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

БАКАЛАВРСКАЯ РАБОТА

Тема работы
Численное исследование условий проявления влияния пород с повышенным содержанием урана на результаты измерения объемной активности радона в почвенном воздухе

УДК 539.163:546.296:553.495

Студент

Группа	ФИО	Подпись	Дата
0А7А	Толмачёв Никита Сергеевич		

Руководитель ВКР

Должность	ФИО	Ученая степень, звание	Подпись	Дата
Профессор ОЯТЦ	Яковлева Валентина Станиславовна	д.т.н		

Консультант

Должность	ФИО	Ученая степень, звание	Подпись	Дата
Старший преподаватель ОЯТЦ	Побережников Андрей Дмитриевич	-		

КОНСУЛЬТАНТЫ ПО РАЗДЕЛАМ:

По разделу «Финансовый менеджмент, ресурсоэффективность и ресурсосбережение»

Должность	ФИО	Ученая степень, звание	Подпись	Дата
Профессор ОСГН ШИП	Гасанов Магеррам Али оглы	д.э.н.		

По разделу «Социальная ответственность»

Должность	ФИО	Ученая степень, звание	Подпись	Дата
Доцент ОЯТЦ ИЯТШ	Передерин Юрий Владимирович	к.т.н.		

ДОПУСТИТЬ К ЗАЩИТЕ:

Руководитель ООП	ФИО	Ученая степень, звание	Подпись	Дата
Доцент ОЯТЦ ИЯТШ	Бычков Петр Николаевич.	к.т.н.		

Томск – 2021 г.

ТOMSK POLYTECHNIC UNIVERSITY ТОМСКИЙ ПОЛИТЕХНИЧЕСКИЙ УНИВЕРСИТЕТ

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

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

BACHELORS WORK

Topic of research work
Seasonal features of variations in atmospheric alpha radioactivity

UDC 539.163:546.296:553.495

Student

Group	Full name	Signature	Date
0A7A	Tolmcahev Nikita Sergeevich		

Scientific supervisor

Position	Full name	Academic degree, academic rank	Signature	Date
Professor of NFCF	Yakovleva Valentina Stanislavovna			

Consultant

Position	Full name	Academic degree, academic rank	Signature	Date
Senior lecturer of NFCF	Poberezhnikov Andrey Dmitrievich	-		

ADVISERS:

Section “Financial Management, Resource Efficiency and Resource Saving”

Position	Full name	Academic degree, academic rank	Signature	Date
Professor	Hasanov Maharram Ali oglu	PhD		

Section “Social Responsibility”

Position	Full name	Academic degree, academic rank	Signature	Date
Associate Professor	Perederin Yuri Vladimirovich	PhD		

ADMITTED TO DEFENSE:

Programme Director	Full name	Academic degree, academic rank	Signature	Date
Associate Professor	Bychkov Petr Nikolaevich.	PhD		

Tomsk – 2021

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)

Школа ________________________инженерная школа ядерных технологий____________
Направление подготовки ________14.03.02 Ядерные физика и технологии_____________
Отделение школы _____________отделение ядерно-топливного цикла________________

УТВЕРЖДАЮ:
Руководитель ООП
_____ _______ Бычков П.Н.
(Подпись) (Дата) (Ф.И.О.)

ЗАДАНИЕ
на выполнение выпускной квалификационной работы

В форме:

бакалаврской работы

Студенту:

Группа	ФИО
0А7А	Толмачёв Никита Сергеевич

Тема работы:

Численное исследование условий проявления влияния пород с повышенным содержанием урана на результаты измерения объемной активности радона в почвенном воздухе	
Утверждена приказом директора (дата, номер)	28.04.2021 г., №118-33/с

Срок сдачи студентом выполненной работы:	09.06.2021

ТЕХНИЧЕСКОЕ ЗАДАНИЕ:

Исходные данные к работе	Физико-геологические характеристики грунтов и пород, удельная активность урана – 238, объемная активность радона в почвенном воздухе

Перечень подлежащих исследованию, проектированию и разработке вопросов	- обзор литературных источников - приборы и методы измерения объемной активности радона в грунте - моделирование вертикального распределения объемной активности радона в многослойной геологической среде - определение условий проявления влияния пород с повышенным содержанием урана на результаты измерения объемной активности радона в почвенном воздухе - анализ полученных результатов - финансовая ответственность - социальная ответственность - заключение по работе
Перечень графического материала *(с точным указанием обязательных чертежей)*	Презентация для защиты ВКР

Консультанты по разделам выпускной квалификационной работы

(с указанием разделов)

Раздел	**Консультант**
Социальная ответственность	Передерин Юрий Владимирович
Финансовый менеджмент, ресурсоэффективность и ресурсосбережение	Гасанов Магеррам Али оглы

Дата выдачи задания на выполнение выпускной квалификационной работы по линейному графику	26.04.2021

Задание выдал руководитель / консультант (при наличии):

Должность	**ФИО**	**Ученая степень, звание**	**Подпись**	**Дата**
Профессор ОЯТЦ	Яковлева Валентина Станиславовна	д.т.н		
Старший преподаватель ОЯТЦ	Побережников Андрей Дмитриевич	-		

Задание принял к исполнению студент:

Группа	**ФИО**	**Подпись**	**Дата**
0А7А	**Толмачёв Никита Сергеевич**		

TASK FOR SECTION

"FINANCIAL MANAGEMENT, EFFICIENCY OF RESOURCES AND ECONOMY OF RESOURCES"

Student:

Group	Full name
0A7A	Tolmachev Nikita Sergeevich

School	**SNTE**	**Research and Education Centr**	**DNFC**
The level of education	bachelor	**Direction/ specialty**	14.03.02 Nuclear physics and technology / Nuclear Power Engineering/Nuclear medicine

Initial data for the section "Financial Management, Resource Efficiency and Resource Saving":	
1. The cost of scientific research resources (SR): material and technical, energy, financial, informational and human	The cost of material resources and special equipment is determined in accordance with the market prices of the city of Tomsk. Performers' tariff rates are determined by the staffing table of NI TPU.
2. Rates and rates of resource consumption	Electricity tariff 2.45 rubles. for 1 kW * h
3. The used system of taxation, rates of taxes, deductions, discounting and crediting	Contributions to extrabudgetary funds - 30%
List of questions to be researched, designed and developed:	
1. Assessment of the potential, prospects and alternatives to the NI position of resource efficiency and resource conservation	Calculation of competitiveness SWOT analysis
2. Formation of a plan and schedule for development and introducing NI	Work structure, determination of labor intensity, development of a research schedule
3. Drawing up the budget of the NI	Calculation of the budget for the implementation of research
4. Assessment of the resource, financial, budget efficiency of scientific research	Integral financial indicator. An integral indicator of resource efficiency. Integral efficiency indicator
List of graphic material (with exact indication of the required drawings)	
1. Assessment of the competitiveness of scientific research *2. SWOT Matrix* *3. Gantt chart* *4. NI budget* *5. The main indicators of the effectiveness of research*	

Date of issue of the task for the section on a line chart	15.02.2020

The assignment was given by the consultant:

Position	ФИО	Academic degree, title	Signature	Data
Full Professor	Hasanov Maharram Ali oglu	Doctor of Economic Sciences		

The student accepted the assignment:

Group	Full name	Signature	Data
0A7A	Tolmachev Nikita Sergeevich		

TASK FOR SECTION"SOCIAL RESPONSIBILITY"

student:

Group	Full name
0A7A	Tolmachev Nikita Sergeevich

School	**SNTE**	**Research and Education Centr**	**DNFC**
The level of education	bachelor	**Direction/ specialty**	14.03.02 Nuclear physics and technology / Nuclear Power Engineering/Nuclear medicine

Subject FQW:

Seasonal features of variations in atmospheric alpha radioactivity	
Initial data for the section "Social responsibility":	
1. Characteristics of the research object (substance, material, device, algorithm, technique, working area) and its scope	- a model for the registration of γ-quanta by a system of NaI (Tl) detectors formed in the study of reactions of synthesis of light nuclei; experimental nuclear physics
List of questions to be researched, designed and developed:	
1. Legal and organizational security issues: - special (typical for the operation of the research object, the projected working area) legal norms of labor legislation; -organizational measures for the layout of the working area.	- Federal law of 09 Jan. 1996 No. 3-F3 "On radiation safety of the population" - SanPiN 2.2.2 / 2.4.2732-10 "Hygienic requirements for personal computers and work organization
2. Industrial safety: **2.1. Analysis of the identified harmful and dangerous factors** **2.2. Rationale for mitigation measures**	Harmful and dangerous factors: - deviation of microclimate indicators; - increased noise level; - insufficient illumination of the working area; - increased level of electromagnetic radiation; - psychophysiological factors; - increased level of ionizing radiation; - danger of electric shock.
3. Environmental safety:	- analysis of the impact of the object and the research process on the environment; - development of organizational and technical measures to protect the environment.
4. Safety in emergencies:	- selection and description of a typical emergency - fire; - justification of measures to prevent emergencies; - the order of actions in the event of an emergency.

Date of issue of the task for the section on a line chart	**05.05.2020**

The assignment was given by the consultant:

Position	Full name	Academic degree, title	Signature	date
Associate Professor	Perederin Yuriy Vladimirovich	Ph.D		

The student accepted the assignment:

Group	Full name	Signature	date
0A7A	Tolmachev Nikita Sergeevich		

TOMSK POLYTECHNIC UNIVERSITY — ТОМСКИЙ ПОЛИТЕХНИЧЕСКИЙ УНИВЕРСИТЕТ

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образовательное учреждение высшего образования
«Национальный исследовательский Томский политехнический университет» (ТПУ)

Школа ________ инженерная школа ядерных технологий ________
Направление подготовки ________ 14.03.02 Ядерные физика и технологии ________
Уровень образования ________ бакалавриат ________
Отделение школы ________ отделение ядерно-топливного цикла ________
Период выполнения ________ весенний семестр 2020 /2021 учебного года ________

Форма представления работы:

бакалаврская работа

КАЛЕНДАРНЫЙ РЕЙТИНГ-ПЛАН
выполнения выпускной квалификационной работы

Срок сдачи студентом выполненной работы:	09.06.2021

Дата контроля	Название раздела (модуля) / вид работы (исследования)	Максимальный балл раздела (модуля)
10.05.2021	Обзор литературных источников	10
24.05.2021	Приборы и методы измерения объемной активности радона в грунте	15
25.05.2021	Моделирование вертикального распределения объемной активности радона в многослойной геологической среде	20
26.05.2021	Определение условий проявления влияния пород с повышенным содержанием урана на результаты измерения объемной активности радона в почвенном воздухе	20
27.05.2021	Анализ полученных результатов	15
04.06.2021	Финансовая ответственность	10
04.05.2021	Социальная ответсвенность	10

СОСТАВИЛ:

Руководитель ВКР

Должность	ФИО	Ученая степень, звание	Подпись	Дата
Профессор ОЯТЦ	Яковлева Валентина Станиславовна	д.т.н		

Консультант (при наличии)

Должность	ФИО	Ученая степень, звание	Подпись	Дата
Старший преподаватель ОЯТЦ	Побережников Андрей Дмитриевич	-		

СОГЛАСОВАНО:

Руководитель ООП

Должность	ФИО	Ученая степень, звание	Подпись	Дата
Доцент ОЯТЦ	Бычков П.Н.	к.т.н.		

TOMSK POLYTECHNIC UNIVERSITY
ТОМСКИЙ ПОЛИТЕХНИЧЕСКИЙ УНИВЕРСИТЕТ

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образовательное учреждение высшего образования
«Национальный исследовательский Томский политехнический университет» (ТПУ)

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

Work submission form:

bachelor's work

CALENDAR RATING PLAN
completion of the final qualifying work

The deadline for the student's completed work:	09.06.2021

Дата контроля	Название раздела (модуля) / вид работы (исследования)	Максимальный балл раздела (модуля)
10.05.2021	Review of literary sources	10
24.05.2021	Devices and methods for measuring the volumetric activity of radon in soil	15
25.05.2021	Modeling the vertical distribution of radon volumetric activity in a multilayer geological environment	20
26.05.2021	Determination of the conditions for the manifestation of the influence of rocks with an increased uranium content on the results of measuring the volumetric activity of radon in soil air	20
27.05.2021	Analysis of the obtained results	15
04.06.2021	Financial management, resource efficiency and resource conservation	10
04.06.2021	Social responsibility	10

COMPOSED:
Head of the WRC

Position	Full name	Academic degree, title	Signature	date
Professor of NFCF	Yakovleva Valentina Stanislavovna	Doctor of Technology		

Consultant (if available)

Position	Full name	Academic degree, title	Signature	date
Senior lecturer of NFCF	Poberezhnikov Andrey Dmitrievich	-		

AGREED:
PLO leader

Position	Full name	Academic degree, title	Signature	date
Associate Professor	Bychkov Petr Nikolaevich.	PhD		

РЕЗУЛЬТАТЫ ОБУЧЕНИЯ (КОМПЕТЕНЦИИ ВЫПУСКНИКОВ)

Код компетенции	Наименование компетенции
	Универсальные компетенции
УК(У)-1	Демонстрировать культуру мышления, способность к обобщению, анализу, восприятию информации, постановке цели и выбору путей ее достижения; стремления к саморазвитию, повышению своей квалификации и мастерства; владение основными методами, способами и средствами получения, хранения, переработки информации, навыки работы с компьютером как средством управления информацией; способность работы с информацией в глобальных компьютерных сетях.
УК(У)-2	Способность логически верно, аргументировано и ясно строить устную и письменную речь; критически оценивать свои достоинства и недостатки, намечать пути и выбирать средства развития достоинств и устранения недостатков.
УК(У)-3	Готовностью к кооперации с коллегами, работе в коллективе; к организации работы малых коллективов исполнителей, планированию работы персонала и фондов оплаты труда; генерировать организационно-управленческих решения в нестандартных ситуациях и нести за них ответственность; к разработке оперативных планов работы первичных производственных подразделений; осуществлению и анализу исследовательской и технологической деятельности как объекта управления.
УК(У)-4	Умение использовать нормативные правовые документы в своей деятельности; использовать основные положения и методы социальных, гуманитарных и экономических наук при решении социальных и профессиональных задач, анализировать социально-значимые проблемы и процессы; осознавать социальную значимость своей будущей профессии, обладать высокой мотивацией к выполнению профессиональной деятельности.
УК(У)-5	Владеть одним из иностранных языков на уровне не ниже разговорного.
УК(У)-6	Владеть средствами самостоятельного, методически правильного использования методов физического воспитания и укрепления здоровья, готов к достижению должного уровня физической подготовленности для обеспечения полноценной социальной и профессиональной деятельности.
	Профессиональные компетенции
ПК(У)-1	Использовать основные законы естественнонаучных дисциплин в профессиональной деятельности, применять методы математического анализа и моделирования, теоретического и экспериментального исследования.
ПК(У)-2	Владеть основными методами защиты производственного персонала и населения от возможных последствий аварий, катастроф, стихийных бедствий; И быть готовым к оценке ядерной и радиационной безопасности, к оценке воздействия на окружающую среду, к контролю за соблюдением экологической безопасности, техники безопасности, норм и правил производственной санитарии, пожарной, радиационной и ядерной безопасности, норм охраны труда; к контролю соответствия разрабатываемых проектов и технической документации стандартам, техническим условиям, требованиям безопасности и другим нормативным документам; за соблюдением технологической дисциплины и обслуживанию технологического оборудования; и к организации защиты объектов интеллектуальной собственности и результатов исследований и разработок как коммерческой тайны предприятия; и понимать сущность и значение информации в развитии современного информационного общества, сознавать опасности и

Код компетенции	Наименование компетенции
	угрозы, возникающие в этом процессе, соблюдать основные требования информационной безопасности, в том числе защиты государственной тайны).
ПК(У)-3	Уметь производить расчет и проектирование деталей и узлов приборов и установок в соответствии с техническим заданием с использованием стандартных средств автоматизации проектирования; разрабатывать проектную и рабочую техническую документацию, оформление законченных проектно-конструкторских работ; проводить предварительного технико-экономического обоснования проектных расчетов установок и приборов.
ПК(У)-4	Готовность к эксплуатации современного физического оборудования и приборов, к освоению технологических процессов в ходе подготовки производства новых материалов, приборов, установок и систем; к наладке, настройке, регулировке и опытной проверке оборудования и программных средств; к монтажу, наладке, испытанию и сдаче в эксплуатацию опытных образцов приборов, установок, узлов, систем и деталей.
ПК(У)-5	Способность к организации метрологического обеспечения технологических процессов, к использованию типовых методов контроля качества выпускаемой продукции; и к оценке инновационного потенциала новой продукции.
ПК(У)-6	Способность использовать информационные технологии при разработке новых установок, материалов и приборов, к сбору и анализу информационных исходных данных для проектирования приборов и установок; технические средства для измерения основных параметров объектов исследования, к подготовке данных для составления обзоров, отчетов и научных публикаций; к составлению отчета по выполненному заданию, к участию во внедрении результатов исследований и разработок; и проведения математического моделирования процессов и объектов на базе стандартных пакетов автоматизированного проектирования и исследований.
ПК(У)-7	Уметь готовить исходные данные для выбора и обоснования научно-технических и организационных решений на основе экономического анализа; использовать научно-техническую информацию, отечественный и зарубежный опыт по тематике исследования, современные компьютерные технологии и базы данных в своей предметной области; и выполнять работы по стандартизации и подготовке к сертификации технических средств, систем, процессов, оборудования и материалов;
ПК(У)-8	Готовность к проведению физических экспериментов по заданной методике, составлению описания проводимых исследований и анализу результатов; анализу затрат и результатов деятельности производственных подразделений; к разработки способов применения ядерно-энергетических, плазменных, лазерных, СВЧ и мощных импульсных установок, электронных, нейтронных и протонных пучков, методов экспериментальной физики в решении технических, технологических и медицинских проблем.
ПК(У)-9	Способность к приемке и освоению вводимого оборудования, составлению инструкций по эксплуатации оборудования и программ испытаний; к составлению технической документации (графиков работ, инструкций, планов, смет, заявок на материалы, оборудование), а также установленной отчетности по утвержденным формам; и к организации рабочих мест, их техническому оснащению, размещению технологического оборудования.

LEARNING OUTCOMES (COMPETENCES OF GRADUATES)

The code competence	Competence name
Universal competences	
UC (U)-1	Demonstrate a culture of thinking, the ability to generalize, analyze, perceive information, set a goal and choose ways to achieve it; striving for self-development, improving their qualifications and skills; possession of the basic methods, methods and means of obtaining, storing, processing information, skills of working with a computer as a means of information management; ability to work with information in global computer networks.
UC (U)-2	Ability to logically correct, reasoned and clearly build oral and written speech; critically assess your strengths and weaknesses, outline ways and choose means of developing strengths and eliminating weaknesses.
UC (U)-3	Willingness to cooperate with colleagues, work in a team; to organizing the work of small teams of performers, planning the work of personnel and payroll funds; generate organizational and managerial solutions in non-standard situations and be responsible for them; to the development of operational plans for the work of primary production units; implementation and analysis of research and technological activities as an object of management.
UC (U)-4	Ability to use regulatory legal documents in their activities; use the main provisions and methods of social, humanitarian and economic sciences in solving social and professional problems, analyze socially significant problems and processes; be aware of the social significance of their future profession, be highly motivated to perform professional activities.
UC (U)-5	Know one of the foreign languages at a level not lower than the spoken one.
UC (U)-6	To own the means of independent, methodologically correct use of methods of physical education and health promotion, is ready to achieve the proper level of physical fitness for full-fledged social and professional activity.
Professional competence	
PC (U)-1	Use the basic laws of natural sciences in professional activities, apply the methods of mathematical analysis and modeling, theoretical and experimental research.
PC (U)-2	Possess the basic methods of protecting production personnel and the population from the possible consequences of accidents, catastrophes, natural disasters; And be ready to assess nuclear and radiation safety, to assess the impact on the environment, to monitor compliance with environmental safety, safety, norms and rules of industrial sanitation, fire, radiation and nuclear safety, labor protection standards; to control the compliance of developed projects and technical documentation with standards, technical conditions, safety requirements and other regulatory documents; observance of technological discipline and maintenance of technological equipment; and to the organization of protection of intellectual property objects and the results of research and development as a commercial secret of the enterprise; and to understand the essence and significance of information in the development of a modern information society, to be aware of the dangers and threats arising in this process, to comply with the basic requirements of information security, including the protection of state secrets).
PC (U)-3	To be able to calculate and design parts and assemblies of devices and installations in accordance with the terms of reference using standard design automation tools; to develop design and working technical documentation, registration of completed design and engineering works; to carry out a preliminary feasibility study of design calculations for installations and devices.
PC (U)-4	Readiness for the operation of modern physical equipment and devices, for the development of technological processes in the course of preparing the production of new materials, devices, installations and systems; to

The code competence	Competence name
	commissioning, tuning, adjustment and experimental testing of equipment and software; for installation, commissioning, testing and commissioning of prototypes of devices, installations, assemblies, systems and parts.
PC (U)-5	Ability to organize metrological support of technological processes, to use standard methods of quality control of manufactured products; and to assess the innovative potential of new products.
PC (U)-6	The ability to use information technology in the development of new installations, materials and devices, to collect and analyze information source data for the design of devices and installations; technical means for measuring the main objects of research, preparing data for compiling reviews, reports and scientific publications; to prepare a report on the completed assignment, to participate in the implementation of research and development results; and carrying out mathematical modeling and carrying out on the basis of standard computer-aided design packages and research objects.
PC (U)-7	To be able to prepare initial data for the selection and justification of scientific, technical and organizational decisions based on economic analysis; to use scientific and technical information, domestic and foreign experience on the research topic, modern computer technologies and databases in their subject area; and carry out work on standardization and preparation for certification of technical means, systems, processes, equipment and materials;
PC (U)-8	Willingness to conduct physical experiments according to a given methodology, compilation of a description of the research being carried out and analysis of the results; analysis of costs and results of activities of production units; to the development of methods for using nuclear energy, plasma, laser, microwave and powerful pulsed installations, electronic, neutron and proton beams, methods of experimental physics in solving technical, technological and medical problems.
PC (U)-9	Ability to accept and master the equipment to be introduced, to draw up instructions for the operation of equipment and test programs; to the preparation of technical documentation (work schedules, instructions, plans, estimates, applications for materials, equipment), as well as established reporting on approved forms; and to the organization of workplaces, their technical equipment, the placement of technological equipment.

ABSTRACT

The final qualifying work consists of 88 pages, 15 figures, 25 tables, 23 sources.

Key words: specific activity, volumetric activity of radon in soil air, advection rate, porosity, radon flux density.

The object of the study is the volumetric activity of radon in the soil air, depending on the content of uranium-238, the geological structure of the territory and the physical and geological characteristics of the soil.

The aim of this work is a numerical study of the volumetric activity of radon in the soil air.

In the course of the study, an analysis was made of the volumetric activity of radon in the soil air in the soil, consisting of two layers with different uranium content - 238 and different depths of the surface layer. The analysis of the flux density in the surface atmosphere was also carried out.

In the Wolfram Mathematica software environment, the volumetric activity of radon in soil air was simulated on the basis of the diffusion-advective equation of radon transport in a porous medium, as well as the radon flux density in the surface atmosphere.

As a result of the study, the values of the pore activity of radon in the soil air were obtained for different geological structures of the territory and the physical and geological characteristics of soils, the values of the radon flux density in the surface atmosphere were calculated.

Economic efficiency of work: high.

Scope: dosimetric control.

Significance: high.

TABLE OF CONTENTS

INTRODUCTION

Radon transport modeling in geological media is an important tool for solving problems and tasks of radioecology and geophysics. Comparison of radon field time series obtained by numerical and experimental methods is one of the most common and widely applicable ways to analyze the influence of state and variability of meteorological, electrical and actinometric parameters of atmosphere, cosmic weather factors, variations of deflected mode of geological medium on the level and variations of radon field. The solutions of stationary and non-stationary diffusion-advection equations of radon transport in many-layered geological media by numerical methods, notably by integro-interpolation method (balance method) are presented. The peculiarity of radon transport in many-layered media is taken into account in the developed numerical model. This peculiarity is connected with the transport equation coefficients which can change very rapidly at the border of two adjacent layers, i.e. they can be discontinuous at the borders of each layer that can be caused by parameters of soils greatly differing in value (density, porosity, radium content, diffusion and emanation coefficients). The present work is provided with an example of application of the developed numerical model for solving a practical problem on assessment of influence of deep seated uranium-containing rock on the value of radon volumetric activity at the depth of $\leq$ 1 m. The article considers non-stationary numerical model calculations showing at what time moments the distribution curves of radon volumetric activity coincide with stationary regime of radon transport in geological media. The validity of the developed numerical solution has been confirmed by these calculations.

Radon transport modeling in geological media is widely applicable to solve practical problems and to explore the regularities of radon behavior [1–4, 6, 9, 10]. Based upon mathematical model the assessment of transport parameters is performed and predictions applicable in different spheres are made, for example: in building to amend the Code of Practice; in geological exploration to explore uranium ore deposits; in radioecology to assess radon danger for areas and buildings; in geophysics to study lithosphere-atmosphere bonds. Radon transport modeling in geological media, which are described as similar to real ones, is a difficult issue, because geological medium is heterogeneous, layered with significantly different geophysical and geochemical characteristics for each layer. In this case a model of radon transport in layered medium with non- -constant coefficients is required. Model coefficients can be the functions of spatial and time coordinates, and moreover, they can change very rapidly at a border of two adjacent layers, i.e. they can be discontinuous at the borders of each layer that can be caused by greatly differing parameters of soils (density, porosity, radium content, diffusion and emanation coefficients). In the explicit form there is no way to obtain analytical solution for such a model, therefore, in this case numerical methods are applicable. The present work deals with obtaining numerical solution for stationary and non-stationary diffusion- -advection equation for radon transport in many- -layered geological media.

1. REVIEW OF LITERATURE ON THE TOPIC

1.1 Registration of radon and physical methods for measuring its activity in soil

Since 1987, the International Center for Cancer Research (CIRC, Lyon, France) has classified radon decay products as carcinogens causing lung cancer in humans (Group 1 of the IARC classification of carcinogens). In 1994, under the leadership of the National Cancer Institute (USA), a combined analysis of data from surveys of 11 underground mine workers was carried out. The analysis was based on data from studies of more than 65 thousand workers and 2620 cases of lung cancer [1].

Radon and its daughter products of its decay (DPD), penetrating into the lungs and settling in the lung tissue, decaying, cause microburns, since all the energy of alpha particles is absorbed practically at the point of decay. The analysis revealed a direct relationship between the incidence of lung cancer and the duration of exposure to high concentrations of radon for miners. After a direct relationship was found between the incidence of lung cancer and the concentration of radon in residential and office premises, international standards were introduced, according to which, when designing new residential and social buildings, the average annual equivalent equilibrium volumetric activity (EEVA) of radon in the air does not must exceed 100 Bq/m^3; in the constructed buildings the EEVA should not exceed 200 Bq/m^3; at its large values, protective measures should be taken [1].

Radon is a radioactive chemical element of the main subgroup of the eighth group, the sixth period of the periodic system of chemical elements of D.I. Mendeleev with atomic number 86, formed during the natural radioactive decay of uranium and having its own half-life of 3.8 days. Under normal conditions, it is a colorless inert gas, odorless and tasteless. Since uranium has been present in the earth's crust since the formation of our planet and its most common isotopes have a very long half-life (4.5 billion years), uranium, radium and, therefore, radon will continue to be present in the earth's atmosphere in constant amounts for a long time[1].

1.1.1 Release of radon into the surface atmosphere

The release (exhalation) of radon from the soil is carried out by two mechanisms: due to recoil and due to diffusion [2]. First, radon, as a radiogenic gas, is continuously generated in rocks during radioactive decay, i.e. is always present in any mountain massif, and a decrease in its concentration both due to decay and due to migration from the massif into the air is constantly compensated by the new generation of this gas. Therefore, the average content of radon in the massif is always constant and is determined by the concentration of uranium (radium) in this massif. Secondly, the migration of radon in the mountain range and its release from the soil surface are determined by the macroscopic diffusion coefficient, which depends on many factors. The most important of these are porosity, permeability and fracturing. In the presence of fracturing (permeability) of the upper part of the massif and ascending gas flows, convection transport of radon with gas jets can be carried out from depths of up to 200 m. Radon is reliably recorded in the presence of approximately 30-50 decays per second in one cubic meter, i.e. radon activity is 30-50 Bq/m$^3 \cdot 10^7$. This means that one cubic meter contains (0.2-0.3) radon atoms, or its concentration in the gas mixture is about 10 - 16% [2].

The content of emanations (Rn^{222} and Th^{220}) and their decay products in the air is determined mainly by their exhalation from the earth's surface (soils, grounds, vegetation cover) and their turbulent diffusion in the atmosphere. To some extent, volcanic activity affects the content of long-lived radon decay products (Bp^{210} и Po^{210}). The content in the surface layer of air sometimes correlates well with the content of a in the surface layer of the soil. However, areas with a high air content are still more often associated with the peculiarities of the geological structure and geochemical characteristics of the underlying rocks.Bp^{210} и $Po^{210} Rn^{222} Ra^{226} Rn^{222}$

Typical rates of radon emanation from the earth's surface vary from 2 for rocks, to (8 - 21) $\cdot 10^{-4}$ $\mathrm{Bq/m^2s}$ for mountain soils, (4 - 50) $\cdot 10^{-3} \mathrm{Bq/m^2s}$ for podzolic soils, (5 - 38) $\cdot$ $10^{-3} \mathrm{Bq/m^2s}$ for desert soils and up to (21 - 53) 10^{-3} $\mathrm{Bq/m^2s}$ for chernozems[1].

Radon accumulates most of all in closed rooms, in basements and on the first floors, and in ventilated rooms its concentration drops sharply, therefore its behavior in underground rooms of residential buildings and office buildings is of natural interest, since the possibility of radon spreading to the upper floors of buildings is not excluded ... The main routes of entry of radon and DPR isotopes into the basement and first floors of buildings and structures are as follows:

- from the bowels of the Earth by tectonic faults, which, being a kind of collectors, contribute to the rise and accumulation of radon near the surface and then it seeps through the foundations of buildings;

- building and finishing materials (cement, crushed stone, brick, granite, marble, etc.). In this case, the exhalation of radon is determined both by the content of radium in the materials and by the value of the emanation coefficient (the fraction of radon that enters the atmosphere from the total amount of radon formed in the material);

- water, especially when it is supplied from artesian wells or rivers flowing through technogenically polluted or naturally contaminated territory. In groundwater, the concentration of radon can exceed the same parameter in the waters of lakes and rivers by a factor of millions. When using large amounts of water (shower, laundry, etc.) with spraying and evaporation, the rate of penetration of radon and DPR isotopes into the air of industrial premises increases sharply;

- natural gas. When used in large quantities in boiler rooms, canteens, kitchens, etc. and inadequate ventilation of premises, the concentration of isotopes of radon and DPR can also exceed the MPC[1].

1.1.2 Methods for registration of radon

Today, there are many different physicochemical and physical methods for registering radon activity[1]. Like any other radioactive material, radon can be detected by dosimetry devices after the decay of its isotopes and subsequent daughter products. With regard to premises, they usually mean the so-called volumetric activity (OA) -

the ratio of the activity of a radioactive substance to the volume of this substance, measured in Becquerels per cubic meter [2]

There are many methods for registering radon, both directly and by its decay products. One of these methods for direct registration is the electrostatic deposition of radon and its daughter decay products (DPD) on the surface of a semiconductor alpha decay detector, followed by particle discrimination by energy level. It is on this principle of operation that modern radon monitors are based, such as a universal radon monitor "AlphaGuard" manufactured by the German company Genitron Instruments GmbH, radon monitors from SARAD GmbH (Germany), Russian RRA-01M-01, RAA-20P2 "Poisk" and others. Air sampling can be done passively - in this case, the chamber inlet is usually closed with a membrane permeable only for radon, in order to increase the selectivity of the device, and actively - with the help of a pump.

1.2 Radiometry radon

1.2.1 Radon radiometer RAD7

RAD7 - A versatile instrument that can form the basis of an integrated radon measurement system. It can be used in many different modes for different purposes.

Fig. 1. Radon radiometer RAD7

RAD7 can be organized into categories:

- continuous monitoring of radon in the air;
- measurement of radon in water;
- soil gas testing;
- measuring emissions of radon and thoron from objects and surfaces.

This work focuses on the use of RAD7 to measure radon and thoron in air without the use of special hardware accessories.

1.2.2 Radiometer RTM 2200

The RTM-2200 is an excellent radon / thoron monitor for all types of radon measurements. The functions of the RTM-2200 are not limited to receiving and storing data, it can also control sampling equipment (pumps, valves, positioning, etc.).

Fig. 2. Radiometer RTM 2200

The measurement chamber is based on the principle of electrostatic deposition in a high voltage field and, despite its small volume, the chamber has incredible sensitivity. This is of decisive importance when analyzing Thoron samples as well as when analyzing small volumes of pumped gas, in particular soil gases. Long-term contamination caused by Po^{210} build-up in the chamber, to which other measuring systems are exposed, is completely eliminated. There is also no cross-sensitivity associated with external gamma radiation. Changes in ambient humidity do not affect the performance of the RTM-2200 measuring chamber, so there is no need for dryers required in other electrostatic deposition devices.

1.2.3 RRA-01M-03 - Radon radiometer

Radon radiometer RRA-01M-03 is designed to measure the volumetric activity (VA) of Ra^{222} and Th^{220} in the air of residential and work premises, as well as in the open air.

The measurement of the OA of Ra^{222} and Th^{220} is based on the electrostatic deposition of daughter decay products of Ra^{222} and thoron-220 - positively charged ions 218Po (RaA) and 21bPo (ThA) - from a selected air sample onto the surface of a semiconductor detector using a high positive potential applied to the electrode of the measuring chamber.

The activity of radon-222 and thoron-220 is determined by the alpha spectrometric method according to the number of registered alpha particles during the decay of RaA and ThA. During the measurement, the following environmental parameters are monitored: temperature, relative humidity and pressure.

Fig. 3. RRA-01M-03 radiometer

Radon radiometer RRA-01M-03 is designed as a portable device with autonomous and mains power supply. Its main nodes are:

- measuring camera from aerosol filter and a semiconductor detector;
- microblower;
- climatic chamber with temperature, humidity and pressure sensors;
- charge sensitive preamplifier;
- high-voltage power supply;
- autonomous power supply;
- control unit with microprocessor-based control and indication elements located in it;
- AC adapter (supplied separately).

1.2.4 Alpharad PLUS - Radon radiometer

This modification includes a complete set of measuring units and sampling devices.

The modification includes two measuring units (EROA measurement unit, OA measurement unit), which are combined in a single housing.

This modification also includes an autonomous blower with sampling devices for sampling when measuring the radon content in water samples, soil air and measuring the radon flux density (RFD) from the soil surface.

The modification is intended for the following operating modes:

- using the EEVA measurement unit to monitor the content of daughter decay products (DPR) of radon and thoron in the air by the aspiration method, when aerosols, by pumping, are deposited on the filter, and then their content is measured by alpha spectrometry;
- using the OA measurement unit to monitor the volumetric

activity of radon and thoron in the air;

- using an autonomous blower and sampling devices to take samples and measure the radon content in water samples, the radon content in soil air samples, measure the SPR from the soil surface.

A single-board PC-computer as a part of the radiometer allows:

- set different measurement modes;
- to process the results;
- test the operating modes of the radiometer units;
- present measurement results;
- store them in a convenient form;
- dump information to flash memory, over a network or to a personal computer via a USB port;

Fig. 4. Radiometer Alpharad PLUS

The radiometer has a high-resolution touchscreen display, which allows data to be displayed on the screen in the form of graphs; it can be used in the field, since the radiometer is powered from an autonomous power supply of increased capacity.

1.2.5 RGA-06P - Radon and Thoron Radiometer

Radiometer RGA-06P provides:

- measurement of instantaneous volumetric activity of radon in atmospheric air;
- measuring the equivalent equilibrium volumetric activity of radon in air;
- integral measurements;

RADIOMETER RGA-06P has additional functions:

- measurement of radon emission from soil and water;
- measurement of radon concentration in wells;
- measurement of the concentration of thoron in the air.

1.3 Registration of radon in water.

Separately, mention should be made of the method of registration of radon VA in water. Since direct measurements, due to the nature of the environment, are usually difficult, they resort to other methods. The selected water sample is placed in a sealed container and then aerated in a closed volume, into which the radon monitor is turned on. The air in the circuit displaces the gas dissolved in the water, and after a while an equilibrium state of radon concentration in air and water is established in the system.

After that, it is easy to calculate the initial concentration of radon in a water sample by measuring the concentration of radon in the system and knowing the volumes of water and air.

1.4 Geological emanation survey

Emanation survey is a field radiometric method based on the study of the spatial distribution of concentrations of free emanation of radioactive free emanation of radioactive gases radon and thoron in the near-surface layer of soils. $Rn^{222}Tn^{220}$

Emanation survey is carried out in order to trace the zones of tectonic disturbances hidden under the sediments, to predict the development of landslide processes, to identify areas of development of deformations of the earth's surface during the formation of a displacement trough above the worked-out mine workings.

A prerequisite for the use of emanation survey in the complex of engineering and geophysical exploration methods during engineering and technical surveys in undermined territories is the emergence of zones of the stress-strain state of the rock mass as a result of mining operations in it.

The local stress-strain state leads to the emergence of acoustic, magnetic, electrical and some other physical phenomena in the massif, leading to a sharp increase in the natural pulsed electromagnetic field of the Earth and the emanating ability of radioactive gases with a clarke content of radioactive elements in the rock mass.

It is believed that the anomalies of radioactive gases near the earth's surface are due to their diffusion from the rock mass along cracks that have arisen as a result of tectonic activity and anthropogenic impact. However, the range of radon and, especially, thoron in the massif is insignificant, for radon it is calculated in the first meters, and for thoron - in centimeters.

It should also be taken into account that radon and thoron are readily soluble in water, therefore, with a high level of groundwater occurrence, the penetration of these gases to the earth's surface is somewhat problematic.

As a result of theoretical studies and carried out in significant quantities of experimental and methodological work, the authors adopted a working hypothesis that radon and thoron are emitted directly in the near-surface layer of soils as a result of an increase in their emanating ability under the influence of acoustic, magnetic, electrical and other physical phenomena.

It should be noted that the rock mass is sensitive to even relatively weak technogenic loads, especially dynamic ones. At relatively weak vibration loads, we have repeatedly noted an increase in the concentration of radioactive gases in soil air samples by 3–5 times, after removing the dynamic loads, the concentration of radioactive gases gradually relaxes and returns to the initial level in 15–25 minutes.

In the practice of engineering and technical surveys in the undermined territories of Donbass for the purposes of construction design, emanation survey began to be widely introduced in 1975. At the first stage of the introduction of emanation survey into the practice of surveys, the main goal was to obtain additional information about the tectonic structure of built-up and built-up areas.

However, in the process of theoretical and practical research, the broad possibilities of this method were revealed, especially after integration with other geological and geophysical exploration methods.

In combination with other geophysical methods by nature, it became possible to apply emanation surveying to identify voids and hovering in the geological section associated with natural and man-made causes (karst, old mine workings), the method was successfully applied in the study of landslide slopes of natural and artificial origin, etc. .d.

1.5 Chapter Conclusions

As a result of the work in this section, scientific articles and studies on the topic of the thesis work were studied.

2. MODELS OF RADON TRANSFER IN GEOLOGICAL ENVIRONMENTS

2.1 Diffusion transport model

The relevance of radon topics in various fields of science and practice continues to grow. The issues related to the identification and description of the processes and mechanisms of radon transfer in various environments, factors that determine the temporal and spatial dynamics of the radon field are still not fully understood. This contributes to the active development of methods for mathematical modeling of the transport of radon and its daughter decay products in various media. Based on the models, predictive estimates are made that find their application in various fields, for example, in construction to introduce amendments to existing norms and rules, in geological prospecting when searching for uranium-containing ores, in radioecology when assessing the radon hazard of territories and buildings, in geophysics when studying lithosphere-atmospheric connections, search for earthquake indication.

To model the transfer of radon, a diffusion-advective (diffusion-convective) model is widely used, which has a simple analytical solution in some special cases, under many restrictions and assumptions (stationary case, homogeneous medium, etc.). The term "advection", which is actively used abroad, was introduced to denote the movement of radon under the influence of external forces, mainly the pressure gradient, and also including the processes of convection, filtration and others that occur in the situation under consideration, except for molecular diffusion. In Russia, the authors of the works introduced the conditional term "convection" to denote the movement of radon under the influence of the same external influences, which for some time took root in Russia and abroad among scientists dealing with radon, and continues to be used now. However, in order to avoid confusion in the radon transfer processes implied by the conventional term "convection", this work uses the term "advection" [].

Modeling the transport of radon in geological environments that are as close as possible in their description to real ones is a difficult task, since the geological environment is heterogeneous, layered with noticeably different physical and geological characteristics. When considering inhomogeneous media, especially when the coefficients of the transport equation are functions rather than constants, an analytical solution is impossible.

Quite often, when modeling, only one process of radon transfer is considered - diffusion.

In [10], it is argued that it is sufficient to use a diffusion model to simulate radon transfer processes in soils, arguing that 75% of the calculated values of the radon flux density (RF) from the earth's surface coincided with the values measured by the storage chamber method.

The analysis carried out by us in the framework of the diffusion-convective model (see the diffusion-convective model) showed that at convection velocities $|\upsilon| \leq 10^{-5}$ cm/s в only the diffusion process can be taken into account in radon transport calculations. However, at high values of the convection velocity, it is necessary to take into account the convective transfer, otherwise it can lead to large errors, for example, when estimating the RFD from the earth's surface.

2.2 Diffusion-convective model of radon transport

The diffusion-convective equation of radon transport in the quasi-homogeneous approximation can be obtained by the standard method from the equation of the balance of radon particles in a small physical volume ΔV for a short time interval Δt. The equation takes into account the production of radon during the decay of radium (^{226}Ra) contained in ΔV, entry and exit as a result of diffusion and convection, as well as the decrease of radon due to radioactive decay [].As ΔV and Δt tend to zero, the equation takes the following form:

$$\frac{\partial N}{\partial t} = -div\vec{j} - \lambda N + S \qquad (2.1)$$

where *N* - the number of radon particles per unit volume of a porous medium; $\vec{j}$ - radon particle current determined by diffusion and convection; *S* - radon source function; λ - radon decay constant. The radon current in a porous medium due to diffusion is described by Fick's law with an effective diffusion coefficient $D_e = D \cdot \eta$, where *D* - diffusion coefficient in pore space, or true diffusion coefficient (diffusion in solid soil is negligible), cm^2/s; η – soil porosity, rel. units. Taking into account convection, the equation for $\vec{j}$ has the form:

$$\vec{j} = -D_e gradN + \vec{\upsilon}N \tag{2.2}$$

In this case, convection should be understood as the movement of radon in the vertical direction, due to the geothermal gradient and pressure gradient in the earth's crust, gas-lifting force in a porous medium when pores are filled with water, turbulent effects in soil air when external conditions change - barometric pressure, temperature, wind, as well as such interaction processes in the “atmosphere-land” system as heat exchange and moisture circulation. If we assume that the radon concentration changes only in the z direction (the z axis is directed downward from the earth's surface), then the transfer equation is transformed to the form:

$$\frac{1}{D_e}\frac{\partial N}{\partial t} = \frac{\partial^2 N}{\partial z^2} + \frac{\upsilon}{D_e}\frac{\partial N}{\partial z} - \frac{\lambda}{D_e}N + \frac{S}{D_e} \tag{2.3}$$

The radon source function S determines the number of radon particles resulting from the radioactive decay of radium per unit volume of the porous medium per unit time, and is called the emanation rate:

$$S = K_{em}A_{Ra}\rho_d \text{, (particles / (cm}^3\text{s))} \tag{2.4}$$

where K_{em} – emanation coefficient equal to the fraction of radon released into a free state in the pores and cracks of the soil, rel. units; A_{Ra} – specific activity of ^{226}Ra in rock (Bq/g); ρ_d – dry soil density (g/cm^3).

The experiment usually measures the pore activity of radon per unit volume of soil air:

$$A = N\lambda / \eta \text{, (Bq/cm}^3\text{)} \tag{2.5}$$

Multiplying equation (3) by λ/η, we obtain the equation for the distribution of pore activity in a layered medium:

$$\frac{1}{D_e}\frac{\partial A}{\partial t} = \frac{\partial^2 A}{\partial z^2} + \frac{\upsilon}{D_e}\frac{\partial A}{\partial z} - \frac{\lambda}{D_e}A + \frac{S\lambda}{\eta D_e} \tag{2.6}$$

The main difficulty arising in solving this equation is the choice of effective coefficients D_e, υ, K_{em}, which generally depend on coordinates and indirectly on time.

For example, the emanating ability of rocks depends on their physical state (in particular, on temperature and humidity varying over time), as well as on the material and mineral composition that changes with depth and can take values from 0.02 to 0.7. The diffusion coefficient of radon depends on the pore structure, the composition of the liquid present in the pores, the adsorption properties of rocks, moisture and temperature. The value of the diffusion coefficient in the pore substance can vary from 10^{-1} cm^2/s (the pores are completely filled with air) to ~ 10^{-6} cm^2/s (the pores are filled with water).

Especially big problems arise when determining the convection speed. This is primarily due to the fact that the authors often do not specify which physical processes are included in the diffusion and convective mechanisms; there is no substantiation of the approximations and model parameters used. For example, an approach is well known when the diffusion coefficient under convection conditions can take into account not only molecular diffusion, but also the movement of radon due to filtration.

The difficulties listed above that arise in the mathematical modeling of radon can be circumvented, bearing in mind that the main task of modeling is to identify the main regularities in the distribution of radon in porous media. Then, when solving the equation

$$\frac{1}{D_e}\frac{\partial A}{\partial t}=\frac{\partial^2 A}{\partial z^2}+\frac{\upsilon}{D_e}\frac{\partial A}{\partial z}-\frac{\lambda}{D_e}A+\frac{S\lambda}{\eta D_e} \tag{2.7}$$

it is advisable to use some obvious simplifications. First, the model parameters can be considered time independent. This assumption is good enough because, according to the recommendations of [8], measurements of pore activity are usually carried out over a fairly long time (several days) and at relatively large depths of ~ 70 cm, at which daily fluctuations in temperature and humidity are insignificant.

Then, under conditions of radioactive equilibrium, the problem of radon transport becomes stationary:

$$\frac{\partial^2 A}{\partial z^2}+\frac{\upsilon}{D_e}\frac{\partial A}{\partial z}-\frac{\lambda}{D_e}A=-\frac{K_{em}A_{Ra}\rho_d\lambda}{\eta D_e}\,. \tag{2.8}$$

Secondly, within the limits of the layer corresponding to a certain type of soil, all coefficients can be considered independent of the coordinates. In this case, equation (1.7) has an analytical solution:

$$A(z) = C_1 \exp^{(n-m)z} + C_2 \exp^{-(n+m)z} + A_\infty , \qquad (2.9)$$

where $m = \frac{\upsilon}{2D_e}$; $n = \sqrt{\left(\frac{\upsilon}{2D_e}\right)^2 + \frac{\lambda}{D_e}}$; A_∞ - пpore activity of radon in radioactive equilibrium with ^{226}Ra, equal to $A_\infty = \frac{K_{em} A_{Ra} \rho_s (1-\eta)}{\eta}$; C_1 and C_2 – integration constants, which are determined from the boundary conditions.

In equation (1.8), the density of dry soil ρ_d expressed in terms of the density of solid soil particles ρ_s and porosity η as $\rho_d = \rho_s(1-\eta)$. For a semi-infinite emanating layer (the z axis is directed downward from the day surface), the boundary conditions have the form:

$$A(0) = 0; \qquad (2.10)$$

$$A(\infty) = \frac{K_{em} A_{Ra} \rho_s (1-\eta)}{\eta} = A_\infty . \qquad (2.11)$$

Condition (1.9) reflects the free release of emanation into the atmosphere, where the radon concentration is lower than in soil air by about three orders of magnitude. Condition (1.10) means that at an infinitely great depth the pore activity of radon reach its equilibrium value A_∞, when ^{222}Rn is in radioactive equilibrium with ^{226}Ra. Taking into account the boundary conditions (1.9) and (1.10), formula (1.8) for pore activity takes the form:

$$A(z) = A_\infty \left(1 - \exp^{-Yz}\right), \qquad (2.12)$$

где $Y = \sqrt{\left(\frac{\upsilon}{2D_e}\right)^2 + \frac{\lambda}{D_e}} + \frac{\upsilon}{2D_e}$.

The radon flux density at a depth z is determined by the equation:

$$q(z) = D_e \frac{\partial(\eta A(z))}{\partial z} + \upsilon\eta A(z) = \upsilon\eta A_\infty + (D_e A_\infty Y - \upsilon A_\infty)\eta \exp^{-Yz} , \qquad (2.13)$$

and the density of radon flux from the earth's surface is:

$$q(z)\big|_{z=0} = \eta D_e A_\infty Y . \qquad (2.14)$$

To elucidate the role of the convective mechanism of radon transfer in the soil, we compared the values of pore activity, calculated taking into account only molecular diffusion, with those measured in soils typical for Tomsk at a depth of 70 cm.

As mentioned above, the convective transport mechanism takes into account all physical processes (except for molecular diffusion) responsible for the movement of radon in the vertical direction. The complexity, diversity and random nature of these processes does not allow constructing a model that adequately reflects the physics of convective transport. It is not possible to measure the convection rate under natural conditions. But if the convection rate is considered as a phenomenological parameter of the model, then it can be found by comparing the calculation and experiment.

2.3 Radon transport processes in heterogeneous porous media

So far in the literature, models have been considered that take into account only one emanating soil layer. This is due to the fact that the surface layers of most populated areas are composed of sedimentary rocks such as clay, loam, sandy loam, sand, etc. thickness of 5-10 m, and the underlying rocks do not contain increased concentrations of uranium (radium).

This simplification was made on the assumption that the specific activity of ^{226}Ra in the underlying uranium-bearing rocks is several orders of magnitude higher than in sedimentary rocks, which often compose the surface layer.

However, in radioecology and geophysics, there are a number of problems, when solving which it is necessary to take into account the presence of two emanating soil layers with noticeably different characteristics.

2.4 Diffusion-convective model of radon transport with two emanating layers

The solution to equation (1.7) for two emanating soil layers, when the characteristics of each layer are constant, has the form:

$$A_1(z) = C_1 \exp^{(n_1 - m_1)z} + C_2 \exp^{-(n_1 + m_1)z} + A_{1\infty}, \qquad (2.15)$$

$$A_2(z) = C_3 \exp^{(n_2 - m_2)z} + C_4 \exp^{-(n_2 + m_2)z} + A_{2\infty}, \qquad (2.16)$$

where $m = \frac{\upsilon}{2D_e}$; $n = \sqrt{\left(\frac{\upsilon}{2D_e}\right)^2 + \frac{\lambda}{D_e}}$; A_∞ - pore activity of radon in radioactive equilibrium with ^{226}Ra, equal to $A_\infty = \frac{K_{em} A_{Ra} \rho_s (1-\eta)}{\eta}$; index 1 corresponds to the surface layer, and index 2 - to the next layer.

Consider the case when the thickness of the second layer is infinite. Then C_3=0 and the boundary conditions for pore activity have the form:

$$A_1(0) = 0, \quad A_2(\infty) = \frac{K_{em2} A_{Ra2} \rho_{s2} (1-\eta_2)}{\eta_2} = A_{2\infty}, \qquad (2.17)$$

Integration constants C_1, C_2, C_4 are found using the boundary conditions (2.18), the conditions for the continuity of volume activities and their derivatives at the interface between two media (at $z = h$):

$$\eta_1 A_1(h) = \eta_2 A_2(h)\,,$$

$$D_{e1}\frac{\partial(\eta_1 A_1(z))}{\partial z} + \upsilon\eta_1 A_1(z) = D_{e2}\frac{\partial(\eta_2 A_2(z))}{\partial z} + \upsilon\eta_2 A_2(z) \text{ при } z = h\,; \qquad (2.19)$$

The distribution of pore activity of radon in layers (1) and (2) in the case of a two-layer model is described by the following formulas:

$$A_1(z) = A_{1\infty}(1 - \exp^{-(n_1+m_1)z}) + \frac{N}{\eta_1}\sinh(n_1 z)\exp^{m_1(h-z)}, \text{ at } 0 < z \le h\,, \qquad (2.20)$$

$$A_2(z) = A_{2\infty} + \left[\frac{N}{\eta_2}(Km_1\sinh(n_1 h) - Kn_1\cosh(n_1 h)) - M\right]\exp^{(n_2+m_2)(h-z)}, \text{ at } z \ge h\,, \qquad (2.21)$$

where $K = \dfrac{D_{e1}}{D_{e2}(n_2 + m_2)}$; $N = \dfrac{\eta_2 A_{2\infty} + \eta_1 A_{1\infty}\{(1 - K(n_1 + m_1))\exp^{-(n_1+m_1)h} - 1\}}{(1 - Km_1)\sinh(n_1 h) + Kn_1\cosh(n_1 h)}$;

$M = A_{1\infty}K(n_1 + m_1)\exp^{-(n_1+m_1)h}$.

The density of radon flux from the earth's surface, according to formula (2.12), is determined by the following expression:

$$q(z)\big|_{z=0} = D_{e1}A_{1\infty}\eta_1(n_1 + m_1) + D_{e1}n_1 N\exp^{m_1 h}. \quad (1.22)$$

The first terms of equations (1.20, 1.22) describe the pore activity of radon and RFD in the case of one emanating layer (formulas (1.11) and (1.13)), and the second ones determine the influence of the second emanating layer.

3. RESULTS OF MODELING THE CONDITIONS OF THE INFLUENCE OF SOILS WITH INCREASED URANIUM CONTENT ON THE RESULTS OF MEASURING THE VOLUME ACTIVITY OF RADON IN SOIL AIR

This chapter will present the results of modeling the transport of radon in multilayer geological environments with different parameters of advection rate and soil porosity in the Wolfram Mathematica software environment. It will briefly describe how the volumetric activity of radon in the soil air changes at different depths, as well as how the density of the radon flux from the soil surface changes from various parameters of the multilayer medium.

3.1 Numerical modeling of the influence of the content of Ra226 on the distribution of radon in the soil

Below are the graphs of the OA activity of radon with the thickness of the first layer 1, 3, 5, 7 m and the activity of the second layer 20 Bq/kg.

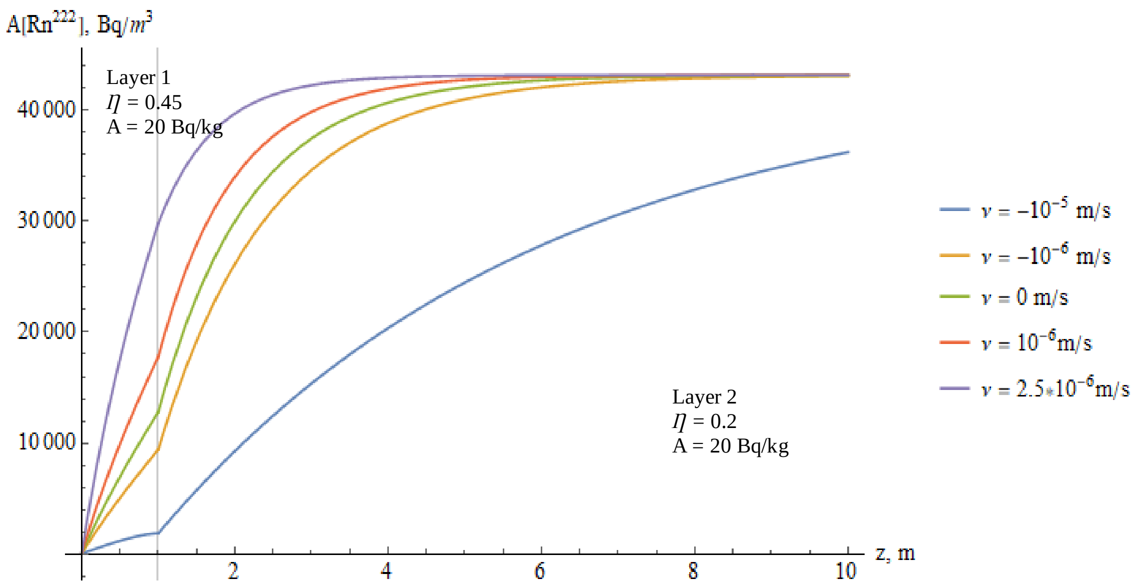

Fig. 3.1 The graph of the distribution of the volumetric activity of Rn^{222} with a thickness of the first layer of 1m.

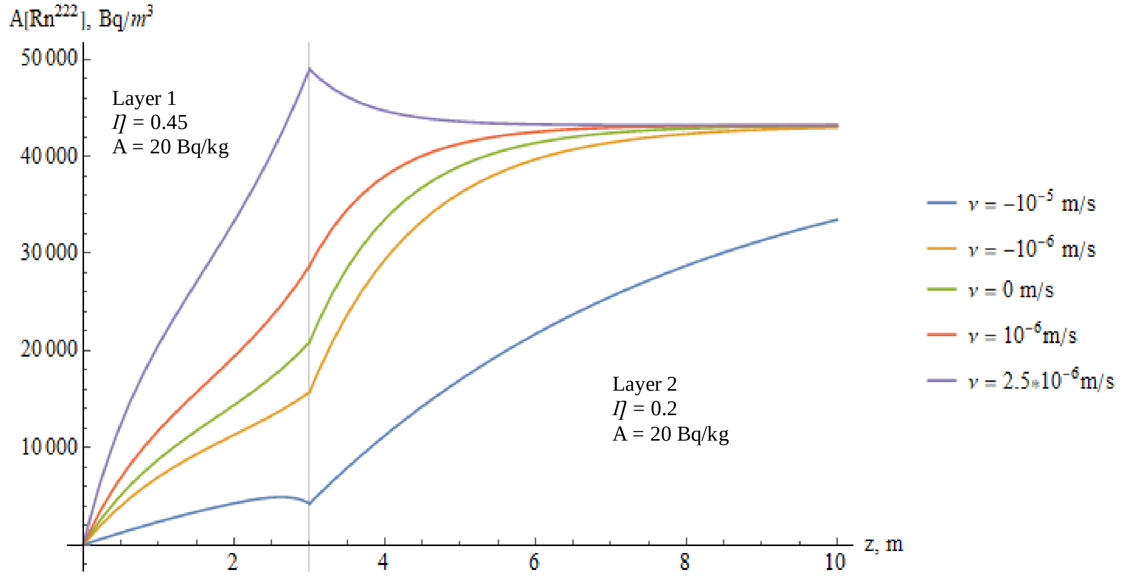

Рис. 3. 2 The graph of the distribution of the volumetric activity of Rn^{222} with a thickness of the first layer of 3m.

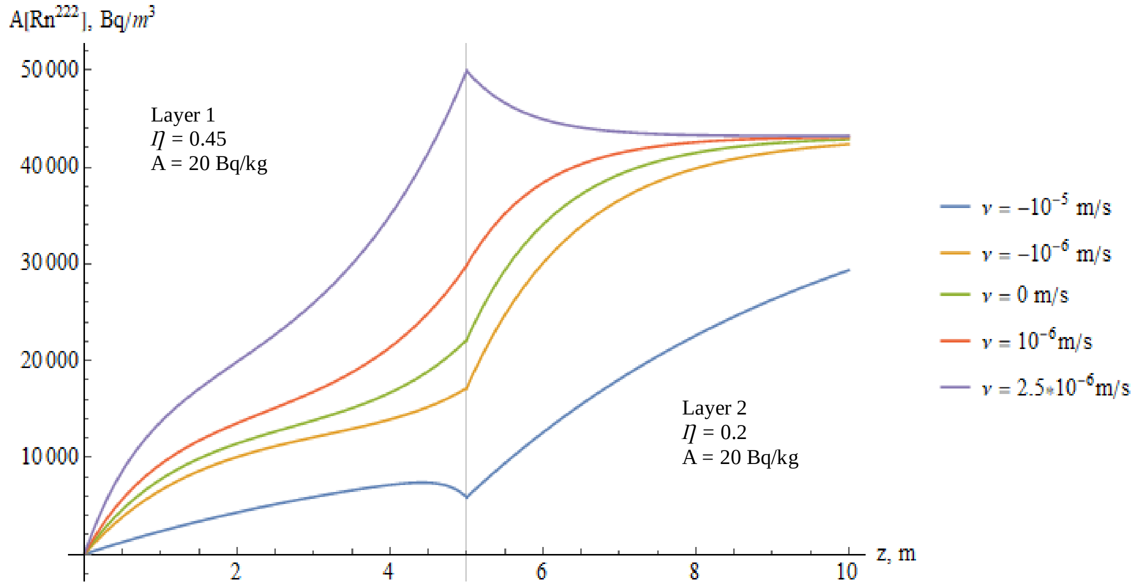

Рис. 3. 3 The graph of the distribution of the volumetric activity of Rn^{222} with a thickness of the first layer of 5 m.

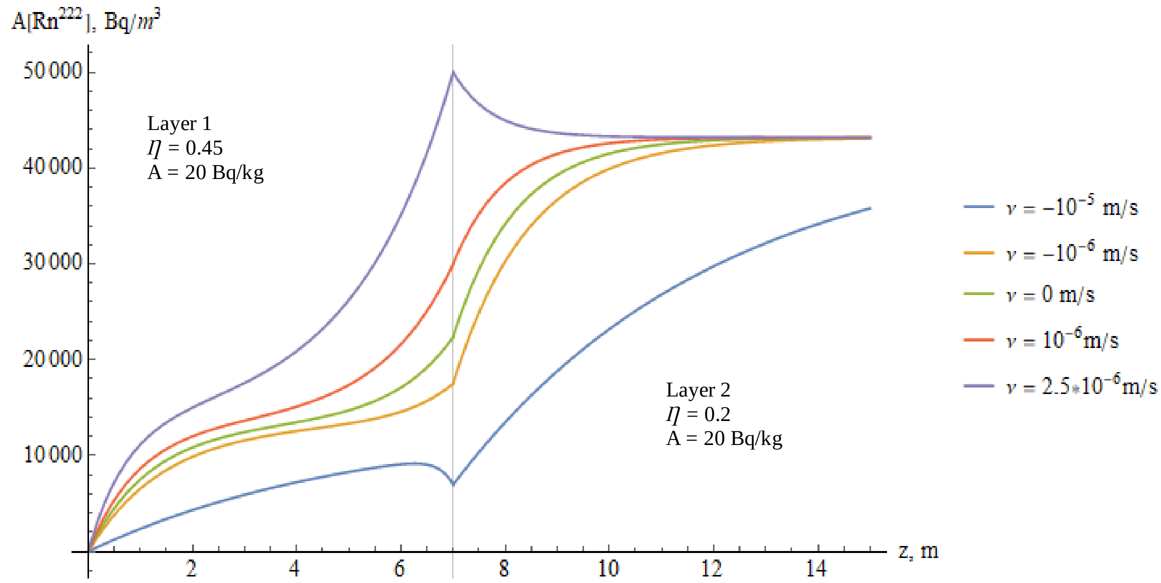

Fig. 3.4 The graph of the distribution of the volumetric activity of Rn^{222} with a thickness of the first layer of 7 m.

As can be seen from the figures 3.4 – 3.5, at the interfaces between the two layers, the radon VA distribution line undergoes a break, which is most pronounced at extreme cases of advection rates. Such fractures were not observed at the same porosity parameters.

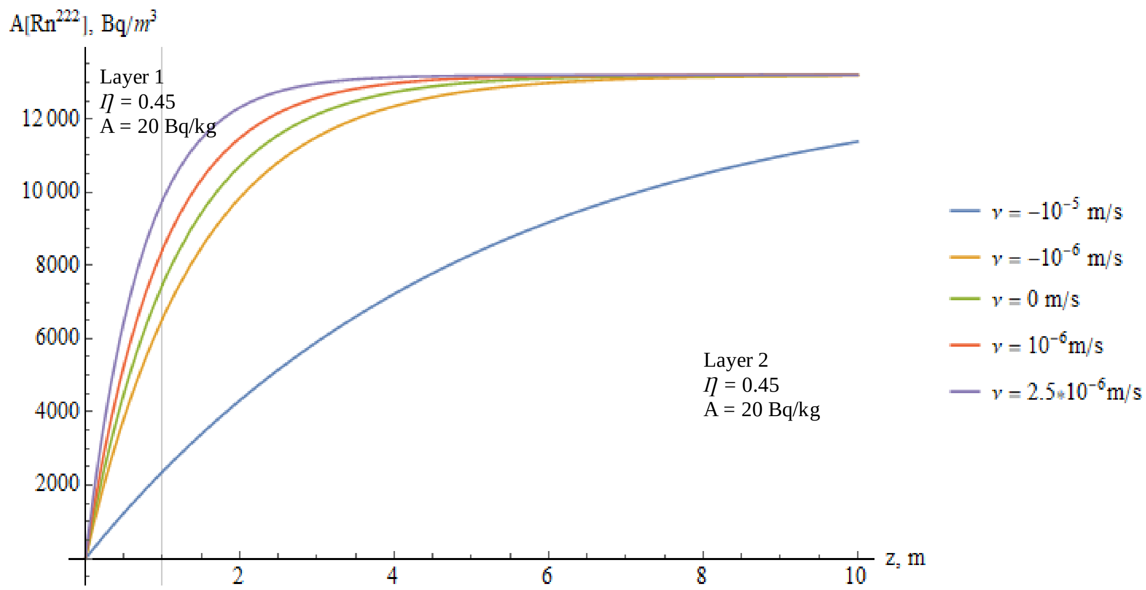

Fig. 3.5 The graph of the distribution of the volumetric activity of Rn222 with a thickness of the first layer of 1 m and the same porosity

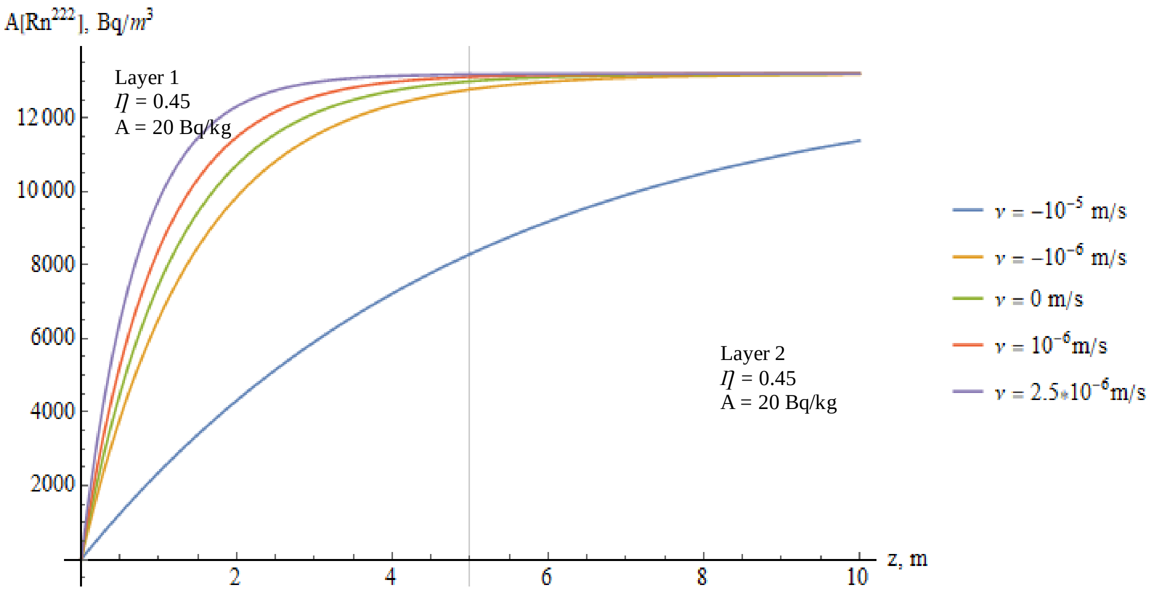

Fig. 3.6 The graph of the distribution of the volumetric activity of Rn^{222} with a thickness of the first layer of 1 m and the same porosity

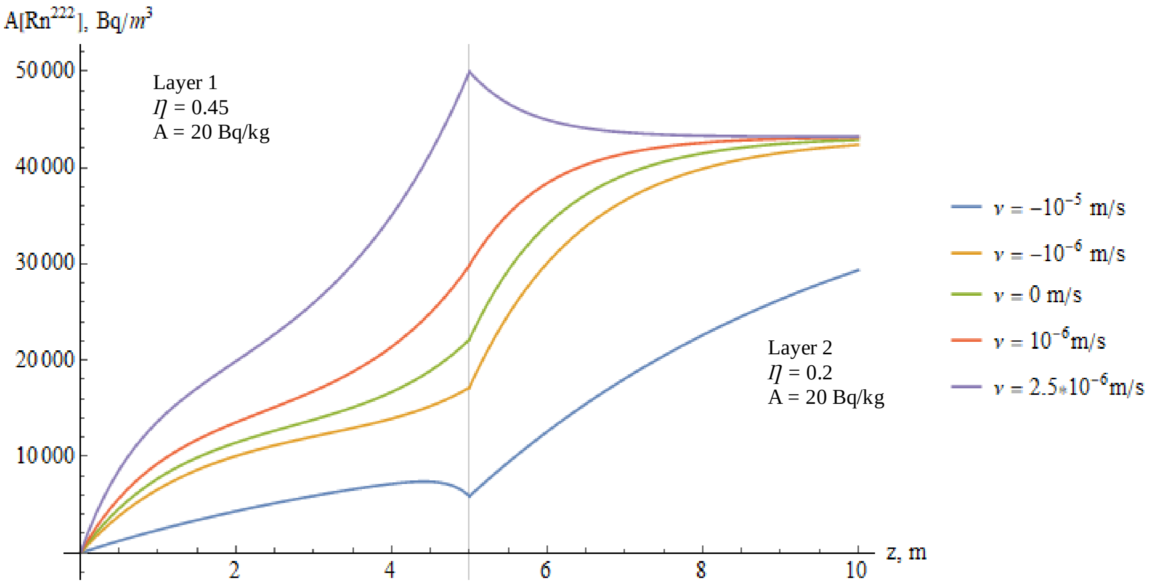

Fig. 3.7 The graph of the distribution of the volumetric activity of Rn^{222} with a thickness of the first layer of 1 m and the same porosity

Arom the figures 3.5 – 3.7 it can be seen that with the same characteristics of a multilayer soil system, it is the difference in porosity that gives breaks in the lines of volumetric activity at the interfaces between the two media.

3.2 Influence of advection rate on radon transport in multilayer media

Below are the graphs of the OA activity of radon with a thickness of the first layer of 1, 3, 5, 7 m. and an increased specific activity of the second layer of 1000 Bq/kg.

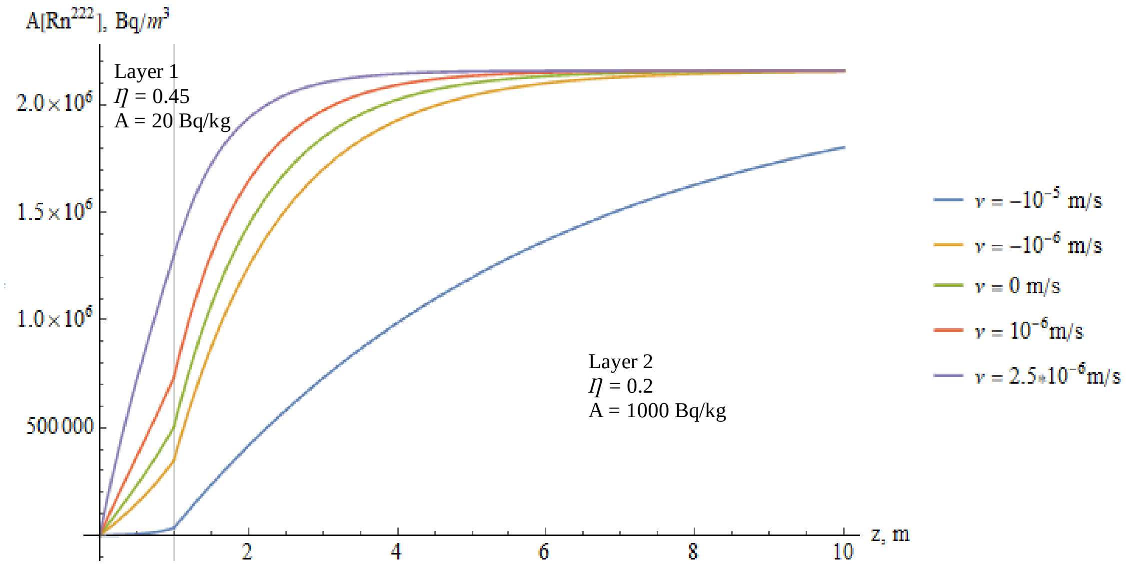

Fig. 3.8 The graph of the distribution of the volumetric activity of radon with a thickness of the first layer of 1 m and an increased specific activity of the second layer

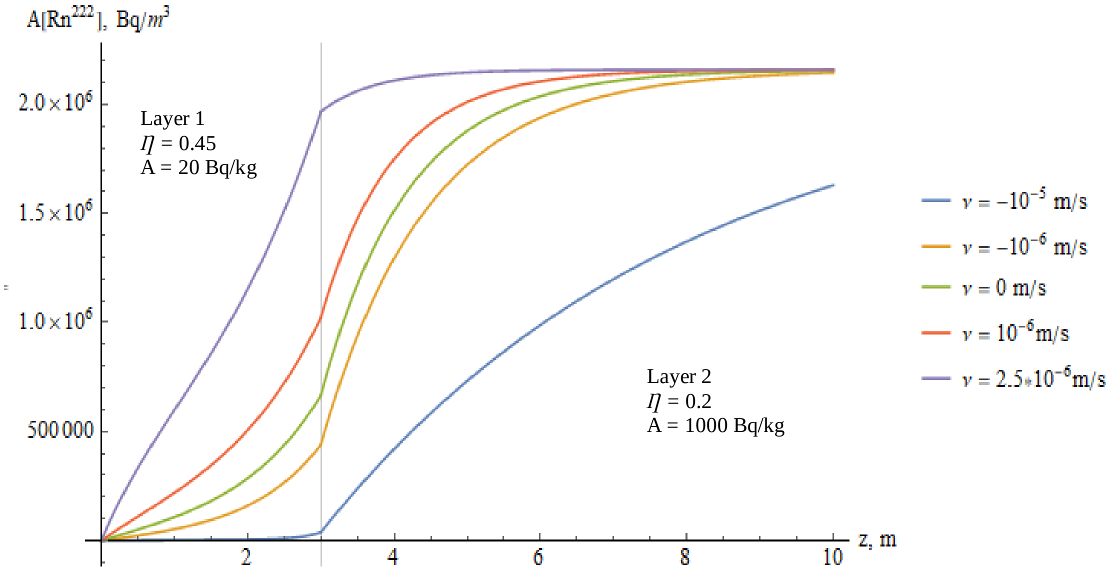

Fig. 3.9 The graph of the distribution of the volumetric activity of radon with a thickness of the first layer of 3 m and an increased specific activity of the second layer

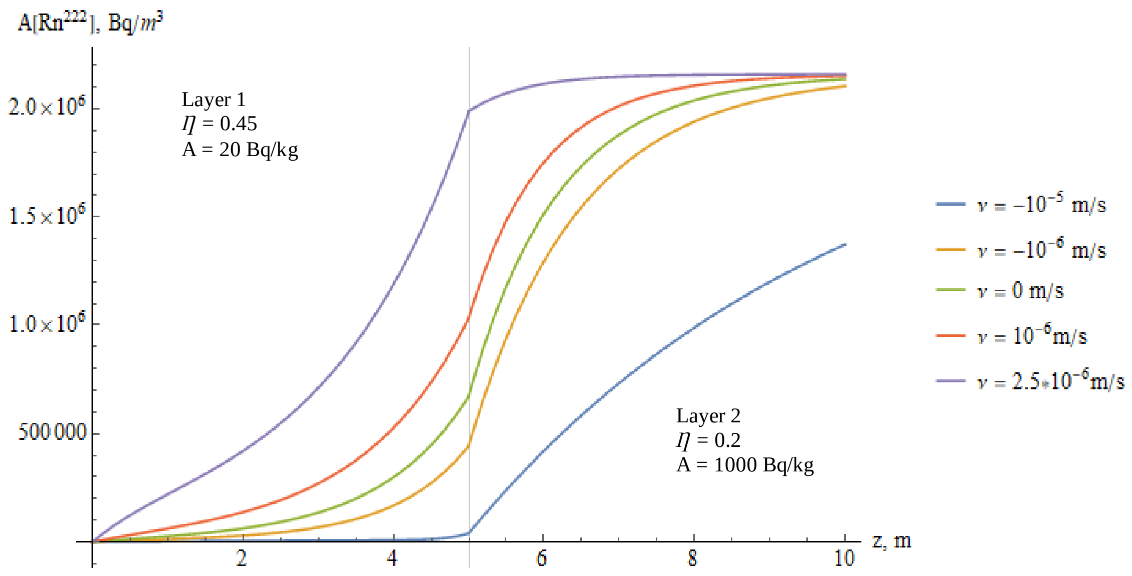

Fig. 3. 10 The graph of the distribution of the volumetric activity of radon with a thickness of the first layer of 5 m and an increased specific activity of the second layer

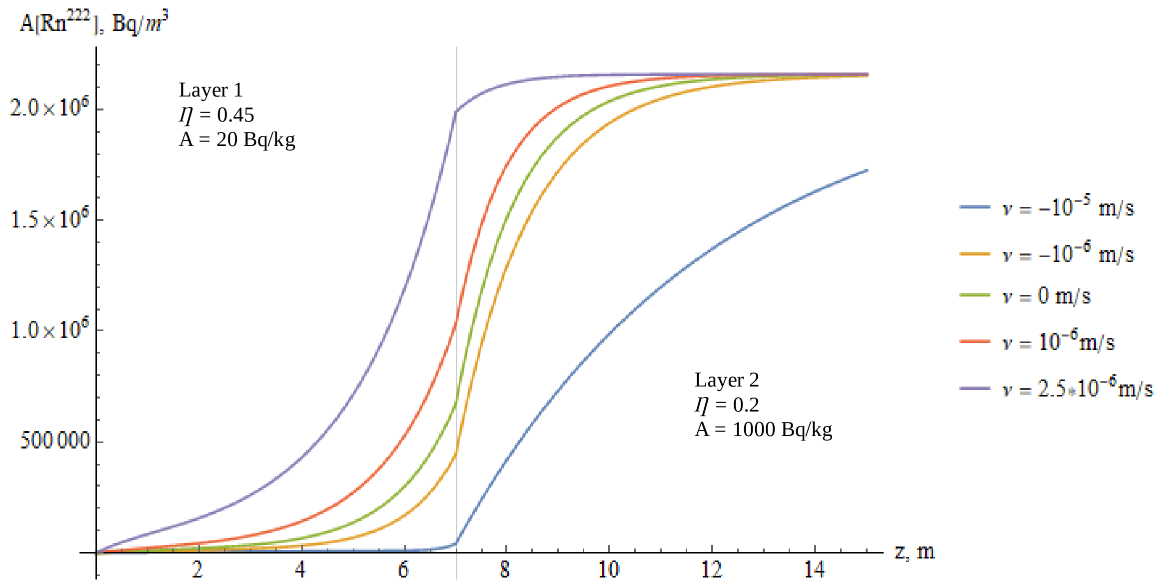

Fig. 3.11 The graph of the distribution of the volumetric activity of radon with a thickness of the first layer of 7 m and an increased specific activity of the second layer

3.3 Numerical modeling of flux density from the soil surface

This section presents the results of modeling the density of radon flux from the soil surface, as well as the activity of the surface layer. The calculations were made in such a way that the obtained values of the volumetric activity exactly at the depth of the surface layer 1 m from the surface, the flux density, in turn, at the very surface of the first layer.

Table 3.1 - Volumetric activity of radon

Volumetric activity of radon at depth 1 m., Bq/ m^3	**Advection speed m/s**				
	-10^{-5}	-10^{-6}	0	10^{-6}	$2.5 * 10^{-5}$
Volumetric activity of radon (h=1)	**35364**	**351376**	**506317**	**737536**	**1305629**
Volumetric activity of radon (h=3)	**2400**	**52504**	**107847**	**219276**	**598697**
Volumetric activity of radon (h=5)	**2373**	**12539**	**26368**	**62126**	**220197**
Volumetric activity of radon (h=7)	**2373**	**921.5**	**7334**	**11026**	**22045**
Volumetric activity of radon (h=9)	**2373**	**921.5**	**8147**	**11886**	**36285**

Table 3.2 - Radon flux density

1st layer radon flux density, mBq/m^2	**Advection speed м/s**				
	-10^{-5}	-10^{-6}	0	10^{-6}	$2.5 * 10^{-5}$
Radon flux density (h=1)	**8.5**	**362.5**	**615.7**	**1051.04**	**2327.4**
Radon flux density (h=3)	**3.5**	**58.5**	**135.8**	**316.9**	**1080.8**
Radon flux density (h=5)	**3.5**	**18.3**	**37.7**	**94.2**	**398.1**

3.4 Chapter Conclusion

Figure 3.1 illustrates how radon VA changes in a two-layer medium with a low specific activity A = 20 Bq/kg. We can say that OA increases with increasing depth until it reaches a certain saturation value. Moreover, with a positive advection rate, saturation occurs earlier.

Analyzing the results presented in Table 1, it can be noted that with an increase in the thickness of the 1st layer, the effect of radium activity in the 2nd layer on the volumetric activity of the first decreases, this is clearly noticeable by a decrease in the flux density and OA, especially at zero advection rate, that is with a natural release of radon.

It is also seen that with an increase in the advection rate, the volumetric activity at a meter depth also increases for all values of the surface layer depth.

The same picture is observed for the radon flux density, with an increase in the thickness of the first layer, the effect of the second layer with a high radium content decreases with an increase in the thickness of the first layer. With an increase in the advection rate, the radon flux density near the surface increases.

This behavior of the flux density and volumetric activity of radon is explained by the fact that at positive values of the advection rate, the advective flux is directed to the earth's surface and is added to the diffusion flux, increasing the total flux of radioactive gases into the atmosphere. At negative values of the advection rate, the advective flow is directed deep into the earth's surface, reducing the total flow of gases into the atmosphere.

It is also worth noting that at a certain value of the depth of the surface layer, the second layer with an increased content of radium ceases to manifest itself in the second layer.

4. FINANCIAL MANAGEMENT, RESOURCE EFFICIENCY AND RESOURCE SAVING

One of the most essential features in any research work is financial management. For every project or research to be started and completed successfully, one has to have a fair knowledge about financial management. Financial management can basically be defined as the process of organizing, directing, controlling, monitoring and strategic planning of financial resources of an institute or an organization, in order to achieve a set of goals and objectives. Application of management principles to financial resources of the institute or organisation plays a very vital part in financial management. Finance or money plays an essential role when it comes to the management of a business because it is needed in order to meet the requirements of the economic world and in addition, every business requires money in order to survive. No matter how small or big a business is, money needs to be put into it so as to keep it running, achieve a set of goals and gain more profit. The main aim of every businessman is to gain lots of profit, no one wants to do a business that would fail or would not generate profits hence to achieve this, one has to manage his or her finance properly.

The purpose of this section "Financial Management, Resource Efficiency and Resource Saving" 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.

In addition, it would help determine the accomplishment of the research work so as to develop a mechanism for managing and supporting specific project solutions at the implementation stage of the project lifecycle to increase productivity. The financial management solves the following objectives:

- Planning and preparation of research work.
- Budget calculation for research work.
- Development of evaluation of commercial potential.

4.1 Competitiveness analysis of technical solutions

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

The monitoring ad measuring of radiation level in the environment has become a very important factor in our world today and this can be achieved by using an appropriate device or equipment known as the radiation detector. Scintillation detectors are mostly used for measuring radiation outdoor and are mostly affected by environmental conditions such as temperature. Since radiation detectors are been developed most often, it is important to find the most effective and accurate method for estimating the correct algorithm for calculating dose rate under different environmental condition, especially at different temperature range, taking into consideration low cost. This algorithm must be able to calculate radiation dose rate at both low and high levels. In this work, a method with a very low cost was chosen to investigate the effect of ambient temperature on the readings of low gamma background radiation and to obtain a temperature correction factor that can be used to calculate the results of low gamma background radiation obtained from the scintillation detector. These methods include:

- The use of climatic chamber to depict the environmental conditions for different temperature range.
- The use of an inorganic scintillation detector and laptop to measure dose rate and count rate at low background gamma radiation.

- The use of excel software to analysis the results.

The scintillation detector (BDKG-03) was used because that is the radiation detector used in TPU for gamma radiation monitoring. An experiment conducted showed that the scintillation detector (BDKG-03) is the best Dosimetric method sensitive to background radiation because it had a smaller standard deviation compared to the gas discharge counter.

There are different sources of low background radiation that can be used as a source to calibrate radiation detectors that are used for monitoring in the environment. For this research, two sources can be considered:

- Gamma background radiation – P_f.
- Low radioactive source – P_i.

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

Evaluation map analysis presented in Table 1. The position of your research and competitors is evaluated for each indicator by you on a five-point scale, where 1 is the weakest position and 5 is the strongest. The weights of indicators determined by you in the amount should be 1. Analysis of competitive technical solutions is determined by the formula:

$$C = \sum W_i \cdot P_i, \qquad (4.1)$$

C - the competitiveness of research or a competitor;

Wi– criterion weight;

Pi – point of i-th criteria.

You can use the following criteria for the model of expert evaluation:

- noise immunity;
- set of terminals relay protection;
- reliability of relay protection;
- smart interface quality;
- energy efficiency;
- ease of operation;

- ability to connect to PC;
- estimated lifetime;
- safety;
- etc.

Table 4.1 Evaluation card for comparison of competitive technical solutions

Evaluation criteria ***Example***	**Criterion weight**	**Points**		**Competitiveness** Taking into account weight coefficients	
		P_{f1}	P_i	C_f	C_i
1	2	3	4	7	8
Technical criteria for evaluating resource efficiency					
1. Energy efficiency	0.1	4	3	0.4	0.3
2. Reliability	0.2	5	4	1	0.8
3. Safety	0.2	5	4	1	0.8
4. Functional capacity	0.1	5	5	0.5	0.5
Economic criteria for performance evaluation					
1. Development cost	0.1	5	4	0.5	0.4
2. Market penetration rate	0.1	3	4	0.3	0.4
3. Expected lifecycle	0.2	5	4	1	0.8
Total	**1**	**32**	**28**	**4.7**	**4.0**

The results of the competitiveness analysis shows that gamma background radiation have the highest value of competitiveness. This shows that they are the best option to choose when investigating the effect of ambient temperature on the readings of low gamma background radiation in order to obtain a temperature correction factor that can be used to calculate the results of low gamma background radiation.

4.2 SWOT analysis

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

Table 4.2 SWOT analysis

	Strengths: S1. Low cost. S2. Simplicity of method. S3. Reliability of results obtained. S4.Small relative error for both the dose rate and the count rate. S4. Very safe. S5. Very important factor for all radiation detectors.	**Weaknesses:** W1. Taking measurement and analyzing takes lots of time. W2. Difficulty in regulating the climatic chamber to get the actual temperature. W3. Need to know how to operate the detector and climatic chamber technically. W4. Software sometimes take long to open.
Opportunities: O1.Data can be used to calculate dose rate for low background radiation in BDKG -03 scintillation detector. O2. Research institute could use the method to find the influence of ambient temperature on gamma background radiation of any radiation detector used outdoor.	***Strategy which based on strengths and opportunities:*** 1. Obtained a method, which can be used to calibrate dose rate in radiation detectors.	***Strategy which based on weaknesses and opportunities:*** Regulating of climatic chamber to attain the actual temperature for measurement.

O3. Researchers can use the method can be used to estimate the algorithm for calculating dose rate under the influence of different temperature range.		
Threats: T1. Lack of financial support in purchasing of equipment. T2. Lack of demand since it is needed only after development of a radiation detector. T3. Need of a climatic chamber to depict the environmental weather conditions.	***Strategy which based on strengths and threats:*** Finding another equipment that can replace the climatic chamber to depict the environmental condition accurately.	***Strategy which based on weaknesses and threats:*** Not being able to complete project due to lack of financial support and lack of climatic chamber.

4.3 Project Initiation

The initiation process group consists of processes that are performed to define a new project or a new phase of an existing one. In the initiation processes, the initial purpose and content are determined and the initial financial resources are fixed. The internal and external stakeholders of the project who will interact and influence the overall result of the research project are determined.

4.3.1 Project Stakeholders

Table 4.3 Stakeholders of the project

Project stakeholders	**Stakeholder expectations**
Tomsk Polytechnic University (TPU)	Supervision and approval of research work came from TPU. The acquired results can be used to calculate the dose rate of low gamma background radiation in the environment when using scintillation detector (BDKG-03).
Environmental Radiation Protection Center (ERPC)	Development of a method for the stabilization of temperature in a radiation detector when there is temperature change.

Project stakeholders	Stakeholder expectations
Ghana Government	Utilization of the intellectual property, developing the scientific knowledge of the academic personnel of radiation monitoring.

4.3.2 Objectives and Outcomes of Project

Table 4.4 Purpose and results of the project

Purpose of project:	To investigate the effect of ambient temperature on the readings of low gamma background radiation and to obtain a temperature correction factor that can be used to calculate the results of dose rate for low gamma background radiation obtained from scintillation detector (BDKG-03).
Expected results of the project:	• The factory's temperature correction coefficient inside the detector (BDKG – 03) to be incorrect for low gamma background radiation. • The factory's algorithm for calculating of dose rate for low background radiation to be incorrect.
Criteria for acceptance of the project result:	Validation of results by using the obtained algorithm for calculating of dose rate to recalculate measurement obtained in Tomsk for different temperatures and getting the same values independent of the temperature range.
Requirements for the project result:	Agreement between the results of project and the results of other authors on similar works.
	Industrial application. The results would help address the stabilization of temperature correction factor in scintillation detectors.
	Technical specification: To be able to measure the correct gamma dose rate at an area, effective stabilization of detectors at any environmental condition especially change in temperature is needed so as not to cause fluctuations in results. This is obtained by following laid down procedures and standard already established for evaluation and performance of radiation detection portal monitors.

4.3.3 Project Participants

The organizational structure of the project involves all participants or people who participated in the research work, the number of hours they spent and the roles they played in the research. In this research work, there were two participants.

- Scientific supervisor
- Engineer

Table 4.5 Structure of the project

№	**Participant**	**Role in the project**	**Functions**	**Labor time, hours (working days (from table 7) × 6 hours)**
1	Scientific Supervisor – A professor and a lecture of the Nuclear Science and Technology department at TPU.	Head of project	Formulating of research topic and giving directions of how to achieve the main aim. Ensuring that all task pertaining to the main objectives are done on time. Verification of results obtained.	48×6 = 288
2	Engineer – A student of the Nuclear Science and Technology department at TPU.	Executor	Performing of task and researching of literature review. Collecting of data and analysing of results.	82×6 = 492

4.3.4 Project limitations and Assumptions

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

Table 4.6 Project limitations

Factors	**Limitations / Assumptions**
3.1. Project's budget	326530.74
3.1.1. Source of financing	TPU
3.2. Project timeline:	25/05/2020 to 25/05/2021
3.2.1. Date of approval of plan of project	25/05/2021
3.2.2. Completion date	25/05/2021

4.3.5 Project Schedule

As part of planning a science project, you need to build a project timeline and a Gantt Chart.

Table 4.7. Project Schedule

Job title	**Duration, working days**	**Start date**	**Date of completion**	**Participants**
Development of the technical task	6	1/02/2021	7/02/2021	Scientific Supervisor
Drafting and approval of terms of reference	11	7/02/2021	21/02/2021	Scientific Supervisor
Choosing of a research direction	2	21/02/2021	24/02/2021	Scientific Supervisor, Engineer
Collection and study of literature	24	24/02/2021	24/03/2021	Engineer
Choosing of experimental method	2	24/03/2021	25/03/2021	Scientific Supervisor, Engineer
Choosing of a place to conduct research	2	25/03/2021	26/03/2021	Scientific supervisor
Conducting of experiment to	3	26/08/2021	29/03/2021	Engineer

Job title	Duration, working days	Start date	Date of completion	Participants
collect data of count rate and dose rate of gamma radiation using the BDKG-03 and climatic chamber				
Analysis of results obtained	16	29/03/2021	16/04/2021	Engineer, Scientific supervisor
Summary of results	4	16/04/2021	20/04/2021	Scientific Supervisor, Engineer
Checking and assessment of results	4	20/04/2021	23/04/2021	Scientific supervisor, Engineer
Compilation of results for report	7	23/04/2021	2/04/2021	Engineer
Preparation of report	4	2/05/2021	6/05/2021	Engineer
Defence preparation	16	6/05/2021	25/05/2021	Engineer

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

Table 4.8 A Gantt chart

№	Activities	Participants	T_c, days	Duration of the project											
				February			March			April			May		
				1	2	3	1	2	3	1	2	3	1	2	3
1	Development of the technical task	Scientific Supervisor	6												

2	Drafting and approval of terms of reference	Scientific Supervisor	11
3	Choosing of a research direction	Scientific Supervisor, Engineer	2
4	Collection and study of literature	Engineer	24
5	Choosing of experimental method	Scientific Supervisor, Engineer	2
6	Choosing of a place to conduct research	Scientific supervisor	2
7	Conducting of experiment to collect data of count rate and dose rate of gamma radiation using the BDKG-03 and climatic chamber	Engineer	3
8	Analysis of results obtained	Engineer, Scientific supervisor	16
9	Summary of results	Scientific Supervisor, Engineer	4
10	Checking and assessment of results	Scientific supervisor, Engineer	4
11	Compilation of results for report	Engineer	7
12	Preparation of report	Engineer	4
13	Defence preparation	Engineer	16

Scientific Supervisor Engineer

4.4 Scientific and technical research budget

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

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

4.4.1 Calculation of material costs

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

$$C_m = (1 + k_T) \cdot \sum_{i=1}^{m} P_i \cdot N_{consi} \qquad (4.2)$$

where

m – the number of types of material resources consumed in the performance of scientific research;

N_{consi} – the amount of material resources of the i-th species planned to be used when performing scientific research (units, kg, m, m^2, etc.);

P_i – the acquisition price of a unit of the i-th type of material resources consumed (rub./units, rub./kg, rub./m, rub./m^2, etc.);

k_T – coefficient taking into account transportation costs.

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

Table 4.9 Material costs

Name	**Unit**	**Amount**	**Price per unit, rub.**	**Material costs, rub.**
Office supplies	-	1	1000	1000.00
Transportation	Unit	8	100	800.00
Printing	Unit	200	4	800.00
Total				2600.00

4.4.2 Calculation of the depreciation.

Depreciation is not charged if an equipment cost is less than 40 thousand rubles, its cost is taken into account in full.

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

$$A = \frac{C_{перв} * H_а}{100} \quad (4.3)$$

A - annual amount of depreciation;

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

$H_а = \frac{100}{T_{сл}}$ - rate of depreciation;

$T_{сл}$ - life expectancy.

For this research, a gamma radiation detector (BDKG-03), a climatic chamber and a laptop, which cost 118000 rubles, 400000 and 30000 respectively, were used. The gamma detector and the laptop both had a life expectancy of 5 years whiles that of the climatic chamber was 10 years. The depreciation for the gamma detector, climatic chamber and laptop can be calculated as follows:

Gamma detector:

$$D = \frac{\text{Cost}}{\text{Time}} \tag{4.4}$$

$$D = \frac{118000}{5 \times 365} = 64.66 \, \frac{\text{rubles}}{\text{day}} \tag{4.5}$$

Since the equipment was used for 3 days

$$A = 64.66 \times 3 = 193.97 \text{ rubles} \tag{4.6}$$

Climatic chamber:

$$D = \frac{\text{Cost}}{\text{Time}} \tag{4.7}$$

$$D = \frac{400000}{10 \times 365} = 109.589 \, \frac{\text{rubles}}{\text{day}} \tag{4.8}$$

Since the equipment was used for 3 days

$$A = 109.589 \times 3 = 328.767 \text{ rubles} \tag{4.9}$$

Table 4.10 Depreciation of special equipment (+software)

№	**equipment identification**	**Quantity of equipment**	**Total cost of equipment, rub.**	**Life expectancy, year**	**Depreciation for the duration of the project, rub.**
1.	Scintillation gamma radiation detector (BDKG-03)	1	118000	10	193.97
2.	Climatic chamber	1	400000	10	328.77
3	Laptop	1	30000	-	30000
Total					30522.74

4.4.3 Basic salary

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

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

$$S_b = S_a \cdot T_w \text{ ,} \tag{4.10}$$

where S_b – basic salary per participant;

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

S_d - the average daily salary of an participant, rub.

The average daily salary is calculated by the formula:

$$S_d = \frac{S_m \cdot M}{F_v} \text{ ,} \tag{4.11}$$

where,

S_m – monthly salary of a participant, rubles;

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

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

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

Table 4.11 The valid annual fund of working time

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

Monthly salary is calculated by formula:

$$S_{month} = S_{base} \cdot (k_{premium} + k_{bonus}) \cdot k_{reg} , \qquad (4.12)$$

where, S_{base} – base salary, rubles;

$k_{premium}$ – premium rate;

k_{bonus} – bonus rate;

k_{reg} – regional rate.

Table 4.12 Calculation of the base salaries

Performers	**S_{base}, rubles**	**$k_{premium}$**	**k_{bonus}**	**k_{reg}**	**S_{month}, rub.**	**W_d, rub.**	**T_p, work days (from table 7)**	**W_{base}, rub.**
Scientific Supervisor	40000	-	-	1,3	52000	1784.86	48	85673.28
Engineer	19870				25831	886.63	82	72703.66
Total								158376.94

4.4.4 Additional salary

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

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

$$W_{add} = k_{extra} \cdot W_{base} , \qquad (4.13)$$

where,

W_{add} – additional salary, rubles;

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

W_{base} – base salary, rubles.

Table 13. Additional Salary

Participant	**Additional Salary, rubles**
Scientific Supervisor	8567.32
Engineer	7270.37
Total	15837.69

4.4.5 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:

$$P_{social} = k_b \cdot (W_{base} + W_{add}) \tag{4.14}$$

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 4.14 Labor tax

	Project leader	**Engineer**
Coefficient of deductions	27.1%	
Salary (basic and additional), rubles	94240.60	79974.03
Labor tax, rubles	25444.96	21672.96
Total		47117.92

4.4.6 Overhead costs

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

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

Overhead is calculated according to the formula:

$$C_{ov} = k_{ov} \cdot (W_{base} + W_{add}) \quad (4.15)$$

where,

k_{ov} – overhead rate.

Table 4.15 Overhead

	Project leader	**Engineer**
Overhead rate	40%	
Salary, rubles	94240.60	79974.03
Overhead, rubles	37696.24	31989.61
Total		69685.85

4.4.7 Other direct costs

Energy costs for equipment are calculated by the formula:

$$C = P_{el} \cdot P \cdot F_{eq}, \quad (4.16)$$

where,

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

P – power of equipment, kW;

F_{eq} – equipment usage time, hours.

Table 4.16 Other direct costs

	Power rates, kWh	**Power of equipment, kW**	**Equipment usage time, hr**	**Energy cost, rubles**
Climatic chamber	5.8	0.5	24	69.60
Laptop	5.8	0.5	492	1426.80
Gamma radiation detector (BDKG-03)	5.8	0.5	24	69.60
Total				1566.00

4.4.8 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 4.17.

Table 4.17 Items expenses grouping

Name	**Cost, rubles**
1. Material costs	2600.00
2. Equipment costs	30522.74
3. Basic salary	158376.94
4. Additional salary	15837.69
5. Labor tax	47117.92
6. Overhead	69685.85
7. Other direct costs	1566.00
Total planned costs	**325707.14**

4.5 Evaluation of the comparative effectiveness of the project

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

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

The integral financial measure of development is defined as:

$$I_f^d = \frac{C_i}{C_{max}} \qquad (4.17)$$

where,

I_f^d – integral financial measure of development;

C_i – the cost of the i-th version;

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

As an analogue, the method of temperature stabilization of a radiation detector is done by placing the detector in the climatic chamber and measuring the dose rate and count rate of a gamma ray source.

The integral financial measure of development can be calculated as:

$$I^d{}_f = \frac{C_i}{C_{max}} \tag{4.18}$$

where,

C_i – the cost of the research work using gamma background radiation = 325707.14

And C_{max} – the maximum cost of execution of research project using a gamma radioactive source = 400,000.00

$$I^d{}_f = \frac{325707.14}{400000.00} \tag{4.19}$$

$$I^d{}_f = 0.814 \tag{4.20}$$

and

$$I^a{}_f = \frac{C_i}{C_{max}} \tag{4.21}$$

$$I^a{}_f = \frac{400000.00}{400000.00} \tag{4.22}$$

$$I^a{}_f = 1 \tag{4.23}$$

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_f^d = 1.

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

$$I_m^a = \sum_{i=1}^{n} a_i b_i^a \qquad I_m^p = \sum_{i=1}^{n} a_i b_i^p \tag{4.24}$$

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 4.18.

Table 4.18 – Evaluation of the performance of the project

Criteria	**Weight criterion**	**Points**	
		I_m^a	I_m^p
1. Energy efficiency	0.2	5	3
2. Reliability	0.1	4	4
3. Safety	0.2	5	5
4. Functional capacity	0.1	4	4
Economic criteria for performance evaluation			
1. The cost of development	0.1	4	4
2. Market penetration rate	0.1	5	5
3. Expected life	0.1	4	4
4. After-sales service	0.1	4	5
Total	**1**	**4.5**	**4.2**

$$I^a{}_m = \sum_{i=1}^{n} a_i b_i^a \qquad (4.25)$$

$$I^{a}{}_{m} = (0.2 \times 5) + (0.1 \times 4) + (0.2 \times 5) + (0.1 \times 4) + (0.1 \times 4) + (0.1 \times 5) + (0.1 \times 4) + (0.1 \times 4) \quad (4.26)$$

$$I^{a}{}_{m} = 4.5 \quad (4.27)$$

$$I^{p}{}_{m} = \sum_{i=1}^{n} a_i b_i^a \quad (4.28)$$

$$I^{p}{}_{m} = (0.2 \times 3) + (0.1 \times 4) + (0.2 \times 5) + (0.1 \times 4) + (0.1 \times 4) + (0.1 \times 5) + (0.1 \times 4) + (0.1 \times 5) \quad (4.29)$$

$$I^{p}{}_{m} = 4.2 \quad (4.30)$$

The integral indicator of the development efficiency (I_e^P) is determined on the basis of the integral indicator of resource efficiency and the integral financial indicator using the formula:

$$I_e^P = \frac{I_m^P}{I_f^d} \quad (4.31)$$

$$I_e^a = \frac{I_m^a}{I_f^a} \quad (4.32)$$

$$I_e^P = \frac{I_m^P}{I_f^d} = \frac{4.5}{0.877} = 5.13 \quad (4.33)$$

$$I_e^a = \frac{I_m^a}{I_f^a} = \frac{4.2}{1} = 4.2 \quad (4.34)$$

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

$$E_C = \frac{I_e^P}{I_e^a} \quad (4.35)$$

$$E_c = \frac{5.13}{4.2} = 1.221 \quad (4.36)$$

Thus, the effectiveness of the development is presented in table 4.19.

Table 4.19 Efficiency of development

№	Indicators	Points	
		P	a
1	Integral financial measure of development	0.814	1
2	Integral indicator of resource efficiency of development	4.5	4.2
3	Integral indicator of the development efficiency	1.221	1

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

4.6 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 include:

- 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.

5. SOCIAL RESPONSIBILITY

5.1 Section introduction

Currently, one of the main directions for improving preventive work to reduce industrial injuries and occupational morbidity is the introduction of an occupational safety management system.

Labor protection is a system of legislative, socio-economic, organizational, technological, hygienic and treatment-and-prophylactic measures and means that ensure safety, preservation of human health and performance in the labor process.

A hazardous production factor is a production factor, the impact of which, under certain conditions, leads to injury or other sudden, sharp deterioration in health.

A harmful production factor is a production factor, the impact of which on the worker, under certain conditions, leads to illness or reduced disability.

The purpose of this section of the work is to develop and analyze industrial safety issues in room 123 of the TPU building 10.

5.2. Legal and organizational security issue

5.2.1. Organizational activities

Allowed to work are persons who have reached 18 years of age, of both sexes, who have passed a preliminary and periodic medical examination, introductory instruction, initial instruction at the workplace, a course of training in safe working methods, an internship for at least 2 shifts and a test of knowledge of labor protection requirements, instructed for 1 group on electrical safety and those who know this instruction. The frequency of re-instruction is at least once every 6 months.

All types of briefings must be documented in the Briefing Register of the established form, with the obligatory signatures of the person receiving and conducting the briefing, indicating the date of the briefing, the name and numbers of the briefing, the name and numbers of the instructions for the types of work for which the briefing is being conducted.

5.2.2. Technical activities

The document establishing the most general requirements for the organization of the workplace when performing work while sitting is GOST 12.2.032-78. According to this document, a workplace for performing work while sitting is organized with light work that does not require free movement of the worker. The design of the workplace and the relative arrangement of all its elements (seat, controls, information display facilities, etc.) must comply with anthropometric, physiological and psychological requirements, as well as the nature of the work. So, for example, the performance of labor operations "often" and "very often" must be ensured within the zone of easy reach and the optimal zone of the motor field.

When choosing a desk, the following requirements should be taken into account. The height of the working surface of the table is recommended within the range of 680 - 800 mm. The height of the working surface on which the keyboard is installed must be 650 mm. The work table must be at least 700 mm wide and

length not less than 1400 mm. There must be legroom at least 600 mm high, at least 500 mm wide, at least 450 mm deep at the knees and at least 650 mm at the extended legs.

The height of the work chair seat above the floor level is 420 - 550 mm. The work chair should be. The design of the working chair should provide: width and depth of the seat surface not less than 400 mm; seat surface with recessed front edge. The monitor should be positioned at eye level of the operator at a distance of 500 - 600 mm.

It should be possible to adjust the screen:

- in height +3 cm;
- tilt from 10 to 20 degrees relative to the vertical;
- in the left and right directions.

The keyboard should be placed on the table surface at a distance of 100-300 mm from the edge. The normal position of the keyboard is to place it at the level of the operator's elbow with an angle of inclination to the horizontal plane of 15 degrees. It is more convenient to work with keys that have a concave surface, a rectangular shape with rounded corners. The key design should provide the operator with a clickable feel. The color of the keys should contrast with the color of the panel.

With monotonous mental work that requires significant nervous tension and great concentration, it is recommended to choose dull, low-contrast floral shades that do not scatter attention (low-saturated shades of cold green or blue colors). For work that requires intense mental or physical stress, warm shades are recommended that stimulate human activity.

5.3 Occupational safety

5.3.1 Analysis of harmful and dangerous factors

Calculations are carried out at the workplace using a personal computer. The identified hazardous and harmful factors are shown in Table 5.1.

Table 5.1 - Possible harmful and dangerous factors

5.3.2. Microclimate

In accordance with SanPiN 1.2.3685-21, hygienic requirements are established for the microclimate indicators of workplaces in industrial premises, taking into account the intensity of energy consumption of workers, the time of work and periods of the year. The indicators characterizing the microclimate of the room are:

- air temperature;
- surface temperature;
- relative humidity;
- air speed;
- the intensity of thermal radiation.

These indicators of the microclimate should ensure the preservation of the thermal balance of a person with the environment and the maintenance of the optimal or permissible level of the thermal state of the body. Optimal and permissible microclimate parameters are presented in tables 5.2, 5.3.

Table 5.1 - Optimal values of microclimate indicators

Period of the year	Category of work	Air temperature, °C	Surface temperature, °C	Relative humidity, %	Air speed
Cold	Ia	22-24	21-25	60-40	0,1
Warm	Ia	23-25	22-26	60-40	0,1

Optimal microclimatic conditions provide a general and local sensation of thermal comfort during an 8-hour working day, with a minimum stress of thermoregulation mechanisms, do not cause deviations in health, create the prerequisites for a high level of efficiency and are preferred at workplaces.

Table 5.2 - Permissible values of microclimate indicators

Period of the year	Category of work	Air temperature, °C		Surface temperature, °C	Relative humidity, %	Air speed	
		T°< T°опт.	T° > T°опт.			T° < T°opt.	T° < T°opt.
Cold	Ia	20,0-21,09	24,1-25,0	19,0-26,0	15-75	0,1	0,1
Warm	Ia	21,0-22,9	25,1-28,0	20,0-29,0	15-75	0,1	0,2

Acceptable microclimatic conditions do not cause damage or health disorders, but can lead to general and local sensations of thermal discomfort, tension in thermoregulation mechanisms, deterioration of well-being and decreased performance.

To select a suitable exhaust fan for room 123 of housing 10 with an area of 25 m^3, we use the following formula

$$L = S \cdot h \cdot k$$

Where L is the fan capacity, m^3/hour; S is the area of the room, m^2; h - ceiling height, m; k is the rate of air exchange, then we get:

$$L = 25 \cdot 3 \cdot 2 = 150 \text{ m}^3\text{/hour}$$

Fan "Event 150C" is able to provide the required air extraction performance for a given room.

5.3.3 Artificial lighting

Artificial lighting is divided into working, emergency, security and duty.

The standardized characteristics of indoor and outdoor lighting are provided both by general lighting fixtures and by their joint action with emergency lighting fixtures.

Work lighting should be provided for all premises of buildings, as well as for areas of open spaces intended for work, the passage of people and traffic. For rooms with zones with different natural lighting conditions and different operating modes, separate control of the lighting of such zones is necessary.

Standard lighting indicators for office premises are shown in Table 5.4.

Table 5.3 - Standard lighting indicators for the main premises of public, residential and auxiliary buildings

Premises	The plane of normalization of illumination and KEO, the height of the plane above the floor, m	Category and sub-category of visual work	Artificial lighting				
			Illumination of working surfaces, lx		UGR combined discomfort score, no more	Illumination ripple coefficient,	Light source color rendering index Ra
			With the combined	In general			

Cabinets and work rooms, offices, representativ e offices	Г-0,8	Б-1	400/20 0	300	21	1 5	8 0

The total illumination in a room with personal computers should be 300 lux.

As sources of artificial lighting at the workplace, 4 office LED lamps are used, the location of which is shown in Figure 5.1.

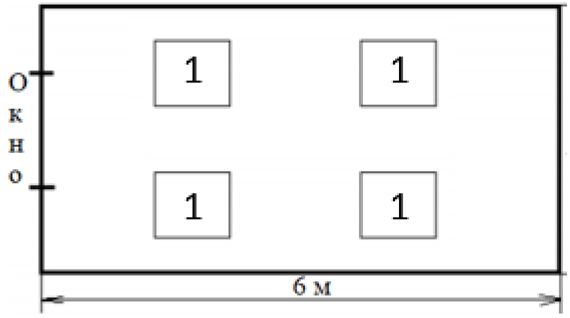

Figure 5.1 - Layout of fixtures at the workplace of a lighting engineer: 1- fixtures.

Let's calculate the artificial illumination of the room using the utilization factor method. The characteristics of the LED luminaire used in office space are as follows:

- power 40 W;
- luminous flux 4240 lm;
- light temperature 4000 K;
- IP 40.

$$i = \frac{A \cdot B}{h \cdot (A + B)}$$

where: A is the length of the room, m; B is the width of the room, m; h is the height of the luminaire suspension above the working surface, m.

$$i = \frac{A \cdot B}{h \cdot (A + B)} = \frac{6 \cdot 4}{2 \cdot (6 + 4)} = 1{,}2$$

The reflection coefficient of the walls is taken ρ = 50%.

According to SP 52.13330.2016, the minimum illumination on the working surface must be at least Emin = 300 lux.

Let's calculate the luminous flux of the lamp. There are 4 lighting devices in the room, N = 2; safety factor of LED luminaires k = 1.1; the numerical ratio of uneven illumination z = 1; the index of the room determines the utilization factor of the luminous flux, η = 0.51. Then the luminous flux is:

$$\Phi = \frac{E \cdot k \cdot S \cdot z}{N \cdot \eta} = \frac{300 \cdot 1{,}1 \cdot 24 \cdot 1}{4 \cdot 0{,}51} = 3882\ lm$$

We compare the calculated value of the luminous flux with the value of the selected light fixture, 4240 lm.

$$-10 \leq \frac{\Phi_{\text{станд.}} - \Phi_{\text{расч.}}}{\Phi_{\text{станд.}}} \cdot 100\% \leq 20$$

$$-10 \leq \frac{4240 - 3882}{4240} \cdot 100\% \leq 20$$

$$-10 \leq 8.44 \leq 20$$

We get that the luminous flux of the selected lighting device is suitable for lighting rooms where computers with an illumination of 300 lux are installed.

Many types of industrial and scientific activities are characterized by an increased load on the visual system and attention processes. In combination with physical inactivity, neuro-emotional stress, long-term preservation of a non-optimal basic working posture leads to the development of visual and general fatigue and a decrease in working capacity.

In the prevention of general and visual fatigue in representatives of a number of professions, an important role belongs to the provision of visual comfort. This includes general illumination, room color, light distribution, etc. The optimal location of objects of the labor process at a distance of 30-100 cm from the eyes.

When working for a long time at a personal computer, regulated breaks during which gymnastics is performed must be taken into account. It consists of general strengthening and special exercises for the eyes. The latter should be based on the principles of training and relaxation of accommodation, as well as manipulations that improve the blood supply to the eyes.

Also, correctly designed and executed lighting ensures a high level of efficiency, reduces the load on the organs of vision, has a positive psychological effect on workers, and helps to increase labor productivity.

5.3.4 Electrical safety

Electrical safety is a system of organizational and technical measures and means to protect people from harmful and dangerous effects of electric current, electric arc, electromagnetic field and static electricity.

The premises for electrical safety are divided into 3 groups:

1. A room without increased danger (dry, well-heated, room with non-conductive floors, with a temperature of 18–20 °, with a humidity of 40–50%).

2. A room with increased danger (where there is one of the following signs: high temperature, humidity 70-80%, conductive floors, metal dust, the presence of grounding, a large amount of equipment).

3. Premises are especially dangerous, in which there are two signs from the second group or there are caustic or poisonous explosive substances in the room.

According to [1], electrical safety must be ensured by the design of electrical installations, technical methods and means of protection. Electrical installations and their parts are designed in such a way that workers are not exposed to dangerous and harmful effects of electric current and electromagnetic fields, and comply with electrical safety requirements.

First of all, safety is ensured by the use of collective protective equipment, and then, if it cannot be ensured, personal protective equipment is used.

The means of collective protection against electric shock include: protective devices, which can be stationary and portable. Fences can be interlocked with devices that cut off the operating voltage when removed; insulating devices and coatings; protective grounding, neutralization and protective shutdown devices; remote control devices; safety devices, etc.

Also, personal protective equipment is divided into basic and additional. The main protective insulating means include insulating rods, insulating pliers and electrical voltage indicators, dielectric gloves, fitting and assembly tools with insulating handles. Additional insulating protective equipment includes means that supplement the main ones, and can also serve to protect against touch voltage and step voltage. Dielectric galoshes, dielectric rugs, insulating supports [2] serve as additional protective equipment.

5.3.5 Noise and vibration

Industrial noise is the noise in workplaces, on sites or on the territory of enterprises, which occurs during the production process. Noise and vibration worsen working conditions, have a harmful effect on the human body, namely, on the hearing organs and on the entire body through the central nervous system. As a result, attention is weakened, memory deteriorates, reaction decreases, and the number of errors during work increases. Noise can be generated by operating equipment, air conditioning units, daylight fixtures, and can also be emitted from outside.

In accordance with SanPiN 1.2.3685-21 [3], the standardized indicators in the workplace are:

- equivalent sound level per work shift;
- maximum sound level;
- peak sound level.

The standard equivalent sound level in the workplace is 80 dB. At noise levels above the permissible level, it is necessary to provide RMS and PPE.

Collective protection means [4]:

- elimination of the causes of noise or its significant attenuation in the source of education;
- isolation of noise sources from the environment by means of sound vibration isolation, sound and vibration absorption;
- the use of means that reduce noise and vibration along the path of their propagation.

Personal protective equipment [4]:

- the use of overalls, footwear and hearing protection: headphones, earplugs, antiphones.

5.3.6 Static electricity

All conductive parts of process equipment and other objects that generate or store static electricity must be grounded, regardless of whether other ESD devices are used. An ESD grounding device must have a maximum resistance of 100 ohms. According to [SanPin 1.2.3685-21] collective protection means against static electricity are: anti-electrostatic substances, humidifying devices, neutralizers, shielding substances. Anti-static footwear, gowns, and anti-electrostatic hand protection should be used as personal protective equipment.

5.4 Fire and explosion safety

Depending on the characteristics of substances and materials in the room, according to the explosion and fire hazard, the premises are subdivided into categories A, B, C, D and F in accordance with [22]. The room in question belongs to category C, since it contains solid combustible substances in a cold state. Possible causes of fire:

- work with open electrical equipment;
- short circuits in power supplies;
- non-observance of fire safety rules.

In order to reduce the risk of fire and minimize possible damage, preventive measures are taken, which are subdivided into organizational, technical, operational and regime. Organizational and technical measures consist in conducting regular briefings of employees responsible for fire safety, training employees in the proper operation of equipment and the necessary actions in the event of a fire, certification of substances, materials and products in terms of ensuring fire safety, production and use of visual agitation tools to ensure fire safety [23]. Operational measures include preventive inspections of equipment.

Regime measures include the establishment of rules for organizing work and compliance with fire safety measures. To prevent a fire, the following fire safety rules must be observed:

- maintenance of premises in accordance with fire safety requirements;
- proper operation of the equipment (correct connection of equipment to the power supply network, control of equipment heating);
- training of production personnel in fire safety rules;
- availability, correct placement and use of fire extinguishing equipment.

In a room with electrical equipment, in order to avoid electric shock, it is advisable to use carbon dioxide or dry powder fire extinguishers. These fire extinguishers are designed to extinguish fires of various substances and materials, electrical installations under voltages up to 1000 V, flammable liquids. Chemical and foam extinguishers are not permitted.[21] Fire extinguishers should be located at the protected object in accordance with the requirements so that they are protected from direct sunlight, heat flows, mechanical influences and other adverse factors (vibration, aggressive environment, high humidity, etc.). They must be clearly visible and easily accessible in the event of a fire. It is preferable to place fire extinguishers near the places where fire is most likely to occur, along the paths of the passage, as well as near the exit from the premises. Fire extinguishers should not interfere with the evacuation of people during a fire. According to fire safety requirements [1,], there are 2 OP 3 fire extinguishers (portable powder fire extinguishers) on the floor, stairwells are equipped with hydrants, and there is a fire alarm button[21].

5.5 Safety in emergencies

Emergency situation - a situation in a certain area resulting from an accident, dangerous natural phenomenon, catastrophe, natural or other disaster that may or have resulted in human casualties, damage to human health or the environment, significant material losses and disruption of the living conditions of people.

The most common emergencies in the building where the bachelor's job was developed are intrusion and fire.

Table 5.5 - Emergency situations, measures to prevent emergencies and eliminate the consequences of an emergency

№	Emergency situation	Emergency prevention measures	Measures to eliminate the consequences of an emergency
1	Falling from height	1. Maintenance of the premises in proper order. 2. Limitation of working space. 3. Timely briefing.	1. Examine or interview the victim; 2.if necessary - call an ambulance; 3. stop bleeding, if any; 4. if there is a suspicion that the victim has a broken spine (sharp pain in the spine at the slightest movement), it is necessary to provide the victim with complete rest in the supine position until qualified medical care is provided.
2	corresponding growth	1. Covering stair steps with anti-slip coating. 2. Timely briefing.	1. Call an ambulance; 2. stop bleeding, if any; 3. if there is a suspicion that the victim has a broken spine (sharp pain in the spine at the slightest movement), it is necessary to provide the victim with complete rest in the supine position until qualified medical care is provided.
3	Falling down the stairs	1. Grounding of all electrical installations. 2. Limitation of working space. 3. Ensuring the inaccessibility of live parts of the equipment. 4. Timely briefing.	1. Quickly release the victim from the action of the electric current [26]; 2. call an ambulance; 3. if the victim has lost consciousness, but breathing is preserved, he should be laid down comfortably, unbuttoned tight clothing, create an influx of fresh air and ensure complete rest; 4. the victim should be allowed to smell ammonia, sprinkle water on his face, rub and warm the body; 5. In the absence of breathing, artificial respiration and heart massage should be done immediately.
4	Electric shock	1. Timely briefing. 2. Establishment of means of automatic fire extinguishing in premises. 3. Installation of smoke and fire detectors.	1. De-energize the room, cut off the air supply; 2. immediately report the fire to the duty officer or to the guard post; 3. If possible, take measures to evacuate people, extinguish a fire and save material assets.

		4. Providing evacuation routes and maintaining them in proper condition. 4. Control of the work of electrical appliances.	

First case: penetration of unauthorized persons. To ensure the safety of the employee and prevent the entry of unauthorized persons into the enterprise, a number of security measures should be used:

1. Organize a checkpoint.

2. Hire a security guard to bypass the building.

3. Install video surveillance systems in production halls, as well as at all entrances and exits from the building.

4. Install warning security systems in case of unauthorized entry into the enterprise outside of working hours.

Second case: fire. Possible causes of sunburn:

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

Fire prevention measures are divided into: organizational, technical, operational and regime.

Organizational measures provide for the correct operation of equipment, the correct maintenance of buildings and territories, fire-prevention instructions for workers and employees, training of production personnel in fire safety rules, the publication of instructions, posters, and an evacuation plan.

Technical measures include: compliance with fire regulations, norms in the design of buildings, in the installation of electrical wires and equipment, heating, ventilation, lighting, proper placement of equipment.

Regime measures include the establishment of rules for organizing work, and compliance with fire safety measures. To prevent a fire from short circuits, overloads, etc., the following fire safety rules must be observed:

- elimination of the formation of a combustible environment (equipment sealing, air control, working and emergency ventilation);
- the use of non-combustible or hardly combustible materials in the construction and decoration of buildings; correct operation of equipment (correct connection of equipment to the power supply network, control of equipment heating);
- correct maintenance of buildings and territories (exclusion of the formation of an ignition source - prevention of spontaneous combustion of substances, limitation of hot work);
- training of production personnel in fire safety rules;
- publication of instructions, posters, availability of an evacuation plan;
- observance of fire safety rules, norms in the design of buildings, in the installation of electrical wires and equipment, heating, ventilation, lighting;
- correct placement of equipment;
- timely preventive inspection, repair and testing of equipment.

In the event of an emergency it is necessary to: Inform the management (duty officer);

Call the appropriate emergency service or the Ministry of Emergency Situations - tel. 112;

Take measures to eliminate the accident in accordance with the instructions.

5.5 Conclusions to the section social security

The industrial safety technique has been developed and analyzed in the course of this scientific and technical research.

Measures to create the necessary microclimate conditions have already been introduced in this room. The noise in the room is in accordance with the established norms. Electrical safety measures are also carried out in this laboratory.

The chapter discusses harmful and dangerous factors:

- microclimate [18];
- noise [20, 30];
- illumination [21];
- fire hazard [22, 23];
- electrical safety [24, 25];
- electromagnetic radiation [32, 33];

Also considered are the causes and means of protection, emergencies and emergencies, measures to prevent them, measures to eliminate their consequences. The radiation safety of work and the potential danger from electromagnetic radiation were considered separately.

The audience in question is assigned to class B for fire hazard [22] and 1 for electrical safety [24,25].

CONCLUSION

In the course of this final qualifying work, the literature was studied on topics related to the topic of the WRC. Methods for registering radon and physical methods for measuring its activity in soil were investigated. Mathematical methods for modeling the transport of radon in multilayer media with specified parameters of thickness, specific activity, porosity and advection rate in layers are also investigated.

On the basis of the studied material, a simulation of radon transport in a two-layer medium with different layer parameters was carried out. Using the model obtained, it was possible to assess the influence of rocks with an increased content of radium on the volumetric activity of radon in the surface layer, as well as on the density of its radon flux at the surface.

As a result, it was revealed that the advection rate strongly affects the volumetric activity and the radon flux density in the first layer. With an increase in the advection rate, the influence of the layer with high specific activity increases, which affected the values of the volumetric activity and the radon flux density.

The thickness of the first layer also influenced the values of the volumetric activity; with its increase, the manifestation of the layer with high specific activity decreased and the activity of the first layer decreased. It was also noted that at certain values of the depth of the first layer ($h = 9$ m), changes in volumetric activity ceased to manifest themselves with an increase in the thickness of the first layer.

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