TOMSK POLYTECHNIC UNIVERSITY
ТОМСКИЙ ПОЛИТЕХНИЧЕСКИЙ УНИВЕРСИТЕТ

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

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

МАГИСТЕРСКАЯ ДИССЕРТАЦИЯ

Тема работы
Исследование влияния хромовых покрытий на эксплуатационные параметры реактора

УДК 621.039.53:621.039.577

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Томск – 2022 г.

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

MASTER THESIS

Topic of research work
Research of the influence of chromium coatings on the operational parameters of the reactor

UDC 621.039.53:621.039.577

Student

Group	**Full name**	**Signature**	**Date**
0AM0I	Proskurin Artem Pavlovich		

Scientific supervisor

Position	**Full name**	**Academic degree, academic rank**	**Signature**	**Date**
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Section “Financial Management, Resource Efficiency and Resource Saving”

Position	**Full name**	**Academic degree, academic rank**	**Signature**	**Date**
Associate Professor	Luibov Y. Spicyna	PhD		

Section “Social Responsibility”

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

ADMITTED TO DEFENSE:

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

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 manage personnel, taking into account the motives of behavior and ways of developing business behavior of personnel, apply methods for assessing the quality and performance of personnel, develop and implement measures aimed at preventing industrial injuries and environmental violations.
PC(U)-2	Ability to develop and ensure the implementation of measures aimed at improving, modernizing, unifying manufactured devices, facilities and their components, developing standards and certificates, improving reliability of equipment operation.
PC(U)-3	Ability to apply basic methods, techniques and means of obtaining, storing, processing information to plan and manage the life cycle of manufactured products and their quality.
PC(U)-4	Ability to create theoretical and mathematical models describing the condensed state of matter, the propagation and interaction of radiation with matter, the physics of kinetic phenomena, processes in reactors, accelerators, the effect of ionizing radiation on materials, humans and environmental objects.
PC(U)-5	Ability to use fundamental laws in the field of nuclear physics, nuclear reactors, condensed matter, ecology in a volume sufficient for independent combination and synthesis of real ideas, creative self-expression.
PC(U)-6	Ability to evaluate prospects for the development of the nuclear industry, use its modern achievements and advanced

	technologies in research activities related to the development of technologies for obtaining new types of fuel and materials, radioactive waste management methods and techniques.
PC(U)-7	Ability to assess risks and determine safety measures applied for new facilities and technologies, draw up and analyze scenarios of potential accidents, develop methods to reduce the risk of their occurrence.
PC(U)-8	Ability to analyze technical and computational-theoretical developments, take into account their compliance with the requirements of laws in the field of industry, ecology and safety, and other regulations.
PC(U)-9	Ability to carry out independent experimental or theoretical research to solve scientific and technical problems using modern equipment, calculation and research methods.
PC(U)-10	Ability to draw up technical assignments, use information technology, standard design automation tools and application software packages in the design and calculation of nuclear facilities, materials and devices, apply knowledge of methods of ecological efficiency and economic-value analysis in the design and implementation of projects.
PC(U)-11	Ability to develop design process documentation, execute engineering design and production projects.
PC(U)-12	Ability to conduct training sessions and develop instructional materials for the training courses within the cycle of professional training programs (bachelor degree programs).

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

APPROVED BY:
Program Director
______________ Verkhoturova V.V.
«____» _____________ 2022

ASSIGNMENT
for the Graduation Thesis completion

In the form:

Master Thesis

For a student:

Group	Full name
0AM0I	Artem P. Proskurin

Topic of research work:

Research of the influence of chromium coatings on the operational parameters of the reactor	
Approved by the order of the Director of School of Nuclear Science & Engineering (date, number):	№ 32-6/c dated February 1, 2022

Deadline for completion of Master Thesis:	06.06.2022

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.)*	- VVER-1000 - 4% enrichment in U^{235} - Cr, CrN, Ni_9Cr, NiCr, $NiCr_9$ materials for coatings - 5, 10, 20, 40 microns of thickness for coatings
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).*	- to determine influence of coatings of different thicknesses and materials on neutron-physical parameters of nuclear reactor VVER-1000 type

List of graphic material *(with an exact indication of mandatory drawings)*	Map of fuel assembly built in MCU program, presentation

Advisors to the sections of the Master Thesis *(with indication of sections)*	
Section	**Advisor**
Financial management, resource efficiency and resource saving	Luibov Y. Spicyna
Social responsibility	Yuriy V. Perederin

Date of issuance of the assignment for Master Thesis completion according to the schedule	03.02.2022

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

Position	Full name	Academic degree, academic status	Signature	Date
Associate professor	Michael S. Kuznetsov	PhD		

Assignment accepted for execution by a student:

Group	Full name	Signature	Date
0AM0I	Artem. P. Proskurin		

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

To the student:

Group	Full name
0AM0I	Artem P. Proskurin

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

Input data to the section «Financial management, resource efficiency and resource saving»:	
1. *The cost of scientific research resources (SR): logistical, energy, financial, informational and human*	The cost of material resources was estimated at the average cost for the city of Tomsk. Salaries in accordance with the salaries of employees of «TPU»
2. *Expenditure rates and expenditure standards for resources*	Overhead costs - 10%; District coefficient - 30%; Depreciation rate - 33.3%.
3. *Current tax system, tax rates, charges rates, discounting rates and interest rates*	Deductions to off-budget funds amount to 30%
The list of subjects to study, design and develop:	
1. *Assessment of commercial and innovative potential of STR*	Comparative analysis with other researches in this field; SWOT-analysis.
2. *Scheduling of STR management process: structure and timeline, budget, risk management*	Work planning; Development of the Gantt chart; Formation of the budget for design costs.
3. *Resource efficiency*	Description of the potential effect.
A list of graphic material *(with list of mandatory blueprints)*:	
1. *Competitiveness analysis* 2. *SWOT- analysis* 3. *Gantt chart and budget of scientific research* 4. *Assessment of resource, financial and economic efficiency of STR* 5. *Potential risks*	

Date of issue of the task for the section according to the schedule	31.01.2022

Task issued by adviser:

Position	Full name	Scientific degree, rank	Signature	Date
Associate professor	Spitsyna L. Yu.	PhD in Economics		31.01.2022

Task was accepted by the student:

Group	Full name	Signature	Date
0AM0I	Artem P. Proskurin		31.01.2022

ASSIGNMENT FOR THE DIPLOMA PROJECT SECTION «SOCIAL RESPONSIBILITY»

For a student:

Group	Full Name
0AM0I	Artem P. Proskurin

School	Nuclear Science and Engineering	Department	Nuclear Fuel Cycle
Education level	Master degree	**Specialization**	14.04.02 Nuclear Science and Technology / Nuclear Power Engineering

Topic of Master Thesis:

Research of the influence of chromium coatings on the operational parameters of the reactor	
Initial data for the section "Social Responsibility":	
1. Information about object of investigation (matter, material, device, algorithm, procedure, workplace) and area of its application	– VVER-1000 reactor – chromium coatings on VVER-1000 type reactor.
Problems to research, design and develop:	
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;	– Labor Code of the Russian Federation; – СанПиН 1.2.3685-21; – СНиП 41-01-2003; – ТОИ Р-45-084-01; – ГОСТ 12.1.038-82; – СНиП 21-01-97; – ГОСТ 12.1.007-76.
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	– indoor climate; – quality of illumination; – ionizing radiation; – noise.
3. Safety in emergency situations:	– selection of possible emergencies during the operation of the object under consideration and the procedure for actions during them.

Date of issuance of the assignment for Master Thesis completion according to the schedule	31.01.2022

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

Position	Full name	Academic degree, academic status	Signature	Date
Associated Professor Division of Nuclear Fuel Cycle of Nuclear Science and Engineering School	Yuriy V. Perederin	PhD		

Assignment accepted for execution by a student:

Group	Full name	Signature	Date
0AM0I	Artem P. Proskurin		

TOMSK POLYTECHNIC UNIVERSITY | ТОМСКИЙ ПОЛИТЕХНИЧЕСКИЙ УНИВЕРСИТЕТ

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«Национальный исследовательский Томский политехнический университет» (ТПУ)

School of Nuclear Science & Engineering
Field of training (specialty): 14.04.02 Nuclear Science and Technology
Specialization: Nuclear Power Engineering

Level of education: Master degree program
Nuclear Fuel Cycle Division
Period of completion: spring semester 2021/2022 academic year

Form of presenting the work:

Master Thesis

SCHEDULED ASSESSMENT CALENDAR
for the Master Thesis completion

Deadline for completion of Master's Graduation Thesis:	06.06.2022

Assessment date	Title of section (module) / type of work (research)	Maximum score for the section (module)
03.02.2022	Goal and objectives setting	
13.02.2022	Special literature section and studying	
16.02.2022	Timetable development	
18.02.2022	Literature discussion	
18.03.2022	Creation of model of VVER-1000 type reactor in MCU	
22.04.2022	Calculation neutron-physical parameters of the model without coating	
20.05.2022	Calculation neutron-physical parameters of the model with considered coatings	
27.05.2022	Settlement explanatory note preparation	
31.05.2022	Provision of a finished master`s thesis	

COMPILED BY:
Scientific supervisor:

Position	Full name	Academic degree, academic status	Signature	Date
Associate professor	Michael S. Kuznetsov	PhD		

APPROVED BY:

Program Director	Full name	Academic degree, academic status	Signature	Date
Nuclear Power Engineering	Vera V. Verkhoturova	PhD		

Abstract

Master thesis consist of 77 pages, 26 figures, 20 tables, 30 sources.

Key words: tolerant fuel, VVER-1000, campaign duration, chromium coatings.

The object of research is a nuclear reactor with chromium compounds coatings on casing of the core.

The purpose of the work: to study the influence of presence of chromium compounds coatings on neutron-physical parameters of the reactor.

In the course of the study, modeling of the core of the VVER-1000 reactor was carried out with the addition of coatings based on chromium compounds of different compositions and thicknesses to the claddings of fuel assemblies and fuel elements.

As a result of the calculations, the neutron-physical characteristics of the reactors were determined and compared.

The main design, technological and technical and operational characteristics are: thermal power of VVER-1000 - 3000 MW, fuel - uranium dioxide, coolant and moderator – water, coatings – chromium, chromium nitride, nichromium.

Scope: nuclear power, design bureaus, power supply of remote areas.

Content

Introduction

In the modern world, the issue of energy production is very acute. Installations developed around the world for the production of energy must meet a number of requirements. Such requirements include the cheapness of the installation and the safety of its operation throughout the entire process. One way to solve this problem is the development of nuclear energy.

Today, about 450 nuclear reactors are operated in the world, and along with them, new power units are being built. There are several options for the design of nuclear reactors - in many countries, development was carried out at the same time. PWR (pressurized water reactor), BWR (boiling water reactor) - is mainly used in Europe and Asia, ВВЭР (водо-водяной энергетический реактор) (российская разработка, нет перевода) is a Russian reactor design, CANDU is a reactor developed in Canada.

Basic nuclear fuel - fuel assemblies (fuel assemblies) containing fuel elements (fuel element). The fuel elements of light-water thermal neutron reactors consist of shells made of zirconium-based alloys and nuclear fuel in the form of tablets of a uranium composite. The cladding of a fuel rod is the first physical security barrier to the exit of fission products of nuclear fuel into the coolant, which means that it must meet certain requirements for wear resistance.

Due to the good balance between corrosion resistance, neutron transparency and mechanical properties, zirconium-based alloys have been used since the 1960s for the production of fuel elements in light-water reactors (LWR). However, after the accident at the Fukushima-Daiichi NPP in 2011, there has been an increase in international efforts to develop cladding materials with increased accident resistance (tolerant fuel) [1-6]. One of the main goals of this development is to increase the resistance of the nuclear fuel shell to oxidation under the influence of steam at high temperature, which is typical for such hypothetical design accidents as accidents with loss of coolant.

When studying the properties of zirconium-based alloys (E110, zirkaloy-4, etc.), a critical point was found with a temperature of 350 °C, at which the mechanical properties of the material change - strength deteriorates, ductility increases. With a further increase to 400-500 °C, we obtain a range of zirconium chemical activity in which an explosive "explosive" mixture of oxygen and hydrogen is released. If you continue to increase the temperature, we come across the interaction of zirconium with steam, which only accelerates the already exothermic reaction of the formation of hydrogen and oxygen [7].

1 Coatings on the shells of the fuel elements

A few words about the choice of materials for coatings. Zirconium is a material that undergoes a form change: firstly, it has a phase alpha-beta transformation; secondly, having an hcp lattice, it is subject to radiation growth, and under prolonged exposure it experiences radiation creep. Therefore, the coating should maintain adhesion to the alloy during the process of forming the shell during normal operation. In addition, the coating should slow down the diffusion of oxygen and hydrogen. The thermal expansion coefficient (TEC) of the coating should be close to the TEC of the zirconium alloy. In addition, a coating technology should be developed. It should not have its own form change, it should adaptively change with the substrate. Finally, the coating should not impair the properties of the sheath material [8].

1.1 Chrome coatings

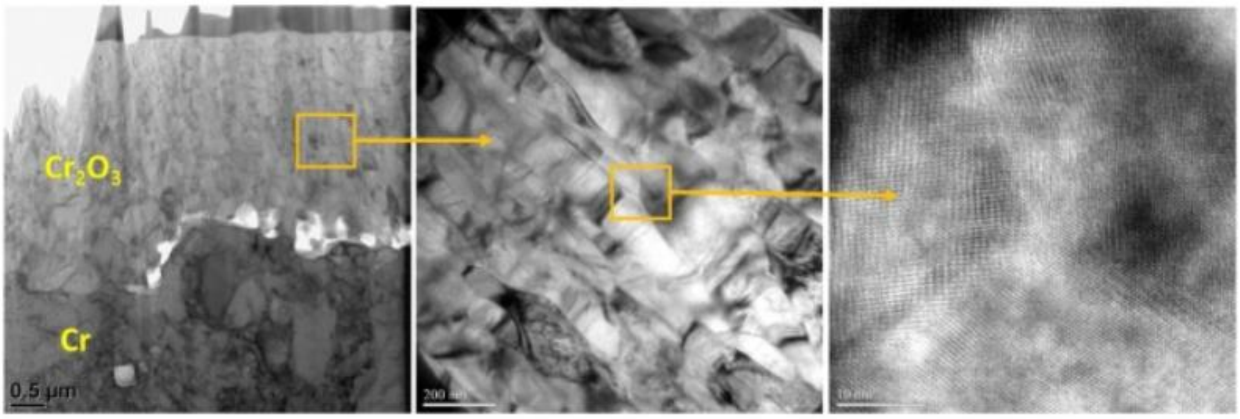
Consider the advantages and disadvantages of chrome coatings. From the pros: high melting point; corrosion resistance in superheated water - up to 1000 °C; high thermal conductivity. However, they also have a number of critical shortcomings. First, natural brittleness: chrome has a very low elongation, and it does not increase when coated. Secondly, chromium diffuses appreciably in bcc zirconium, penetrating considerable distances; also chromium with zirconium forms a brittle phase - $ZrCr_2$ and eutectic at a temperature of 1332 °C. Thirdly, chromium has a larger neutron capture cross section than that of zirconium, and you may have to think about fuel enrichment ^{235}U.

Tests of chrome coatings (for resistance to various types of oxidation in water and steam over a wide temperature range from 350 °C to 1200 °C; for wear resistance; mechanical, including resistance to creep and expansion of the shell, welding of coated shells) gave positive results [8].

1.1.1 Kinetics of the Cr-Zr interface

This issue was disclosed in [9-15]. To describe the kinetics of the oxidation of the chromium coating and the interaction of chromium with zirconium, samples of ciraloy-4 with a chromium coating deposited on it using the PVD method described above were used. Isothermal oxidation tests were carried out in a steam stream at atmospheric pressure, at various temperatures from 800 to 1500 °C. An electron probe microanalysis was performed after oxidation to obtain additional information about the potential diffusion of oxygen (and other chemicals such as chromium) into a Zr-based substrate. After the tests, detailed microstructural studies were carried out on a microscopic scale, using scanning electron microscopy in combination with electron backscattered diffraction analysis, up to the nanoscale scale, using high-resolution transmission electron microscopy.

Typical microstructures obtained for the first generation of samples of zirkaloy-4 sheets with a Cr coating of 5-10 μm thickness after oxidation with steam for 300 s at 1200 °C and water quenching are shown in fig. 1



(a) Overall view of Cr_2O_3/Cr outer scales (low magnification)

(b) Intermediate magnification - Cr_2O_3 scale

(c) HRTEM examination of a triple grain boundary - Cr_2O_3 scale

Fig. 1 – TEM photographs of the external surfaces obtained by oxidation

Three outer layers are highlighted:

1. External chromium film of chromium oxide with submicron grains. This oxide layer is a typical Cr_2O_3 rhombohedral structure with a specific crystallographic texture, and the crystallographic planes are mainly perpendicular to the coating surface. In TEM photographs in fig. 1 shows that the bulk outer chromium film is

sufficiently dense without visible defects or cracks, while numerous cavities are observed at the chromium oxide/metal interface. It can be assumed that these cavities were formed by a Kirkendall type mechanism due to the external cationic diffusion of Cr from the suboxide metal layer Cr, which induces the back diffusion of vacancies at the interface Cr_2O_3/Cr interface. In addition, the internal diffusion of oxygen over the entire remaining suboxide metal chromium layer should also contribute to the formation of vacancies at the oxide-metal interface and, therefore, the nucleation and growth of Kirkendall cavities at this interface. However, in this case, oxygen diffusion occurs at the grain boundaries of chromium. Therefore, it can be assumed that this heterogeneous (intergranular) oxygen diffusion mechanism is less susceptible to inducing a high density of Kirkendall cavities at the oxide-metal interface, since it is known that grain boundaries are effective recombination/annihilation sites for vacancies. Then, even if it cannot be ignored, the internal mechanism of intergranular diffusion of oxygen in chromium seems less effective than the mechanism of external bulk diffusion of cations in chromium for the formation of reverse vacancies and, therefore, Kirkendall cavities at the chromium/chromium oxide boundary. In addition, TEM micrographs in fig. 1 - (c) a certain crystallographic coherence can be seen between adjacent grains of chromium oxide. This confirms the high density and defect-free structure of the formed external chrome scale. This explains the effective protective properties of the coating observed at the beginning of oxidation.

2. A suboxide residual layer of metallic chromium with micrometric grains showing a crystallographic texture of a fibrous type with a centered volume-centered structure perpendicular to the surface of the coating. It is likely that this particular texture was inherited from the already obtained crystallographic texture caused by the PVD deposition process.

3. Chromosirconium micrometric layer during the Cr/Zr transition. This layer is due to the mutual diffusion between the Zr substrate and the Cr coating, which occurs with increasing temperature. According to the Zr-Cr phase diagram, it was noted that this thin layer consists mainly of the intermetallic $Zr(Cr, Fe)_2$, C15

(face-centered cubic) Lavs phase. From the DOE analysis, intermetallic grains show no significant overall crystallographic texture (almost isotropic distribution). In addition, one can observe on the EBSD orientation maps fig. 2 - (b) a typical dual Loves intermetallic phase substructure. In addition, cavities are observed at the interface between intermetallic compounds and zirconium. Again, it can be assumed that these cavities were obtained due to the Kirkendall effect. This induces the internal diffusion of metal Cr atoms into the βZr substrate significantly more than the potential external diffusion of zirconium atoms into the Cr layer. Then, the dissymmetric atomic diffusion on both sides of the Zr/Cr interface induces a reverse diffusion flux of vacancies from βZr. Finally, the clustering of Kirkendall vacancies contributes to the nucleation and growth of the observed interfacial cavities (several tenths of a nanometer in diameter).

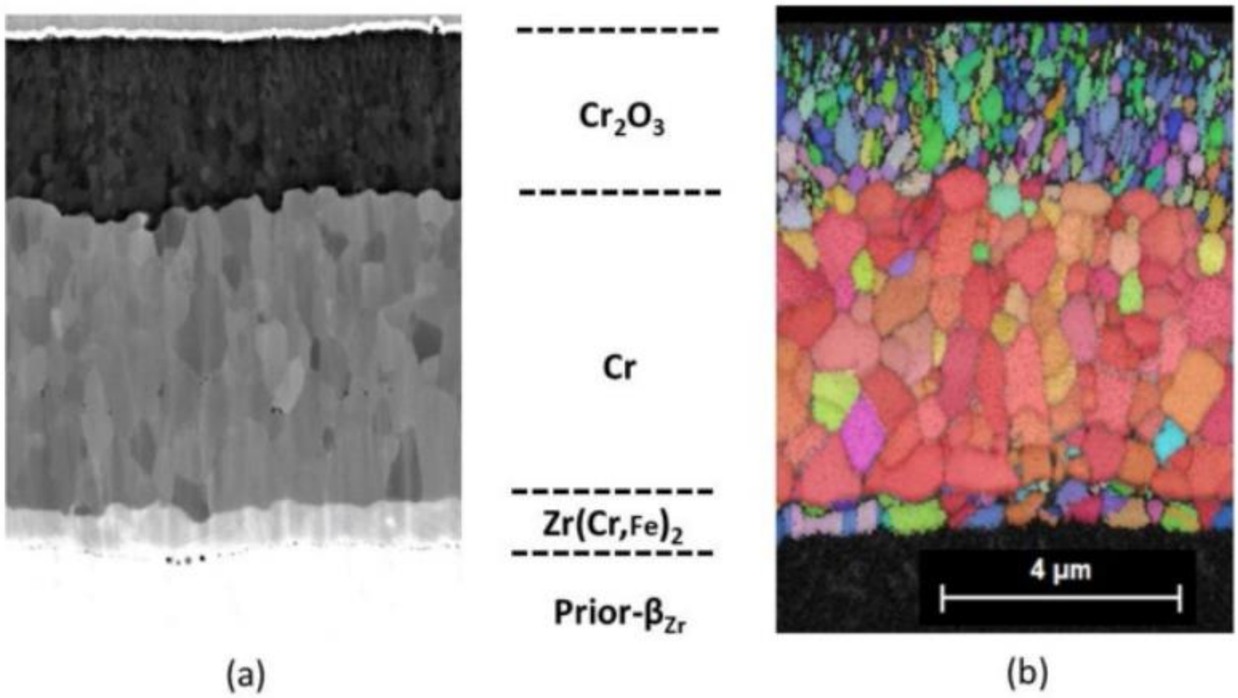


Fig. 2 – Microstructure of a sample of zircaloy-4 with a Cr coating 5-10 microns thick after oxidation with steam for 300 s at 1200 °C (protective coating): (a) SEM image, (b) DOE crystallographic map.

During prolonged oxidation (1400 s), a continuing mass increment was found in the samples under study, however, the growth rate of the chromium oxide film was not observed. This means that at this oxidation stage, a significant fraction of the oxygen interacting with the Cr-coating material (which contributes to the measurement of the positive evolution of the mass gain) diffuses deeper into the substrate. Indeed, as shown in fig. 3, post-oxidative studies of DOE and TEM have shown that a new oxygen transport mechanism is activated under a layer of chromium oxide:

1. Inside the residual layer of metallic chromium, oxygen diffuses inward and intergranular diffusion of zirconium outward.

2. Then zirconia stringers nucleate and grow at the boundaries of chromium grains, probably due to the higher thermodynamic stability of zirconium dioxide compared to chromium.

3. Thus, we can assume that this more or less continuous network of zirconium at the grain boundaries of chromium contributes to the (internal) diffusion of oxygen anions.

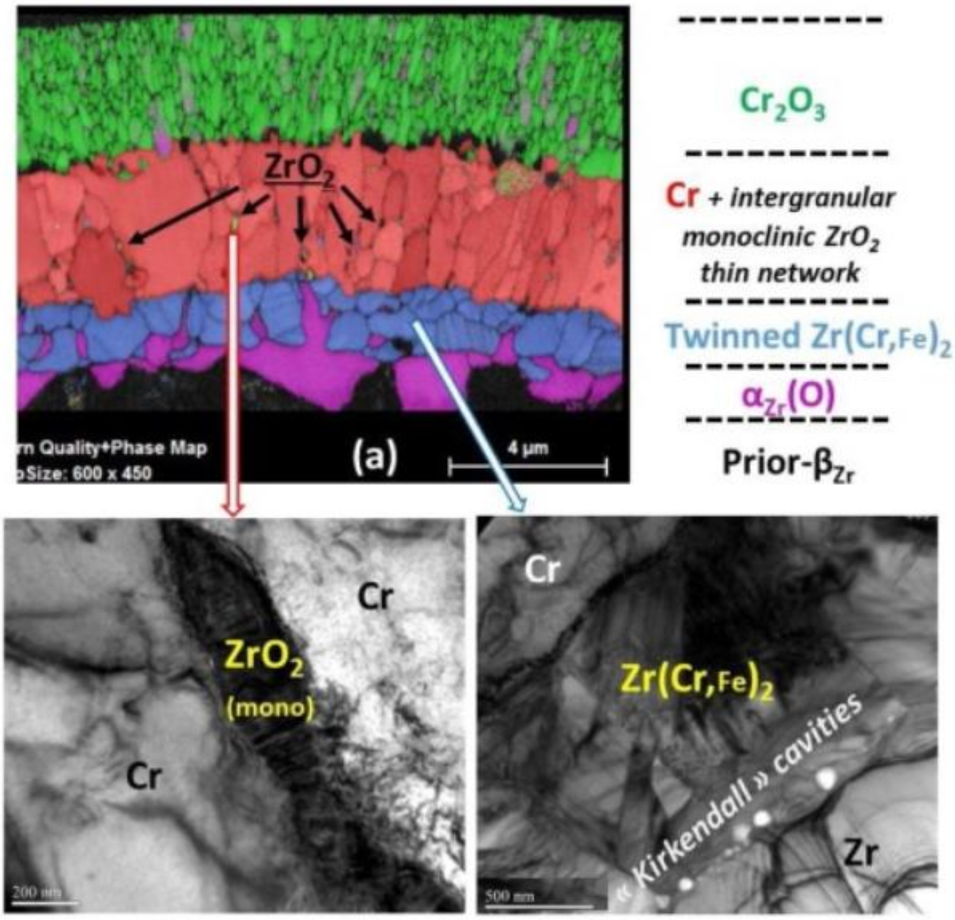


Fig. 3 – Microstructure of a sample of a sheet of zircaloy-4 with a Cr coating 5-10 µm thick after oxidation with steam for 1400 s at 1200 °C (transition stage): phase map of SEM and DOE

Consider the behavior of the chromium coating at a temperature of 1200 ° C and a long oxidation exposure period (over 1400 s). In fig. 3 shows a typical microstructure of a sample of zircaloy-4 coated with chromium, 5-10 microns thick, highly oxidized. At this stage, due to its limited initial thickness, the residual Cr coating is no longer protective, since a thick layer of zirconium oxide grows under the strongly oxidized residual coating of Cr. This causes a significant acceleration of the overall oxidation kinetics (not protective oxidation of the Zr substrate). The various layers observed on the DOE maps shown in fig. 4 are as follows:

External severely damaged residual chrome scales. Numerous cracks and potential local delamination of the residual outer scale of Cr show that the scale does not protect at this stage.

The underlying residual layer of metallic (non-oxidized) chromium, showing a quasicontinuous intergranular network of zirconium dioxide. As discussed previously, it is likely that this zirconium network is the preferred path for accelerated oxygen access to the zirconium substrate.

Probably, due to the high diffusion flow of oxygen inwardly at the Zr/Cr interface, when the coating no longer protects, it can be observed that (previously) the $Zr(Cr, Fe)_2$ layer disappeared and turned back into metallic chromium together with zirconia grains in accordance with the intended chemical reaction described below:

$Zr(Cr)_2 + 2O \Rightarrow ZrO_2 + 2Cr$

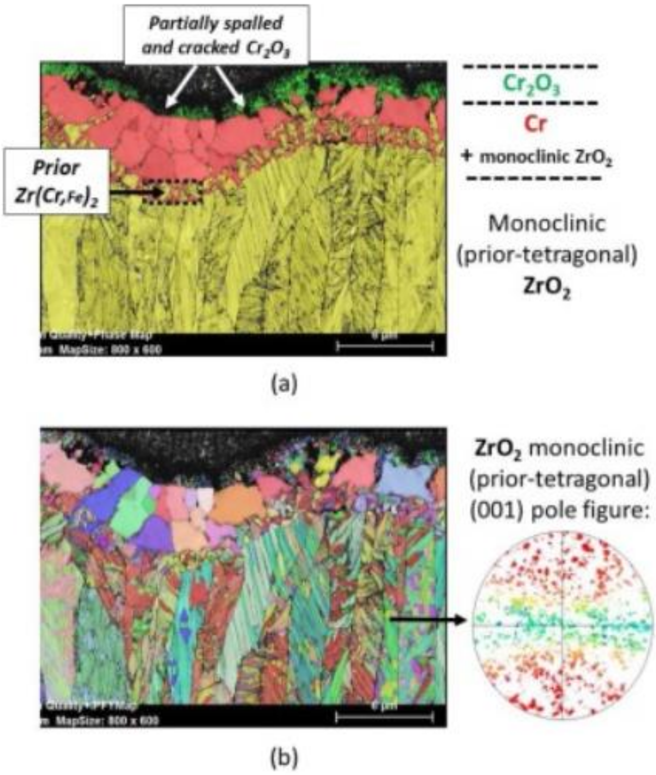


Fig. 4 – Microstructure of a thin Cr-coated sample of zircaloy-4 sheet after steam oxidation for more than 1400 s at 1200 °C (no longer a protective coating): (a) DOE phase map, (b) DOE crystallographic orientation map and corresponding (001) monoclinic ZrO_2 pole figure

In the present study, there is still an external metallic (not oxidized) chromium film that remains, while a thick layer of zirconium dioxide has already grown (fig. 4). It can be assumed that during the longest oxidation periods occurring here, all oxygen atoms reacting with the zirconium surface mainly diffuse due to the short path from zirconium dioxide (formed through the remaining layer of chromium oxide) to the zirconium substrate, causing the growth of a thick layer of zirconium dioxide and thus not oxidizing neighboring metallic chromium.

Fig. 5 is a schematic overview of the various stages of a steam oxidation process of Cr coated zirconium alloys.

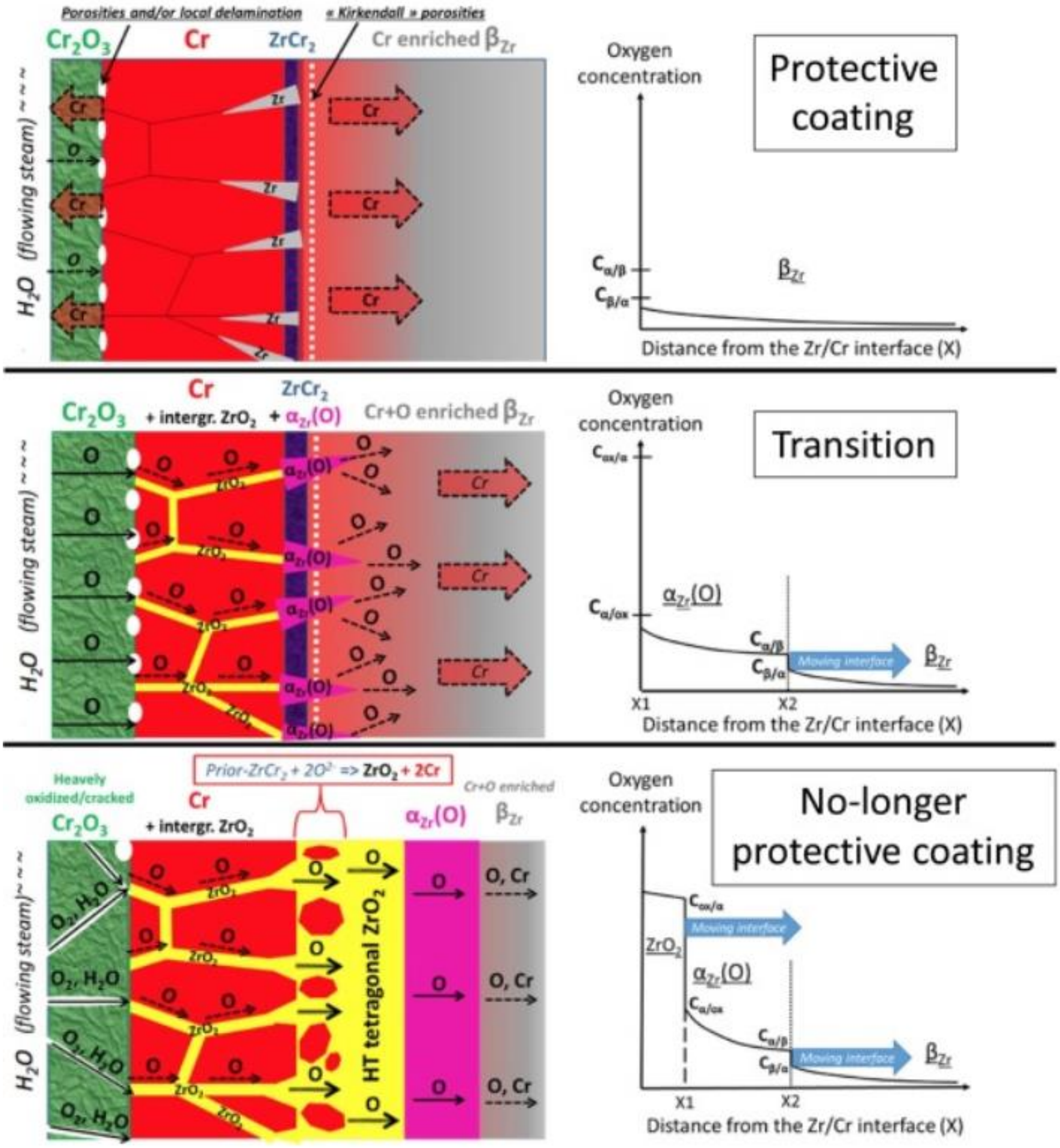


Fig. 5 – Schematic overview of the various stages of the oxidation process

For oxidation temperatures above 1300 °C, a eutectic reaction between pure zirconium and chromium can occur with a theoretical eutectic temperature close to 1332 °C according to the binary Zr-Cr phase diagram.

In fig. 6 shows a typical coated sample after one-sided steam oxidation at temperatures above temperatures at which the Zr-Cr eutectic reaction occurs (~ 1305–1325 ° C). Under such oxidation conditions at high temperatures, a Cr-coated surface exhibits a “crocodile skin” morphology with some continuous bubbles forming an external protruding pattern. This aspect of "crocodile skin" should be due to the small formation of a Zr-Cr eutectic film on the outer surface of the samples.

Fig. 6 – Sample coated with chromium steamed at a temperature of 1400 °C for 100 s

Consider the phase diagram in fig. 7. This phase diagram was calculated using Thermocalc® software and the CEA Zircobase thermodynamic database for zirconium alloys. Various metallurgical precipitates upon heating above 1300 °C, annealing for 100 s at a temperature of 1400-1450 °C and the final cooling of water to room temperature can be summarized as follows:

1. Process (a): upon heating above 1300 °C, rapid mutual diffusion between Zr and Cr occurs, then the intermediate metal layer $ZrCr_2$ reacts with the β-Zr substrate to form a liquid eutectic phase;

2. Process (b): after annealing for 100 s at 1400–1450 °C, the liquid (eutectic) phase is gradually enriched in zirconium coming from the Zr substrate (taking into account that Cr is no longer accessible due to its early consumption for the formation of the liquid phase eutectics when heated in the temperature range 1305-1325 °C);

3. Process (c): when quenching from 1400 to 1450 °C, β-Zr dendrites precipitate together with enrichment in Cr of the residual interdendritic liquid phase of Zr-Cr with decreasing temperature; then the residual liquid phase Zr-Cr solidifies

when the temperature drops below the eutectic point of the phase diagram, which corresponds to approximately 30% at. chromium.

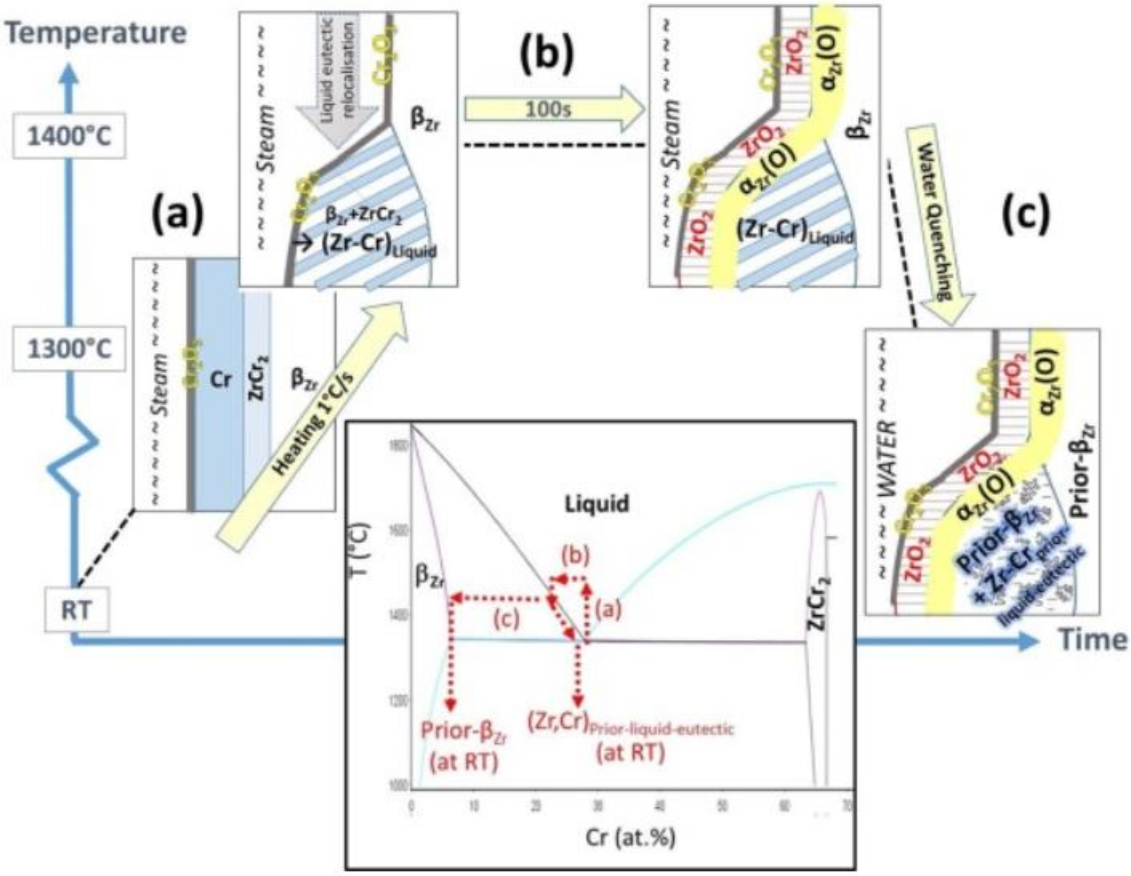


Fig. 7 – Phase diagram of oxidation processes at temperatures above 1300 °C.

1.1.2 CrN coating

In article [16] the results of experimental studies of the effect of protective vacuum-arc coatings based on zirconium-chromium compounds and their nitrides on the resistance of tubes made of zirconium alloys E110 and Zr-1Nb (a calcium-thermal alloy of Ukrainian origin) to oxidation in air at temperatures of 660, 770 , 900, 1020, 1100 °C for 3600 s was presented.

In fig. 8 shows an electron microscopic image of a transverse section of a tube with a two-layer ZrCr/CrN coating.

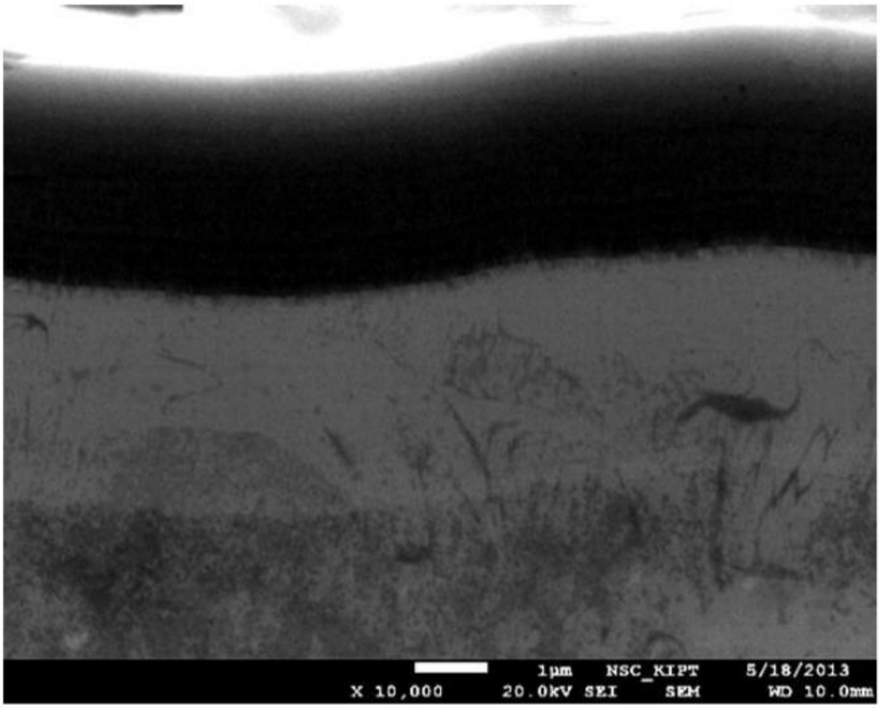
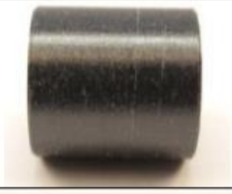
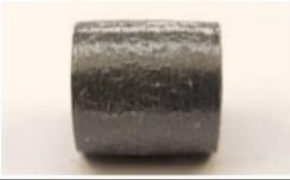
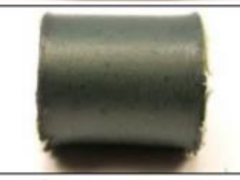
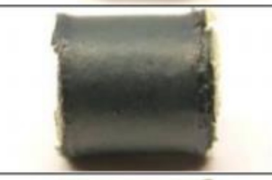


Fig. 8 – SEM image of a thin section of a tube of alloy E110 with a two-layer coating ZrCr/CrN (thickness ≈ 7 μm)

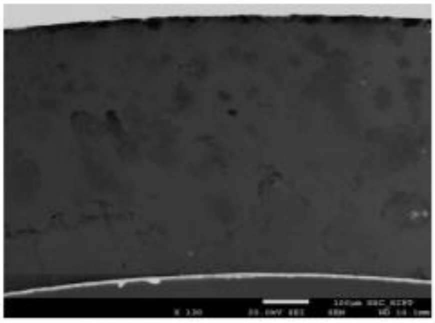
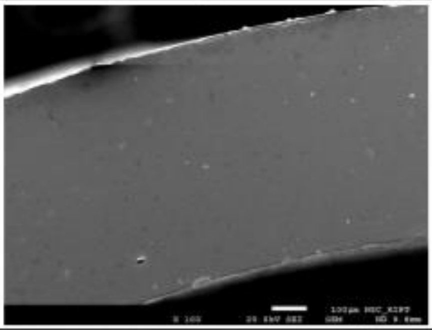
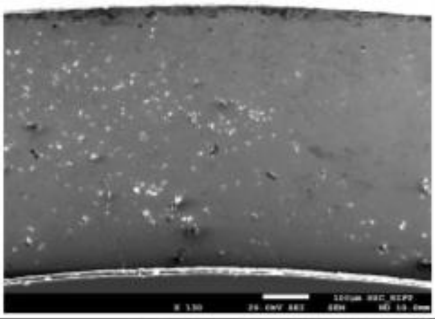
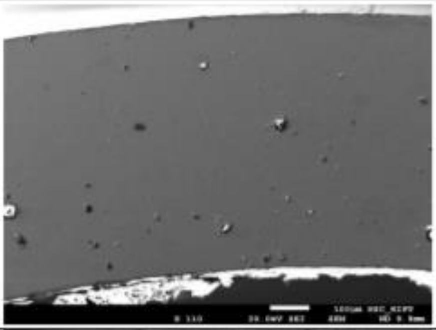
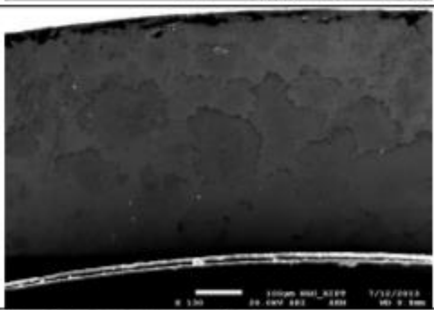
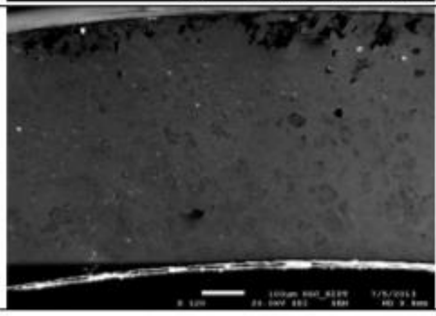
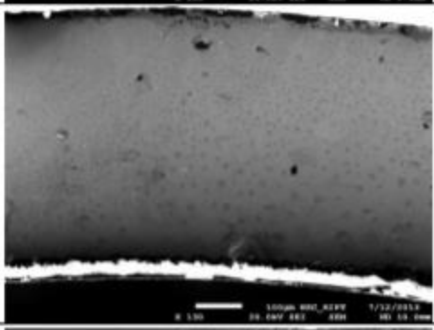
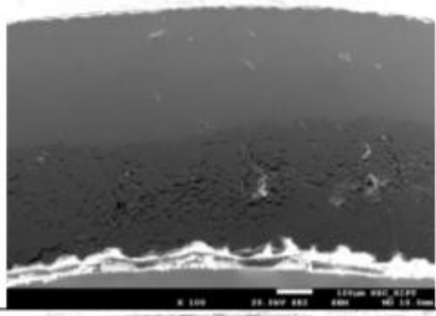
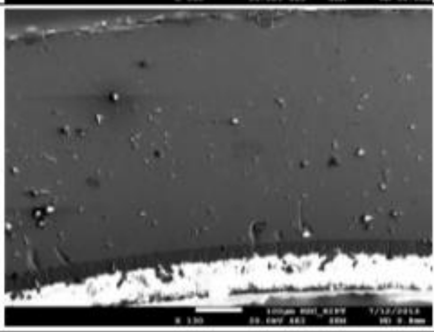
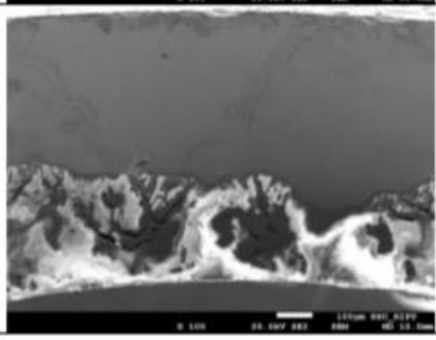
In the table 1 shows photographs of samples of the initial tubes and with ZrCr/CrN coating before and after atmospheric annealing for 1 h at the indicated temperatures. It can be seen that even at 770 °C, white bands appear on the uncoated tubes in the oxide layer, which increase at higher temperatures, and the samples are destroyed. At temperatures of 1020 and 1100 °C, the samples acquired a white color, were deformed with the formation of through cracks and with crumbling oxide. At the same time, coated samples do not exhibit such damage. They only slightly changed color - from black to black-green, completely retaining their shape regardless of the type of alloy from which they are made. After annealing at 900 °C and above, destruction is observed at the ends of the tubes. This is due to the peeling of the oxide layer from the inner surface and the fact that the coating did not deposit on the ends.

Table 1 – Photos of tubes with and without coating

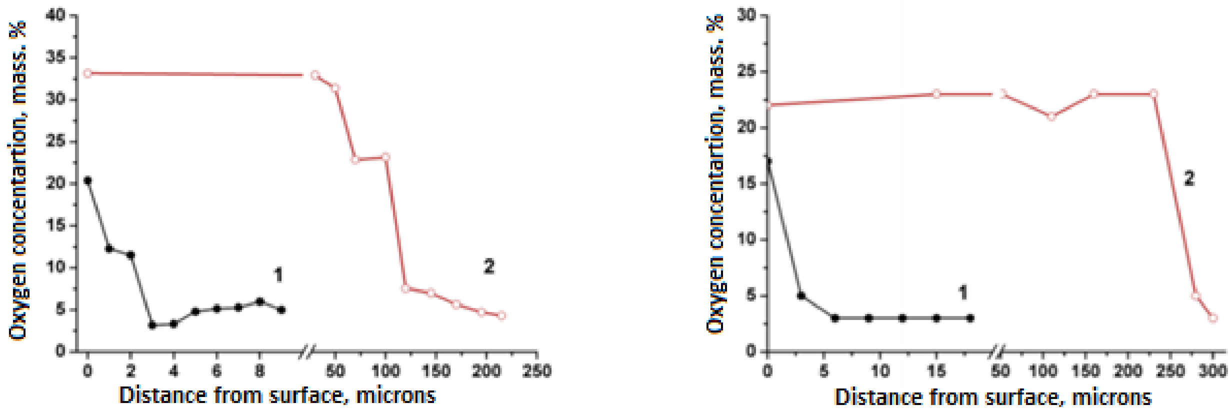
T, °C	Zr-1Nb без покрытия	Zr-1Nb с покрытием	Э110 с покрытием
20			
660	–		
770			
900			
1020			
1100			

The protective role of the obtained coatings on zirconium alloys during atmospheric annealing of SEM images of thin sections of the samples is clearly visible (table 2). On the outside of the tubes under the coating, no changes are seen in both alloys, while on the inside (without coating), an increase in the temperature of the oxide layer is observed, which after T ≥ 900 °C increases significantly, becomes loose and deteriorates. Moreover, in the E110 alloy at a temperature of 1020 °C, changes already occur at a depth exceeding half the thickness of the tube, and annealing at T = 1100 °C leads to destruction of the tube from the inside. This behavior of the E110 alloy is associated with its phase transformation in the temperature range 900 ... 1020 °C, which leads to volumetric changes in the contacting alloy and oxide. In the Zr-1Nb alloy, an initial increased oxygen content up to 0.15 wt.% Leads to an increase in the phase transition temperature, where it proceeds more quickly and does not exert such a destructive effect on the oxide film.

Table 2 – SEM images of thin sections of Zr-1Nb and E110 alloy tubes after oxidation in air at temperatures of 660 ... 1100 °C.

$T_{отж}$, °C	Zr-1Nb	Э110
660		
770		
900		
1020		
1100		

In fig. 9 shows the dependence of oxygen concentration on the surface of the tubes after annealing at T = 1100 °C, as determined by SEM-EDS analysis. The oxidation of the Zr-1Nb and E110 alloys from the coating side after annealing of the samples at T = 1100 °C is characterized by the penetration of oxygen to a depth of ~2 μm at a level of ~15 ... 20 wt.%, And decreases deeper to ~2 wt.%. The penetration of oxygen is prevented by dense chromium oxide, which is formed during the oxidation of the upper layer of the CrN coating. In uncoated zirconium alloys, oxygen is determined at a level of 25 ... 35 wt.% To a depth of ≥ 250 μm for the E110 alloy and ~ 120 μm for the Zr-1Nb alloy.



a *б*

Fig. 9 – Oxygen concentration depending on the distance from the surface for the zirconium tube Zr-1Nb (a) and E110 (b) from the coating side (1) and without it (2) after annealing at T = 1100 °C for 3600 s.

1.1.3 CrNi coating

In this article [17], the aim of the study is to determine the effect of the ratio of Ni to Cr on the resistance to high-temperature oxidation and hydrogen absorption of the nickel-plated Zr-1Nb alloy.

Table 3 – The elemental composition of the coatings

Sample	Ratio Ni/Cr
Ni_9Cr	83/17
NiCr	55/45
$NiCr_9$	17/83
Cr	0/100

The elemental composition deposited in the form of NiCr coatings are shown in table 3. The ratio of nickel to chromium (in at.%) In Ni9Cr, NiCr, NiCr9, and Cr coatings is 83/17, 55/45, 17/83, and 0/100, respectively. The cross section of SEM images of deposited coatings on Si substrates is shown in fig. 10. The coating thickness is (2.2 ± 0.1) μm.

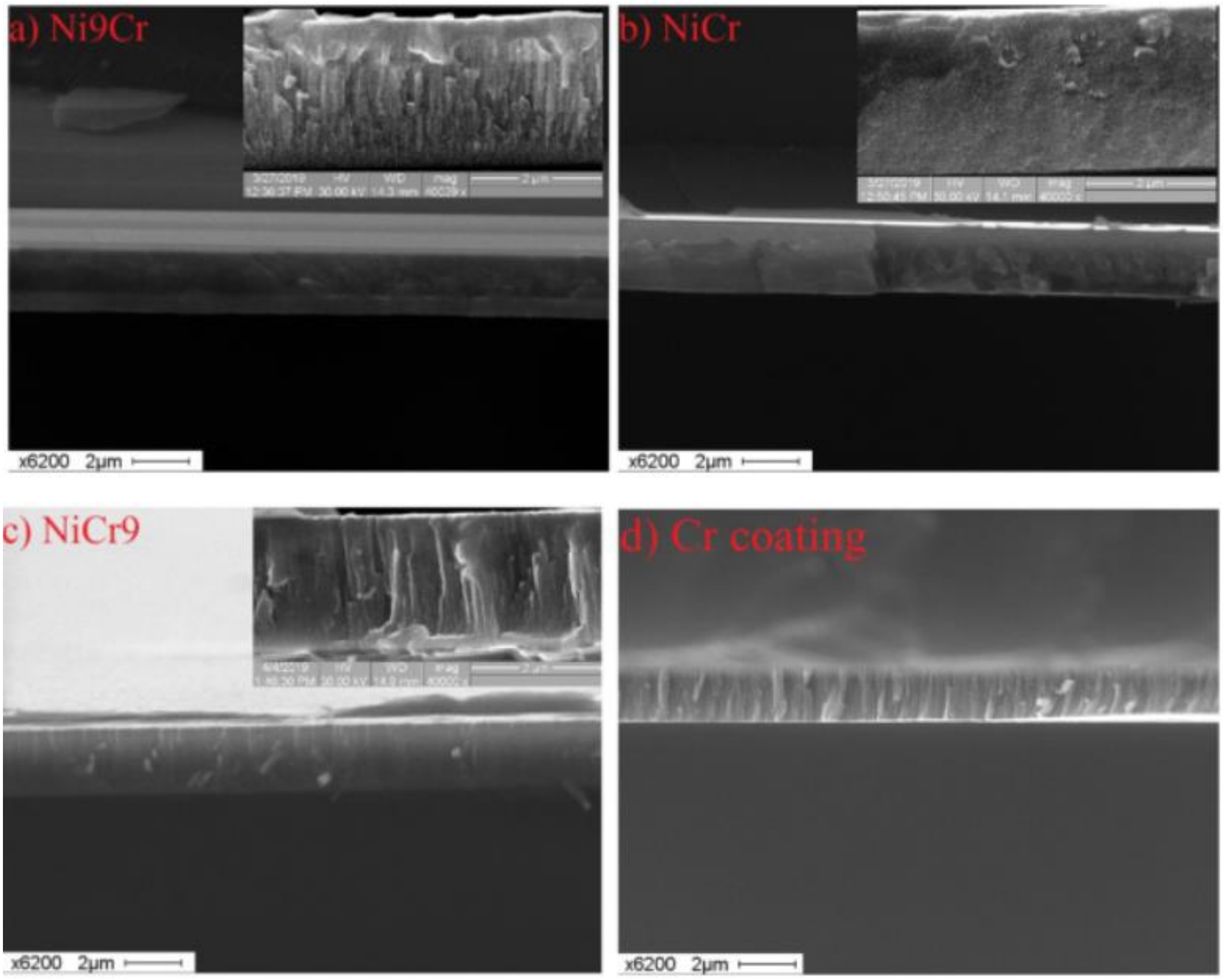


Fig. 10 – SEM images of deposited coatings on a Si substrate: a - Ni_9Cr; b - NiCr; c - $NiCr_9$; d - Cr.

Zr-1Nb samples subjected to hydrogenation and oxidation tests are shown in Fig. 11. It was shown that the Ni_9Cr coating exfoliates from the Zr-1Nb alloy after hydrogenation, which may be due to hydride precipitation and volume expansion of the alloy compared to the coating. The appearance of other samples after hydrogenation has not changed. The uncoated Zr-1Nb alloy strongly oxidizes even at 1173 K. The white film on its surface indicates the oxidation of zirconium (ZrO_x). Cracks and peeling of ZrO_x layers were also observed. At a higher temperature (1373

K), the oxidation of the bare alloy occurred more strongly, and the destruction of this sample was observed. Color of the coated samples was changed from light gold or silver (as it was deposited) to dark green or gray-blue, which indicates the formation of chromium and nickel oxides on the surface after an oxidation test. The coated samples had an unprotected corner portion that was intensively oxidized. The Ni9Cr coating was partially disintegrated from the Zr-1Nb alloy, while other samples maintained their integrity.

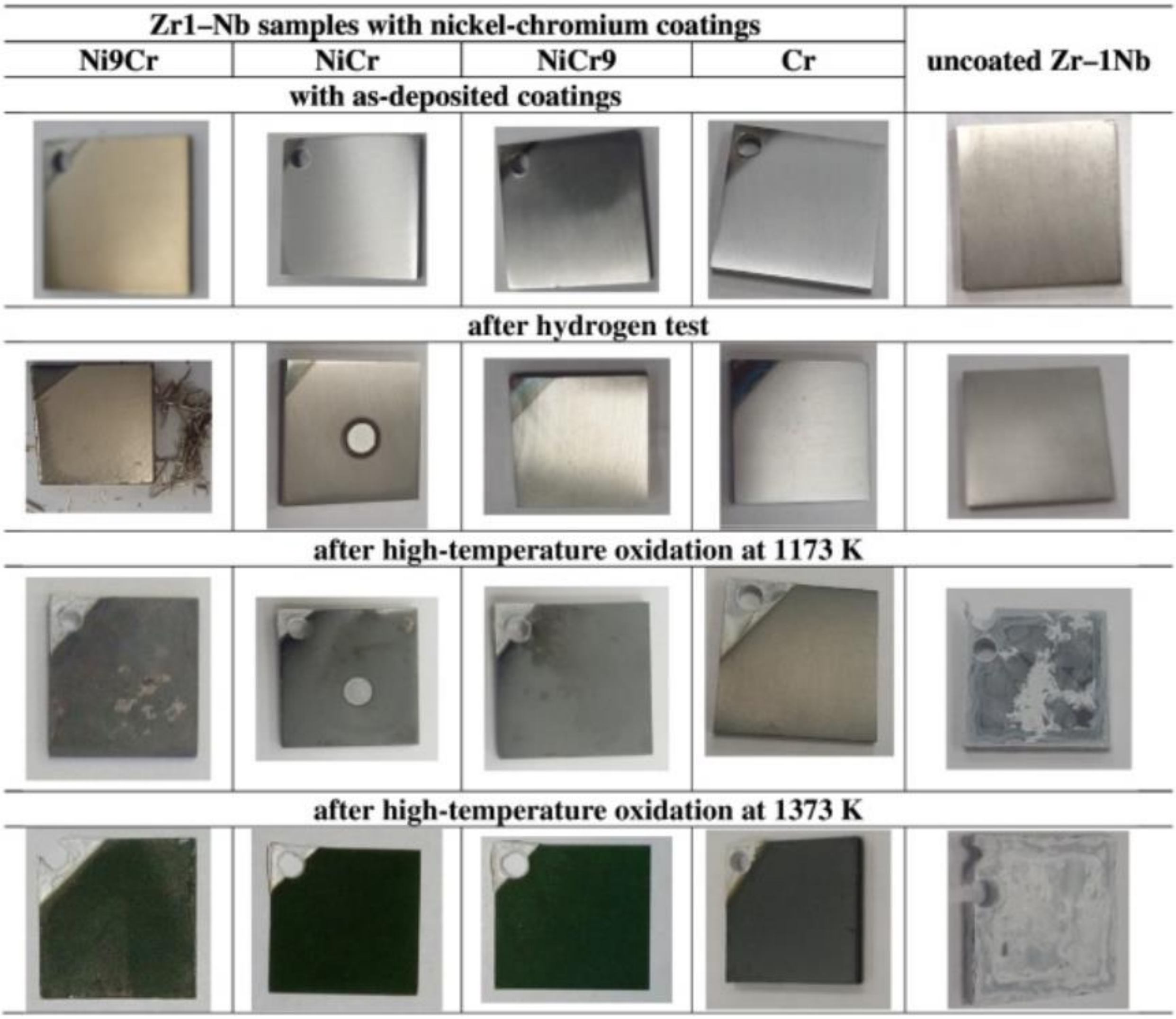


Fig. 11 – Appearance of samples with and without coating after testing

In fig. 12a shows the kinetics of hydrogen sorption of the Zr-1Nb alloy during gas phase hydrogenation at 633 K. The deposition of a coating with a high nickel content (Ni_9Cr) leads to an increase in the rate of hydrogen absorption by the alloy. The absorbed hydrogen concentration of this sample is higher (~0.3 wt.%). Than for samples with NiCr, $NiCr_9$ and Cr coatings (less than 0.03 wt.%) Or without coating (0.09 wt.%). It is known that the permeability of hydrogen through pure nickel is high and nickel oxides are easily reduced by hydrogen. It is assumed that the chromium content in the Ni_9Cr coating is insufficient for the formation of a protective layer of chromium oxide on the surface; therefore, the coating does not exhibit protective properties against hydrogen absorption. Measurements of the mass gain after the hydrogenation test are in good correlation with the absorption kinetics (fig. 12b). The maximum weight gain of 2.3 mg/cm^2 is observed for a sample coated with Ni_9Cr, while other coated samples have less than 0.1 mg/cm^2 (fig. 12b).

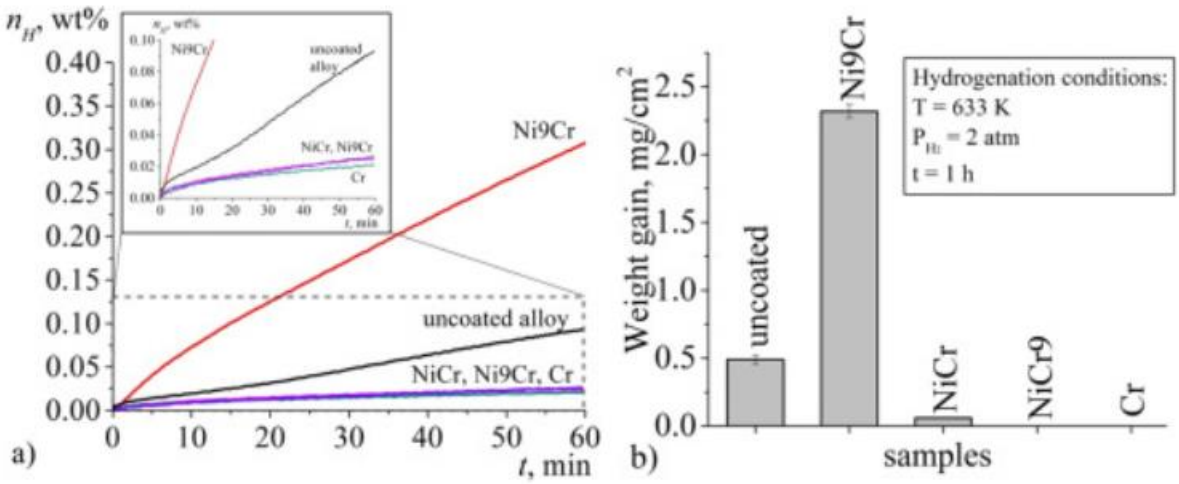


Fig. 12 – Kinetics of hydrogen sorption (a) and mass increase (b) at 633 K for Zr-1Nb samples.

Samples were oxidized in the atmosphere at two temperatures (1173 K and 1373 K).

In fig. figure 13 shows the weight gain (Δm) of the samples after high-temperature oxidation at a temperature of 1373 K. untreated Zr -1Nb has the largest value Δm (46.5 mg/cm^2). The weight gain of the coated samples is lower and depends on the composition of the coating (5.2–35.9 mg/cm^2). The best oxidation resistance is observed for a sample coated with pure chromium having the lowest weight gain compared to the rest.

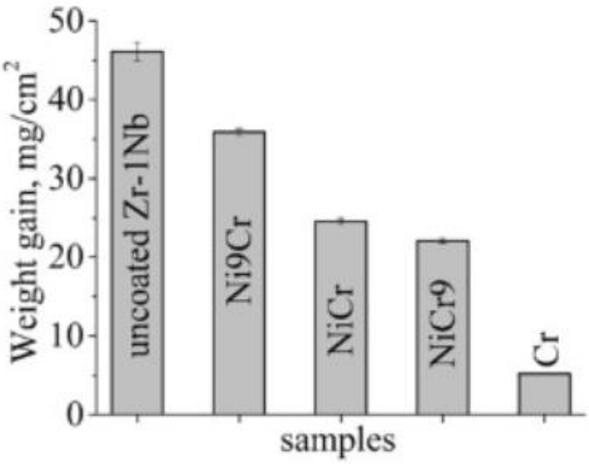


Fig. 13 – Weight gain of the samples after high temperature oxidation at a temperature of 1373 K.

Based on weight gain measurements, a Ni_9Cr-coated sample showed poor oxidation resistance (figure 11). Therefore, transverse SEM observations and measurements of elemental composition were carried out only for oxidized samples with NiCr, $NiCr_9$, and Cr coatings (fig. 14). It can be seen from the SEM images that the oxidation of the samples occurs uniformly and the thickness of the oxide layer decreases from 86 µm for the sample with NiCr coating to 8 µm for the sample with Cr coating.

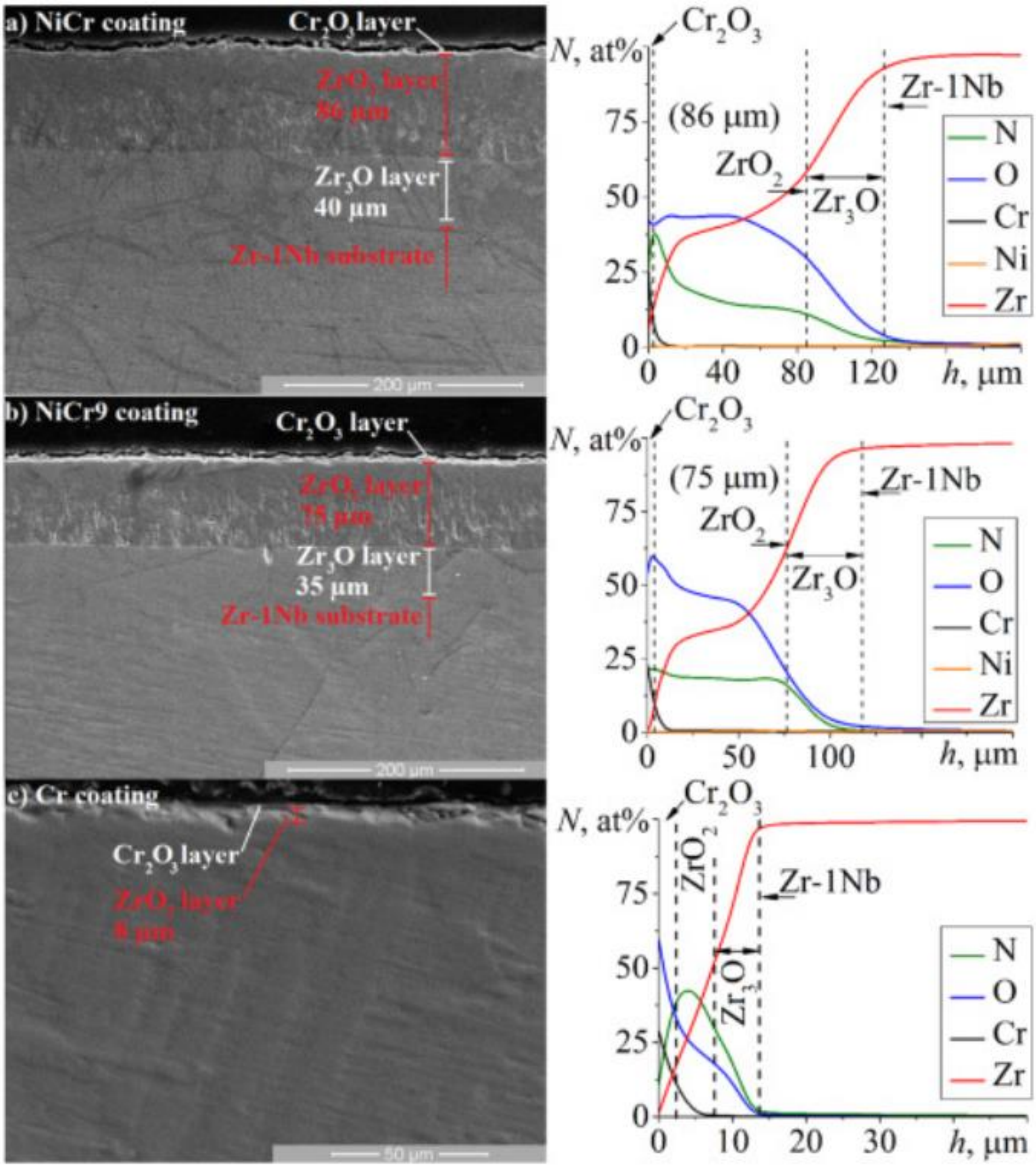


Fig. 14 – SEM images and corresponding graphs of the distribution of elemental composition with depth dependence.

1.2 MAX phase coatings

Given the shortcomings of chrome coatings, scientists are working on other areas, for example, on MAX-phase alloys. MAX are complex compounds (carbides and nitrides - X) of transition metals (for example, chromium, zirconium and titanium - M) with aluminum and silicon (A). The advantages of such alloys are stability during water-heat treatment above 1000 °C, good adhesion and coating strength; high thermal conductivity, heat resistance, low coefficients of thermal expansion; maintaining phase stability after a small neutron exposure. However, there are also critical disadvantages: low fracture toughness and ductility; noticeable interaction of aluminum and silicon with zirconium and other elements; formation of alumina under operating conditions is possible [8].

1.3 Steel coatings

Fe-Cr-Al coating is considered to be very advanced - it is an alloy of iron, chromium and aluminum with various alloying additives. Its advantages: good adhesion and density; noticeably slow kinetics of oxidation; coefficient of thermal expansion is close to zirconium; resistance to reaction with steam up to 1300 °C; coating strengthens the shell. However, when using this coating, its numerous disadvantages also appear, so it is unlikely to be applied. All coating components are soluble in zirconium; intermetallic compounds are formed, barrier layers between the shell and the coating are required [8]. Neutron capture, as well as stress corrosion cracking (for austenitic steels) and radiation embrittlement (for ferritic steels). The deterioration of neutron physics (K-inf) when using steel shells requires either an increase in fuel enrichment of more than 5%, or a significant thinning of the shell thickness to 0.25-0.35 mm instead of 0.6 mm for zircaloy.

2 MCU model

In the MCU software package designed to simulate the transfer of certain types of radiation, a model of a fuel assembly of a nuclear reactor of the pressurized water power reactor type with an electric power of 1000 MW (VVER-1000) was built. (fig. 15)

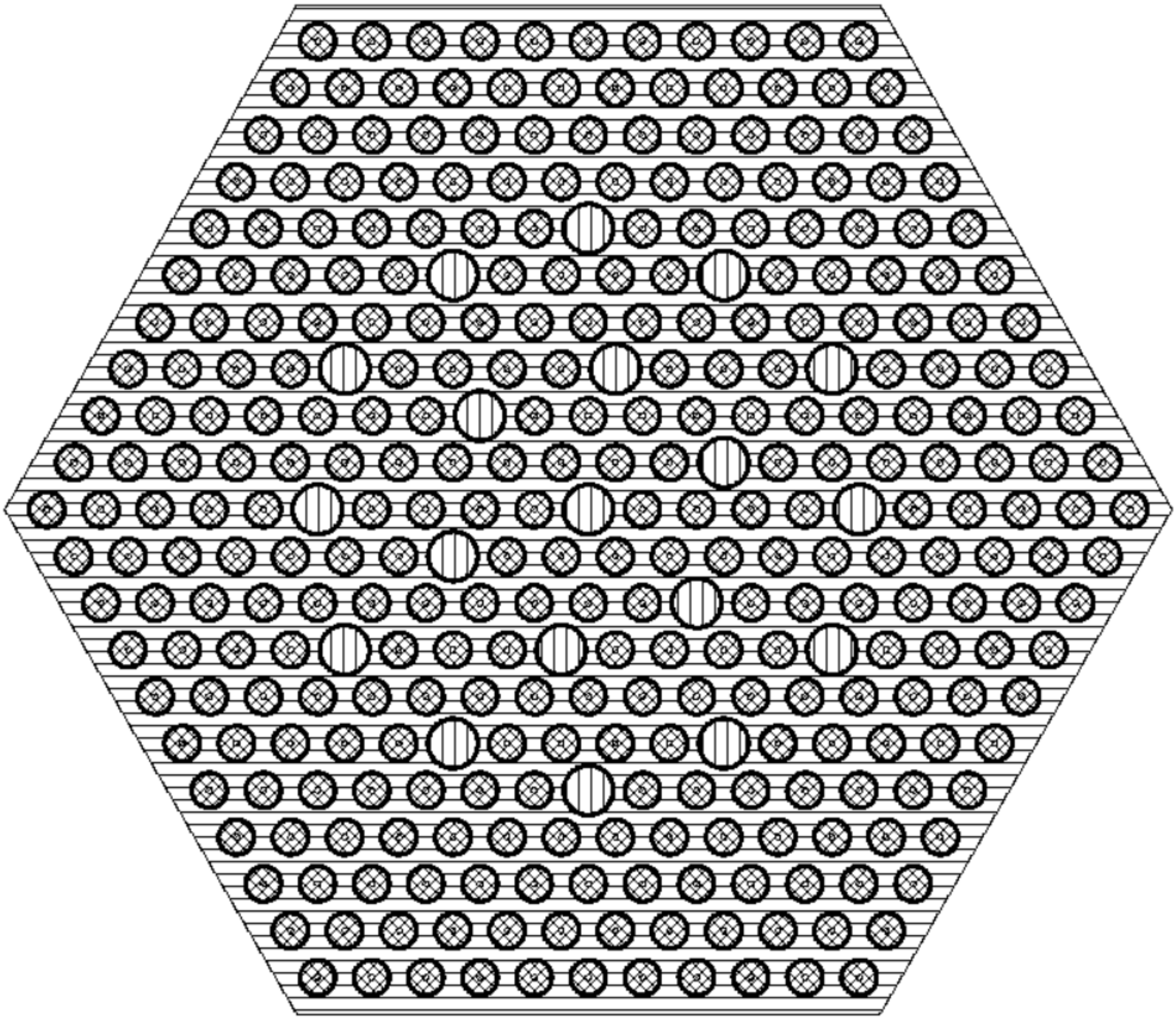


Fig. 15 – Fuel assembly VVER-1000

As can be seen from the figure, fuel assembly is a zone with a repeating element - an elementary cell. The elementary cell contains structurally repeating elements of the zone, namely: fuel, helium layer, fuel shell, water environment. The elementary cell is shown in fig. 16.

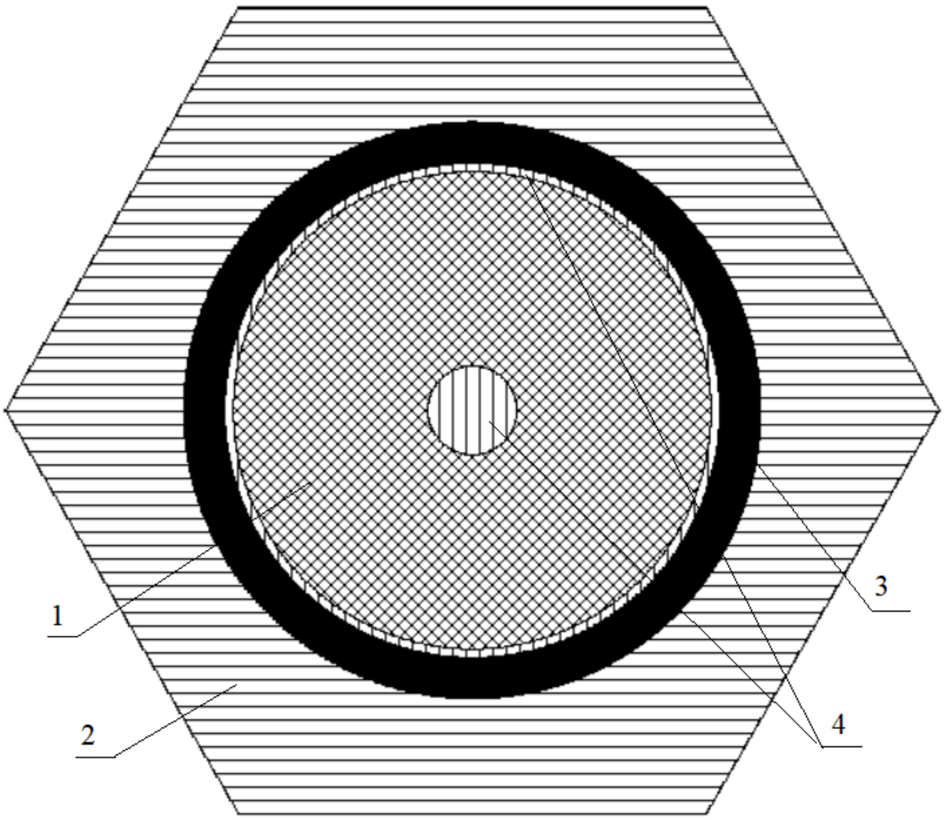


Fig. 16 – Elementary cell: 1 – fuel pellet, 2 – water, 3 – casing, 4 – helium layer.

19 cells, different from the elementary one, is a cover made of a shell material into which absorber rods are immersed to control the chain reaction of fuel fission, immersed in the same water.

Layer of the researched coating was added on the casing i. e. between casing and water.

Zone input parameters that were adopted during the development of this model:

1. Spectrum of whole neutrons were divided to four groups: 0 – 0,625 eV is thermal neutrons; 0,625 – 10^5 eV is transient neutrons; 10^5 – rest energies eV fast neutrons;

2. Fuel pellet was divided by 5 registration zones to build the distribution of the flux among the radius of the fuel pellet: from 0,07 cm to 0,3765 cm with step of 0,0613 cm

3. Power of the fuel assembly was considered 18404,9 kW

4. Time steps of calculation were taken 0, 50, 100, 600, 1100, 1350, 1600, 1700, 1800, 1900, 2000 days

5. Materials of application: Cr, CrN, Ni9Cr, NiCr, NiCr9

6. Thickness of application: 5, 10, 20, 40 microns

2.1 Campaign calculation

Nuclear power plant is primarily a structural unit of the economy, and in this case, one of the most important parameters influencing the efficiency of using the plant is the fuel campaign.

At the initial stage, the change in the fuel campaign was evaluated for a coating thickness of 5 microns. According to a literature review, several materials containing chromium were taken. Materials for which studies have been carried out on the change in physical characteristics in an equivalent design basis lost of coolant accident (LOCA) environment.

Methodic of calculation of campaign:

1. Calculate k_{eff} in each time step
2. Add linear approximation
3. Obtain equation
4. Set k_{eff} equal unity (end of the campaign)

Results of such research presented on the fig. 17. Clear is the fuel assembly without any coating, it was added to compare it with samples with coatings.

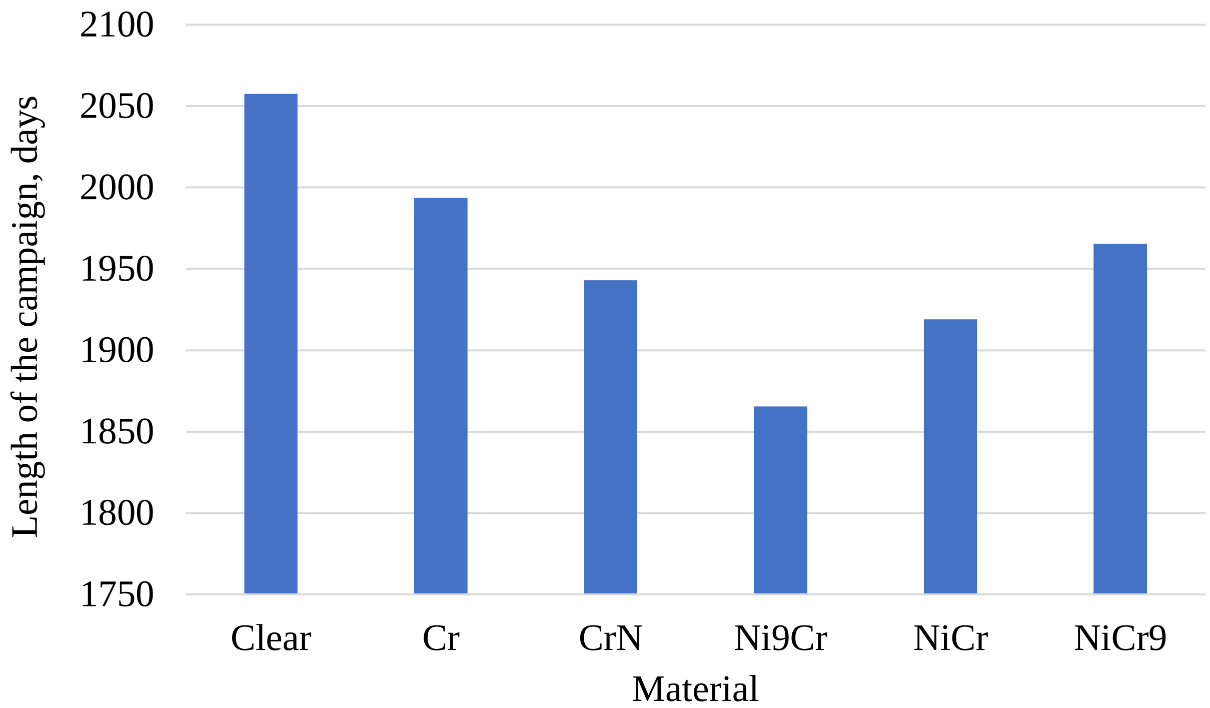


Fig. 17 – Length of the campaign for different materials

As this might be seen, pure chromium shows us the best result. and in case of pure chromium campaign length is shortened for least amount of days.

For the nichromium alloy influence on the campaign length depends on concentration of the nickel: the higher concentration of the nickel, the higher loses in days of campaign. Uses [18] we can see that for thermal neutrons nickel have total cross-section σ^t_{Ni} = 21,6 barn, where cross-section of capture is equal to σ^c_{Ni} = 4,6 barn and cross-section of elastic scattering is equal to σ^e_{Ni} = 17 barn. From this data we can make an suggestion that nickel shields thermal neutrons which goes from moderator, water, to fuel pellet.

Presence of chromium nitride gives us length of the campaign approximately equal to that of nichromium alloy with lowest concentration of nickel. According to [18] total cross-section of nitrogen for thermal neutrons is equal to σ^t_N = 11,6 barn, where cross-section of capture is equal to σ^c_N = 1,85 barn and cross-section of elastic scattering is equal to σ^e_N = 9,8 barn.

The essence why CrN campaign lower than that of $NiCr_9$ despite the fact that total cross-section of nitrogen approximately in two times lower than for nichromium could be described from the side of concentration of doping (Ni, N) in this materials. $NiCr_9$ compound concentration of nickel in at.% is equal to 17 % which is much lower than concentration of nitrogen in CrN compound where it is 50 % in at.%.

From this analysis we can say that nichromium materials could be applied as a coatings for casing but with the lowest possible concentration of nickel. After all this consequences related to the nickel, further calculation of nichromium coatings of every thicknesses decided not to conduct.

For the rest materials (Cr, CrN) calculation were done for all thicknesses. Results presented on the table 4 and fig. 18.

Table 4 – Loses of the campaign with dependence on thickness of coating

Cr				CrN			
Thickness, microns	Campaign, days	Loses, days	Loses, %	Thickness, microns	Campaign, days	Loses, days	Loses, %
0	2057,5	0	0,00	0	2057,5	0	0
5	1993,5	64	3,11	5	1943	114,5	5,89
10	1934	123,5	6,00	10	1930,5	127	6,58
20	1913	144,5	7,02	20	1918	139,5	7,27
40	1872	185,5	9,02	40	1845	212,5	11,52

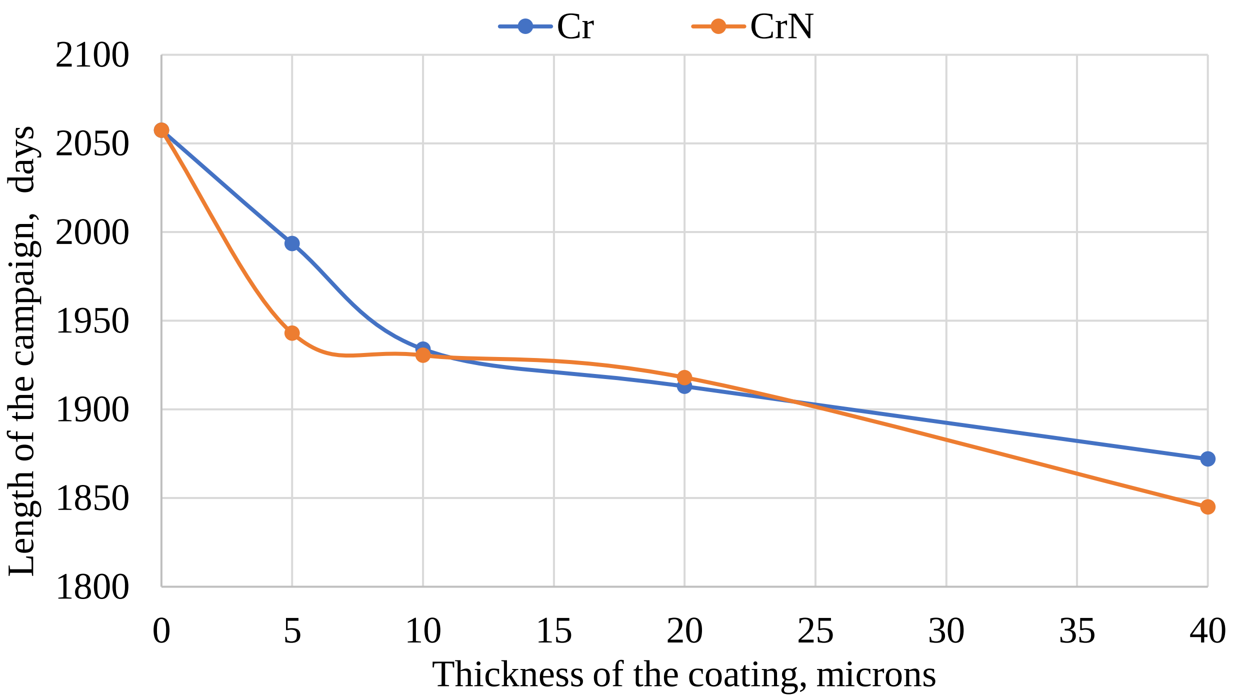


Fig. 18 – Dependence of the campaign length on thickness of coating

As it could be seen, campaign duration has a steep drop over a certain range of coating thickness, which is unique ащк each coating. After a certain point, the decrease in the duration of the campaign with increasing thickness acquires a gentle dependence. From which it can be concluded that for all materials there is a certain coating thickness, after which the neutron-physical characteristics of the core change very slightly. It can be assumed that the reasons for this phenomenon may be the mean free path of neutrons of given energies in given compounds with a certain concentration of components. According to [18], the total neutron interaction cross-section for both pure chromium and nitrogen increasing with decreasing energy of neutrons, so, we can make a suggestion that thick coatings after some point, which is considered inflection point on the graph, completely shields neutron with energies below thermal one from diffusion from water to fuel. That is why for thick coatings campaign the line of dependence of the campaign on the thickness is almost flat.

2.2 Flux calculation

There should be several reasons why length of the campaign drops with increasing of thickness of coating. In the MCU program fluxes of thermal neutrons for fresh (beginning of the campaign) and burned (end of the campaign) fuel assembly for all thicknesses of coating and considered materials were calculated and results presented on the fig. 19-26.

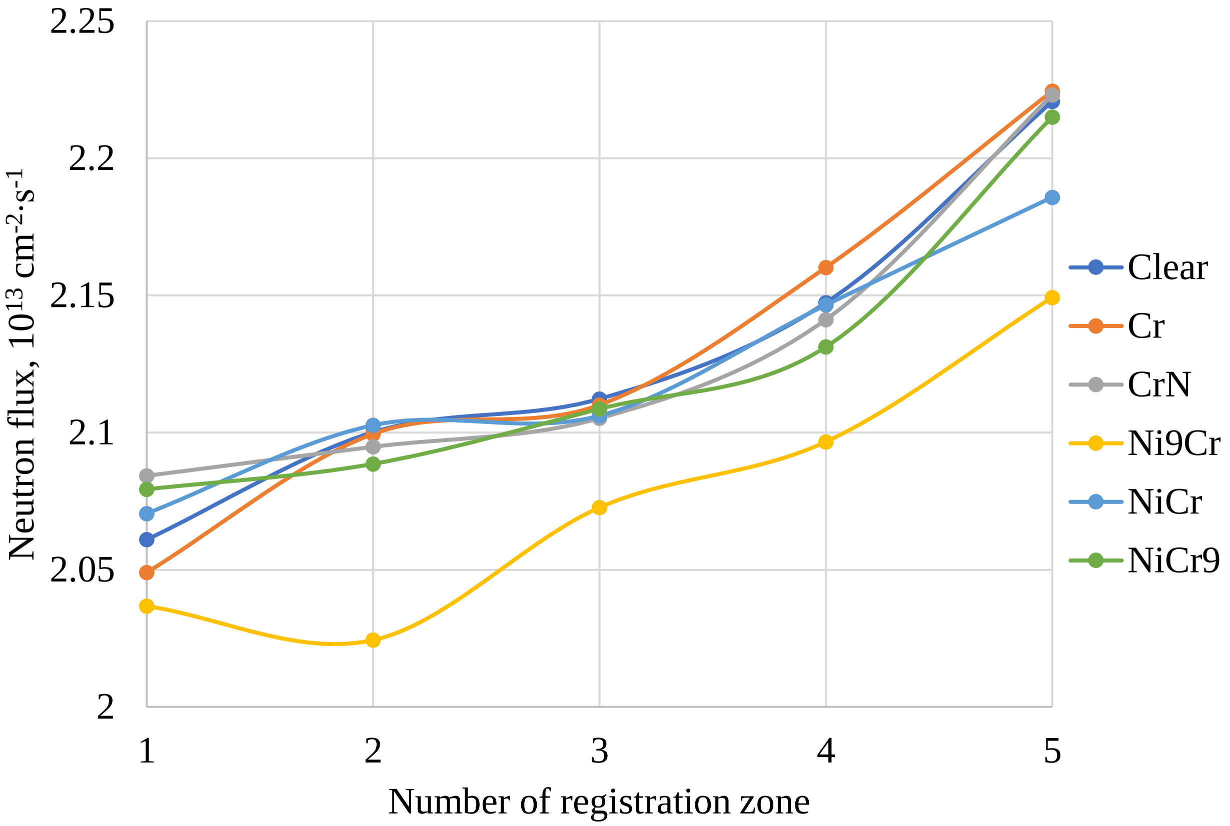


Fig. 19 – Distribution of neutron flux among fuel pellet: 5 microns, fresh fuel

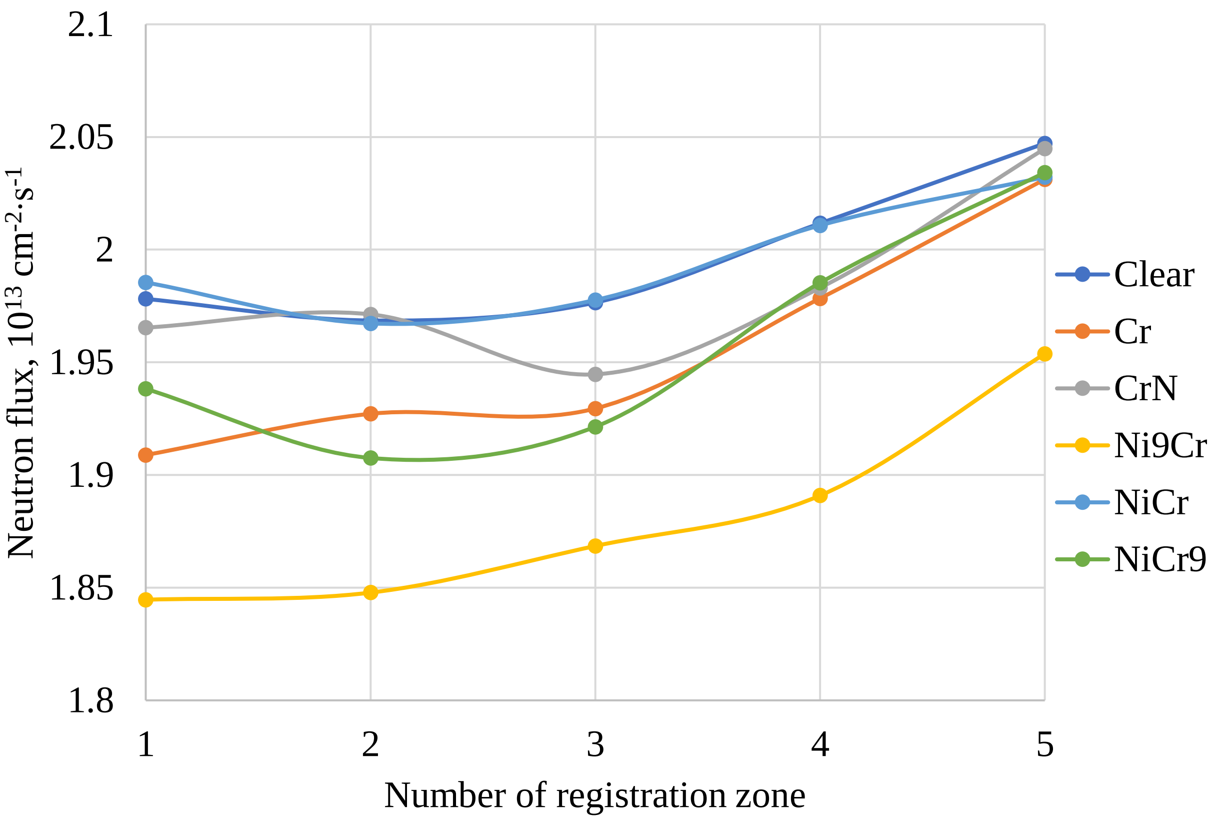


Fig. 20 – Distribution of neutron flux among fuel pellet: 5 microns, burned fuel

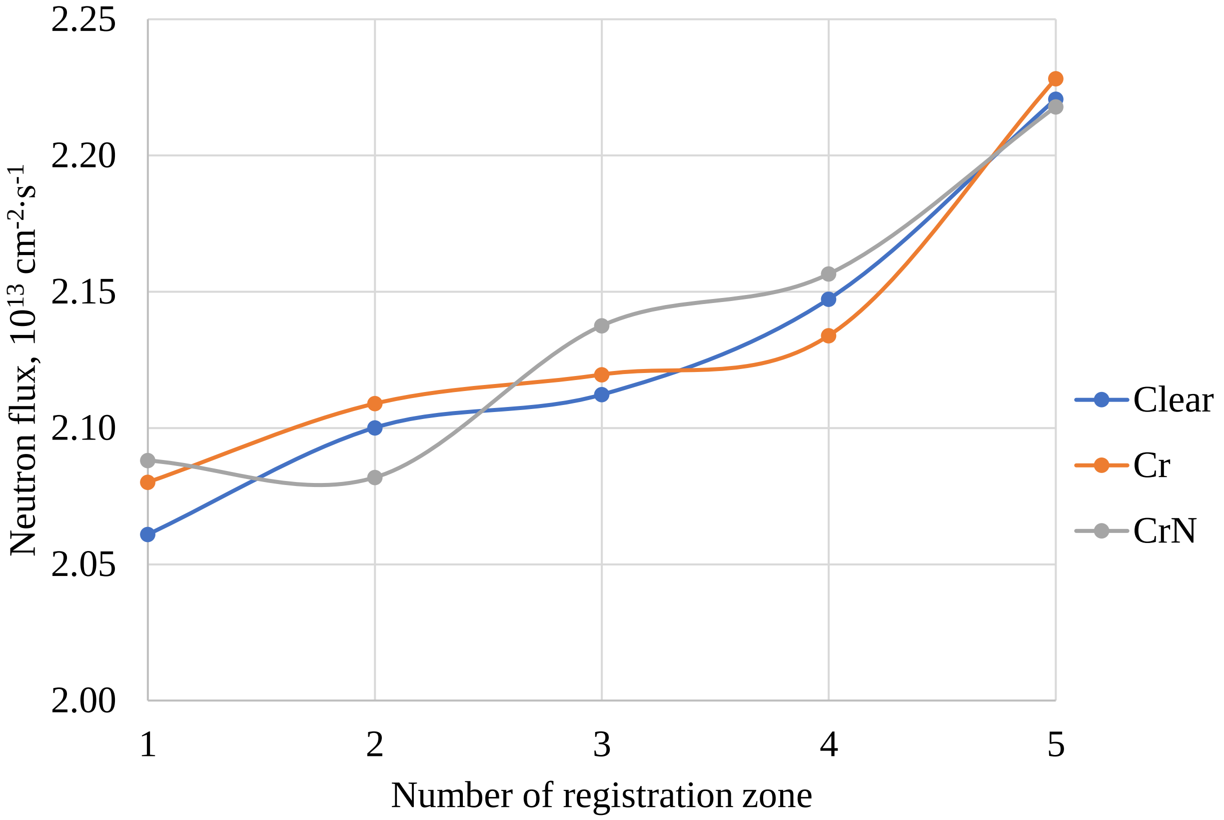


Fig. 21 – Distribution of neutron flux among fuel pellet: 10 microns, fresh fuel

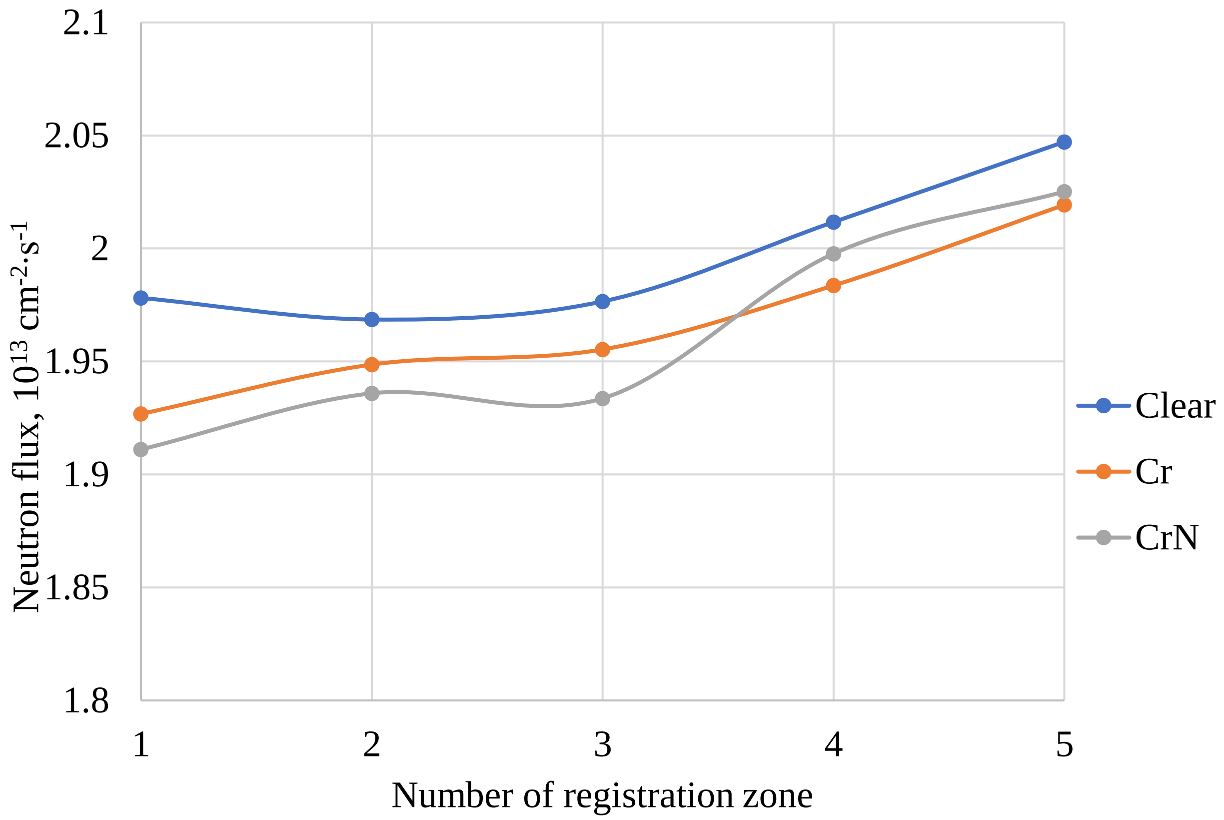


Fig. 22 – Distribution of neutron flux among fuel pellet: 10 microns, burned fuel

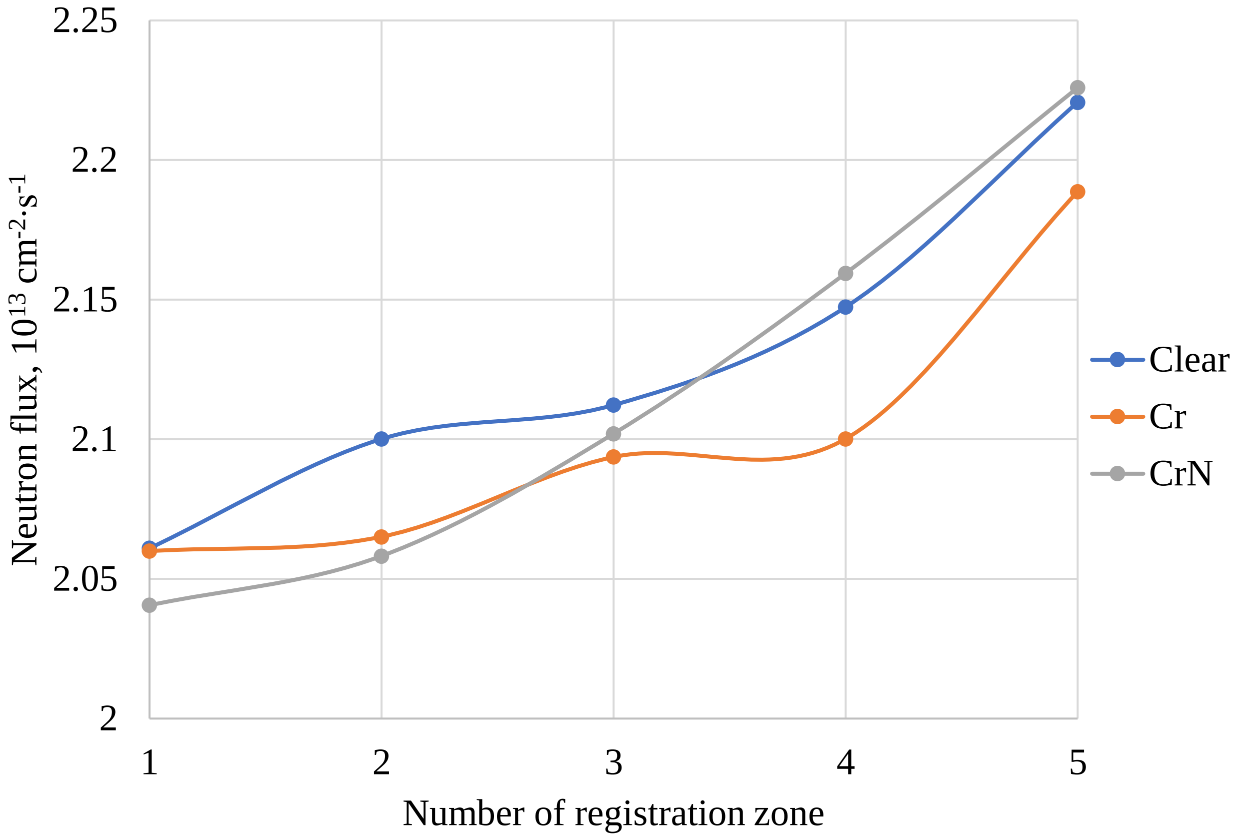


Fig. 23 – Distribution of neutron flux among fuel pellet: 20 microns, fresh fuel

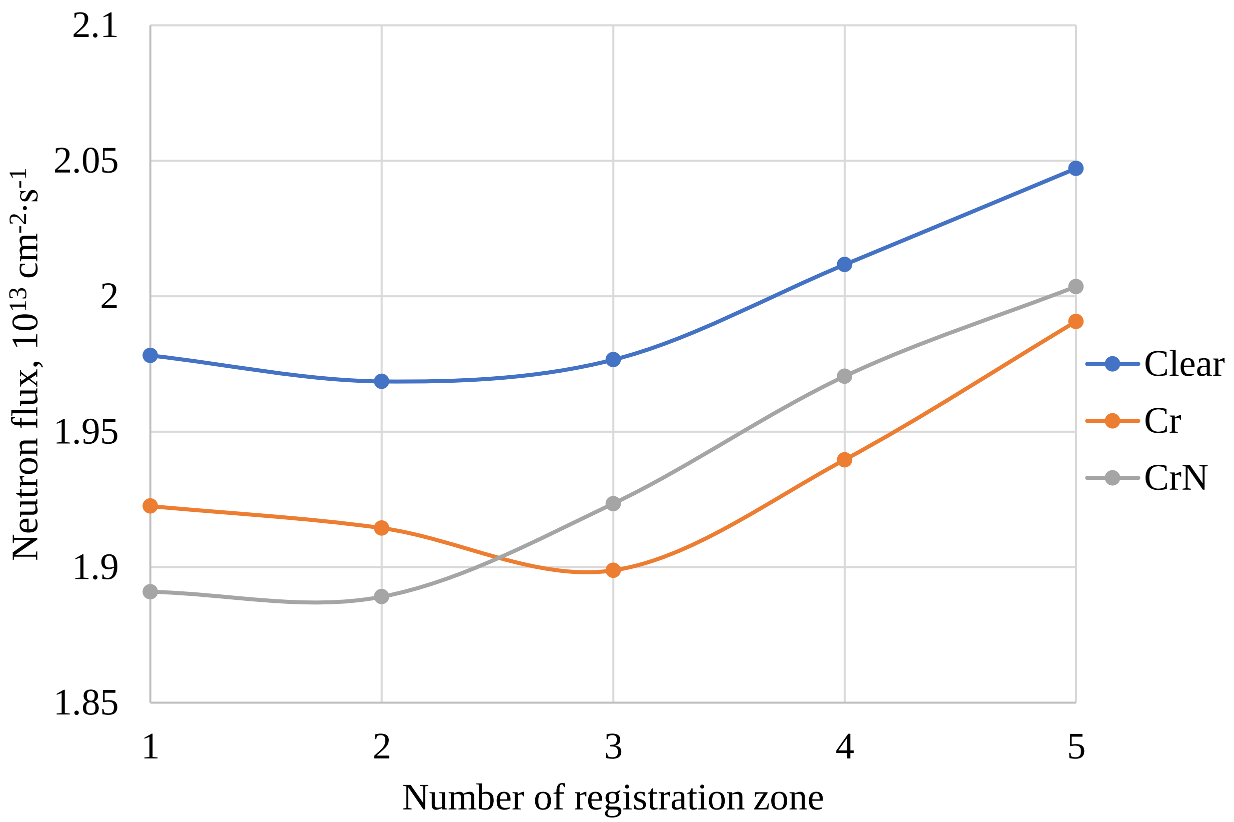


Fig. 24 – Distribution of neutron flux among fuel pellet: 20 microns, burned fuel

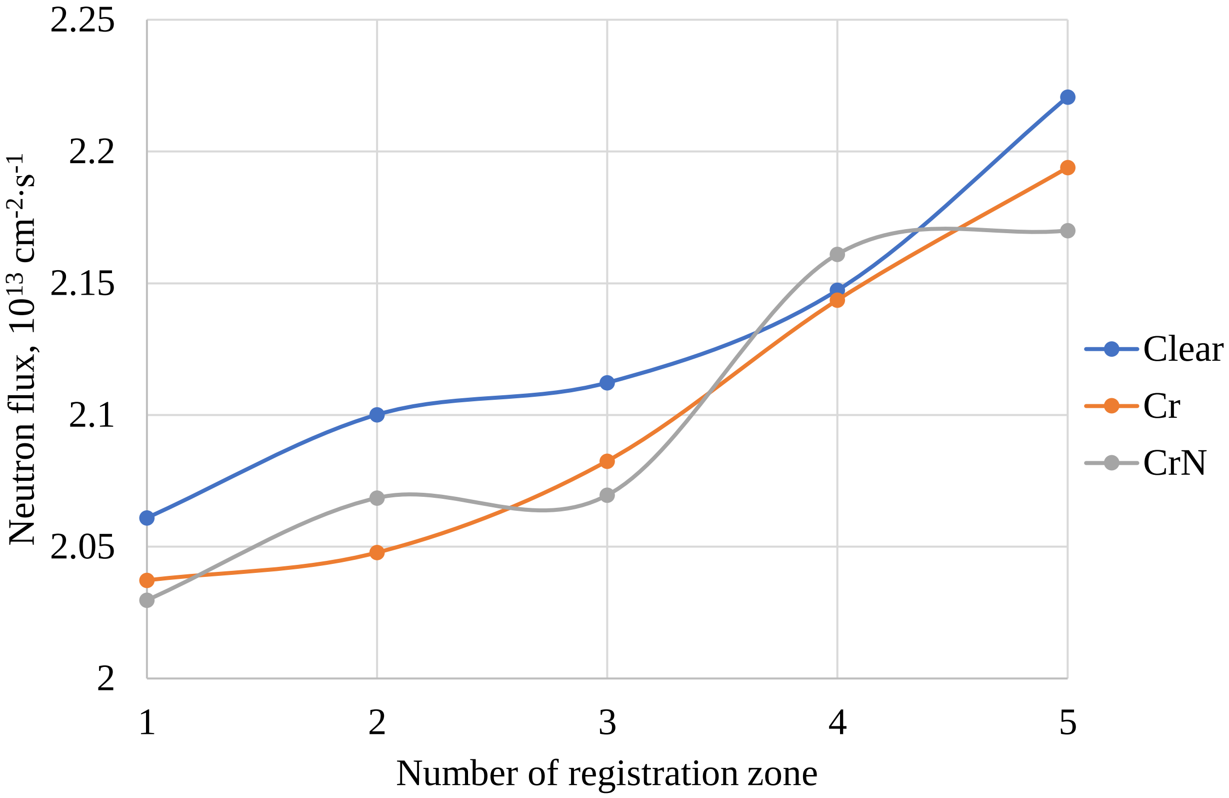


Fig. 25 – Distribution of neutron flux among fuel pellet: 40 microns, fresh fuel

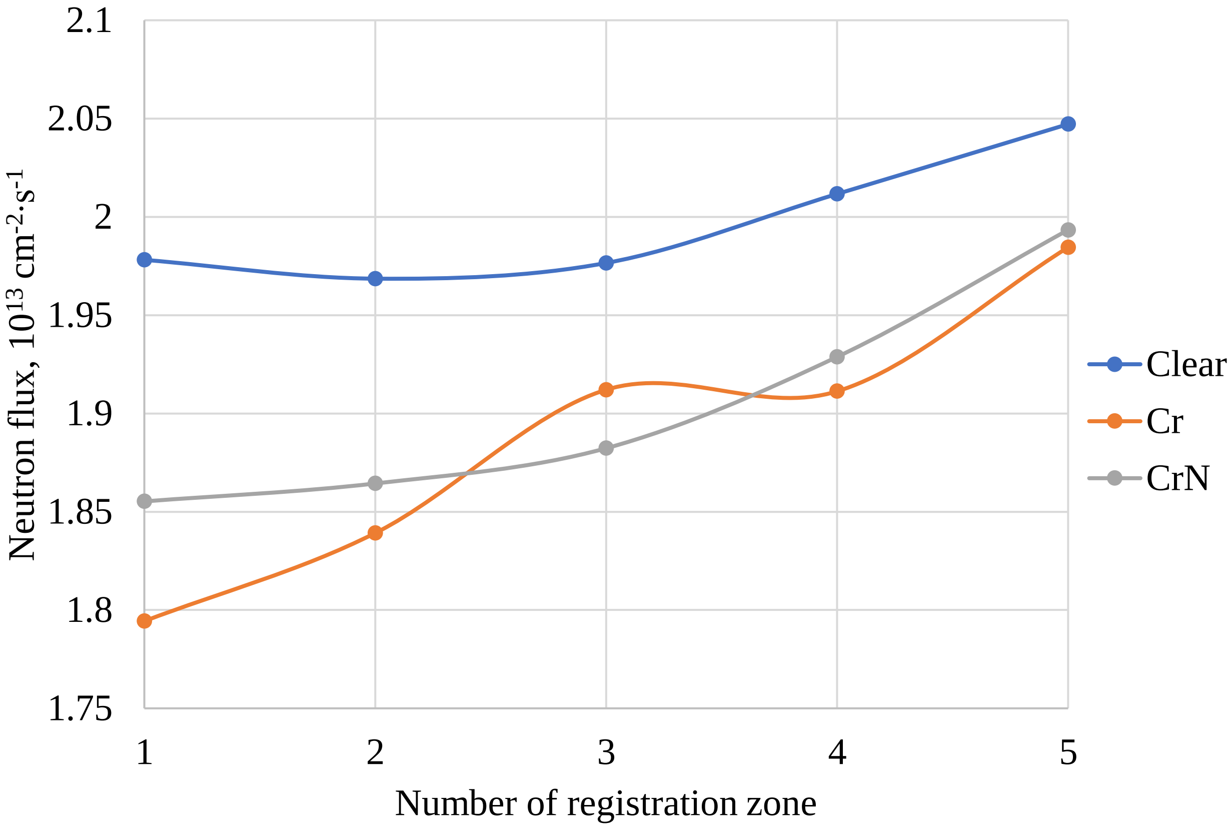


Fig. 26 – Distribution of neutron flux among fuel pellet: 40 microns, burned fuel

Analyzing the thermal neutron fluxes among the fuel pellet radius for a 5 micron thick coating, it can be seen that the distribution of thermal neutron fluxes among the radius of the fuel pellet depends on the material chosen. The nichrome alloy shows the worst result, the lowest average thermal neutron flux over the volume of the entire fuel pellet.

The remaining graphs for pure chromium and chromium nitride show that with increasing thickness, the average thermal neutron flux over the volume of the fuel pellet decreases, which may be one of the reasons for the decrease in the fuel campaign.

The decrease in the average thermal neutron flux along the radius of the fuel pellet can be caused by the screening effect of thermal neutrons, which assumes that neutrons of low energies (thermal and lower) do not have enough energy to overcome the thick coating.

3 Financial management, resource efficiency and resource conservation

The theme of the final qualification work is the study of the effect of chromium coatings on the neutron-physical parameters of the VVER-1000 type reactor. The relevance of the method is to increase the safety of operation of the installation in emergency conditions without loss in neutron-physical parameters.

The purpose of the work: to study the change in neutron-physical parameters depending on the used chromium compounds and their thickness.

The purpose of the section "Financial management, resource efficiency and resource saving" is to determine the prospects and success of the project, assess its effectiveness, the level of possible risks, develop a mechanism for managing and supporting specific design decisions at the implementation stage. Achievement of the goal is ensured by solving the following tasks:

- assessment of the commercial potential for the implementation of this technique;
- planning of research work;
- calculation of the research budget;
- determination of the resource efficiency of the study.

3.1 Assessment of the commercial potential and the prospects for conducting scientific research from the standpoint of resource efficiency and resource conservation

The object of research is a nuclear reactor with spectral regulation. Potential consumers of the research can be experimental design bureaus, as well as the nuclear industry and related areas.

Market segmentation is carried out according to the degree of need by the result of the study. The segmentation map is presented in table 5.

Table 5 – Segmentation map

		Scope of use		
		Design bureaus	Atomic industry	Foreign atomic agencies
Degree of need	High			
	Medium			
	Low			

When analyzing the map, it can be noted that the results of the study are most in demand in the design bureau, as well as in the nuclear industry.

3.2 Analysis of competitive technical solutions

Analysis of competitive technical solutions from the standpoint of resource efficiency and resource saving makes it possible to evaluate the comparative effectiveness of scientific development and determine directions for its future development. According to the subject of the final qualification work, three competitive options for the calculation method are presented for analysis:

– calculation of neutron-physical characteristics in the MCU program (variant 1);

– calculation of neutron-physical characteristics in the WIMS-D5 program (variant 2);

– theoretical calculation of neutron-physical characteristics (variant 3).

The scorecard of the analysis is presented in table 6. The position of the development and competitors is evaluated on a five-point scale, where 1 is the weakest position, and 5 is the strongest.

The calculation of competitiveness was carried out according to the formula:

$$C = \sum_{i=1}^{n} P_i \cdot W_i$$

where C – project competitiveness;

W – indicator weight (in fractions of a unit);

P – indicator score.

Table 6 – Scorecard for Comparing Competitive Research Developments

Criteria for evaluation	Criteria weight	Points			Competitiveness		
		Var. 1	Var. 2	Var. 3	Var. 1	Var. 2	Var. 3
Technical criteria for evaluating resource efficiency							
Accuracy, flexibility of methodology	0,18	5	3	3	0,9	0,54	0,54
Functional power	0,17	5	3	2	0,68	0,85	0,34
Ease of use	0,03	5	4	3	0,15	0,12	0,09
Energy efficiency	0,05	4	5	4	0,2	0,25	0,2
Memory resource requirement	0,04	5	2	1	0,2	0,08	0,04
Ease of operation	0,07	4	5	3	0,28	0,35	0,21
Economic criteria for evaluating efficiency							
Competitiveness of the method	0,1	5	4	2	0,5	0,4	0,2
Availability	0,21	4	5	5	0,84	1,05	1,05
Estimated service life	0,05	5	5	5	0,25	0,25	0,25
Financing of the developed method	0,1	5	5	3	0,5	0,5	0,3
Total	1	47	41	31	4,67	4,05	3,22

Data analysis shows that the chosen calculation method (variant 1) is the best despite the increased memory costs. However, such costs are associated with the best accuracy and functional power, as well as high competitiveness.

3.3 SWOT analysis

SWOT analysis is a universal tool for strategic analysis and planning, used to evaluate the phenomena and factors influencing a project or development. All analysis parameters are divided into 4 categories: strengths (strengths), weaknesses (weaknesses), opportunities (potential opportunities) and threats (potential threats). The task of a SWOT analysis is to give a structured description of the situation regarding which a decision needs to be made. The conclusions drawn from it are descriptive without recommendations or prioritization.

Table 7 presents the final SWOT analysis matrix compiled by matching the strengths and weaknesses of the research project.

Table 7 – SWOT analysis

	Strengths: S1. Relevance of the chosen topic. S2. Minimum research costs S3. Possibility of analysis of neutron-physical characteristics. S4. Reliability of results S5. Ability to control the calculation process	Weak sides: W1. Availability of software licenses W2. Need for good coding skills W3. Limited number of calculated parameters
Opportunities: O1. Relevance of the topic for publication in scientific journals. O2. Conducting various studies in this area O3. Ability to use calculations for OKB	The results of the analysis of the interactive matrix of the project fields "Strengths and Opportunities": 1. Scientific novelty, and, as a result, publications in cited scientific journals. 2. The possibility of applying the technique in various fields of activity due to neutron-physical analysis and minimal costs	The results of the analysis of the interactive matrix of the project fields "Weaknesses and Opportunities": 1. The presence of licensed programs allows other researchers to verify calculations, and also inspires more confidence
Threats: T1. Human factor (inattention, mistake) T2. Availability of competing programming codes T3. Low demand for results in the absence of publications	The results of the analysis of the interactive matrix of the project fields "Strengths and Threats": 1. The occurrence of errors due to incorrect interpretation of the results and, as a result, a drop in competitiveness	The results of the analysis of the interactive matrix of the draft fields "Weaknesses and Threats": 1. The influence of the human factor can negatively affect the reliability of the results, which will lead to a drop in the chance of publication. However, with complex work, it is possible to minimize the occurrence of errors.

In the course of the SWOT analysis, it was revealed that the advantages of this calculation method prevail over the shortcomings, which are easily eliminated.

3.4 Project initiation

The initiation process group consists of processes that are performed to define a new project or a new phase of an existing one. As part of the initiation processes, the initial goals and content are determined, and the initial financial resources are recorded.

3.4.1 The goals and results of the project

In table 8, information about the hierarchy of project goals and the criteria for achieving the goals are provided.

Table 8 – Goals and results of the project

Purpose of project:	Research of influence of chromium coating on neutron-physical parameters of nuclear reactor
Expected results of the project:	Confirmation of the possibility of using chromium coatings in a nuclear reactor
Criteria for acceptance of the project result:	Small deviations of neutron-physical parameters from the value corresponding to the reactor without coating
Requirements for the project result:	High accuracy
	Simplicity of adjusting the project to specific conditions
	Cheapness

3.5 Organization and planning of work

When organizing the process of implementing a specific project, it is necessary to rationally plan the employment of each of its participants and the timing of individual work.

In this paragraph, a complete list of ongoing work is compiled, their performers and rational duration are determined. A clear result of work planning is a network or linear schedule for the implementation of the project. Since the number of performers does not exceed two, a line chart is preferable. For its construction, the chronologically ordered above data are presented in table 9.

Table 9 – List of works and duration of their implementation

№	Participant	Role in the project	Functions	Labor time, hours.
1	Associate professor	Supervisor	Responsible for the implementation of the project within the specified resource constraints, coordinates the	64,0

			activities of the project participants	
2	Student	Executor	Specialist who performs individual work on the project	89,6

3.5.1 Development of a schedule for scientific and technical research

The complexity of the study is estimated by an expert due to the probabilistic nature of the value. Man-days are taken as the unit of labor input. Expected labor intensity is calculated by the formula:

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

where $t_{\exp}$ – expected labor intensity of the work, man-days;

$t_{\min}$ – the minimum possible labor intensity of performing a given work, man-days;

$t_{\max}$ – the maximum possible labor intensity of performing a given work, man-days.

To build a schedule for conducting scientific work in the form of a Gantt chart, the duration of each of the stages of work in working days is translated into calendar days according to the formula:

$$T_{CD} = T_{WD} \cdot K_{CD},$$

where T_{CD} – the duration of the work in calendar days;

T_{WD} – the duration of the work in working days;

K_{CD} – calendar factor.

The calendar coefficient is calculated by the formula:

$$K_{CD} = \frac{T_{CD}}{T_{CD} - T_{DOff} - T_{HD}},$$

where T_{CD} – number of calendar days in a year;

T_{DOff} – number of days off per year;

T_{HD} – the number of holidays in a year.

The value of the calendar coefficient for 2022:

$$K_{CD} = \frac{365}{365-66} = \frac{365}{299} = 1,22$$

Taking into account the data and the above formulas, a calculation table 10 is compiled. A Gantt chart, which is a work schedule, is shown in table 11.

Table 10 – Labor costs for the project

Step	Performers	Duration of work, days			Labor intensity of work by performers, man-days.			
					T_{WD}		T_{CD}	
		t_{min}	t_{max}	t_{exp}	Supervisor	Executor	Supervisor	Executor
Setting goals and objectives of the study	Supervisor, Executor	2	4	2,80	2,69	0,67	3,26	0,81
Development and approval of terms of reference (TOR)	Supervisor, Executor	2	4	2,80	2,69	0,67	3,26	0,81
Selection and study of materials on the topic	Supervisor, Executor	12	15	13,20	1,58	14,26	1,92	17,28
Development of the calendar plan	Supervisor, Executor	2	4	2,80	3,02	0,34	3,67	0,41
Performing calculations	Supervisor, Executor	30	35	32,00	–	38,40	–	46,54
Processing and analysis of the obtained results	Supervisor, Executor	8	14	10,40	1,25	11,23	1,51	13,61
Making an explanatory note	Executor	12	14	12,80	–	15,36	–	18,62
Design of graphic material	Executor	12	14	12,80	–	15,36	–	18,62
Total:				89,60	11,23	96,29	13,61	116,70

Table 11 – Linear work schedule

Step	Number of calendar days		February			March			April			May			June		
	Supervisor	Executor	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**
1	3,26	0,81															
2	3,26	0,81															
3	1,92	17,28															
4	3,67	0,41															
5	–	46,54															
6	1,51	13,61															
7	–	18,62															
8	–	18,62															

Supervisor – ; Executor –

3.6 Research budget

The cost of creating a project includes the amount of all costs necessary for the implementation of a set of works that make up the content of this development. The calculation of the estimated cost of its implementation is carried out according to the following cost items:

- materials and purchased products;
- wage;
- social tax;
- depreciation deductions;
- other (overhead) expenses.

3.6.1 Calculation of material costs

This item of expenditure includes the cost of materials, purchased products, semi-finished products and other material assets consumed directly in the process of performing work on the design object. This also includes specially purchased equipment, tools and other items classified as fixed assets worth up to 40,000 rubles. inclusive. The price of material resources is determined by the relevant price tags or supply contracts. In addition, the article includes the so-called transportation and procurement costs associated with transportation from the supplier to the consumer, storage and other processes that ensure the movement (delivery) of material resources from suppliers to the consumer. This also includes the costs of a purchase and sale transaction (so-called transactions). Approximately they are estimated as a percentage of the selling price of purchased materials, as a rule, it is 5 - 20%. The performer of the work independently chooses their value within the limits presented in Table 12.

Table 12 – Calculation of the cost of materials

Name of materials	Unit price, rub	Amount	Cost, rub
A4 printer paper	250	1 pack	250
Printer cartridge	1550	1 unit	1550
Total:			1800

Let's assume that transportation and procurement costs are 5% of the selling price of materials, then the costs of materials, taking into account transportation and procurement costs, are equal to:

$$C_{\text{Mat}} = 1800 \cdot 1{,}05 = 1890.$$

3.6.2 Salary

This item of expenditure includes the salary of the scientific adviser and the engineer, in his role is the project executor, as well as bonuses included in the payroll. The calculation of the basic salary is carried out on the basis of the complexity of the implementation of each stage and the value of the monthly salary of the contractor. The average daily tariff salary is calculated by the formula:

$$\text{ЗП}_{Day-T} = \frac{\text{MS}}{25{,}083}$$

where 25,083 – the average number of working days in a month with a six-day working week.

The time spent for each performer in working days rounded to the nearest integer is taken from Table 13. To account for bonuses, additional wages and regional allowances, the following series of coefficients is used: $\text{К}_{\text{Bonus}} = 1{,}1$; $\text{К}_{\text{Add.Sal.}} = 1{,}188$; $\text{К}_{\text{Region}} = 1{,}3$. Thus, in order to switch from the tariff amount of the contractor’s earnings associated with participation in the project to the corresponding full earnings, it is necessary to first multiply by the integral coefficient:

$$\text{К}_{\text{I}} = \text{К}_{\text{Bonus}} \cdot \text{К}_{\text{Add.Sal.}} \cdot \text{К}_{\text{Region}}$$

$$К_I = 1{,}1 \cdot 1{,}188 \cdot 1{,}3 = 1{,}699$$

Table 13 – Salary

Performer	Salary, rub/month	Average daily salary, rub/workday	Time spent, workdays	$К_I$	Salary, rub
Supervisor	36174	1442,17	12	1,699	29403
Executor	18426	734,60	97	1,62	115435
Total:					144838

3.6.3 Calculation of social tax costs

The cost of the unified social tax (UST), which includes contributions to the pension fund, social and medical insurance, is 30% of the total salary for the project:

$$C_{\text{UST}} = C_{\text{Sal}} \cdot 0{,}3;$$

$$C_{\text{UST}} = 144838 \cdot 0{,}3 = 43451.$$

3.6.4 Depreciation calculation

Writing a final qualification work according to the plan takes 5 months. For modeling and calculations, a personal computer with an initial cost of 30,000 rubles is used. The useful life for office equipment is from 2 to 3 years

The normal depreciation rate is calculated as:

$$N_D = \frac{1}{T} \cdot 100\%$$

where T – time of beneficial utilization, years.

If we take the useful life equal to 3 years, then the depreciation rate:

$$N_D = \frac{1}{3} \cdot 100\% = 33{,}3\%$$

Annual depreciation charges:

$$A_{year} = 30000 \cdot 0{,}33 = 9900 \text{ rub}$$

Monthly depreciation charges:

$$A_{month} = \frac{9900}{12} = 825 \text{ rub}$$

The total amount of depreciation of fixed assets:

$$C_{Depr} = 825 \cdot 5 = 4125 \text{ rub}$$

3.6.5 Calculation of other expenses

The article "Other expenses" reflects the costs of the project, which are not taken into account in the previous articles, they should be taken equal to 10% of the sum of all previous expenses:

$$C_{\text{Other}} = \left(C_{\text{Mat}} + C_{\text{Sal}} + C_{\text{UST}} + C_{\text{Depr}}\right) \cdot 0{,}1$$

Other expenses in our case:

$$C_{\text{Other}} = \left(1890 + 144838 + 43451 + 4125\right) \cdot 0{,}1 = 19430 \text{ rub}$$

3.6.6 Calculation of the total cost of development

Having carried out the calculation for all items of the development cost estimate, it is possible to determine the total cost of researching a nuclear reactor with spectral control. The results are presented in table 14.

Table 14 – Estimated project development costs

Cost item	Symbol	Cost, rub
Materials and purchased products	C_{Mat}	1890
Basic salary	C_{Sal}	144838
Contributions to social funds	C_{UST}	43451
Depreciation deductions	C_{Depr}	4125
Other expenses	C_{Other}	19430
Total:		213734

Thus, the development costs amounted to C = 213734 rubles.

3.7 Determination of resource (resource-saving), financial, budgetary, social and economic efficiency of the study

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

This technique has no direct analogues: only a partial replacement of the program code with another is possible. Consequently, the determination of the effectiveness of the study occurs as a result of calculating the integral indicator of efficiency, consisting only of the value of resource efficiency.

The integral indicator of resource efficiency of the options for the execution of the object of study can be determined as follows:

$$I_{pi} = \sum a_i \cdot b_i$$

where I_{pi} – integral indicator of resource efficiency for the i-th version of the development;

a_i – weight coefficient of the i-th version of the development;

b_i^a, b_i^p – scoring of the i-th version of the development, is established by an expert according to the selected evaluation scale;

n – number of comparison parameters.

A comparative assessment of the characteristics of the study options is presented in table 15, where variant 1 represents WIMS-D5 modeling, and variant 2 is a theoretical calculation.

Table 15 – Comparative evaluation of the characteristics of research options

Criteria	Parameter weighting factor	Current work	Variant 1	Variant 2
1. Contributes to the growth of labor productivity when using the method	0,25	5	4	3
2. Ease of operation	0,2	5	4	3
3. Method accuracy	0,05	5	3	3
4. Energy saving	0,2	4	5	4
5. Need for memory resources	0,15	5	2	1
6. Functional power	0,15	5	3	2
TOTAL	0,25	4,80	3,70	2,75

The results obtained confirm the advantages of the chosen variant of the scientific research methodology and prove its greatest efficiency.

3.8 Section conclusions

In this section, the economic aspects and resource efficiency of this study are evaluated, the following results are obtained:

– potential consumers of the results of this study are design bureaus and the nuclear industry;

– an analysis of competitive technical solutions of a scientific study was carried out, in which it was found that the method chosen in the study is the most preferable due to the best accuracy and functional power, which makes it the most competitive. The conducted SWOT analysis showed that the advantages of the developed methodology prevail over its shortcomings, and the identified threats are removable;

– a Gantt chart was built, which clearly illustrates the time spent for the implementation of scientific research. The total number of calendar days during which the executor worked was 117, and the total number of calendar days during which the supervisor worked was 14;

– the estimate of scientific research is determined, the main items of expenditure are identified. The budget for this research work amounted to 231734 rubles; the main item of expenditure is salaries for the supervisor and engineer (67.8%).

– the value of the integral indicator of resource efficiency was 4,80, while for analogs these indicators were 3,70 and 2,75, respectively, which indicates the greatest efficiency of the chosen research methodology.

4 Social responsibility

In this paper, a study of a influence of casing chromium coatings on neutron-physical parameters of VVER-1000 type reactor is carried out. The work is carried out using a personal computer in room 321 of the 10th TPU building. The section deals with dangerous and harmful factors that are possible during research work, legal and organizational issues, as well as measures in emergency situations.

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

A hazardous production factor, according to [19], is such a production factor, the impact of which, under certain conditions, leads to injury or other sudden, sharp deterioration in health.

A harmful production factor is such a production factor, the impact of which on a worker, under certain conditions, leads to illness or a decrease in working capacity.

4.1 Legal and organizational issues of security

According to the Labor Code of the Russian Federation [20], each employee has the right to:

- a workplace that meets the requirements of labor protection;
- obtaining reliable information from the employer, relevant state bodies and public organizations about the conditions and labor protection at the workplace, about the existing risk of damage to health, as well as about measures to protect against exposure to harmful and (or) dangerous production factors;
- refusal to perform work in the event of a danger to his life and health due to violation of labor protection requirements, except in cases;
- providing means of individual and collective protection;
- training in safe working methods and techniques at the expense of the employer;

– an extraordinary medical examination in accordance with medical recommendations while retaining his place of work and average earnings during the examination;

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

4.2 Analysis of identified harmful and dangerous factors arising during the study

Harmful and dangerous factors affecting an employee are established in accordance with [21].

Harmful factors when performing work using a PC are:

- deviations of microclimate indicators;
- increased level of electromagnetic radiation;
- increased noise level;
- neuropsychic overload;
- insufficient illumination of the working area.

The above factors can affect the health of researchers, so control over compliance with standards and requirements should be established.

4.3 Deviations of microclimate indicators

For the qualitative implementation of work and ensuring the normal life of the employee, the premises must be provided with appropriate meteorological conditions that affect a person during work. The microclimate is a complex of factors that affect the thermoregulation of the human body, its well-being and productivity, as well as its health. The main parameters of the microclimate are temperature, humidity, air velocity. In connection with the working conditions, when calculating using a computer, category 1a is established. Microclimate requirements are set in accordance with [22]. For category 1a, the optimal microclimate indicators are presented in table 16.

Table 16 – Optimum microclimate indicators

Period of year	Air temperature, ^0C	Relative humidity, %	Air speed, m/s
Cold	22-24	15-75	0,1
Warm	23-25	15-75	0,1-0,2

In computer rooms, daily wet cleaning and systematic ventilation after each hour of work should be carried out. To maintain normal microclimate parameters in the working area, devices of ventilation, air conditioning and heating systems are used.

Ventilation allows you to create normal sanitary and hygienic conditions in the premises. The ventilation process makes it possible to continuously remove polluted air from the production room and at the same time supply fresh air in such an amount that the concentration of harmful substances in the air will be below the maximum permissible level, and the temperature, humidity and air velocity will comply with sanitary standards. According to [23], this auditorium requires an air exchange rate of 20 m^3/h per person. Room 321 is designed for 12 workplaces, so the ventilation performance will be:

$$L=20\cdot12=240\ m^3/h.$$

This performance is provided by a Vents BEHTC 150 fan with a capacity of 270–292 m^3/h and a power of 24 W [24].

4.4 Level of electromagnetic radiation

Electromagnetic radiation is a significant danger to humans in comparison with other harmful factors. In the case under consideration, the source of electromagnetic radiation is computer equipment (monitor and system unit). Prolonged exposure to intense electromagnetic radiation can cause increased fatigue, the appearance of heart pain, and dysfunction of the central nervous system. It should be noted that heating the processor during operation causes the production of some harmful compounds, which in turn lead to deionization of the surrounding space.

The norms of electromagnetic fields generated by the PC are given in table 17 in accordance with [22].

Table 17 – Permissible levels of EMF created by PC at workplaces

Quantity	Frequency	Temporary allowable EMF levels
Electric field strength	5 Hz – 2 kHz	25 V/m
	2 kHz – 400 kHz	2,5 V/m
Magnetic flux density	5 Hz – 2 kHz	250 nTl
	2 kHz – 400 kHz	25 nTl
Electrostatic potential of the video monitor screen		500 V

There are a number of recommendations, following which, you can reduce the negative impact of computer technology:

– if several computers or laptops are constantly in the same room, then they should be placed around the perimeter of the room, leaving the center free, since the sides and back of the monitor generate much more harmful radiation;

– turn off the computer after finishing work: the longer it works, the more radiation it generates and releases a significant amount of harmful substances into the environment;

– use of a special protective film;

– systematic dusting, wet cleaning and the use of ionizers [25].

4.5 Noise level

Noise in the workplace has an irritating effect on the employee, increases his fatigue, and when performing tasks that require attention and concentration, it can lead to an increase in errors and an increase in the duration of the task. Prolonged exposure to noise leads to hearing loss of the worker up to his complete deafness.

Table 18 shows the permissible noise levels in the working area of the PC.

Table 18 – Values of noise limit [22]

Sound pressure levels (dB) in octave bands with geometric mean frequencies, Hz									Maximum sound level, dB
31,5	63	125	250	500	1000	2000	4000	8000	
79	63	52	45	39	35	32	30	28	55

The noise level at workplaces while working on a PC should not exceed 55 dB. To reduce the noise level, the ceiling or walls should be lined with sound-absorbing material with a maximum sound absorption coefficient in the frequency range from 63 to 8000 Hz [22]. Curtains on the windows, made of dense heavy fabric, serve as additional sound absorption.

4.6 Neuropsychic overload

Neuropsychic overload is divided into:

– mental strain, including those caused by information load;
– overvoltage of analyzers, including those caused by information load;
– monotony of work - emotional overload.

Overstrain of visual analyzers can lead to fatigue and disruption of the contractile function of the eye muscles. Neuro-emotional stress can be caused by responsibility for the work performed, high requirements for the quality of the work performed, the complexity of the work, especially in conditions of time pressure. Neuro-emotional stress can disrupt the functional state of the cardiovascular and central nervous systems [22].

To reduce the impact of harmful factors, a framework for the duration of breaks is established. Table 19 shows the total rest time for each category of work [25].

Table 19 – Total break time depending on the category of work and load

Work category	The level of load per work shift for types of work with a PC			Total time of regulated breaks at 8-hour shift, min
	group A, number of characters	group B, number of characters	group B, hours	

I	until 20 000	until 15 000	until 2	50
II	until 40 000	until 30 000	until 4	70
III	until 60 000	until 40 000	until 6	90

In this case, the load level refers to group B, work category III. According to the table, it is required to set breaks, the sum of which per shift will be at least 90 minutes, i.e. breaks of 15 minutes each working hour [25].

4.7 Illumination of the working area

In industrial premises, three different types of lighting are used [22]: natural, artificial and mixed.

Illumination on the surface of the table in the area where the working document is placed should be 300-500 lux. Lighting should not create glare on the screen surface. The illumination of the screen surface should not exceed 300 lux.

The required number of lamps is determined as follows:

$$n = \frac{E \cdot S \cdot Z \cdot K}{F \cdot \Phi \cdot m};$$

where E – normalized illumination, E=300 lux;

S – room area, S=40 m^2;

Z – coefficient of illumination unevenness, Z=1,15;

K – safety factor, K=1,1;

F – luminous flux of one lamp, F=1050 lm;

Φ – utilization factor, Φ=0,52;

m – number of bulbs in a lamp, m=4 pcs.

$$n = \frac{300 \cdot 40 \cdot 1{,}15 \cdot 1{,}1}{1050 \cdot 0{,}52 \cdot 4} = 6{,}95 \text{ шт.}$$

In order to avoid areas with insufficient illumination, the required number of fixtures is rounded up to a whole number. Thus, the number of lamps will be 7 pieces.

4.8 Fire and explosion safety

According to [26], depending on the characteristics of the substances used in production and their quantity, according to fire and explosion hazard, the premises are divided into categories А, Б, В, Г, Д. Room 321 belongs to class В, since it contains solid combustible materials such as wooden cabinets and tables.

Measures for fire prevention are divided into: organizational, technical, operational and regime.

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

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

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

– the use of non-combustible or hardly combustible materials in the construction and decoration of buildings;
– correct operation of the equipment (correct connection of the equipment to the power supply network, control of equipment heating);
– training of 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 installation of electrical wires and equipment, heating, ventilation, lighting;
– correct placement of equipment;
– timely preventive inspection and repair of equipment.

In the event of an emergency, it is necessary [27]:

– notify management

– call the emergency service or the Ministry of Emergency Situations - tel. 112;

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

4.9 Electrical safety

According to [28], this room belongs to the 1st category of electrical safety, since there are no electrical installations with a voltage of more than 1000 V in it. The main requirements for 1st category:

– air humidity does not exceed 60 %;
– the presence of supply and exhaust ventilation;
– absence of conductive dust and chemical compounds in the air;
– air temperature not more than 35 ºC;
– non-conductive floors.

You should not work with a computer in conditions of high humidity (relative air humidity exceeds 75 % for a long time), high temperature (more than 35 °C), the presence of conductive dust, conductive floors and the possibility of simultaneous contact with ground-connected metal elements and the metal case of electrical equipment. The computer operator works with electrical appliances: a computer (display, system unit, etc.) and peripheral devices. There is a danger of electric shock in the following cases:

– with direct contact with current-carrying parts during computer repair;
– when touching non-current-carrying parts that are energized (in case of violation of the insulation of the current-carrying parts of the computer);
– when touching the floor, walls that are energized;
– in case of a short circuit in high-voltage units: power supply unit and display scanner unit.

If any part of the computer malfunctions, electrical current may be present in the case, which may result in electrical injury or electric shock. To eliminate this, it is necessary to ensure the connection of the metal cases of the equipment to the grounding conductor.

Organizational measures for electrical safety are periodic and unscheduled briefings. Periodic briefing is carried out for non-electrotechnical personnel performing the following work: turning on and off electrical appliances, cleaning rooms near electrical panels, sockets and switches, etc. [28].

Non-electrotechnical personnel are certified for the first qualification group in electrical safety. Periodic training is carried out at least once a year. Unscheduled briefing is carried out by the head of the department when new technical electrical equipment is put into operation [28].

4.10 Emergencies

Table 20 considers emergency situations, prevention measures and actions in case of occurrence that may arise when performing work in room 321 of TPU building 10.

Table 20 – Emergency situations, prevention measures and actions in case of occurrence [27, 29, 30]

№	Emergencies	Prevention measures	Actions in case of occurrence
1	Fire	- check the condition of electrical devices, in case of detection of problems, do not proceed with self-elimination; - comply with fire safety rules in accordance with the requirements of regulatory documentation; - train and instruct employees, develop fire fighting skills	- turn off electrical equipment; - use powder and carbon dioxide fire extinguishers; - in case of a threat to life, evacuate; - call 01, 101, 112
2	Electric shock	It is forbidden: - work with wet and dirty hands; - touch the connectors of the connecting cables; - independently troubleshoot equipment - touch the power wires and grounding devices	- eliminate the effect of current on the victim; - lay the victim on a hard surface; - check for breathing and pulse; - call 03(103) or 112 is mandatory in all cases
3	Falling from height with injuries	- make sure that computer wires are not in the way of movement, in case of violation, inform the manager;	- inspect the body and head of the victim for open wounds and abrasions;

		- do not use a chair, table, etc. instead of a ladder; - do not allow the placement of equipment and documentation on shelves and cabinets, access to which is impossible without a stepladder; - when moving up stairs, always hold on to the handrail and look at your feet; - do not keep your hands in your pockets, because in case of a fall, instinctive movements will help you stay on your feet; - never carry objects by holding them in front of you, blocking the view; - clean your shoes from dirt, ice and other contaminants before entering the building	- ask to make movements with your fingertips, which will eliminate damage to the spine; - movement of arms and legs will eliminate the presence of fractures; - to interrogate the victim about violations of general well-being: dizziness, drowsiness, nausea - these signs indicate a concussion; - in the absence of serious injuries, a cold compress is placed on the site of the bruise and the victim is escorted home; - the forced adoption of the “frog” pose indicates the presence of serious injuries, in this case it is forbidden to try to lift the victim or take off his clothes. In this case, you need to call 03 (103) or 112 and report the incident

4.11 Section conclusions

The section considers harmful and dangerous factors:

– deviations of microclimate indicators [22, 23];
– increased level of electromagnetic radiation [22];
– increased noise level [22];
– neuropsychic overload [22, 25];
– insufficient illumination of the working area [22].

It was determined that room 321 10 of the TPU building refers to:

– to category B in terms of fire and explosion safety [26];
– to class 1 in electrical safety [28].

It will also calculate the illumination and ventilation of the room and it was found out that the room meets the established standards [22, 23]. When considering emergencies in the workplace, preventive and liquidation measures are proposed. The most likely emergency is a short circuit followed by a fire. To prevent such cases, it is necessary to regularly check the condition of the devices and take precautions against electric shock [27].

Conclusion

The main methods of coating are thermal and cathodic evaporation, also a more advanced method of cathodic evaporation is magnetron sputtering.

Also in fig. 5 shows a phased schematic depiction of the processes of oxidation of chromium coatings on zirconium alloys: starting from the moment when the coating performs its protective function, the transition with the loss of protective properties, and then no longer protective coating.

Chromium shows us good resistance to accident conditions of reactor operation, to be precisely, to steam of high temperature and pressure. According to kinetics of Cr-Zr interface from the side of material science it gives us approximately additional 20 minutes to deal somehow with accident to prevent complete melt down of nuclear reactor core.

Verified model of VVER-3000 with coatings on casing in MCU program was built. Thickness of coating was taken 5 microns and several material contains chromium were taken. For each material length of the campaign was calculated. In obtained results casing with no coating, Cr, CrN, Ni_9Cr, NiCr, $NiCr_9$ has 2057,5; 1993,5; 1943; 1865,5; 1919; 1965,5 days respectively. Nichromium with highest concentration of Ni considered as the worst material for coatings because of high elastic scattering cross-section which probably shields thermal neutrons from fuel while them trying to diffuse from moderator (water) to uranium (fuel).

Based on the information presented on the distribution of thermal neutron fluxes along the radius of the fuel pellet, one can conclude that one of the reasons for the decrease in the fuel run. The reason is a decrease in the thermal neutron flux along the radius of the fuel pellet with an increase in the thickness of the coating on the cladding of fuel assemblies and fuel elements. The dependence of thermal neutron fluxes on the selected chromium composition at a fixed layer thickness (5 microns) is also presented.

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