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 safety assurance for medical staff during radiotherapy sessions

UDC 539.16.04:614.876:331.471

Student

Group	Full name	Signature	Date
0AM8M	Tran Nhan Hau		

Scientific supervisor

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

Adviser

Position	Full name	Academic degree, academic rank	Signature	Date
Medical physicist Cancer Research Institute of Tomsk NRMC RAS	Turgunova N.D.			

ADVISERS:

Section "Financial Management, Resource Efficiency and Resource Saving"

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

Section "Social Responsibility"

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

ADMITTED TO DEFENSE:

Director of programme	Full name	Academic degree, academic rank	Signature	Date
Nuclear medicine	Cherepennikov Yu.M.	Ph.D		

Tomsk – 2020

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,	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

	instruments, installations, and systems.	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 Yu.M.
(Signature) (Date) (Full name)

ASSIGNMENT
for the Graduation Thesis completion

In the form:

Master's thesis

For a student:

Group	**Full name**
0AM8M	Tran Nhan Hau

Topic of research work:

Radiation safety assurance for medical staff during radiotherapy sessions.	
Approved by the order of the Director of School of Nuclear Science & Engineering (date, number):	

Deadline for completion of Master's Graduation Thesis:	

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.)*	Calculation of radiation protection of the canyon and labyrinth to ensure the safety of radiation therapy sessions by gamma beams and high-energy photon radiation.

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).*	1) Conducting a review of the literature on the research topic. 2) Choosing research methods. 3) Conducting experiments and calculations. 4) Analysing results. 5) Financial management. 6) Social responsibility. 7) Conclusions
List of graphic material *(with an exact indication of mandatory drawings)*	Presentation in Microsoft office PowerPoint

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 (if any):

Position	Full name	Academic degree, academic status	Signature	Date
Associate Professor	Cherepennikov Yu.M.	Ph.D		
Medical physicist Cancer Research Institute of Tomsk NRMC RAS	Turgunova N.D.			

Assignment accepted for execution by a student:

Group	Full name	Signature	Date
0AM8M	Tran Nhan Hau		

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:	

Assessment date	Title of section (module) / type of work (research)	Maximum score for the section (module)
27.01.2020	Compilation and approval of technical tasks	10
24.02.2020	Selection and research of materials on the topic	10
23.03.2020	Conducting experiments	20
13.04.2020	Conducting calculations	20
27.04.2020	Analysis and description of results	20
29.05.2020	Preparation for graduation work defence	20

COMPILED BY:
Scientific supervisor

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

Adviser (if any)

Position	Full name	Academic degree, academic rank	Signature	Date
Medical physicist Cancer Research Institute of Tomsk NRMC RAS	Turgunova N.D.			

AGREED BY:
Director of the programme

Position	Full name	Academic degree, academic rank	Signature	Date
Nuclear medicine	Cherepennikov Yu.M.	Ph.D		

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

For a student:

Group	Full name
0AM8M	Tran Nhan Hau

School	Nuclear Science and Engineering	Department	Nuclear fuel cycle
Degree	Master programme	**Specialization**	14.04.02. Nuclear physics and technology/ Nuclear medicine

Initial data for section «Financial management, resource efficiency and resource saving»:	
1. *Resource cost of scientific and technical research (STR): material and technical, energetic, financial and human*	Material costs 1 860 rub. Basic salary of the theme executors 83 223 rub. Additional salary of the theme executors 8 322 rub. Labor tax 24 809 rub. Overhead costs 7 379 rub.
2. *Expenditure rates and expenditure standards for resources*	Tariff on industrial electricity 5,8 per 1 kWt·h Region coefficient of Tomsk city -1,3
3. *Current tax system, tax rates, charges rates, discounting rates and interest rates*	Insurance premiums - 30%. Reduced rate - 27,1%.
List of the issues to be investigated, designed and developed:	
1. *Assessment of commercial and innovative potential of STR*	Score-card of competitive technical solutions
2. *Development of charter for scientific-research project*	Hierarchical structure
3. *Scheduling of STR management process: structure and timeline, budget, risk management*	Evaluating the competitiveness of technical solutions Schedule and budget of R&D Gantt chart
4. *Determination of resource, financial, economic efficiency*	SWOT matrix
List of graphic material *(with list of mandatory blueprints):*	
1. *"Portrait" of the consumer of the results of STR* 2. *Market segmentation* 3. *Evaluation of the competitiveness of technical solutions* 4. *SWOT- analysis* 5. *Gantt chart and budget of scientific research* 6. *Assessment of resource, financial and economic efficiency of STR* 7. *Potential risks*	

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

Task issued by adviser:

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

The task was accepted by student:

Group	Full name	Signature	Date
0AM8M	Tran Nhan Hau		

TASK FOR SECTION
«SOCIAL RESPONSIBILITY»

For a student:

Group	Full name
0AM8M	Tran Nhan Hau

School	Nuclear Science and Engineering	Department	Nuclear fuel cycle
Degree	Master programme	**Field of training/programme**	14.04.02. Nuclear physics and technology/ Nuclear medicine

Title of graduation thesis:

Radiation safety assurance for medical staff during radiotherapy sessions	
Initial data for section «Social Responsibility»:	
1. Information about object of investigation (matter, material, device, algorithm, procedure, workplace) and area of its application	Radiation exposure to medical staff of radiation therapy department; the bunker protection during radiation therapy sessions. Application area: radiation safety during radiotherapy sessions.
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	– Enhanced 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
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 consultant:

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

The task was accepted by the student:

Group	Full name	Signature	date
0AM8M	Tran Nhan Hau		

Abstract

Master's graduation thesis consists of 133 p., 9 fig., 55 tab., 27 sources, 2 appl.

Keywords: radiation protection, gamma therapeutic equipment, clinical linear accelerator, gamma-ray, high-energy photon radiation, photoneutrons, bremsstralungs.

The object of research is procedure room (canyon) of gamma-therapeutic equipment and medical linear electronic accelerator.

The aim of work is calculation of radiation protection of the canyon and labyrinth to ensure the safety of radiation therapy sessions by gamma beams and high-energy photon radiation.

In the process of research, we assessed the dose loads on personnel when conducting radiation therapy sessions, studied methods of calculating the biological protection of gamma-therapeutic equipment and medical electronic accelerators, calculated the biological protection of the canyon for radiation therapy of the oncological center and analyzed the results.

As a result of the study, the calculation of biological protection of the procedure room of the gamma-therapeutic equipment and medical linear electronic accelerator was conducted.

Application area: radiation safety, nuclear medicine.

Cost effectiveness/significance the appearance of new, modern, and complex medical linear electron accelerators on the market has allowed the introduction of high-tech radiotherapy in oncological institutions in different countries. The application of high-tech radiotherapy has led to the complication of radiation protection procedures for personnel. There was a problem of estimating the doses created by neutrons on high-energy accelerators. Methods for calculating the protection of procedure rooms where accelerators are installed have become more complex.

Contents

Introduction

Radiation safety is a set of technical, hygienic and organizational measures that ensure safety conditions for medical staff and the public with a reduction in doses of ionizing radiation to the lowest possible level [1].

Radiotherapy is the treatment using ionizing radiation (x-ray, gamma radiation, beta radiation, neutron radiation, beams of elementary particles from a medical accelerator). It is used mainly for the treatment of malignant tumors [2].

Radiotherapy of malignant neoplasms differs from other types of medical radiation by the high values of the absorbed dose, which can cause both stochastic and deterministic effects in patients – radiation reactions and complications from normal tissues. In contrast to diagnostic irradiation, radiotherapy does not simply reduce the absorbed dose of patients, which is connected to the need of having a cancericidal effect on the tumor site or target [3].

The appearance of new, modern, and complex medical linear electron accelerators on the market has allowed the introduction of high-tech radiotherapy in oncological institutions in different countries. The application of high-tech radiotherapy has led to the complication of radiation protection procedures for personnel. The maximum values of the absorbed dose rate released to patients increased to 6 Gy/min on accelerators, and in recent years it has been up to 24 Gy / min for small fields of stereotactic irradiation. There was a problem of estimating the doses created by neutrons on high-energy accelerators. Methods for calculating the protection of procedure rooms where accelerators are installed have become more complex.

Aim of this work is calculation of radiation protection of the canyon and labyrinth to ensure the safety of radiation therapy sessions by gamma beams and high-energy photon radiation.

In accordance with the intended aim, it is necessary to solve the following objectives:

1. Performing a literature review on the research topic;

2. Study the basics of radiation control for the staff of radiotherapy departments;

3. Study a software program that allows to carry out numerical simulation of radiation load during radiation therapy;

4. Establish a principal scheme of the mutual arrangement of the canyons with a gamma-therapeutic equipment and a linear accelerator;

5. Calculate the thickness of the walls (concrete) and the ceiling (concrete) for canyons with gamma-therapeutic equipment and linear accelerator;

6. Calculate the equivalent dose rate from gamma-ray at the entrance to the labyrinth for the canyon of the gamma therapeutic equipment;

7. Calculate the equivalent dose rate from bremsstralung, capture gamma-ray, photoneutrons at the entrance to the labyrinth for the canyon with a linear accelerator;

8. Collect materials and calculate the thickness of the protective door of the labyrinth for the canyons with gamma-therapeutic equipment and linear accelerator;

9. Calculate the average ozone concentration in the canyons during the operation of the gamma-therapeutic equipment and linear accelerator.

1. Literature review on the research topic

1.1 Radiation safety assurance for medical staff during external beam therapy (EBT)

Radiation protection of medical staff during external beam therapy (EBT) depends mainly on the quality of the protection, the duration and number of wedges on gamma-equipment, and the system of measurements to prevent emercency situations. EBT rooms are located in separate buildings or in isolated parts of the medical buildings. All persons except the patient are removed from the irradiation room during the session. The control console is moved to an adjacent room, and communication with the patient during the radiation procedure is maintained by using phone and a closed-circuit television system. The entrance to the room where the megavolt source or gamma-ray equipment looks like a labyrinth.

By blocking the security door, it is guaranteed that no staff will suddenly appear in the radiation zone.

In EBT rooms it is forbidden to take any actions that are not prescribed in the job description and other normative documents, unless they are aimed at preventing accidents and other circumstances that threaten the staff's health and normal operation of the institution.

Rebooting of gamma-therapeutic equipmentes should only be carried out by specialized organizations which have the permission from SES (sanitary and epidemiological service).

The main factors of radiation hazard in the operation of gamma-therapeutic equipmentes with ^{60}Co radiation sources are: the beam of gamma quanta extracted from the equipment and scattered radiation through the walls of radiation head [3].

Scattered radiation in machines reaches maximum on the protective container's side through which the equipment loads the source of cobalt, so in using high-power charges that create the dose rate at the reference distance up to 3-4 Gy/min, it is

necessary to limit the staff's presence from this side when placing the equipment at 90° and 270° angles from vertical position.

On average, the effective dose of staff constantly taken in gamma therapy, according to S. A. Kalnitsky et al., is at the level of 1 mSv / year [4]. The staff can take higher doses in the event of emergency radiation exposure due to jamming of the equipmentes' gates, the fault of timers, etc. In these cases, the staff must enter the treatment room to evacuate patients. Doses in the use of correct evacuation techniques may also be low. But the staff must be constantly trained in case of emergency radiation conditions.

When operating a medical accelerator, the main radiation hazard factors are:

- the beam of accelerated electrons from the accelerator;
- bremsstrahlung that occurs when accelerated electrons interact with the environment; photoneutrons that appear when high-energy bremsstrahlung interacts with the nuclei of environmental substances;
- removable radioactive contamination of the environment in the accelerator treatment room that appears as a result of activation of dust, metals, fume of activated materials of the target and other contaminants of the accelerator under the action of an electron beam, radiation processes, etc.;
- radioactive gases and aerosols produced during irradiation of air components and substances entering it from irradiated objects, as well as from activated water cooling the accelerator joints;
- unused x-ray radiation from the accelerator's high-voltage electronic equipment.

Modern medical linear electron accelerators are the sources of high-energy photon radiation. At a distance of 1 m from the target, the absorbed dose rate can range from 0.5 to 6 Gy / min, and in small-field radiosurgery it can reach up to 24 Gy / min. In the latter case, the photons are removed from the accelerator without using compensating filter. In addition, when the end-point photon energy is more than 10 MV,

relatively large neutron fluxes will appear. Still, the rooms' protection is quite effective with proper design and construction of bunkers. However, on medical accelerators, there are several factors that require special consideration when evaluating doses the staff receive.

1.2 Main problems in radiation safety assurance for medical staff during external beam therapy

Calculation of stationary radiation safety is solving physical tasks. In the calculation the type of radiation (photons, neutrons), dose rate of radiation and its energy, architectural features of the room, requirements for permissible levels of the radiation field in adjacent rooms and on-site are taken into account. The calculation is usually carried out at the stage of designing room for EBT. The result of calculation must be recommendations for the choice of protective materials used for the manufacture of stationary radiation protection; determine the requirements for the protective properties of these materials, i.e. wall thickness and materials for their manufacture, floor and ceiling coverings, doors, window openings, etc.

What are the problems arising in the calculation of the radiation safety zones for the installation of the gamma-equipment for EBT and medical accelerators? [3, 5]

The current sanitary regulations do not cover all the issues being faced both at the design stage and during the further exploitation of medical accelerators. The current method of calculating protection against ionizing radiation does not take into account a number of important conditions: the presence of scatters from various targets (patient, accelerator design elements and auxiliary equipment); the formation of photoneutrons on the accelerator head and filler structures, etc. All these factors can significantly affect the parameters of necessary protection.

In addition, the normative documents do not contain reference data on the thickness of the shield when energies are above 6 MeV; the possibility of using many types of building materials for protection is not taken into account, and the method for calculating combined protection is not specified. There is no information about the

standardized weekly workload in the isocenter for one shift of the installation. The existing method of calculating protection also raises many questions and contains a number of shortcomings that may affect the radiation safety for the staff and the public. As a rule, when designing, they forget about the need to develop a radiation control instruction. The above facts make it difficult to correctly determine the necessary shielding thickness and subsequent assessment of radiation safety on the object, which can lead to cases of exceeding the main dose limits for personnel when operating medical accelerators. Untill now the issue of regulation and instrumentation of dosimetric measurements of pulsed fields remains unresolved.

During occupational activities, it is often necessary to conduct dosimetric monitoring, design and expert evaluation of project documentation. Summarizing the materials of the last 10 years of work and comparing the data of technical documentation and protection calculations of the majority of medical accelerators located in the territory of Moscow, we came to the conclusion that the most objective way to reflect the essence of the ongoing physical processes and the real radiation situation around the treatment room for radiotherapy is possible with the help of standardized workload indicator (W_0). That means the standardized workload introduces a balance in regulatory documents between the physical capabilities of the equipment and the needs of the health care facility, preventing the abuse of project organizations, health care facilities and Supervisory authorities when assessing the necessary protection.

At the time being the workload of the accelerator is calculated individually, taking into account the number of patients receiving treatment sessions per shift, the number of working days per week and the average dose released to the patient for one procedure. When summarizing the available data on the operating mode of radiotherapy departments used in the project documentation for calculating protection, it, as a rule, can be concluded that the it is planned on the accelerator to receive up to 25 patients per shift on a 5-day working week for 50 weeks per year, design value released to the patient per fraction is 4 Gy, the maximum dose rate at the maximum energy photon

radiation in the isocenter is 6 Gy/min.. When using these data, the standardized weekly workload (W_0) in the isocenter makes up 500 Gy per shift, while the equipment is operated in two shifts of 1000 Gy.

The existing normative documentation for determining the thickness of the filler structures (walls and ceilings) calculates the necessary ratio of radiation attenuation as the ratio of the average dose rate per shift to the design dose rate, taking into account the coefficients of direction, shift and employment. This approach introduces a significant commotion in the subsequent dosimetric control, during which the design dose rate is often used as a normative value. In accordance with NRB-99/2010, the main criterion for ensuring radiation safety is not exceeding the dose limit for personnel and the public. Thus, the transition from the dose limit to the design dose rate and vice versa is an impractical and unnecessary mathematical action [5]. When calculating the required ratio of overlap attenuation, the ratio of the workload to the dose limit should be evaluated, taking into account the specified coefficients and the distance to the walls.

1.3. Basic definitions and dose values

Dose limit (DL) – the amount of the annual effective or equivalent dose of technogenic irradiation, which should not be exceeded under normal operating conditions. Compliance with the limit of the annual dose prevents the occurance of deterministic effects, and the probability of stochastic effects is maintained at an acceptable level [6].

Radiation monitoring – Receiving information about the radiation situation in the organization, in the environment, and about the exposure levels of people (includes dosimetric and radiometric monitoring).

Workplace – the place of permanent or temporary stay of the staff to perform working functions under the conditions of exposure to radiation for more than half of the working time or two hours continuously.

Dose rate – radiation dose per unit of time (second, minute, hour).

Absorbed dose (D) – the amount of ionizing radiation energy transmitted to the substance [6]:

$$D = \frac{\overline{de}}{dm} \quad (1.1)$$

where $\overline{de}$ – the average energy transmitted by ionizing radiation to a substance located in an elementary volume, and dm is the mass of the substance in this volume. In SI units, the absorbed dose is measured in joules, divided by kilogram (j/kg), and has a special name – gray (Gy). The previously used non-system unit of rad is 1 rad = 0.01 Gy.

Equivalent dose ($H_{T,R}$) – the absorbed dose in the body or tissue, multiplied by the corresponding weighting coefficient for this type of radiation emanation [6]:

$$H_{T,R} = W_R . D_{T,R} \quad (1.2)$$

where $D_{T,R}$ – the average absorbed dose in the body or tissue T, and W_R – weighting coefficient for radiation R. The unit of equivalent dose is sievert (Sv).

Effective dose (E) – the value used as a risk measure of distant irradiation consequences of the entire human body and its seperate organs and tissues, taking into account their radiation sensitivity. It represents the sum of the equivalent dose in organs and tissues for the corresponding weighting factors [6]:

$$E = \sum_T W_T . H_T, \quad (1.3)$$

where H_T – the equivalent dose in the body or tissue T, and W_T – weighting coefficient for the organ or tissue T.

The unit of equivalent dose is Sievert (Sv). Non-systemic unit of equivalent and effective dose – rem (roentgen equivalent man).

$$1 \text{ Sv} = 100 \text{ rem} \quad (1.4)$$

Annual effective (equivalent) dose – the sum of the effective (equivalent) dose of external irradiation received for the calendar year and the expected effective

(equivalent) dose of internal irradiation, determined by the entry into the body of radionuclides for the same year.

The unit of annual effective dose – Sievert (Sv).

Exposure dose is the ratio of the total charge dQ of all of the same sign ions created in the air, when all the electrons and positrons are separated by masses in the air passage, released by photons in an elementary volume of air with mass dm completely stopped, to the mass dm of the air in this volume [6]:

$$X = dQ/dm. \quad (1.5)$$

Exposure dose unit set in SI – Coulomb per kilogram (C/kg). Previously, in practice and scientific literature, the common non–system unit of exposure dose was roentgen (R) [7].

$$1\ P = 2{,}58 \times 10^{-4}\ C/kg. \quad (1.6)$$

In conditions of electronic equilibrium, the exposure dose of 1 C/kg corresponds to an absorbed dose of 33,8 g in the air or 37,2 g in biological tissue; for non-system units, 1 R corresponds to an absorbed dose of 0,873 rad in the air or 0,96 rad in biological tissue.

Based on the obtained values, the arithmetic average value of the exposure dose rate $\bar{\dot{X}}$,mR/h, is calculated according to the formula:

$$\bar{\dot{X}} = \frac{1}{n}\sum_{i=1}^{n} \dot{X}_i \quad (1.7)$$

The average square deviation that characterizes the random component of the error in measuring the dose rate $S(\bar{\dot{X}})$ is calculated using the formula:

$$S(\bar{\dot{X}}) = \sqrt{\frac{\sum_{i=1}^{n}(\dot{X}_i - \bar{\dot{X}})^2}{n\,(n-1)}} \quad (1.8)$$

The limits of non-excluded systematic error are determined when calibrating the dosimeter and are indicated in the passport (for the dosimeter DRG-01T1 $\widetilde{\theta_{\dot{X}}} = 15\%$). The limits of non-excluded systematic error are determined in mR/h from the formula:

(1.9)

$$\theta_{\dot{X}} = \widetilde{\theta_{\dot{X}}}.\frac{\bar{\dot{X}}}{100\%}$$

Confidence limits of the total unexcluded systematic component of the measurement result error of the radiation exposure dose rate θ(p) at a confidence probability of p = 0.95 are estimated by the formula:

$$\theta(0{,}95) = 1{,}1\sqrt{\theta_{\dot{X}}^2} \tag{1.10}$$

The confidence limits of the random error of the measurement result B (p) for the confidence probability p are determined by the formula:

$$\mathrm{B(p)} = t_p\left(f_{эф}\right) * S(\bar{\dot{X}}) \tag{1.11}$$

where $t_p\left(f_{эф}\right)$ – quantile of the student's t-distribution for the confidence probability (confidence level) p and the number of freedom degrees $f_{ef;}$

f_{ef} – Evaluation of the effective number of freedom degrees, adopted in the normative documents of the state system for ensuring the measurement unity of metrology, in direct measurements $f_{эф} = n - 1$.

The confidence limits of the total error of the measurement result Δ_p for the confidence probability p = 0,95 are determined by the formulas:

$$\Delta_{0{,}95} = B(0{,}95), \text{ if } \frac{\theta(0{,}95)}{S(\bar{\dot{X}})} < 0{,}8 \tag{1.12}$$

$$\Delta_{0{,}95} = \theta(0{,}95), \text{ if } \frac{\theta(0{,}95)}{S(\bar{\dot{X}})} > 8 \tag{1.13}$$

$$\Delta_{0{,}95} = K(\gamma)[B(0{,}95) + \theta(0{,}95)], \text{ if } 0{,}8 \le \frac{\theta(0{,}95)}{S(\bar{\dot{X}})} \le 8 \tag{1.14}$$

$$\text{where } K(\gamma) = \frac{\sqrt{1+\gamma^2}}{1+\gamma}, \gamma = \frac{\theta(0{,}95)}{\sqrt{3} * 1{,}1 * S(\bar{\dot{X}})}$$

Evaluation of the extended uncertainty $\widehat{U}_{0{,}95}$ of the gamma-ray exposure dose rate measurement is:

$$\widehat{U}_{0{,}95} = \Delta_{0{,}95} \tag{1.15}$$

In RSS-99/2009, the dose limit for group A staff is 20 mSv per year. Evaluation of the individual effective dose according to the formula is:

(1.16)

$$E = \bar{\dot{X}} * 0{,}873 * 0{,}01 * w_R \sum_i \omega_i * T_{cp} * 10^6$$

where w_R – weighting coefficient for photon = 1; $\sum_i \omega_i$ – the sum of the weighting coefficients of an organ or tissue, for the entire human body = 1.

For the SL-75M linear accelerator canyon, the operating mode is 2 hours a day, 5 days a week. For the canyon of Theratron gamma therapeutic equipment – the operating mode is 2 hours a day, 5 days a week.

1.4. Basic standards for security design

The main document in the Russian Federation which establishes requirements for ensuring human safety under various conditions of exposure to ionizing radiation of artificial or natural origin is the sanitary rules and norms 2.6.1.2523-09 **"Radiation safety Standards (RSS-99/2009)"**.

RSS-99/2009 was approved by the Decree of the Chief state sanitary doctor of the Russian Federation from July 7, 2009 and entered into force on the territory of the Russian Federation from September 1, 2009. Since then the previous radiation safety standards -RSS-99 have been expired [8].

In accordance with RSS-99/2009, the categories of exposed persons are as followed:

- ***The personnel*** - persons who work with man-made sources of ionizing radiation (group A) or are under working conditions in the sphere of radiation influence (group B);
- ***The population***, including persons from the staff, outside the scope and the conditions of their working activities.

3 classes of standards are established for categories of irradiated persons according to RSS-99/2009:

1. The main dose limits (DL);

2. Permissible levels (from one type of radiation) – those which are derived from the main dose limits: limits of annual intake, volumetric permissible average annual activities, permissible dose rate, permissible flux density, etc.;

3. Reference levels (doses, activity, flux density, etc.).

Their values must be below acceptable levels. The main dose limits are given in table 1.1.

The main dose limits do not include doses:

- from natural sources,
- from medical sources,
- from radiation accidents.

These types of radiation are subject to special restrictions. The effective dose for the staff (gr. A) during the period of employment (50 years) must not exceed 1000 mSv, and for the public with the period of (70) years - 70 mSv. The beginning of the periods was from January 1, 2000.

The limit of individual risk of the personnel (gr. A) for technogenic exposure during the year in normal use (without accidents) is approximately 1.10^{-3}, and for gr. B staff is approximately 5.10^{-5}. Note that the level of negligible risk is 10^{-6}.

Table 1.1- Main dose limits

Normalized values	Dose limits	
	Personnel (group A)	Population
Effective dose	20 mSv per year on average for any consecutive period of 5 years, but no more than 50 mSv per year	1 mSv per year on average for any consecutive period of 5 years, but no more than 5 mSv per year
Equivalent dose per year: in the lens skin hands and feet	 150 mSv 500 mSv 500 mSv	 15 mSv 50 mSv 50 mSv

Notes of tab. 1.1:

- All normative values for the personnel category are given in RSS-99/2009 for group A only;
- The dose limits and acceptable levels of the staff of group B must not exceed 1/4 of the values for group A.

Table 1.2 - Equivalent dose rate used in the design of the shield against external ionizing radiation

Category of irradiated persons.		Designation of sites and premises	Designed capacity of equivalent dose, μSv/h.	Duration of irradiation, h / year.
Personnel	Group A	Premises of permanent stay of staff	6,0	1700
		Premises of temporary stay of staff	12	850
	Group B	Premises of the organization and the site of SPZ where gr. B staff are located	1,2	2000
Population		Any other sites and premises	0,06	8800

Persons who are at least 18 years old and do not have medical contraindications are allowed to work with sources of ionizing radiation (personnel gr.A).

Additional restrictions are imposed on women under the age of 45 who work with ionizing radiation sources. In addition, the administration of the enterprise is obliged to move a woman during her pregnancy and breastfeeding to other sections that are not related to ionizing radiation.

For students and learners at the age of at least 16 years who are learning how to use ionizing radiation sources, annual doses must not exceed the values set for personnel group B.

The design of protection against external radiation of staff and the public must be carried out with a safety factor of at least 2 of the effective dose per year (due to possible errors in the design and construction of protection). At the same time, it is necessary to take into account the presence of other radiation sources and the future increase in their rate. The design of external ionizing radiation protection should be carried out taking into account the type of the accomodations and depending on the category of trained persons and the duration of exposure. The values of the designed capacity of the equivalent dose with a safety factor of 2 are shown in table 1.2. This is data from **BSRFRS-99/2010 (Basic sanitary rules for radiation safety)** [9].

2. Materials and methods

2.1 Methods for calculating biological protection canyon

2.1.1 Calculation of protection from radionuclide gamma radiation

2.1.1.1 Methods for calculating primary protection from gamma radiation

When calculating the protection from primary gamma-ray of radionuclides using universal tables and nomograms, the form of multiplicity of radiation attenuation is:

$$\kappa = \frac{\mathrm{H}\,(\dot{R}, 0)}{\mathrm{ADR}} = \frac{\alpha}{\mathrm{ADR}} . \frac{\delta_D}{R^2}\,, \qquad (2.1)$$

where $\alpha = 3.6.10^{-9}$ A.$G_н$ (μSv.m^2/h) – if the activity of the source is set in Bc; α = 1.09. $\overline{w}$.7,3.M (μSv. м^2/h) – if the gamma-equivalent of the source is set in mg Ra (in fact, α – the equivalent dose rate at a distance of 1m from the source); ADR - acceptable dose rate; δ_D – correction for barrier [6].

If the distance to the shied is clearly identified and iteration method is applied, we will get an expression that can be used in the calculation

$$\kappa_n = \frac{\alpha}{\mathrm{ADR}} . \frac{\delta_D}{(R_s + d_{n-1})^2}\,, (d_0 = 0) \qquad (2.2)$$

where $R_з$ is the distance from the source to the shield (m) and d is the thickness of the shield (m). The number of iterations determines the accuracy of the calculations. As a rule, it is enough to perform 2-3 iterations.

For a known value of the attenuation layer, for example, $\Delta_{1/10}$ – first and $\Delta^{as}_{1/10}$ – asymptotic, the thickness of the shield can be calculated from the expression

$$d_n = \Delta_{1/10} + \frac{\Delta^{as}_{1/10}}{ln10}\, ln\left[\frac{\alpha}{10ADR} \cdot \frac{\delta_D}{(R_s + d_{n-1})^2}\right] \text{ when } (d_0 = 0), \qquad (2.3)$$

where δ_D –barrier correction. The barrier correction must be taken into account if the attenuation layers are obtained for an infinite geometry.

2.1.1.2 Methods for calculating secondary protection from gamma radiation

To calculate the protection from scattered radiation with the use of universal tables the factor of radiation attenuation has the form:

$$\kappa_n = \frac{\alpha . \cos\theta_0 \ . S . a_D(E_0, \theta_0)}{2\pi . ADR . F^2 . (R_s + d_{n-1})^2} \text{ when } (d_0 = 0), \qquad (2.4)$$

where θ_0 is the angle of descent of the primary radiation on the surface of the lens relative to the normal; F is the distance from the source to the center of the site S; $a_D(E_0,\theta_0)$ is the integral dose albedo.

When calculating the protection from scattered radiation, it is necessary to focus on the highest energy of this radiation (the large thickness of the shield), which corresponds with the smallest angle of scattering of the primary radiation θ_S. In most practical cases, the primary radiation falls down vertically, and then the smallest scattering angle $\theta_S = 90^o$ and the scattered radiation propagates along the surface of the lens. It is assumed that the average energy of scattered gamma-ray of radionuclides $\overline{E_S} = 0{,}15$ MeV [10]. But the effective energy of the primary gamma-ray of radionuclides can be less than 0.15 MeV, so we will use the following values for $\overline{E_S}$:

- $\overline{E_S} = 0{,}15$ MeV , if $E_{eff} > 0{,}15$ MeV;
- $\overline{E_S} = E_{eff}$, if $E_{eff} < 0{,}15$ MeV.

2.1.2 Calculation of protection from bremsstrahlung

When calculating the protection of premises from bremsstrahlung for high energy, it is divided into:

- primary protection (primary barrier) – this is the part of the protection that is directly affected by the bremsstrahlung and photoneutrons of the accelerator's working beam.
- secondary protection (secondary barrier) – the rest of the protection.

The thickness of the secondary shield is determined by the following radiations:

- bremsstrahlung scattered from the walls and the floor of the room;

- bremsstrahlung leakage – radiation from the accelerator head outside the working area of the beam;
- secondary protection (photoneutrons and gamma radiation of radiative absortion) generated in the rotary head and in the accelerator room.

The primary and secondary materials for the shield can be the same. However, to reduce the size of the shield, the primary is made of heavy concrete, and the secondary is made of ordinary concrete.

The thickness of the primary shiled is determined by the weakening of the primary bremsstrahlung, while the transverse dimensions of the primary barrier are determined by the shielding area on which the primary bremsstrahlung beam decreases at the maximum size of the irradiation field.

In foreign publications on the calculation of bremsstrahlung protection [11], it is proposed to set the width of the primary barrier according to the maximum transverse dimensions of the working beam and additionally add at least 30 cm on each side. An example of defining a security setting is shown in Fig. 2.1.

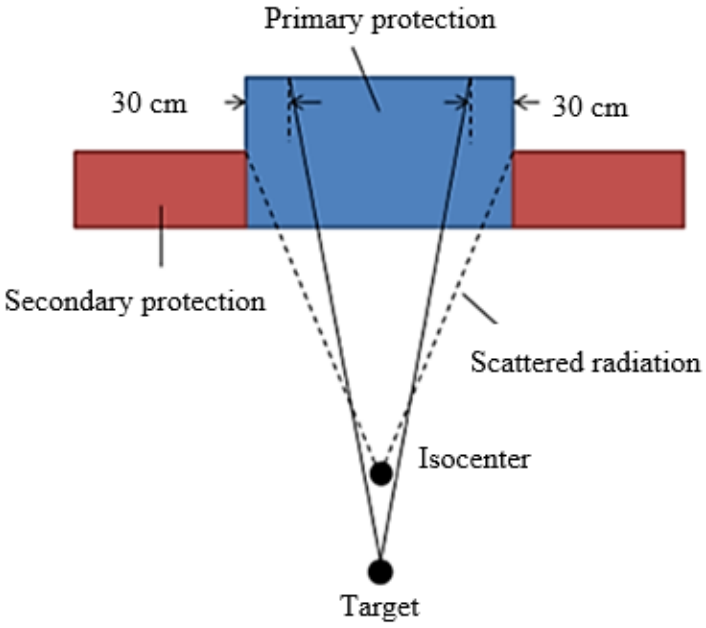

Figure 2.1 – Width’s selection of the primary barrier

2.1.2.1 Methods for calculating primary protection from bremsstrahlung

When calculating the protection from primary bremsstrahlung by nomogram method, the dimensionless coefficient *K*, which takes into account the main working conditions behind the shield thickness of *d*, is determined by the expression:

$$K_n = \frac{\dot{D}_a}{\dot{D}_{sa}} \cdot \frac{\overline{w} \cdot i \cdot 10}{ADR \cdot (R_s + d_{n-1})^2} \text{ when } (d_0 = 0), \qquad (2.5)$$

where $\overline{w}$ is the weighting factor for bremsstrahlung; i – current, mA; $\dot{D}_{sa}$ is the indicator of tissue absorbed dose rate of bremsstrahlung of "standard" accelerator (Gy·m^2/h·mA) ($\dot{D}_{sa}$ values determined from the graph of a value of tissue absorbed dose rate of radiation are based on the electron energy).

If the value of coefficient K is larger than that on the nomograms when calculating the protection, then this coefficient should be represented as: $K = K_1 \cdot 10^n$. The shield thickness for K_1 must be determined by nomograms, and the additional thickness for the attenuation factor 10^n must be found using the tenfold attenuation layer method. Value of $\Delta_{1/10}$ can be determined from nomograms in the field K_1. When calculating the protection in CL program, this value is calculated by the program itself. Values of $\Delta_{1/10}$ for the attenuation of the tissue absorbed dose rate for primary bremsstrahlung are given in the tables. These values are calculated for the thickness of the shield corresponding to K=10^4, and change slightly with its further increase [12].

Using the data on the thickness of the tenfold attenuation layer of $\Delta_{1/10}$, we can find the thickness of the shield from bremsstrahlung of the electronic accelerator. Such data is available for the energy range of 0.1...100 MeV and for the three main shield substances: concrete, iron and lead. Moreover, [6] provides data for both the first layer of ten-fold attenuation and the next $\Delta_{1/10}^{as}$ (asymptotic). The attenuation layers for concrete are shown in fig.2.2.

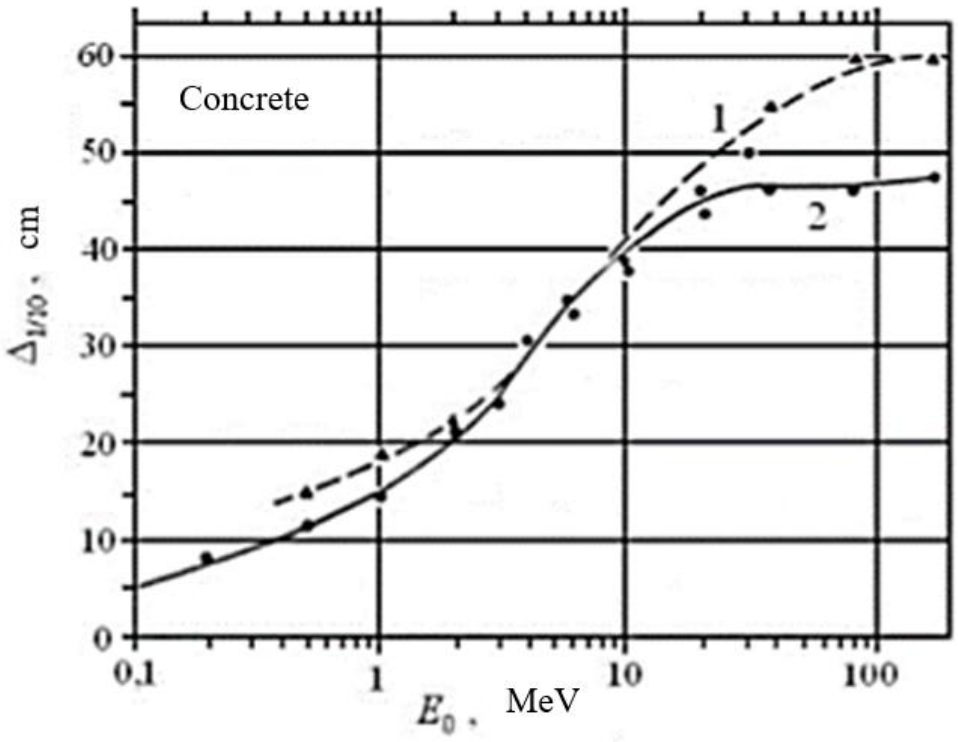

Figure 2.2 – value of tenth-time attenuation layer for concrete

1 – the first layer; 2-asymptotic

The calculation of bremsstrahlung protection is based on the formula and using the iteration method:

$$d_n = \Delta_{1/10} + \frac{\Delta_{1/10}^{as}}{ln10} ln\left[\frac{\dot{H}_0^{\mathrm{br}}}{10 \cdot \mathrm{ADR}\,(R_s + d_{(n-1)})^2}\right] \text{ when } (d_0 = 0), \qquad (2.6)$$

2.1.2.2 Methods for calculating secondary protection from bremsstrahlung

For accelerators that generate bremsstrahlung, protection at high angles relative to the direction of the primary electron beam can be determined not only by scattered radiation, but also by the primary bremsstrahlung coming out of the target in this direction (radiation leakage), since the effective energy and penetration ability of the primary bremsstrahlung coming out of the target at any angles is much higher than that of scattered radiation. Therefore, the design of the accelerator must provide a sufficient reduction in the dose rate from the primary bremsstrahlung outside the working beam of the accelerator.

For calculation of shield thickness from scattered bremsstrahlung obtained previously, the coefficient K must be transformed considering the fact that this type of radiation “single equivalent dose rate” for protection at a distance of 1 m from the accelerator at a current of 1mA is equal to 6 μSvm^2/h·mA [6]. Then:

$$K_n = \frac{\dot{D}_a}{\dot{D}_{as}} \cdot \frac{\Delta\Omega}{\Delta\Omega_0} \cdot \frac{i \cdot 6}{\mathrm{ADR} \cdot (R_s + d_{n-1})^2} \text{ when } (d_0 = 0). \qquad (2.7)$$

As same as for the primary protection, if the value of coefficient K is larger than that on the nomograms, then the additional shield thickness must be found using tenth-time attenuation layers. The values of $\Delta_{1/10}$ for attenuation of tissue absorbed dose rate for scattered bremsstrahlung are given in the tables. They are obtained for attenuation multiplicity K = 10^4.

The calculation of the shield thickness from radiation leak will be carried out using the methods already presented in section 6.2.1 for calculating the protection from primary bremsstrahlung. In accordance with [3], the absorbed dose of bremsstrahlung radiation leak in the patient's plane must not exceed 0.1% on average of the maximum absorbed dose. The absorbed dose of bremsstrahlung leak outside the patient's plane (in the direction of 90°) at a distance of 1 m from the beam axis must not exceed 0.5% of the maximum absorbed dose in the isocenter.

2.1.3 Calculation of protection from photoneutron radiation

Medical accelerators with electron energies of more than 10 MeV are sources not only of bremsstrahlung, but also of photoneutrons. Photoneutron protection should be calculated in the same detail as bremsstrahlung protection, but engineering methods of calculation are less accurate. This is due to the following reasons:

- large spatial dimensions of the neutron source. The walls, floor, ceiling of the room and the equipment located in it are sources of low-energy neutrons;
- photoneutrons scattered from the patient must be taken into account;
- for medical accelerators, the output of photoneutrons depends on the size of the working field created by the diaphragm;

- it is necessary to evaluate the contribution of the capture gamma-ray, which has an average energy of 3 MeV and has a high penetrating power;
- complex dependence of the weighting radiation coefficient for neutrons from their energy;
- shield materials from bremsstrahlung and neutron radiation differ significantly [6].

2.1.3.1 Methods for calculating primary protection from photoneutron radiation

The thickness of the primary shield from neutrons is determined taking into account the geometric attenuation of radiation and the iteration method [11]:

$$d_n = \boldsymbol{\lambda} \cdot ln \frac{H_{n,0}^{\cdot}}{ADR\left(R_s + d_{(n-1)}\right)^2}, \qquad (2.8)$$

where λ is the relaxation distance of neutrons in concrete, cm (For concrete with density of 2.3 g/ cm^3 relaxation distance is equal to 16 cm [13]); R_s – distance from target to the shield, m; $H_{n,0}^{\cdot}$ - the average equivalent dose rate from photoneutrons at a distance of 1m from the target (ISO-center), μSv·m^2/h.

The average equivalent dose rate from photoneutrons is determined by this formula:

$$H_{n,0}^{\cdot} = D_1^{\dot{\gamma}} \cdot \delta_0 \quad (2.9)$$

Where $D_1^{\dot{\gamma}}$– the maximum dose rate of photon radiation; δ_0 – the ratio of the equivalent dose of photoneutrons to the absorbed dose of bremsstrahlung (mSv/Gy).

For an accelerator with an energy of 10 MeV, we apply the value δ_0 = 1 mSv/Gr. Hence, $H_{n,0}^{\cdot}$ = 1,44.10^6 μSv/h.

2.1.3.2 Methods for calculating secondary protection from photoneutron radiation

Secondary protection is determined by photoneutrons that are born in the rotary head and in the accelerator room, which is the radiation leak.

The thickness of the shield is calculated using the layer attenuation method of $\Delta_{1/10}$. For neutrons escaping through the shield of the radiation head of the accelerator, the value of this layer is suggested to be equal to $\Delta_{1/10}$ = 25 cm [14]:

$$d_n = \frac{\Delta_{1/10}}{ln10} ln \frac{H_{n,1}^{\cdot}}{\text{ADR}\left(R_s + d_{(n-1)}\right)^2}, \qquad (2.10)$$

The absorbed dose of neutrons outside the working beam area in and outside the patient's plane must not exceed 0.05 % of the peak value of absorbed dose of bremsstralung [6]. Therefore, the equivalent dose rate of photoneutron leak at a distance of 1 m from the target outside the working beam must not exceed $H_{n,1}^{\cdot} = 14{,}4 \cdot 10^6 \frac{\mu\text{Sv}}{\text{h}}\text{m}^2$ (for "Varian Truebeam" accelerator) and $H_{n,1}^{\cdot} = 3{,}6 \cdot 10^6 \frac{\mu\text{Sv}}{\text{h}}\text{m}^2$ (for "Elekta Synergy" accelerator).

2.1.4 Statistical methods for analysis

The task of statistical methods for analysis is to determine the nature of the relationship between the factorial (determining) feature and the effective (dependent) feature. As a rule, objects are grouped by factorial feature, and the average is located in the effective feature group, then comes the tendency and the conclusion about the presence and nature of the relationship is formed. [15,16,17]

Dispersion is a measure of the spread of possible outcomes relative to the expected value. Therefore, the higher the dispersion, the greater the spread, and the risk. The formula for calculating dispersion is as follows:

$$S^2 = \frac{\sum_{i=1}^{n} (x_i - \bar{x})_i^2}{n-1}; \qquad (2.11)$$

where: X_i – calculation value corresponding to the i calculation;

$\overline{X}$ – average calculation value;

n – calculation number.

Dispersion is measured in the square, and since this interpretation is very unusual and difficult, the "mean square deviation" (standard deviation), which is the square root

of the dispersion, is used as another indicator of the deviation of the yield values from the expected value:

$$\sigma = \sqrt{\frac{\sum_{i=1}^{n}(x_i - \bar{x})_i^2}{n-1}}; \qquad (2.12)$$

Coefficient of variation is the ratio of the mean square deviation to the arithmetic mean, expressed in percentage. It is used to compare the fluctuation of the same attribute in several aggregates with different arithmetic mean. Coefficient of variation is used not only for comparative evaluation of complex units, but also to characterize the homogeneity of the complex. A complex is considered homogeneous if coefficient of variation does not exceed 33%. The coefficient is calculated using the formula:

$$V = \frac{\sigma \cdot 100}{\overline{X}}; \qquad (2.13)$$

2.1.5 Computer program “Computer lab” (CL / PCLab)

The calculation was conducted in the PCLab program “Computer laboratory”. The PCLab program allows us to simulate the processes of ionizing radiation transfer in the enviroment using Monte-Carlo method. The PCLab program allows us to obtain both integral and differential results of the interaction of photons and charged particles, including the distribution of absorbed energy and dose in a substance.

When modeling for electrons and positrons, the types of particle interactions are taken into account, such as the annihilation effect of positrons, ionization collisions, and bremsstrahlung radiation; when modeling for photons – the effect of the formation of electron-positron pairs, Compton effect, photoeffect; for protons – elastic and inelastic Coulomb collisions, nuclear interactions are not taken into account [6].

Radiation propagation has a cascade nature. The construction of photons’ trajectories is carried out in the model of individual collisions. These works are used as total cross sections of photons’ interaction with substance for particle energies less than 100 MeV. The construction of charged particles’ trajectories (electrons, positrons and

protons) is carried out in a grouping model of small transmissions. Fluctuations, energy losses of particles in distant collisions, as well as fluctuations in longitudinal and transversal displacements that occur as a result of scattering are taken into account.

PCLab allows the user to choose from several operating modes which are designed for different types of calculations of radiation propagation processes in a substance and which have the corresponding functionality. In this work “PROTECT)” mode was used.

In this operation mode of the CL program, it is possible to calculate the protective thickness from concrete, iron and lead from primary and scattered x-rays for voltages of 75...450 kV, from primary and scattered bremsstrahlung for accelerated electron energies of 0.5...50 MeV.

Calculations are conducted using nomogram method. It is also possible to calculate the dose rate from a cylindrical volumetric source with and without protection, and to calculate the protection from monoenergetic isotropic point sources using universal Gusev tables [6].

A distinctive feature of the PCLab program is the simplified system of entering geometry data of the experiment without requiring knowledge of programming languages, which makes this program available to a wide range of users.

However, the numerical simulation requires a fairly high productive capacity of the computer. The simulation results are displayed online on the monitor screen, allowing you to adjust the input data at the initial stage of the calculation, which allows you to conduct model debugging process much faster.

2.2 Methods for calculating dose rates

Consider a method for calculating the equivalent dose rate of each component included in the total equivalent dose rate at the entrance to the labirynth.

2.2.1 Dose rate from bremsstrahlung

The equivalent dose rate is calculated from the primary bremsstrahlung without calculating cross-reflections (wall-floor). To account for reflections from the floor and ceiling, we enter coefficient 2.

The absorbed dose rate on the entire site on which the primary radiation falls is determined by the following expression:

$$\dot{D_{S_1}} = \dot{D}_1 \cdot S_1 = C \frac{S_1 \cdot \cos\theta_1}{R_1^2}, \quad (2.14)$$

where: $\dot{D}_1$ – the dose rate of the bremsstrahlung at a distance of 1m from the accelerator target; R_1 – the distance from the source to the center of the site S_1, m; θ_1 – the angle between the normal to S_1 and R_1.

The area of each workspace is determined by the formula:

$$S = L \cdot H, \quad (2.15)$$

where L – the length of the area (determined according to the sketch on a millimeter scale with taking into account a given scale), m; H – the height of the room, m.

The fraction of the radiation, reflected from the site S_1 and falling on S_2 (δ_1), is equal to:

$$\delta_1 = \frac{a_1(E_0,\theta_1)}{2\pi} \cdot \frac{1}{R_2^2} \cdot \cos\theta_2, \quad (2.16)$$

where E_0 is the energy of the primary electron radiation.

The fraction of the radiation, reflected from the site S_2 and falling on S_3 (δ_2), is equal to:

$$\delta_2 = \frac{a_2(\overline{E_1},\theta_2)}{2\pi} \cdot \frac{1}{R_3^2} \cdot \cos\theta_3, \quad (2.17)$$

where: $\overline{E_1}$ is the average energy of photons backscattered from the site S_2.

The fraction of radiation reflected from the platform S_3 and reaching the safety door is equal to:

$$\delta_3 = \frac{a_3(\overline{E_2},\theta_3)}{2\pi} \cdot \frac{1}{R_4^2} \cdot \cos\theta_4, \quad (2.18)$$

where: $\overline{E_2}$ is the average energy of photons backscattered from the site S_3.

Then the dose rate near the safety door is:

$$\dot{D_B} = \dot{D_{S_1}} \cdot \delta_1 \cdot S_2 \cdot \delta_2 \cdot S_3 \cdot \delta_3 = C \left[\frac{S_1 \cdot \cos\theta_1}{R_1^2} \cdot \frac{a_1(E_0,\theta_1)}{2\pi} \cdot \frac{S_2}{R_2^2} \cdot \cos\theta_2 \cdot \frac{a_2(\overline{E_1},\theta_2)}{2\pi} \cdot \frac{S_3}{R_3^2} \cdot \cos\theta_3 \cdot \frac{a_3(\overline{E_2},\theta_3)}{2\pi} \cdot \frac{1}{R_4^2} \cdot \cos\theta_4 \right], \quad (2.19)$$

2.2.2 Dose rate from capture gamma radiation

Capture gamma radiation (gamma radiation of radiation capture) – radiation that is formed when the moderated neutrons are absorbed in the accelerator room (labirynth) and reach the entrance.

The fluence and dose of neutrons entering the labyrinth depend on many parameters:

- accelerator energy;
- the size of the diaphram. For conservative assessment, the fluence and dose of neutrons should be determined with a closed diaphragm;
- To calculate protection from neutrons and capture gamma radiation, the position of the gentry is used, when the bremsstrahlung beam is directed down into the floor;
- the distance between the isocenter and A point;
- the entire surface area of the treatment room;
- the exit area of the labyrinth and the cross-sectional area of it.

The equivalent dose of capture gamma radiation at the entrance to a single-angled labyrinth can be calculated using the formula [18]:

$$H_{G,0} = 6{,}9 \cdot 10^{-16} \cdot \Phi_n \cdot 10^{-d_2/TVD}, \quad (2.20)$$

where: TVD – the distance of tenfold attenuation of the dose in the labyrinth (m); d_2 – from the figure, m; Φ_n – the full fluence of neutrons inside the labyrinth for 1g of the absorbed bremsstrahlung dose in the isocenter:

$$\Phi_n = \Phi_1 + \Phi_2 + \Phi_3, \quad (2.21)$$

Φ_1 – the primary fluence of neutrons:

$$\Phi_1 = \frac{\beta Q_N}{4\pi d^2}, \quad (2.22)$$

where $d1$ – the distance to the given point of the room (from the figure), m; Q_N – the power source of neutrons (neutr/Gy) – the number of neutrons emitted from the radiation head of the accelerator per 1 gr of the absorbed bremsstrahlung dose in the isocenter. The values are given in [18]; β is the attenuation coefficient of neutrons coming out of the accelerator head (0.85 – for protection from tungsten).

Φ_2 – the fluence of scattered neutrons:

$$\Phi_2 = \frac{1}{2\pi}\frac{5{,}4\cdot\beta Q_N}{S}, \quad (2.23)$$

where S – the entire surface area of the accelerator room (treatment room) in figure B.1 (floor, ceiling, walls) without the surface area of the labirynth, m^2.

$$\Phi_3 = \frac{1}{2\pi}\frac{1{,}3\cdot Q_N}{S}, \quad (2.24)$$

Coefficient $1/2\pi$ for scattered and thermal neutrons takes into account the ratio of neutrons entering the labirynth.

2.2.3 Dose rate from photoneutrons

The equivalent dose rate from neutrons for labirynths with two rotations can be determined by the formula:

$$\dot{H_N} = \dot{H_{N,0}} \cdot \frac{S_0}{S_M}\frac{1}{d_1^2}10^{-d_2/TVD}, \quad (2.25)$$

Where S_0 – the exit area of the labyrinth, m^2; $\dot{H_{N,0}}$ – the equivalent dose rate of neutrons in the isocenter for a given absorbed bremsstrahlung dose rate in the isocenter, $3{,}75 \cdot 10^4$ mSv· m^2/h; d_1 – from the figure, m; S_M – cross-sectional area of the labirynth, m^2; TVD – the distance of tenfold attenuation of the dose in the labyrinth (m), which depends on the sectional area of the labyrinth S_M:

$$TVD = 2{,}06\sqrt{S_M}, \quad (2.26)$$

2.2.4 Method of calculating the labyrinth's safety door

For electronic medical accelerators with energies greater than 10 MeV, as a rule, the dose at the entrance to the labyrinth is determined by the capture gamma radiation and neutrons.

The average neutron energy at the entrance to the labyrinth is about 100 Kev. To weaken such neutrons, it is necessary to use a hydrogen – containing substance – polyethylene. It is better to use borinated polyethylene with the addition of 5% boron by weight, which effectively absorbs thermal neutrons. When protecting the labyrinth's doors, the layer of $\Delta_{1/10}$ polyethylene is equal to 45 mm and borinated polyethylene is 38 mm.

The spectrum of capture gamma radiation in concrete extends to energies greater than 8 MeV with an average energy of 3.6 MeV. $\Delta_{1/10}$ layer of lead is approximately 6 mm, and the steel is 48 mm.

The calculation of the safety door from photoneutrons and gamma-capture radiation at the entrance to the labyrinth must be carried out on the condition that the equivalent dose rate from all types of radiation should not exceed ADR (acceptable dose rate)

$$ADR \geq \frac{\dot{H_G}}{k_G} + \frac{\dot{H_N}}{k_N}, \quad (2.27)$$

Behind the safety door is the staff of group A, ADR from all types of radiation is 6 mSv/h. Therefore, the calculation for neutrons and capture gamma radiation will be carried out under the condition that ADR = 3 mSv/h.

The thickness of the bremsstrahlung shield in accordance with [6] is determined by the attenuation tables for a point gamma source with an effective bremsstrahlung energy (0.1 MeV).

The thickness of the safety door from gamma radiation and neutrons is determined by the formula:

$$d = lgK \cdot \Delta_{1/10}, \quad (2.28)$$

2.3 Medical equipment for radiation therapy sessions

2.3.1 Gamma-therapeutic equipment “Theratron Equinox 80”

The gamma therapeutic equipment Theratron Equinox 80 is designed for the treatment of oncological diseases by remote gamma therapy, in which a radioactive source stored in a sealed capsule locating inside the radiation head of the equipment emits ionizing radiation. The equipment conducts irradiation automatically according to a given program without the presence of the staff in the procedure room, by operating the collimator in a given time with given deflected gantry angles [19].

When preparing for the treatment of patient, all manipulations of the setup can be controlled from the manual control panel in the room for treatment. Remote control of the platform from the outdoor control panel can be configured. On the screen of Equinox monitor located in the room the installed and actual parameters of installation, as well as the location of the table are displayed.

The radiation head consists of a protective shield made of lead and tungsten, which provides radiation output in only one direction through the output window. When irradiation does not occur, the window is closed with a shutter.

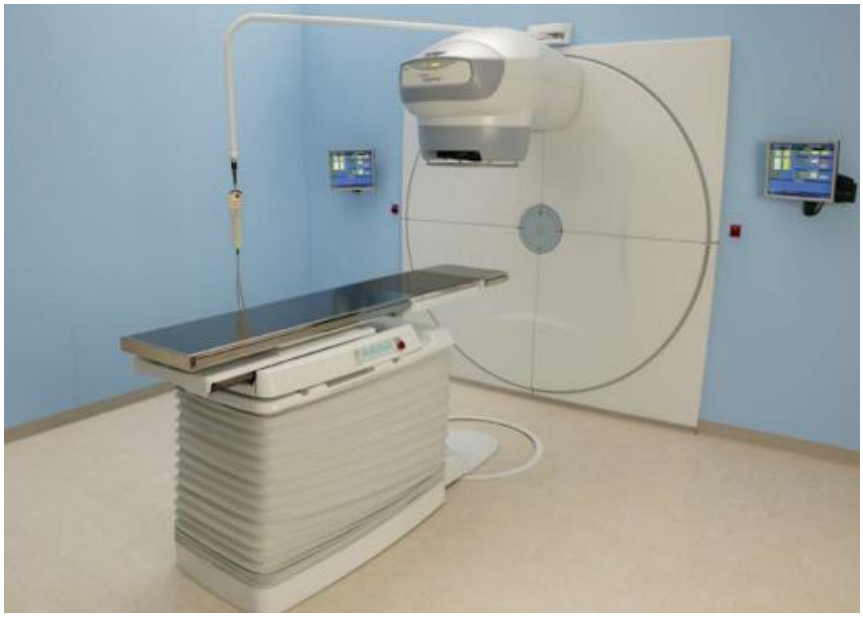

Figure – 2.3 Gamma-therapeutic appararus Theratron Equinox 80 for remote radiation

2.3.2 Linear electron accelerator SL-75-5MT

Linear accelerator is an isocentric rotating megavolt therapeutic equipment designed for radiation therapy by bremsstrahlung.

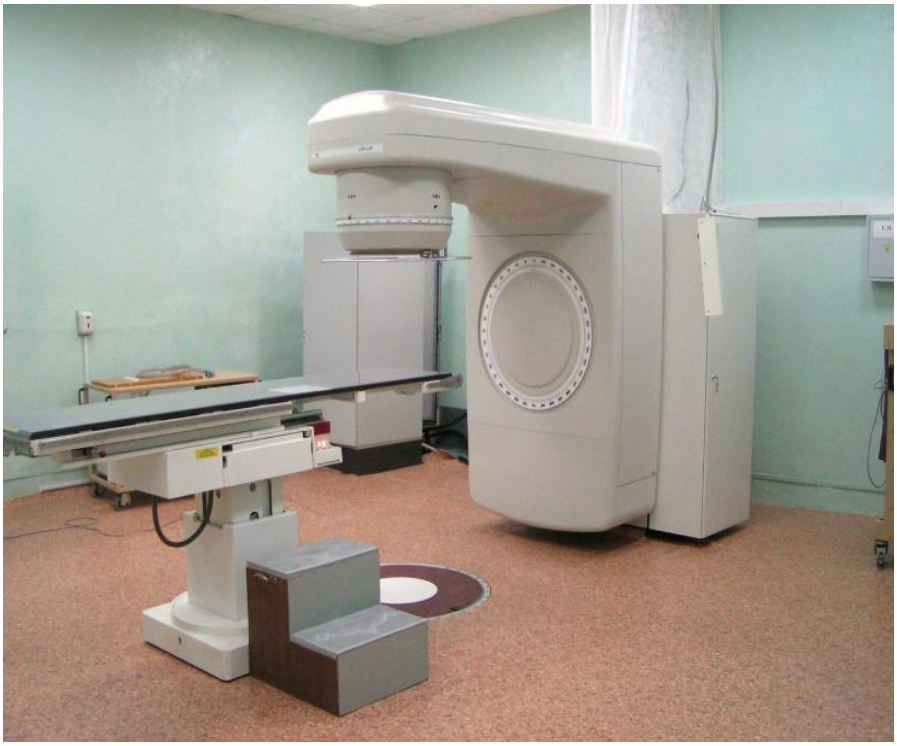

Figure – 2.4 Linear electron accelerator SL-75-5MT

The accelerator generates bremsstrahlung with a nominal energy of 6 MeV and ensures the maximum absorbed dose rate at a distance of 100 cm from the target in the range of 350-500 sGy/min. The designed elements of the radiation head of the accelerator allow forming various radiation fields with the size from 2x2 cm^2 to 40x40 $cm^{2.}$[20].

The main components of the accelerator are: emitter, control cabinet, control terminal, hanging control panel, patient tracking system.

The emitter includes a fixed support frame and a rotating part (Gantry). The Gantry consists of a balanced rotating console with an accelerating waveguide inside and a radiation head attached to the console. The modulator cabinet and the control cabinet are held on a support frame from two sides.

The accelerated electron beam is rotated 98º by a permanent magnet and is brought to the target that generates bremsstrahlung. The cone collimator and independent radiation head diaphragms form a rectangular radiation field of any scale from 2x2 cm^2 to 40x40 cm^2. In the radiation head of the SL-75-5MT accelerator, a wedge-shaped filter is installed that turns the isodose from 0º to 60º. The gantry can rotate 360º around the patient, allowing the treatment to be conducted in static and rotational modes at any angle.

2.3.3 Clinical accelerator "Varian Truebeam"

Medical linear particle accelerator is a device that is used for external radiotherapy for malignant neoplasms of any tissues and organs.

Varian TrueBeam is the most modern and high-tech linear accelerator that combines the capabilities to conduct radiotherapy and radiosurgical operations with millimeter accuracy.

Figure – 2.5 Clinical accelerator "Varian Truebeam"

TrueBeam technology is the latest generation of innovative developments, a universal platform for using all forms of advanced methods of radiotherapy in the treatment of malignant tumors of any localization, including Image Guided Radiotherapy (IGRT) and radiosurgery (IGRS) with modulated intensity of radiation

therapy (IMRT), Volumetric modulated arc therapy (RapidArc) and stereotactic body radiation therapy (SBRT) along with conventional and 3-D conformal radiation therapies.

The accelerator has four energies of photons – 6, 8, 10, 15 MeV, two photons' energies without using an equalizing filter with an increased dose rate of 6 and 10 MV, and 8 electron energies to choose from– 6, 9, 12, 15, 16, 18, 20, 22 MeV. The maximum dose rate of 2400 ME / min allows you to reach the necessary dose in the shortest possible time [21].

2.3.4 Clinical accelerator "Elekta Synergy"

The high-energy linear accelerator Elekta Synergy with intensity modulated and advanced visual control is designed for radiation therapy purposes.

Elekta Synergy is the first linear accelerator in which a 3D visualization system is integrated into the treatment process (IGRT). The system is equipped with visualization tools that help the doctor accurately define the contours of the tumor to be treated and neighboring healthy tissues, as well as take into account their possible movements during fractions and between them.

Integration of this technology into the gantry (mobile part) of the Elekta Synergy linear accelerator makes it possible to optimize the patient's placement prior to the therapy.

This accelerator was developed to supply therapeutic beams of x-rays and electrons for a wide range of standard and advanced radiotherapy methods. The accelerator has a wide energy range for photon beams (4-18 MeV) and for electron beams (4 – 22 MeV) [21].

The accelerator includes a number of effective components: MLC multi-petal collimator, iViewGT portal visualization system, and XVI visualization system.

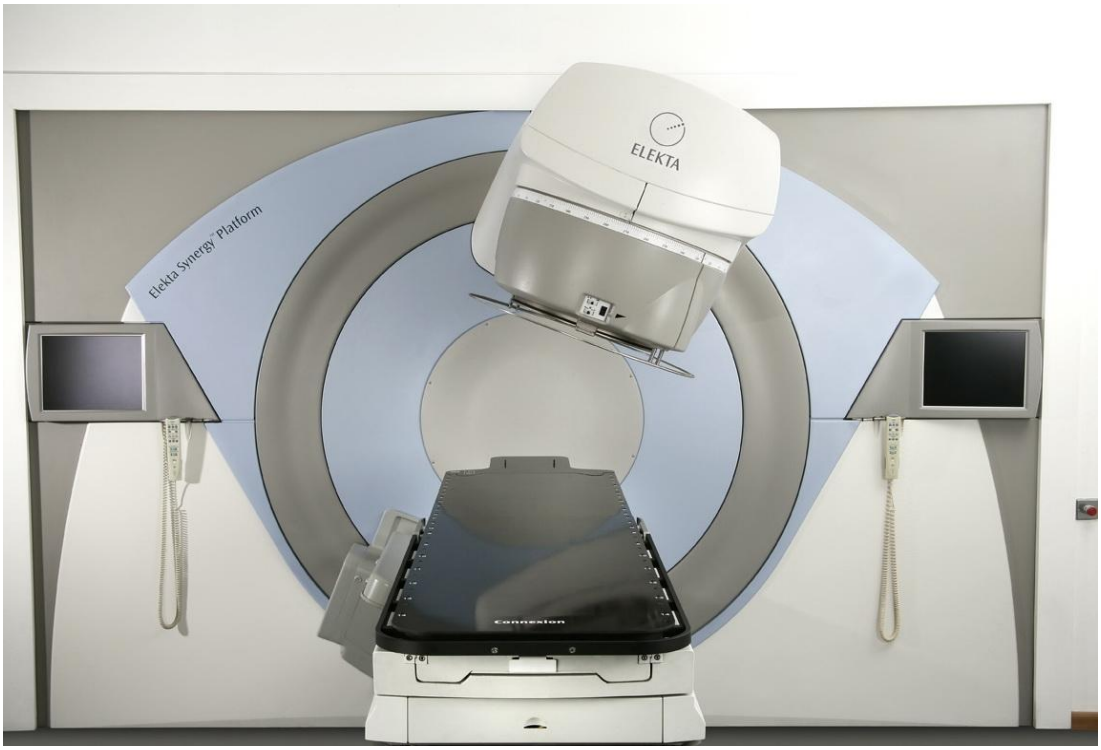

Figure – 2.6 Clinical accelerator “Elekta Synergy”

In this work, we have reviewed the operation mode of the Varian Truebeam medical accelerator without using an equalizing filter with a photon radiation energy of 10 MeV (the maximum photon radiation dose rate is 2400 ME/min). And the medical accelerator “Elekta Synergy” with a photon radiation energy of 18 MeV (the maximum dose rate of photon radiation is 600 ME/min).

2.4 DRG-01T1 dosimeter

The DRG-01T1 dosimeter is a digital wide-range portable dosimeter for the exposure dose rate of the photonic radiation.

The dosimeter is designed to measure the exposure dose rate in the workplace, in adjacent locations and in the territory of enterprises that use radioactive substances and other sources of ionizing radiation, in the sanitary protection zone and the observation zone. In addition, the dosimeter can be used to control the effectiveness of biological protection, radiation packages and radioactive waste, as well as to measure the exposure dose rate during the occurrence, happening and liquidation of emergencies’ consequences.

The dosimeter is used for operational grouping monitor of the exposure dose rate by employees of radiation safety services, defectoscopic laboratories, sanitary and epidemiological stations, etc.

The operational principle of DRG-01T1 dosimeter is based on the registration of electric current pulses arising during the passing of gamma quanta through a gas-discharge counter. The current pulses are converted by the input cascade into voltage pulses with the amplitude necessary for their registration.

Figure – 2.7 Basic configuration of the DRG-01T1 dosimter

Pulses through the frequency divider come to the four-digit counter. Cumulative information on the measurement cycle on the counter come to the indicator through a decoder that converts the binary-decimal counter information into a seven-segment positional code of the indicator. The measurement time is set by an adjustable reference frequency generator. The input information from the detectors is scaled to the absolute value of the output parameter (mR/h, R/h) by changing the measurement time. The generator ensures a number of frequencies to control the indicator and monitor the dosimeter's performance.

Indications in the dosimeter of gamma radiation are carried out on the digital plate of the liquid crystal indicator with the dimension of the set measuring range. The dosimeter is controlled with the help of two switches “Operating mode” and “Measuring

range", button "Reset". In addition, a button for illuminating the digital plate is located on the front panel.

Tab. 2.1 - Main technical characteristics of dosimeter [22]

Detector	Gas-discharge counter
Measurement range of exposure dose rate	
"Search" mode	100,0 μR/h – 99,99 R/h
"Measurement" mode	10,0 μR/h – 9,999 R/h
Energy range of gamma-ray	0,05 – 3,0 MeV
Measuring time, no more than	
"Search" mode	2,5 sec
"Measurement" mode	25 sec
Constructive execution	Metal shell
Energy source	1 element of the "Cron" type
Overall dimensions, weight	175×90×55 mm, 0,6 kg

6. Financial management, resource efficiency and resource conservation

At the present, the prospects of the scientific research are determined not so much by the scale of the invention, which is difficult to assess at the first stages of the life cycle of a high-tech and resource-efficient product, as by the commercial value of it. Evaluation of the commercial value of the product is a necessary condition when searching for funding sources for scientific research and commercialization of its results. This is important for developers who need to understand the state and prospects of the ongoing research.

The commercial attractiveness of the scientific research is determined not only by the excess of technical parameters over previous developments, but also how quickly the developer will be able to find answers to questions – whether the product will be in demand by the market, how much it will cost, how much the budget will cost, how long it will take to enter the market, etc.

The purpose of this section is to design and create a competitive method that meets the requirements in the field of resource efficiency and resource conservation.

The goal is achieved by solving these tasks:

- assessment of commercial potential and prospects of scientific research;
- determination of possible alternatives for conducting scientific research that meet modern requirements in the field of resource efficiency and resource conservation;
- planning of research activities;
- determination of resource (resource-conservation), financial, budgetary, social and economic efficiency of the research.

6.1. Pre-project analysis

6.1.1 Potential consumers of the research's results

The result of the research is the possibility of creating a new unified method for calculating protection for high-energy medical accelerators by considering similar foreign methods. In the Russian Federation, there is only one established method in the

Sanitory rules and regulations 2.6.1.2573-10, which does not give a detailed calculation of protection.

The target market for this study will be the state corporations for nuclear energy and healthcare of the Russian Federation, as well as research institutes dealing with medical care issues that may be interested in the ability to reduce the dose loads to personnel during radiation therapy sessions. Table 6.1 shows how the segmentation for this project looks like.

Table 6.1 – Table of service market segmentation

		Organizations	
		Nuclear energy and healthcare state corporations of the Russian Federation	Research institutes
Field of application	Design of rooms where the accelerator will be located, buildings for radiation therapy of oncological diseases.		
	The ability to reduce radiation exposure of staff in conducting radiation therapy sessions		

6.1.2. Analysis of competitive technical solutions

To analyze the competitiveness of the development will be used scorecard given in Table 6.2. As a competing development, we take method for calculating protection for high-energy medical accelerators in the Sanitory rules and regulations 2.6.1.2573-10 (K1). The position of developers and competitors was evaluated by experts on a five-point scale for each indicator, where 1 – the weakest position, and 5 – the strongest. The weights of the indicators determined by experts must be 1 in total.

Analysis of competitive technical solutions is determined by the formula:

$$C = \sum W_i \cdot P_i \tag{6.1}$$

where C – the competitiveness of research or a competitor; W_i – criterion weight; P_i – point of i-th criteria.

Table 6.2 – Evaluation table of competitive technical developments

Evaluation criteria	**Weight of criterion**	**Scores**		**Competitiveness**	
		P_f	P_{k1}	C_f	$C_{к1}$
Technical criteria for evaluating resource efficiency					
1. The dose load on the staff	0,2	5	4	1	0,8
2. The reliability of the equipment	0,18	5	5	0,9	0,9
3. Security	0,16	4	4	0,64	0,64
4. simple operation	0,09	5	4	0,45	0,36
5. Availability of expensive equipment	0,18	5	4	0,9	0,72
Economic criteria for evaluating effectiveness					
1.The competitiveness of the product	0,05	5	3	0,25	0,15
2. The penetration level into the market	0,04	3	5	0,12	0,2
3. Price	0,1	5	3	0,5	0,3
Total:	**1**	-	-	**4,76**	**4,07**

The method will be competitive and the penetration level into the market will be high, as at the moment, there is no method of calculating the protection of electronic medical accelerators for large energy, so at the end of the project, the received method will have no analogues.

This method will be convenient and easy to use, because it uses simple, easy-to-understand equations describing the processes of mutual interaction of radiation with substance. To calculate protection, you will only need to use any computing machinery (CM), special equipment, devices, computers are not required. In this regard, the use of this method will be energy-efficient for companies.

When using the method in the construction of accelerator rooms, the staff working with the device will be better protected from ionizing radiation. It will be possible to conduct more radiotherapy sessions; therefore, labor productivity will be increased.

Thus, based on the results of the analysis, it can be concluded that the study is effective, since it ensures the quality of the results. Further investment in this development can be considered feasible.

6.1.3 SWOT-Analysis

SWOT (Strengths – Weaknesses – Opportunities – Threats) – Methodology for analyzing scientific projects and technical solutions. The SWOT method is used to analyze the factors of the external and internal environment of the project.

Strengths – internal environmental factors that characterize the competitive side of a project. Through strengths we understand the distinctive advantages or special resources contributing to the success of the project in the competition. In other words, strengths are resources or capabilities available to the project management that can be effectively used to achieve the objective goals.

Weaknesses are also a factor of the internal environment. It is a lack, omission, or limitation of a research project that hinders the achievement of its goals.

Opportunities include any preferable situation in the present or future that occur or will occur in the project environment, such as a trend, a change, or an anticipated need.

Threats are any undesirable situation or restriction imposed by the external environment on the project. A threat can be a barrier, restriction, or anything else that can cause problems, destruction, damage, or loss to the project.

The SWOT analysis of this research project is presented in table 6.3.

Table 6.3 SWOT Matrix

	Strengths of the research project: S1. Small amount of source data. S2. Advantageous processing of the results. S3. At the moment, there is no complete method for calculating the biological protection of high-energy medical accelerators. S4. The possibility of using the method both at enterprises belonging to Rosatom and in medical institutions. S5. Project readiness for implementation.	**Weaknesses of the research project:** Wk1. Long term research for better results. Wk2. To use high-energy accelerators, you need a complete method for calculating their biological protection, which does not currently exist. Wk3. The complexity of the calculations. Wk4. The need for experimental confirmation. Wk5. Dependence on the type of medical accelerator.
Opportunities: P1. Using the results of the study to calculate the biological protection of medical accelerators. P2. Improving radiation safety for the staff. P3. The emergence of additional demand for a new product. B4. Collaboration with a number of new organizations. P5. Publications in highly rated journals will help to raise the status of the University.	**Results of the fields "Strengths and opportunities":** 1. The ease of processing results will allow us to increase the demand for our product. 2. The reliability and security of the method will make it possible to establish cooperation with a number of new organizations. 3. The research is applicable and has no analogues.	**Results of the fields "Weaknesses and opportunities":** 1. Due to long term of research, competitive organizations may gain the priority. 2. It is necessary to check the received method for different types of accelerators with their own parameters and, if possible, to conduct an experiment.
Threats: T1. Competition. T2. Lack of funding from both the University and	**Results of the fields "Strengths and opportunities":** 1. Processing results	**Results of the fields "Weaknesses and Threats":** 1. Conducting similar

the state. T3. Unwillingness of many companies to cooperate. T4. The possibility of not using the method due to the calculations' complexity. T5. Limited use of high-energy accelerators for medical purposes.	without using complex programs will not cause us any delay in getting complete results for the study. 2. The research is applicable and has no analogues.	calculations by competitive companies. 2. The need to simplify calculations. 3. The possibility of foreign organizations' involvement.

Based on the results of the analysis, we can draw a conclusion about the difficulties and problems that our research project may face in one way or another. Due to the strengths of the study project, we are able to establish cooperation with new organizations.

However, we are also faced with weaknesses that, one way or another, there is a need for a long period of research and the lack of a method for calculating the biological protection of medical accelerators at high energies. Therefore, this research has such threats, like the demand for technology due to its unstable competitiveness and the stagnation of research due to the lack of funding. To cover such weaknesses, it is necessary to process the results using existing equations for calculating the biological protection of medical accelerators. This will speed up data processing.

Based on the received positive and negative aspects, we consider it necessary to bring this method to the Russian market.

6.1.4 Assessment of the project's readiness for commercialization

At whatever stage of the life cycle of a scientific research, it is useful to assess the degree of its readiness for commercialization and find out the knowledge level for its implementation. To do this, we will fill in a special form (Table 6.4) containing indicators on the degree of researching the project from the viewpoint of commercialization and the researcher's competence of the scientific project.

Table 6.4 – Form for evaluating the degree of readiness of a scientific project for commercialization

No.	Description	Carefully studied degree of the scientific project	Knowledge level of the researcher
1.	Available scientific-technical potential is specified.	4	4
2.	Perspective areas of commercialization of scientific-technical potential are specified.	3	3
3.	Fields and technologies (goods, services) to offer on the market are determined.	3	3
4.	The commodity form of the scientific-technical potential for submission to the market is defined.	4	4
5.	Authors are identified with protected rights.	2	2
6.	Assessment of the value of intellectual property was made.	3	3
7.	Sales marketing was conducted.	1	2
8.	A business plan for commercialization has been researched.	2	3
9.	Ways of entering to the market are defined.	4	4
10.	The strategy (form) of realization of the research has been worked out.	4	4
11.	The issues of international cooperation and entering the foreign market have been worked out.	2	3
12.	The issues of using the support infrastructure services and receiving benefits have been worked out.	3	3
13.	The issues of financing the commercialization of scientific research have been worked out.	4	5
14.	There is a team working on commercialization of scientific research.	4	5
15.	The mechanism for realization of the scientific project has been worked out.	4	4
	TOTAL POINTS	**47**	**52**

When analyzing the table above, each indicator is rated on a five-point scale. Thus, when assessing the degree of elaboration of a scientific project, 1 point means that the project is not well researched, 2 points – weak elaboration, 3 points – completed, but not sure of the quality, 4 points – qualitatively researched, 5 points – there is a positive conclusion of an independent expert. To assess the knowledge level available to the developer, the point system follows this assessment: 1 – do not know or know just a little, 2 – accquire only theoretical knowledge, 3 – know the theory and practical examples, 4 – know the theory and research individually, 5 – know the theory, research individually and can give advice.

Assessment of the readiness of a scientific project for commercialization (or the level of knowledge available to the developer) defined by the formula:

$$P_{sum} = \sum P_i, \qquad (6.2)$$

where P_{sum} – the total number of points for each course;

P_i – the point for each *i* indicator.

The value of P_{sum} allows us to comment about the readiness's degree of the scientific research and its developer for commercialization. The received values are in the range from 59 to 45. This means that the prospects of a scientific project are above the average.

6.1.5 Methods of commercializing the results of scientific-technical research

When commercializing scientific-technical research, the seller pursues a well-defined goal, which largely depends on where in the future he intends to direct (use, invest) the received commercial effect. This may be receiving funds to continue the scientific research, temporary receiving financial resources for certain purposes or accumulation, ensuring a constant flow of financial resources, as well as various combinations of them.

Here are the following methods of commercializing the scientific research.

1. Trade in patent licenses, i.e. to transfer to third parties the right to use the objects of intellectual property by means of license. At the same time, the patent legislation distinguishes types of licenses: exclusive (simple), exclusive, full licenses, sublicenses, options.

2. Know-how transmision, i.e. the owner of the know-how allows another person to use it, carried out by disclosing know-how.

3. Engineering as an independent type of commercial operations involves the provision on the basis of engineering contract by one party, referred to as consultant, the other is customer, complex or individual types of engineering services related to design, construction and putting the object into operation, with the research of new technological processes at the enterprise of the customer, improvement of existing productive processes until the introduction of the product into production and even its sales.

4. Franchising, i.e. the transmission or assignment (on commercial conditions) of permission to sell someone's goods or provide services in certain areas.

5. Organization of your own business.

6. Transmission of intellectual property to the authorized capital of the business.

7. Organization of a joint businesses, i.e. the association of two or more persons for organizing the business.

8. Organization of joint businesses operating under the scheme "Russian production – foreign distribution".

After analyzing the listed methods of commercialization, it can be concluded that the most appropriate methods are the trade in patent licenses (if it is possible to obtain a patent for this method), or the transmission of know-how through experience exchange in scientific community.

6.2 Lauching project

The group of initiating processes consists of those which are done to determine a new project or a new phase of an existing one. As part of the initiating processes, the

initial goals and content are determined and the initial financial resources are fixed. Internal and external stakeholders of the project are identified, which will interact and influence the overall result of the scientific project. This information is fixed in the project Charter.

The project Charter documents the business requirements, current understanding of the project customer's needs, and a new product, service, or result that has been planned.

6.2.1 Goals and results of the project

This section provides information about project stakeholders, the hierarchy of project goals, and criteria for achieving them.

Project stakeholders are defined as individuals or organizations that are actively involved in the project or whose interests may be affected either positively or negatively during the research or completion of the project. Information on the project stakeholders is provided in table 6.5.

Table 6.5 – Project stakeholders

Project stakeholders	Expectations of the stakeholders
State corporations on nuclear energy and healthcare of the Russian Federation	Creating a method for calculating high-energy medical electronic accelerators. This method should help specialists in designing rooms where the accelerator will be located, corps for radiation therapy of oncological diseases.
Russian oncological research institutes	Expanding the abilities to reduce the dose load on staff during radiation therapy sessions and the basis for new research in this area.
Medical physicists	The realization of radiotherapy with a lower dose load on the staff during radiation therapy sessions.

Table 6.6 provides information about the hierarchy of project goals and criteria for achieving goals.

Table 6.6 − Goals and project results

Project goals:	Assessment of the problems of radiation safety of medical staff and calculation of bunker protection for radiation safety during radiation therapy sessions.
Expected results of the project:	1. The values of dose loadings to medical staff are lower than the dose limits assigned by radiation safety standards (RSS) 99/2009. 2. Reducing the impact of radiation on the staff at the entrance to the room. 3. Reducing the concentration of ozone in the accelerator room.
Acceptance criteria of the project result:	1. Values of dose loadings on medical staff is lower than 20 mSv per year. 2. To reduce the impact of radiation on the staff at the entrance to the room, we use a labyrinth. 3. The value of the MPC (maximum permissible concentration) of ozone on staff is equal to 0.1 mg/m^3.
Requirements for the project result:	**Requirement:**
	1. The project must be completed prior to 1st of June, 2020.
	2. The received results must meet the acceptance criteria of the project result.
	3. The results of the scientific research must be presented at one of the all-Russian/regional conferences.
	4. In the case of unsatisfactory results, it is necessary to conduct additional research using other sources of radiation.

6.2.2. Organizational structure of the project

At this stage, it was necessary to solve the following questions: who will be part of the working group of this project, determine the role of each participant in this project, as well as specify the functions performed by each of the participants and their labor expenditures in the project. This information is presented in table 6.7.

Table 6.7 − Working group of the project

No.	Full name, main place of work, position	Role in the project	Functions	Labor expenditures, h.
1.	Turgunova Natalia Juraboeva, medical physicist, cancer research Institute Tomsk NRMC	Project supervisor	Responsible for implementing project within the given resource limits, coordinates the activities of project participants.	126
2.	Tran Nhan Hau , master TPU	Project executor	Writing a review of literary sources and technical literature. Assessing dose loadings on medical staff during radiation therapy sessions. Calculating the bunker protection for ensuring radiation safety during radiation therapy sessions. Calculating the average concentration of ozone in the canyon. Writing a report on the research (writing master's thesis).	470
TOTAL:				596

6.2.3. Limitations and assumptions of the project.

Project limitations are all factors that can limit the freedom degree of the project team members, as well as “project boundaries” – parameters of the project or its product which will not be implemented within this project.

Таблица 6.8 − Ограничения проекта

Factor	**Limitations/assumptions**
1. Project budget	952 141 rub.
1.1. Source of funding	Government funding
2. Duration of the project:	01.02.2020 − 01.06.2020
2.1. Date of approval of the project management plan	11.02.2020
2.2. Completion date	01.06.2020
3. Other limitations and assumptions	The maximum acceptable effective dose for the staff of group B is less than 12,5 mSv per year

6.3. Planning of the scientific research

This section show a list of stages and tasks for the conducting the research, as well as the distribution of executors by type of tasks. The order of stages and tasks when conducting the graduate research is presented in table 6.9.

Table 6.9 – List of stages, tasks and distribution of executors

Main stages	No. of tasks	Task's content	Executor
Research of technical specifications	1	Choosing research direction	Supervisor
Choosing research direction	2	Preparation and approval of technical specifications	Supervisor Student
	3	Scheduling tasks on the theme	Supervisor Student
Theoretical and experimental research	4	Review of literary sources and technical literature	Student
	5	Experimental measurements and processing of received data	Student
	6	Practical calculation	Student
Summarizing and evaluating results	7	Adjustment, preparation and execution of calculations	Student

	8	Evaluating the effectiveness of received results	Supervisor Student
Presentation of report on graduate research	9	Drafting explanatory statement	Student
	10	Preparation for defence	Supervisor Student

6.3.1 Determination of the research's labor intensity

At the next stage of the research, the labor intensity is determined. It is estimated by experts in special quantities – man-days and is reliable, because it depends on a variety of factors that are difficult to account for. The following formula is used to determine the expected (average) labor intensity:

$$t_{expi} = \frac{3t_{mini}+2t_{maxi}}{5}, \quad (6.3)$$

where t_{expi} – expected labor intensity of the i task, (m.-d.);

t_{mini} – the minimum possible labor intensity of the given i task (optimistic assessment: assuming the most favorable combination of circumstances), (m.-d.);

t_{maxi} – the maximum possible labor intensity of the given i task (pessimistic assessment: assuming the most unfavorable combination of circumstances), (m.-d.).

Based on the expected labor intensity of the tasks, the duration of each task in the working days T_w is determined, taking into account the parallelism of the task performed by several executors. This calculation is necessary for a reasonable calculation of wage, since the percentage of wage in the total estimated cost of scientific research is about 65 %. Based on the dimensionality of the expected labor intensity, the long-term i-type of the task is determined by the formula:

$$T_{wi} = \frac{t_{expi}}{N_i}, \quad (6.4)$$

where T_{wi} – duration of one task, (m.-d.);

t_{expi} – expected labor intensity of one task, (m.-d.);

N_i – the number of executors doing the same task at the same time at this stage, (m.).

In the course of this work, the number of people doing each of the tasks at each of the stages is equal to one.

6.3.2 Schedule of conducting the scientific research

At the next stage, a calendar plan for implementing the research is developed. A bar chart of the research was constructed in the form of Gantt diagrams. The Gantt Diagram is a horizontal bar chart where the tasks on a theme are represented as extended segments in time, characterized by the starting and ending dates of these tasks.

For the convenience of creating the plan-chart, the duration of stages in working days is converted to calendar days and calculated using the following formula:

$$T_{ki} = T_{wi} \cdot c, \tag{6.5}$$

where T_{ki} – the duration of accomplishing one task, (ca. d.);

T_{wi}– the duration of one task, (w. d.);

c – the calendar coefficient is used for converting working time to calendar time.

The calendar coefficient is calculated using the following formula:

$$c = \frac{T_{cy}}{T_{cy} - T_{we} - T_{ph}}, \tag{6.6}$$

where T_{cy} – number of calendar days per year ($T_{cy} = 365d.$);

T_{we} – number of weekends per year ($T_{we} = 52$);

T_{ph} – number of public holidays per year, ($T_{ph} = 14$).

The estimated value of the duration of the tasks T_{ki} was rounded to integers.

The value of the calculated calendar coefficient:

$$\mathrm{c} = \frac{365}{365 - 52 - 14} = 1{,}22.$$

The calculated data are summarized in table 6.10, on the basis of which the calendar plan-chart was built.

Table 6.10 – Time indicators of conducting the scientific research

i	Executor	$t_{min\ i}$	$t_{max\ i}$	$t_{ож\ i}$	$Ч_i$	$T_{р\ i}$, раб.дн	T_k, кал.дн.
1	Supervisor	3	7	4,6	1	4,6	6
2	Supervisor Student	2	4	2,8	2	1,4	2
3	Supervisor Student	2	4	2,8	2	1,4	2
4	Student	14	30	20,4	1	20,4	25
5	Student	7	14	9,8	1	9,8	12
6	Student	20	45	30	1	30	37
7	Student	7	14	9,8	1	9,8	12
8	Supervisor Student	7	14	9,8	2	4,9	6
9	Student	7	14	9,8	1	9,8	12
10	Supervisor Student	5	14	8,6	2	4,3	6
Total		74	160	108,4	-	16,6/91,8	22/114

6.3.3 Calendar plan-chart in the form of a Gantt chart

Based on the calculated data, a chart was built in the form of a Gantt chart. The chart is built with a timeline divided into months and decades, covering the entire period of researching and writing the graduate research. Each executor is assigned his own hatching type. The plan-chart of this thesis is presented in table 6.11.

Table 6.11 – Calendar plan-chart of conducting the scientific research

№	T_{ki}, cal.d.	Duration of tasks'accomplishment															
		February				March				April				May			
		1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
1	6																
2	2																
3	2																
4	25																
5	12																
6	37																
7	12																
8	6																
9	12																
10	6																

- student; - supervisor.

6.4 Budget for scientific-technical research

When planning the budget for scientific-technical research (STR), a full and reliable reflection of all types of expenditures related to its implementation must be ensured. In the process of forming the STR budget the following grouping of costs by section is used:

1. Material costs of scientific and technical research;
2. Costs of special equipment for scientific work (Depreciation of equipment used for design);
3. Basic salary;
4. Additional salary;
5. Labor tax;
6. Overhead costs.

6.4.1 Calculation of material costs

The main costs in this research are from electricity. The results of calculations for material costs are shown in table 6.12.

The absence of a division into funding sources in the table indicates that there is only one source. The financial source in this research is from the student.

Capacity of working PC: 0,1 kWt.

Electricity costs are calculated using the formula:

$$C = P_{el} \cdot P \cdot F_{eq} = 5{,}8 \cdot 0{,}1 \cdot 360 = 210, \quad (6.7)$$

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

P – power of equipment, kW;

F_{eq} – Equipment usage time, h.

Table 6.12 – Material costs

Name	Brand, size	Quantity	Price per unit, rub.	Total, rub.
Electrical power comsumed by PC	–	36 kWt·hour	5,8	210
Print on A4 sheet	–	150	1,5	225
Pen	Cello Writer	1	25	25
Internet access	–	4 months	350	1400
Material costs				1860
Transport and procurement expenses				0
Total:				1860

6.4.2 Calculation of equipment depreciation for experimental tasks

This article includes all costs associated with the purchase of special equipment necessary for carrying out work on the subject of final qualification work (FQW).

In this research, the special equipment required for experimental work includes the dosimeter DRG-01T1, the cost of which is shown in table 6.13.

Table 6.13 – Costs of special equipment

No.	Name of the equipment	Number of the equipment's units	Price of the equipment's unit, rub.	Total cost of the equipment, rub.
1	dosimeter DRG-01T1	1	32 800	32 800
Total:				32 800

6.4.3 Calculation of basic salary

This article includes the basic salary of individuals directly involved in conducting the research. The amount of salary expenses is determined based on the labor intensity of the tasks performed and the current system of salaries and tariff rates. The basic salary includes a bonus paid monthly from the salary fund with the amount of 20 – 30 % of the tariff or salary.

The article includes the basic salary of the individuals directly engaged in the implementation of STI (including bonuses, surcharges) and additional wages:

$$S = S_{bas} + S_{add}, \quad (6.8)$$

where S_{bas} – basic salary;

S_{add} – additional salary (12-20 % от S_{bas}).

The basic salary of research supervisor is calculated on the basis of labor specialized salary. The specialized system of labor salary in TPU assumes the following salary composition:

1) salary – determined by the organization. In TPU, salaries are distributed according to the positions, for example, assistant, senior teacher, associate Professor, Professor.

2) incentive payments – set by the head of departments for effective work, accomplishment of additional duties, etc.

The basic salary of the supervisor is calculated using the formula:

$$S_{bas} = S_a \cdot T_w \quad (6.9)$$

where S_{bas} – basic salary per participant;

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

S_a – the average daily salary of an participant, rub.

The average daily salary is calculated using the formula:

$$S_a = (S_m \cdot M) / F_v, \quad (6.10)$$

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

M – the number of months of work without leave during the year, with a leave of 48 working days M=10,4 months, 6-day week;

F_v – valid annual fund of working time of scientific and technical personnel (251 days).

Table 6.14 – Working time balance

Woking time indicators	**Supervisor**	**Student**
Calendar days' number	365	365
Number of non-working days - weekends - public holidays	52 14	52 14
Loss of working time - vacation - absenteeism due to illness	48	48
actual annual fund of working time	251	251

The monthly salary of the employee taking into account the district coefficient for Tomsk k_{region} = 1,3, is calculated:

$$S_m = S_{tr} \cdot 1{,}3. \quad (6.11)$$

S_{tr} – base for tariff rate, rub; $K_{regioin}$ – regional rate, equal to 1,3 (for Tomsk).

The main salary of the supervisor for the research period is equal to:

$$S_m = S_{tr} \cdot 1{,}3 = 25\,000 \cdot 1{,}3 = 32\,500 \text{ rub./month};$$

$$S_a = (S_m \cdot M) / F_v = (32\,500 \cdot 10{,}4) / 251 = 1\,347 \text{ rub./day};$$

$$S_{bas} = S_a \cdot T_w = 1\,347 \cdot 16{,}6 = 21255 \text{ rub.}$$

Table 6.15 – Calculation of main salary

Executors	S_{tr}, rub.	K_{region}	S_m, rub./month	S_a, rub./day	T_w, working days	T_{bas}, rub.
Supervisor	25 000	1,3	32 500	1 347	16,6	22 360
Student	12 316	1,3	16 011	663	91,8	60 863
Total T_{bas}						**83 223**

6.4.4 Additional salary of the research executors

The additional salary includes payment for non-working time (regular and academic leave, fullfilment of state duties, payment of remuneration for period of service, etc.) and is calculated based on 10-15 % of the basic salary of the employees directly involved in the implementation of the theme:

$$S_{add} = k_{extra} \cdot S_{bas}, \quad (6.12)$$

where S_{add} – additional salary, rubles;

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

S_{bas} – base salary, rubles.

The additional salary for the supervisor is calculated as follows::

$$S_{add} = 22360 \cdot 0{,}1 = 2236 rub.$$

The additional salary is presented in table 10.16.

Table 6.16 – Calculation of the additional wage

Executor	K_{extra}	S_{bas}	S_{add}
Supervisor	0,1	22 360	2 236
Student	0,1	60 863	6 086
Total			**8 322**

6.4.5 Labor tax

This article of expenditure reflects compulsory taxes in accordance with the standards of state social insurance agencies (SSI), pension fund (PF) and medical insurance from labor salary of employees, established by the legislation of the Russian Federation

The rate of labor taxes is determined based on the following formula:

$$P_{social} = k_b \cdot (S_{bas} + S_{add}) \quad (6.13)$$

where k_b – coefficient of deductions for labor tax

In 2015, in accordance with Federal law No. 212-FZ since 24.07.2009, the rate of insurance premiums has been set at 30%. On the basis of paragraph 1, article 58 of the law No. 212-FZ for institutions engaged in educational and scientific activities in 2014, there is a reduced rate of 27.1%.

Thus, labor taxes of the supervisor are calculated as follows:

$$P_{social} = 0{,}271 \cdot (22360 + 2236) = 6666 rub.$$

Table 6.17 – Labor tax

Executor	Supervisor	Student
Basic salary, rubles	22 360	60 863
Additional salary, rubles	2 236	6 086
Coefficient of deductions	0,271	0,271
Labor tax, rubles	6 666	18 143
Total	**24 809**	

6.4.6 Overhead costs

To account for overhead costs, we need to take into account the costs of maintaining the management equipment and general economic (university-wide) services, which equally apply to all conducted research. This article takes into account the labor salary of administrative and managerial staff, maintenance of buildings, office equipment and household equipment, depreciation of property, labor protection and training.

Overhead costs include other expenses of the organization that were not included in the previous expenditure expenses: printing and photocopying of research materials, payment for communication services, electricity, postal and telegraph expenses, duplicating photocopying of materials, etc. Overhead costs are 12-16% of the amount of the basic and additional wage of employees directly involved in the implementation of the research. The value of the overhead expenses'coefficient is taken at the rate of 30%.

$$C_{ove} = k_{ove} \cdot (S_{bas.} + S_{add}) \quad (6.14)$$

$$C_{ove} = 0{,}3 \cdot (22\,360 + 2\,236) = 7\,379 \text{ rub.}$$

6.4.7 Budget for scientific-technical research expenses

The calculated expenses' value of the research is the basis for building the budget project of the budget's expenses. The cost budget for the research project for each option of implementation is shown in table 6.18.

Table 6.18 – Budget for the research project

Name	Sum, rub.
1. Material costs	1 860
2. Basic salary	83 223
3. Additional salary	8 322
4. Labor tax	24 809
5. Overhead expenses	7 379
Total	**125 619**

6.5 Risks' list of the project

Identified project's risks include possible uncertain incidents that may occur in the project and cause consequence entailing undesirable effects. Information on this section is provided in table 6.19.

Table 6.19 − Risks' list

№	Risk	Potential impact	Probability of occurrence (1-5)	Risk's influece (1-5)	Risk's level	Ways to reduce the risk	Conditions of engagement
1.	Inconsistency of experimental and simulated data	Failure to meet the project goals	3	5	High	Take into account the adjustments to the physical interaction of radiation with matter in the modeling process	Incorrect modeling of the radiation path
2.	Failure of experimental equipment (dosimeter)	The experiment cannot be conducted	3	4	Aver.	The use of the equipment in accordance with technical documentation	Careless use of experimental equipment
3.	Inconsistency of the received data with the expected results	Failure to meet the project goals	2	4	Aver.	Better analysis of literature sources	Error in predicting expected results
4.	Lack of commercial interest in the method	Loss of the possibility of introducing the method to the consumption market	2	2	Low	Presentation of the research at conferences	No plan for commercial realization of the method

6.6 Determination of the research's resource efficiency

We can determine the effectiveness by calculating integral indicator of the scientific research's effectiveness. Its value consists of the coefficients of financial efficiency and resource efficiency.

The integral indicator of the research's financial efficiency is obtained in the course of evaluating the cost budget of three (or more) executive variants of the research.

To do this, the highest integral indicator of implementing technical task is taken as the calculation base (as a denominator), which is correlated with the financial values for all executive variants.

The integral financial indicator of the research is defined as:

$$I_{fin.}^{exe.i} = \frac{\Phi_{pi}}{\Phi_{max}}, \qquad (6.15)$$

where $I_{fin.}^{exe.i}$ – the integral financial indicator of the research;

Φ_{pi} – the value of i variant;

Φ_{max} – the maximum value of executing a research project (including analogs).

The received value of the integral financial indicator of the research reflects either the corresponding numerical increase in the budget expenses significantly (value is greater than unit), or the corresponding numerical decrease in the cost of the research significantly (value is less than unit, but greater than zero). The research has one method, so:

$$I_{fin.}^{exe.i} = \frac{\Phi_{pi}}{\Phi_{max}} = 1.$$

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

$$I_{\text{pi}} = \sum a_i \cdot b_i, \qquad (6.16)$$

where I_{pi} – Integral indicator of resource efficiency for i variant of conducting the research;

a_i – weight coefficient of i variant of conducting the research;

b_i – the scoring of i variant of conducting the research is set by an expert way according to the selected rating scale;

n – number of comparison parameters.

The calculation of integral indicator of resource efficiency is presented in the form of table (table 6.20).

Table 6.20 – Evaluation of characteristics of conducting the project

Research object / Criteria	Weight coefficient of parameter	Evaluation
1. Helps to increase user's productivity	0,20	5
2. Convenience in operation	0,15	3
3. Noise immunity	0,15	4
4. Energy saving	0,20	4
5. Reliability	0,25	4
6. Material consumption	0,05	5
TOTAL	1	

$$I_{pi} = 5 \cdot 0.2 + 3 \cdot 0.15 + 4 \cdot 0.15 + 4 \cdot 0.20 + 4 \cdot 0.25 + 5 \cdot 0.05 = 4.1$$

Intergral efficiency indicator of variants conducting the research $I_{exe\ i}$ is determined based on the integral indicator of resource efficiency and integral financial indicator according to the formula:

$$I_{exe1} = \frac{I_{p-exe1}}{I_{fin}^{exe1}}, \quad I_{exe2} = \frac{I_{p-exe2}}{I_{fin}^{exe2}} \tag{6.17}$$

Comparing integral efficiency indicator of variants conducting the research will allow us to determine the comparative effectiveness of the project (table 6.21) and select the most appropriate variant from the proposed ones. Comparative effectiveness of the project (E_{com}):

$$E_{com} = \frac{I_{exe1}}{I_{exe1}} \tag{6.18}$$

Table 6.21 – Research's effeciency

No.	Indicators	Evaluation
1	Integral financial indicator of research	1
2	Integral indicator of research's resource efficiency	4,1
3	Integral indicator of efficiency	4,1

Comparing the values of integral efficiency indicators allows us to understand and choose a more effective solution to the supplied technical problem from the point of view of financial and resource efficiency. In this case, there is only one solution to the problem. Therefore, the provided option is assumed to be the best.

Conclusion

Thus, in this section was developed stages for design and create competitive development 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.

7. Social responsibility

7.1 Introduction

The result of the research is the possibility of creating a new unified method for calculating protection for high-energy medical accelerators by considering similar foreign methods. In the Russian Federation, there is only one established method in the Sanitory rules and regulations 2.6.1.2573-10, which does not give a detailed calculation of protection.

Application area is radiation safety during radiotherapy sessions.

The target market for this study will be the state corporations for nuclear energy and healthcare of the Russian Federation. They can design of rooms where the accelerator will be located, buildings for radiation therapy of oncological diseases.

7.2 Legal and organizational items in providing safety

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

Occupational safety is a system of legislative, socio-economic, organizational, technological, hygienic and therapeutic and prophylactic measures and tools that ensure the safety, preservation of health and human performance in the work process [24].

According to the Labor Code of the Russian Federation, every employee has the right:

- to have a workplace that meets Occupational safety requirements;
- to have a compulsory social insurance against accidents at manufacturing and occupational diseases;
- to receive reliable information from the employer, relevant government bodies and public organizations on conditions and Occupational safety at the workplace,

about the existing risk of damage to health, as well as measures to protect against harmful and (or) hazardous factors;

- to refuse carrying out work in case of danger to his life and health due to violation of Occupational safety requirements;
- be provided with personal and collective protective equipment in compliance with Occupational safety requirements at the expense of the employer;
- for training in safe work methods and techniques at the expense of the employer;
- for personal participation or participation through their representatives in consideration of issues related to ensuring safe working conditions in his workplace, and in the investigation of the accident with him at work or occupational disease;
- for extraordinary medical examination in accordance with medical recommendations with preservation of his place of work (position) and secondary earnings during the passage of the specified medical examination;
- for warranties and compensation established in accordance with this Code, collective agreement, agreement, local regulatory an act, an employment contract, if he is engaged in work with harmful and (or) hazardous working conditions.

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

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

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

The workplace when working with a PC should be at least 6 square meters. The legroom should correspond to the following parameters: the legroom height is at least 600 mm, the seat distance to the lower edge of the working surface is at least 150 mm,

and the seat height is 420 mm. It is worth noting that the height of the table should depend on the growth of the operator.

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

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

7.4 Occupational safety

A dangerous factor or industrial hazard is a factor whose impact under certain conditions leads to trauma or other sudden, severe deterioration of health of the worker [24].

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.

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

There are two objects of investigation in this research. First, that is radiation exposure to medical staff of radiation therapy department. Second, that is the bunker protection to ensure radiation safety during radiation therapy sessions. In both cases, the harmful factor is increased levels of ionizing radiation.

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

The working conditions in the workplace are characterized by the presence of hazardous and harmful factors, which are classified by groups of elements: physical,

chemical, biological, psychophysiological. The main elements of the production process that form dangerous and harmful factors are presented in Table 7.1.

Table 7.1 - Possible hazardous and harmful factors

Factors (GOST 12.0.003-2015)	Work stages			Legal documents
	Development	Manufacture	Exploitation	
1. Deviation of microclimate indicators	+	+	+	Sanitary rules 2.2.2 / 2.4.1340–03. Sanitary and epidemiological rules and regulations "Hygienic requirements for personal electronic computers and work organization." Sanitary rules 2.2.1 / 2.1.1.1278–03. Hygienic requirements for natural, artificial and combined lighting of residential and public buildings. Sanitary rules 2.2.4 / 2.1.8.562–96. Noise at workplaces, in premises of residential, public buildings and in the construction area. Sanitary rules 2.2.4.548–96. Hygienic requirements for the
2. Excessive noise		+	+	
3.Increased level of electromagnetic radiation	+	+	+	
4.Insufficient illumination of the working area		+	+	

				microclimate of industrial premises.
5. Abnormally high voltage value in the circuit, the closure which may occur through the human body	+	+	+	Sanitary rules GOST 12.1.038-82 SSBT. Electrical safety. Maximum permissible levels of touch voltages and currents.
6. Increased levels of ionizing radiation	+	+	+	Sanitary Rules 2.6.1. 2523 -0 9. Radiation Safety Standards (NRB-99/2009).

The following factors effect on person working on a computer:

- physical:
  - temperature and humidity;
  - noise;
  - static electricity;
  - electromagnetic field of low purity;
  - illumination;
  - presence of radiation;
- psychophysiological:psychophysiological dangerous and harmful factors are divided into:
  - physical overload (static, dynamic)
  - mental stress (mental overstrain, monotony of work, emotional overload).

Deviation of microclimate indicators

The air of the working area (microclimate) is determined by the following parameters: temperature, relative humidity, air speed. The optimum and permissible

values of the microclimate characteristics are established in accordance with [25] and are given in Table 7.2.

Table 7.2 - Optimal and permissible parameters of the microclimate

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

Excessive noise

Noise and vibration worsen working conditions, have a harmful effect on the human body, namely, the organs of hearing and the whole body through the central nervous system. It 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.

Increased level of electromagnetic radiation

The screen and system blocks produce electromagnetic radiation. Its main part comes from the system unit and the video cable. According to [25], the intensity of the electromagnetic field at a distance of 50 cm around the screen along the electrical component should be no more than:

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

The magnetic flux density should be no more than:

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

Abnormally high voltage value in the circuit

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

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

Table 7.3 - Upper limits for values of contact current and voltage

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

Insufficient illumination of the working area

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

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

surface of the monitor. Illumination of the monitor surface should not be more than 300 lux.

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

Increased levels of ionizing radiation

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

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

a) keep individual radiation doses from all radiation sources not higher than permissible exposure;

b) forbid all activity with using radiation sources if profit is low than risk of possible hazard;

c) 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.

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.

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

Deviation of microclimate indicators

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

- at least 30 m^3 per hour per person for the volume of the room up to 20 m^3 per person;

- natural ventilation is allowed for the volume of the room more than 40 m^3 per person and if there is no emission of harmful substances.

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

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

Excessive noise

In research audiences, there are various kinds of noises that are generated by both internal and external noise sources. The internal sources of noise are working equipment, personal computer, printer, ventilation system, as well as computer equipment of other engineers in the audience. If the maximum permissible conditions are exceeded, it is sufficient to use sound-absorbing materials in the room (sound-absorbing wall and ceiling cladding, window curtains). To reduce the noise penetrating outside the premises, install seals around the perimeter of the doors and windows.

Increased level of electromagnetic radiation

There are the following ways to protect against EMF:

- increase the distance from the source (the screen should be at least 50 cm from the user);
- the use of pre-screen filters, special screens and other personal protective equipment.

When working with a computer, the ionizing radiation source is a display. Under the influence of ionizing radiation in the body, there may be a violation of normal blood coagulability, an increase in the fragility of blood vessels, a decrease in immunity, etc. The dose of irradiation at a distance of 20 cm to the display is 50 μrem / hr. According

to the norms [25], the design of the computer should provide the power of the exposure dose of x-rays at any point at a distance of 0.05 m from the screen no more than 100 μR / h.

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

Increased levels of ionizing radiation

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

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

The radiation control is control of:

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

The main controlled parameters are:

- Annual effective and equivalent doses
- intake and body content of radionuclides
- volume or specific activity of radionuclides in air, water, food products, building materials and etc.

- radioactive contamination of skin, clothes, footwear, working places and etc.
- dose and power of external irradiation.
- particles and photons flux density.

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

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

- characteristics of radioactive contamination of the environment;
- probability of radiation accidents and scale of accidents;
- degree of readiness to effective elimination of radiation accidents and its 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.

Abnormally high voltage value in the circuit

Measures to ensure the electrical safety of electrical installations:

- disconnection of voltage from live parts, on which or near to which work will be carried out, and taking measures to ensure the impossibility of applying voltage to the workplace;
- posting of posters indicating the place of work;

- electrical grounding of the housings of all installations through a neutral wire;
- coating of metal surfaces of tools with reliable insulation;
- inaccessibility of current-carrying parts of equipment (the conclusion in the case of electroporating elements, the conclusion in the body of current-carrying parts) [26].

Insufficient illumination of the working area

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

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

7.5 Ecological safety

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

Sources of ionizing radiation used in medicine could be divided into two groups: radioactive substances and radiation generators. The difference is that radiation generators like accelerators and x-ray tubes emit ionizing radiation only when they are turned on.

In ordinary work with necessary safety precautions, there are insignificant impact of using sources of ionizing radiation on environment. The immediate effect of ionizing radiation is ionization of air in room, but after a specified time the ionization disappears.

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

7.5.2 Analysis of the environmental impact of the research process

Process of investigation itself in the thesis do not have essential effect on environment. One of hazardous waste is fluorescent lamps. Mercury in fluorescent

lamps is a hazardous substance and its improper disposal greatly poisons the environment.

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

7.5.3 Justification of environmental protection measures

Pollution reduction is possible due to the improvement of devices that produces electricity, the use of more economical and efficient technologies, the use of new methods for generating electricity and the introduction of modern methods and methods for cleaning and neutralizing industrial waste. In addition, this problem should be solved by efficient and economical use of electricity by consumers themselves. This is the use of more economical devices, as well as efficient regimes of these devices. This also includes compliance with production discipline in the framework of the proper use of electricity.

Simple conclusion is that it is necessary to strive to reduce energy consumption, to develop and implement systems with low energy consumption. In modern computers, modes with reduced power consumption during long-term idle are widely used.

7.6 Safety in emergency

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

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

- malfunction of current-carrying parts of installations;
- work with open electrical equipment;
- short circuits in the power supply;
- non-compliance with fire safety regulations;

- presence of combustible components: documents, doors, tables, cable insulation, etc.

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

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

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

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

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

- elimination of the formation of a flammable environment (sealing equipment, control of the air, working and emergency ventilation);
- use in the construction and decoration of buildings of non-combustible or difficultly combustible materials;
- the correct operation of the equipment (proper inclusion of equipment in the electrical supply network, monitoring of heating equipment);
- correct maintenance of buildings and territories (exclusion of the source of ignition - prevention of spontaneous combustion of substances, restriction of 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.

7.7 Conclusions

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

In this work, the followings have been conducted:

1. Performing a literature review on the research topic;
2. Study the basics of radiation control for the staff of radiotherapy departments;
3. Study a software program that allows to carry out numerical simulation of radiation load during radiation therapy;
4. Establish a principal scheme of the mutual arrangement of the canyons with a gamma-therapeutic equipment and a linear accelerator;
5. Calculate the thickness of the walls (concrete) and the ceiling (concrete) for canyons with gamma-therapeutic equipment and linear accelerator;
6. Calculate the equivalent dose rate from gamma-ray at the entrance to the labyrinth for the canyon of the gamma therapeutic equipment;
7. Calculate the equivalent dose rate from bremsstralung, capture gamma-ray, photoneutrons at the entrance to the labyrinth for the canyon with a linear accelerator;
8. Collect materials and calculate the thickness of the protective door of the labyrinth for the canyons with gamma-therapeutic equipment and linear accelerator;
9. Calculate the average ozone concentration in the canyons during the operation of the gamma-therapeutic equipment and linear accelerator.

Based on the analysis of the results obtained in the study, the conclusions are drawn as follows:

1. The thickness of the shield from gamma-ray of radionuclide ^{60}Co is determined by the thickness of the shield from primary radiation, because of the small thickness of the secondary shield.
2. The values of the shield thickness from bremsstralung for the canyon of the linear accelerator, calculated by the nomogram method and the attenuation layer method, have good compatibility with each other.

3. The thickness of the primary and secondary shields of the walls of the linear accelerator canyon is determined by bremsstralung.

4. The secondary shield thickness from bremsstralung of the linear accelerator is determined by the radiation leak (radiation from the accelerator head outside the working area of the beam).

5. The safety door at the entrance to the labyrinth of the canyon with gamma-therapeutic equipment must be homogeneous. In the work two materials were addressed: steel and lead. The thickness of the steel protective door is 2,4 cm, lead – 0,2 cm.

6. The safety door at the entrance to the labyrinth for the canyon with a linear accelerator must be heterogeneous and consist of three layers. For accelerator "Truebeam Varian" the layer of borated polyethylene with a thickness of 9,5 cm must be placed between two layers of steel with a thickness of 4 cm, and for accelerator "Elekta Synergy" the layer of borated polyethylene with a thickness of 9,6 cm must be placed between two layers of steel with a thickness of 4,7 cm;

7. The value of the average ozone concentration in the canyon during the operation of the gamma therapeutic equipment does not exceed the maximum permissible concentration.

8. The value of the average ozone concentration in the canyon when the linear accelerator is running at maximum mode exceeds the maximum permissible concentration; therefore, a prohibited period is required: 8 min. for the "Varian Truebeam" accelerator; 17 min. – for "Elekta Synergy". The value of the average ozone concentration in the procedure room of the accelerator when calculating the maximum dose rate assigned to the patient during radiation therapy does not exceed the MPC.

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