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)

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Направление подготовки 14.04.02 Ядерная физика и технологии
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МАГИСТЕРСКАЯ ДИССЕРТАЦИЯ

Тема работы
Исследование радиационно-защитных свойств композиционных материалов на основе бинарных систем несмешивающихся металлов

УДК 621.039.53:621.762.2-022.532

Студент

Группа	ФИО	Подпись	Дата
0АМ01	Доржиев Антон Евгеньевич		

Руководитель

Должность	ФИО	Ученая степень, звание	Подпись	Дата
Доцент	Тимченко С.Н.	к.т.н.		

КОНСУЛЬТАНТЫ ПО РАЗДЕЛАМ:

По разделу «Финансовый менеджмент, ресурсоэффективность и ресурсосбережение»

Должность	ФИО	Ученая степень, звание	Подпись	Дата
Доцент	Клемашева Е.И.	к.э.н.		

По разделу «Социальная ответственность»

Должность	ФИО	Ученая степень, звание	Подпись	Дата
Доцент	Передерин Ю.В.	к.т.н.		

ДОПУСТИТЬ К ЗАЩИТЕ:

Руководитель ООП	ФИО	Ученая степень, звание	Подпись	Дата
Изотопные технологии и материалы	Видяев Д.Г.	д.т.н.		

Томск – 2022 г.

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«Национальный исследовательский Томский политехнический университет» (ТПУ)

School of Nuclear Science & Engineering
Field of training: 14.04.02 Nuclear Science and Technology
Specialization: Isotope technologies and materials
Nuclear Fuel Cycle Division

MASTER THESIS

Topic of research work
Investigation of radiation shielding properties of composite materials based on binary systems of immiscible metals

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Student

Group	Full name	Signature	Date
0AM01	Dorzhiev Anton Evgenievich		

Scientific supervisor

Position	Full name	Academic degree, academic rank	Signature	Date
Associate Professor	Timchenko S.N.	PhD		

ADVISERS:

Section “Financial Management, Resource Efficiency and Resource Saving”

Position	Full name	Academic degree, academic rank	Signature	Date
Associate Professor	Klemasheva E.I.	PhD		

Section “Social Responsibility”

Position	Full name	Academic degree, academic rank	Signature	Date
Associate Professor	Perederin Y.V.	PhD		

ADMITTED TO DEFENSE:

Programme Director	Full name	Academic degree, academic rank	Signature	Date
Isotope technologies and materials	Vidyaev D.G.	ScD		

Tomsk – 2022

LEARNING OUTCOMES

Competence code	Competence name
Universal competences	
UC(U)-1	Ability to make critical analysis of problem-based situations using the systems analysis approach, and generate decisions and action plans.
UC(U)-2	Ability to run a project at all life-cycle stages.
UC(U)-3	Ability to organize and lead the teamwork and generate a team strategy to achieve the target goal.
UC(U)-4	Ability to use modern communication technologies to realize academic and professional interaction.
UC(U)-5	Ability to analyze and account for cultural diversity in the process of intercultural interaction.
UC(U)-6	Ability to set and pursue individual and professional activity priorities and ways to modify professional activity based on the self-esteem.
General professional competences	
GPC(U)-1	Ability to formulate goals and objectives of the research study, select assessment criteria, identify priorities for solving problems.
GPC(U)-2	Ability to apply modern research methods, evaluate and present the results of the performed research.
GPC(U)-3	Ability to present research outcomes in the form of articles, reports, scientific reports and presentations using computer layout systems and office software packages.
Professional competences	
PC(U)-1	Ability to use fundamental laws in a volume sufficient for independent combination and synthesis of new ideas, creative self-expression
PC(U)-2	Ability to create new methods for calculating modern physical installations and devices, develop methods and advanced technologies
PC(U)-3	Ability to create mathematical and physical models that describe processes and phenomena in separation cascades, installations for the separation and fine purification of substances, processing and neutralization of industrial waste
PC(U)-4	Ability to assess the prospects for the development of the nuclear industry, use its modern achievements and advanced technologies in research work
PC(U)-5	Ability to independently perform experimental and theoretical research to solve scientific and industrial problems using modern instruments for scientific research and mathematical calculation methods
PC(U)-6	Ability to carry out calculation, conceptual and design development of modern physical installations and devices
PC(U)-7	Ability to formulate terms of reference, use information technologies and application packages in the design and calculation of physical installations, use knowledge of methods for analyzing environmental and economic efficiency in the design and implementation of projects
PC(U)-8	Ability to objectively analyze technical and computational-theoretical developments, solutions and projects, taking into account their compliance with the requirements of laws in the field of industry, ecology, technical, radiation and nuclear safety, other regulations at the Russian and international level, prepare an expert opinion
PC(U)-9	Readiness for teaching activities in the main educational programs of higher education and additional professional education (APE)
PC(U)-10	Ability to develop plans and programs for the organization of innovative activities, carry out a feasibility study of innovative projects, manage programs for the development of new products and technologies

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Nuclear Fuel Cycle Division

APPROVED BY:
Program Director
_____________ Vidyaev D.G
«____» ____________ 2022

ASSIGNMENT
for the Graduation Thesis completion

In the form:

Master Thesis

For a student:

Group	Full name
0AM01	Dorzhiev Anton Evgenievich

Topic of research work:

Investigation of radiation shielding properties of composite materials based on binary systems of immiscible metals	
Approved by the order of the Director of School of Nuclear Science & Engineering (date, number):	№ 32-51/C dated February 1, 2022

Deadline for completion of Master Thesis:	01.06.2022

TERMS OF REFERENCE:

Initial date for research work: *(the name of the object of research or design; performance or load; mode of operation (continuous, periodic, cyclic, etc.); type of raw material or material of the product; requirements for the product, product or process; special requirements to the features of the operation of the object or product in terms of operational safety, environmental impact, energy costs; economic analysis, etc.)*	Literature sources on the use of nanopowders for radiation shielding. Composite materials based on binary systems of immiscible metals. Materials: bimetallic nanopowders W-Cu, Fe-Pb and Fe-Cu, ED-20 epoxy resin. Gamma-isotope facility "ROCUS-AMT" for studies of radio-absorbing properties.

List of the issues to be investigated, designed and developed *(analytical review of literary sources with the purpose to study global scientific and technological achievements in the target field, formulation of the research purpose, design, construction, determination of the procedure for research, design, and construction, discussion of the research work results, formulation of additional sections to be developed; conclusions).*	1. Review and analysis of literature. 2. Synthesize and investigate bimetallic W-Cu, Fe-Pb and Fe-Cu nanopowders. 3. Obtain composite materials and investigate their radiation protection properties. 4. Analysis of results. 5. Economic calculation. 6. Occupational health and safety. 7. Conclusions.
List of graphic material *(with an exact indication of mandatory drawings)*	Presentation

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

Section	Advisor
Financial management, resource efficiency and resource saving	PhD in Economics, Klemasheva E.I.
Social Responsibility	PhD in Technical Sciences, Perederin Y.V.

Date of issuance of the assignment for Master Thesis completion according to the schedule	01.02.2022

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

Position	Full name	Academic degree, academic status	Signature	Date
Associate Professor	Timchenko S.N.	PhD		

Assignment accepted for execution by a student:

Group	Full name	Signature	Date
0AM01	Dorzhiev Anton Evgenievich		

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

To the student:

Group	Full name
0AM01	Dorzhiev Anton Evgenievich

School	Nuclear science & Engineering	Division	Nuclear-Fuel cycle
Degree	Master	**Education program**	14.04.02 Nuclear Science and Technology

Input data to the section «Financial management, resource efficiency and resource saving»:	
1. *Resource cost of scientific and technical research (STR): material and technical, energetic, financial and human*	Work with the information presented in Russian and foreign scientific publications, analytical materials, statistical bulletins and publications, normative legal documents.
1. *Expenditure rates and expenditure standards for resources*	
2. *Current tax system, tax rates, charges rates, discounting rates and interest rates*	
The list of subjects to study, design and develop:	
1. *Assessment of commercial and innovative potential of STR*	Conducting a pre-project analysis; Identification of the target market and its segmentation; Performing a SWOT analysis of the project.
2. *Development of charter for scientific-research project*	Formulation of the goal and results of the project. Definition of the organizational structure of the project. Definition of project constraints and assumptions.
1. *Scheduling of STR management process: structure and timeline, budget, risk management*	Formation of development plan and schedule: – STR work organization; – defining the structure of the work; – development of Gantt schedule. Formation of the budget for the costs of scientific research.
4. *Resource efficiency*	Determination of the indicator of comparative efficiency of development. Calculation of the absolute efficiency of development..
A list of graphic material (with list of mandatory blueprints):	
1. *Segmentation of the market.* 2. *Assessment of competitiveness of technical solutions.* 3. *SWOT matrix.* 4. *STR schedule..*	

Assignment date for section according to schedule	01.02.2022

Task issued by consultant:

Position	Full name	Scientific degree, rank	Signature	Date
Associate professor	Klemasheva E.I.	PhD in Economics		

Task was accepted by the student:

Group	Full name	Signature	Date
0AM01	Dorzhiev Anton Evgenievich		

TASK FOR SECTION
«SOCIAL RESPONSIBILITY»

To the student:

Group	Full name
0AM01	Dorzhiev Anton Evgenievich

School	**Nuclear science & Engineering**	**Division**	**Nuclear-Fuel cycle**
Degree	Master	**Education program**	14.04.02 Nuclear Science and Technology

Topic of the thesis:

Investigation of radiation shielding properties of composite materials based on binary systems of immiscible metals	
Initial data for section «Social responsibility»:	
1. Information about object of investigation (matter, material, device, algorithm, procedure, workplace) and area of its application	Object of the research: composite materials based on binary systems of immiscible metals. Area of application: aerospace and nuclear industry, medicine.
List of items to be investigated and to be developed::	
1. Legal and organizational issues to provide safety: – Special (specific for operation of objects of investigation, designed workplace) legal rules of labor legislation; – Organizational activities for layout of workplace.	– Legal norms of labor law; – Requirements for the organization and equipment of workplaces with PCs: – GOST 22269-76. System "man-machine". The operator's workplace. Mutual arrangement of elements of the workplace. General ergonomic requirements.
2. Work Safety: 2.1. Analysis of identified harmful and dangerous factors. 2.2. Justification of measures to reduce probability of harmful and dangerous factors.	Harmful and dangerous factors: – chemical hazardous substances; – ionizing radiation; – deviation of microclimate indicators – increased level of electromagnetic radiation; – insufficient lighting of working area; – increased noise level; – psychophysiological factors; – danger of electric shock.
3. Ecological 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 emergency:	– selection and description of a typical emergency: fire; – substantiation of measures to prevent emergencies; – the order of actions in case of emergency.

Assignment date for section according to schedule	01.02.2022

Task issued by consultant:

Position	Full name	Scientific degree, rank	Signature	Date
Associate professor	Perederin Y.V.	PhD in Technical Sciences		

Task was accepted by the student:

Group	Full name	Signature	Date
0AM01	Dorzhiev Anton Evgenievich		

ABSTRACT

The final qualification work contains: 87 pages, 45 tables, 19 figures, 49 references.

Key words: nanopowders, bimetallic nanoparticles, nanocomposites, radiation shielding, electrical explosion of conductors.

Object of research: composite materials based on binary systems of immiscible metals.

The aim of the work: study of radiation shielding properties of composite materials based on binary systems of immiscible metals.

Bimetallic W-Cu, Fe-Pb, and Fe-Cu nanopowders were synthesized during the study. The main characteristics of the obtained powders were studied. Composite materials based on the synthesized nanoparticles were obtained and the absorbed dose rate of the obtained composites was measured.

The nanopowders had core-shell and Janus-particle structures. The average size of the W-Cu, Fe-Pb, and Fe-Cu nanoparticles was 46, 98.2, and 62.8 nm, respectively. All powders had a normal logarithmic distribution and no supersaturated solution-based phases. Determined that the greatest shielding effect was achieved for composites with W nanoparticles, the absorbed dose rate decreased by 8.11 μGy/s. Composites with bimetallic W-Cu, Fe-Pb and Fe-Cu nanoparticles showed similar results, the reduction of the absorbed dose rate was 7.34, 7.66 and 7.33 μGy/s, respectively.

The results obtained can be used to create radiation shielding materials in the aerospace and nuclear industries.

Table of contents

Introduction

The creation of new materials for special purposes, including radiation shielding materials, is an urgent task today. The demand in creation of such materials is caused by constant increase of requirements to their functional characteristics. Recently, for these purposes the tendency of using composite materials filled with nanoparticles has been outlined. One of the promising solutions to improve the functional characteristics of radiation shielding materials can be the use of nanoparticles based on binary systems of immiscible metals, because the interface surfaces of immiscible layers can be more resistant to radiation mixing.

To obtain binary immiscible systems, it is necessary to choose metals with limited mutual solubility in the solid state. Some of these metal pairs are copper and tungsten, lead and iron, and iron and copper. The high density of tungsten, lead and iron makes it possible to use the resulting system for the manufacture of radioprotective materials, and the cost of the metals attracts much attention in terms of the prospects for commercial use.

The study of radiation shielding properties of composite materials based on binary systems of immiscible metals was carried out. Bimetallic nanopowders W-Cu, Fe-Pb and Fe-Cu were synthesized. The main characteristics of the obtained powders were investigated. Composite materials based on synthesized nanoparticles were created and the absorbed dose rate of the obtained composites was measured.

1 LITERATURE REVIEW

1.1 Application of nanopowders for creation of radiation shielding materials

Nowadays nanopowders are widely used in various fields of science, technology and industry. Thus oxide nanopowders (silicon, titanium, aluminum, etc.) are used to create a wide range of structural materials [1-6]. Nickel oxide nanopowders are used to create semiconductor devices, highly active adsorbents, electrochromic materials and electrodes in lithium-ion batteries [7-9]. Nanopowders (iron, copper, etc.) are widely used in the agricultural sector [10], and materials based on silver nanoparticles are promising for the creation of new antibacterial drugs and various medical products [11].

One of the actual directions of using nanopowders is the creation of new radiation shielding materials. To protect against gamma and X-ray radiation, protective shields are used, which are filled with materials with large atomic number and high density (iron, lead, tungsten, etc.). Tungsten and lead have the best protective effectiveness among traditional materials [12].

In work [13] calculation-experimental studies of attenuation ability of homogeneous radiation shielding materials with different fillers in relation to gamma-radiation were conducted. It was found that for sources with gamma radiation energies from 0.4 to 3 MeV the optimal percentage content of an absorber (barite, lead, tungsten) is the range from 20 to 90%.

In [14] the influence of different concentrations of refractory and fusible metal nanopowders on the radiation shielding properties of the composite was studied. Polyvinyl acetate adhesive was used as a compound [15]. The following materials were used as fillers: copper oxide, titanium carbide, aluminum oxide, iron oxide, corundum, tungsten carbide, titanium-tantalum-tungsten-cobalt hard alloys (TTC) and annealed TTC.

Measurements were performed using a dosimeter-radiometer MKG-01. The following assumptions were made during the measurements: the source is located on the detector axis during measurement; ionizing radiation is not absorbed by the air layer and is not reflected from the radiation shielding material.

The most optimal filler of the composite material that improves the radiation shielding properties turned out to be TTC annealed nanopowder. (attenuation multiplicity 29.8) with a percentage of 30%. A further increase in the concentration of nanomodifiers in all samples led to a decrease in the attenuation coefficient due to the reflection effect and the appearance of false pulses.

In [16] the radiation shielding properties of a composite material based on tungsten carbide nanopowder and their dependence on the methods and conditions of measurement were considered. The compound was polyvinyl acetate adhesive [15]. Samples were made with different contents of the filler (from 10 to 30%). Measurements were carried out on a KRC-1 radiometer. The radiation source was ^{209}Tl with an energy of 0.51 Mev, the distance from the source to the detector was 18 cm.

As a result of studies [16] it was found that the half attenuation layer of WC-30% is one and a half times less than that of WC-10%. If we compare samples with tungsten carbide filler, their half attenuation layer is ten times less than that of aluminum samples. For the refractory material, the influence of geometric conditions (distance from the material over the sample to the detector) on the measurement results is practically not observed. At the same time, the optimal distance (3 to 6 cm) should be observed for the fusible material, because at a different distance the effect of scattering of radiation increases.

The study of radiation shielding properties of composite materials with bismuth (III) oxide filler (modification α-Bi_2 O_3) was carried out in [17]. Fluoroplastic-4 (polytetrafluoroethylene) was used as a polymer matrix in the work [18]. Proton irradiation was considered as corpuscular radiation in the work. Proton beam energy in the tests was up to 4.2 MeV, fluence was $4 \cdot 10^{14}$ proton/cm^2.

The optimum composition of the composite material was determined, which contains 50% of the filler - bismuth oxide and 50% of the matrix - fluoroplate. The proton penetration depth in the composite in the whole considered energy range does not exceed 0.2 mm, which speaks of the high radiation shielding properties of the developed composite.

In [19] the radiation shielding properties of polyimide composites with nanodispersed lead filler were studied. Polyimide track (nuclear) membranes produced by it4ip (Belgium) were used as polymer matrix for composites synthesis. The pore diameter was 200 nm, the pore density was $5 \cdot 10^8$ cm^{-1}, and the polyimide membrane thickness was 25 μm. Electrochemical deposition method was used to fill the membrane tracks with nanodispersed lead.

The sources of irradiation were: ^{137}Cs (E=0.662 MeV) and ^{60}Co (average energy of γ-quanta - 1.252 MeV). In the experiment differential and integral energy distributions of flux densities of γ-quanta of the incident radiation from the source without the investigated samples and behind the investigated samples were measured. The composite material half attenuation layer (d1/2) for each of the sources was calculated: $d1/2_{(137Cs)}$ = 0.97±0.07 cm, $d1/2_{(60Co)}$ = 2.16±0.12 cm. According to the obtained results, we can conclude about the high radiation shielding characteristics of the polymeric nanocomposite in relation to gamma radiation.

In [20] a protective material based on nanoparticles of iron oxide and boron carbide for fast neutron shielding was developed. Fe_3O_4 and B_4C nanoparticles were introduced into a silicone resin matrix. The diameters of iron nanoxide and boron nanocarbide were 20-30 nm and 55 nm, respectively. Cylindrical samples were made separately at filler concentrations of 10, 20, and 30 % by weight.

An americium-beryllium source was used to create the fast neutron beam. The shielding material consisted of two layers. First there was a layer of iron nanoxide, followed by a layer of boron nanocarbide.

It is shown that the developed two-layer protective material has a better macroscopic cross-section compared to the two single-layer materials and more effectively eliminates fast photoneutrons. The transmittance factor for the bilayer material is 0.62 ± 0.01. It is also found that the optimal filler concentration is 30 % of the mass, because with a higher content, the silicone resin and nanoparticles mixture did not cure properly after mixing.

Based on a literature review, it can be concluded that nanopowders are used as modifiers to increase the radiation shielding properties.

1.2 Application of multicomponent powders

One promising area of modification of various materials is the use of multicomponent nanoparticles, including those based on immiscible metals.

In [21], a system of W-Cu nanoparticles with a core-shell structure was considered as a modification of electrical materials. The immiscible metallic system was obtained by electrical explosion of two W and Cu wires. The obtained composition had the following elemental composition: W – 52.64 wt. %, Cu – 44.74 wt. %, O – 1.73 wt. %, C – 0.89 wt. %. Determined that the W-Cu composition has the raised microhardness (2.68–2.87 GPa) in comparison with theoretically calculated (1.95 GPa), it is explained by fine-grained structure of a two-phase composite. At the same time, due to the homogeneous structure and high copper content, the material has an electrical conductivity (64.1 ± 1.2% IACS) close to the theoretical one (64.68% IACS).

In [22] the antibacterial properties of immiscible Ag-Cu nanoparticles were studied. An immiscible Ag-Cu bimetallic system was obtained by pulsed plasma in liquid. Agar plates coated with Ag-Cu nanoparticles were found to effectively inhibit the growth of bacteria strains of E. coli and Staphylococcus aureus.

In [23], the absorption of electromagnetic radiation by a composite material based on bimetallic Ag - Au, Au - Ag, and Cu - Ag nanoparticles with a core-shell structure was analyzed based on the Maxwell-Granett theory. The geometrical characteristics of the particle-inclusions and their composition are shown to have a significant influence on the composite's optical properties.

Nanocomposite electrode materials based on bimetallic platinum-nickel and palladium-nickel nanoparticles were developed in [24]. The matrix substrate of the composite electrodes was porous nickel with a pore size of 10-45 μm and a thickness of 2 mm. Bimetallic nanoparticles were synthesized by joint reduction of platinum and nickel salts and palladium and nickel salts in aqueous pools of reversed microemulsions. It is shown that the membrane-electrode unit based on nanocomposite nickel electrodes significantly reduces the overvoltage of hydrogen and oxygen release, thus providing a reduction in specific power consumption at elevated temperatures up to 80°C and high current densities up to 500 mA/cm^2.

In [25] a composite material based on gadolinium oxide and tungsten with a core-shell structure for obtaining protective materials against neutron and gamma radiation was considered. An aluminum matrix was used as the basis, into which the metal system Gd_2O_3-W was introduced. Using a high-energy ball mill 5% Gd_2O_3 powder (10 μm) was mixed with 20% W nanopowder (200 nm) to create particles with a core-shell structure, then the resulting particles were mixed with 20% W (10 μm) and Al (13 μm) micropowders. The resulting mixture was sintered by spark plasma sintering. The software method MCNP5 (Monte Carlo N-Particle Transport Code) was used to simulate the shielding efficiency of neutron and gamma radiation.

It was found that the neutron absorption efficiency reaches 99% at a material thickness of 3 mm. The linear gamma ray absorption coefficient increases and the thickness of the half-attenuation layer decreases with increasing hybrid tungsten content. With a hybrid tungsten content of 40% in the composite, the half-value layer meets the requirements for gamma ray protection with a sample thickness of 6 mm. It is also shown that the material modified with particles with a core-shell structure has a higher tensile strength than the same material without particles with this structure.

Thus, we can conclude that multicomponent nanoparticles are currently used as modifiers of various special purpose materials.

1.3 Nanopowders production

A nanopowder is a solid dispersed material containing particles up to 100 nm in all three dimensions. Ways of obtaining nanopowders are diverse. They are conventionally divided into two groups: physical and chemical [26].

1.3.1 Chemical methods

Various reactions and processes are used to produce nanopowders by chemical methods. These include gas-phase chemical reactions, thermal decomposition processes, hydrolysis, reduction and electrodeposition reactions. By changing the ratio of the number of reagents, the degree of supersaturation and the process temperature it is possible to regulate the parameters of the new phase formation.

The precipitation method consists in the precipitation of various metal compounds from solutions of their salts with the help of precipitators. The products of precipitation are metal hydroxyls. Alkaline solutions of sodium, potassium and others are used as a precipitant.

Nanopowders of complex composition are produced by co-precipitation. For this purpose, two or more solutions of metal salts and alkali are fed simultaneously into a reactor at a given temperature and stirring. As a result, hydroxide compounds of the desired composition are obtained.

The method of heterophase interaction consists in step-by-step heating of mixtures of solid metal salts with alkali solution. The result is the formation of an oxide suspension. After that, the metal reduction reaction produces metal powders with a particle size in the range of 10-100 nm.

The gel method consists in the precipitation of insoluble metal compounds from aqueous solutions in the form of gels. The next stage is metal reduction. This method is used to produce powders of iron and other metals.

The method of reduction and thermal decomposition is usually the next operation after obtaining ultrafine oxides or hydroxides in solution, followed by precipitation and drying. As reducing agents, depending on the type of product required, gaseous agents are used - usually hydrogen, carbon monoxide, or solid reducing agents - carbon, metals or metal hydrides.

Nanopowders of Fe, W, Ni, Co, Cu and a number of other metals are produced by reduction of their oxides with hydrogen. Nanopowders of some metals such as Mo, Cr, Pt, Ni and others are produced using solid reducing agents. As a rule, the particle size of such powders is in the range of 10-30 nm. Stronger reducing agents are hydrides, usually calcium hydride. This is how nanopowders of Zr, Hf, Ta, Nb are made [26].

1.3.2 Physical methods

Evaporation (condensation) methods, or gas-phase synthesis for producing metal nanopowders, are based on the evaporation of metals, alloys or oxides and their subsequent condensation in a reactor with a controlled temperature and atmosphere. The "vapor-liquid-solid" or "vapor-solid" phase transitions occur in the volume of the reactor or on the surface of the cooled substrate or walls.

The essence of the method consists in the fact that the initial substance is evaporated by intense heating, with the help of carrier gas is fed into the reaction space, where it is sharply cooled. The vaporized substance is heated by plasma, laser, electric arc, resistance ovens, induction heating, electric current flowing through the wire. Depending on the type of starting materials and the resulting product, evaporation and condensation are carried out in a vacuum, in an inert gas, in a gas stream or plasma. Particle size and shape depend on the process temperature, atmosphere composition and pressure in the reaction space. This method is used to produce powders of Ni, Mo, Fe, Ti, Al. The particle size is tens of nanometers.

Also, one of the methods of obtaining nanosized powders is the electrical explosion of wires (conductors). Metal (Ti, Co, W, Fe, Mo) and oxide (TiO_2, Al_2O_3, ZrO_2) nanopowders with particle sizes up to 100 nm are produced this way [26].

1.3.3 Mechanical methods

These methods are based on grinding materials mechanically in mills of various types - ball, planetary, centrifugal, vibratory. Metals, ceramics, polymers, oxides, brittle materials are crushed mechanically. The degree of grinding depends on the type of material. Thus for oxides of tungsten and molybdenum the particle size is of the order of 5 nm, for iron - of the order of 10–20 nm.

A form of mechanical milling is mechanosynthesis, or mechanical alloying, when the milling process involves the interaction of milled materials to produce a milled material with a new composition. This is how nanopowders of alloyed alloys, intermetallides, and dispersion-strengthened composites with a particle size of 5–15 nm are obtained.

The positive side of mechanical methods is the simplicity of installations and technology, obtaining nanopowders of alloys, as well as the possibility of obtaining material in large quantities.

The disadvantages of the method include the possibility of contamination of the milled powder with plant materials, as well as difficulties in obtaining powders with a narrow particle-size distribution, difficulties in regulating the product composition during milling [26].

1.4 Production of multicomponent nanopowders

In [27], palladium and ruthenium nanoparticles in the form of solid solution were synthesized by the pulsed plasma-in-liquid method. This method is based on the dispersion of metal electrodes under the action of an electric discharge immersed in a dielectric liquid. The size of the alloy nanoparticles in the solid solution was less than 10-20 nm. This method was also used in [22] to obtain immiscible Ag-Cu nanoparticles.

In [28] the systems of nanoparticles made of immiscible metals in rhodium-silver, rhodium-gold, platinum-gold, and iridium-silver combinations were obtained by the polyol method. The polyol method is a liquid-phase method that uses high-boiling and multi-atomic alcohols that act as both solvent and reducing agent. The obtained particles had different structures. For example, for the Ag-Rh composition, Ag was the nucleus of the nanoparticle, and Rh islands of different sizes were randomly arranged on Ag nuclei. The Au-Ir composition had the core-shell structure.

In [21,29], immiscible bimetallic iron-copper and tungsten-copper nanoparticles were obtained by electrical explosion of wires. The method is based on the instantaneous heating and evaporation of the metal as a result of a powerful current pulse passing through the wires placed between the electrodes. The metal vapors are then dispersed, cooled, and condensed. The resulting bimetallic particles had Janus particle and core-shell structures.

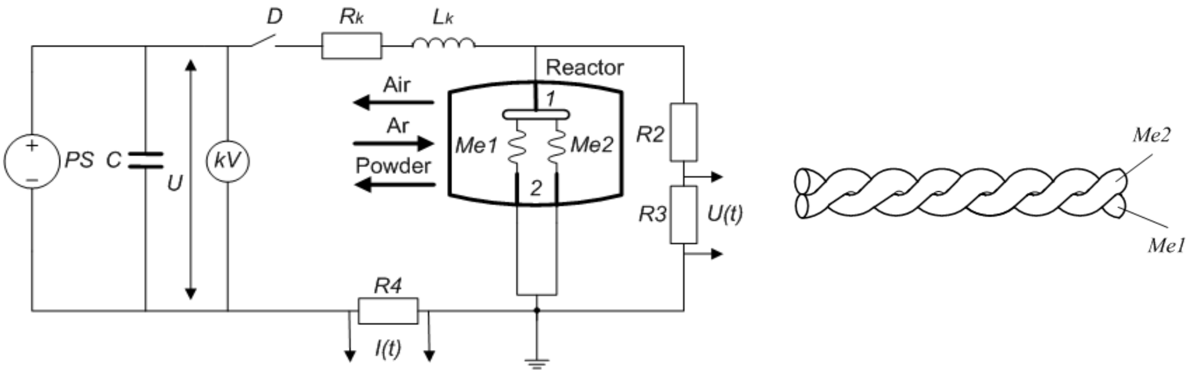
Thus, we can conclude that the method of electric explosion of wires is used to obtain multicomponent powders based on immiscible metals.

2 EXPERIMENTAL PART

2.1 Nanopowders production

Tungsten, copper, lead, and iron wires were used to produce nanopowders [30-33], as well as argon to form an inert atmosphere in the electroblast chamber.

Samples of W-Cu, Fe-Pb, and Fe-Cu nanopowders were obtained by joint electrical explosion of conductors described in [34]. The basic scheme of the unit is shown in Fig. 2.1.1. Conductors made of the metals *Me1* and *Me2* twisted together (Fig. 2.1.1 b) were placed in the reactor (Reactor) between high voltage electrode 1 and electrodes 2.



a b

Fig. 2.1.1 – Installation diagram (a) and a picture of the stranded conductors (b): R_k and L_k – eigen-resistance and inductance of the electrical circuit of the installation L_k=0.68 μH, R_k=0.056 Ohm, C - capacitance of the capacitor bank, U - charging voltage of capacitors C; Me1 and Me2 - metal conductors

The reactor was preliminarily evacuated to a residual pressure of 10^{-2} Pa. Then, the reactor was filled with argon to a pressure of $2 \cdot 10^5$ Pa. The capacitive energy accumulator *C* (a battery of high voltage capacitors IK-100-0.4 connected in parallel) was charged by a high voltage source *SP*. The value of voltage *C* was monitored by a voltmeter *Kv*. By turning on the arrester *D*, the accumulated energy in *C* was transferred to two wires *Me1* and *Me2*, resulting in electric explosion of the conductors. The produced nanopowder was collected in a hopper connected to the reactor (the hopper is not shown in Fig. 2.1.1).

Registration of current pulse *I(t)* was carried out by current sensor *R4*, voltage pulse *U(t)* by divider *R3-R4* using oscilloscope TDS2022B. The energy transferred to the conductors was estimated from the oscillogram of discharge current *I(t)* and voltage *U(t)* by the integral replacement method by a finite sum:

$$E = \int_{t_0}^{t_n} U(t)I(t)dt \tag{2.1.1}$$

The magnitude of overheating of the system of 2 conductors was determined by the expression:

$$E = E_{EJC}/m \tag{2.1.2}$$

where E_{EJC} – energy injected into the conductors; $m=m_1+m_2$, m_1 – first conductor mass, m_2 – second conductor.

Before use, the conductors were cleaned with an organic solvent to remove contaminants from their surface. The content of metals in twisted conductors was varied by their diameter d and length *l*, energy transferred to metals by capacitance *C* and charging voltage of capacitor bank *U*. The nanopowder synthesis parameters are presented in Table 2.1.1.

Table 2.1.1 – Parameters of nanopowder synthesis W-Cu, Fe-Pb and Fe-Cu

Samples	*d*, mm	*l*, mm	Metal content, wt. %	*U*, kV	C, μF
W-Cu	0.2 W	65	70	28	1,2
	0.2 Cu		30		
Fe-Pb	0.36 Fe	90	54	32	2
	0.28 Pb		46		
Fe-Cu	0.2 Fe	60	47	26	12
	0.2 Cu		53		

After obtaining the W-Cu, Fe-Pb and Fe-Cu nanoparticles were passivated with air oxygen for 48 hours.

2.2 Devices and research methods for nanopowders

The morphology of W-Cu, Fe-Pb, and Fe-Cu nanoparticles was determined by transmission electron microscopy (TEM) using a JEM 2100 microscope (JEOL, Japan).

The elemental composition and element distribution in the nanoparticles were performed using an X-Max X-ray detector (Oxford Instruments, GB) combined with a microscope. At least 1500 particle diameters were measured to plot the particle size distribution. The average size was determined by the expression $a_n = \Sigma n_i a_i / \Sigma n_i$, where n_i – the number of particles falling within the selected size interval, a_i – average particle diameter in the selected interval.

The phase composition of Fe-Pb nanoparticles was determined using a Dron-7 diffractometer with CoKα radiation. For W-Cu and Fe-Cu nanoparticles a Shimadzu XRD 6000 diffractometer on CuKα-radiation was used. Phase identification was performed using the PDF-2 Release 2014 software package.

2.3 Main characteristics of nanopowders

Fig. 2.3.1 and 2.3.2 show the diffractogram and characteristic microphotographs of W70-Cu30 wt. % nanoparticles.

X-ray microanalysis data showed that the obtained sample is characterized by the formation of nanoparticles with nucleus-shell and janus-particle structures. Particles with the core-shell structure have a tungsten core and a copper shell. XRD data show that the obtained nanopowder is characterized by the presence of α, β - phases W, Cu and copper oxide (Cu_2O). The crystal lattice parameters are close to the standard values, indicating the absence of phases based on supersaturated solid solutions in the samples.

The analysis of microphotographs of nanoparticles showed that the average size of nanoparticles is 46 nm. The nanopowder has a normally logarithmic nanoparticle size distribution (Fig. 2.3.3).

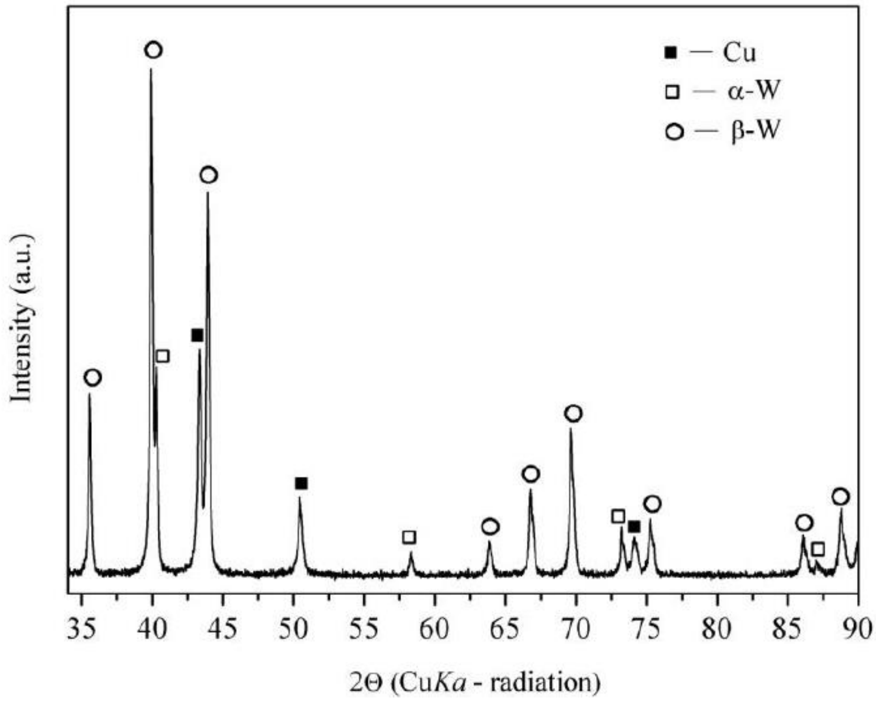
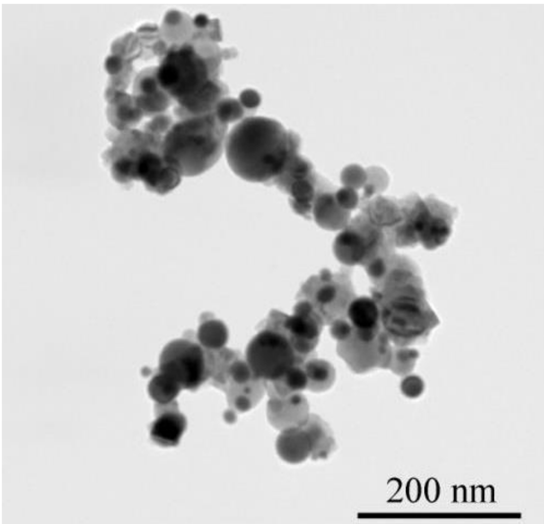
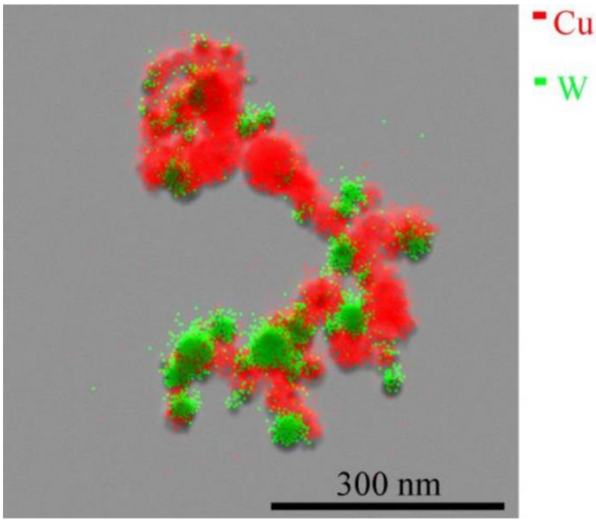


Fig. 2.3.1 – Diffractogram of W70-Cu30 wt. % nanoparticles





a b

Fig. 2.3.2 – Microphotograph of W-Cu nanoparticles (a) and TEM-EDS (transmission electron microscopy-energy dispersive X-ray spectroscopy) element distribution over W-Cu nanoparticles in mapping mode (b)

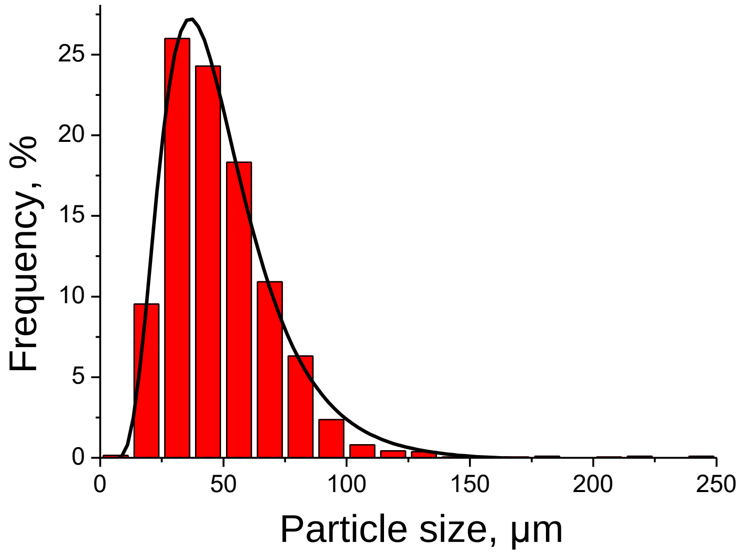


Fig. 2.3.3 – W-Cu particle size distribution

Fig. 2.3.4 and 2.3.5 show the diffractogram and characteristic microphotographs of Fe54-Pb46 wt. % nanoparticles.

X-ray microanalysis data showed that all obtained samples are characterized by the formation of nanoparticles with a Janus-particle structure. XRD data showed that all obtained samples are characterized by the presence of α-, β - phases of lead oxide, as well as α-phase Fe and Pb. The crystal lattice parameters of the α-phase Fe and Pb are close to the standard values, indicating the absence in the samples of phases based on supersaturated solid solutions.

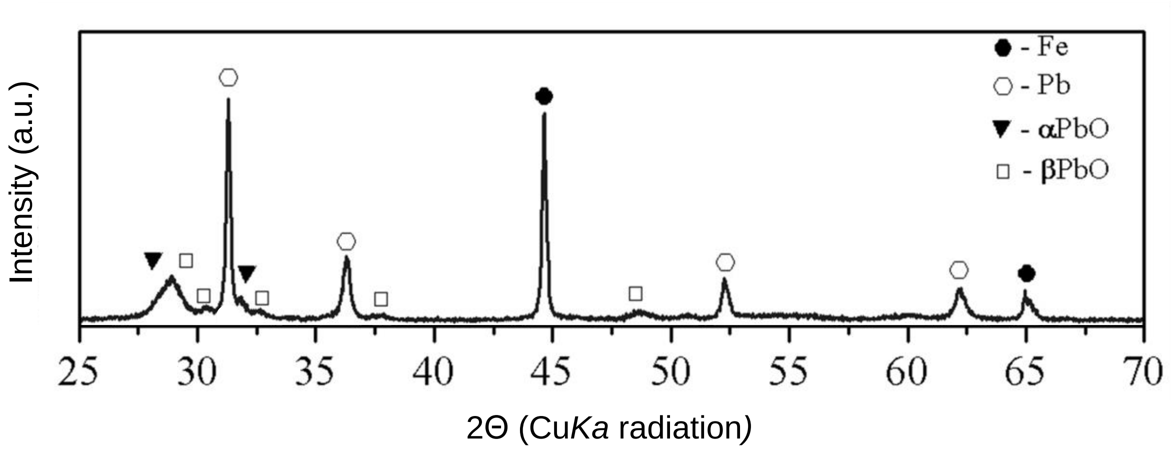
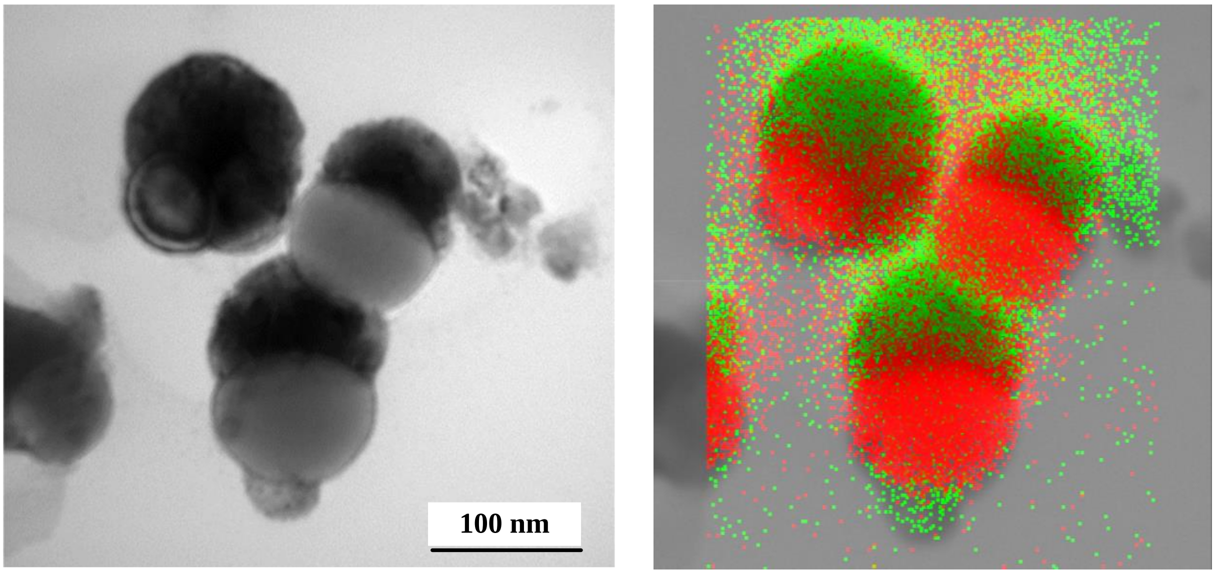


Fig. 2.3.4 – Diffractogram of Fe54-Pb46 wt. % nanoparticles



a b

Fig. 2.3.5 – Microphotograph of Fe-Pb nanoparticles (a) and TEM-EDS distribution of elements over Fe-Pb nanoparticles in the mapping mode (b)

The analysis of microphotographs of nanoparticles showed that the average size of nanoparticles is 98.2 nm. The nanopowder has normally logarithmic nanoparticle size distribution (Fig. 2.3.6).

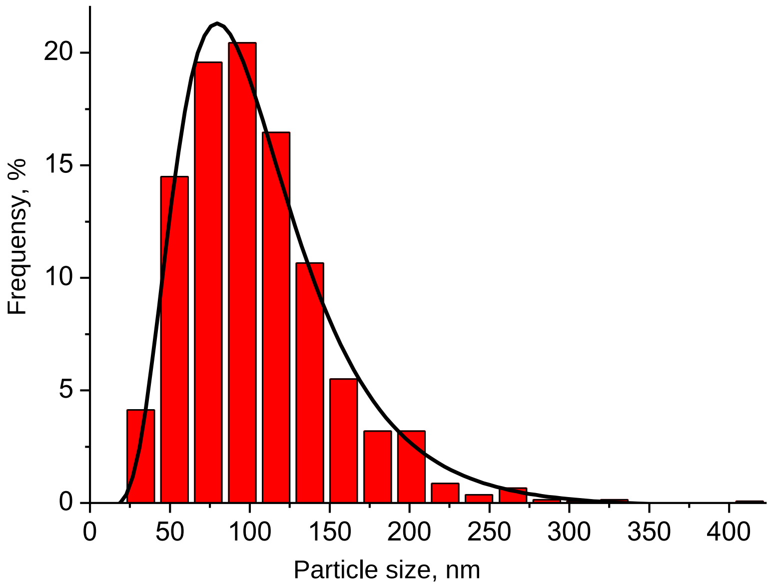


Fig. 2.3.6 – Fe-Pb particle size distribution

Fig. 2.3.7 and 2.3.8 show the diffractogram and characteristic microphotographs of Fe47-Cu53 wt. % nanoparticles.

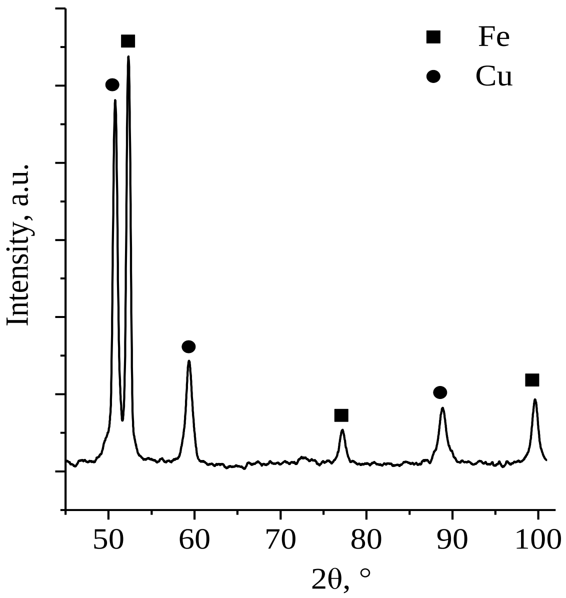
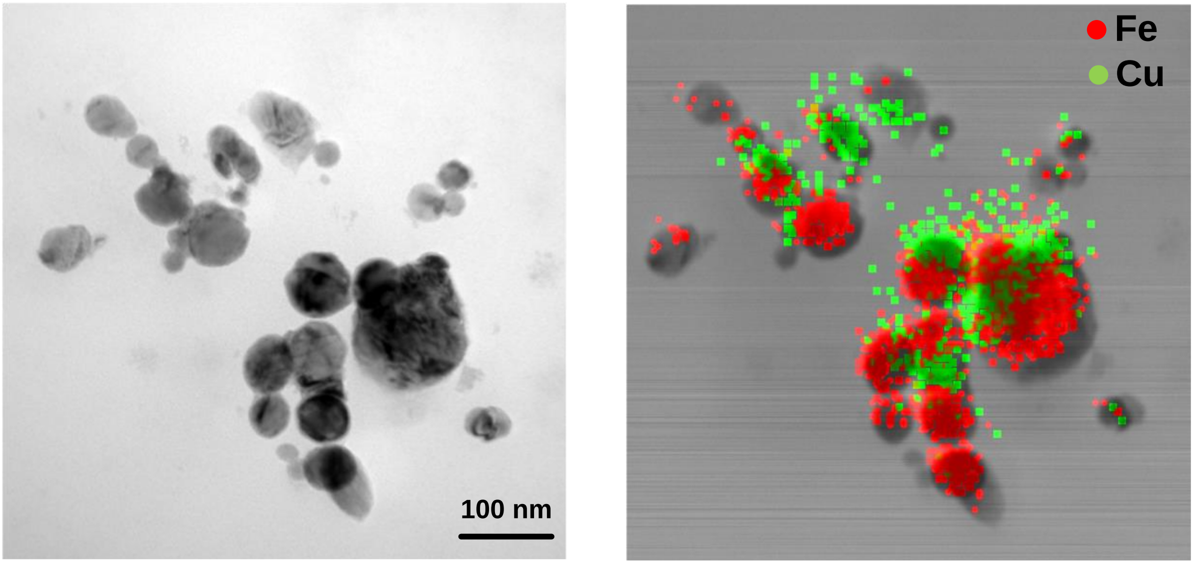


Fig. 2.3.7 – Diffractogram of Fe47-Cu53 wt. % nanoparticles



a b

Fig. 2.3.8 – Microphotograph of Fe-Cu nanoparticles (a) and TEM-EDS distribution of elements over Fe-Cu nanoparticles in the mapping mode (b)

Analysis of microphotographs of nanoparticles showed that the average nanoparticle size is 62.8 nm. The nanopowder has a normally logarithmic nanoparticle size distribution. (Fig. 2.3.9).

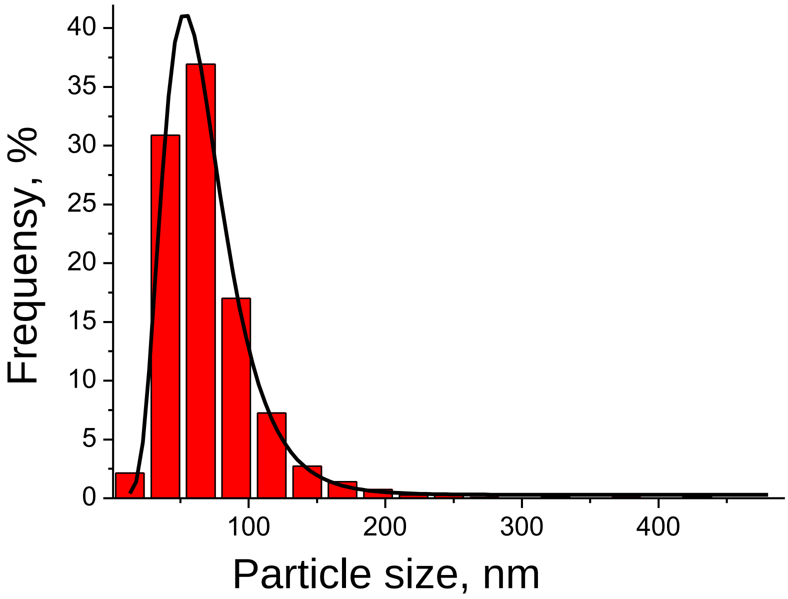


Fig. 2.3.9 – Fe-Cu particle size distribution

X-ray microanalysis data showed that all obtained samples are characterized by the formation of nanoparticles with the structures of core-shell and Janus-particle. Particles with core-shell structure have iron core and copper shell. XRD data show that all obtained samples are characterized by the presence of Fe and Cu α-phase. The crystal lattice parameters are close to the standard values, indicating the absence of phases based on supersaturated solid solutions in the samples.

2.4 Production of composites

Samples of composite materials modified with nanoparticles were made for research. A schematic representation of the sample is shown in Fig. 2.4.1.

ED-20 epoxy resin was used as a compound [35]. The fillers were: Cu and W nanoparticles; immiscible bimetallic systems of metals W-Cu, Fe-Pb and Fe-Cu; a mechanical mixture of W and Cu nanoparticles. The mass ratio of filler to compound in all samples is 50% by mass.

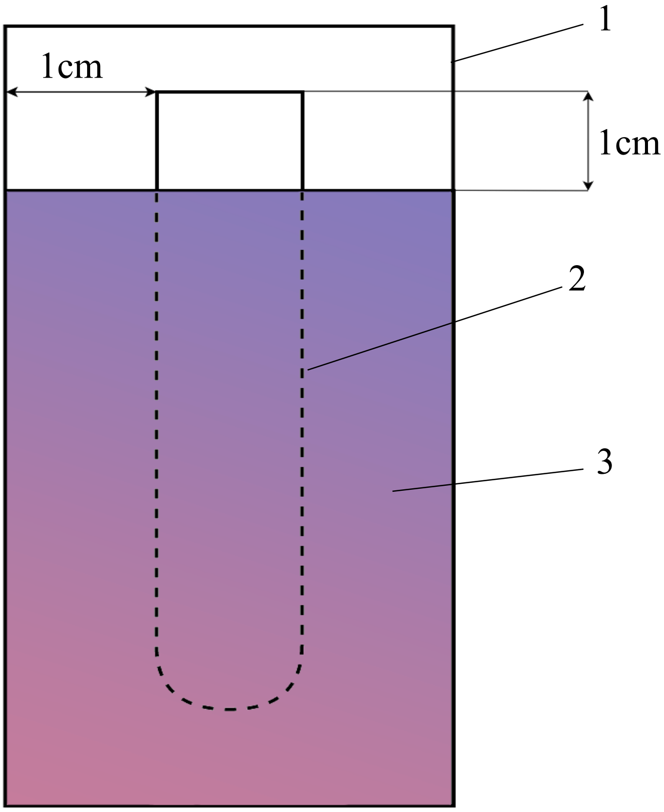


Fig. 2.4.1 – Schematic of the research sample: 1 – vessel, 2 – cap,
3 – composite material

The characteristics of the composites are presented in Table 2.4.1.

Table 2.4.1– Characteristics of composites

Composite, №	Filler	Metal content in the filler, mass %
1	Cu	–
2	W	–
	Bimetallic systems	
3	W-Cu	70–30
4	Fe-Pb	54–46
5	Fe-Cu	47–53
	Mechanical mix	
6	W and Cu	70–30

The creation of the samples was as follows:

1. The container was weighed, and then the epoxy resin was placed in it. The volume of the epoxy placed in the container varied depending on the density of the filler, so that the mass ratio of the filler to the compound remained constant for each sample.

2. The epoxy resin was weighed and the weight of the filler was calculated as 50% of the weight of the compound.

3. The filler was added to the container with the epoxy resin, and then the components were mixed in an ultrasonic bath for 5 minutes with constant agitation.

4. A hardener equal to 10 parts by volume of the mixture was added. The hardener was also mixed in an ultrasonic bath for 5 minutes with constant agitation.

5. A cap made of organic glass was placed in the container with the material. The cap acted as a water equivalent during the tests on the radio- absorbing properties.

6. The produced composite was cured within 24 hours.

2.5 Method for investigating radio-absorbing properties

Studies of radio-absorbing properties were carried out using the gamma-isotope facility "ROCUS-AMT". The source of gamma-radiation was cobalt-60 isotope (average energy of gamma-quanta – 1.25 MeV). Measurements of the absorbed dose rate (ADR) by the composite were performed for water. The water equivalent was an organic glass cap placed in the composite, the density of which is close to water. A universal dosimeter DCS-101 with the ionization chamber (IC) "BMK-06" was used to measure ADR. Relative error of IC measurements is 2.5%.

The scheme of the experiment is shown in Fig. 2.5.1.

The composite material 3 was placed around the ionization chamber, and the thickness of the composite layer before the IC was 10 mm. The ionization chamber with the material under study was placed on the tripod 2. The tripod was placed perpendicular to the geometrical axis of the gamma ray beam at a distance of 9 meters from the emitter 1. At this distance the value of ADR was the minimum in the conditions of the test bunker. The smaller the value of ADR, the easier it is to trace the difference in radio-absorbing capacity in different composites.

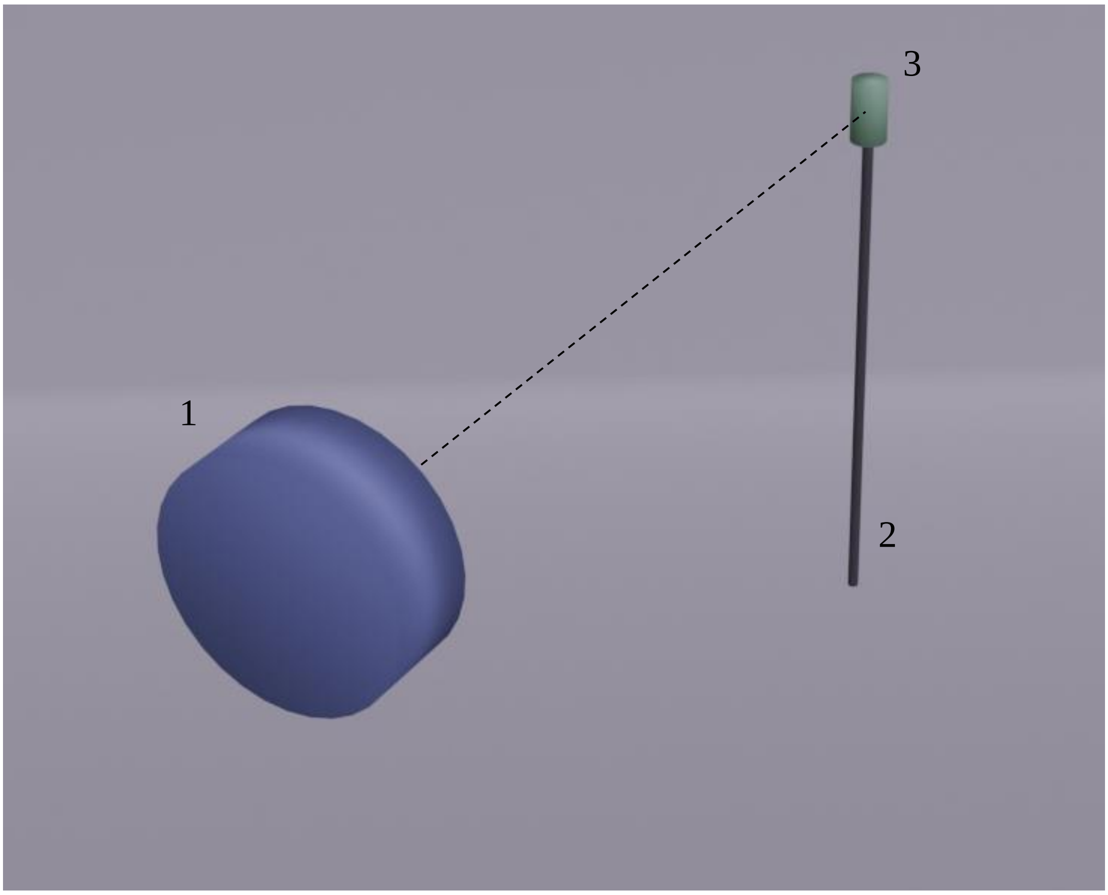


Fig. 2.5.1 – Schematic of the experiment: 1 – Rocus-AMT, 2 – tripod, 3 – composite

In order to estimate the degree of gamma-radiation attenuation, the ADR was first measured without the composite material. Then the composites under study were irradiated. In order to account for the possibility of the cap in the sample being tilted, the samples were irradiated from 3 sectors. The scheme of the irradiated composite is presented in Fig. 2.5.2.

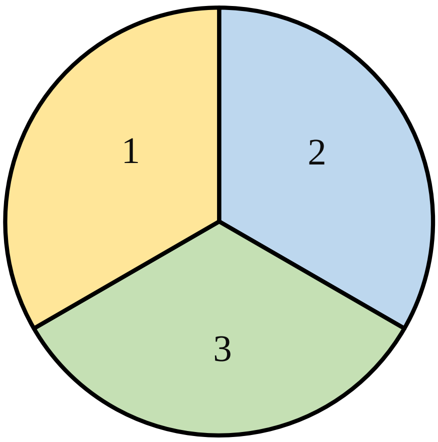


Fig. 2.5.2 - Scheme of the irradiated composite

After measuring the ADR, linear, mass attenuation coefficients and the thickness of the half-attenuation layer were calculated according to formulas 2.5.1-2.5.3, respectively.

$$\mu = \frac{\ln(\frac{F_0}{F})}{x}, \qquad (2.5.1)$$

where μ – linear attenuation coefficient, F_0 – ADR without composite material, F_0 – ADR with composite material, x – composite layer thickness.

$$\mu_m = \frac{\mu}{\rho}, \qquad (2.5.2)$$

where, μ_m – mass attenuation coefficient, ρ – composite density.

$$d_{1/2} = \frac{\ln(2)}{\mu}, \qquad (2.5.3)$$

where, $d_{1/2}$ – thickness of the half-attenuation layer.

The experiments were repeated at least three times, the results were mathematically processed according to the scheme given in [36] using formulas (2.5.4) and (2.5.5):

$$S_r = \sqrt{\frac{\sum_{i=1}^{n}(X_i - \overline{x})^2}{n(n-1)}} \qquad (2.5.4)$$

$$X = \overline{x} \pm \frac{S_r}{\sqrt{n}} t_p \qquad (2.5.5)$$

where X – determinable value, $\bar{x}$– the average value of the determined value in a series of experiments; S_r – standard error, n – number of experiments; t_p – Student coefficient, for n=3 and confidence probability P=0.95 t_p=3.18.

2.6 Radio-absorbing properties of composites

Studies of radio-absorbing properties of composite materials were conducted in accordance with the methodology described in Section 2.5. The results of measurement of absorbed dose rate are presented in Table 2.6.1.

Table 2.6.1 – Absorbed dose rate by composites

Composite, №	Filler	Absorbed dose rate, μGy/s			
		1 sector	2 sector	3 sector	Mean
Pure epoxy resin		76.69	76.47	76.43	76.53
1	Cu	71.74	71.56	71.43	71.58
2	W	71.25	70.77	70.77	70.93
3	W70-Cu30 wt. % (bimetallic system)	71.73	71.73	71.63	71.70
4	W70-Cu30 wt. % (mechanical mix)	71.25	70.8	71.25	71.10
5	Fe54-Pb46 wt. %	71.64	71.31	71.2	71.38
6	Fe47-Cu53 wt. %	71.31	72.15	71.68	71.71
Empty ionization chamber		79.04			

Linear and mass attenuation coefficients relative to the empty ionization chamber and the thickness of the half-attenuation layer were calculated according to formulas 2.5.1–2.5.3. Mathematical processing of the obtained results was carried out according to the formulas 2.5.4–2.5.5. The results of the calculations are presented in Tables 2.6.2–2.6.5.

Table 2.6.2 – Radio-absorbing characteristics of composites

Composit, №	Filler	Linear attenuation coefficients, cm^{-1}	Mass attenuation coefficient, cm^2/g	Thickness of the half-attenuation layer, cm
1	Cu	0.099 ± 0.002	0.0194 ± 0.0005	6.99 ± 0.16
2	W	0.108 ± 0.004	0.0106 ± 0.0004	6.41 ± 0.25
3	W70-Cu30 wt. % (bimetallic system)	0.0975 ± 0.0009	0.0112 ± 0.0001	7.11 ± 0.06
4	W70-Cu30 wt. % (mechanical mix)	0.106 ± 0.004	0,0122 ± 0.0004	6.55 ± 0.23
5	Fe54-Pb46 wt. %	0.102 ± 0.003	0,0190 ± 0.0006	6.81 ± 0.23
6	Fe47-Cu53 wt. %	0.0973 ± 0.0062	0,0201 ± 0.0013	7.14 ± 0.46

Table 2.6.3 – Processing of linear attenuation coefficient results

Composit, №	Filler	Mean	Standard Deviation	Standard error	Confidence interval
1	Cu	0.0992	0.0022	0.0013	0.0023
2	W	0.1083	0.0039	0.0023	0.0041
3	W70-Cu30 wt. % (bimetallic system)	0.0975	0.0008	0.0005	0.0009
4	W70-Cu30 wt. % (mechanical mix)	0.1059	0.0037	0.0021	0.0039
5	Fe54-Pb46 wt. %	0.1019	0.0032	0.0019	0.0034
6	Fe47-Cu53 wt. %	0.0973	0.0059	0.0034	0.0062

Table 2.6.4 – Processing the results of the mass attenuation coefficient

Composit, №	Filler	Mean	Standard Deviation	Standard error	Confidence interval
1	Cu	0.0194	0.0004	0.0002	0.0005
2	W	0.0106	0.0004	0.0002	0.0004
3	W70-Cu30 wt% (bimetallic system)	0.0112	0.0001	0.0001	0.0001
4	W70-Cu30 wt% (mechanical mix)	0.0122	0.0004	0.0002	0.0004
5	Fe54-Pb46 wt. %	0.0190	0.0006	0.0003	0.0006
6	Fe47-Cu53 wt. %	0.0201	0.0012	0.0007	0.0013

Table 2.6.5 – Processing the results of thickness of the half-attenuation layer

Composit, №	Filler	Mean	Standard Deviation	Standard error	Confidence interval
1	Cu	6.9906	0.1538	0.0888	0.1631
2	W	6.4080	0.2359	0.1362	0.2501
3	W70-Cu30 wt. % (bimetallic system)	7.1088	0.0584	0.0337	0.0619
4	W70-Cu30 wt. % (mechanical mix)	6.5522	0.2220	0.1281	0.2353
5	Fe54-Pb46 wt. %	6.8072	0.2171	0.1254	0.2302
6	Fe47-Cu53 wt. %	7.1421	0.4346	0.2509	0.4607

As a result of measurements of the absorbed dose rate by composites and determination of their radioabsorption properties it was found that the greatest shielding effect was achieved for composites with W nanoparticles, the absorbed dose rate decreased by 8.11 μGy/s. Composites with bimetallic W-Cu, Fe-Pb and Fe-Cu nanoparticles showed similar results, the reduction of the absorbed dose rate was 7.34, 7.66 and 7.33 μGy/s, respectively.

Fig. 2.6.1-2.6.3 show the comparison of the radio-absorbing properties of the obtained composites.

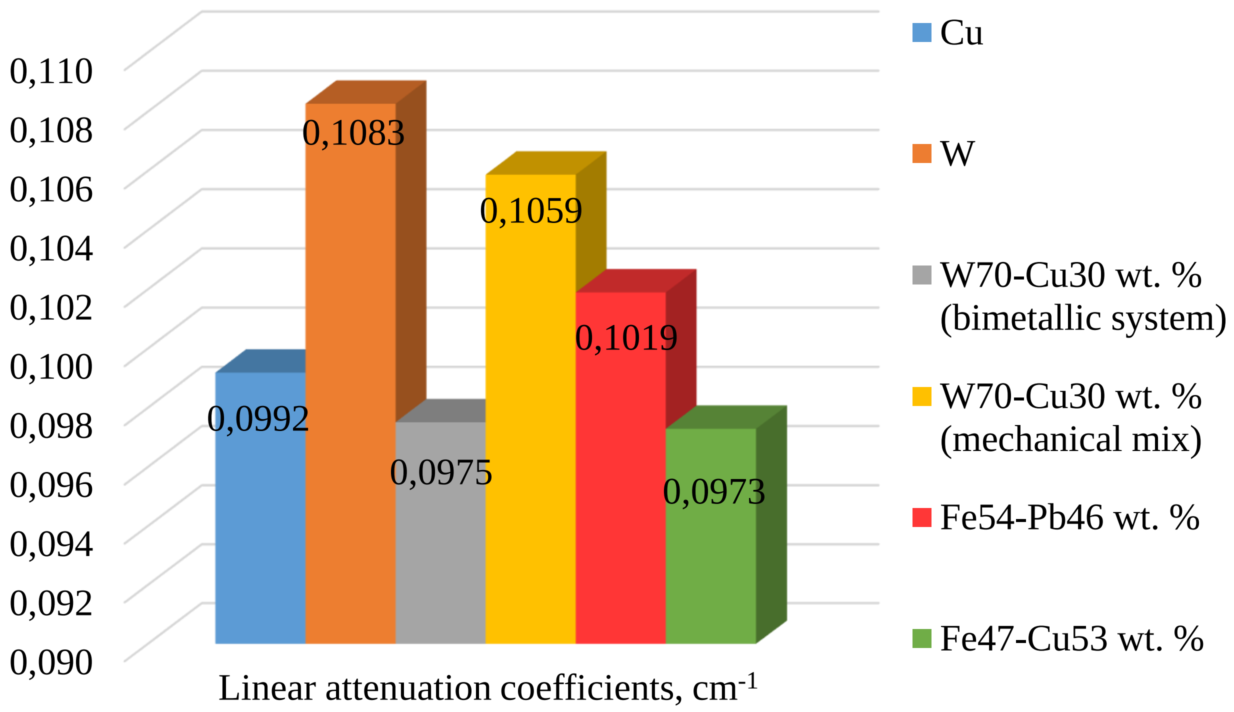


Fig. 2.6.1 – Comparison of linear attenuation coefficients

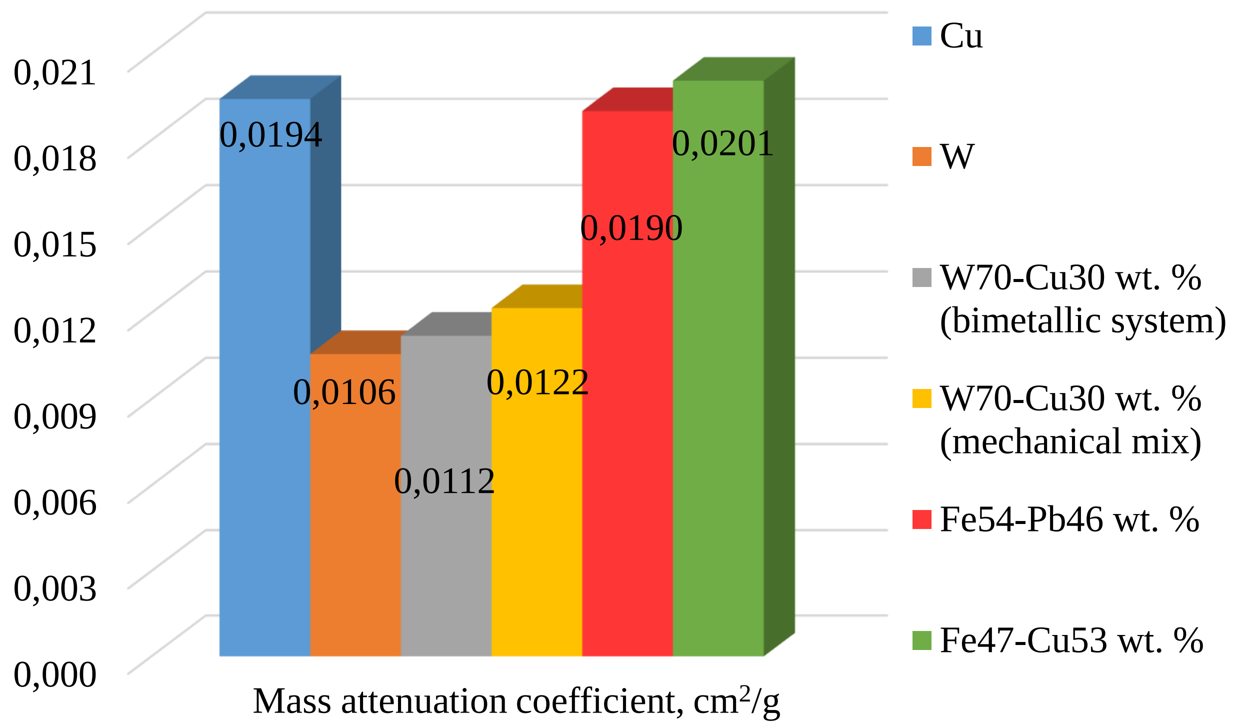


Fig. 2.6.2 – Comparison of mass attenuation coefficients

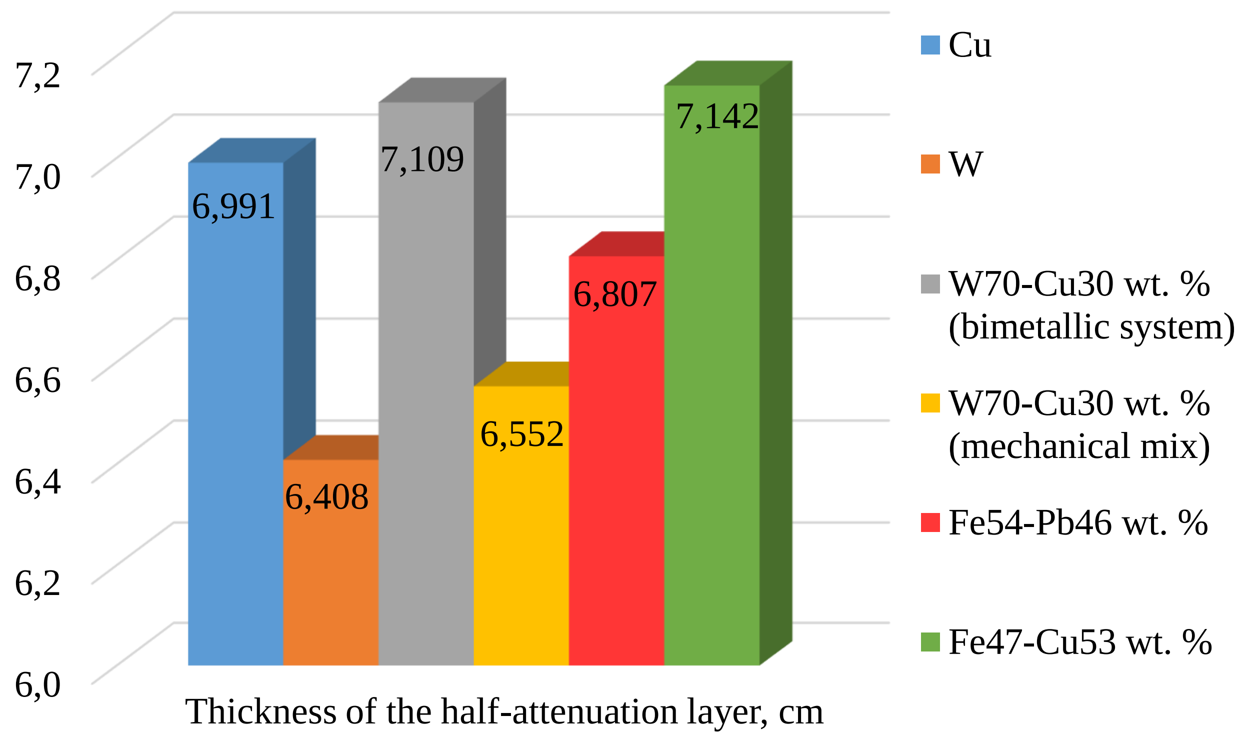


Fig. 2.6.3 – Comparison of thickness of the half-attenuation layer

3 Financial Management, Resource Efficiency and Resource Saving

The purpose of this section is to determine the economic feasibility of studying the radiation protection properties of composite materials based on binary systems of immiscible metals

To achieve the purpose it is necessary to solve the following tasks:

1. Identify potential consumers of the research results.
2. Analyze the competitive technical solutions.
3. Perform a SWOT analysis: describe project strengths and weaknesses, identify opportunities and threats to project implementation.
4. Evaluate the degree of readiness of the scientific development for commercialization.
5. Create a time schedule for the research project.
6. To calculate the budget of scientific research.
7. Determine the resource, financial, budget, social and economic effectiveness of the research.

3.1 Pre-project analysis

3.1.1 Potential users of the research results

In the process of writing the master's thesis the potential consumers of the research results were identified. The target market of this research will be the areas of science and industry interacting with ionizing radiation (nuclear power, medicine, aerospace industry, etc.). In order to analyze consumers it is necessary to consider the target market and conduct its segmentation.

It is possible to segment the service market according to the degree of demand for radiation protection materials. The results of segmentation are presented in Fig. 3.1.

		Radiation shielding composite nanomaterials			
		Nuclear industries	Medicine	Aerospace	Agricultural industry
Demand	Strong				
	Weak				

Fig. 3.1 – Map of service market segmentation

3.1.2 Analysis of competitive technical solutions

Analysis of competitive solutions allows you to assess the comparative effectiveness of scientific development and identify areas for its future improvement.

In this paper, composite materials based on epoxy resin and metallic nanoparticles Cu-W, Fe-Pb and Fb-Cu as a competitor selected a radio shielding plate made of Bi (bismuth).

Let's conduct this analysis using the scorecard, which is shown in Table 3.1.

The position of the development and competitors is evaluated on a five-point scale. The weights of the indicators in total should be 1.K_f– composite materials based on epoxy resin and metal nanoparticles Cu-W, Fe-Pb and Fb-Cu. K_k– radio shielding plate of Bi.

Table 3.1 – Scorecard for comparing competitive technical solutions (developments)

Evaluation criteria	Criteria weight	Points		Competitiveness	
		P_f	P_k	K_f	K_k
1. The cost of materials	0.4	5	3	2.5	1.5
2. Radiation shielding properties	0.3	5	4	1.5	1.2
3. Difficulty of manufacturing	0.1	4	5	0.4	0.5
4. Reliability	0.1	4	4	0.4	0.4
5. The weight of the finished product	0.05	3	4	0.15	0.2
6. After-sales service	0.05	5	5	0.25	0.25
Total	1	26	25	5.2	4.05

The position of the development and competitors is evaluated on a five-point scale. The weights of the indicators should total 1.

The analysis of competitive technical solutions is determined by the formula:

$$K = \sum W_i \cdot P_i , \qquad (3.1)$$

where: W_i – weight of the indicator (in fractions of one); P_i – point of the i-th indicator [37].

Thus, we can conclude that composite materials based on epoxy resin and metal nanoparticles Cu-W, Fe-Pb and Fb-Cu are preferable to the X-ray protection plate, because the value of 5.2 is greater than the value of 4.05.

3.1.3 SWOT-analysis

SWOT-analysis is a summary table illustrating the relationship between internal and external factors of the company. The purpose of this analysis is to describe the strengths and weaknesses of the project, identifying opportunities and threats to the project that have emerged or may emerge in its external environment [38]. Here is the SWOT-analysis matrix for composite materials based on epoxy resin and metal nanoparticles Cu-W, Fe-Pb and Fb-Cu.

Table – 3.2 SWOT analysis matrix

	Strengths	**Weaknesses**
	S1. Commercial perspective of the materials used. S2. Wide field of application of the obtained materials. S3. Scientific novelty of the project consisting in establishment of new regularities of influence of composition and morphology of nanoparticles on radiation protective properties of composites.	W1. Difficulty in gaining access to the necessary equipment for more in-depth research. W2. Difficulty of apparatus design in the production of materials. W3. Insufficient funding for the project.
Opportunities O1. Opportunity of attracting investors. O2. Emergence of additional demand for the new product. O3. Use of other metallic immiscible systems for research.	**1. O1S2**– appearance of additional financing in the form of investors and receiving of patent promotes development of research works in the field of creation of composite material of necessary quality. **2.O2S1S2**– appearance of additional demand in connection with a wide spectrum of application of the received composites promotes introduction on large volumes of manufacture of a new material. **3.O3S3** – the use of other metallic immiscible systems will expand the existing ideas on the laws of influence of the composition and morphology of nanoparticles.	**1. O3W1** – lack of access to the necessary research equipment can hinder the study of other metal systems. **2. O1O2W2** – the complexity of the hardware design may adversely affect the demand for the resulting product, as well as reduce the interest of potential investors. **3. O3W2W3** – poor project funding and difficulty in obtaining raw materials may pose a problem for research on other bimetallic immiscible systems.
Threats T1. Lack of demand for the product. T2. Developed competition of production technologies.	**1. T1T2S1S2** – A wide range of applications and commercial prospects of the obtained materials will ensure the necessary demand for the products and their competitiveness.	**1.T1T2 W2W3** – Due to complex hardware design and weak funding, the ability to produce products of proper quality is undermined, and therefore there is a risk of lack of product demand in the market and bankruptcy due to high competition.

According to the obtained results of SWOT-analysis, it has been revealed that in obtaining additional funding it is possible to eliminate many of the weaknesses of this research project. This will contribute to further improvement of functional characteristics of the manufactured material, will allow to bring modified polymer composite materials to the market, where it will create a high competition to other manufacturers.

3.1.4 Assessment of project readiness for commercialization

Let's estimate the degree of readiness of scientific development to commercialization and find out the level of own knowledge for its implementation. For this purpose let's fill the special form containing indicators about the degree of project elaboration from a position of commercialization and competences of the developer of the scientific project.

Table 3.3– Assessment of the degree of readiness of a scientific project for commercialization

№ п/п	Title	The degree of development of the research project	The level of knowledge available to the developer
1.	The existing scientific and technical foundation has been identified	4	4
2.	Promising directions for commercialization of scientific and technical achievements were identified	4	3
3.	Identified industries and technologies (goods, services) to offer in the market	4	3
4.	The commercial form of scientific and technological advance to be presented to the market is defined	3	2
5.	Authors are identified and their rights protected	3	2
6.	The value of intellectual property was assessed	2	2
7.	Market research has been conducted on sales markets	2	2
8.	A business plan for the commercialization of scientific development has been developed	2	2
9.	Ways to promote scientific development to the market are determined	2	2

10.	A strategy (form) for the implementation of scientific development has been developed	3	3
11.	International cooperation and access to foreign markets have been worked out	2	2
12.	The issues of using the support infrastructure services, getting benefits are worked out	3	2
13.	The issues of financing the commercialization of scientific development are worked out	2	2
14.	There is a team for commercialization of scientific development	2	2
15.	Development of a mechanism for the implementation of a scientific project	3	2
	Total	41	35

As a result, we can conclude that the prospects for commercialization are at an average level. This level can be increased by a more detailed study of the commercial component of the project, which includes an analysis of sales markets, the development of a business plan, etc.

3.1.5 Methods of commercialization of the results of scientific and technical research

The time of promotion of the product on the market largely depends on the correct choice of commercialization method. For this scientific and technical research, the most preferable commercialization method is engineering. Since the consultant has knowledge and experience in providing engineering and technical services, but does not have the ability to build his own enterprise, an agreement is concluded with the customer. The customer has its own production, but needs additional narrowly focused projects, which act as auxiliary for the implementation of the work process. Although the methodology is available in the public domain, resources are needed to hire employees. In this case, it is more advantageous for the customer to contract an outside company, rather than create his own department to calculate any component of the process. A consultant, on the other hand, is capable of performing a large number of tasks and is flexible in terms of the number of tasks and the time spent on the project.

3.2 Project initiation

The Charter of the scientific project of the master's thesis should have the following structure:

1. Project purpose and results.

Here is information about the project stakeholders, the hierarchy of project purpose and the criteria for achieving the purpose.

Project stakeholders are defined as individuals or organizations that are actively involved in the project or whose interests may be affected either positively or negatively by the execution or completion of the project. Information on project stakeholders is presented in Table 3.4.

Table 3.4 – Project stakeholders

Project stakeholders	Stakeholder expectations
RESEARCH INSTITUTE	Study of influence of nanoparticles composition and morphology on radiation shielding properties of materials.
State corporations	Creation of new radiation protective materials.
Private investors	Obtaining maximum profitability depending on investments.

Let's present information about the hierarchy of project goals and goal achievement criteria in Table 3.5.

Table 3.5 – Purpose and results

Purpose project:	Investigation of radiation shielding properties of composite materials based on binary systems of immiscible metals.
Expected results of the project:	Increase of radiation shielding properties of composite materials.
Acceptance criteria for the result of the project:	Confirmation or refutation of existing ideas about the effect of nanoparticles on the radiation shielding properties of materials.

Requirements for the result of the project:	Requirements:
	Meeting the needs of research institutes, state corporations, and investors.

2. Organizational structure of the project.

Let's define the participants of the working group of this project, the role of each participant in this project, as well as the functions performed by each of the participants and their labor costs in the project. Let's present this information in Table 3.6.

Table 3.6 – Project working group

№	Full name, main place of work, position	Role in the project	Functions	Labor costs, hours.
1	A.E. Dorzhiev, TPU, M.A.	Creation of composites, research of radio-absorbing properties of obtained materials	The main developer of the project	490
2	A.S. Lozhkomoev, ISPMS SB RAS, PhD, Head of the Laboratory of Nano Bioengineering	Advice on the main issues of the topic	Project Manager	64
Total:				554

3. Constraints and assumptions of the project.

Project constraints - all factors that may limit the degree of freedom of project team members, as well as "project boundaries" - parameters of the project or its product that will not be implemented as part of this project. Let's present this information in Table 3.7.

Table 3.7 – Project constraints

Factor	Constraints / assumptions
3.1. Project budget	394102
3.1.1. Source of funding	ISPMS SB RAS
3.2. Project timeline:	4 months
3.2.1. Date of approval of the project management plan	01.02.2022
3.2.2. Project completion date	01.06.2022

Thus, the goals and results of the project have been established, the organizational structure of the project has been reviewed, and the limitations and assumptions of the project have been determined.

3.3 Project risk register

Identified project risks include possible uncertain events that may occur in the project and cause consequences that will have undesirable effects.

Table 3.8 – Risk register

№	Risk	Potential impact	Probability of occurrence (1-5)	Level of risk (1-5)	Level of risk	Ways to mitigate risk	Conditions of the onset
1	External	Crisis	5	3	Medium	Use of alternative equipment for nanopowder characterization	Changing global market conditions
2	Financial	Increase in the inflation rate during the implementation of the project	3	3	Medium	Using cheaper alternative pairs of immiscible metals	Changing global market conditions
3	Manufacturing	Changes in the scope or timing of work	3	2	Low	Optimizing the research process	Depending on management objectives

3.4 Planning a research project

To perform the work a working group is formed, which includes a scientific leader of the project (SD) and the performer (P). After that, within the framework of scientific research a number of basic stages presented in table 3.9 are carried out.

Table 3.9 – List of stages, works and distribution of performers

The main stages	№	Content of work	Position performer
Development of the technical assignment	1	Writing and approving the assignment	P, SD
	2	Timetable of work on the topic	P
	3	Studying materials on the topic	P

Choice of research direction	4	Creating composite materials	P
	5	Choosing a method of performing the work	P, SD
Theoretical and experimental investigations	6	Study of radio-absorbing properties of composite materials	P
	7	Analysis of the results of work	P
Summary and evaluation of results	8	Writing a report on the work	P

As part of the planning of the research project it is necessary to build a timetable for the project. The linear schedule is shown in Table 3.10.

Table 3.10 – Project timetable

№	Title	Duration, days	Start date of work	Completion date	Composition of participants
1	Writing and approval of the master's thesis assignment	2	01.02.2022	02.02.2022	A.E. Dorzhiev A.S. Lozhkomoev
2	Timetable of work on the topic	4	03.02.2022	07.02.2022	A.E. Dorzhiev
3	Studying materials on the topic	14	08.02.2022	23.02.2022	A.E. Dorzhiev
4	Analysis of input parameters	5	24.02.2022	01.03.2022	A.E. Dorzhiev
5	Choosing a method of performing the work	8	02.03.2022	10.03.2022	A.E. Dorzhiev A.S. Lozhkomoev
6	Applying the method to the initial parameters	27	12.03.2022	09.04.2022	A.E. Dorzhiev
7	Analysis of the results of work	30	10.04.2022	10.05.2022	A.E. Dorzhiev
8	Writing a report on the work	10	11.05.2022	25.05.2022	A.E. Dorzhiev
Total:		97			

Gantt chart is a type of bar charts (histograms) used to illustrate a project schedule, in which the work on a topic is represented by time-spanning segments characterized by the start and end dates of these activities [37, 39].

The schedule is built in the form of Table 3.11 with a breakdown by months and decades (10 days) for the time period of the research project. In this case, the work on the schedule should be highlighted with different shading, depending on the performers responsible for this or that work.

Table 3.11 – Schedule of works

№	Type of work	Performers	$T_{\kappa i}$	The duration of the work											
				February			March			April			May		
				1	2	3	1	2	3	1	2	3	1	2	3
1	Writing and approval of the master's thesis assignment	Scientific director, Performer	2												
2	Timetable of work on the topic	Performer	4												
3	Studying materials on the topic	Performer	14												
4	Creating composite materials	Performer	7												
5	Choosing a method of performing the work	Scientific director, Performer	9												
6	Study of radio-absorbing properties of composite materials	Performer	35												
7	Analysis of the results of work	Performer	16												
8	Writing a report on the work	Performer	6												

■ – Performer, ■ – Scientific director.

Thus, the management plan of the scientific project is built, the types of work are defined, the dates of the beginning and end of work and the composition of participants are set.

3.5 Research budget

When planning the STR budget, a full and accurate reflection of all types of costs associated with its implementation must be ensured. The following grouping of costs by item is used in the STR budgeting process:

– STR intangible assets;

– basic salary of the performers of the topic;

– Contributions to non-budgetary funds (insurance contributions);

– overhead.

These costs relate to direct costs, the amount of which, as a rule, should be determined by direct account, these costs associated directly with the implementation of a specific scientific and technical research, the remaining costs are calculated indirectly, this cost for the maintenance of general technical services.

3.5.1 Calculation of material costs

All work on the study of radiation shielding properties was carried out with the help of gamma-isotope installation ROCUS-AMT. As material costs will be presented the costs of raw materials for creation of composites: epoxy resin ED-20, nanopowder W-Cu, Fe-Pb, Fe-Cu. Material costs necessary for this development are entered in Table 3.12.

Table 3.12 – Material costs

Title	Price per unit, rubles	Quantity	Amount, rubles
ED-20 epoxy resin	500	1 L.	500
Nanopowder W-Cu	29.5	200 g.	5900
Nanopowder Fe-Pb	15.59	200 g.	3118
Nanopowder Fe-Cu	12.43	200 g.	2486
Total:	11504 rubles		

Thus, the total amount of material costs for this development was 11504 rubles. The most expensive material is W-Cu nanopowder, the necessary amount of which is 200 g, at a price of 29.5 rubles per unit.

3.5.2 Calculation of depreciation of equipment for experimental works

In work research of radio absorbing properties of composite materials was carried out. Researches were carried out by means of gamma-isotope installation ROCUS-AMT and a personal computer. All data and results are given in table 3.13.

Table 3.13 – Equipment costs

№	Title	Quantity, pcs.	Useful life, years	Unit price of equipment, rubles.	Total cost of equipment, rubles.
1	Rockus-AMT gamma-isotope unit	1	15	8000000	8000000
2	Personal computer	1	3	45000	45000
Total:	1045000 rubles.				

Depreciation is calculated as follows [37, 38]:

Depreciation rate is calculated according to the formula 3.3:

$$H_A = \frac{1}{n}, \tag{3.3}$$

where n – useful life, years.

Depreciation is calculated according to the formula 4.4:

$$A = \frac{H_A \cdot И}{12} \cdot m, \tag{3.4}$$

where $И$ – grand total, rubles;

m – time of use, months.

Let's calculate the depreciation of the gamma-isotope plant ROCUS-AMT, given that the useful life is 15 years:

$$H_A = \frac{1}{n} = \frac{1}{15} = 0.06$$

Let's calculate the depreciation for a personal computer, given that the useful life of 3 years:

$$H_A = \frac{1}{n} = \frac{1}{3} = 0.33$$

The total amount of depreciation charges is as follows:

ROCUS-AMT gamma-isotope unit:

$$A = \frac{H_A \cdot И}{12} \cdot m = \frac{0,06 \cdot 8000000}{12} \cdot 4 = 160000 \text{ rubles.}$$

Personal computer:

$$A = \frac{H_A \cdot И}{12} \cdot m = \frac{0,33 \cdot 45000}{12} \cdot 4 = 4950 \text{ rubles.}$$

The total cost of depreciation deductions:

$$A = 160000 + 4950 = 164950 \text{ rubles.}$$

This section calculates the depreciation of equipment for experimental works. The depreciation for the gamma-isotope installation ROCUS-AMT, given that the useful life of 15 years was 0.06, and the total amount of depreciation charges was 160000 rubles. Depreciation for a personal computer, given that the useful life of 3 years was 0.33, and the total amount of depreciation charges 4950 rubles. The total cost of depreciation charges 164950 rubles.

3.5.3 Labor costs of scientific and technical research performers

The item includes the basic salary of employees (including bonuses, additional payments) and additional wages:

$$C_{\cos t} = C_{\text{basic}} + c_{add}, \tag{3.5}$$

where C_{basic} – basic salary; C_{add} – additional salary.

The research supervisor's basic salary is calculated on the basis of the branch payroll. The sectoral system of remuneration of labor in the ISPMS SB RAS assumes the following composition of salaries:

1) Salary - determined by the company. At ISPMS SB RAS, salaries are distributed according to the positions held, e.g., assistant, lecturer, docent, professor.

2) Incentive payments - established by the head of departments for effective work, performance of additional duties, etc. Additional pay includes payment for time not worked (regular and training leave, performance of public duties, payment

of bonuses for length of service, etc.) and is calculated on the basis of 10-15% of the basic salary, employees directly involved in the implementation of the subject:

$$C_{add} = K_{add} \cdot C_{basic}, \quad (3.6)$$

where C_{add} – additional wages in rubles; K_{add} – additional wage rate; C_{basic} – basic salary in rubles.

The manager's basic salary is calculated according to the formula:

$$C_{basic} = T_{work} \cdot C_{aver.day}, \quad (3.7)$$

where C_{basic} – basic salary of one employee; T_{work} – duration of work performed by the research worker in working days; $C_{aver.day}$ – average daily salary of an employee in rubles.

The average daily wage is calculated by the formula 3.8:

$$C_{aver.day} = \frac{C_M \cdot M}{T_{work}}, \quad (3.8)$$

where $C_М$– employee's monthly salary, rubles.; M – the number of months of work without leave during the year: T_{work} – actual annual fund of working time of scientific and technical personnel, working days (Table 3.14).

Table 3.14 – Balance of working hours

Working time indicators	Director	Performer
Calendar number of days	365	365
Number of non-working days: Weekends/Holidays	118	66
Sick leave/non-sick leave	56	48
Actual annual working time fund	191	251

The performer during the writing of the master's thesis receives a monthly remuneration in the amount of the minimum wage of 13890 rubles. The research director's basic salary is calculated on the basis of the industry salary system. The industry salary system assumes the following salary composition:

– salary – determined by the company;

– incentive payments – established by the head of departments for effective work, performance of additional duties, etc.;

– extra pay for working in hazardous conditions;

– operational bonus.

The formula is used to calculate the monthly salary of an employee:

$$C_M = C_{salary} \cdot k_c, \tag{3.9}$$

where C_{salary} – salary, rubles;

$k_з$ – regional coefficient equal to 1.3.

The director of this research work is the head of the laboratory of nanobioengineering ISPMS SB RAS with a salary of 50000 rubles. Calculation of the basic salary is given in Table 3.15.

Table 3.15 – Calculation of basic wages

Performers	C_{salary}, rubles	C_M, rubles	$C_{aver.day}$, rubles	T_{work}, day	C_{basic}, rubles
Director	50000	65000	3209	11	35299
Performer	13890	18057	863	93	80817
Total C_{basic}	116116 rubles				

The cost of additional pay for executors of the topic takes into account the amount of additional payments for deviations from normal working conditions stipulated by the Labor Code of the Russian Federation, as well as payments related to the provision of guarantees and compensations.

The additional salary is calculated on the basis of 10-15% of the basic salary of the employees directly involved in the implementation of the topic.

We take the coefficient of additional wages for the research supervisor to be 15%. The results of the calculation of basic and additional salaries of research executors are presented in Table 3.16.

Table 3.16 – Salaries of the performers of the research work

Salary	Director	Performer
Basic salary	35299	80817
Additional salary, rubles	5294	12122
Performer's salary, rubles	40593	92939
Total C_{cost}, rubles	133532 rubles	

Thus, the section calculates the labor costs of the performers of scientific and technical research. The salary of the director – 40593 rubles, and that of the performer – 92939 rubles. The total salary of the executors was 133532 rubles.

3.5.4 Contributions to non-budgetary funds

The amount of contributions to non-budgetary funds is determined based on the following formula:

$$C_{non-budget} = k_{non-budget} \cdot (C_{basic} + C_{add}), \qquad (3.10)$$

где $k_{non\text{-}budget}$ – the coefficient of contributions to non-budgetary funds (pension fund, compulsory health insurance fund and social insurance). The total contribution rate is 30.2%.

The coefficient of deductions for payments to non-budgetary funds is:

$$k_{non-budget} = 0.302$$

Thus, deductions to non-budgetary funds from the cost of remuneration of the director are calculated as follows:

$$C_{non-budget} = 0.302 \cdot 40593 = 12259 \text{ rubles}$$

Contributions to non-budgetary funds from the labor costs of the performer are calculated as follows:

$$C_{non-budget} = 0.302 \cdot 92939 = 28067 \text{ rubles}$$

As a result of the calculations were determined deductions to non-budgetary funds from the labor costs of the head and executor, while the coefficient of deductions for payment to non-budgetary funds was 0.302. For the head, deductions made 12259 rubles, and for the executor 28067 rubles.

3.5.5 Overhead costs

This item includes the cost of maintaining the management and general services. This item includes wages of administrative and management personnel, maintenance of buildings, office equipment and supplies, depreciation of property, labor protection and training costs.

Overhead costs are calculated using the following formula:

$$C_{over} = k_{over} \cdot (\text{sum 1-6}), \qquad (3.11)$$

where k_{over} – coefficient of overhead costs equal to 0.16.

Overhead costs will be:

$$C_{over} = (164950 + 11504 + 133532 + 12259 + 28067) \cdot 0.16 = 56049 \text{ rubles}$$

Based on the obtained data on individual cost items, a calculation of the planned cost of the research project is made.

Table 3.17 – Grouping of costs by items

Items							
Depreciation charge	materials	Basic salary	Additional wages	Contributions to non-budgetary funds	Total without overhead	Overhead costs	Total project budget
164950 rubles	11504 rubles	116116 rubles	17416 rubles	28067 rubles	338053 rubles	56049 rubles	394102 rubles

As a result, the budget cost of scientific research was 394102 rubles. This cost includes: depreciation, the cost of raw materials, materials, basic wages, additional wages, deductions for social needs and overheads, which amounted to 56049 rubles at a ratio of overheads of 0.16.

3.6. Assessment of the absolute effectiveness of research

To assess the overall cost-effectiveness, the main indicators are used:

– net present value (NPV);

– profitability index (PI);

– internal rate of return (IRR);

– discounted payback period (DPP).

Net present value (NPV) – is an indicator of economic efficiency of an investment project, which is calculated by discounting (bringing to present value, i.e. at the time of investment) the expected cash flows (both income and expenses).

Calculation of NPV is carried out by the following formula:

$$NPV = \sum_{t=1}^{n} \frac{NCF_t}{(1+i)^t} - I_0$$

where: NCF_t – net cash flows from operating activities; I_0 – one-time investment made in year zero; t – number of calculation step (t = 0, 1, 2...n) n – calculation horizon; i – discount rate (desired level of return on invested funds).

The discount factor is calculated according to the formula:

$$DF = \frac{1}{(1+i)^t}$$

where: i – discount rate; t – calculation step.

Calculation of NPV allows you to judge the feasibility of investing money. If NPV>0, the project is effective.

The calculation of the net present value is presented in Table 3.18.

Table 3.18 – Calculation of the net present value of the project

№	Title	Calculation step				
		0	1	2	3	4
1	Proceeds from sales, rubles	0	120502	120502	120502	120502
2	Total inflow, rubles	0	120502	120502	120502	120502
3	Investment costs, rubles	394102	0	0	0	0
4	Operating costs, rubles	0	40000	40000	40000	40000
5	Taxable income (1-4)	0	80500	80500	80500	80500
6	Taxes, rubles (20%)	0	16100	16100	16100	16100
7	Net profit, rubles(5-6)	0	64400	64400	64400	64400
8	Net cash flow (NCF), rubles	-394102	162926	162926	162926	162926
9	Discount factor at i=10% (DF)	1	0.83333	0.69444	0.5787	0.48225
10	Net discounted cash flow (NDF), rubles (9·10)	-394102	135771	113142	94285	78571
11	$\sum NDF$, rubles	421769				
12	Total NPV, rubles	27667				

The profitability index (PI) is an indicator of investment efficiency, which is the ratio of discounted income to the amount of investment capital. This index allows you to determine the investment efficiency of investments in a given project. The profitability index is calculated according to the formula:

$$PI = \sum_{t=1}^{n} \frac{NCF_t}{(1+i)^t} / I_0 > 1,$$

where: NCF – net cash flow, rubles; I_0 – initial investment capital, rubles.

If PI>1, then the project is effective.

$$PI = \sum_{t=1}^{n} \frac{NCF_t}{(1+i)^t} / I_0 = 0.375828 + 0.341662 + 0.310602 + 0.282365 = 1.31$$

Internal Rate of Return (IRR). The value of the rate at which it turns to zero is called the "internal rate of return" or IRR. The formal definition of the "internal rate of return" is that it is the discount rate at which the sum of discounted cash inflows equals the sum of discounted outflows or =0. The difference between the IRR and the discount rate i indicates the economic strength of the investment project. The closer IRR is to the discount rate i, the greater the risk of investing in the project.

The most acceptable method of establishing a discounted payback period is the calculation of cumulative (cumulative) cash flow (Table 3.19).

Table 3.19 – Discounted payback period

№	Title	Calculation step				
		0	1	2	3	4
1	Discounted net cash flow, rubles	-394102	135771	113142	94285	78571
2	Same cumulative total, rubles.	-394102	-258331	-145189	-50904	27667
3	Discounted payback period	DPP_{disc} = 2.35 years				

Based on these results, we can conclude that the project is effective in terms of feasibility of investing cash, which is confirmed by the calculation of NPV, which was more than zero. The discounted payback period of the project is 2.35 years.

3.7. Determination of resource, financial, budgetary, social and economic efficiency of scientific research

Determination of effectiveness is based on the calculation of the integral indicator of the effectiveness of scientific research. Its finding is connected with the determination of two weighted averages:

Integral financial indicator of development:

$$I_{fin}^{per.i} = \frac{F_{pi}}{F_{max}}, \quad (3.12)$$

F_{pi} – the cost of the i-th performance option; F_{max} – maximum value of the research project.

Integral resource efficiency indicator:

$$I_{pi} = \sum a_i \cdot b_i , \quad (3.13)$$

where: a_i– weighting coefficient of the i-th development option; b_i – the i-th version of the development.

Calculation of the integral resource efficiency indicator is shown in Table 3.20.

Table 3.20 – Comparative assessment of the characteristics of project execution options

Criteria	Parameter weighting factor	Current project	Analogue
1. Helps to increase user productivity	0.10	4	3
2. Ease of use (meets the requirements of consumers)	0.15	5	4
3. Interference resistance	0.15	5	4
4. Energy Conservation	0.20	4	4
5. Reliability	0.25	4	4
6. Material-intensive	0.15	3	3
Total:	1	25	22

$$I_{cp} = 4 \cdot 0.1 + 5 \cdot 0.15 + 5 \cdot 0.15 + 4 \cdot 0.2 + 4 \cdot 0.25 + 3 \cdot 0.15 = 4.15$$

$$I_{\text{analogue}} = 3 \cdot 0.1 + 4 \cdot 0.15 + 4 \cdot 0.15 + 4 \cdot 0.2 + 4 \cdot 0.25 + 3 \cdot 0.15 = 3.75$$

The integral financial indicator of the development is determined by the formula $I_F^p = \frac{F_i}{F_{max}}$, where F_i – cost of the i-th version; F_{max} – maximum cost of STR performance (including analogues).

$$I_F^p = \frac{F_p}{F_{max}} = \frac{394102}{440000} = 0.897;$$

$$I_F^a = \frac{F_a}{F_{max}} = \frac{184000}{200000} = 0.92.$$

Integral indicator of the effectiveness of development options (I_{fin}^{p}) and analogue (I_{fin}^{a}) is determined on the basis of the integral index of resource efficiency and integral financial index by the formulas $I_{fin}^{p} = \frac{I_p}{I_F^p}$, $I_{fin}^{a} = \frac{I_a}{I_F^a}$:

$$I_{fin}^{p} = \frac{I_p}{I_F^p} = \frac{4.15}{0.897} = 4.627;$$

$$I_{fin}^{a} = \frac{I_a}{I_F^a} = \frac{3.75}{0.92} = 4.076.$$

Comparison of the integral efficiency of the current project and peers will determine the comparative effectiveness of the project.

The comparative effectiveness of the project is determined by the formula $E_{av} = \frac{I_{fin}^{p}}{I_p}$.

Table 3.21 – Comparative development effectiveness

Indicators	Analogue	Research
Integral index of resource efficiency of development and analogues	3.75	4.15
Integral indicator of the effectiveness of design variants and analogue	4.076	4.424
Comparative development effectiveness	1.087	1.115

Based on the calculation of the integral index with the definition of two weighted averages: financial efficiency and resource efficiency of scientific research, we can conclude that the project under development is a more effective option to solve the problem compared to the proposed analogue.

Conclusions of the section

1. Potential consumers of the results of the study are investment companies, private investors.
2. As a result of the analysis of competitive technical solutions the conclusion was made that composite materials based on epoxy resin and metal nanoparticlesCц-W, Fe-Pb and Fb-Cц due to their functional properties and cost are preferable to the X-ray shielding plate of Bi.
3. Strengths and weaknesses of the project are defined, opportunities and threats to the implementation of the project are identified. Based on the results of the SWOT-analysis, the most effective strategies are selected.
4. Assessment of the degree of readiness of scientific development for commercialization showed an average level, which can be improved through a more detailed study of the commercial component of the project.
5. In the process of planning a research project a management plan of the research project is built, types of work are defined, the dates of beginning and end of work and the composition of participants are set.
6. In planning the budget calculated material costs, the basic salary of the head and engineer, deductions to non-budgetary funds. The cost budget amounted to 394102 rubles.
7. Evaluation of the effectiveness of research has shown that the developed project is more effective option to solve the problem compared to the proposed analogue.
8. Assessment of the absolute efficiency of research showed that the project is effective in terms of feasibility of investing money, with a payback period of 2.35 years.

4 Social Responsibility

The paper studies composite materials based on epoxy resin and metallic nanoparticles obtained by electric wire explosion and evaluates the effect of the composition and morphology of nanoparticles on the radiation protective properties of composites.

The experiments were carried out in lecture room №009, Building 18, TPU at the Laboratory for Radiation Testing of Materials and Products (LRTMP) of the IS NDT&S. The gamma isotope facility ROCUS-M was used.

The section considers dangerous and harmful factors affecting the research process, considers the impact of the object under study on the environment, legal and organizational issues, as well as measures in emergency situations.

4.1 Legal and organizational security issues

4.1.1 Special (specific to the researcher's work area) legal norms of labor law

The main provisions on labor protection are set forth in the Labor Code of the Russian Federation. This document states that protecting the health of workers, ensuring safe working conditions, and eliminating occupational diseases and occupational injuries are among the main concerns of the state.

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

– a workplace that meets occupational safety requirements;

– mandatory social insurance against accidents at work and occupational diseases;

– o receives reliable information from the employer, relevant government agencies and public organizations about working conditions and labor protection at the workplace, the existing risk of health damage, as well as measures to protect against the effects of harmful and/or hazardous production factors;

– refusal to perform work in case of danger to his life and health due to violation of occupational safety requirements;

– provision of personal and collective protective equipment in accordance with labor protection requirements at the expense of the employer;

– training in safe work methods and techniques at the expense of the employer;

– personal participation or participation through his/her representatives in the review of issues related to safe working conditions in his/her workplace and in the investigation of a work-related accident or occupational disease that has occurred to him/her;

– an unscheduled medical examination in accordance with medical recommendations with preservation of his place of work (position) and average earnings while undergoing this medical examination;

– guarantees and compensations established in accordance with this Code, a collective agreement, an agreement, a local normative act, or an employment contract, if he/she is employed in harmful and (or) dangerous working conditions.

The Labor Code of the Russian Federation states that normal working hours may not exceed 40 hours per week, the employer must keep records of the time worked by each employee [40].

4.1.2 Organizational arrangements for the layout of the researcher's workspace

Rational planning of the workplace involves a clear order and consistency in the placement of items, tools and documentation. What is required to perform the work more often should be located within easy reach of the workspace, as shown in Fig. 4.1.

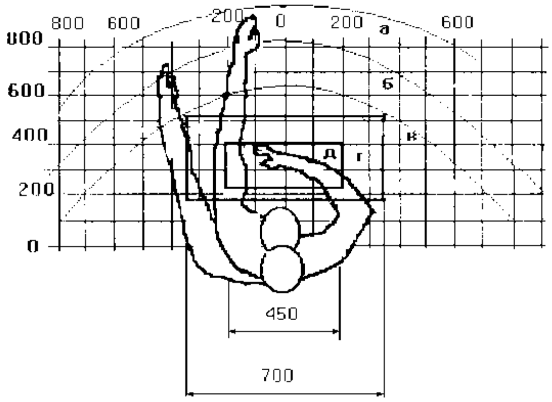


Fig. 4.1 – Hand reaches in the horizontal plane: a – maximum hand reach zone; b – finger reach zone with outstretched hand; c – light palm reach zone; d – optimal space for rough manual work; e – optimal space for fine manual work

Optimal placement of work items and documentation in hand-accessible areas:

- the display is placed in the area a (center);
- keypad – in area d, e;
- the system unit is placed in area b (left);
- the printer is in zone a (right);
- the literature and documentation needed for the work is within easy reach of the palm of your hand – in (left);
- in the drawers of the desk – literature that is not constantly used [41].

When selecting a workplace, namely a desk, the following requirements must be taken into account, which are presented in Table 4.1.

Table 4.1 – Requirements for the equipment of the workplace, which provides for prolonged work at a PC

Desktop width	From 80 to 140 cm
Desk height	75 cm
Desk depth	60 to 80 cm
Distance from eyes to the monitor	50 to 60 cm
Distance of keyboard from edge of desk	10 to 30 cm
Seat	Must allow for adjustments of height, rotation and angle of recline (adjustments must be independent of each other)
Legroom	Width from 30 cm, depth from 40 cm, with a tilt angle up to 20 degrees

The monitor must be positioned at eye level of the operator at a distance of 500-600 mm. According to the standards, the viewing angle in the horizontal plane should not be more than 45 degrees to the normal of the screen. Better if the viewing angle is 30 degrees. In addition, it should be possible to choose the level of contrast and brightness of the image on the screen [41].

It should also be possible to adjust the monitor screen:

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

If the operator's work involves monotonous mental work that requires considerable nervous tension and great concentration, it is best to choose dim, low-contrast color shades (weakly saturated shades of cool blue or green) that do not weaken attention. If work requires great mental and physical exertion, then warmer shades that help increase concentration should be used [41].

4.2 Industrial safety

4.2.1 Analysis of harmful and dangerous factors

For the experiments in the work is used gamma isotope unit ROCUS-M.

Industrial conditions at the place of work are characterized by the presence of dangerous and harmful factors, which by the nature of occurrence are divided into the following groups:

– physical;

– chemical;

– psychophysiological;

– biological [43].

Biological hazardous and harmful factors that may affect personnel when creating materials, conducting experiments, and working on a computer are shown in Table 4.2.

Table 4.2 – The main elements of the production process, forming hazardous and harmful factors

Name of types of work and parameters of the production process	Factors		Regulatory documents
	Harmful	Dangerous	
Working with composite materials	Chemical harmful substances.	–	GOST 12.1.007-76 SBT. Harmful substances [43], SanPiN 1.2.3685-21 "Hygienic Standards and Requirements to Ensure Safety and (or) Harmlessness to Man of Environmental Factors". [44]
Working with a gamma isotope facility.	Noise, vibration, microclimate; exposure to radiation (HF, UHF, microwave, etc.).	Ionizing radiation	SanPiN 1.2.3685-21 "Hygienic Norms and Requirements to Ensure Safety and (or) Harmlessness to Man of Environmental Factors" [44]. [44], Basic Sanitary Rules for Radiation Safety (OSPORB-99/2010) [45], SanPiN 2.6.1.2523-09 "Radiation Safety Standards (NRB-99/2009) [46]
		Fire hazard	GOST 12.1.004-91 SSBT. Fire safety [47].
Data processing on a PC.	Noise, vibration, microclimate; exposure to radiation (HF, UHF, microwave, etc.).	Electric current	The safety standards and requirements to ensure safety and (or) harmlessness for humans of environmental factors" [44], GOST 12.1.038-82 SSBT. Electrical safety [44], GOST 12.1.038-82 SSBT [48].

Psychologically harmful factors affecting personnel include:

- emotional overload;
- mental stress;
- physical overload.

There are no biological hazardous industrial factors in the LRTMP room of the 18th building of the TPU.

4.3 Rationale for measures to protect the researcher from harmful and dangerous factors

4.3.1 Chemical harmful substances

The composite materials used were ED-20 epoxy resin with a PEPA (polyethylene polyamines) hardener. While the epoxy compound is slightly toxic, the hardener can cause burns when in contact with the skin and release volatile toxic substances during the chemical reaction.

Table 4.3 shows the maximum allowable concentrations (MAC) of the main hardener components and their hazard class [43].

Hazard classes:

1 – extreme hazards;

2 – highly hazardous substances;

3 – moderately hazardous substances;

4 – low-hazard substances [45].

Table 4.3 – Maximum permissible concentrations (MPC) of the main hardener components and their hazard class

№	Substance	MAC, mg/m^3	Hazard classes
1	Ethylenediamine	2.0	3
2	Diethylentriamine	0.3	2

Thus, personal skin, eye and respiratory protection must be worn when working with epoxy and hardener.

The following personal protective equipment was used: rubber gloves, lab coat, "petal" respirator [49].

4.3.2 Ionizing radiation

As a result of exposure to ionizing radiation, the normal course of biochemical processes and metabolism is disturbed in the human body. Depending on the magnitude of the absorbed dose of radiation and on the individual characteristics of the body, the changes caused may be reversible or irreversible.

When working with sources of ionizing radiation, the total annual effective doses should not exceed 20 mSv/year for Group A personnel, 5 mSv/year for Group B personnel, and 1 mSv/year for the general population [46].

The experiments were performed using the ROCUS-M gamma isotope facility. The gamma radiation source was cobalt-60 isotope. Operation of this facility is regulated in the normative legal act [45] and refers to the section "Work with sealed radionuclide sources and devices generating ionizing radiation. According to it, the following requirements must be satisfied:

1. For radioisotope devices intended for use in production conditions, the equivalent dose rate at the surface of a unit with a closed radionuclide source should not exceed 100 μSv/h, and at a distance of 1 m from it - 3.0 μSv/h [45].

2. The operating part of stationary devices and installations with an unrestricted beam of radiation shall be located in a separate room (preferably in a separate building or a separate wing of the building); the material and thickness of walls, floor, ceiling of this room at any position of the source and the direction of the beam of radiation shall provide attenuation of ionizing radiation in adjacent rooms and in the organization territory to permissible values. The control panel for such an apparatus (installation) shall be located in a room separate from the source of ionizing radiation. The entrance door to the room where the apparatus is located should be blocked with a mechanism to move the ionizing radiation source or with a high (accelerating) voltage turned on so as to exclude the possibility of accidental exposure of personnel [45].

These requirements are fully satisfied by the lecture room № 009 LRTMP of the 18th building of the TPU.

4.3.3 Deviation of microclimate indicators

The air of the working area (microclimate) of the production facilities is determined by the following parameters: temperature, relative humidity, air velocity. The optimum and permissible values of the characteristics of the microclimate are established in accordance with the standards and are shown in Table 4.4.

Table 4.4 – Optimal microclimate parameters

Period of the year	Temperature, ºC	Relative humidity, %	Air velocity, m/s
Cold	23-25	40-60	0,1
Warm	22-24	40	0,1

Deviation of microclimate parameters from the norm does not cause injuries or health disorders, but can lead to general and local sensations of thermal discomfort, tension of thermoregulatory mechanisms, deterioration of well-being and lowered performance [44].

To ensure the established norms of microclimatic parameters and air purity in the workplace and rooms, ventilation is used.

Ventilation can be carried out by natural and mechanical means. The optimum rate of air exchange in production facilities is in a fairly wide range: from 3 to 40 times per hour [42]. The used laboratory is equipped with high-pressure exhaust fan VR-12-26-4 with capacity Q = 2400 - 4400 m^3/hour. The volume of the LRTMP room of the 18th building of the TPU is:

$$V = a \cdot b \cdot h = 11\ \text{m} \cdot 5\ \text{m} \cdot 4\ \text{m} = 220\ \text{m}^3. \quad (1)$$

This fan provides the following air exchange ratio (AER) in the laboratory:

$$BO = \frac{Q}{V} = (2400 \div 4400) / 220 = 10.9 \div 20\ \text{h}^{-1}. \quad (2)$$

Thus, it was found that the microclimate in the lecture room № 009 LRTMP of the 18th building of the TPU corresponds to the optimum working conditions.

4.3.4 Increased level of electromagnetic radiation

Electromagnetic radiation is a disturbance (change of state) of an electromagnetic field that propagates in space.

The screen and the computer system units produce electromagnetic radiation. Most of it comes from the system unit and video cable. The electromagnetic field strength at a distance of 50 cm around the screen in the electric component must comply with the allowable standards [44] given in Table 4.5.

Increased levels of electromagnetic radiation can adversely affect the human body, namely lead to nervous disorders, sleep disorders, significant deterioration of visual activity, weakening of the immune system, disorders of the cardiovascular system [44].

Table 4.5 – Permissible levels of electromagnetic field parameters

Title		Value of permissible level
Electromagnetic field strength	Frequency range 5 Hz – 2 kHz	25 V/m
	Frequency range 2 kHz – 400 kHz	2.5 V/m
Magnetic flux density	Frequency range 5 Hz – 2 kHz	250 nT
	Frequency range 2 kHz – 400 kHz	25 nT

There are the following ways to protect against EMF:

− increased distance from the source (the screen should be at least 50 cm from the user);

− the use of near-shield filters, special screens, and other personal protective equipment [44]

Thus, it was found that the level of electromagnetic radiation in lecture room № 009 of LRTMP of the 18th building of the TPU complies with sanitary norms.

4.3.3 Insufficient lighting of the work area

Visual fatigue can be associated with both insufficient light and excessive light, as well as with the wrong direction of light.

According to the regulations the illumination on the surface of the table in the area of the working document should be 300-500 lux. Lighting should not create glare on the screen surface. Illumination of the screen surface should not be more than 300 lux [44].

The brightness of general lighting fixtures in the zone of radiation angles from 50 to 90° with the vertical in the longitudinal and transverse planes should be no more than 200 cd/m, the protective angle of fixtures should be at least 40°. The safety factor (K_s) for general lighting installations shall be 1.4. Pulsation factor should not exceed 5%.

Artificial lighting in the rooms for the operation of PCs should be:

1. A system of general uniform lighting.
2. In production and administrative and public spaces, in cases of preferential document handling, systems should be used:

– combined lighting (in addition to the general lighting, luminaires are installed;

– local lighting designed to illuminate the document area) [44].

Room area:

$$S = a \cdot b, \tag{3}$$

where A – length, m; B – width, m.

$$S = 4 \cdot 5 = 20 \text{ m}^2,$$

Reflection coefficient of freshly whitewashed walls with windows, without curtains $\rho_w = 50$ %, freshly whitewashed ceiling $\rho_c = 70$ %. The safety factor, which takes into account the contamination of the luminaire, for rooms with low dust emission is equal to $K_s = 1.5$. Unevenness factor for LED strips Z = 1,1.

We choose Varton 9w LEDs, whose luminous flux is equal to $F_{lf} = 2900$ lm.

We choose the luminaires with LEDs type Diora LPO. This luminaire has two LED strips of 9 W each, the length of the luminaire is 1260 mm, width - 124 mm.

Integral criterion for the optimality of the location of lighting fixtures is the value of λ, which for LED lighting fixtures with a protective diffuser is in the range of 1.1–1.3. We take λ the distance of the luminaires from the ceiling (overhang) $h_c = 0{,}5$ m.

The height of the luminaire above the work surface is determined by the formula:

$$h = h_c - h_{ws}, \tag{4}$$

where h_c – height of the luminaire above the floor, suspension height, h_{ws} – work surface height above the floor.

Minimum permissible suspension height above the floor for double luminaires Diora: h_c = 3,5 m.

The height of the luminaire above the work surface is determined by the formula:

$$h = H - h_c - h_{ws} = 3{,}5 - 1 - 0{,}5 = 2 \text{ m.} \tag{5}$$

From the formula:

$$F_l = \frac{(E \cdot S \cdot K_s \cdot Z)}{N \cdot \eta} \tag{6}$$

find the number of LED strips N:

$$N = \frac{(E \cdot S \cdot K_s \cdot Z)}{F_l \cdot \eta}. \tag{7}$$

η is determined by the room index according to the formula:

$$i = \frac{(a \cdot b)}{h \cdot (a + b)} = \frac{4 \cdot 5}{2 \cdot (4 + 5)} = 1.1. \tag{8}$$

Luminous flux utilization factor, showing what part of the luminous flux of the lamps reaches the working surface, for Diora luminaires with LED strips at $\rho_c = 70$ %, $\rho_w = 50$ % and room index i = 1.1 is equal to η = 0.45.

Then

$$N = \frac{(E \cdot S \cdot K_s \cdot Z)}{F_l \cdot \eta} = \frac{300 \cdot 20 \cdot 1.5 \cdot 1.1}{2900 \cdot 0.45} = 7.59\ LED.$$

Take the number of LED strips 8. This results in 4 luminaires, i.e. 2 rows of 2 luminaires.

Required luminous flux of LED luminaries:

$$F_l = \frac{(E \cdot S \cdot K_s \cdot Z)}{N \cdot \eta} = \frac{300 \cdot 20 \cdot 1.5 \cdot 1.1}{8 \cdot 0,45} = 2750 \text{ lm}.$$

From the conditions of uniformity of illumination we determine the distances L_1 and $\frac{L_1}{3}$, L_2 and $\frac{L_2}{3}$ by the following equations:

$$4000 = L_1 + \frac{2}{3} \cdot L_1 + 2 \cdot 124;\ L_1 = 2251 \text{ mm},\ \frac{L_1}{3} = 750 \text{ mm}; \quad (9)$$

$$5000 = L_2 + \frac{2}{3} \cdot L_2 + 2 \cdot 1260;\ L_2 = 1488 \text{ mm},\ \frac{L_2}{3} = 496 \text{ mm}; \quad (10)$$

Fig. 4.2 shows the plan of the room and the location of the LED strip lights in the LRTMP room of the 18th building of the TPU.

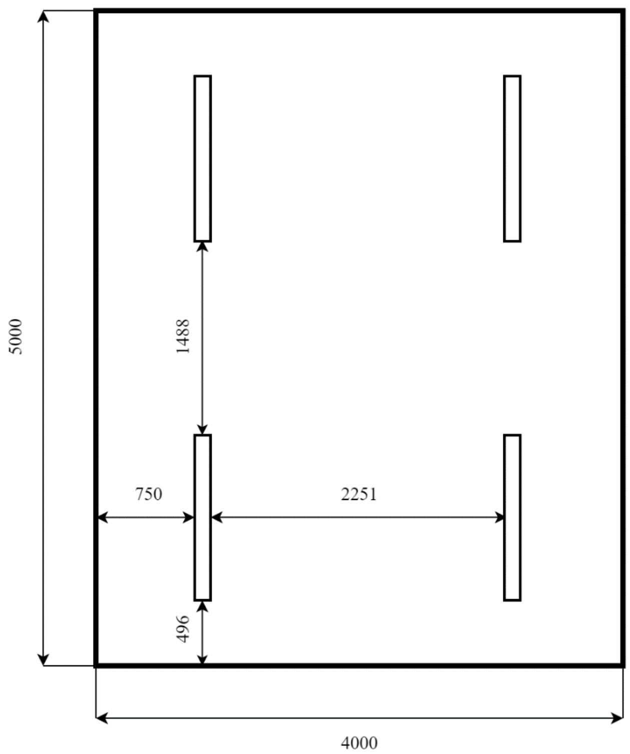


Fig. 4.2 – Plan of the room and placement of LED strip lights

We check if the condition is met:

$$\frac{-10\% \le (F_{lf} - F_l)}{F_{lf}} \cdot 100\% \le 20\%; \qquad (11)$$

$$\frac{(F_{lf} - \Phi_l)}{F_{lf} \cdot 100\%} = \frac{(2900 - 2750)}{2900} \cdot 100\% = 5.17\%.$$

Thus, we obtained that the required luminous flux does not go beyond the required range. The power of the lighting installation turned out to be:

$$P = 8 \cdot 9 = 72\ W.$$

The calculated number of lights corresponds to the actually installed in the lecture room № 009 LRTMP of the 18th building of the TPU.

4.3.4 Excessive noise level

Noise, as a general biological stimulus, affects not only the auditory analyzer, but also affects the structures of the brain, causing shifts in various functional systems of the body. Among numerous manifestations of the adverse effects of noise on the human body are: decreased speech intelligibility, unpleasant sensations, the development of fatigue and reduced productivity. In our case, the source of noise is a pumping compressor. Noise level of the compressor is less than 55 dB, which corresponds to sanitary norms [44].

Table 4.6 shows the noise level standards for various types of work.

Table 4.6 – Noise level standards for various types of work

	Maximum allowable noise level (dB), in the following octave bands (Hz)									Equivalent noise levels, dB
Scientific work, calculations, design	86	71	61	54	49	45	42	40	38	50
Offices, laboratories	93	79	70	68	58	55	52	52	49	55

4.3.5 Psychophysiological factors

Psychophysiological hazardous and harmful work factors are divided into: physical overload (static, dynamic) and neuropsychological overload (mental overload, monotony of work, emotional overload).

Labor activity of workers of non-productive sphere refers to the category of work associated with the use of large amounts of information, with the use of computerized jobs, with the frequent adoption of critical decisions in conditions of time deficit, direct contact with people of different types of temperament, etc. This causes a high level of neuro-psychological overload, reduces functional on the activity of the central nervous system, leads to disorders in its activity, the development of fatigue, overwork, stress.

The most effective means of preventing fatigue at work are the means that normalize the active work activity of a person. Against the background of the normal course of production processes one of the important physiological measures against fatigue is the correct mode of work and rest [44].

4.3.6 Electric shock

The working room according to the danger of electric shock can be classified as Class 2, i.e., it is a room without an increased hazard due to the possibility of simultaneous human contact with metal structures having a connection with the ground, technological devices, mechanisms, etc., on the one hand, and with metal housings of electrical equipment – on the other hand [48].

There is a risk of electric shock in the following cases:

- by direct contact with live parts during repair;
- when touching live, non-current parts that have been energized (in case of a fault in the insulation of live parts);
- when touching the floor, walls, which have been energized;

– when there is a short circuit in the high-voltage units: power supply unit and display sweep unit [48].

The degree of dangerous effects of electric current on the human body depends on:

- type and magnitude of voltage and current;
- frequency of electrical current;
- the paths of current through the human body;
- duration of exposure to the human body;
- environmental conditions [44].

Electric current has thermal, electrolytic, mechanical, and biological effects on humans [48].

Thermal effects of current manifest themselves in burns, heating of blood vessels and other organs, resulting in functional disorders in them [48].

The electrolytic effect of current is characterized by the decomposition of blood and other organic fluids, which causes violations of their physical and chemical composition [48].

The mechanical effect of current manifests itself in damage (tearing, splitting, etc.) to various tissues of the body as a result of the electrodynamic effect [18].

The biological effect of current on living tissue is expressed in dangerous excitation of cells and tissues of the body, accompanied by involuntary convulsive muscle contractions. As a result of such excitation there may be a disruption or even complete cessation of respiratory and circulatory activity [44].

The main measures to protect against electric shock are [48]:

- ensuring the inaccessibility of live parts through the use of insulation in equipment enclosures;
- use of means of collective protection against electric shock;
- use of protective earthing, protective grounding, protective disconnection;
- use of uninterruptible power supply devices.

Technical methods and means are used separately or in combination with each other so as to provide optimum protection.

Organizational measures for electrical safety are periodic and unscheduled briefings. Periodic briefings are held for all non-electrotechnical personnel performing the following work: switching on and off electrical appliances, cleaning rooms near electric boards, sockets and switches, etc. All non-electrotechnical personnel must be certified to the first qualification group for electrical safety. Periodic briefings are held at least once a year [48].

Unscheduled briefings are conducted by the head of the unit when new technical electrical equipment is put into operation.

4.4 Environmental safety

Radiation shielding properties of composite materials based on epoxy resin and metallic nanoparticles are investigated in this work. At the same time, the gamma-isotope installation ROCUS-AMT is used for the experiments, and a PC is used for data processing.

The impact of equipment operation on the environment is minimal. The greatest harm is possible only in case of improper transportation of cobalt-60 and failure of the protective hopper as a result of which radioactive contamination of the area may occur. The probability of this accident is minimal, so the main factor negatively affecting the environment is increased power consumption. Increased consumption of electricity leads to increased demand for the generation of WPP, TPP or NPP, which, in turn, leads to increased consumption of natural resources and an increase in greenhouse gas emissions into the atmosphere, deterioration of the microclimate, flora and fauna of geographical space (in the case of WPP) or to an increase in the amount of spent nuclear fuel.

The production and disposal of PCs is a serious environmental problem. Heavy metals, alkaline-earth metals, mercury, plastics and glass are used in the production of PCs and other devices that, without proper recycling, at the end of their service life enter the environment and remain in unprocessed form for centuries to a thousand and a half years [44].

Measures to maintain environmental safety while in the workplace [44]:

– proper disposal of PCs and other systems and their components;
– using energy-saving lamps;
– using rechargeable batteries instead of saline batteries.

Reducing the level of environmental pollution is possible through more efficient and economical use of electricity by the consumers themselves. This is the use of more economical equipment, as well as the efficient loading mode of this equipment. This also includes the observance of production discipline as part of the proper use of electricity [44].

4.5 Fire and explosion safety

Depending on the characteristics of the substances used in production and their quantity, the premises are divided into categories A, B, C, D, E in terms of fire and explosion hazard [47]. Since the laboratory room belongs to category C in terms of fire and explosion hazard, i.e., to rooms with solid combustible substances, it is necessary to provide a number of preventive measures.

Possible causes of fire [47]:

– working with exposed electrical equipment;
– short circuits in the power supply;
– failure to comply with fire safety rules;
– presence of combustible components.

Fire prevention measures are divided into: organizational, technical, operational and regime [47].

Organizational measures include proper operation of equipment, proper maintenance of buildings and territories, fire instruction of workers and employees, training of production personnel in fire safety rules, publication of instructions, posters, availability of an evacuation plan [47].

Technical measures include: compliance with fire regulations, standards in the design of buildings, construction of electrical wiring and equipment, heating, ventilation, lighting, proper placement of equipment [47].

Regulatory measures include the establishment of work organization rules and the observance of fire safety measures. To prevent fires from short circuits, overloads, etc., the following fire safety rules must be observed [47]:

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

– correct operation of the equipment (correct connection of the equipment to the electric power supply network, control of the equipment heating);

– proper maintenance of buildings and areas (avoiding the formation of an ignition source - preventing spontaneous combustion of substances, limiting fire work);

– training of production personnel in fire safety rules;

– publication of instructions, posters, availability of an evacuation plan;

– compliance with fire regulations, standards in the design of buildings, in the construction of electrical wiring and equipment, heating, ventilation and lighting;

– correct placement of equipment;

– timely preventive inspection, repair and testing of equipment.

In the event of a fire, inform the manager, the fire safety authorities of the company and proceed to extinguish the fire with a fire extinguisher.

In the event of an emergency situation, it is necessary to [47]:

– to inform the management (the person on duty);

– call the appropriate emergency service or the Ministry of Emergency Situations at 112;

– take measures to eliminate the consequences of the accident in accordance with the instructions.

4.7 Safety in emergency

4.7.1 Analysis of a typical emergency when conducting research

Emergency – the situation developed in a particular territory as a result of an accident, natural hazard, catastrophe, natural or other disaster, which may cause human casualties, damage to human health or the environment, significant material losses and disruption of human life.

Fire is the most probable emergency in the study. Fire in the working room can occur due to non-electrical and electrical causes. Table 4.7 describes possible emergencies, methods of their prevention and elimination of their consequences.

Table 4.7 – Emergencies, methods of prevention and elimination of consequences

№	Emergency	Emergency prevention methods	Elimination of consequences of emergencies
1	Fire	Conducting introductory and repeated (after 6 months) briefing; Observance of technological modes of production; Creating conditions for evacuation of personnel	Calling the fire department and rescuers (tel. 112); Calling an ambulance
2	Electric shock	Conducting introductory and repeated (after 6 months) briefings; Maintaining energy systems in good working order	Calling an ambulance (tel. 030, 112); Providing first aid
3	Injury from falling from a height	Conducting introductory and repeated (after 6 months) briefings; Establishing fall prevention systems; Comply with safety requirements when working at height	Calling an ambulance (tel. 030, 112); Providing first aid

Conclusions of the section

This section analyzes harmful and hazardous factors that may occur in the workplace during research:

- chemical harmful substances [43];
- ionizing radiation [45,46];
- microclimate [44];
- noise and vibration [44];
- electromagnetic radiation [44];
- illumination [44];
- psychophysiological factors [44];
- electrical safety [48];
- fire and explosion safety [47].

The LRTMP room of the 18th building of the TPU is referred to:

- electrical safety – 2nd grade [48];
- fire and explosion safety – category C [47].

Possible emergencies, methods of their prevention and elimination of consequences are also considered.

Conclusions

1. Bimetallic W-Cu, Fe-Pb, and Fe-Cu nanopowders were produced by the method of joint electric explosion of conductors.
2. The produced nanopowders had core-shell and Janus-particle structures. The average size of the W-Cu, Fe-Pb, and Fe-Cu nanoparticles was 46, 98.2, and 62.8 nm, respectively. All powders had a normal logarithmic distribution and no supersaturated solution-based phases.
3. Radiation shielding properties of composite materials based on epoxy resin and synthesized nanopowders were investigated. The sample filled with W powder (half-attenuation layer thickness 6.408 cm) showed the best shielding effect among all composites. Among the bimetallic systems, the sample filled with Fe-Pb (half-attenuation layer thickness 6.807 cm) has the best parameters. These results correspond to the classical concepts of radiation shielding.
4. Bimetallic systems W-Cu, Fe-Pb and Fe-Cu showed insignificant difference of shielding effect among themselves and in comparison with other fillers. At the same time, composites based on W-Cu and Fe-Cu combine good electrical and thermal conductivity of the copper skeleton with the high strength and electrical erosion resistance of iron and tungsten [21, 29], which demonstrates the wide possibilities of using these materials in the aerospace and nuclear industries.

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