.1-1_ showing gamma passing rates at different segment width and treatment location

Lung location		
Minimum segment (cm)	**2D %GPR**	**3D %GPR**
0.5	95.4	97.7
1.0	93.6	95.5
1.5	94.4	97.1
2.0	91.4	95.8
Prostate location		
Minimum segment (cm)	**2D %GPR**	**3D %GPR**
0.5	84.5	79.8
1.0	88.1	83.1
1.5	82.7	83.4
2.0	86.8	89.3
Thorax location		
Minimum segment (cm)	**2D %GPR**	**3D %GPR**
0.5	93.8	97
1.0	97.9	99
1.5	97.9	99
2.0	94.7	97.4

3.2.1.1 ArcCHECK-SNC(2D) verification

The results obtained here show comparison of ArcCHECK-SNC measured dose and TPS calculated dose, the level of agreement was obtained from the gamma pass rate as indicated in the table above hence the following were the results:

For lung cancer the gamma pass rate was 95.4%, 94.6%, 94.4% and 91.4%, at 0.5cm,1.0cm,1.5 and 2.0cm respectively, hence, increasing segment width the pass rate slightly decreases and the plan quality did not improve much compared to plans at lower segment width. The estimated deviation is said to be within a <3%. The plan of 0.5cm showed a pass rate greater than 95%.

Thorax case indicated 93.8%, 97.9%, 97.9% and 94.1% at 0.5cm,1.0cm,1.5 and 2.0cm respectively, the highest pass rate is seen at 1.0cm and 1.5cm segment width and prostate cancer the gamma pass rate recorded 84.5%, 88.1%, 82.7%, and 86.8% at 0.5cm,1.0cm,1.5 and 2.0cm respectively with a deviation higher than 3%, the results for prostate cancer were poor as they did not pass the set criteria of ≥95%.

In general, the highest GPR% for lungs are observed at minimum segment width of 0.5cm, Thorax case indicated highest GPR% value 97.9% and 97.15 at 1.0cm and 1.5cm respectively while prostate cancer shows a high pass rate but below the acceptable level of 88.1% respectively at minimum segment width of 1.0cm and can considered for QA treatment planning. In case of thorax, deviation falls at ≤3%. Meanwhile, for lung cancer at MSW at 1.0 and 1.5 a slightly higher deviation outside 3% was seen the value does not show clinical significance.

3.2.1.2 ArcCHECK-3DVH(3D)

From table 3.2.1.2-1. results obtained from 3DVH verification using 3D gamma pass rate at 3%/2mm criterion for plans are shown. At 0.5cm segment width the GPR% was 95%, 93.8%, and 84.5% for lung cancer, thorax cancer and prostate cancer respectively. Thorax case shows a 100% GPR% at 1.0 and 1.5cm (table 2) therefore 1.0cm or 1.5cm minimum segment width is effectively suitable and can be considered for IMRT and VMAT thorax case plans as optimum. Meanwhile 0.5cm and 1.5cm MSW is suitable and can be considered in the planning of lung tumor case as it indicates a 97.7% and 97.1%GPR respectively.

For prostate cancer GPR% recorded was below 95% indicating poor pass rate with regard to the set criteria, no plan passed in this case. In order to find out the reasons for poor results 3D dosimetric system ArcCHECK was recalibrated and plans delivered again. The following were the results obtained. In both 2D and 3D plans

Table 3.2.1.2-2 _ showing gamma pass rate of prostate cancer after recalibration of the dosimetric ArcCHECK system

Prostate location		
Parameter	2D	3D
0.5	84.5	79.8
1.0	98.7	98.6
1.5	97.8	98.7
2.0	86.8	89.3

After recalibration we see improved results that passed the acceptance level, segment width 1.0cm and 1.5cm indicate better agreement and consistence. Hence can be considered in clinical practice as they have indicated optimum results. It can be noted that poor results can come from different aspects such as beam output by linac, TPS set up and dosimetric device calibration therefore it is important to investigate the problem so as to provide good results.

3.2.2 Dose distribution per segment width with respect to pass rate (GPR%)

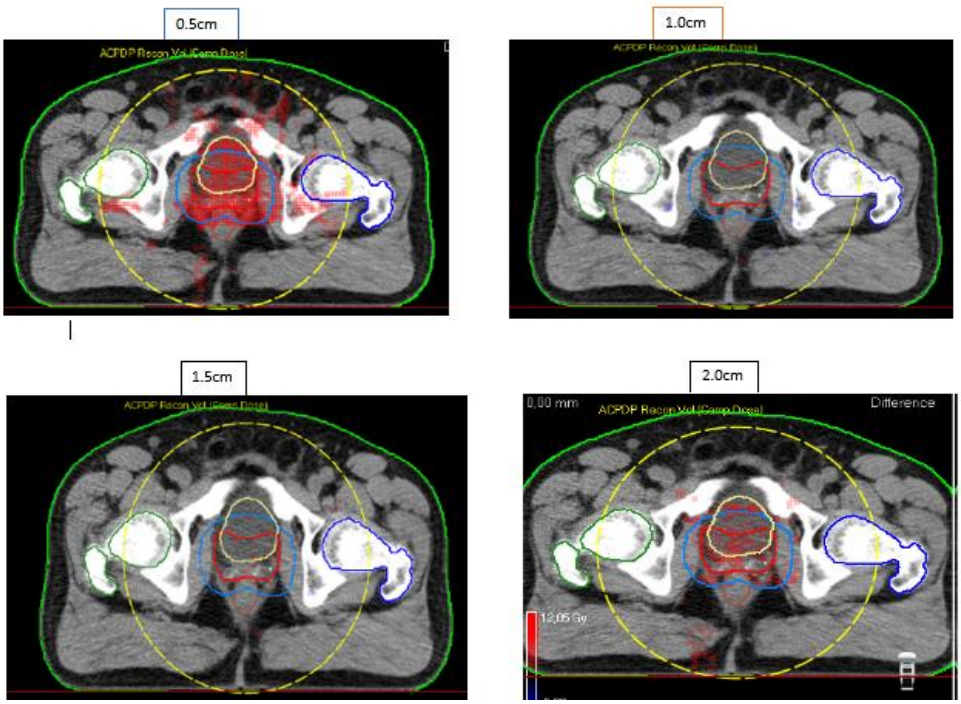

Figure 3.2.2-1_ example of dose distribution per segment width for prostate case

In order to understand GPR% in relation to dose distribution the results were evaluated and the results indicated that for:

Prostate: some hot spots in risk organs increases at 0.5cm and 2.0cm Hence reduction of GPR% at these segment widths. There is high pass rate at 1.0cm and 1.5cm due to improved good agreement in the measured dose and calculated dose.

Thorax: presences of some cold areas in target volume at minimum segment of 0.5cm and 2.0cm resulting in lower GPR% while 1.0cm and 1.5cm show uniform distribution with high GPR%.

Lung: at 0.5cm high areas of hot spot in target volume and cold spots in organs at risk, similar case is observed at 1.5cm resulting in high GPR% while at 2.0cm cold spots in target volume and at 1.0 high hot spots in organs at risk resulting in low GPR%.

3.2.3 Dose volume histogram

The solid lines indicate reference dose while the thin lines/dashed line represent comparison doses, color block is shown respective of the targeted structures and organs at risk

Lung case

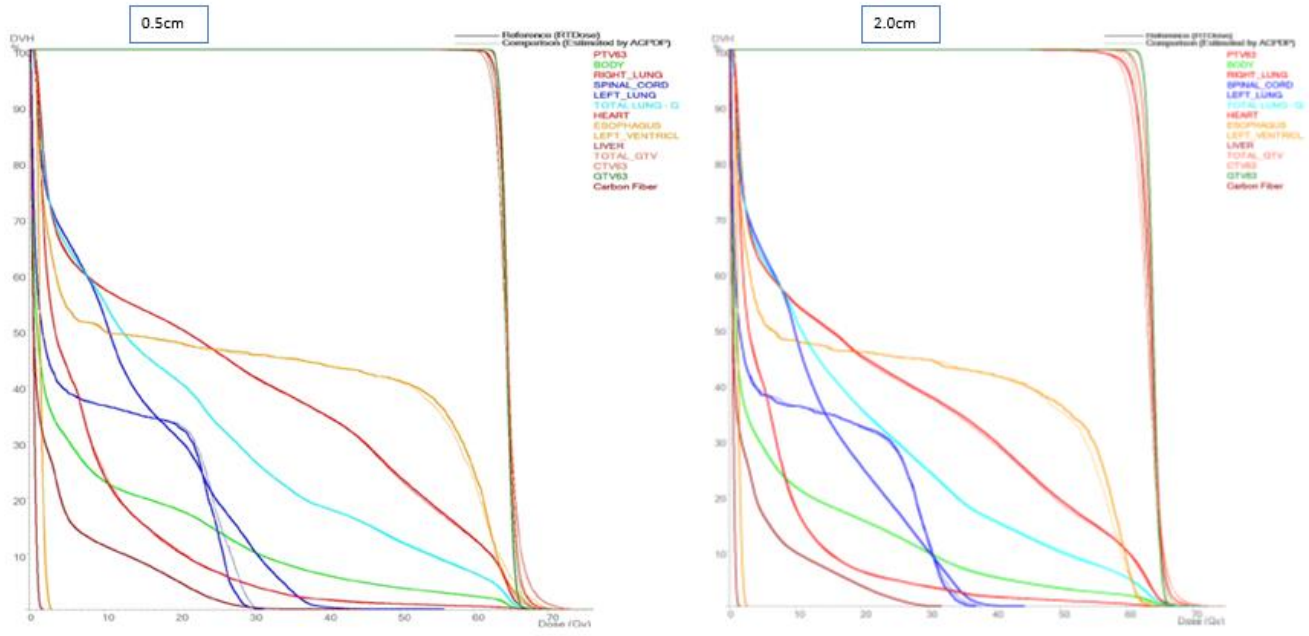

Figure 3.2.3-1_ An example of dose for lung case at segment width 0.5cm and 2.0cm

The solid lines indicate dose reference dose while the thin line represent the comparison dose, alongside is the color representing the structure under study. In all the plans 99% of the volume covered the prescribed dose to the target.

In terms of dose consistent between the reference dose and the comparison dose to target volume at different segment width there is observed more improved good agreement at segment width of 0.5cm and 1.5cm compared to segment with of 1.0cm and 2.0cm where small variations are seen between reference doses and comparison doses. In terms of organs at risk there is not much differences except for the spinal cord which shows a slight difference at segment width 0.5cm. otherwise all the plans showed very minimal dose at 99% of volume to organs at risk.

Thorax localization

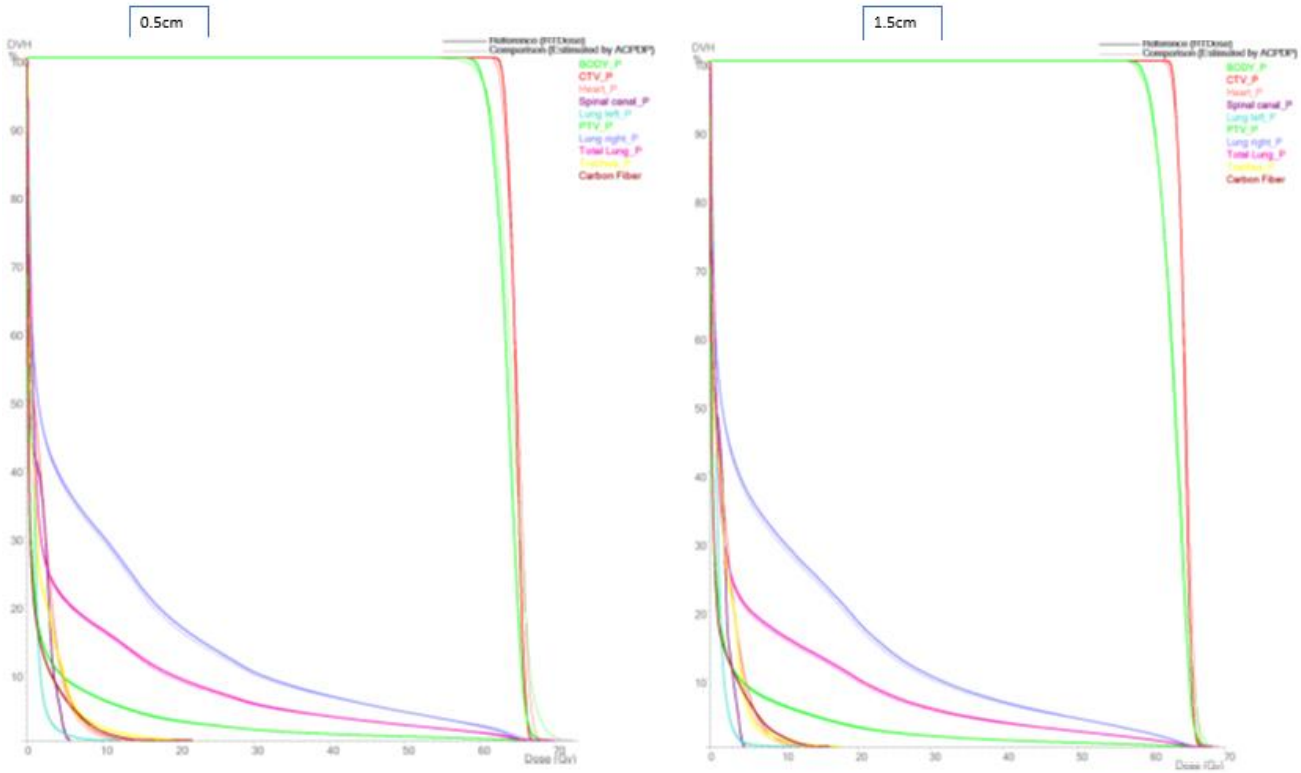

Figure 3.2.3-2_ Dose volume histogram at 0.5cm and 1.5cm for thorax case

For thorax localization DVH obtained in all plans showed no big differences between planned and comparison doses. However, the plan of 1.0cm and 1.5 showed greater agreement compared to other plans. Organs at risk obtained minimum doses which were within the constraint.

Prostate case

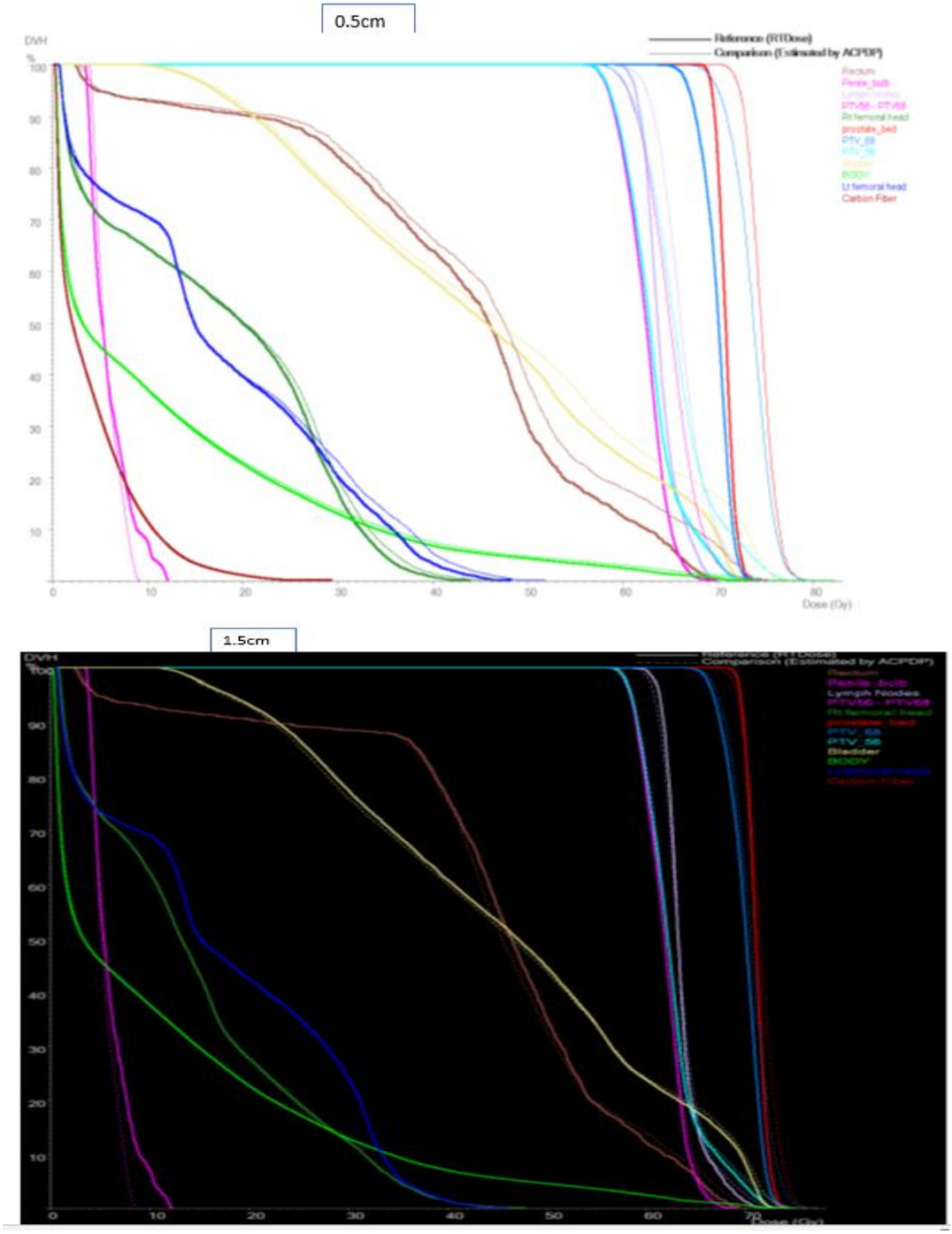

Figure 3.2.3-3_ Dose volume histogram at 0.5cm and 1.5cm for prostate case

Results obtained from DVH at segment width 1.0cm and 1.5cm improved consistent agreement between reference and comparison doses is observed while at 0.5 poor agreement and at 2.0cm we see significant dose variation in the reference dose and comparison dose.

3.2.4 DVH -based metrices evaluation

DVH -based parameters include reference dose, comparison dose and relative deviation dose given in Gy, for organs at risk (OARs) and target volume (PTV min, mean, max, CTV mean, min, max, GTV min, mean max) and %GPR were determined at different minimum segment widths.

DVH-based metrices for lung cancer (ROI)

Lung case

Table below shows the reference dose distribution, comparison dose distribution, the deviation dose and GPR% For lung cancer at different minimum segment width. There was very little differences between the planned doses and reconstructed doses resulting in a very insignificant relative deviation of ±1% at every segment width. The plans resulted in very good agreement at 0.5cm and 1.5cm segment width. There was total target coverage, although slightly increased target coverage at lower minimum segment width is observed. The GPR% was >95% despite the change in minimum segment width. The segment width at 1.5cm and 0.5 showed higher pass rate compared to another segment width hence can be considered.

Table 3.2.1.2-1_ DVH-based metrices for lung cancer (ROI)

MSW		Ref(Gy)			Comp(Gy)			Diff (Abs/%) Gy			GPR%
		Min	Mean	Max	Min	Mean	Max	Min	Mean	Max	
0.5	**PTV-63**	53.6	64.5	72	49.2	64.4	75.9	-5/-8	-0.01/-0.02	3.9/5.5	96.7
1.0		47.2	64	71.1	46	64.1	75.5	-1.2/-2.6	0.1/0.1	4.5/6.3	95.2
1.5		53.7	64	74	49.7	63.3	76.8	-4/-1.1	-0.7/-1.1	2.8/3.7	97.1
2.0		43.5	63.4	72.2	45.9	63	74.6	2.4/5.7	-0.3/-0.6	2.3/3.2	96
0.5	**CTV-63**	61.3	64.5	72	59.3	64.5	75	-1.9/-3.7	-0.09/-0.1	3/ 4.2	97.3
1.0		53	64.3	71.1	53.9	64.3	75.5	0.8/1.5	-0.01/-0.02	4.5/6.3	96
1.5		59.3	64.3	74	56.6	63.5	76.8	-2.6/-4.4	-0.8/-1.2	2.8/3.7	96.7
2.0		53	63	72.2	53.6	63.4	58.1	0.6/1.2	-0.4/-0.7	2.3/3.2	96
0.5	**GTV-63**	61.1	64.4	67.7	58.9	64.1	70	-1.9/-3.2	-0.2/-0.3	2.2/3.2	98.8
1.0		61.1	64.2	68.1	59.5	64	70.1	-1.6/-2.6	-0.2/-0.3	1.9/2.8	97.5
1.5		61.2	64.2	67.2	58.9	63.3	67.8	-2.3/-3.7	-0.9/-1.4	0.55/0.8	96.4
2.0		60	63.9	67.1	58.1	63.3	69.1	-2.2/-3.6	-0.6/-1	1.9/2.9	95.9

To further evaluate dose distribution to surrounding structures outside the target volume, DVH -based matrices were obtained analyzing minimum and maximum dose and GPR% for each plan.

With organs at risk for lung cancer, results indicate that the dose maximum, dose minimum to these structures (table 5) was even below the institutional recommended dose, not only that the dose was consistent too with very small deviation within ±3. The GPR% indicate that the plans were in good agreement hence minimum segment width of 1.5cm is more suitable and should be considered.

Table 3.2.1.2-2 _ DVH-based metrices for lung cancer (ROI/OARs)

MSW (cm)	ROI	Reference	Comparison	Diff (Abs/%)	GPR%
0.5	**Spinal-cord (max)**	31.5	31.8	0.28/0.9	93.8
1.0		32	34.9	2.8/9	93.1
1.5		30	31.6	1.6/5.3	99.4
2.0		37.2	37.9	0.6/1.8	98.6
0.5	**Heart (min)**	0.66	0.66	0/0	95.3
1.0		0.63	0.63	0	88.4
1.5		0.65	0.65	0	96.1
2.0		0.58	0.58	0	89
0.5	**Esophagus (min)**	0.69	0.69	0	94.8
1.0		0.64	0.64	0	96.2
1.5		0.71	0.71	0	97.5
2.0		0.59	0.59	0	97

DVH-based metrices for thorax cancer (ROI)

Thorax case

Thorax localization, there were some tiny differences observed in the minimum dose, mean dose and maximum dose between reference and comparison doses at segment width of 0.5cm and 2.0cm this showed very low pass rate. However greater agreement is observed at segment width of 1.0cm and 1.5cm indicating high pass rate of approximately 100%.

Table 3.2.1.2-3_ DVH-based metrices for Thorax cancer (ROI)

MSW		Ref			Comp			Diff (Abs/%)			
		Min	Mean	Max	Min	Mean	Max	Min	Mean	Max	GPR%
0.5	**PTV-P**	58.3	63.6	69.7	54.3	64.2	71.6	-3.8/-6.6	0.6/1	1.9/2.7	89.6
1.0		56.3	62.8	68.2	56.3	63.2	69.3	0/0.01	0.3/0.6	1.0/0.6	98.3
1.5		56.3	62.8	68.2	56.1	63	69	-0.2/-0.3	0.1/0.2	0.7/1.1	99
2.0		57	63.3	68.6	58.5	64.6	70.6	1.4/2.6	1.3/2.1	1.9/2.8	84.3
0.5	**CTV-P**	62	64.7	67.3	61.3	64.9	68.8	-5/-0.8	0.1/0.2	1.4/2.2	99
1.0		61.6	64.4	67.2	61.2	64.8	67.8	-0.3/0.5	0.3/0.5	0.6/0.8	100
1.5		61.2	64.4	67.2	61.1	64.5	67.6	-0.5/-0.8	0.1/0.2	0.4/0.6	100
2.0		62.4	64.8	67.1	62.2	65.3	68.8	-0.1/-0.2	0.5/0.8	1.7/2.5	97.6

From the table it be can deduced that varying minimum segment width did not affect the dose distributed to organs at risk, there was no notable difference between reference dose and comparison dose, therefore all plans were good and showed excellent dose consistent of 100% pass rate.

Table 3.2.1.2-4 _ DVH-based metrices for thorax cancer (ROI/OARs)

MSW (cm)	ROI	Reference	Comparison	Diff (Abs/%)	GPR%
0.5	**Heart (min)**	0.05	0.05	0	100
1.0		0.04	0.05	0	100
1.5		0.04	0.04	0	100
2.0		0.03	0.03	0	100
0.5	**Trachea (min)**	0.05	0.05	0	100
1.0		0.04	0.04	0	100
1.5		0.04	0.04	0	100
2.0		0.05	0.05	0	-

The minimum dose to organs at risk like the heart and the trachea shows no much differences there is better agreement especially at 0.5cm,1.5cm and 2.0cm segment width. In the cases the dose is within the acceptable standards are not significant to cause complications.

DVH-based metrices for prostate cancer (ROI)

Prostate case

The minimum deviation results between comparison measurement and reference showed a decrease with minimum segment width of 1.0cm and 1.5cm ±2, hence target coverage decreased at 0.5cm and 2.0cm for the case of prostate cancer. The %GPR is seen to have increased at segment width 1.0cm and 1.5cm it is at these segments where we see very consistent results agreeing between reference doses and comparison doses, these segments are preferred.

Table 3.2.1.2-5 _DVH-based metrices for prostate cancer (ROI)

MSW		Ref			Comp			Diff (Abs/%)			GPR%
		Min	Mean	Max	Min	Mean	Max	Min	Mean	Max	
0.5	**PTV-68**	63.2	69.7	74.5	66.3	73.5	82.1	3.0/4.8	3.7/5.4	7.6/10.2	1.9
1.0		64.1	69.8	74.7	63.0	68.9	76.2	-1/-1.7	0.1/0.1	1.4/1.8	95.8
1.5		63.0	69.7	74.3	63.1	70.0	77.1	0.1/0.3	0.6/0.9	2.8/3.7	95.7
2.0		62.8	69.6	75	64.3	72.2	79.9	1.5/2.3	2.5/3.6	4.8/6.4	53.8
0.5	**PTV-56**	55.2	62.9	73.4	56.2	65.7	78.9	1.0/1.8	2.7/4.4	5.4/7.4	44.8
1.0		55.6	63.0	74.7	55.2	63.2	75.6	-0.4/-0.7	0.2/0.3	0.8/1.1	96.2
1.5		55.8	62.4	73.7	54.9	62.4	75.5	-0.9/-1	0.2/0.3	1.8/2.4	97.6
2.0		55.1	62.1	73.5	55.7	64.3	77.7	0.6/1.1	2.1/3.4	4.1/5.6	65.4

The minimum dose between reference and comparison doses showed no much variation to OARs despite the segment width used, except for the bladder whose minimum dose differed and increased with increasing segment width. The segment 1.0cm and 1.5cm showed greater rate of agreement with high pass rates of 98.4% at 1.0cm and 98.1% at 1.5cm.

Table 3.2.1.2-6 _ DVH-based metrices for prostate cancer (ROI)

MSW (cm)	OAR	Reference	Comparison	Diff (Abs/%)	GPR%
		Min	Min	Min	
0.5	**Rectum**	2.1	2.6	0.4/23	84
1.0		2.2	2.5	0.3/14	98.4
1.5		2.1	2.6	0.5/23	98.1
2.0		2.3	2.6	0.3/14	86.9
0.5	**Bladder**	8.3	9.7	1.3/16	66.7
1.0		10.9	11.7	0.8/7.4	99
1.5		13	14	1/8	99.5
2.0		13.2	13.9	0.7/5	83.5

3.2.5 Analysis of 2D and 3D gamma pass rate comparison

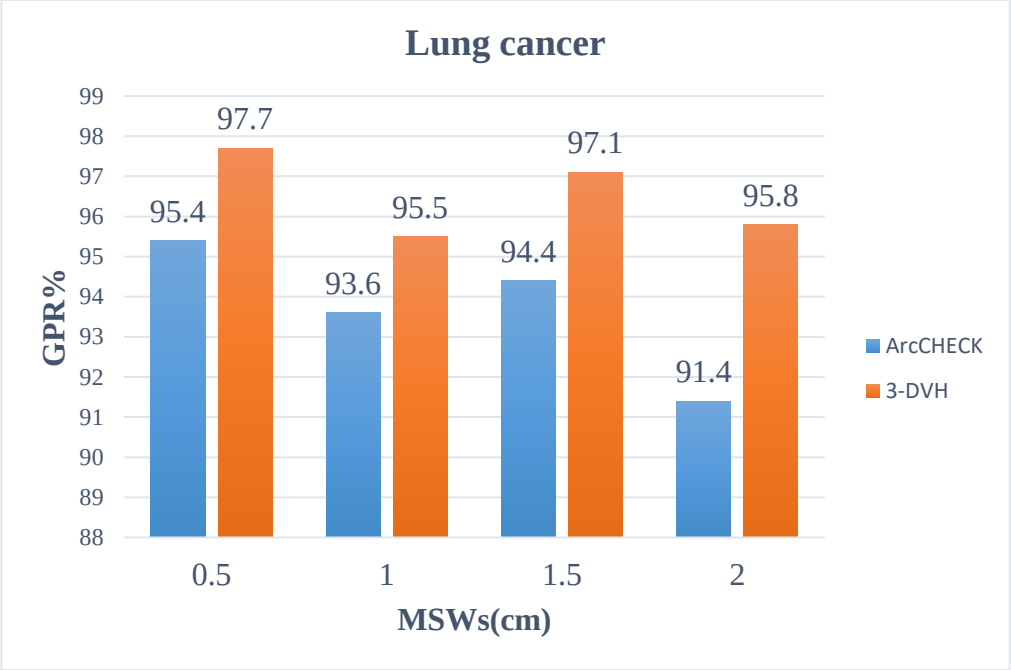

Figure 3.2.5-1_ gamma pass rate at various minimum segment width for lung cancer

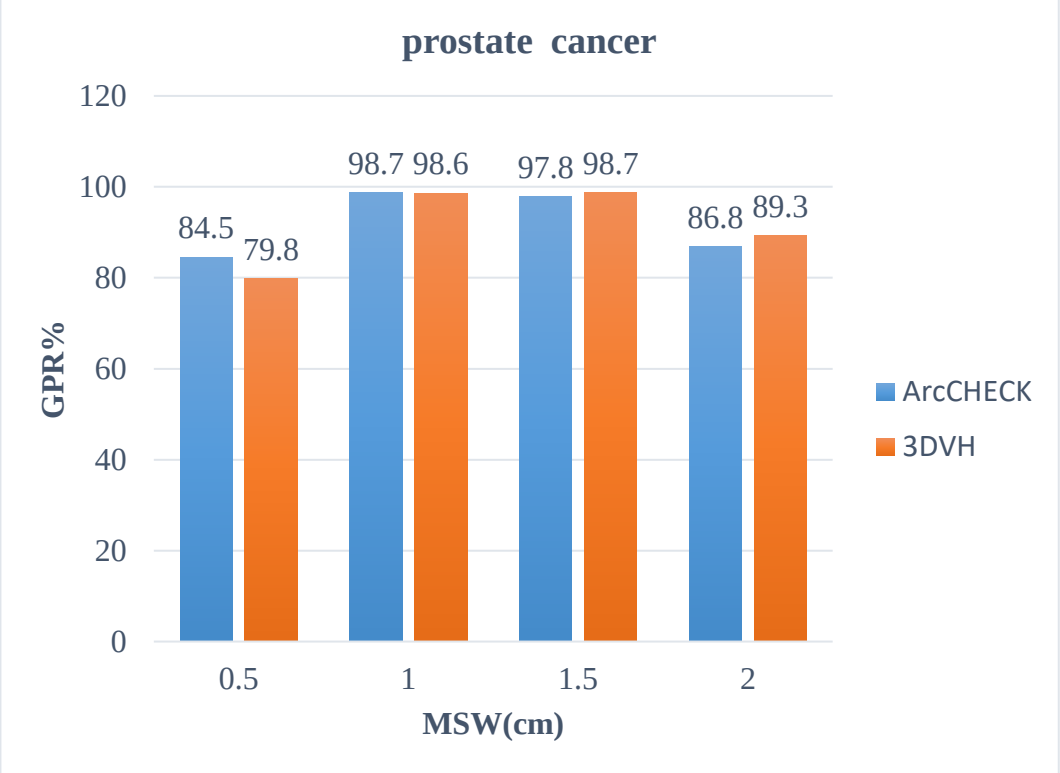

Figure 3.2.5-2_ gamma pass rate at various minimum segment width for prostate cancer

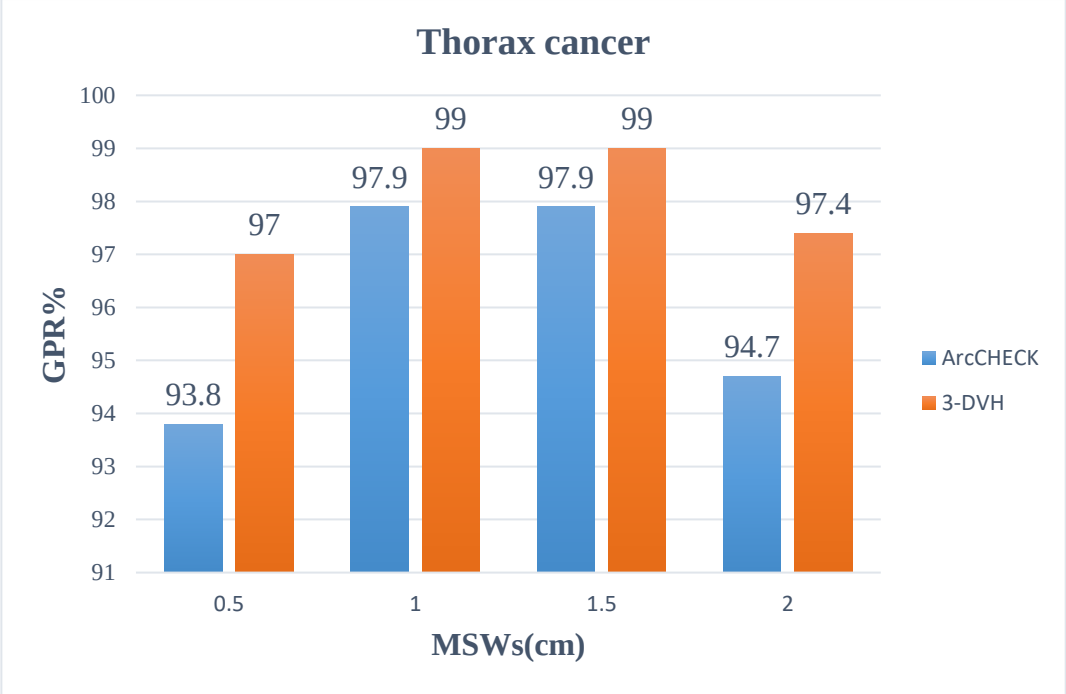

Figure 3.2.5-3_ gamma pass rate at various minimum segment width for thorax cancer

Figure 5_ 1 shows a plotted graph of %GPR for ArcCHECK and for 3DVH, the results indicate that using minimum segment width of 0.5cm is optimum, therefore in clinical practice one can consider using minimum segment of 0.5cm and 1.5cm for lung case. The proceeding figure is for prostate cancer, planning treatment for this case showed good results at minimum segment width of 1.0cm and 1.5cm. Considering figure 5_3 which shows the pass rate for thorax cancer, the study obtained excellent 99% pass rate at 1.5cm and 2.0cm minimum segment width, henceforth when planning for thorax it is recommended that one considers using 1.5cm and 2.0cm for an excellent plan delivery.

Conclusion

The need for optimal quality assurance in complex treatment plan such as IMRT/VMAT cannot be never be over emphasized. The goal was to optimize dose distribution and to determine universal minimum segment width (MSW) for IMRT and VMAT plans based on 3D dosimetric phantom for thorax cancer, prostate cancer and lung cancer. It is important to recognize that by varying the minimum segment width we change the complexity of the plan and the linac may not be able to deliver the dose to the patient as it was calculated in TPS.

From the results obtained it was determined that changing the minimum segment width changes the complexity of the plan and can increase or decrease number of segments and total monitor units calculated. There was improved plan quality, delivery accuracy and efficiency at optimum segment width with respective to tumor sites.

From quality assurance (QA) results optimum segment width results were determined to be 0.5cm and 1.5cm is optimal for lung cancer, 1.0cm and 1.5cm is optimal for thorax case. For prostate cancer only after recalibration of ArcCHECK dosimetry system were good results obtained, the reason for inconsistency was determined and poor results were eliminated, hence 1.0cm and 1.5cm was determine to be optimum. This segment width optimally meets the clinical requirement, therefore can be considered in clinical practice to improve accuracy dose delivery to patients undergoing IMRT and VMAT treatment for thoracic, lung and prostate cancers. The results of the study are vital to prostate, thorax and lung IMRT/VMAT only and the procedure used to determine the optimum segment width would be used in studies of other sites of IMRT/VMAT plans. It is also important to note that results may vary depending on the linear accelerator that is used, in this study Elekta synergy was employed.

Chapter 4 Financial management, resource efficiency and resource saving

The research investigates the influence of minimum segment width of intensity modulated radiotherapy plan based on QA plans, to this regard several resources were used and before the implementation of the research it is important to undertake the economic aspect of the project.

Radiotherapy is one effective mode of cancer treatment which has continued to gain popularity and advances. Complex treatment plans have been in clinical implementation since technological advances in radiotherapy, among these are intensity modulated radiotherapy and volumetric modulated arc therapy (IMRT/VMAT). These techniques have several advantages and are widely accepted, among the main reason of usage is that they allow maximum dose to be delivered to the tumor target and spare as much as possible dose exposure to critical organs. VMAT and IMRT increase the target coverage, conformity significantly compared with conformal radiotherapy (CRT), IMRT/VMAT also increase protection on OARs when compared to CRT. VMAT achieves a better dose conformity, less MU and shorter delivery time than IMRT. It has been reported on several cancer location that IMRT and VMAT can generate non uniform fields to achieve better planning target volume coverage while decreasing unnecessary radiation exposure to normal organs[46]. [47] study showed that 99.9% of PTV was covered by the prescribed dose with IMRT and VMAT compared to 88.9% of CRT. [48]study reported that VMAT showed significant dosimetric advantages both on target coverage and OAR sparing compared with CRT in the treatment of postoperative cervical cancer. However, no significant difference between IMRT and VMAT was observed except for slightly better dose conformity, slightly less MU and significant shorter delivery time achieved for VMAT. However, the use of such complex plan requires high levels of accuracy in exaction.

In this study three cancer sites were selected for the study and IMRT/VMAT plans generated with different penalties of minimum segment width during plan optimization. The research was conducted on clinical base at Tomsk oncology clinic

in Tomsk, Russia. Complex equipment and software were used for the research, Elekta synergy linear accelerator and ArcCHECK-3DVH dosimetric system for dose delivery and verification respectively. Elekta Synergy provides a suite of advanced guidance tools, imaging of soft tissue at the time of treatment allows efficient verification of tumor and critical structure position, providing increased confidence in dose placement. In terms of treatment Delivery Individualized patient care is possible through a range of techniques from 3D conformal techniques, through static and dynamic IMRT to VMAT. Enhanced dose conformance for individualized patient care is observed. [49]Elekta provides excellent beam-shaping capabilities across the range of delivery techniques with a range of advanced integrated multi-leaf collimators. Through fully integrated digital control with continuous real-time optical verification, accurate placement of all leaves allows for faster, safer and more accurate delivery.[50] its application is widely seen in several reports.

Because we cannot irradiate the actually patient during patient quality, we used the diode detector which works with 3DVH for dose verification. In order to check the accuracy of dose, compare between the planned dose and calculated dose and determine the gamma pass rate of each plan. Planning treatment, Monaco treatment planning system was used.

Financial management, resource efficiency and resource saving are an important aspect in implementing a project, it helps to measure the prospects and success of a research project enabling a plan to for managing and acquiring special support for implementation. It involves assessing the commercial potential, attractiveness to the target audience, SWOT analysis and so on as will show in this research.

The purpose of this section discusses the issues of competitiveness, resource efficiency and resource saving, 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 give an idea of working with them in each particular case. For the development of the project requires funds that go to the salaries of project participants

and the 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

4.1 Competitiveness analysis of technical solutions

In order to find sources of financing for the project, it is necessary, first, to determine the commercial value of the work. Analysis of competitive technical solutions in terms of resource efficiency and resource saving allows to evaluate the comparative effectiveness of scientific development. This analysis is advisable to carry out using an evaluation card.

The first aspect is to analyze possible technical solutions and choose the best one based on the considered technical and economic criteria.

Evaluation map analysis presented in Table below. In order to choose the optimal method, IMRT (C1), VMAT (C2), 3DCRT (C3) radiotherapy treatment planning techniques were adopted for competitiveness analysis. Where IMRT is intensity modulated radiotherapy, VMAT is volumetric modulated arc therapy and 3D-conformal radiotherapy. The position of this research and competitors is evaluated for each indicator on a five-point scale, where 1 is the weakest position and 5 is the strongest. The weights of indicators determined in the amount is 1. Analysis of competitive technical solutions is determined by the formula:

$$C = \sum W_i \cdot P_i,,$$

C - the competitiveness of research or a competitor;

Wi– criterion weight;

Pi – point of i-th criteria.

Table 3.2.1.2-1 _ Evaluation card for comparison of competitive technical solutions

Evaluation criteria	**Criterion weight**	**Points**			**Competitiveness** Taking into account weight		
		P_1	P_2	P_3	C_1	C_2	C_3
1	2	3	4	5	6	7	8
Technical criteria for evaluating resource efficiency							
1. Delivery time	0,1	4	5	3	0,4	0,5	0,3
2. Planning efficiency	0,25	4	4	3	1	1	0,75
3. Dose conformity	0,05	3	5	3	0,15	0,25	0,15
4. Energy efficiency	0,2	4	5	4	0,8	1	0,8
5. Reliability of results	0,1	5	5	4	0,5	0,5	0,4
6. Hardware availability	0,1	4	4	4	0,4	0,4	0,4
Economic criteria for performance evaluation							
1. Widely accepted method	0,1	5	5	3	0,5	0,5	0,3
2. Power application	0,05	4	5	4	0,2	0,25	0,2
3. Price	0.05	4	4	4	0,2	0,2	0,2
Total	1	37	42	32	4,15	4,6	3.5

The results from the table indicate that every technique has its own pros and cons which make them applicable for specific situation in clinical practice, with VMAT the best results are seen due to short delivery time and reliability of results but the hardware is readily available. However, 3DCRT is simple and easily available but there is less dose conformity as compared to the other methods, IMRT show similar score to VMAT and is popular however its time-consuming compared to VMAT. These techniques can be chosen depending on the specific requirement. However, and (C_1) and ($C_{2)}$ were used in the study.

4.2 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 stages. The first stage consists of describing 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.

Strengths are factors that characterize the competitive side of a research project. Strengths indicate that the project has a distinctive advantage or special resources that are special in terms of competition. In other words, strengths are the resources or opportunities that the project management has and which can be effectively used to achieve the goals.

Weaknesses are a lack, omission or limitation of a research project that impedes the achievement of its objectives. This is something that does not work well within the framework of the project or where it has insufficient capabilities or resources compared to competitors.

Opportunities include any preferable situation in the present or future that arises in the environment of the project, for example, a trend, change, or perceived need that supports the demand for project results and allows project management to improve their competitive position.

A threat is any undesirable situation, tendency or change in the environmental conditions of a project that is destructive or threatening in nature for its competitiveness in the present or in the future. A threat can be a barrier, restriction, or anything else that could cause problems, destruction, harm, or damage to the project.

Table 3.2.1.2-1 _ the Summary table of the SWOT analysis

	Strengths: S1. Accurate dose delivery. S2. Development of optimal and universal criterial for reproducibility based on clinical evidence.	Weaknesses: W1. Lack of equipment and software for dose verification; W2. Fewer stuff expertise. W3. No known acceptable criterial value for plan reproducibility.

Opportunities: O1. Improved tumor control for patients with lung, thorax and prostate cancers. O2. Increased ability to verify calculated dose before patient treatment. O3. Reduced treatment planning time	Strategy which is based on strength and opportunities: 1.Overall improvement in radiation treatment quality 2.There is confidence that the patient receives the prescribed dose correctly hence reducing underdose and overdose errors.	Strategy which is based on weaknesses and opportunities: 1.conducting clinical based studies on different tumor site will help provide clinical evidence studies which will in turn reduce treatment planning time. 2. Acquiring of equipment and software, training of medical physicists to work with treatment planning system (TPS) will help improve planning and verification QA system thereby improving tumor control and treatment time.
Threats: T1. Linear accelerator unable to deliver segment dose intensity as planned in treatment planning system. T2. Lack of interest among clinicians due to lack of evidence base in clinical research.	Strategy which is based on strength and threats: 1.It is necessary to always verify the ability of equipment reproducibility so that the planned dose is delivered accurately during patient treatment. 2.Publication of benefits and obtained results from studies and application of the methodology as standards in oncology center will create awareness and interest among users	Strategy which is based on weaknesses and threats: 1. Regular training of medical stuff will enable them to conduct Equipment QA verification 2. Encouraging clinical case studies within the center will help acquire interest and improve patient specific QA verification.

The results of the SWOT analysis are taken into account when developing the structure of work carried out as part of a research project.

4.3 Project Initiation

The initiation process group consists of 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 3.2.1.2-1 _Stakeholders of the project

Project stakeholders	Stakeholder expectations
Russian oncological clinic and cancer patients	Provides necessary radiotherapy equipment and resources to ensure completion of the project
Medical physicists	Create radiotherapy plans and dosimetric plans for QA plans Provides guidelines to decrease treatment plans errors
Oncologists	perform regular examination of patients and approve radiotherapy plans

This table shows the stake holders that will benefit from the results of the research, we have medical physicists who will have less time to plan for lung, thorax and prostate cancer. Quality assurance QA procedure will be less consuming.

Table 3.2.1.2-2 _Purpose and results of the project

Purpose of project:	To determine the optimal minimum segment width of Intensity modulated radiotherapy plan in treatment of thorax, lung and prostate cancers
Expected results of the project:	-Consistent dose distribution between planned dose and measured dose. -Improved target dose coverage and dose reduction to organs at risk. -Accurate dose delivery and decreased treatment time
Criteria for acceptance of the project result:	Dose to organs at risk to fall within defined constraints Adequate coverage of target volume at the level V95> 95% prescribed dose. Gamma index of 3%/2mm at 20% threshold with a pass rate ≥95%
Requirements for the project result:	The project to be completed by 1 june,2021 and meet the acceptance criteria
	Results should be presented at least two conferences and have a publication in the medical physics scientific journal.
	Industrial applicability
	Significance for research

In this table we see the purpose of the project being highlighted, criteria for acceptance of the project results, that is the dose delivered to critical structure should fall within the defined constraints, the target volume (PTV) should be covered adequately following prescribed dose. To understand the outcome of the results a gamma index criterion of 3%/2mm at 20% threshold will be used and with a pass rate ≥95% to know that the plan has passed.

4.3.1 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.

Table 3.2.1.2-1 _The working group of the project

№	Participant	Role in the project	Functions	Labor time, hours.
1	Scientific Supervisor	Head of project	-Formulation of research topic and direction of research -Review and Verification of the project Control of deadlines and research	45
2	Master's student	Executor	-Selection of main evaluation and scientific literature - Analyzing collected results - Writing up the dissertation	74

The table indicates the main working group of people that is the scientific supervisor who is the head of the project and the master's student who is responsible for executing the project, alongside is shown the number of hours for the entire project for each member the scientific supervisor is accounted for 45 hours while the student is accounted for 74 hours. The project takes a total of 119hours.

4.3.2 Project limitations

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

Table 3.2.1.2-1 _Project limitations

Factors	Limitations / Assumptions
3.1. Project's budget	**306661.63 Rubles**
3.1.1. Source of financing	Internal TPU
3.2. Project timeline:	01.02.2021-01.06.2021
3.2.1. Date of approval of plan of project	01.02.2021
3.2.2. Completion date	01.06.2021

This is the summary of the project budget it is scheduled for 01.02.2021 through to 01.06.2021. the total amount required is 306661.63 Rubles and the source of financing is from the internal TPU. Various aspects were considered in the calculations to finally arrive at the stated budget price.

4.3.3 Project Schedule

As part of planning a science project, one needs to build a project timeline and a Gantt Chart.

Table 3.2.1.2-1 _project timeline

Job title	Duration, days	Start date	Date of completion	Participants
Development of technical specifications	10	1.02.2021	11.02.2021	Scientific supervisor
Drafting and approval of the Terms of Reference	5	12.02.2021	17.02.2021	Scientific supervisor
Selection and study of scientific literature	25	18.02.2021	20.03.2021	Master’s student
Work scheduling	5	22.03.2021	26.03.2021	Scientific supervisor, master’s student
Selection of cases and creation of RT plans	10	27.03.2021	8.04.2021	Scientific supervisor

Performing measurements	5	9.04.2020	14.04.2021	Scientific supervisor, Master's Student
Analysis of the obtained experimental data	10	15.04.2021	26.04.202	Scientific supervisor, Master's Student
Compilation of results for report preparation	3	27.04.2021	29.04.2021	Master's student
Composition of master thesis report	6	30.04.2021	8.05.2021	Master's student
Defense preparation	20	10.05.202	1.06.2021	Master's student

Here it is shown the time line of the project, and the working group in charge, their responsibilities and duration, it is observed that the longer period is required for defense preparation and analysis of results.

A Gantt chart, or Harmon gram, is a type of bar chart that illustrates a project schedule. 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 3.2.1.2-2 _Calendar schedule of master's thesis performing

№	Activities	Participants	T_c, days	Duration of the project													
				February			March			April			May			June		
				1	2	3	1	2	3	1	2	3	1	2	3	1	2
1	Development of technical specifications	Scientific supervisor	10														
2	Drafting and approval of the Terms of Reference	Scientific supervisor	5														
3	Selection and study of scientific literature	Masters Student	25														
4	Work scheduling	Scientific supervisor, student	5														
5	Selection of cases and creation of RT plans	Scientific supervisor	10														

6	Performing measurements	Scientific supervisor, student	5													
7	Analysis of the obtained experimental data	Scientific supervisor, Student	10													
8	Compilation of results for report preparation	Masters Student	3													
9	Composition of master thesis report	Masters Student	6													
10	Defense preparation	Masters Student	20													

 – Scientific supervisor,  – Master's Student

4.4 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 Technician 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.

4.4.1 Calculation of material costs

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

$$C_m = (1 + k_T) \cdot \sum_{i=1}^{m} P_i \cdot N_{consi},$$

where m – 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 3.2.1.2-1 _Material costs

Name	Unit	Amount	Price per unit, rub.	Material costs, rub.
Office supplies	-	1	800	800
Internet	month	4	350	1400
Total				1200

The total cost of materials was calculated and found to be 1200 rubles; therefore, this amount is required to successfully obtained the materials for the project.

4.4.2 Calculation of the depreciation

For this research available equipment were used, hence the need to calculate depreciation:

$$A = \frac{C_{\text{перв}} * \text{Н}_\text{а}}{100}$$

A - annual amount of depreciation;

$C_{перв}$ - initial cost of the equipment;

$\text{Н}_\text{а} = \frac{100}{\text{Т}_\text{сл}}$ - rate of depreciation;

$T_{сл}$ - life expectancy

Table 3.2.1.2-1 _special equipment

№	Equipment identification	Quantity of equipment	Total cost of equipment (rub)	Life expectancy(year)	Depreciation for the duration of the project (rub).
1.	Irradiation unit	1	3000000	60	684.9
2.	ArcCHECK-diode detector	1	120000	10	164.4
3.	Computer	1	30000	5	1623.6
Total					2472.9

Following the above formular it was necessary to calculate the depreciation, for this project the depreciation amounts to 2472.9 rubles, taking into account the life expectancy and the quantity unit.

4.4.3 Basic salary

This point includes the basic salary of participants directly involved in the implementation of work on this research. 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:

$$S_{\text{b}} = S_a \cdot T_{\text{w}}\,, \tag{3.3}$$

where S_b – basic salary per participant;

T_{w} – the duration of the work performed by the scientific and technical worker, working days;

S_a - the average daily salary of a participant, rub.

The average daily salary is calculated by the formula:

$$S_d = \frac{S_m \cdot M}{F_{\text{v}}}\,, \tag{3.4}$$

where S_m – monthly salary of a participant, rub.;

M – the number of months of work without leave during the year:

at holiday in 48 days, M = 11.2 months, 6 day per week;

F_{v} – valid annual fund of working time of scientific and technical personnel (251 days).

Table 3.2.1.2-1 _The valid annual fund of working time

Working time indicators	
Calendar number of days	365
The number of non-working days - weekend - holidays	 52 14
Loss of working time - vacation - sick absence	 48 –
The valid annual fund of working time	251

Monthly salary is calculated by formula:

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

where S_{base} – base salary, rubles;

$k_{premium}$ – premium rate;

k_{bonus} – bonus rate;

k_{reg} – regional rate.

Table 3.2.1.2-2 _Calculation of the base salaries

Performers	S_{base}, rubles	$k_{premium}$	k_{bonus}	k_{reg}	S_{month}, rub.	W_d, rub.	$T_{p,}$ work days	$W_{base,}$ rub.
Scientific Supervisor	35120	–	–	1,3	45656	1891,7	45	85127,5
Master's Student	17310				22503	932,4	74	68997,6
Total								154125,1

The monthly basic salary was calculated using the formular stated under monthly basic salary. The salary of the scientific supervisor is at 35120 rubles according to TPU salary of associate professors, it was the calculated the base salary to be 85127,5 rubles. For a person with master's degree, it is estimated that they are paid 17310 rubles and the base salary calculated in this project leads to 68997,6. Therefor the total base salary for the working group is 154125,1rubles.

4.4.4 Additional salary

This stage includes the number 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:

$$W_{add} = k_{extra} \cdot W_{base},$$

where W_{add} – additional salary, rubles;

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

W_{base} – base salary, rubles.

Table 14. _additional salary

Table 3.2.1.2-1 _additional salary

Participants	Additional salary
Scientific supervisor	8512,75
Master's student	6899,76
Total	15412,51

Then it is necessary to calculate additional salary as explained above, the additional salary was calculated and is shown to be 15412,51 rubles in total for all working group.

4.4.5 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:

$$P_{social} = k_b \cdot (W_{base} + W_{add}) \quad \text{(x)}$$

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 3.2.1.2-1 _Labor tax

	Scientific supervisor	Master's Student
Coefficient of deductions	0.271	
Salary, rubles	93640,25	75897,36
Labor tax, rubles	25376,5	20568.2
Total	45944.71	

Tax to extra-budgetary funds is compulsory according to the norms established by the legislation of the Russian Federation. In this study it was calculated at 27%, the records show a total amount of 45944.71 rubles.

4.4.6 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:

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

where k_{ov} =50% – overhead rate.

Table 3.2.1.2-1 _Overhead cost

	Scientific supervisor	Master's student
Overhead rate	0.5	
Salary, rubles	93640,25	75897,36
Overhead, rubles	46820,13	37948,7
Total	84768,81	

The overhead cost calculated at 50% for both the scientific supervisor and the student amounts to a total of 84768,81rubles taking into account the base salary then determining the overhead cost.

4.4.7 Other direct costs

Energy costs are calculated by the formula:

$$C = P_{el} \cdot P \cdot F_{eq},$$

where P_{el} − power rates (5.8 rubles per 1 kWh);

P − power of equipment, kW;

F_{eq} − equipment usage time, hours.

Assuming that the PC work duration for this research is about 296 hours, where it operates 4 hours per day then in 74 days it operates for 222 kW/h(0.75kW). the linear accelerator measurement duration is 5 hours if measurement is taken in 1 hour, then in 5 days the linac operates at 250Kw/h (power is 50Kw). Energy costs which include equipment and computer work are calculated by the formula:

$$C = P_{el} \times P \times F_{eq} = 5.8 \times (50\text{kW} \times 5\text{hours} + 0.75\text{kW} \times 296\text{hours}) = 2737.6$$

Table 3.2.1.2-1 _other cost

Name	Power of equipment,	Amount	Price per unit, rub.	Material costs, rub.
1.Energy cost	50	250	5.8	472
2. Energy cost	0.75	296	5.8	222
Total				2737.6

The study also took into account other direct cost such as the electricity usage by the main equipment used that is the linear accelerator and the computer. The amount power was calculated the total cost is 2737.6 rubles.

4.4.8 Formation of budget costs

The calculated cost of research is the basis for budgeting project costs.

Table 3.2.1.2-1 _Items expenses grouping

Name	Cost, rubles
1. Material costs	1200
2. Depreciation	2472.9
3. Basic salary	154125.1
4. Additional salary	15412.51
5. Labor tax	45944.71
6. Overhead	84768.81
7. Other direct cost	2737.6
Total planned cost	**306661.63**

Table 17 indicates the total cost of research that is taking into account the material costs, depreciation cost, basic salary, additional salary, labor tax, overhead and other direct cost hence the total cost obtained from all calculation is stated at 306661.63 rubles.

4.5 Evaluation of the comparative effectiveness of the project

Determination of efficiency is based on the calculation of the integral indicator of the effectiveness of scientific research. Its finding is associated with the definition of two weighted average values: financial efficiency and resource efficiency.

The integral indicator of the financial efficiency of a scientific study is obtained in the course of estimating the budget for the costs of three (or more) variants of the execution of a scientific study. For this, the largest integral indicator of the implementation of the technical problem is taken as the calculation base (as the denominator), with which the financial values for all the options are correlated.

The integral financial measure of development is defined as:

$$I_{\phi}^{p} = \frac{\Phi_{pi}}{\Phi_{\max}}, \qquad \text{(x)}$$

where I_{ϕ}^{p} – integral financial measure of development;

Φ_{pi} – the cost of the i-th version;

Φ_{max} – the maximum cost of execution of a research project (including analogues).The obtained value of the integral financial measure of development reflects the corresponding numerical increase in the budget of development costs in times (the value is greater than one), or the corresponding numerical reduction in the cost of development in times (the value is less than one, but greater than zero).

Since the development has one performance, then $I_{\phi}^{p} = 1$.

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

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

where I_m – integral indicator of resource efficiency for the i-th version of the development;

a_i– the weighting factor of the i-th version of the development;

b_i^a, b_i^p – score rating of the i-th version of the development, is established by an expert on the selected rating scale;

n – number of comparison parameters.

The calculation of the integral indicator of resource efficiency is presented in the form of table below, where P_p is project point and A_a is analogy point, the method in comparison with project method is 3D-Conformal radiotherapy, taking into account weight coefficients are classified as C_p and C_a for project and analogy respectively.

Table 3.2.1.2-1 _Evaluation of the performance of the project

Evaluation criteria	**Criterion weight**	Point		Competitiveness Taking into account weight	
		A_a	P_p	C_a	C_p
1	2	3	4	6	7
Technical criteria for evaluating resource efficiency					
1. Delivery time	0,1	4	5	0,4	0,5
2. Planning efficiency	0,25	4	4	1	1
3. Dose conformity	0,05	3	5	0,15	0,25
4. Energy efficiency	0,2	4	5	0,8	1
5. Reliability of results	0,1	5	5	0,5	0,5
6. Hardware availability	0,1	4	4	0,4	0,4
Economic criteria for performance evaluation					
1. Widely accepted method	0,1	5	5	0,5	0,5
2. Power application	0,05	4	5	0,2	0,25
3. Price	0.05	4	4	0,2	0,2
Total	1	37	42	4,15	4,6

The points were evaluated in terms of delivery time, plan efficiency dose conformity, power application and many other as can be seen from the table.

The integral indicator of the development efficiency ($I^{p}_{финр}$) is determined on the basis of the integral indicator of resource efficiency and the integral financial indicator using the formula:

$$I^{p}_{финр} = \frac{I^{p}_{m}}{I^{p}_{ф}}, I^{a}_{финр} = \frac{I^{a}_{m}}{I^{a}_{ф}} \text{ and etc.} \quad (=)$$

Comparison of the integral indicator of the current project efficiency and analogues will determine the comparative efficiency. Comparative effectiveness of the project:

$$Э_{ср} = \frac{I^{p}_{финр}}{I^{a}_{финр}}. \quad (=)$$

Thus, the effectiveness of the development is presented in table 18.

Table 3.2.1.2-2 _Efficiency of development

№	Indicator	Project	Analog
1	Integral financial indicator	1	1
2	Integral resource efficiency indicator	4,15	4,6
3	Integral efficiency indicator	4,15	4,6
4	Comparative evaluation of the project execution variants	0,9	1,1

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.

Conclusion

During the calculations, the most important indicators were determined, which include: labor costs, social security contributions, overhead costs. The smallest expense item is material research costs. An article that makes up the high cost of a scientific project is the salary of people directly involved in creating a scientific project. The number of work performers is two: master's student and a supervisor from the TPU university. From the implementation of the economic part, calculations were made of the planned cost of the scientific project and the time required to carry out this work. The planned cost of work is 306661.63 rubles, the main component of which is the wages of employees.

The financial management, resource efficiency and resource saving analysis it can see that a large amount is distributed to paying salaries taking a share of 154125.1 ruble in basic salary plus additional salaries of 15412.51rubles as well as overhead cost taking 84768.81rubles. In every scientific undertaking financial management, resource efficiency and serving is a very import aspect to ensure successful completion of project

Chapter 5 Social responsibility

5.1 Introduction

Radiation therapy is a mode of cancer treatment which makes use of radiations, it can be delivered externally known as external beam radiotherapy or internally known as brachytherapy treatment. Because of this, medical stuffs and patients are at risk of exposure to ionizing radiation, not only this but work is done indoors there are harmful factors that can arise during work. It is necessary to limit exposure, analyze harmful factors that arises and ensuring occupation and public safety by following legal recommendations. This project investigates the influence of minimum segment width of intensity modulated radiotherapy (IMRT)plan based on quality assurance (QA) for three cancer sites that is lung, thorax and prostate cancer, it important to determine optimum and universal minimum segment width (MSW) for IMRT and VMAT plans based on 3D dosimetric phantom for thorax cancer, prostate cancer and lung cancer treatment. The study was conducted at Tomsk oncology clinic, Russia. The results of the project will benefit medical oncologist, medical physicists, and patients with prostate, thorax and lung cancer treated with IMRT and VMAT, giving confidence that the dose is delivered to the patient as was planned.

5.2 Legal and organizational items in providing safety

Nowadays one of the main ways 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 [51].

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.

5.3 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.

5.4 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 [51]. 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.

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

The object of investigation intensity modulated radiotherapy (IMRT) and volumetric modulated arc therapy (VMAT). The IMRT and VMAT plans are scheme for delivering ionizing radiation to the tumor. Therefore, object of investigation can create harmful factor of increased levels of ionizing radiation while implementing IMRT and VMAT plans for cancer treatment.

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

Working conditions in places of work are characterized by presence of hazardous and harmful factors, that are categorized in groups of physical, chemical, biological, psychophysiological. The main elements of the production process that form dangerous and harmful factors are presented in Table 1.

Table 3.2.1.2-1 _ Possible hazardous and harmful factors

Factors (GOST 12.0.003-2015)	Work stages			Legal documents
	Develop-ment	Manu-facture	Exploi-tation	
1. Deviation of microclimate indicators	+	+	+	Sanitary rules 2.2.2 / 2.4.1340–03. Sanitary and epidemiological rules and regulations "Hygienic requirements for personal electronic computers and work organization." Sanitary rules 2.2.1 / 2.1.1.1278–03. Hygienic requirements for natural, artificial and combined lighting of residential and public buildings. Sanitary rules 2.2.4 / 2.1.8.562–96. Noise at workplaces, in premises of
2. Excessive noise		+	+	
3.Increased level of electromagnetic radiation	+	+	+	
4.Insufficient illumination of the working area		+	+	

				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:

temperature and humidity;

noise;

static electricity;

electromagnetic field of low purity;

illumination;

presence of radiation;

psychophysiological:

psychophysiological dangerous and harmful factors are divided into:

physical overload (static, dynamic)

mental stress (mental overstrain, monotony of work, emotional overload).

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 [52] and are given in Table 2.

Table 3.2.1.2-2_Optimal and permissible parameters of the microclimate

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

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.

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 [52], 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.

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.

Table 3.2.1.2-3_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

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%.

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 as in table 5-4.

Table 3.2.1.2-4_ 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.

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

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 20 m^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.

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.

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 [52], 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.

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 aftermaths;

• 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.

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) [53].

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.

5.5 Ecological safety

5.5.1 Analysis of the impact of the linear accelerator 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.

5.5.2 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.

5.5.3 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 [53].

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.

5.6 Safety in emergency

5.6.1 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, etc.

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

5.6.2 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 [54].

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

In this section about social responsibility the hazardous and harmful factors were revealed. All necessary safety measures and precaution to minimize probability of accidents and traumas during investigation are given.

Possible negative effect on environment were given in compact form describing main ecological problem of using nuclear energy.

It could be stated that with respect to all regulations and standards, investigation itself and object of investigation do not pose special risks to personnel, other equipment and environment.

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