TOMSK POLYTECHNIC UNIVERSITY
ТОМСКИЙ ПОЛИТЕХНИЧЕСКИЙ УНИВЕРСИТЕТ

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

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

МАГИСТЕРСКАЯ ДИССЕРТАЦИЯ

Тема работы
Определение оптимального спектрального состава пучка нейтронов при проведении НЗТ

УДК 539.125.5:543.42:004.42

Студент

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Томск – 2020 г.

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School of Nuclear Science and Engineering
Field of training (specialty) 14.04.02 Nuclear Science and Technology, Nuclear Power Installation Operation
Nuclear Fuel Cycle Division

MASTER THESIS

Topic of research work
Determination of the optimal neutron beam spectrum during NCT

UDC 539.125.5:543.42:004.42

Student

Group	Full name	Signature	Date
0AM8I	Maistrenko Alexandr Sergeyevich		

Scientific supervisor

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

Section “Social Responsibility”

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

ADMITTED TO DEFENSE:

Programme Director	Full name	Academic degree, academic rank	Signature	Date
Nuclear Power Installation Operation	Vera V. Verkhoturova	PhD		

Tomsk – 2020

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School of Nuclear Science and Engineering
Field of training (specialty) 14.04.02 Nuclear Science and Technology, Nuclear Power Installation Operation
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APPROVED BY:
Programme Director
_____________ Verkhoturova V.V.
«____» ____________ 2020

ASSIGNMENT
for the Graduation Thesis completion

In the form:

Master Thesis

For a student:

Group	Full name
0AM8I	Maistrenko Alexandr Sergeyevich

Topic of research work:

Determination of the optimal neutron beam spectrum during NCT	
Approved by the order of the Director of School of Nuclear Science & Engineering (date, number):	

Deadline for completion of Master Thesis:	01.06.2020

TERMS OF REFERENCE:

Initial date for research work: *(the name of the object of research or design; performance or load; mode of operation (continuous, periodic, cyclic, etc.); type of raw material or material of the product; requirements for the product, product or process; special requirements to the features of the operation of the object or product in terms of operational safety, environmental impact, energy costs; economic analysis, etc.)*	– Object of study: Biological tissues exposed to neutron flows, their distribution and optimal values of the neutron flow.
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).*	– Study of anatomical data of biological tissues of human body; – Study of neutron flux distribution in biological tissues; – Determination of the optimal neutron spectrum for the irradiation of biological tissues.

List of graphic material *(with an exact indication of mandatory drawings)*	– Presentation

Advisors to the sections of the Master Thesis *(with indication of sections)*	
Section	**Advisor**
Financial Management, Resource Efficiency and Resource Saving	Ekaterina V. Menshikova
Social Responsibility	Dan A. Verigin

Date of issuance of the assignment for Master Thesis completion according to the schedule	01.02.2020

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

Position	Full name	Academic degree, academic status	Signature	Date
Senior science master	Artem G. Naymushin	PhD		

Assignment accepted for execution by a student:

Group	Full name	Signature	Date
0AM8I	Maistrenko Alexandr Sergeyevich		

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

To the student:

Group	Full name
0AM8I	Maistrenko Alexandr Sergeyevich

School	Nuclear Science and Engineering	**Division**	Nuclear Fuel Cycle
Degree	Master	**Educational Program**	14.04.02 Nuclear Science and Technology, Nuclear Power Installation Operation

Input data to the section «Financial management, resource efficiency and resource saving»:	
1. *Resource cost of scientific and technical research (STR): material and technical, energetic, financial and human*	– Salary costs – 106542 rub – STR budget – 171778.
2. *Expenditure rates and expenditure standards for resources*	– Electricity costs – 5,8 rub per 1 kW
3. *Current tax system, tax rates, charges rates, discounting rates and interest rates*	– Labor tax – 27,1 %; – Overhead costs – 30%;
The list of subjects to study, design and develop:	
1. *Assessment of commercial and innovative potential of STR*	– comparative analysis with other researches in this field;
2. *Development of charter for scientific-research project*	– SWOT-analysis;
3. *Scheduling of STR management process: structure and timeline, budget, risk management*	– calculation of working hours for project; – creation of the time schedule of the project; – calculation of scientific and technical research budget;
4. *Resource efficiency*	– integral indicator of resource efficiency for the developed project.
A list of graphic material *(with list of mandatory blueprints):*	
1. *Competitiveness analysis* 2. *SWOT- analysis* 3. *Gantt chart and budget of scientific research* 4. *Assessment of resource, financial and economic efficiency of STR* 5. *Potential risks*	

Date of issue of the task for the section according to the schedule	01.02.2020

Task issued by adviser:

Position	Full name	Scientific degree, rank	Signature	Date
Associate professor	E.V. Menshikova	PhD		

The task was accepted by the student:

Group	Full name	Signature	Date
0AM8I	Maistrenko Alexandr Sergeyevich		

Task for section
«Social responsibility»

To student:

group	Full name
0AM8I	Maistrenko Alexandr Sergeyevich

School	**Nuclear Science and Engineering**	**Department**	**Nuclear fuel cycle**
Degree	Master programme	**Specialization**	14.04.02 Nuclear Science and Technology, Nuclear Power Installation Operation

Topic of graduation thesis:

Determination of the optimal neutron beam spectrum during NCT	
Initial data for section «Social Responsibility»:	
1. Information about object of investigation (matter, material, device, algorithm, procedure, workplace) and area of its application	Biological tissues exposed to neutron flows, their distribution and optimal values of the neutron flow. Application area: boron neutron capture therapy units
List of items to be investigated and to be developed:	
1. Legal and organizational issues to provide safety: – Special (specific for operation of objects of investigation, designed workplace) legal rules of labor legislation; – Organizational activities for layout of workplace.	– Labour code of Russian Federation #197 from 30/12/2001 GOST 12.2.032-78 SSBT – Sanitary Rules 2.2.2/2.4.1340-03. Hygienic requirements for PC and work with it
2. Work Safety: 2.1. Analysis of identified harmful and dangerous factors 2.2. Justification of measures to reduce probability of harmful and dangerous factors	– Enchanced electromagnetic radiation level – Insufficient illumination of workplace – Excessive noise – Deviation of microclimate indicators – Electric shock
3. Ecological safety:	– Indicate impact of nuclear power plant on hydrosphere, atmosphere and lithosphere
4. Safety in emergency situations:	– Fire safety;

Assignment date for section according to schedule	01.02.2020

The task was issued by consultant:

Position	Full name	Scientific degree, rank	Signature	Date
Assistant professor	Verigin D.A.	Cand.of Sc.		

The task was accepted by the student:

Group	Full name	Signature	Date
0AM8I	Maistrenko Alexandr Sergeyevich		

Министерство науки и высшего образования Российской Федерации
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«Национальный исследовательский Томский политехнический университет» (ТПУ)

School of Nuclear Science and Engineering
Field of training (specialty) 14.04.02 Nuclear Science and Technology, Nuclear Power Installation Operation
Level of education: Master degree programme
Nuclear Fuel Cycle Division
Period of completion: spring semester 2019/2020 academic year

Form of presenting the work:

Master Thesis

SCHEDULED ASSESSMENT CALENDAR
for the Master Thesis completion

Deadline for completion of Master's Graduation Thesis: 01.06.2020

Assessment date	Title of section (module) / type of work (research)	Maximum score for the section (module)
01.02.2020	*Issuance of a task*	
05.02.2020	*The choice of research areas*	
15.03.2020	*Selection and study of materials on the topic*	
01.04.2020	*Study of irradiation of biological tissues*	
19.04.2020	*Analysis of the obtained experimental data*	
22.04.2020	*Summary and assessment of results*	
01.06.2020	*Work delivery*	

COMPILED BY:
Scientific supervisor:

Position	Full name	Academic degree, academic status	Signature	Date
Senior science master	Artem G. Naymushin	PhD		

AGREED BY:

Programme Director	Full name	Academic degree, academic status	Signature	Date
Nuclear Power Installation Operation	Vera V. Verkhoturova	PhD		

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 (PC-1,2, 3, 6, UC-1,3), Criterion 5 RAEE (p 1.1)
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-2,6,9,10,14, UC-2,3,4, BPC1,2), Criterion 5 RAEE (p 1.2)
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-4,5,6,9,22, UC-1,2,5,6), Criterion 5 RAEE (p 1.3)
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-7,10,11,12,13, UC-1-3,BPC1,3), Criterion 5 RAEE (p 1.4)
LO5	To operate modern physical equipment and instruments, to master technological processes in the course of preparation for the production of new materials, instruments, installations, and systems.	FSES HE Requirements (PC-8,11,14,15, BPC-1), Criterion 5 RAEE (p 1.3)
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-12,13,14,16, BPC-2), Criterion 5 RAEE (p 1.3)
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 (PC-2,6,9,10,14, UC-1,2,3), Criterion 5 RAEE (p 1.2,2.4,2.5)
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 (PC-16,17,21, UC-5,6, BPC-1), Criterion 5 RAEE (p 2.6) coordinated with the requirements of the international standard EURACE & FEANI
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 (BPC-3, UC-2,4), Criterion 5 RAEE (p 2.2)

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-18,20,21,22,23, UC-1,4, BPC-2), Criterion 5 RAEE (p 1.6,2.3) coordinated with the requirements of the international standard EUR-ACE & FEANI

Abstract

Master's Thesis contains 80 pages, 12 figures, 25 tables, 19 references.

Keywords: IRT-T, nuclear reactor, boron neutron capture therapy, cancer tumors.

The object of study in this work are biological tissues exposed to neutron flows, their distribution and optimal values of the neutron flow.

The purpose of the work is to determine optimal neutron spectrum for boron neutron capture therapy.

During the study data about biological tissues, its structure and materials were studied, irradiation models of human body were created, irradiation of biological tissues was conducted.

As a result of the study, values of the neutron fluxes were obtained, the optimal value was determined. Analysis of the obtained data was carried out.

Extent of implementation: high

Scope: radiotherapy, boron neutron capture therapy units

Economic efficiency / significance of work: high.

List of content

Introduction

Neutron capture therapy is one of the most promising treatments for malignant tumors. Work on the development of NCT is carried out in more than 40 countries, and Russia is no exception. Neutron capture therapy is a radiotherapy technique. This is a method of treating cancer using reactions that occur between radiosensitive drugs and neutrons. Moreover, boron or gadolinium is pre-accumulated in the tumor, which increases its sensitivity to neutron radiation. Then the tumor is irradiated with a stream of thermal neutrons. In oncology clinics, boron-based therapy is already being used.

As a result of neutron absorption by boron, a nuclear reaction occurs with a large release of energy in the cell, which leads to its destruction. Boron absorbs a neutron very efficiently: the thermal neutron absorption cross section is 3837 barn, while the neutron absorption cross section by most elements is on the order of several barn.

As a result of neutron absorption by boron-10, an excited boron-11 nucleus is formed, which in 10-12 seconds decays into a lithium-7 nucleus and an alpha particle, which fly apart with high energy. In 6% of cases, their total energy is 2.8 MeV, and in 94% - 2.3 MeV, since 0.48 MeV is carried out by a gamma quantum. These charged particles are quickly decelerated: a lithium core at a length of 5 microns, an alpha particle at 7 microns. Since the cell size is of the order of 10 μm, it can be seen that 80% of the energy of the nuclear reaction is released exactly in the cell that contained the boron nucleus that absorbed the neutron. At the moment, the HEC-1 channel is being reconstructed at the IRT-T reactor for subsequent use in neutron capture therapy. The IRT-T reactor is a basin-type research reactor using distilled water and beryllium as a reflector as a moderator, coolant and top protection. Highly enriched dispersed fuel in an aluminum matrix is used as fuel.

Despite the fact that the active zone of the IRT-T reactor was designed in the eighties of the last century, only recently it became possible to create a full-scale neutron-physical model of the active zone, which allows determining the density of neutron fluxes and energy release at each point of the active zone. However, the current flux density of thermal and epithermal neutrons does not satisfy the requirements, but with the help of modernization it is possible to achieve the necessary values. To simulate processes in the HEC-1 channel, it is necessary to use the MCU-PTR software package. This program, assembled from modules of the MCU-5 package, is designed to simulate the processes of neutron, photon, electron and positron transfer by analog and weight (non-analog) Monte Carlo methods, based on estimated nuclear data in nuclear reactors, taking into account changes in the isotopic composition of the reactor materials in company process.

The goal of this work is to determine optimal neutron spectrum for conduction of boron neutron capture therapy. To achieve this goal following tasks were set:

- Conduct the anatomical data analysis of biological tissues and human body;
- Create model of human body for modeling irradiation;
- Conduct the experimental irradiation of created models;
- Test various initial energies of the neutron source.

1 Literature overview

1.1 Basic information about BNCT

1.1.1 The situation of BNCT in the world

In recent decades, the number of cancer patients has been increasing all over the world, and cancer mortality is one of the leading causes of premature death. This trend is likely to continue in the near future. Despite the fact that the standard method of treatment - surgery, chemotherapy and radiation therapy (RT) have achieved some success in combating this disease, it is still not possible to completely cure all forms of cancer. Therefore, the search and development of promising technologies that can overcome this difficult disease continues.

Currently, the treatment of malignant neoplasms by exposing the tumor to various types of radiation (α- and β-particles, electrons, protons, neutrons, X-rays and γ-radiation) has become widespread in almost all developed countries of the planet. Modern technologies using RT are one of the most effective methods of treating malignant tumors. Therefore, it is not surprising that almost half of cancer patients are exposed to some form of RT during treatment. According to modern concepts, about 70% of cancer patients need some form of radiation therapy. In Russia alone, radiotherapy is needed annually to treat about 50,000 people. Including about 4000 patients with thyroid cancer, 2500 with thyrotoxicosis, 14000 with other oncological diseases, 7000 with diseases of the musculoskeletal system. In fact, this help is provided to only 2,000 patients annually.

The fundamental difference between normal and cancerous cells is the increased growth and division rate of the latter. This means that cancer cells absorb a much larger amount of the substances necessary for cell replication. Thus, compounds that are cellular “building blocks” (mainly nucleic acid precursors, as well as amino acids and peptides or their analogs) will be absorbed mainly by cancer cells, which makes it possible in principle to selectively deliver small amounts of certain elements to the tumor, for example, strong neutron absorbers.

In 1936, Gordon Lo Cher proposed the concept of neutron capture therapy (NRT) - "... a simple illustration would be an injection of a soluble non-toxic compound of boron, lithium, gadolinium or gold into a shallow cancerous tumor followed by irradiation with slow neutrons." In 1951, it was first shown that certain boron compounds provide a higher concentration of boron in cancer cells compared with a healthy cell. During the 1950s and early 1960s. in Brookhaven and Massachusetts (USA), the first clinical trials of boron-neutron capture therapy (BNCT) technology were conducted on specially constructed medical reactors. These studies, unfortunately, did not demonstrate the therapeutic efficacy of this method and were discontinued. The reason, as it turned out later, was the low concentration of boron in the tumor cells.

Despite the failure, the intensive search for new compounds for BNCT continued, and notable successes were soon achieved in the synthesis of effective pharmaceutical preparations containing the ^{10}B isotope. The obtained compounds created the concentration of the desired isotope in the tumor tissue up to 40 μg/g, which is 3.5 times more than in healthy tissue. Such a concentration made it possible to make the contribution of background radiation acceptably small and indeed provide the possibility of selective damage to a cancerous tumor. This led to the resumption in 1994 of treatment for patients with cerebral glioblastoma at the Brookhaven and Massachusetts reactors. In 1997, clinical trials began in the Netherlands, in 1999 in Finland. Subsequently, these works were joined in England, Australia, Argentina, Italy, Germany, Sweden, and Russia.

Initially, NCT was closely associated with the treatment of brain tumors. However, the results obtained over the past 10 ... 15 years in various medical centers and, in particular, by Professor Mishima (Japan) on NCT for malignant melanoma (skin cancer), opened up new opportunities for NCT. Malignant melanoma is a highly lethal disease resistant to existing treatments. The use of NCT for its treatment gives an effect of 80 ... 90% with five-year survival. Clinical studies have shown that NCT can be an effective treatment for many other diseases, such as cancer of the colon and rectum, prostate, breast, lung, oral cavity, thyroid gland and other ailments. A non-oncological application is also possible - the treatment of rheumatoid arthritis and other diseases.

For some types of cancerous tumors, especially slow-growing or late-stage ones, gamma radiation, protons and electrons are ineffective, and neutron therapy in combination with surgical methods is the only possible way of effective treatment. Intraoperative radiation therapy - irradiation of malignant neoplasms in an open surgical wound and maximum protection of surrounding organs and tissues - allows high single doses of ionizing radiation to be delivered directly to the tumor or to the area of its bed during surgery. As a result of accurate irradiation of a diseased organ, the possibility of radiation complications is minimized, which is especially important in the treatment of deep tumors, for example, cancer of the abdominal cavity and retroperitoneal space. The experience of its clinical use is still small, but today it gives encouraging results in the treatment of not only brain tumors, but also late stages of gastric cancer, as well as a number of other localizations.

1.1.2 Neutron capture therapy

Currently, the world is actively developing a new technology for radiation therapy of cancer - NRT. It is designed for the selective effect of radiation on the tumor. NRT uses tumor-tropic pharmaceutical preparations containing ^{10}B - BNCT or ^{157}Gd (gadolinium neutron capture therapy (GUT)). A huge thermal neutron absorption cross section for these isotopes of (3837 ± 9) barn for the ^{10}B nucleus and (254000 ± 815) barn for ^{157}Gd leads to the intense absorption of the latter and the formation of secondary radiation, which is detrimental to tumor cells.

Gadolinium isotopes have the highest thermal neutron capture cross sections of all non-radioactive elements. As a result of neutron absorption by the ^{157}Gd nucleus, high-energy photon and electron radiation (conversion and Auger electrons) arise, which is localized within 1 ... 40 μm from the reaction point. Initially high toxicity free, i.e. non-complex, inorganic salts of gadolinium prevented their use for therapeutic purposes. A new interest in the concept of GNCT arose in the early 1990s with the introduction of gadolinium-containing drugs for magnetic resonance contrast diagnostics. In parallel, similar studies were carried out in various radiological scientific centers of the world, where a number of promising pharmaceutical preparations based on ^{10}B and ^{157}Gd were synthesized. Currently, the effectiveness of the clinical use of these compounds is being intensively studied.

They have advanced far in their research in the field of the use of BNCT and GNCT in the nuclear reactor IRT MEPhI (Russia). Here, preclinical biomedical studies are conducted on the use of BNCT and GNCT for the treatment of malignant tumors in animals. Studies on the effectiveness of NCT have been successfully conducted on cell culture and on small laboratory animals carrying tumors (rats with S-45 sarcoma and mice with B-16 melanoma). The experiments showed complete tumor resorption in at least 60% of the animals, and this effect was 100% on a suspension of S-45 sarcoma tumor cells.

Despite the activation and certain successes in GNCT, in real clinical therapy, compounds based on the ^{10}B isotope remain the only working chemical tool for NCT. Natural boron isotope composition contains two isotopes ^{10}B (20%) and PV (80%). As a result of the absorption of a thermal neutron by a stable isotope ^{10}B, a nuclear reaction occurs:

$$^{10}B + n \rightarrow {}^{11}B \rightarrow {}^{7}Li + {}^{4}He + 2.79 \text{ MeV}$$

$$^{10}B + n \rightarrow {}^{11}B \rightarrow {}^{7}Li^{*} + {}^{4}He + 2.31 \text{ MeV}$$

$$^{7}Li^{*} \rightarrow {}^{7}Li + 477.6 \text{ keV}$$

The cross section of this reaction substantially depends on the energy of incident neutrons. Therefore, to achieve maximum reaction efficiency, it is necessary to have thermal neutrons guaranteed. The probability of a reaction in which a lithium core is formed in an excited (ground) state is 94% (6%). Excitation is removed by emission of gamma rays with an energy of 477.6 keV. The reaction energy is divided between fragments in proportion to their masses. The resulting α particle (LET ~ 100 keV/μm) and the ^{7}Li recoil nucleus are decelerated at a length of ~9 and ~5 μm, respectively. Since the cell size is ~10 μm, the energy of the nuclear reaction is mainly released within the cell that contained boron nuclei that absorbed the neutron. This leads to their death. The higher the concentration of ^{10}B in a cancer cell compared to a healthy one, the more effective is the selective defeat of malignant cells.

1.1.3 Boron neutron capture therapy

Corresponding pharmaceuticals introduced into the patient's body are carried by the blood stream through the body and accumulate in the affected tissues or organs, creating a high concentration of the ^{10}B isotope in the tumor (~ 10^9 atoms in the cell), which is several times more than in healthy tissue. This makes it possible to selectively damage a cancerous tumor. Thus, in contrast to traditional radiation therapy, the treatment of malignant tumors in NRT is carried out, first of all, as a result of the interaction of a neutron with the corresponding isotope concentrated in the tumor, and not just by aiming the beam.

For the successful implementation of the capabilities of NRT, the interaction of thermal neutrons with the chemical elements that make up the human body should be taken into account. These are mainly hydrogen, oxygen, carbon and nitrogen. In particular, the nuclear reactions of $^{14}N(n,p)^{14}C$ and $^{1}H(n, \gamma)^{2}H$ lead to the appearance of recoil nuclei and γ quanta. Although the cross sections for the interaction of neutrons with hydrogen and nitrogen are several orders of magnitude smaller than the cross section for neutron absorption by the ^{10}B isotope, hydrogen and nitrogen are present in such a high concentration that this additional indiscriminate "background" irradiation by recoil protons and γ quanta makes a significant contribution to the absorbed dose. This factor must be considered when determining the dose of radiation absorbed by healthy tissues. In order to reduce the effect of this "background" exposure, it is necessary to ensure the highest possible concentration of boron in the cells of the cancerous tumor.

A positive factor of thermal neutrons is that neutrons of this energy do not lead to severe radiation damage to surrounding tissues due to recoil protons formed during their interaction with hydrogen atoms. At the same time, poor penetration limits the possibility of their use, allowing the treatment of tumors with a depth of no more than

2 s. Epithermal neutrons are used to process formations with a greater depth. The higher their average energy, the greater the depth of penetration.

The interaction of neutrons with biological tissue inevitably leads to radiation damage to healthy cells during inhibition and capture of neutrons as they pass from the surface of the body to the tumor. Already at a depth of 10 cm, the neutron flux from the primary beam of epithermal neutrons decreases by almost 10 times, and thermal neutrons are completely shielded. At a depth of 7 cm, the dose absorbed in healthy tissue is more than 30% of the dose in the tumor, at a depth of -10 cm they are compared, i.e. healthy cells are destroyed as intensively as cancer cells. Thus, the real impact of external beams of thermal and epithermal neutrons in the treatment of cancer is limited to layers of biological tissue <10 cm.

Table 1.3.1 – The mass of the isotope in human tissue and the cross section for the capture of thermal neutrons

Isotope	Capture cross section, barn	Mass of an isotope in human tissue, %	Isotope	Cross section capture, barn	Mass of an isotope in human tissue,%
^{1}H	0.333	10	^{31}P	0.18	1.16
^{12}C	0.0035	18	^{32}S	0.53	0.2
^{14}N	1.83	3	^{35}Cl	32.68	0.16
^{16}O	0.00019	65	^{39}K	2.1	0.2
^{23}Na	0.43	0.11	^{40}Ca	0.4	2.01
^{24}Mg	0.0053	0.04	^{56}F	2.57	0.01

In order to minimize the patient's exposure time, the neutron source must create a flux of $10^{12}...10^{13}$ neutrons$\cdot$cm^{-2} (flux density of $5\cdot10^{8}...10^{9}$ neutrons$\cdot$cm$^{-2}\cdot$s^{-1}) during a therapy session. This requirement substantially limits the range of nuclear reactors suitable for use in BNCT. Another negative feature of traditional NCT is the presence of an accompanying background of gamma rays in a therapeutic neutron beam. formed in biological tissue, as well as fast neutrons, exacerbating the radiation burden on healthy tissues. The measures used to suppress the accompanying background: the use of tangent horizontal channels of the reactors, focusing of the neutron beam, filtering of background γ-quanta and fast neutrons, can only minimize associated dose loads, but do not completely eliminate this harmful side effect.

The development and implementation of NCT are working in 47 countries of the world, including Japan, Sweden, Finland, USA, Czech Republic, Slovenia, Taiwan. About 2,000 people went through clinical trials. The most impressive results were obtained by Italian Pinelli and Japanese Hatanaka. In Italy, a liver treatment technology was developed: it is cut out from a sick patient, irradiated in a reactor, and reimplanted back to the patient. In this way, in particular, a patient with 14 liver metastases was successfully treated, although a similar diagnosis is a death sentence without the right to delay. Japanese professor Hatanaka conducted experimental treatment of hopeless patients with stage 3–4 brain tumors. He opened his skull, removed about 70% of the tumor, saturated the remaining part with a boron-containing preparation and irradiated the surgical field. Moreover, the 10-year survival rate of patients with gliomas was 9.6%, and in the control - 0%. Under optimal conditions, the 10-year survival rate reached 29.2%.

The relevance of the BNCT task has led to intensive research in this direction. The feasibility of developing high-tech and expensive BNCT technology is associated with the fact that it is focused on the treatment of such types of malignant tumors as glioblastomas of the brain, anaplastic astrocytomas or metastases of melanoma, which are practically not amenable to any other methods. At the same time, the stake was placed on epithermal neutrons, which, slowing down to thermal energies in the tissues of the skull and brain, provided the maximum therapeutic dose in the tumor. So the use of BNCT in the treatment of brain tumors made it possible to achieve 55% 5-year survival versus 1 ... 2% with conventional radiation therapy. Potential new areas of application of BNCT are also the treatment of cancer of the neck, liver, and also non-tumorous diseases of a localized nature, such as rheumatoid arthritis, etc.

Epithermal neutrons entering the tissue create a radiation field with a maximum heat flux at a depth of 2...3 cm, which then drops exponentially. The penetration depth can be increased by raising the average energy of epithermal neutrons.

Many foreign reactors with high-quality neutron beams and appropriate equipment for conducting BNCT have been used in the recent past and are currently used to treat patients with malignant tumors. Such reactors include: MITR-II FCB (USA), HFR (Netherlands), JRR4 (Japan), LVR-15 (Czech Republic), Studsvik AB (Sweden), FiR1 P-01 and FiR1 P-03 (Finland), RA-6 (Argentina), TAPIRO (Italy). Corresponding installations have been developed at reactors in South Korea and China. For various reasons, the reactors HTR (Musashi, Japan), BMMR (Brookhaven, USA), MITR-II M-67 (Masachusetts, USA), which were previously used for clinical BNCT, were deactivated. The reactors BR-10 (Obninsk, Russia) and FRM (Munich, Germany) were shut down, conducting radiation therapy with fast neutrons of average energy of 0.8 ... 1.4 MeV. It is interesting that some of the reactors were redone for BNCT tasks by using moderators and neutron filters in the reactor core, although they were originally built for research in the field of radiation diagnostics and clinical therapy of small and large animals. This, for example, Studsvik AB (Sweden), FIR1 (Finland), the reactor of Washington State University.

One of the best foreign installations for BNCT is located in Massachusetts (USA), where a national center for the research and development of BNCT methods has been created. Here there are extracted beams of thermal neutrons with a flux density of $5\cdot10^9$ neutrons$\cdot$cm$^{-2}\cdot$s^{-1} and epithermal neutrons (MITR-II FCB) with a flux density $(3.2...4.6)\cdot10^9$ neutrons$\cdot$cm^{-2}s^{-1}. The diameter of the irradiated area is d = 8...16 cm. A beam of epithermal neutrons is obtained using a converter, which is 10 spent fuel rods of the MITR-II reactor located outside the core and cooled by D_2O. In Obninsk (Russia), on the basis of the VVR-c reactor, a project was developed for a high-tech medical complex for NT and NRT with a throughput of at least 200 patients per year. The neutron source is intended:

• for remote radiation therapy: a) a wide energy spectrum close to the fission spectrum, with an average energy of ~ 1 MeV; b) the flux density of fast neutrons with energies> 0.5 MeV ~ $(3...5)\cdot10^8$ neutrons$\cdot$cm^{-2}s^{-1}; c) the γ-component of the dose does not exceed 15%;

• for NRTs of surface-located tumors: a) thermal neutron flux density > $5 \cdot 10^9$ neutrons$\cdot$cm^{-2}s^{-1}; b) fast neutrons contribution <10^6 neutrons$\cdot$cm$^{-2}\cdot$s^{-1}; c) the contribution of the γ-component to the dose of not more than 5...10%;

• for NRT of deeply located tumors: a) the flux density of epithermal neutrons with energies from 10 keV to 0.1 MeV ~ $5 \cdot 10^9$ neutrons$\cdot$cm$^{-2}\cdot$s^{-1} (the fluence of thermal neutrons in the tumor tissue is ~ 10^{12} neutrons$\cdot$cm$^{-2}\cdot$s^{-1}); b) the γ-component of the dose is not more than 10%; c) fast neutron flux density <10^8 neutrons. cm^{-2}s^{-1}.

In addition to the complex mentioned above, there is a preliminary design of a small-sized medical reactor MARS. It is intended for the treatment of oncological patients in a hospital-stationary mode (unit weight <70 t allows placing it directly in the clinic). It is assumed that MARS will only work during a therapy session for 1 ... 2 hours per day at a rated power of 10 kW. In the current state of the design study of the MARS reactor, it is supposed to ensure the output of two beams for carrying out NRT and GNT. It is believed that the characteristics of the neutron beams of the MARS and VVR-c reactors are not inferior to the best world analogues. The possibility of using TVR-50 heavy water reactor for NRT is also being considered. Canals for the treatment of cancer patients are laid in new facilities under design, for example, Ruta and liquid-fuel nuclear reactors.

1.2 General characteristics of the IRT-T reactor

The research reactor IRT-T was built in 1959–1967. and commissioned in July 1967. After 10 years, in June 1977 the reactor was stopped for reconstruction due to progressive corrosion of the aluminum shell of the reactor tank and corrosion of aluminum heat exchangers. During the reconstruction process, a new 12X18H10T steel tank was mounted, the equipment of I and II reactor cooling circuits was completely replaced, the control system was brought in line with the requirements of the rules in force during this period. The equipment of I and II circuits is mounted in the newly constructed premises of the IR. The reactor was put into operation after reconstruction in 1984. In 2000, instrumentation sensors were replaced in the channels for measuring flow, pressure, and coolant level in the reactor cooling circuits. In 2005, his control and protection system was modernized. During the operation of the IRT-T research reactor, there have not been a single nuclear and radiation incident related to the release of radioactive substances into the environment.

The IRT-T reactor is a pool-type research reactor using distilled water as a moderator, coolant and overhead protection. The reactor is intended for carrying out scientific research on solid state physics, neutron activation analysis of the elemental composition of substances, production of radionuclides, silicon doping, neutron radiography. Students of the physical, technical and thermal power faculties of the National Research Tomsk Polytechnic University (NR TPU) undergo laboratory practice at the reactor.

A longitudinal section of the reactor is shown in Figure 1.2.1.

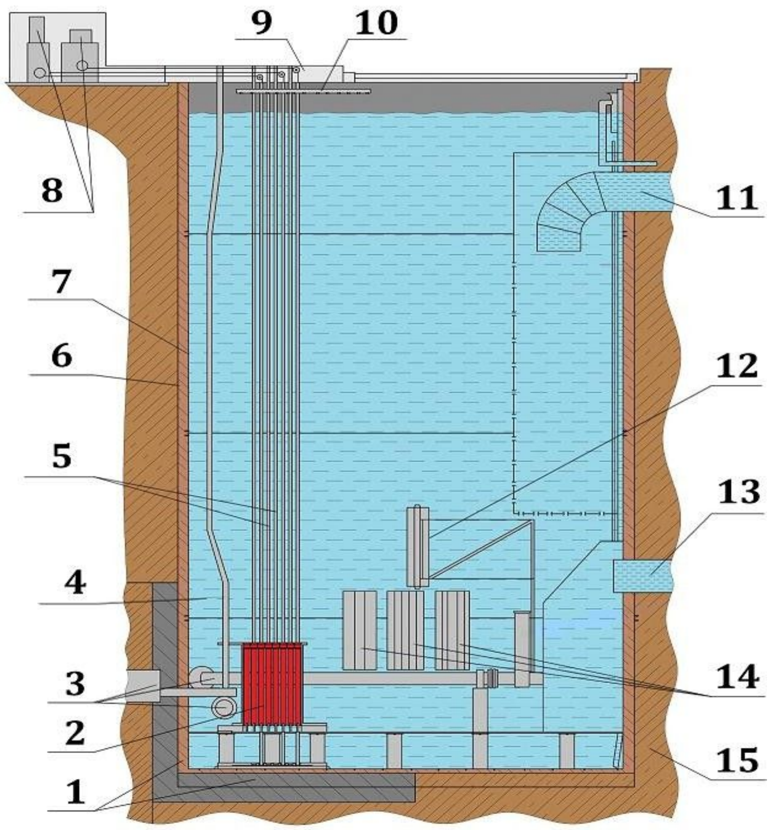

Figure 1.2.1 - Longitudinal section of the IRT-T reactor:

1 - heat shield; 2 - active zone; 3 - horizontal experimental channels;
4 - vertical experimental channels; 5 - CPS channels; 6 - aluminum tank;
7 - stainless steel tank; 8 - drive rods CPS; 9 - CPS site; 10 - sprinkler;
11 - pressure pipe; 12 - fuel transportation device; 13 - suction pipe;
14 - temporary storage of fuel assemblies; 15 - heavy aggregate concrete

1.2.1 The core of the IRT-T reactor

The reactor core is located in a pool filled with demineralized water at a depth of 6.5 m (center of the zone). A three-dimensional cross-sectional view of the core is shown in Figure 1.2.1.1 The core body is made of aluminum alloy AD-1. The upper case body together with the supporting spacer grid are mounted on a 29 mm thick steel flange. The flange is welded to the sheets of the built-in holding tank and rests on six posts made of steel pipes Ø108 mm. The racks from below are welded to a supporting steel plate 30 mm thick. The plate is attached to the bottom of the tank by welding. The lower grating for the CPS channels 30 mm thick is welded on top to the base plate. The base plate and the lower grill protect the concrete under the bottom of the tank from radiation heating. In the places where aluminum alloy parts come into contact with steel parts, titanium gaskets are installed to prevent aluminum corrosion. The core body has 56 cells for the installation of fuel assemblies and beryllium blocks.

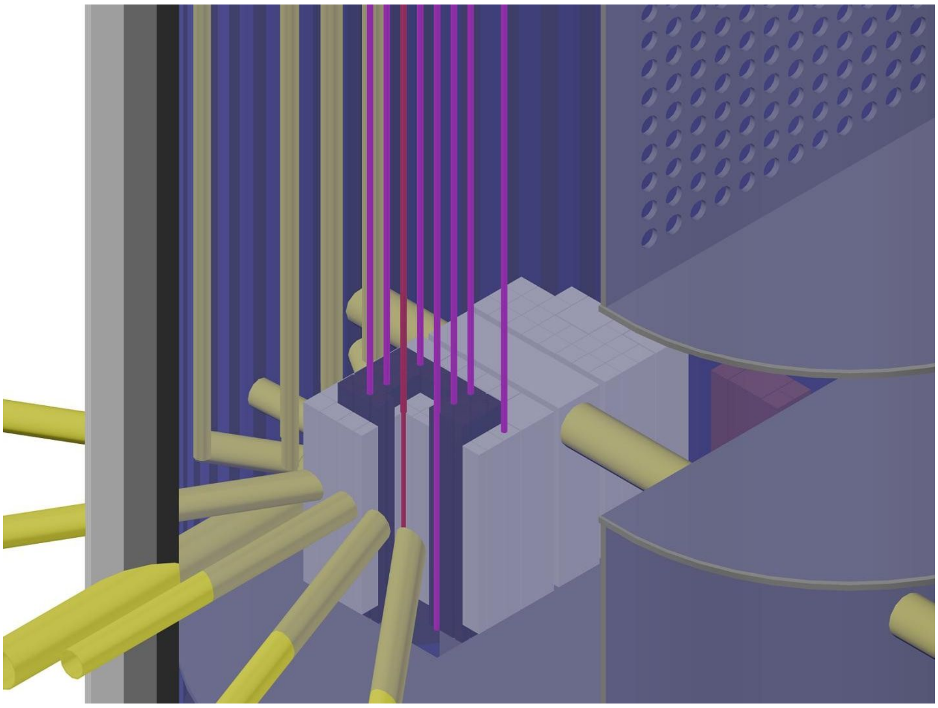

Figure 1.2.1.1 - Volumetric model of the active zone of the IRT reactor with experimental channels

FAs, beryllium reflector blocks, neutron trap blocks, displacers are mounted on a supporting separation grid. At the top of the fuel assemblies, reflector blocks, displacers are separated by special protrusions on their upper tips. At the bottom, they are fixed on the separation grid using slots in the lower tips.

The reactor core is assembled from fuel assemblies of the IRT-3M type with a short migration length and a high reproduction coefficient, which allows obtaining geometrically small sizes of the zone and a large neutron leakage to the reflector. The maximum number of core cells into which fuel assemblies can be installed is 56 pieces. Regular loading consists of 12 standard fuel assemblies (eight-pipe) and 8 fuel assemblies with CPS rods (six-pipe).

30 beryllium blocks form a lateral reflector. Beryllium has a density of 1.84 g/cm^3. The beryllium content in it is 97.8%. According to the height of the active zone, beryllium blocks are installed symmetrically.

Beryllium blocks adjacent to the core have external dimensions of 69x69x660 mm. On the right side in the corners are two large beryllium blocks of 138.5x138.5x660 mm with plugs of 96 mm and 44 mm in diameter.

Through two rows of beryllium blocks surrounding the active zone on the right side, a large beryllium block is installed, surrounding one of the main horizontal channels - HEC-4. This channel is mainly used for neutron-transmutation doping of silicon.

The reflector uses both solid blocks and blocks with central holes 48 mm in diameter and 44 mm beryllium plugs installed in them. The weight of a solid beryllium block is 5.7 kg.

All absorbent rods are made in the form of boron carbide rods (with a density of 1.813 g / cm3) with a stainless steel sheath with a diameter of 23 mm and a thickness of 0.7 mm. The absorbing part has a diameter of 21.2 mm, length

600.0 ± 1.5 mm and contains 383.9 ± 2.0 g of naturally occurring boron carbide. From the bottom, an end displacer made of SAV-1 alloy is attached to the absorbing rod. Fastening is carried out using a part made of stainless steel 12X18H9T with a length of 18 mm and a density of 7.9 g/cm^3. The length of the aluminum part of the end displacer 457 mm, diameter 23 mm

The reactor operates, as a rule, five days a week with a stop on the weekend. Preventive maintenance of equipment is carried out quarterly. The effective operating time at a nominal power level of 6 MW per year of operation is ~ 3500 hours. At the same time, the average energy production per year is 875 MW · day.

1.2.2 Experimental channels of the IRT-T reactor

The IRT-T reactor has 10 horizontal experimental channels (HEC) for outputting neutron beams (Figure 1.2.2.1). Eight radially spaced of them have an inner diameter of 100 mm. Two channels located in relation to the active zone (HEC-1 and HEC-4) have an internal diameter of 150 mm. Horizontal channels with a diameter of 100 mm are made of stainless steel with a wall thickness of 4 mm. The ends of the channels are machined to a thickness of 6 mm. Tangent channels with a diameter of

150 mm have a wall thickness of 5 mm. The HEC-1 channel is made of aluminum alloy, the HEC-4 channel is made of stainless steel (12X18H10T). The channel runs tangentially with respect to the core and is equipped with mechanical devices for irradiating single-crystal silicon. All horizontal channels are filled with air.

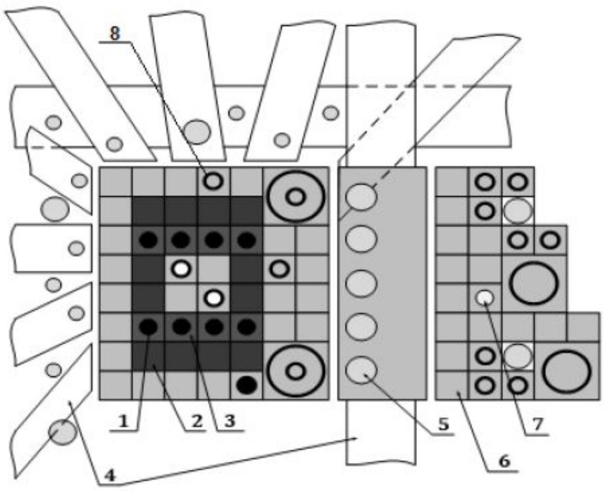

Figure 1.2.2.1 - Scheme of the active zone of the IRT-T reactor:
1) control rods; 2) 8 pipe fuel assemblies; 3) 6 pipe fuel assemblies;
4) horizontal experimental channels; 5) vertical experimental channels;
6) beryllium blocks; 7) experimental channels with water;
8) experimental channels in peripheral beryllium

For irradiation outside the active zone (in the water reflector), 14 vertical experimental channels (VEC) of aluminum alloy (Figure 1.2.2.1) with a diameter of 70x2 mm and a diameter of 55x2 mm were installed.

Along the right side, outside the second row of standard beryllium blocks (Figure 1.2.2.1), a 190x550x648 mm beryllium block is installed, covering the experimental channels of HEC-4 and HEC-2. The most important of all channels are HEC-4, CEC-1 and CEC-2. The maximum values of the flux density of thermal and fast neutrons along the axis of the HEC-4 channel are, respectively:

$$\Phi_{\text{therm}}\ (E_n \leq 0.625\ \text{eV}) = 1.2\cdot10^{13}\ \text{cm}^{-2}\cdot\text{s}^{-1};$$

$$\Phi_{\text{fast}}\ (E_n \geq 0.5\ \text{MeV}) = 7.2\cdot10^{10}\ \text{cm}^{-2}\cdot\text{s}^{-1}.$$

The complex for irradiating samples for the production of technetium generators includes two central vertical channels located in a central beryllium trap.

These channels are filled with water and made of aluminum pipes with a diameter of 36 mm. The maximum values of the flux density of thermal and fast neutrons along the axis of the vertical channels in the central moderating cavity are, respectively:

$$\Phi_{\text{therm}} (E_n \leq 0.625 \text{ eV}) = 1.8 \cdot 10^{14} \text{ cm}^{-2} \cdot \text{s}^{-1};$$

$$\Phi_{\text{fast}} (E_n \geq 0.5 \text{ MeV}) = 1.3 \cdot 10^{13} \text{ cm}^{-2} \cdot \text{s}^{-1}.$$

1.2.3 Neutron-physical characteristics of the core of the IRT-T reactor

The neutron-physical characteristics of the reactor are determined by its physical scheme based on the use of fuel assemblies of the IRT-3M type with a short migration length of neutrons and a beryllium reflector.

In the core, reflector, working bodies of the CPS, as well as in other parts of the reactor, materials have been used that have been sufficiently tested in research reactor engineering with well-studied properties, including when working in radiation conditions: metal-ceramics, metal beryllium, stainless steel, aluminum alloys.

The reactor core has sufficiently high breeding properties ($k_\infty \approx 1.75$), which determines the possibility of obtaining high neutron-physical parameters in experimental volumes.

The minimum critical mass is 3.01 kg, the reactivity margin is ~ 0.14% (experimental channels are installed in 4 central beryllium blocks).

The reactivity balance of the workload of 20 fuel assemblies with the periodic replacement in the core of one of the most burnt fuel assemblies with “fresh” (partial overload mode):

- maximum reactivity margin at the beginning of the cycle after overload - 7.2%;
- equilibrium poisoning with isotopes Xe^{135} and Sm^{149} - 4.8%;
- temperature effect - 0.4%;
- operational stock - 1.0%;
- burn-out - 1.0%.

3 Financial management, resource efficiency and resource conservation

The purpose of this section discusses the issues of competitiveness, resource efficiency and resource saving, as well as financial costs regarding the object of study of Master's thesis. Competitiveness analysis is carried out for this purpose. SWOT analysis helps to identify strengths, weaknesses, opportunities and threats associated with the project, and give an idea of working with them in each particular case. For the development of the project requires funds that go to the salaries of project participants and the necessary equipment, a complete list is given in the relevant section. The calculation of the resource efficiency indicator helps to make a final assessment of the technical decision on individual criteria and in general.

3.1 Competitiveness analysis

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

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

To make the analysis of the competitiveness, there will be used an evaluation map, which is shown in table 3.1.1. The developing project and its competitor are evaluated for each criterion on a five-point scale, where 1 – the weakest position, and 5 – the strongest. Summary, the weights of criteria should equal 1.

Analysis of the competitiveness of technical solutions could be calculated as follows:

$$K = \quad B_i \; S_i \qquad (3.1.1)$$

Where K – competitiveness of developing project or competitor;

B_i – weight of criteria i (in unit fraction);

S_i – a score of criteria i.

Block modeling method was chosen as a competitor. This method is differ from the method used in current research because all models are presented by throngs of blocks which increases the complexity of the model. There were chosen five criteria to evaluate rival methods. The most important ones were chosen the computational speed and results in accuracy. Computational speed cuts the time costs and results accuracy mitigates the probability of error.

Besides, there was marked out criteria of model detailization because the close model to the real object the more accurate results could be obtained.

Criteria of interface and functionality were marked out less important. Interface criteria show the convenience of interaction between end-user and model. Functionality shows the relative amount of functions, which model can do.

Table 3.1.1 – A map for evaluation of the competitiveness

Criteria		Criteria weight	Score		Competitiveness	
			P_f	P_{i1}	C_f	C_{i1}
1	Results accuracy	0.27	4	3	1.08	0.81
2	Functionality	0.13	2	2	0.54	0.54
3	Interface	0.16	2	3	0.54	0.81
4	Model detailization	0.24	3	2	0.81	0.54
5	Computation speed	0.2	3	1	0.81	0.27
Total		1	14	11	3.78	2.97

As a result of the analysis it could be said that method of current research provides higher accuracy and computation speed. Due to this fact method of the research is more efficient has great perspectives in future researches which makes it competitive to the block modeling method.

3.2 SWOT-analysis

The goal of SWOT analysis is to determine all the strengths and weaknesses of the project, which are considered as inner factors. Moreover, SWOT considers outer factors, which are opportunities and threats.

Table 3.2.1 shows the interactive matrix of the project, which contains the correlation between strengths and opportunities, which allows describing prospects of the project.

Therefore, by completing the SWOT analysis it could be summarized, that the current advantages of the project are dominating the above disadvantages.

Table 3.2.1 – Interactive matrix of the project

	Strengths: S1. The relevance of the selected topic. S2. Modern technology. S3. Practical work at the reactor plant. S4. Full analysis of neutron physical parameters.	Weaknesses: W1. The presence of the human factor. W2. Long time calculations. W3. The possibility of an error in the calculations. W4. Usage of a specialized software.
Opportunities: O1. The interest of well-known scientific journals in this topic. O2. Interest of the Rector of IRT-T in the implementation of the project. O3. The interest of ROSATOM in the results obtained. O4. The interest of the world nuclear community in the development of neutron capture therapy	Interest of ROSATOM will attract more funding, which in turn makes it possible to improve the technology and allow to apply it at the IRT-T reactor.	The results of the analysis of the interactive matrix of the project fields "Weaknesses and opportunities": 1. Errors due to lengthy calculations. This factor can be eliminated with careful work. 2. Additional funding from ROSATOM will allow to use modern systems to increase calculation rates.
Threats: T1. Lack of demand for new production technologies. T2. Technology export restrictions. T3. Introduction of additional state requirements for product certification. T4. Untimely financial security scientific research by the state.	The results of the analysis of the interactive matrix of the project fields "Strengths and threats": - Despite the scientific novelty, the state may refuse to fund scientific research. However international foundations could be used as alternative source funds.	The results of the analysis of the interactive matrix of the project fields "Weaknesses and threats": - The influence of the human factor can adversely affect the reliability of the results. However higher automatization of the calculation process may decrease the human factor effect.

3.3 Project initiation

As concerned parties, there are organizations or individuals who are actively taking part in the project or which interests can be considered both positively or negatively in duration of the project or after its finish. These parties could be customers, sponsors, public sphere and etc. Information about concerning parties is represented in table 3.3.1.

Table 3.3.1 – Stakeholders of the project

Stakeholder	Stakeholder's expectations
Division of nuclear fuel cycle, ESNT TPU, IRT-T research reactor	A model, clearly simulating the irradiation process of cancer tumors Possibility to include applicate the process at ITR-T reactor

Table 3.2.2 provides necessary information on the hierarchy of project goals and criteria for achieving these goals.

Table 3.2.2 – Goals and results of the project

Project goals:	Development of a computer model for cancer tumors irradiation
Project expectations:	Computer model describing process of irradiation
Acceptance criteria for results:	Absence of errors during the simulation; Accuracy in modeling of the process
Requirements to project results:	Requirement:
	Model allows various neutron specter
	Model allows various tumor location
	The model includes radiation protection for non-cancerous tissue
	The model should be similar to the IRT-T reactor conditions

At the current stage it is important to decide who will be in the workgroup of this project, to define roles for each participant and to assign the functions for each participant. Besides, there should be considered working hours. This information is represented in table 3.2.3

Table 3.2.3 – Project workgroup

№	First name, Second name, primary employment, position	Project role	Functions	Working hours, h
1	Naimushin A.G.	Scientific advisor	Consulting	54
2	Maistrenko A.S.	Engineer	Creation of the computer-aided model	540
Total				594

3.4 Project budget

Project constraints are the factors, which are limiting the degree of freedom for project team members and serving as boundaries of the project.

Table 3.4.1 – Project constraints

Factor	Constraints/Admissions
4.1. Project budget, roubles	170394.6
4.1.1. Funding source	National Research Tomsk Polytechnic University
4.2. Project lifetime:	01.01.2020-09.05.2020
4.2.1. The certified date for the plan of project management	05.03.2020
4.2.2. Project deadline	25.05.2020
4.3. Other constraints*	–

3.5 Timing schedule of the project

As part of the planning of a research project, it is necessary to build a timetable and a calendar schedule for the project. The timetable is shown in table 3.5.1

Scientific advisor and an engineer are the main contributors to the report.

Table 3.5.1 – Timetable of the project

№	Milestone	Duration, days	Start date	Finish date	Performer
1	Development of research task	5	01.02.2020	07.02.2020	Scientific advisor Engineer
2	Selecting and studying the related literature	10	08.02.2020	22.02.2020	Engineer
3	Work scheduling	2	23.02.2020	26.02.2020	Engineer
4	Research task writing and accepting	2	27.02.2020	29.02.2020	Scientific advisor Engineer
5	Familiarization with MCU-PTR program package	11	01.03.2020	16.03.2020	Engineer
6	Development of a irradiation models	9	17.03.2020	29.03.2020	Engineer
7	Development of a irradiation source model	10	30.03.2020	12.04.2020	Engineer
8	Development of appropriate conditions for irradiation	10	13.04.2020	26.04.2020	Engineer
9	Intermediate inspection, conversation with scientific advisor	1	27.04.2020	28.04.2020	Scientific advisor Engineer
10	Detailed report writing	63	27.02.2020	1.05.2020	Engineer
11	Inspection of detailed report on standard compliance	1	29.04.2020	30.04.2020	Scientific advisor
12	Preparations to the defense of the thesis	19	1.05.2020	25.05.2020	Engineer

Calendar schedule of the project, implemented by Gantt chart is represented in table 3.5.2

Table 3.5.2 – Gantt chart

Stage	Content of work	Tc, days	Duration of works			
			February	March	April	May
1	Development of research task	5				
2	Selection and studying the related literature	10				
3	Work scheduling	2				
4	Research task writing and accepting	2				
5	Familiarization with MCU-PTR program package	11				
6	Development of a irradiation models	9				
7	Development of a irradiation source model	10				
8	Development of appropriate conditions for irradiation	10				
9	Intermediate inspection, conversation with scientific advisor	1				
10	Detailed report writing	63				
11	Inspection of detailed report on standard compliance	1				
12	Preparations to the defense of a thesis	19				
	Total days	90		Scientific advisor		1
				Scientific advisor + Engineer		8
				Engineer		71

3.6 Budget of scientific research

3.6.1 Material costs of scientific research

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

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

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

– Material costs of scientific and technical research;

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

– basic salary;

– additional salary;

– labor tax;

– overhead.

3.6.2 Calculation of material costs

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

For current work, academic version MCU-FREE software was used, which is free.

Material costs, required for this research are shown in table

Table 3.6.2.1 – Material costs

Name	Amount (S_{mat}), rub.
Office supplies	1000
Total:	1000

3.6.3 Calculation of the depreciation

If you use available equipment, then you need to calculate depreciation:

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

A - annual amount of depreciation;

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

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

$\text{Т}_{\text{сл}}$ - life expectancy.

A personal computer was used for 250 hours during the semester.

Table 3.6.3.1 – Used equipment

№	Equipment identification	Quantity of equipment	Total cost of equipment, rub.	Life expectancy, year	Depreciation for the duration of the project, rub.
1.	Personal computer	1	80000	5,5	415,11
Total					415,11

3.6.4 Calculation of the base salary

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

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

$$S_{\text{b}} = S_a \cdot T_{\text{w}}, \qquad (3.6.4.1)$$

where Sb – 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 main student earnings during pre-graduation practice are:

$$S_b = S_a \cdot T_w$$

The average daily salary is calculated by the formula:

$$S_a = \frac{S_m \cdot M}{F_v}, \qquad (3.6.4.2)$$

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

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

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

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

The valid annual fund of working time

Table 3.6.4.1 – Balance of working time

Criteria for working time	Scientific advisor	Engineer
Calendar amount of days	365	365
Amount of non-work days: weekend; holidays.	66 52 14	66 52 14
Loss of working days, days: vacation; sick absence.	48 48 0	48 48 0
Current annual working hours Fд, days	251	251

Monthly salary is calculated by formula:

$$S_{month} = S_{em} \cdot k_{reg} \qquad (3.6.4.3)$$

where S_{em} – monthly emolument of the worker, rub.

k_{reg} – regional rate.

Table 3.6.4.2 – Base salary calculation

Performers	Sem, rub	kr	Sm, rub	Sd, rub.	Tw, w.days.	Sbase, rub
Scientific advisor, Associate Professor	33600	1,3	43680	1859.85	9	16740
Engineer	17310	1,3	22503	1004	79	79316
Total						96056

The base salary for a scientific advisor from TPU is calculated based on industrial remuneration. In TPU this remuneration considers next content for salary:

- emolument, determined by the enterprise;
- incentive payments, determined by the head of departments for efficient work, the accomplishment of job duties and etc.;
- other payments;
- regional salary coefficient.

3.6.5 Contributions in non-budget funds

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

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

$$W_{add} = k_{extra} \quad W_{base} \, , \qquad (3.6.5.1)$$

where W_{add} – additional salary, rubles;

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

W_{base} – base salary, rubles.

Additional salary equals to 10% from the base salary.

Table 3.6.5.1 – Additional salary calculation

Salary, rub	Scientific advisor	Engineer
W_{base}	16740	79316
k_{extra}	0.10	0.10
W_{add}	1674	7931.6
W_{base}+ W_{add}	18414	87247.6
C	105661.6	

3.6.6 Labor tax

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

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

$$P_{social} = k_b \ (W_{base} + W_{add}) \qquad (3.6.6.1)$$

where k_b – coefficient of deductions for labor tax.

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

Table 3.6.6.1 – Labor tax

	Scientific advisor	Engineer
Coefficient of deductions	27.1	
Salary, rubles	18414	87247.6
Labor tax, rubles	4990	23644

3.6.7 Overhead costs

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

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

Overhead is calculated according to the formula:

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

where k_{ov} – overhead rate.

Table 3.6.7.1 – Overhead

	Scientific advisor	Engineer
Overhead rate	0.30	
Salary, rubles	18414	87247.6
Overhead, rubles	5524	26174.2

3.6.8 Other direct costs

Energy costs are calculated by the formula:

$$C = P_{el} \cdot P \cdot F_{eq} = 5.8 \cdot 0.6 \cdot 858 = 2985.84$$

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

P – power of equipment, kW;

F_{eq} – equipment usage time, hours.

The cost of electricity amounted to 2985,84 rubles.

Formation of budget costs

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

Determining the budget for the scientific research is given in the table.

Table 3.6.8.1 – Items expenses grouping

Name	Cost, rubles
Material costs	1000
Depreciation	415
Basic salary	96056
Additional salary	9605.6
Labor tax	28634
Overhead	31698
Other direct costs	2986
Total planned cost	170394.6

3.7 Evaluation of the comparative effectiveness of the project

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

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

The integral financial measure of development is defined as:

$$I_{\phi}^{p} = \frac{\Phi_{pi}}{\Phi_{\max}}, \qquad (3.7.1)$$

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

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

Φ_{max} – the maximum cost of execution of a research project (including analogues).

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

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

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

$$I_m^a = \sum_{i=1}^{n} a_i b_i^a, \quad I_m^p = \sum_{i=1}^{n} a_i b_i^p \tag{3.7.2}$$

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

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

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

n – number of comparison parameters.

The calculation of the integral indicator of resource efficiency is presented in the form of table 3.7.1. Another model was adopted as an analog due to similar functionality and methods.

Table 3.7.1 – Evaluation of the performance of the project

Criteria		Criteria weight	Score	
			P_f	P_{i1}
1	Results accuracy	0.27	4	3
2	Functionality	0.13	2	2
3	Interface	0.16	2	3
4	Model detailization	0.24	3	2
5	Computation speed	0.2	3	1
Total		1	14	11

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

$$I^{p}_{финр} = \frac{I^{p}_{m}}{I^{p}_{ф}}, \quad I^{a}_{финр} = \frac{I^{a}_{m}}{I^{a}_{ф}} \text{ and etc.} \tag{3.7.3}$$

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

$$Э_{ср} = \frac{I^{p}_{финр}}{I^{a}_{финр}}. \tag{3.7.4}$$

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

Table 3.7.2 – Efficiency of development

№	Indicators	Points	
		Current project	Analogue
1	Integral financial measure of development	1	1
2	Integral indicator of resource efficiency of development	3.78	2.97
3	Integral indicator of the development efficiency	3.78	2.97

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

3.8 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.

4. Social responsibility

4.1 Introduction

In this research work the features of neutron flux distribution in biological tissues were studied. During the study optimal neutron spectrum was determined. All work was carried out using computer model of the irradiating source and biological tissues without exposure to ionizing radiation. The developed system will allow to determine the condition for BNCT for various cases.

4.2 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.

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.

4.3 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.

4.4 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.

A harmful factor or industrial health hazard is a factor, the effect of which on a worker under certain conditions leads to a disease or a decrease in working capacity.

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

The object of the study is "Investigation of the influence of the various parameters of the neutron source on the biological tissues through the simulation on a PC." Therefore, the object of study itself cannot cause harmful and dangerous factors.

4.4.2. 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 4.4.2.1.

Table 4.4.2.1 - 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 microclimate of industrial premises.
2. Excessive noise		+	+	
3.Increased level of electromagnetic radiation	+	+	+	
4.Insufficient illumination of the working area		+	+	
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.

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 [2] and are given in Table 4.4.2.2.

Table 4.4.2.2 - Optimal and permissible parameters of the microclimate

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

Excessive noise

Noise and vibration worsen working conditions, have a harmful effect on the human body, namely, the organs of hearing and the whole body through the central nervous system. It 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 [2], 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 4.4.2.3 – Upper limits for values of contact current and voltage

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

Insufficient illumination of the working area

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

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

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

4.4.3 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 [2], 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.

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) [3].

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.

4.5 Ecological safety

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

Most nuclear power plants release gaseous and liquid radiological effluents into the environment, which must be monitored. Civilians living within 80 km of a nuclear power plant typically receive about 0.1 μSv per year.

All reactors are required to have a containment building in according to international requirements. The walls of containment buildings are several feet thick and made of concrete and therefore can stop the release of any radiation emitted by the reactor into the environment

Large volumes of water are used during the process of nuclear power generation. The uranium fuel inside reactors undergoes induced nuclear fission which releases great amounts of energy that is used to heat water. The water turns into steam and rotates a turbine, creating electricity. Nuclear plants are built near bodies of water.

All possible impact of nuclear power plant on environment is greatly reduced in operating regime by many safety precautions means. The most danger of nuclear energy come because of different sorts of disaster

4.5.2 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.

4.5.3 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.

4.6 Safety in emergency

4.6.1 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.

4.6.2 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.

4.7 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.