TOMSK POLYTECHNIC UNIVERSITY ТОМСКИЙ ПОЛИТЕХНИЧЕСКИЙ УНИВЕРСИТЕТ

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

School School of Nuclear Science & Engineering
Field of training (specialty) 14.04.02 «Nuclear physics and technology»
Division Division for Nuclear-Fuel Cycle

MASTER'S GRADUATION THESIS

Topic of research work
Radiation dose optimization based on personalized numerical voxel models of exposure area

UDC 539.16.04:615.849:519.876

Student

Group	Full name	Signature	Date
0AM8M	Stepan V. Melchenko		

Scientific supervisor

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

Adviser

Position	Full name	Academic degree, academic rank	Signature	Date
Full Professor	Brazovskii K.S.	PhD		

ADVISERS:

Section "Financial Management, Resource Efficiency and Resource Saving"

Position	Full name	Academic degree, academic rank	Signature	Date
Associate Professor	Menshikova E.V.	PhD		

Section "Social Responsibility"

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

ADMITTED TO DEFENSE:

Director of programme	Full name	Academic degree, academic rank	Signature	Date
Nuclear Medicine	Cherepennikov Yu.M.	PhD		

Tomsk – 2020

LEARNING OUTCOMES

Expected learning outcomes

Learning outcome (LO)code	Learning outcome (a graduate should be ready)	Requirements of the FSES HE, criteria and / or interested parties
	Professional competencies	
LO1	To apply deep mathematical, scientific, socio-economic and professional knowledge for conducting theoretical and experimental research in the field of the use of nuclear science and technology.	FSES HE Requirements (BPC-1,2, PC-3, UC-1,3), Criterion 5 RAEE (p 1.1) requirements of the Ministry of Health and Social Development of the Russian Federation under the unified skills guide for positions of managers, specialists and non-manual workers for the position of "medical physicist"
LO2	To demonstrate ability to define, formulate, and solve interdisciplinary engineering tasks in the nuclear field using professional knowledge and modern research methods.	FSES HE Requirements (PC-9,10,13,14,15, BPC-1,3), Criterion 5 RAEE (p 1.2) requirements of the Ministry of Health and Social Development of the Russian Federation under the unified skills guide for positions of managers, specialists and non-manual workers for the position of "medical physicist"
LO3	To plan and conduct analytical, simulation and experimental studies in complex and uncertain conditions using modern technologies, and to evaluate critically research results.	FSES HE Requirements (PC-1,13,22, UC-2, BPC-1), Criterion 5 RAEE (p 1.3) requirements of the Ministry of Health and Social Development of the Russian Federation under the unified skills guide for positions of managers, specialists and non-manual workers for the position of "medical

		physicist”
LO4	To use basic and special approaches, skills and methods for identification, analysis, and solution of technical problems in the field of nuclear science and technology.	FSES HE Requirements (PC-2,4,6,8, UC-2, BPC-1), Criterion 5 RAEE (p 1.4) requirements of the Ministry of Health and Social Development of the Russian Federation under the unified skills guide for positions of managers, specialists and non-manual workers for the position of “medical physicist”
LO5	To operate modern physical equipment and instruments, to master technological processes in the course of preparation for the production of new materials, instruments, installations, and systems.	FSES HE Requirements (PC-5,7,11,12, UC-2, BPC-1), Criterion 5 RAEE (p 1.4) requirements of the Ministry of Health and Social Development of the Russian Federation under the unified skills guide for positions of managers, specialists and non-manual workers for the position of “medical physicist”
LO6	To demonstrate ability to develop multioption schemes for achieving production goals with the effective use of available technical means and resources.	FSES HE Requirements (PC-16-21,23), Criterion 5 RAEE (p 1.5) requirements of the Ministry of Health and Social Development of the Russian Federation under the unified skills guide for positions of managers, specialists and non-manual workers for the position of “medical physicist”
Cultural competencies		
LO7	To demonstrate ability to use a creative approach to develop new ideas and methods for designing nuclear facilities, as well as to modernize and improve the applied technologies of nuclear production.	FSES HE Requirements (BPC-1,3, UC-3), Criterion 5 RAEE (p 2.4,2.5)
Basic professional competencies		

LO8	To demonstrate skills of independent learning and readiness for continuous self-development within the whole period of professional activity.	FSES HE Requirements (UC-3, PC-1, BPC-1), Criterion 5 RAEE (p 2.6) requirements of the Ministry of Health and Social Development of the Russian Federation under the unified skills guide for positions of managers, specialists and non-manual workers for the position of "medical physicist"
LO9	To use a foreign language at a level that enables a graduate to function successfully in the international environment, to develop documentation, and to introduce the results of their professional activity.	FSES HE Requirements (PC-11,16,17, BPC-3), Criterion 5 RAEE (p 2.2) requirements of the Ministry of Health and Social Development of the Russian Federation under the unified skills guide for positions of managers, specialists and non-manual workers for the position of "medical physicist"
LO10	To demonstrate independent thinking, to function efficiently in command-oriented tasks and to have a high level of productivity in the professional (sectoral), ethical and social environments, to lead professional teams, to set tasks, to assign responsibilities and bear liability for the results of work.	FSES HE Requirements (PC-18,23, UC-2), Criterion 5 RAEE (p 1.6,2.3) requirements of the Ministry of Health and Social Development of the Russian Federation under the unified skills guide for positions of managers, specialists and non-manual workers for the position of "medical physicist"

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School School of Nuclear Science & Engineering
Field of training (specialty) 14.04.02 Nuclear physics and technology
Division Division for Nuclear-Fuel Cycle

APPROVED BY:
Director of the programme
_____ _____ Cherepennikov Y.M
(Signature) (Date) (Full name)

ASSIGNMENT
for the Graduation Thesis completion

In the form:

Master's thesis

For a student:

Group	Full name
0AM8M	Stepan V. Melchenko

Topic of research work:

Radiation dose optimization based on personalized numerical voxel models of exposure area	
Approved by the order of the Director of School of Nuclear Science & Engineering (date, number):	

Deadline for completion of Master's Graduation Thesis:	19.06.2020

TERMS OF REFERENCE:

Initial data for research work: *(the name of the object of research or design; performance or load; mode of operation (continuous, periodic, cyclic, etc.); type of raw material or material of the product; requirements for the product, product or process; special requirements to the features of the operation of the object or product in terms of operational safety, environmental impact, energy costs; economic analysis, etc.)*	Computer Tomography data of patients with oncology diseases; 3D Slicer software with SlicerRT applications with open source code

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).*	Get familiar and analysis with the literature on the topic of work; Get familiar and analysis with the literature on the topic of work; work with source code of VIDA and XCOM applications; processing of computed tomography data in applications; radiation therapy planning; comparison of dose distributions on the processed and initial CT data; formulation of conclusions; financial management, resource efficiency and resource saving; social responsibility.

Advisors to the sections of the Master's Graduation Thesis

(with indication of sections)

Section	Advisor
Financial Management, Resource Efficiency and Resource Saving	Menshikova E.V.
Social Responsibility	Verigin D.A.

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

Assignment issued by a scientific supervisor / advisor:

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

Assignment accepted for execution by a student:

Group	Full name	Signature	Date
0AM8M	Stepan V. Melchenko		

TOMSK POLYTECHNIC UNIVERSITY ТОМСКИЙ ПОЛИТЕХНИЧЕСКИЙ УНИВЕРСИТЕТ

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School School of Nuclear Science & Engineering
Field of training (specialty) 14.04.02 Nuclear physics and technology
Level of education Master Degree Program
Division Division for Nuclear-Fuel Cycle
Period of completion 2018/2019 and 2019/2020 academic years

Form of presenting the work:

Master's Thesis

SCHEDULED ASSESSMENT CALENDAR

for the Master's Graduation Thesis completion

Deadline for completion of Master's Graduation Thesis:	19.06.2020

Assessment date	Title of section (module) / type of work (research)	Maximum score for the section (module)
03.02.2020	Drawing up and approving the terms of reference	10
03.03.2020	Selection and study of materials on the topic	10
10.03.2020	Choice of research area	15
27.04.2020	Conducting experiments	25
17.05.2020	Analysis and description of results	25
01.06.2020	Preparing for thesis defense	15

COMPILED BY:
Scientific supervisor

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

Adviser

Position	Full name	Academic degree, academic rank	Signature	Date
Full Professor	Brazovskii K.S.	PhD		

AGREED BY:
Director of the programme

Position	Full name	Academic degree, academic rank	Signature	Date
Associate Professor	Cherepennikov Yu.M.	PhD		

TASK FOR SECTION

«FINANCIAL MANAGEMENT, RESOURCE EFFICIENCY AND RESOURCE SAVING»

For a student:

Group	Full name
0AM8M	Stepan V. Melchenko

School	School of Nuclear Science & Engineering	Division	Division for Nuclear-Fuel Cycle
Degree	Master Degree Program	Field of training/programme	14.04.02 Nuclear physics and technology / Nuclear medicine

Input data to the section «Financial management, resource efficiency and resource saving»:	
1. Resource cost of scientific and technical research (STR): material and technical, energetic, financial and human	Depreciation and amortization of equipment and electricity costs 45 rubles Main salary of performers 155676 rubles Additional salary of performers of the project 15567,6 rubles Contributions to extrabudgetary funds 46407,02 rubles
2. Expenditure rates and expenditure standards for resources	Tariff for industrial electricity 2,45 per 1 kW Tomsk city district coefficient - 1,3
3. Current tax system, tax rates, charges rates, discounting rates and interest rates	The amount of insurance premiums is 30% Reduced rate in Tomsk - 27,1 %
The list of subjects to study, design and develop:	
1. Assessment of commercial and innovative potential of STR	Competitive technical solutions evaluation map
2. Scheduling of STR management process: structure and timeline, budget, risk management	Hierarchical structure of work
3. Determination of resource, financial, economic efficiency	Evalution of technical solutions competitiveness SWOT Matrix Schedule and budget for the scientific research Gantt Chart
A list of graphic material *(with list of mandatory blueprints):*	
1. Evaluation of the competitiveness of technical solutions *2. SWOT- analysis* *3. Gantt chart and budget of scientific research* *4. Assessment of resource, financial and economic efficiency of STR* *5. Potential risks*	

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

The task was issued by adviser:

Position	Full name	Academic degree, academic rank	Signature	Date
Associate Professor	Menshikova E.V	PhD		

The task was accepted by the student:

Group	Full name	Signature	Date
0AM8M	Stepan V. Melchenko		

TASK FOR SECTION
«SOCIAL RESPONSIBILITY»

For a student:

group	Full name
0AM8M	Stepan V. Melchenko

School	School of Nuclear Science & Engineering	Division	Division for Nuclear-Fuel Cycle
Degree	Master Degree Program	Field of training/programme	14.04.02 Nuclear Physics and Technology/Nuclear Medicine

Title of master work:

Radiation dose optimization based on personalized numerical voxel models of exposure area	
Initial data for section «Social Responsibility»:	
1. Information about object of investigation (matter, material, device, algorithm, procedure, workplace) and area of its application	Study of the possibility of using voxel-based analysis in planning radiation therapy on PC. Application area: radiation therapy 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.	–Labour 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	–Enchanced electromagnetic radiation level –Insufficient illumination of workplace –Excessive noise –Deviation of microclimate indicators –Electric shock –Ionizing radiation
3. Ecological safety:	–Indicate impact of linear accelerator on hydrosphere, atmosphere and lithosphere –Indicate impact of high frequency radio waves

	generators on hydrosphere, atmosphere and lithosphere
4. Safety in emergency situations:	Fire safety;

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

The task was issued by adviser:

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

The task was accepted by the student:

Group	Full name	Signature	date
0AM8M	Stepan V. Melchenko		

ABSTRACT

Master's Graduation work 90p., 19 fig., 22 tab., 30 sources.

Keywords: voxel-based analysis, voxel-based method, radiation therapy, medical physics, dose-volume histogram.

The object of research is voxel-based method in radiotherapy accounting elemental composition of the tissue substance.

Purpose of work – investigation of the voxel-based method of external radiation therapy planning using elemental composition analysis.

In the process of research, a literature review was conducted on the topic of scientific research, the study of the use of the voxel-based method in radiotherapy studies, the possibility of taking into account the elemental composition of body tissues when planning radiation therapy, the effect of taking into account coherent scattering taking into account the elemental composition in tissues on the construction of a dose-volume histogram.

As a result of the study, the elemental composition of some body tissues was analyzed using databases; graphically investigated the effect of taking into account coherent scattering on the elements when planning radiation therapy; analysis and comparison of the data; evaluated the financial component of the work; external factors affecting the work are described.

Degree of implementation: currently, the subject of research is at the stage of theoretical study and computer modeling.

Application area: medical physics, radiation therapy planning.

Cost effectiveness/significance not installed at the moment, because the subject of the study is at the stage of theoretical study.

Planned in the future: to test the method in medical planning systems on real cases of patients.

Contents

Introduction

Oncological diseases are an urgent problem of modern medicine and one of the main causes of death nowadays. An increase in the quantity and quality of medical care provided to cancer patients is highly required. Significant funds are invested by governments of ionizing radiation with the tissues of the body, and specifically, the tumor, after which it dies. The potential of radiation therapy is realized through detailed radiation planning and the careful implementation of all the rules and regulations during the long-term treatment. all states to explore new ways of treating and preventing cancer. The development of a variety of treatment methods can reduce the number of deaths and increase the duration and quality of life for cancer patients.

At the moment, one of the best and widely demanded methods of treating cancer is radiation therapy. It is based on the interaction.

RT has gone through many modernizations and has now achieved high accuracy in bringing AI to the tumor volume. Initially, with the discovery of the effects of radiation on biological structures, it became clear that oncological diseases behave similarly to normal tissues when interacting with radiation, however, during radiotherapy, healthy organs were often exposed to radiation, and most importantly, risk organs were vital components of the human body.

To reduce the radiation damage on critical organs and improve target coverage, various dose computation algorithms have been developed, of which there are several. This paper proposes a new method for dose computation in anatomical images based on voxel analysis that includes accounting of various elements instead of only electron density. A comparison is made for radiation therapy planning on CT images with and without voxel-based method.

Relevance: today requires a more accurate delivery of radiation doses to targets, minimizing damage to healthy tissues by radiation. Modern dose calculation algorithms rely on heterogeneity based on different densities of water-equivalent tissue without considering its elemental composition. The method under consideration is expected to reduce the dose load on critical structures due to

greater sensitivity to the heterogeneity of the elemental composition of the target and adjacent organs.

1 Theoretical part

1.1 History of radiation therapy

Radiation therapy is a branch of the clinical discipline that uses ionizing radiation to treat tumor and some non-tumor diseases. The history of radiotherapy began with the discovery of X-rays by William Roentgen in 1895. The first empirical cancer therapy using gamma rays to treat a superficial tumor was performed only a few months after the first discovery report. Radioactivity was discovered by Henri Becquerel in 1896, followed by Maria and Pierre Curie in 1898.

After 1898, techniques based on radium treatment began to grow. The first empirical therapies using gamma rays were performed to affect mainly superficial tumors. However, the first experiments of radiation treatment were unsuccessful due to ignorance of many physical properties of radiation and the characteristics of its biological effect. Then scientists working with radiation, drew attention to the burns. The case is well known when A. Becquerel demonstrated the properties of radium at one of the conferences and put the test tube with the sample in his pocket. A few days later severe burns and ulcers appeared on the skin in the pocket area. This led scientists to the idea of using radiation to treat cancer patients.

During the next three decades, only a few specialists practiced radiotherapy, who varied with various treatment parameters (for example, dose, field size, position) in accordance with their experience and the daily condition of the patients. This lasted until the early 1940s, when the basic laws of modern radiation therapy (RT) were created and cancer treatment became better. The new laws at that time made it possible to create a set of rules that determined that it was necessary to determine the size, shape and volume of the irradiated area and that this volume should receive a uniform dose distribution as much as possible. It was also clear that the dose for healthy tissues outside the irradiation area should be minimized and it was important to collect statistics on patients with this type of

disease in order to collect information on the correct dose distribution. Modern radiation therapy is largely based on the above principles.

External radiation therapy developed with early radium (Ra-226) therapy in the 1920s, then through 700-800 kV orthovoltage units in the 1930s, and ultimately 1.25 MeV (average energy) Co-60 in the 1950s . Since the introduction of the 6-MeV medical linear accelerators (linac) in 1953. the practicality and effectiveness of the multidisciplinary RT procedure has been significantly increased. The improvements were due to a significant increase in the percentage depth of the dose of the curves and a decrease in the scattering of kilovolt X-ray radiation, which allowed the use of fewer treatment fields. This in turn led to a reduction in the dose to normal tissues and better coverage of the target. A linear accelerator has a clear advantage in that it does not require replacement of a radioactive radiation source. Instead, x-rays are created by electron acceleration in the waveguide, which allows particles to collide with a metal plate, the so-called x-ray target. The bremsstrahlung generated by the incident electron beam is used for treatment. Currently, medical linear accelerators can have several energy modes (accelerating voltage) from 4 MeV to 25 MeV. The linear accelerator largely replaced the previously created installations for an external RT. Although Co-60 is still used in countries where radiation therapy is only developing, mainly because of its ease of maintenance. Co-60 gamma rays are also used for special radiosurgical tasks, such as a gamma knife device.

After the invention of the medical linear accelerator, major advances in radiation therapy were made in the field of treatment planning, which is controlled by computer systems. The multi-petal collimator (MLC), which appeared on the market in the 1980s, made it easy to deliver the dose for the corresponding projection onto the target. For more advanced use, individual MLC lobes move independently under computer control at the desired speed. This allows you to create spatially modulated radiation fields, since each lobe weakens the beam with a different time period. As a result, transverse beam intensity modulation (IMRT) therapy has created high dose levels that best match the shape of a complex target.

Integration of the X-ray image receptors for the linear accelerator made it possible to obtain patient images before each treatment session in order to track the movement of the tumor during treatment. These modifications of RT allowed to improve the accuracy of patient positioning and to limit the movement of the tumor during treatment [23].

Modern radiation therapy is based on complex calculation systems using various algorithms for calculating the dose received by the target. The type of algorithm used depends on the location of the target and critical organs in the patient's body. For the simple geometry of their arrangement, relatively simple algorithms, such as the pencil and conimbus, can be used. But in most cases, the use of these algorithms is unacceptable, since tumors are surrounded by critical organs. For such cases, algorithms such as covolution, superposition, and the Monte Carlo method are used.

Another important parameter is the method of reading medical images. Computed tomography and radiation therapy uses the Hounsfield number philosophy. It assumes a difference in the patient’s tissues and organs in the images, as a combination of a substance with different electron density. The known electron density is used to estimate the transmission capacity for radiation. The disadvantage of this method is the neglect of differences in the elemental composition of tissues. For example, bone contains much less water and its components, oxygen and hydrogen, unlike bone, where carbon and calcium predominate.

In this paper, we consider the option of accounting for data of elemental differences in tissues and calculation of dose loading adjusted for elemental composition.

1.2 Model-based dose computation algorithms

A model-based computational algorithm computes dose distribution in target with a physical model that simulates the factual radiation transport. Because of its ability to model photon energy fluence incident at a point and the distribution

of energy subsequent to primary photon interaction, it's able to simulate the scattered photons and electrons transport away from the interaction area. A class of model-based algorithms, called convolution-superposition, has been under development since the mid-1980s.

1.2.1 Convolution-superposition

A convolution-superposition method involves a convolution equation that separately considers the transport of primary photons and that of the scatter photon and electron emerging from the primary photon interaction. The dose $D(\vec{r})$ at a point r is given by

$$D(\vec{r}) = \int \frac{\mu}{\rho} \Psi_p(\vec{r}\,') A(\vec{r} - \vec{r}\,') d^3\vec{r}\,' = \int T_p(\vec{r}\,') A(\vec{r} - \vec{r}\,') d^3\vec{r}\,' \quad (1)$$

where μ/ρ is the mass attenuation coefficient, $\Psi_p(\vec{r}\,')$ is the main photon energy fluence, and $A(\vec{r} - \vec{r}\,')$ is the convolution kernel (a matrix of dose distribution deposited by scattered photons and electrons set in motion at the primary photon interaction site). Figure 1 shows the geometry of the radiation transport. The mass attenuation coefficient and the main energy fluence product is called terma, $T_p(\vec{r}\,')$, which stands for total energy released per unit mass. Terma is analogous to kerma, which represents the kinetic energy released per unit mass in the form of electrons set in motion by photons. The product of terma and the dose kernel when integrated (convolved) over a volume gives the dose $D(\vec{r})$ as given in Equation (1).

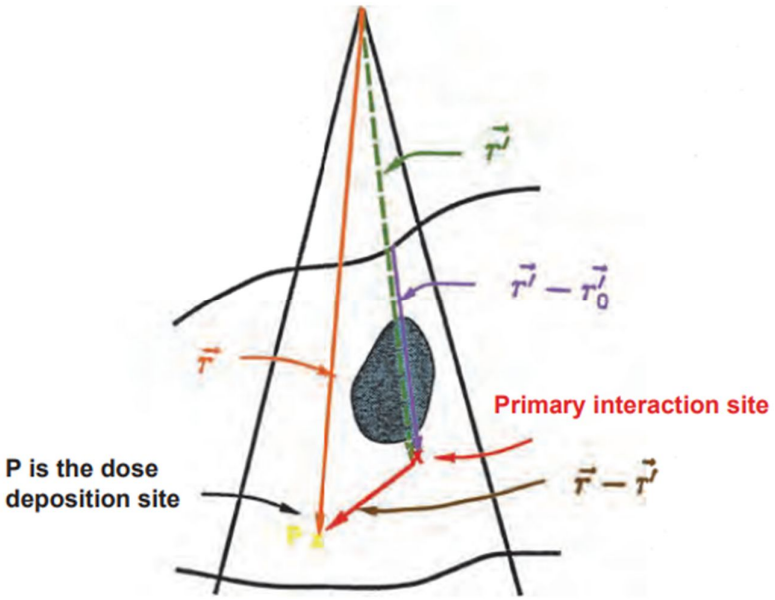


Figure 1. Geometry of photon interaction and radiation transport from the site of interaction

The convolution kernel, $A(\vec{r}-\vec{r}')$, can be represented by a dose spread array obtained by calculation or by direct measurement. The most commonly used method is the Monte Carlo, which simulates interactions of a large number of primary photons and determines dose deposited in all directions by electrons and scattered photons originating at the primary photon interaction site. Figure 2 shows a ^{60}Co kernel for water generated by a Monte Carlo program (EGS4 Monte Carlo code). Examination of dose distribution in the kernel indicates that the dose deposition by the kernel is forward peaked, as expected for a megavoltage photon beam.

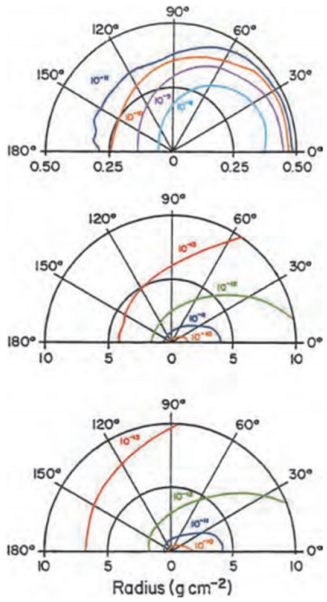


Figure 2. Cobalt-60 dose kernels for water computed with Monte Carlo simulation. Top: Primary contribution by electrons set in motion by primary photons. Middle: The first-scatter contribution. Bottom: The sum of primary and scatter contributions.

Modeling of primary photon transport and the calculation of dose kernel for a linear accelerator x-ray beam requires knowledge of the photon energy spectrum. Monte Carlo may be used to calculate the energy spectrum of a linac beam. Such spectra can be used both for the transport of primary photons and the generation of a dose kernel by the Monte Carlo method.

Thus, the Monte Carlo–generated energy spectrum and the kernel are essential ingredients of the convolution equation to compute dose at any point in the patient. One of the important tasks of commissioning a treatment-planning system that uses a convolution equation such as Equation (1) is to modify (tweak) the Monte Carlo–generated energy spectrum in order to fit the modeled beam with the measured depth dose distribution and cross-beam dose profiles as a function of field size and depth.

A convolution equation modified for radiologic path length (water relative distance which corrected for electron density) is called the convolution-superposition equation:

$$D(\vec{r}) = \int T_p(\rho_{\vec{r}} \cdot \vec{r}\,') A(\rho_{\vec{r}-\vec{r}\,'} \cdot (\vec{r} - \vec{r}\,')) d^3\vec{r}\,' \quad (2)$$

where $(\rho_{\vec{r}} \cdot \vec{r}\,')$ is the radiologic path length from source to the main photon interaction area and $\rho_{\vec{r}-\vec{r}\,'} \cdot (\vec{r} - \vec{r}\,')$ is the radiologic path length from the area of main photon interaction to the dose deposition site. The dose kernel $A(\rho_{\vec{r}-\vec{r}\,'} \cdot (\vec{r} - \vec{r}\,'))$ can be calculated by using range scaling by electron density of the Monte Carlo–generated kernel in water. Figure 3 shows that the kernel obtained with the range-scaling method compares well with that generated by Monte Carlo directly for the heterogeneous medium [2,3].

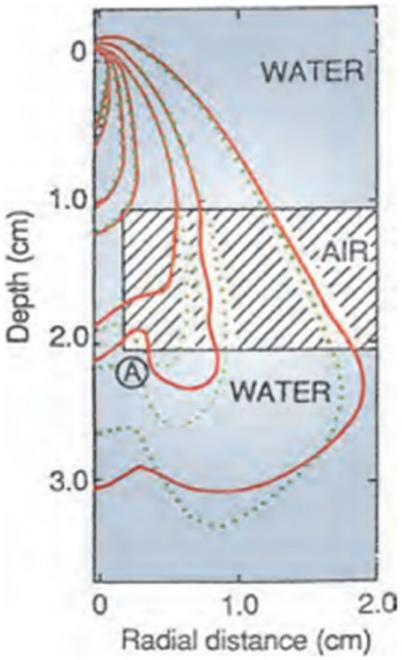


Figure 3 Comparison of Monte Carlo–generated 6-MeV primary photon kernel in a water phantom containing a ring of air. The continuous line is a kernel computed expressly for the heterogeneous situation. The dashed line is a kernel modified for the heterogeneous phantom using range scaling.

1.2.2 Monte Carlo method

The Monte Carlo technique consists of a computer program (MC code) that simulates the transport of millions of photons and particles through matter. It uses fundamental laws of physics to determine probability distributions of individual

interactions of photons and particles. The larger the number of simulated particles (histories), the greater the accuracy of predicting their distributions. However, as simulated particles number is increased, the computational time becomes prohibitively long. So the challenge in writing an MC code is that of being able to use a relatively small sample of randomly selected particles to predict the average behavior of the particles in the beam. The dose distribution is calculated by accumulating (scoring) ionizing events in bins (voxels) that give rise to energy deposition in the medium. It is estimated that the transport of a few hundred million to a billion histories will be required for radiation therapy treatment planning with adequate precision. A number of MC codes has been used in radiation transport simulation and, more recently, in treatment planning [4-7].

Notwithstanding inordinate amounts of computational times, Monte Carlo is the most precise method of dose distribution calculation in a patient. Sample plans done with Monte Carlo simulation have shown improvements in dose calculation accuracy, especially at interfaces of heterogeneous tissues and in lung where particle disequilibrium can occur under certain conditions. With the continuing advancement in computer technology and computation algorithms, it now seems probable that the Monte Carlo methodology will be implemented for routine treatment planning in the not too distant future.

1.3 Dose evaluation methods

To achieve the most favorable outcome of treatment, it is necessary to achieve the most accurate dose delivery to the target organ, as well as to avoid excessive irradiation of critical organs and normal body tissues. For this, it is necessary at the planning stage of radiation therapy to know how the dose will be distributed in the patient's body. For this, various methods for assessing the dose load on the patient’s tissue are used.

1.3.1 Isodose curves

The absorbed dose values on the central beam axis can be described in table or graphically for data like the central axial percentage dose distribution,

tissue-air ratio, or tissue-maximum ratio. However, these data do not allow to determine dose in the tissue outside central axis. This problem can be solved by isodose curves (IC). Each isodose curve shows point geometric location at which the absorbed dose is a certain dose percentage on the central beam axis at a depth d_{max} in a tissue-equivalent medium of unit density.

A set of isodose curves defines dose changes as a depth and distance function from the central axis which is called an isodose map. There are two categories of these maps:

a) irradiation at SSD = const, regardless of the direction of the beam (Fig. 4, A);

b) the isodose curves are normalized at a certain depth behind the point D_{max} corresponding to the rotation axis of the isocentric setup (Fig. 4, B).

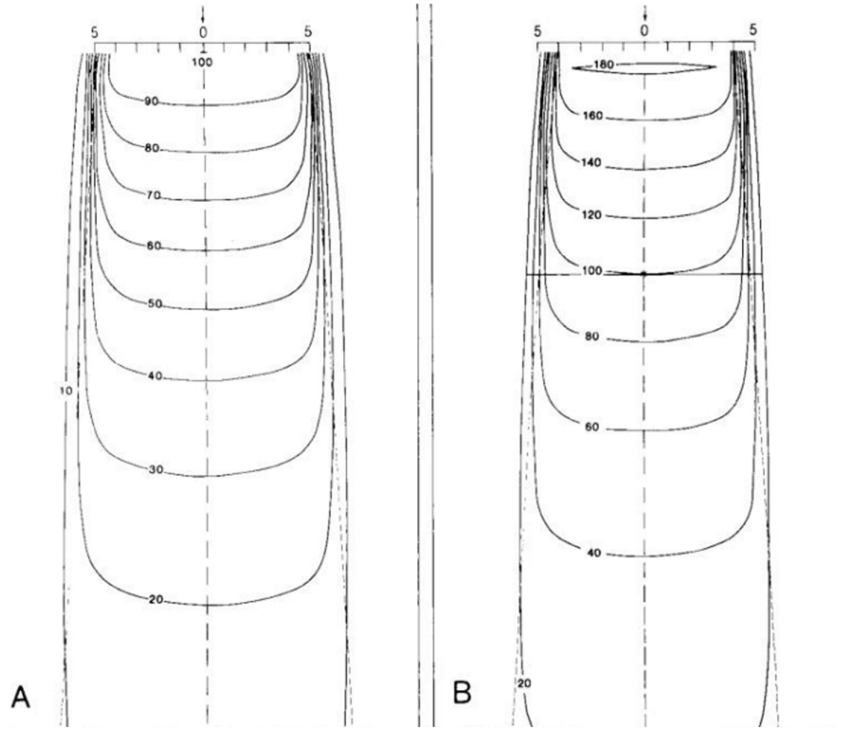


Figure 4 – Isodose maps: A – constant SSD method, Co-60 beam, field size 10x10 cm^2, SSD = 80 cm, dose normalization on the axis at a depth of D_{max};

B – isocentric method, Co-60 beam, field size 10x10 cm^2 in the isocenter at a depth of 10 cm, SSD = 100 cm

General properties of isodose maps for photon beams:

– doses are maximized on the central axis and inchemal decrease by beam edges (with the exception of the “horn” region for linear accelerators);

– near the beam edge (zone of penumbra) the dose decreases harshly with increasing lateral distance;

– near the edge of the beam, a decrease in dose is associated not only with the geometry of the penumbra, but also with a decrease in the contribution of lateral scattering. Hence the term “physical penumbra”. Its width is determined by the transverse distance between two selected isodose curves at a certain depth (for example: the distance between 90 and 20% isodose lines at a depth of d_{max});

– in the shadow zone, the dose distribution is determined by transverse scattering from the medium and leakage from the apparatus head.

Treatment devices have a procedure for “tuning” the beam, in which the light field of the beam coincides with the 50% isodose lines of the radiation beam projected onto a plane perpendicular to the beam axis with a standard SSD or SAD.

A drawing of isodose curves in the plane perpendicular to the central axis (Fig. 5) is very useful for determining the “coverage” of a tumor with isodose curves (for example, 90%).

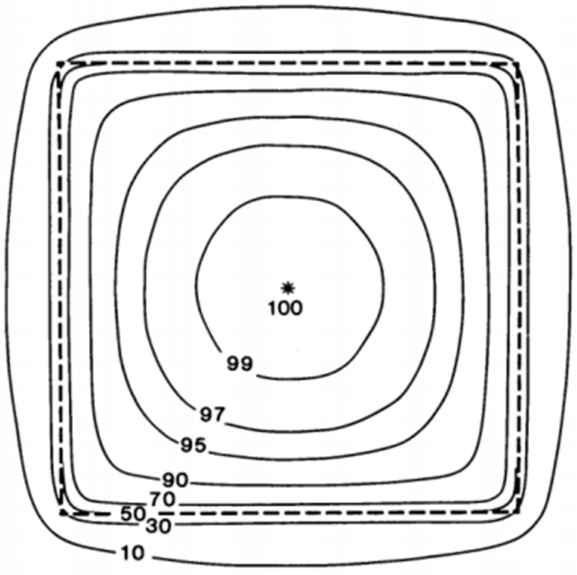


Figure 5 – Isodose distribution in a plane perpendicular to the beam axis

The greatest influence on IC is exerted by: beam quality, field size, collimation, SSD and source-diaphragm distance (SDD).

1.3.2 Target volumes and organs-at-risk

According to the recommendations of the ICRU 50, five main volumes are introduced in the patient (Fig. 6), in which the calculation and registration of doses is carried out. The following description is given to these volumes:

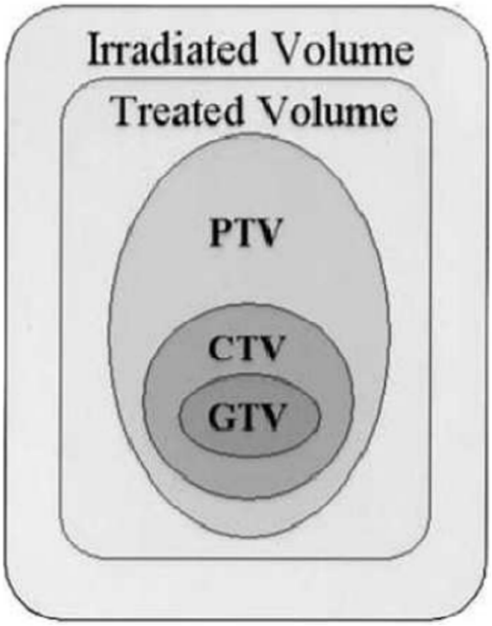


Figure 6 – Schematic diagram showing ICRU recommendations for describing volumes and doses

Gross Tumor Volume – GTV – demonstrates the extension and localization of a malignant neoplasm. Its extension can be determined by palpation, direct visualization, or indirectly through an image recovery technique.

Clinical Target Volume – CTV. GTV is usually surrounded by an area of normal tissue that can be affected by microscopic tumor metastases. Additional volumes may also exist due to presumed subclinical spreads. Such volumes are called CTV. CTV is an anatomical concept representing a known or suspected tumor volume.

Planning Target Volume – PTV – varies in time both in size and in location as a result of the movement of the patient and tissues containing CTV. Therefore, an imaginary surface is drawn around the CTV, including all of these changes. This is an extreme imaginary surface. The resulting planned volume (PTV) is a

geometric concept that takes into account the chain effect of all possible geometric variations.

Treated Volume – TV – is often called the therapeutic volume. The goal of radiation therapy is to ensure a high and uniform dose in PTV and limit the dose in the rest of the area to a minimum. Due to the limited (in practice) number and shape of the radiation fields, the therapeutic volume usually has a regular shape that covers the CTV. The treated volume is the volume covered by some selected isodose surface selected by the oncologist as the most appropriate to achieve the goal of treatment.

Irradiated Volume – IV. In the process of PTV irradiation, naturally occurring irradiation of surrounding tissues also occurs. Irradiated volume is defined as the volume of tissue receiving a significant dose, for example, more than 20% of the target dose. The comparison between TV and IV for different beams and their combinations can be used in optimization.

ICRU defines organs-at-risk as normal tissues, whose high sensitivity to radiation can significantly affect treatment planning and/or the amount of prescribed dose. In other words, these are organs whose sensitivity to radiation is such that the doses they receive during irradiation can become significant with respect to their tolerance. This, in turn, may require a change in exposure plan. Particular attention should be paid to organs that may not directly adjoin CTV, but have a very low tolerated dose (for example, optic nerve, bone marrow, etc.).

ICRU recommends that doses should always be recorded near the center of the PTV, as well as maximum and minimum doses in the PTV. If possible, the average dose, its standard deviation and the dose-volume histogram should also be recorded [8].

1.3.2 Dose Volume Histogram (DVH)

In three-dimensional planning, the irradiation plan is a 3D array of dose values at points (more precisely, in volumetric cells — voxels) distributed in the patient's PTV. There are up to several hundred thousand such points. The analysis

of such data is not trivial. Recently, dose-volume histograms (DVH) have become widely used for this. They allow you to summarize the information contained in three-dimensional dose distributions, and are a powerful tool for quantifying the exposure plan.

In its simplest form, DVH represents the frequency distribution of dose values within a given volume. Instead of the frequency, the value “percentage of the volume of the total volume” is usually applied, which is plotted along the ordinate axis, and the dose value is plotted along the abscissa axis. In practice, two types of DVH are used:

– differential (or direct) DVH;

– integral (or cumulative) DVH.

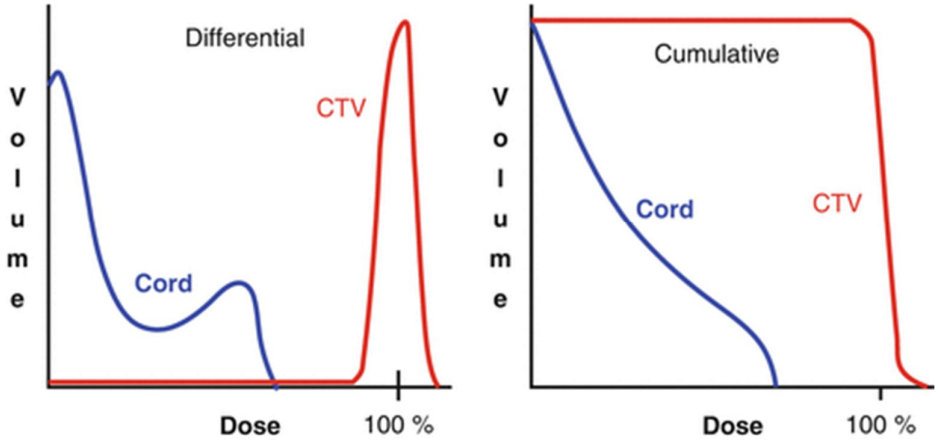


Figure 7 – Differential (left) and cumulative (right) DVH

The disadvantage of DVH is the loss of spatial information about the dose distribution.

When creating a differential DVH, the number of voxels with an average dose within a given interval is summed up and a percentage of the total organ volume is drawn as a function of the dose. The ideal differential DVH should have one column indicating that 100% of the volume receives the prescribed dose. For the critical structure, DVH may have several peaks indicating that certain parts of the organ receive different doses.

When planning radiation therapy, it is necessary to know what part of the target will be covered by a 95% isodose curve. Direct DVH cannot provide an

answer to this question. But it is easily obtained from cumulative DVH. Therefore, cumulative GDOs are used more often than direct ones.

When creating a cumulative DVH, the computer calculates the volume of the target (or OAR), which receives a dose less than or equal to the specified value, and draws a graph of the dependence of the volume (or percentage of the total volume) on the dose.

The ideal cumulative DVH for the target has the form of a Heaviside function (step), and for OAR the ideal option is the segment y = 0 at $x \in [0,100\%]$. In practice, of course, other DVHs are obtained, but one should strive for the ideal when planning [9].

1.4 Voxel-based analysis in RT

Most of the biological models developed for radiation therapy accepted that normal tissue damage could be predicted from the dose-volume histograms for dose distribution. This is not entirely true and has consequences. [10]. The use of DVH suggests that the risk organ is a homogeneous object, when calculating the dose, not taking into account its complex structure and elemental composition [11]. However, modern studies can show us it is not true. There is a heterogeneous regional radiation sensitivity and various radiation effects of the consequences, depending on it. The validity of this statement has been proven for various bodies. [12,13].

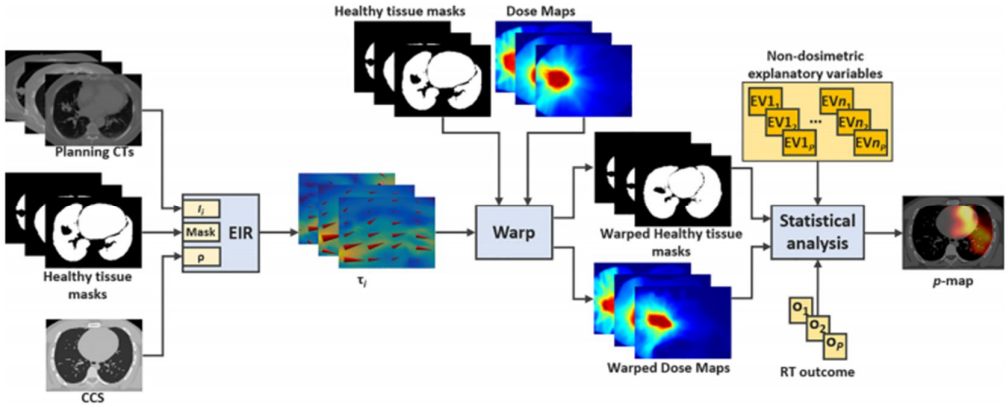
The dose-volume histogram also implies the use of an approach based on a priori determination of the anatomical regions involved in predicting the consequences. Thus, the study of the interaction of various organs with each other and their influence on radiation-induced effects is difficult and the interaction of radiation effects between such organs is not taken into account. [14,15]. This, in turn, can affect the prognosis of subsequent radiation-induced effects [16].

This has generated interest in finding an alternative for dose-volume histograms to take into account spatial information about the distribution of doses. [17,18].

Voxel-based analysis came up for this purpose. It is widely used to evaluate functional and structural changes in anatomical images. Spatial normalization of all images in one anatomical space is carried out, followed by statistical analysis to identify differences.

In radiation therapy, voxel-based analysis is used to study dose distribution, when all the philosophies of an organ are evaluated in the local response to a dose. Computing tools are used to make full use of the information in three-dimensional dose distribution. Voxel-based analysis in this area is widespread in the study of radiation-induced effects to determine heterogeneous areas of radiosensitivity [19]. The likelihood of treatment failure using this method was also studied [20].

Spatial normalization is the first step in voxel-based analysis. All images are reduced to a common coordinate system. After linking the dose maps of radiation therapy for comparison by points or areas where there are correlations between local dose allocation and the expected clinical outcome, they are identified statistically by comparing the dose received and the tissue response to it.



(fig 111)

Figure 8 – Block diagram of a voxel-based analysis

One of the main aspects of voxel-based analysis is the use of spatial structures of the organ's radiosensitivity to the results of radiation therapy planning and its consequences. This approach is now actively discussed in the scientific community and, presumably, may open up new ways for implementing the optimization of personalization of radiation therapy plans [21].

In modern treatment planning systems, the calculation of the therapeutic dose is carried out by means of recognition of the electron density of tissues located on the computed tomography image. The program converts this information into Houndsfield units that reflect the electronic density of the tissue. After recognition of the electron density, it is converted to mass density. Then the material is assigned properties based on its mass density, after which the dose is calculated. The calculation is carried out according to the above algorithms. The most acceptable is the Monte Carlo method due to its consideration of many factors. But the material is not assigned properties based on its elemental composition.

The elemental composition is needed for calculations to take into account scattering interactions, which strongly depend on the elemental composition. There

are general data that allow, as a first approximation, to take into account the composition of the tissue and, depending on it, take the necessary coefficients for calculation (Table 1).

Table 1. Material Definitions in Voxel-Based Internal Dosimetry Application Monte Carlo Simulation (ICRU 46) [22]

		Chemical composition (% by mass)				
Material	Density (g/cm^3)	H	C	N	O	Elements Z>8
Air	0.00121	–	0.01	75.53	23.18	Ar (1.28)
Soft tissue[a]	1.03	10.5	25.6	2.7	60.2	Na (0.1), P (0.2), S (0.3), Cl (0.3), K (0.2)
Lung[b]	0.26	10.3	10.5	3.1	79.9	Na (0.2), P (0.2), S (0.3), Cl (0.3), K (0.2)
Whole skeleton[c]	1.35	6.5	28.6	3.6	41.7	Na (0.1), Mg (0.1), P (5.9), S (0.2), Cl (0.1), K (0.2), Ca (13.2), Fe (0.1)

[a] Average adult male.
[b] Adult healthy, inflated.
[c] Composite material defined using average density and elemental compositions of adult whole bones (excluding cranium and mandible).

2 Research part

2.1 Materials and methods

2.1.1 Main interaction of photons with matter in RT

Because the lack of data abuot molecular photoelectric cross section (σ_{ph}) for the compound or mixture, it was assumed that σ_{ph} (cm^{-1}) (the corresponding conversion between the cm^{-1} and barn was made for each element) can be calculated in accordance with the formula

$$\sigma_{ph} = \rho N_A \sum_i \frac{W_i}{A_i} \sigma_i \tag{3}$$

Where ρ is the density of the material, N_A is the Avogadro number, Ai, σ_i, and w_i are the atomic mass, atomic cross section, and mass fraction of the ith component, respectively. Cross sections of molecular photoelectric absorption were obtained using the equation. (3) depending on the composition and density of tissues.

At low incident energies, the electron binding energy decreases the probability of incoherent scattering interactions. With Incoherent Scatter Function (ISF) taken into account, the total cross section of incoherent scattering per atom for inelastic scattering can be written as

$$\sigma_{inc} = \int_{\theta=0}^{\theta=\pi} d\sigma_{KN}(\theta) S(x,Z) \tag{4}$$

where $S(x,Z)$ is correction factor which can be approximated by the Independent Atomic Model, therefore there is no interference of scattered waves, and the effect of molecular binding on S (x,Z) is very small. Therefore, it seems that the sum rule is valid for calculating the ISF for a molecule or mixture. Molecular ISF Sm (x) is calculated for all x values in accordance with the compositions and densities of fabrics from atomic ISF Si (x,Z_i) using

$$\frac{S_m(x)}{W} = \sum_i \frac{w_i}{M_i} S_i(x, Z_i) \tag{5}$$

where w_i is the mass fraction of element *i*, M_i is the atomic mass of element *i*, *W* is the molecular weight. Z_i is the atomic number of element *i*. $S(x,Z)$ is correction factor for ith element.

The coherent (Rayleigh) scattering cross section can be found by integrating the differential cross section over all possible scatter angles per atom given as

$$\sigma_{coh} = \int_{\theta=0}^{\theta=\pi} d\sigma^T(\theta)\left[F(x,Z)\right]^2 \tag{6}$$

where $d\sigma^T$ is the Thomsom cross section for a free single electron; $F(x,Z)$ – atomic form factor, which is a function of the variable *x*, where $x = \lambda^{-1}\sin(\theta/2)$.

For large momentum transfer values, asymptotic convergence is observed between the experimental data and the data obtained using IAM, and therefore the sum rule can be applied. A simple sum rule is used for a molecule to find the molecular form factor

$$\frac{F_m^2(x)}{W} = \sum_i \frac{w_i}{M_i} F_i^2(x, Z_i) \tag{7}$$

where w_i is the mass fraction of element i, M_i is the atomic mass of element *i* and *W* the molecular weight. Z_i is the atomic number of element *i*. The $F_m(x)$, molecular form factor, is calculated by using Eq. (7) according to compositions and densities of tissues for values of $x \geq 1$ Å^{-1}. For values of $x \leq 1$ Å^{-1} , the $F_m(x)$ is taken from experimental data.

The linear attenuation coefficient μ (cm^{-1}) can be decomposed into the contributions from each photon interaction mode as

$$\mu = \mu_{ph} + \mu_C + \mu_R \tag{8}$$

where *ph, C, R* designate photoelectric absorption, incoherent (Compton) and coherent (Rayleigh) scattering, respectively.

So, let *x* be a random variable with a probability density function *f(x)* and a cumulative distribution function *F(x)*. For realization *x** of random variable x follows by definition

$$q = F(x^*) = \int_{-\infty}^{x^*} f(x)dx \tag{9}$$

The range of the cumulative distribution function is restricted, $0 \le F(x^*) \le 1$ with x^* in $[-\infty, \infty]$. If it is possible to calculate the inverse of the distribution function, F^{-1} , then a random sample x^* can easily be obtained by substituting an uniformly distributed random number $q\left(q \in [0,1]\right)$ into Eq. (9) and calculating $x^* = F^{-1}(q)$.

When it is determined that an interaction occurs in the medium, one of the three possible interaction processes are selected by random sampling. The probability that a given type of interaction occurs, *p(i)*, is proportional to its cross section σ_i

$$p(i) = \frac{\sigma_i}{\sigma_t} \tag{10}$$

where σ_t t is the total cross section. Then *i* the number of the interaction which occurs, is a random variable with a cumulative distribution function given by

$$P(i) = \frac{\sum_{j=1}^{i} \sigma_i}{\sigma_t} = \sum_{j=1}^{i} p(i) \tag{11}$$

The number *i* is selected by generating an uniformly distributed random number *q* on [0,1] and finding the *i* which satisfies

$$P(i-1) \le q \le P(i) \tag{12}$$

Thus, the ith interaction process is selected as the interaction that occurs. The construction of the probability density function over the differential and total sections makes it possible to apply the MC method.

The program takes into account coherent incoherent scattering cross sections in addition to photoelectric absorption cross sections. The input energy of the photon is controlled. For each photon energy, the MK simulation is repeated 5000 times. The type of photon interaction is determined by a random number q using the following conditions:

if $0<q<P_{inc}$, it is decided that the interaction is incoherent scattering (Compton). So the scattering angle should be sampled by re-generating random number and so the scattered photon energy should be determined.

if $P_{inc}<q<(P_{inc}+P_{coh})$, it is decided that the interaction is coherent scattering (Rayleigh). The scattered photon retains its original energy and no energy is deposited.

if $(P_{inc}+P_{coh})<q<1$, it is decided that the interaction is photoelectric and the photon is absorbed [23].

2.1.2 XCOM Database program

In practice, it is not possible to fulfill all cross-sectional requirements using printed tables. In addition, cross sections are often necessary at photon energies different from those indicated in the tables.

Of course, that the photon cross sections for compounds can be obtained quite accurately (with the exception of energies close to the absorption edges) in the form of weighted sums of the cross sections of atomic components. However, the required work is monotonous, and the task is more complicated by the fact that photoabsorption cross sections and the total attenuation coefficients are discontinuous at the absorption edges. The presence of these discontinuities makes it desirable that the cross-section tables for the compounds include the photon energies directly above and below all absorption edges for all atomic components, and this requires a lot of additional interpolation.

A alternative approach is to create cross sections and attenuation coefficients for compounds and mixtures as needed. XCOM program quickly performs this task for any element, compound, or mixture at energies from 1 keV to 100 GeV.

XCOM can generate cross sections on a standard energy grid (approximately logarithmically spaced), or on a grid selected by the user, or for a combination of both grids. The cross sections at energies directly above and below

all absorption edges are automatically switched on. XCOM can generate two forms of output: tables and graphical tabular data display.

The program provides full cross sections and total attenuation coefficients, like partial cross sections for the following processes: incoherent (Compton) scattering, coherent (Rayleigh) scattering and also photoelectric absorption and pair production in the region of the atomic nucleus and in the region of atomic electrons. For compounds, the values given in the table are partial and total mass interaction coefficients, which equals to the product of corresponding cross sections by the number of target molecules per unit material mass. The reciprocal of these interaction coefficients is the mean free path between scatters, between photoelectric absorption events, or between pair formation events. The sum of the interaction coefficients for individual processes is equal to the total attenuation coefficient. The general attenuation coefficients are also given without taking into account the contribution of coherent scattering, since they are often used in calculations of gamma radiation transfer.

The interaction coefficients and the general attenuation coefficients for the compounds or mixtures are obtained as sums of the corresponding values for the atomic components. Weighting factors, that is, mass fractions of the constituents, are calculated by XCOM from a chemical formula entered by the user. However, for mixtures, the user must indicate fractions by weight of the various components.

Some limitations should be noted. The cross-sections of the elements in the XCOM database are isolated neutral atoms and do not take into account molecular and solid-state effects that change cross-sections, especially near the absorption edges. Relatively small cross sections, such as the Delbrück section, two-photon Compton scattering, or the birth of photomesons, are not taken into account. Also omitted is the nuclear photoelectric effect, which in the region of giant dipole resonance from 5 MeV to 30 MeV can contribute several percent to the total attenuation coefficient. XCOM does not calculate energy absorption coefficients, which are the conversion of photon energy into kinetic energy of secondary Compton, photo and pair electrons [24].

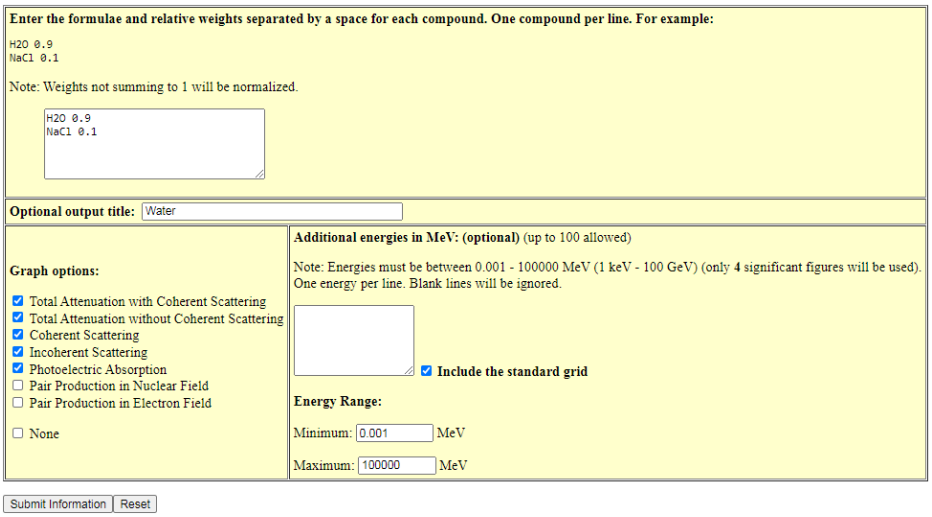


Figure 9 – XCOM interface

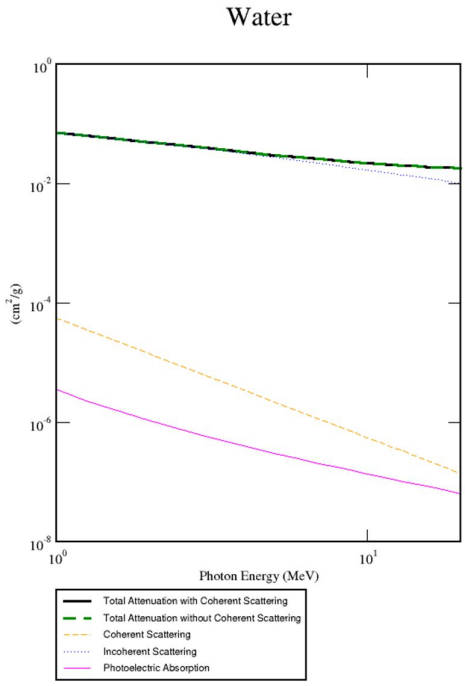


Figure 10 – Example of XCOM output

2.1.3 Slicer 3D software

3D Slicer is free open source software (BSD-style license), which is a flexible image analysis and visualization modular platform. Program has been expanded to develop interactive and batch tools for various applications.

3D Slicer ensure image registration, DTI (diffusion tractography) processing, an interface with external devices to support image navigation and 3D

visualization with GPU support, as well as other functions. Program has a modular organization which allows us to add new features and provides a number of base features which are not available in competing implements.

3D Slicer has capabilities of interactive visualization that include the ability to display randomly oriented slices of images, create surface models from image labels, and hardware-accelerated volume visualization. 3D Slicer also supports a wide range of annotation features (validation and measurement widgets, customizable color maps).

The program features are constantly updated. Because open software, anyone can participate in the development of new functions and features.

In 2011, an additional extension was created for Slicer 3D called SlicerRT (Slicer Radiation Therapy) and has since been constantly updated. By adopting 3D Slicer, RT users can gain access to a well-established, widely used software application and multiple state-of-the-art computational algorithm toolkits. 3D Slicer also fulfills the requirements of flexibility, extensibility, free, non-restricted use, full source code, data, and documentation availability, support of common data formats, widely known development environment, ease of use, comprehensive data visualization and numerical analysis of research data, and flexible data import and export. The capabilities of this application include creating and setting parameters for beams, creating dose-volume histograms (DVH) and comparing them, creating isodose maps, creating dose accumulation maps and comparing them.

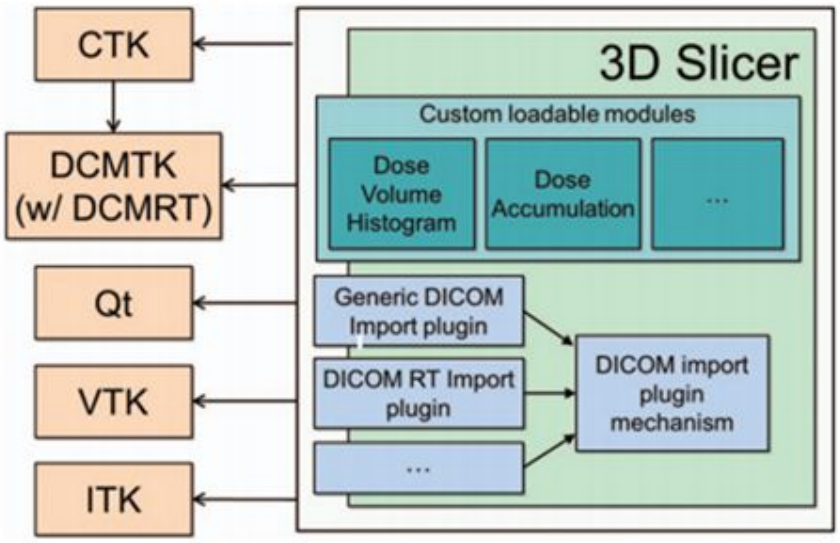


Figure 11 – Architecture of SlicerRT: Custom loadable modules added in 3D Slicer

In this paper, we considered a software option for creating a three-dimensional model: 3D Slicer 4.10.2 [23].

2.2 Calculation of scattering cross sections using XCOM

In this work four tissues were taken for comparison: kidney, liver, muscle and fat tissue [25]. Knowing the elemental composition of each tissue [26], one can use the XCOM program to obtain scattering cross sections at graph in the same way as at Fig. 9. We are interested in the energy range from 1 to 20 MeV since this range is most often used for various kinds of photon radiation therapy.

The data, in addition to the graphical view, can be obtained from the program in the form of a text set of values, to facilitate their subsequent processing. Having the ability to obtain the numerical value of the total cross section with and without coherent scattering, respectively, we can calculate the standard deviation (σ) in percent to find out how significant these scatterings contribute. Having the ability to obtain the numerical value of the total cross section with and without coherent scattering, respectively, we can calculate the standard deviation in percent to find out how significant these scatterings contribute.

Further, for clarity, we can construct a graphical dependence of standard deviation on radiation energy.

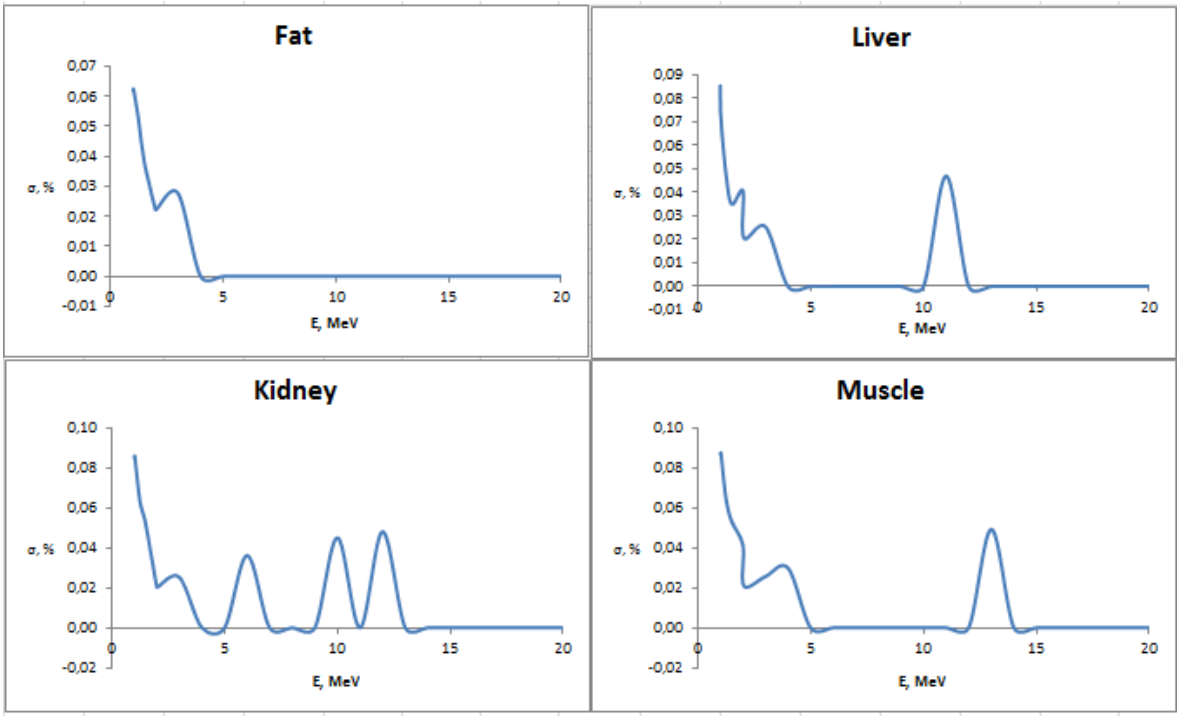


Figure 12 – Dependence of standard deviation on energy

Knowing that in radiotherapy a water model is used for calculation, we can perform similar operations for water.

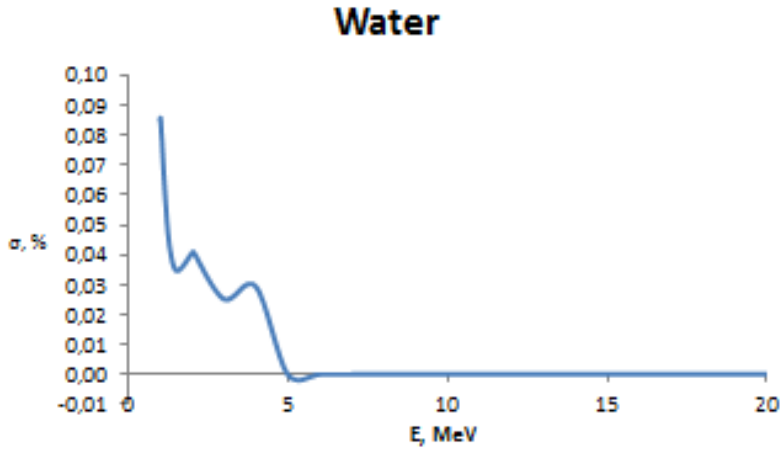


Figure 13 – Dependence of standard deviation on energy

We can observe significant differences in the behavior of the graphs, which gives us reason to assume that in practical applications there may be a difference.

2.3 Comparison of results

With the help of the 3D slicer, we can both plan radiation therapy and open ready-made plans. To illustrate the effect of the elemental composition of tissues on planning, a uterine cancer treatment plan was taken. Having the opportunity to get dose-volume histograms in the program, we clearly see the dose received by various tissues (Fig. 13).

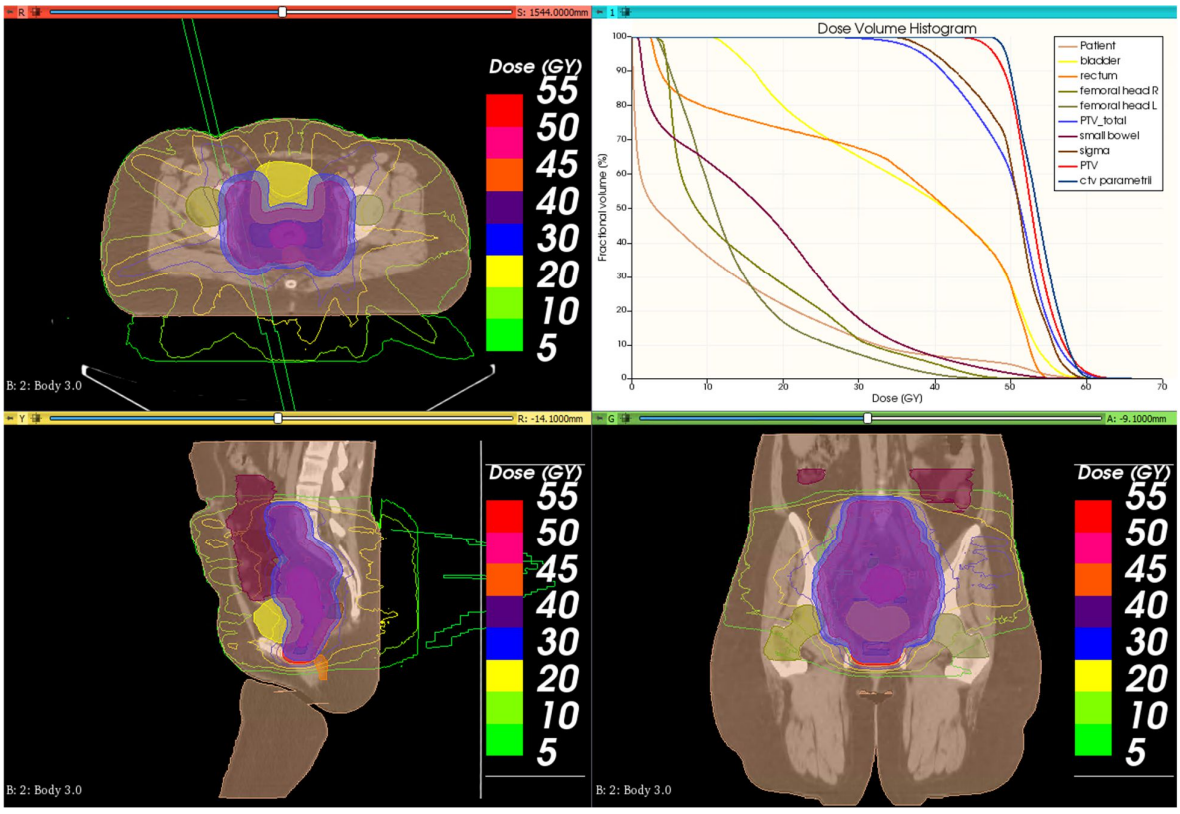


Figure 14 – Planning in Slicer 3D

Slicer 3D also makes it possible to obtain histogram data in numerical form for the convenience of work.

As before, we compare the dependence of the standard deviation on energy for the studied tissues.

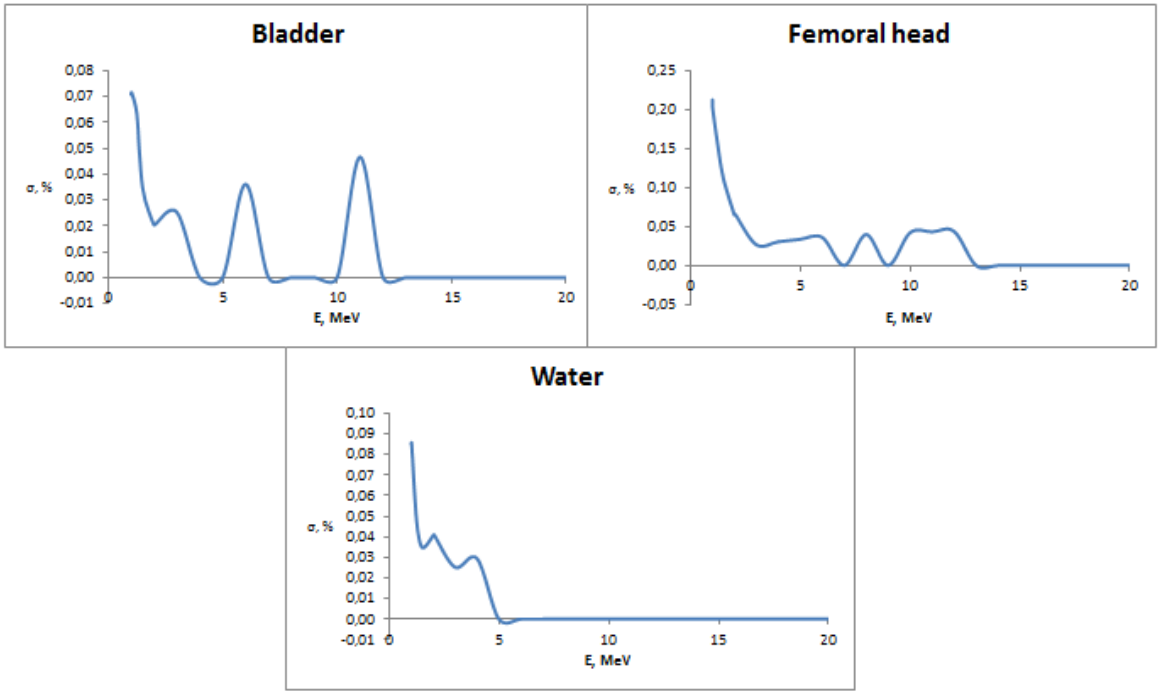


Figure 15 – Comparison of dependence of standard deviation on energy between bladder, femoral head and water

This treatment plan was compiled for a photon source with an energy of 6 MeV. To find out the effect of elemental composition on planning, in comparison with the water model of calculation, we take the ratio of the linear attenuation coefficient of radiation in water without scattering to the linear attenuation coefficient of radiation in the tissue. As examples of tissues, the heads of the femur were taken (very different from the water in terms of elemental composition) and the bladder (slightly different from the water in terms of elemental composition).

The ratio of linear attenuation coefficients was: for the bladder – 1,001222; for femoral heads – 1,074653 (0,1% and 7,5%, respectively).

Given this relationship, we construct comparatively histograms of the studied tissues in cases of standard calculation by the water model (W) and by the elemental composition (E).

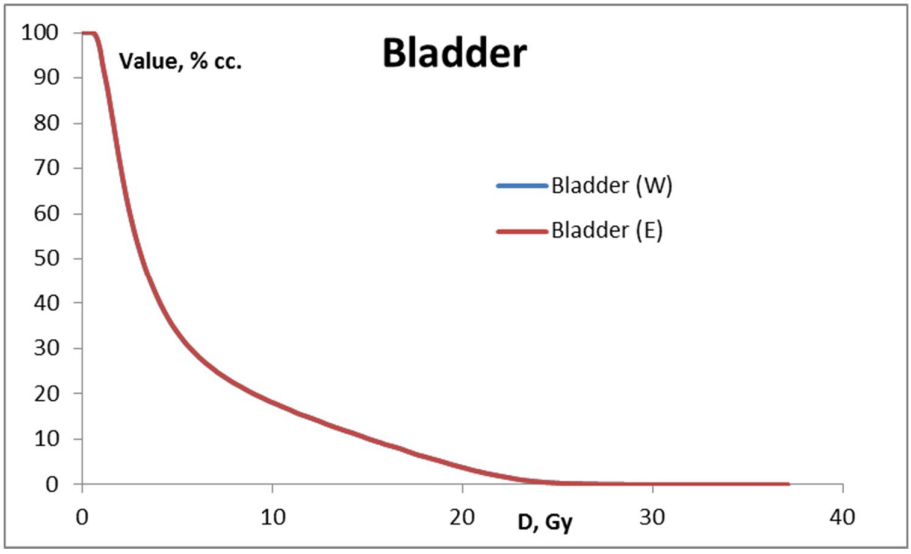


Figure 16 – Comparison of bladder DVH of two methods

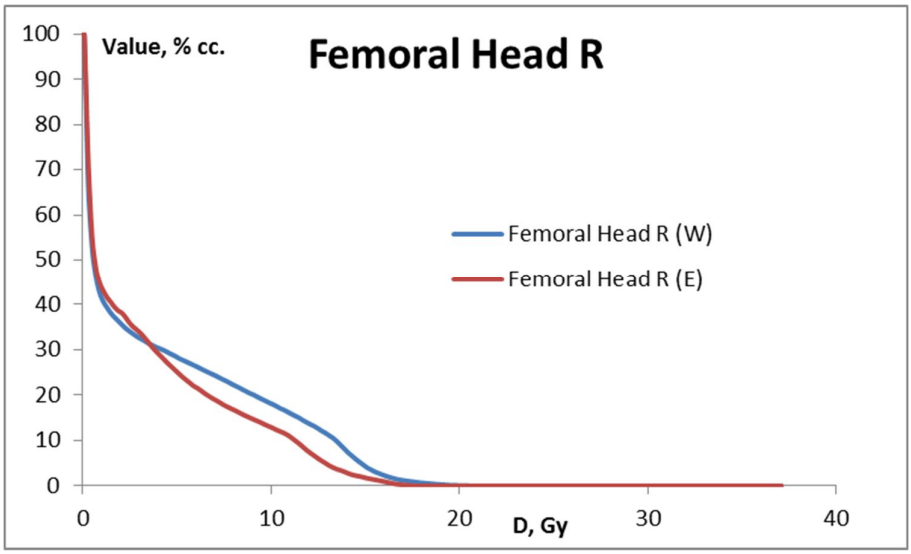


Figure 17 – Comparison of right femoral head DVH of two methods

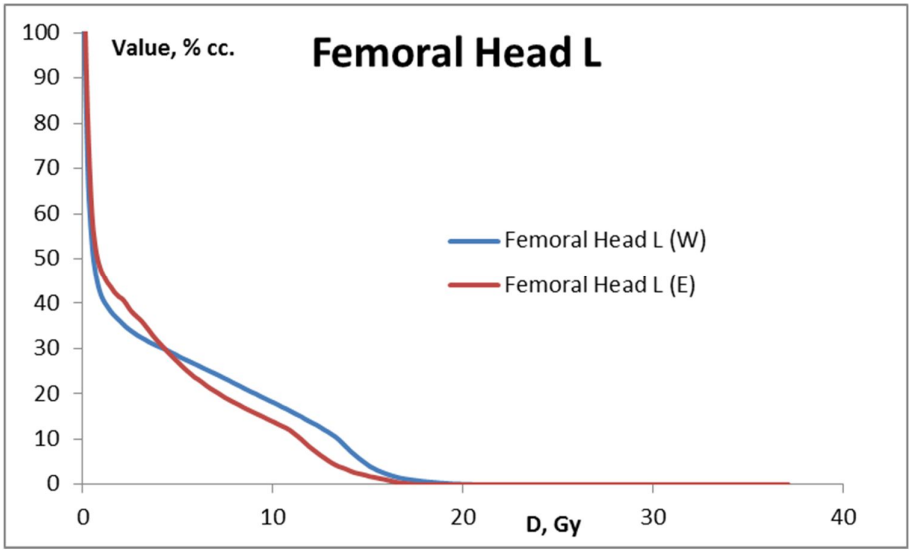


Figure 18 – Comparison of left femoral head DVH of two methods

As we can see, there are almost no differences in the histograms of the bladder. The reason of such fact is that elemental composition of water is almost identical to the composition of the bladder, due to the predominance of hydrogen and oxygen in the composition of water.

We can observe the opposite situation for the femurs. The elemental composition of bones is very different from the composition of water, since bones in their composition have relatively little hydrogen and oxygen. Mineral elements prevail in them.

3 Financial management, resource efficiency and resource saving

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.

3.1 Pre-project analysis

Nowadays the perspective of scientific research is determined not so much by the scale of discovery, which is difficult to estimate at the first stages of the life cycle of a high-tech and resource-efficient product, but by the commercial value of the development. Assessment of the commercial value of the development is a necessary condition when searching for sources of financing for scientific research and commercialization of its results. It is important for developers, who should represent the state and prospects of ongoing scientific research.

It is necessary to understand that the commercial attractiveness of scientific research is determined not only by the excess of technical parameters over previous developments but also by how quickly the developer will be able to find answers to such questions - whether the product will be in demand in the market, what will be its price, what is the budget of the scientific project, how long it will take to enter the market, etc.

The achievement of the goal is ensured by solving the tasks:

– evaluation of the commercial potential and prospects of scientific research;

– identifying possible alternatives to scientific research that meets current resource efficiency and resource conservation requirements;

– research planning;

– resource (resource-saving), financial, budgetary, social, and economic efficiency of research.

3.1.1 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. Strengths and weaknesses of competitors should be evaluated realistically and impartially.

Today, radiation therapy in the treatment of oncology mainly relies on images obtained using computed tomography (CT) (P_{i1}) and magnetic resonance therapy (MRI) (P_{i2}). These methods use electron density as a way of differentiating the tissues of the human body. The disadvantage is that the body is regarded as a volume of water with different densities. Due to the lack of accounting for the various elements that are contained in the human body, in addition to water, some inaccuracy in the delivery of the dose is allowed. The latest voxel-based method of image analysis (P_f) are able to take into account elements other than those that are part of the water, due to which greater accuracy can be achieved in dose delivery.

This analysis was carry out using an evaluation card (see Table 1). Two competitive developments were selected for this. The criteria for comparing and evaluating resource efficiency and resource conservation, shown in Table 1, were selected based on the selected objects of comparison, taking into account theirtechnical and economic features of development, creation and operation.

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

Evaluation map analysis presented in Table 1. The position of your research and competitors is evaluated for each indicator by you on a five-point scale, where

1 is the weakest position and 5 is the strongest. The weights of indicators determined by you in the amount should be 1. Analysis of competitive technical solutions is determined by the formula:

$$C = \quad W_i \; P_i,$$

,

where C – the competitiveness of research or a competitor;

Wi– criterion weight;

Pi – point of i-th criteria.

Table 1. Evaluation card for comparison of competitive technical solutions

Evaluation criteria ***example***	**Criterion weight**	**Points**			**Competitiveness** Taking into account weight coefficients		
		P_f	P_{i1}	P_{i2}	C_f	C_{i1}	C_{i2}
1	2	3	4	5	6	7	8
Technical criteria for evaluating resource efficiency							
1. Easy to use	0,02	4	4	3	0,08	0,08	0,06
2. Data processing time	0,15	3	4	3	0,45	0,6	0,45
3. Reliability	0,05	4	3	3	0,2	0,15	0,15
4. Safety	0,05	4	4	5	0,2	0,2	0,25
5. Resource requirement for memory	0,05	3	4	3	0,15	0,2	0,15
6. Functional capacity	0,06	5	4	4	0,3	0,24	0,24
7. Accuracy of dose delivery	0,1	5	3	4	0,5	0,3	0,4
8. Availability of expensive equipment	0,04	4	4	4	0,16	0,16	0,16
Economic criteria for performance evaluation							
1. Development cost	0,1	4	4	4	0,4	0,4	0,4
2. Market penetration rate	0,02	3	4	4	0,06	0,08	0,08
3. Product competitiveness	0,1	5	3	3	0,5	0,3	0,3
4. Popularity of the method	0,06	3	5	4	0,18	0,3	0,24
5. Interest in scientific	0,2	5	3	3	1	0,6	0,6

development							
Total	**1**				**4,18**	**3,61**	**3,48**

This analysis suggests that the study is effective because it provides acceptable quality results. Further investment in this development can be considered reasonable.

3.1.2 SWOT analysis

Complex analysis solution with the greatest competitiveness is carried out with the method of the SWOT analysis: Strengths, Weaknesses, Opportunities and Threats. The analysis has several 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.

The SWOT analysis of this research project is presented in Table 2.

Table 2 – SWOT analysis

	Strengths: S1. Reducing the dose load on critical organs S2. High precision of dose delivery S3. A local increase in tumor energy release	**Weaknesses:** W1. Relatively high data processing time W2. High computing power requirement W3. Additional licensed software
Opportunities: O1. The modernization of treatment methods will lead to the development of nuclear medicine O2. Applying of new software to a different sets of data. O3. Use of financial aid of parties concerned	*1. Reduced dose loads on critical organs and local increases will reduce interest in standard treatments;* *2. The possibility of using the measurement results in further research in various fields of science.* *3. Creation of new directions in radiation*	*1. Possible reduction of the system cost by obtaining financial support, due to the prospect of possible applications* *2. The ability to adapt new software for less powerful computers* *3. Obtaining licensed software from potential partners*

	therapy and image processing	
Threats: T1. New and untested method T2. The existence of a classic method of imaging in medicine T3. The difficulty of implementation in medical institutions	*1. Improving the quality of radiation therapy will increase competitiveness in the market* *2. Benefits in treatment may prevail over the lack of testing of a new method* *3. Classic methods can take advantage of some improvements to the new method.*	*1. Introduction into medical facilities is complicated by the by the requirements for the settlement system* *2. Writing articles and speaking at conferences will increase the number of stakeholders and raise awareness of the project.* *3. Additional research in this area will increase interest in the new method and increase demand.*

Based on the results of the analysis of this matrix, it can be concluded that the difficulties and challenges that this research project may face in one way or another can be addressed by the existing strengths of the research

3.2 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.

3.2.1 Project objectives and results

This section describes the project stakeholders, the hierarchy of project objectives and the criteria for achieving the objectives.

Project stakeholders refer to individuals or organisations that are actively involved in the project or whose interests may be affected positively or negatively during project implementation or completion. Information about project stakeholders provides in Table 3.

Table 3 – Stakeholders of the project

Project stakeholders	Stakeholder expectations
Patients with cancer	Reducing the risk of late radiation reactions in the body. Reduced recovery time after radiation treatment, due to reduced radiation load.
Oncology physicians	Implementation of radiation treatment with less dose load on critical organs and structures. Increased control of the tumor and, as a result, reduces the probability of relapse.
Cancer Research Institutes	Improved capabilities of dose delivery and distribution inside the patient and a basis for new research in this field.
Cancer clinics and dispensaries	A new innovative technique for patient treatment by lower dose burden on normal tissues and better target damage, easy to use, and inexpensive.

Table 4 shows information on the hierarchy of project objectives and criteria for achieving the objectives.

Table 4 – Purpose and results of the project

Purpose of project:	Study of voxel-based analysis of medical images to improve the results of radiation therapy planning
Expected results of the project:	1. Studying the possibilities of the voxel-based analysis in the reconstruction of medical images 2. Improving the accuracy of dose delivery to the target and reducing the dose on normal tissues 3. Comparison of radiation therapy of the standard method with voxel-based analysis
Criteria for acceptance of the project result:	1. Voxel-based analysis dose delivery accuracy improved by more than 3% compared to standard methods 2. Reduced dose of voxel-based analysis by more than 3% compared to standard methods
Requirements for the project result:	1. The research carried out under this project should be completed by June 1, 2020 2. The results obtained must meet the criteria for accepting the project result 3. If unsatisfactory results are obtained, additional studies should be conducted using received results

3.2.2 Organizational structure of the project

It is necessary to solve the 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 5).

Table 5 – Project working group

№	Participant	Role in the project	Functions	Labor time, hours.
1	Sukhikh Evgeniya, Head of the Department of Medical Physics, Tomsk State Oncology Center	Supervisor	Responsible for the project implementation within the set resource constraints, coordinates the activities of the project participant.	102
2	Melchenko Stepan, Master, TPU	Executor	Review of literary sources and technical literature; Source code preparation and medical image processing. Processing received data. Comparative radiation therapy planning. Writing the master's thesis.	720
3	Brazovskii Konstantin, Professor of the Research School of Chemistry and Applied Biomedical Sciences	Consultant	Responsible for assisting the Master in the preparation of source code, documentation and protection of the diploma	42
Total				864

3.2.3 Project limitations

Project limitations are all factors that can be as a restriction on the degree of freedom of the project team members. Table 6 shows the main limitations of this work.

Table 6 – Project limitations

Factors	Limitations / Assumptions
3.1. Project's budget	357184,67 RUB
3.1.1. Source of financing	State financing
3.2. Project timeline:	03.02.2020 – 01.06.2020
3.2.1. Date of approval of plan of project	10.02.2020
3.2.2. Completion date	01.06.2020

3.3 Scientific research planning

The Graduate Qualification Study (GQR) is a work of a scientific nature related to scientific inquiry, research to obtain scientific generalizations, to find principles and ways of creating (modernizing) products, it includes:

1. fundamental research carried out with a view to enhancing scientific knowledge, phenomena and patterns of their development without regard to their specific practical application;

2. search research carried out with the purpose of finding ways to use the revealed phenomena and regularities in a concrete field of science and technology for creation of principally new products, materials and technologies;

3. applied research aimed at solving scientific problems, improvement of methods in order to obtain specific results used in experimental and design developments in the creation of scientific and technical.

3.3.1 Structure of work within the scientific research

Planning of the complex of proposed works is carried out in the following order:

– determination of the structure of works within the scientific research;

– definition of participants of each work;

– determination of the duration of work;

– construction of the schedule for scientific research.

To carry out scientific research, a working group is formed, which may include researchers and teachers, engineers, technicians, and laboratory technicians, the number of groups may vary. For each type of work to be carried out, an appropriate position for the executors shall be established. In this section, it is necessary to make a list of stages and works within the framework of scientific research, to make a distribution of performers by type of work. An approximate order of drawing up stages and works, distribution of performers by these types of work is shown in Table 7.

The table contains a list of the main stages of the study, the work performed in the study, and the distribution of roles of the work performers.

3.3.2 Development of a schedule for scientific research

During the performance of the thesis, for convenience and clarity, a ribbon schedule of scientific works is constructed in the form of a Gantt chart. The works on the topic are presented as long sections of time, characterized by the start and end dates of these works.

For the convenience of drawing a chart, the duration of each stage of work should be translated from working days to calendar days. To do this, you are should use the following formula:

$$T_{Ki} = T_{Pi} \ k_{cal} \ ;$$

where T_{Ki} – the duration of the i-th job in calendar days;

T_{Pi} – duration of the i-th job in working days;

k_{cal} – calendar factor.

Table 7 – List of stages, works and distribution of performers

Main steps	№	Content of work	Executioner's position
Development of technical specifications	1	The choice of research direction.	Supervisor, Consultant, Executor
Determination of research direction.	2	Drafting and approval of technical specifications.	Supervisor, Consultant, Executor
	3	Scheduling.	Supervisor, Consultant, Executor
Theoretical and experimental research	4	Review of literature and technical literature.	Executor
	5	Studying researches and applications of the voxel-based analysis in other countries.	Executor
	6	Creating code for voxel-based method calculation	Executor
Summary and assessment of results	7	Processing received data	Executor
	8	Data Analysis	Executor
Registration of qualifying work	9	Compilation of an explanatory note	Executor
	10	Preparing to defend a diploma thesis	Supervisor, Consultant, Executor

Labor costs in most cases form the bulk of the development cost, so an important point is the determination of the complexity of the work of each of the participants in the scientific research. The complexity of the implementation of

scientific research is assessed expertly in man-days and is probabilistic in nature. depends on many difficult factors to consider. The following formula is used to determine the expected (average) labor intensity value:

$$t_{\exp i} = \frac{3t_{\min i} + 2t_{\max i}}{5},$$

where $t_{\exp i}$ – the expected complexity of the i-th work, person-day;

$t_{\min i}$ – the minimum possible complexity of the performance of a given i-th job (optimistic assessment: assuming the most favorable set of circumstances), person-day;

$t_{\max i}$ – the maximum possible complexity of a given i-th job (pessimistic assessment: assuming the most unfavorable set of circumstances), person-day.

Based on the expected complexity of the work, the duration of each work in working days T_{wd} is determined, taking into account the parallel work performed by several performers.

$$T_{wd} = \frac{t_{\exp i}}{N_i},$$

where T_{wd} – the duration of one work, working days;

$t_{\exp i}$ – the expected complexity of one job, person-days;

N_i – the number of performers performing simultaneously the same work at this stage, people.

In the course of this work, the number of people performing each of the work at each stage is equal to one.

The coefficient of calendar is determined by the following formula:

$$k_{cal} = \frac{T_{cal}}{T_{cal} - T_{weekend} - T_{hol}} = \frac{366}{366 - 52 - 14} = 1,22$$

where T_{cal} – calendar day amount per year;

$T_{weekend}$ – a number of days off per year;

T_{hol} – a number of holidays per year.

All calculated values are summarized in Table 8.

Table 8 – A project timeline in working days

№	Labour intensity			Participants	T_{Pi}	T_{Ki}
	t_{min}	t_{max}	t_{exp}			
1	1	5	3	Supervisor, Consultant, Executor	1	1,22
2	3	8	5	Supervisor, Consultant, Executor	1,67	2,03
3	1	3	2	Supervisor, Consultant, Executor	0,67	0,81
4	4	10	7	Executor	7	8,54
5	5	10	7	Executor	7	8,54
6	10	25	15	Executor	15	18,3
7	7	15	10	Executor	10	12,2
8	6	13	10	Executor	10	12,2
9	5	12	10	Executor	10	12,2
10	5	12	10	Supervisor, Consultant, Executor	3,33	4,06
Total	47	113	79		66	80

On the basis of Table 8, a time schedule is constructed (see Table 9). The schedule is constructed for the maximum duration of the research project by months and decades (10 days) for the period of writing the diploma. At the same time, the works on the schedule should be distinguished by different shading depending on the executors responsible for this or that work (– Supervisor, – Consultant, – student)

Table 9 – Calendar plan-graph in the form of a Gantt chart

№	T_{Ki}, days	Duration of the project											
		February			March			April			May		
1	1,22												
2	2,03												
3	0,81												
4	8,54												
5	8,54												
6	18,3												
7	12,2												
8	12,2												
9	12,2												
10	4,06												

3.4 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 student are summed.

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

– material costs of scientific and technical research;

– costs of special equipment for scientific work (Depreciation of equipment used for design);

– basic salary;

– additional salary;

– labor tax;

– overhead.

3.4.1 Material and equipment cost calculation

Electricity costs are calculated by the formula:

$$C_{el} = T_{el} \quad P \quad F_{sum} = 2,45 \quad 0,65 \quad 636 = 1012,83 \text{ rub;}$$

where T_{el} – tariff for industrial electricity (2,45 rubles per 1 kW·h);

P – equipment power is measured in kW;

F_{sum} – time of use of the equipment in hours (106 days of using by 6 hours).

Table 10 – Cost of equipment

Name	Brand	Quantity	Price per unit, rub	Amount, rub
Matlab software	MATHWORKS	1 license	164500	164500
Laptop	Hewlett-Package	1	35900	35900

Equipment was not specifically purchased for this work, therefore, it is necessary to calculate the depreciation of used equipment. The annual amount of depreciation is calculated as follows:

$$A = \frac{C_{eq} \quad N_{dep}}{100},$$

where A – annual deprecation;

C_{eq} – equipment cost;

N_{dep} – norm of deprecation.

The norm of deprecation are equal:

$$N_{dep} = \frac{100}{T_{lt}};$$

where T_{lt} – equipment lifetime (10 years).

In order to find the depreciation charge per duration of work (66 days) A was divided by the number of days per year (in 2020, 366 days) and multiplied on 66 days. A = 3621,19 rub.

3.4.2 Basic and additional salary

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

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_{base}) is calculated according to the following formula:

$$S_{base} = S_{day} \ T_w,$$

where S_{day} – an average daily salary of a participant, rub;

T_w – a duration of the work performed by the scientific and technical worker, working days.

The average daily salary (S_{day}) is calculated by the formula:

$$S_{day} = \frac{S_{month} \ M}{F_V};$$

where – S_{month} – a mouthly salary of a participant, rub;

M – an average daily salary of a participant, rub;

F_V – valid annual fund of working time of scientific and technical personnel (247 days).

The number of months of work without vacation during the year is calculated as follows: at 24 working days of vacation M = 11,2 months, 5-day

week, and at 48 working days of vacation M = 10,4 months, 6-day week. Table 11 calculates the actual annual fund of scientific and technical staff.

Table 11 – The valid annual fund of working time

Working time indicators	**Supervisor**	**Consultant**	**Student**
Calendar number of days	366	366	366
The number of non-working days – weekend – holidays	 52 14	 52 14	 52 14
Loss of working time– vacation – sick absence	 48 0	 48 0	 48 0
The valid annual fund of working time	252	252	252

Monthly salary is calculated by formula:

$$S_{month} = S_{base} \ (k_{premium} + k_{bonus}) \ k_{reg};$$

where $k_{premium}$ – premium rate;

k_{bonus} – bonus rate;

k_{reg} – regional rate.

Table 12 shows calculation of base salary of supervisor, consultant and student.

Table 12 – Calculation of the basic salary

Performers	Salary, rub	k_{reg}	S_{month}, rub	S_{day}, rub	T_w, work-days	S_{base}, rub
Supervisor	35120	1,3	45656	2029,16	6,67	13534,5
Consultant	21760	1,3	28288	1257,24	6,67	8385,79
Student	17890	1,3	23257	1033,64	66	68220,24

Total base salary is equal 90140,53 rub.

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

Additional salaries (S_{add}) are calculated on the basis of 10-15% of the base salary of workers:

$$S_{add} = S_{base} \quad k_{extra} \;;$$

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

S_{base} – base salary, rubles;

k_{bonus} – regional rate.

The additional salaries are equal to:

1) Supervisor:

$$S_{add} = S_{base} \cdot k_{extra} = 13534,5 \cdot 0,1 = 1353,45$$

2) Consultant:

$$S_{add} = S_{base} \cdot k_{extra} = 8385,79 \cdot 0,1 = 838,58$$

3) Student:

$$S_{add} = S_{base} \cdot k_{extra} = 68220,24 \cdot 0,1 = 6822,02$$

Total additional salary is equal 9014,05 rub.

3.4.3 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: $P_{social} = k_b \quad S_{base} + S_{add}$;

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%.

The labor tax is presented in Table 14.

Table 13 – Labor tax

Performers	Supervisor	Consultant	Student
Coefficient of deduction	0,271		
Salary, rub	14887,95	9224,37	75042,26
Labor tax, rub	4034,63	2499,80	20336,45
Total, rub	26870,88		

3.4.4 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 4.11:

$$C_{ov} = k_{ov} \cdot (W_{base} + W_{add}), \quad (4.11)$$

where k_{ov} – overhead rate.

Overhead costs are presented in the table 4.15.

Table 14 – Overhead

	Supervisor	Consultant	Student
Overhead rate	0,3		
Salary, rubles	14887,95	9224,37	75042,26
Overhead, rubles	4466,39	2767,31	22512,68
Total	29746,378		

3.5 Formation of budget costs

The calculated amount of research and development work costs is the basis for forming the project cost budget. The definition of the research project cost budget for each option is given in Table 15.

Table 15 – The budget for scientific and technical research

Name of expenditure items	Cost, rubles
Material costs	1012,83
Costs of special equipment	200400
Basic salary	90140,53
Additional salary	9014,05
Labor tax	26870,88
Overhead	29746,38
Total	357184,67

3.6 Project risk register

Identified project risks include possible undefined events that may occur in the project and cause unintended consequences. Information on this section is presented in Table 16.

Table 16 – Register of risks

	Risk	Potential effects	Probability (1-5)	Effect of risk (1-5)	Level of risk	Ways to mitigate risk	Conditions of occurrence
	Incorrect functioning of Matlab software due to its updating, installation of additional add-ons,	Impossibility of image processing	2	5	Low	Consultation with a specialist; installing the latest software	External factor independent of student work

	etc.						
	Inconsistency of the received data with expected results	Failure to achieve the project objectives	3	4	Med	Better literary analysis	Error in predicting expected results
	Lack of commercial interest in the methodology	Loss of opportunity to introduce the methodology to the consumer market	2	2	Med	Presentation of work at conferences. Implementation of the methodology in medical institutions	The lack of a plan for the commercial implementation of the methodology

3.7 Determining research resource efficiency

Determination of efficiency is based on the calculation of the integral indicator of scientific research efficiency. Its location is related to the definition of two weighted average values: financial efficiency and resource efficiency.

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

$$I_{pi} = \quad a_i \quad b_i \quad ;$$

where I_{pi} – integral resource efficiency index for the i-th variant of development execution;

a_i – development weighting factor;

b_i^a, b_i^b – an evaluation of the i-th variant of the development's execution is set by the expert by the selected evaluation scale.

The calculation of the integral resource efficiency index of this study is presented in the form of Table 17.

Table 17 – Comparative assessment of the characteristics of the project implementation options

Criteria	Parameter weighting factor	Current projec	Analog
Computing power	0,2	4	5
Computation time	0,2	4	4
Planning accuracy	0,3	5	3
Treatment result	0,3	5	4
Total	1	4,5	4

An integrated financial indicator for development is defined as:

$$I_f^p = \frac{F_i}{F_{\max}};$$

where F_i – a cost of the i-th option;

F_{max} – a maximum cost of execution of the scientific and technical research (including analogues).

$$I_f^p = \frac{F_p}{F_{\max}} = \frac{357184,67}{357184,67} = 1$$

$$I_f^{a1} = \frac{F_{a1}}{F_{\max}} = \frac{340059,25}{357184,67} = 0,95$$

The integrated index of efficiency of development variants (Ipf in) and analogues (Iaf in) is determined on the basis of the integrated index of resource efficiency and integrated financial index by formulas:

$$I_{fin}^p = \frac{I_m^p}{I_f^p} = \frac{4,5}{1} = 4,5$$

$$I_{fin}^{a1} = \frac{I_m^{a1}}{I_f^p} = \frac{4}{1} = 4$$

Comparison of the integral performance indicator of the current project and its analogues will allow to determine the comparative efficiency of the project (see Table 18).

Comparative effectiveness of the project:

$$C_{Eff} = \frac{I_{fin}^p}{I_m^p} = \frac{4,5}{4,5} = 1$$

Table 18 – Comparative efficiency of the project

Indicators	Project	Analog
Integral resource efficiency indicator	4,5	4
Integral performance indicator for variants	4,5	4
Comparative performance of the variants	1	1

Based on the calculation of the integral indicator with the definition of two weighted average values: financial efficiency and resource efficiency of scientific research, we can conclude that the comparative assessment of the current project is relatively higher than analog.

3.8 Conclusion under financial management

Thus, in this section was developed stages for design and creation competitive developed that meet the requirements in the field of resource efficiency and resource-saving.

These stages includes:

– development of a common economic project idea, formation of a project concept;

– organization of work on a research project;

– identification of possible research alternatives;

– research planning;

– assessing the commercial potential and prospects of scientific research from the standpoint of resource efficiency and resource saving;

– determination of resource (resource saving), financial, budget, social and economic efficiency of the project.

In the course of performing the economic part of the qualification master work, calculations were made of the planned cost of research and the time spent.

The total cost of work is 357184,67 RUB, the main component of which is the cost of wages to perform scientific and technical research.

4 SOCIAL RESPONSIBILITY

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

4.1 Occupational safety

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 [23].

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.

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 [23].

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.

4.1.1 Analysis of hazardous and harmful factors

The working conditions in the workplace are characterized by the presence of hazardous and harmful factors, which are classified by groups of elements: physical, chemical, biological, psychophysiological. The main elements of the production process that form dangerous and harmful factors are presented in Table 4.1.

Table 4.1 – The main elements of the production process, forming hazardous and harmful factors

	FACTORS GOST 12.0.003-74 Occupational safety standards system		Documents
	harmful	Dangerous	
	Chemical Toxic		GOST 12.1.007-76 Occupational safety standards system.Harmful substances.
		Electricity	GOST 12.1.038-82 Occupational safety standards system.electrical safety
	The impact of radiation (HF, UHF, SHF, etc.)		SanPiN 2.2.2/2.4.1340-03 Sanitary-epidemiological rules and regulations. "Hygienic requirements for personal computers and organization of work"
	Increased level of ionizing radiation in the work area		Radiation Safety Standards (NRB-99/2009). SP 2.6.1. 2523 -0 9.
		Fire	Fire and explosion safety of industrial installations GOST R12.1.004-85 SSBT

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).

4.2 Justification and development of measures to reduce the levels of hazardous and harmful effects, and eliminate their influence

4.2.1 Organizational arrangements

All personnel are required to know and strictly observe the safety rules. The training of personnel in occupational safety and industrial sanitation consists of introductory briefing and briefing at the workplace by the responsible person.

The qualification commission or by the person responsible for the workplace check the knowledge of safety rules after training at the workplace. After that, commission assign the safety qualification group corresponding to the employee's knowledge and experience of work and issue a special certificate.

Persons serving electrical installations must not have injuries and illnesses that interfere with manufacturing activity. The state of health is established by medical examination before being employed.

4.2.2 Technical Activities

The rational layout of the workplace provides for a clear order and permanent placement of objects, means of labor and documentation. Object, what is required to perform the work more often, should be located in the easy reach of the workspace, as shown in Fig. 4.1:

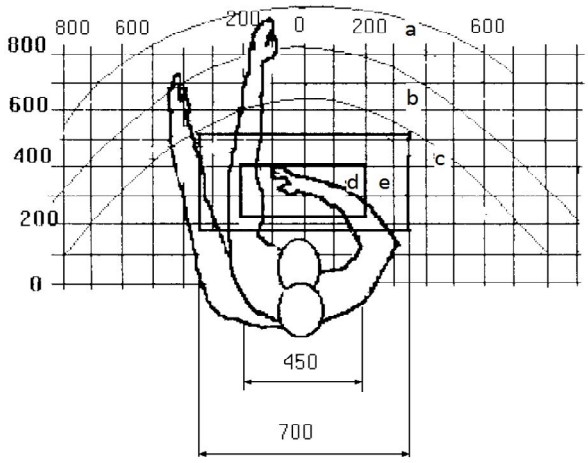


Figure 19 – Hand reach zones in the horizontal plane

a – Zone of maximum reach of hands;

b – reach zone of fingers with outstretched arm;

c – easy reach zone of the palm;

d – Optimum space for fine handmade work

e – the optimum space for rough manual work;

Optimal placement of objects of labor and documentation in the reach of hands:

– the display is located in zone a (in the center);

– keyboard – in the area of e/d;

– the system unit is located in zone b (on the left);

– the printer is in zone a (right);

The documentation is placed in the easy reach of the palm – in (left) – literature and documentation necessary for work; In the drawers of the table – literature that is not used constantly.

When designing a desk, the following requirements must be taken into account.

The height of the working surface of the table should be within 680–800 mm. The height of the working surface with the keyboard should be 650 mm. The working table must be at least 700 mm wide and at least 1400 mm long. There

should be a legroom of not less than 600 mm in height, a width of at least 500 mm, a depth at the knee level of at least 450 mm and at the level of elongated legs – not less than 650 mm.

The work chair must be liftable and adjustable in height and angle of inclination of the seat and backrest, as well as the distance of the backrest to the front edge of the seat. It is recommended that the height of the seat be above the floor level of 420 to 550 mm. The design of the working chair should ensure: the width and depth of the seat surface is not less than 400 mm; Seat surface with recessed front edge.

The monitor should be located at the eye level of the operator at a distance of 500 – 600 mm. According to the norms, the viewing angle in the horizontal plane should be no more than 45º to the normal of the screen. It is better if the viewing angle is 30. In addition, it should be possible to select the level of contrast and brightness of the image on the screen.

It should be possible to adjust the screen:

– height +3 cm;

– slope from 10 to 20 degrees with respect to the vertical;

– in the left and right directions.

The keyboard should be placed on the surface of the table at a distance of 100 – 300 mm from the edge. The normal position of the keyboard is at the elbow level of the operator with an angle of inclination to the horizontal plane of 15º. It is more convenient to work with keys that have a concave surface, a quadrangular shape with rounded corners. The key design should provide the operator with a click sensation. The color of the keys should contrast with the color of the panel.

It is recommended to choose soft, low-contrast floral shades that do not disperse attention (low-saturated shades of cold green or blue colors) in the case of monotonous mental work requiring considerable nervous tension and great concentration. Shades of warm tones are recommended at work, which requires intense mental or physical tension, due to excitation of human activity.

4.2.3 Safe work conditions

The main parameters characterizing the working conditions are microclimate, noise, vibration, electromagnetic field, radiation, illumination.

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 [30] and are given in Table 4.2.

Table 4.2 – 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

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.

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 result 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.

The screen and system blocks produce electromagnetic radiation. Its main part comes from the system unit and the video cable. According to [30], 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.

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 [30], 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.

4.2.4 Radiation safety

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.

Table 4.3 – Dose limits

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.

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 id a main part of radiation safety and radiation protection. It is aimed at not exceeding the established basic dose limits and permissible levels of radiation, obtaining the necessary information to optimize protection and making decisions about interference in the case of radiation accidents, contamination of the environment and buildings with radionuclides.

The radiation control is control of:

– Radiation characteristics of radiation sources, pollution in air, liquid and solid wastes.

– Radiation factors developed with technological processes in working places and environment.

– Radiation factors of contaminated environment.

– Irradiation dose levels of personnel and population.

The main controlled parameters are:

– Annual effective and equivalent doses

– intake and body content of radionuclides

– volume or specific activity of radionuclides in air, water, food products, building materials and etc.

– radioactive contamination of skin, clothes, footwear, working places and etc.

– dose and power of external irradiation.

– particles and photons flux density.

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

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

– characteristics of radioactive contamination of the environment;

– probability of radiation accidents and scale of accidents;

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

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

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

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

4.2.5 Electrical safety

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.

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) [28].

4.2.6 Fire and explosive safety

According to [29], depending on the characteristics of the substances used in the production and their quantity, for fire and explosion hazard, the premises are divided into categories A, B, C, D, E.

The room belongs to category B according to the degree of fire and explosion hazard. It is necessary to provide a number of preventive measures.

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.

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, the existence of an evacuation plan.

The technical measures include: compliance with fire regulations, norms for the design of buildings, the installation of electrical wires and equipment, heating, ventilation, lighting, the correct placement of equipment.

The regime measures include the establishment of rules for the organization of work, and compliance with fire-fighting measures. To prevent fire from short circuits, overloads, etc., the following fire safety rules must be observed:

– elimination of the formation of a flammable environment (sealing equipment, control of the air, working and emergency ventilation);

– use in the construction and decoration of buildings of non-combustible or difficultly combustible materials;

– the correct operation of the equipment (proper inclusion of equipment in the electrical supply network, monitoring of heating equipment);

– correct maintenance of buildings and territories (exclusion of the source of ignition - prevention of spontaneous combustion of substances, restriction of fire works);

– 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.

4.3 Conclusion under social responsibility

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.

Conclusion

Based on the data obtained as a result of the calculation, it can be concluded that the inclusion or absence of such a parameter as coherent scattering, when considering the total cross section for the interaction of a substance as a function of energy, causes deviations in the value of the total interaction seed. By comparing the percentage difference in the values of the total cross section, with and without taking into account coherent scattering, water and body tissues (fat, muscles, kidneys, liver, bone, bladder), we can conclude that they differ significantly (in some cases up to 10+ %).

Having received dose-volume histograms for critical organs (femoral heads, bladder) in the 3D Slicer program, they were compared with histograms adjusted for elemental scattering. The results showed that taking scattering into account avoids unnecessary stress on critical organs.

Based on the results of the work done, we can conclude that taking into account the elemental composition of target tissues and critical organs can improve the accuracy of planning radiation therapy, in particular dose delivery, and avoid excessive radiation exposure to critical organs and body tissues, preventing their radiation damage.

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