REVIEW

by official reviewer Assem Bakhytzhanovna Issayeva for Kunarbekova Mahabbat Seit-Zadaevna's dissertation on "Obtaining modified carbon materials for removing radionuclides from contaminated water", submitted for the degree of Doctor of Philosophy (PhD) in the specialty "8D07109 – Innovative technologies and new inorganic materials"

№ p/p	Criteria	Meeting the criteria (underline one of the possible answers)	Justification of the official reviewer's position (italicized remarks)
1.	The topic of the dissertation (as of the date of its approval) corresponds to the directions of scientific development and/or state programs.	1.1 Compliance with priority areas of science development or government programs: 1) the dissertation was completed within the framework of a project or target program funded from the state budget (specify the name and number of the project or program); 2) the dissertation was completed within the framework of another state program (specify the name of the program); 3) the dissertation corresponds to the priority area of science development approved by the Higher Scientific and Technical Commission under the Government of the Republic of Kazakhstan (specify the direction).	In this dissertation, doctoral student Kunarbekova Mahabbat Seit-Zadaevna substantiates the relevance of the research, referring to accumulated radioactive waste and future use in nuclear waste management in initiatives related to the construction of a nuclear power plant in Kazakhstan. At the same time, it should be noted that it is recommended to indicate regulatory documents in force at the time of writing the dissertation, for example, the results of the Referendum on the Use of Atomic Energy in Kazakhstan dated October 6, 2024. *This remark is not essential and does not require amendments to the completed dissertation. Nevertheless, when further developing the topic, preparing publications or participating in scientific events, it is advisable to take into account the state strategic documents in force at the time of publication and the priority directions of science development in the Republic of Kazakhstan.* Doctoral student Kunarbekova Mahabbat Seit-Zadaevna is the executor of the program-targeted financing of the Committee of the Ministry of Internal Affairs of the Republic of Kazakhstan for 2023-2025. BR21881939 "Development of resource–saving energy production technologies for the mining and metallurgical complex and the creation of an innovative engineering center" and the responsible executor of the competition project for grant financing of young scientists for 2023-2025. AP19577049 "Synthesis, characterization and physical-chemical research of sorbents from biomass for purification of industrial waters from radionuclides." The dissertation work of Kunarbekova Mahabbat Seit-Zadaevna corresponds to the priority direction of science development, approved by the Higher Scientific and Technical Commission under the Government of the Republic of Kazakhstan on the rational use of water Resources.
2.	Importance for science	The work makes/does not make a significant contribution to science, and its importance is well disclosed / not disclosed.	The study demonstrates a high level of scientific study and relevance. The thesis is aimed at solving one of the most important problems of our time - pollution of water resources with radionuclides. In particular, the work aims to selectively remove radionuclides using the example of caesium (Cs^+) and triiodide anions (I_3^-) from the groundwater of the Degelen test site (Kurchatov, Kazakhstan). Fundamentally important is the completion of the work, in terms of synthesis, characterization, laboratory testing and testing on really polluted natural waters. This work is interdisciplinary in nature and is located at the intersection of chemical technology, ecology, and engineering, which makes it promising for further applied research.
3.	The principle of independence	The level of independence: **1) high;** 2) Average; 3) Low; 4) there is no independence.	Kunarbekova Mahabbat Site-Zadaevna's dissertation work is an independent study with scientific and practical significance. As part of the work, a number of modified sorbents were developed for the extraction of radionuclides Cs^+ and I_3^- from aqueous solutions. The sorption process is modeled using Gaussian software. The practical significance is confirmed by the existence of a patent for a utility model and the

			results of tests conducted at the National Nuclear Center of the Republic of Kazakhstan. These achievements attest to the author's independence and her contribution to the implementation of scientific work.
		4.1 Substantiation of the relevance of the dissertation: **1) justified;** 2) partially justified; 3) is not justified.	The relevance of the dissertation research is determined by the need to create domestic effective sorbents for the sorption of radionuclides from polluted reservoirs. The work well demonstrates the practical significance, as well as the process of synthesizing sorbents from waste from the agro-industrial complex, which makes the work valuable from the point of view of the circulation economy. The relevance of the work is also confirmed by the support of the international project Horizon Europe 2024 project "Multifunctional sustainable adsorbents for water treatment assisted with plasma technologies and for health protection from xenobiotics". *However, in the justification it would be desirable to distinguish between scientific and applied significance.*
		4.2 The content of the dissertation reflects the topic of the dissertation: **1) reflects;** 2) partially reflects; 3) does not reflect.	The content of the dissertation fully reflects the stated topic, as well as corresponds to the formulated purpose and objectives of the research.
4.	The principle of internal unity	4.3. The purpose and objectives correspond to the topic of the dissertation: **1) corresponds;** 2) partially corresponds; 3) they don't match.	The goals and objectives set in the work fully correspond to the topic of the dissertation and logically reveal its content. They are aimed at solving an urgent scientific problem related to the contamination of water sources with radionuclides and offer a solution in the form of synthesis and modification of carbon sorbents and testing their effectiveness in laboratory conditions and on radioactive isotopes in pure form (Poland) and heterogeneous environment (National Nuclear Center). The implementation of the tasks set ensured the achievement of the intended goal and contributed both to the theoretical justification of the approaches and to their practical application.
		4.4 All sections and provisions of the dissertation are logically interrelated: **1) completely interconnected;** 2) the relationship is partial; 3) there is no relationship.	The thesis traces the logical relationship between the sections and the formulated provisions. Each section details the provisions to be defended. The work is distinguished by its internal unity, consistency of presentation and the interconnectedness of the results obtained in all the aspects studied.
		4.5 The new solutions (principles, methods) proposed by the author are reasoned and evaluated in comparison with the known solutions: **1) there is a critical analysis;** 2) partial analysis;	The new solutions proposed in the thesis, including the development and experimental evaluation of the modified sorbents obtained, are well-founded and confirmed by the results of a comprehensive study of the textural and structural features of the sorbents obtained, testing and comparing modified and unmodified sorbents with the justification of their structural units (section computer modeling). The effectiveness of the obtained sorbents was compared with a commercially available analogue. *An analysis of the method of obtaining and properties of available analogues has been carried out, however, an approximate economic calculation of the cost of sorbent synthesis or the cost of water*

		3) the analysis is not your own opinions, but quotes from other authors.; 4) There is no analysis.	*purification has not been presented. The above remark is not essential and does not require making edits to the completed dissertation.*
5.	The principle of scientific novelty	5.1 Are the scientific results and provisions new? **1) Completely new;** 2) partially new (25-75% are new); 3) not new (less than 25% are new).	Scientific results and statements are confirmed by publications in journals included in the list of publications recommended by the Committee for Quality Assurance in Education and Science of the Ministry of Science and Higher Education of the Republic of Kazakhstan, reports at international conferences and symposiums, articles published in journals indexed in the Scopus database. The rationale for the novelty is as follows: - development and optimization of activated carbon sorbents from various biomass sources using physical and chemical activation, including a new method of hydrothermal impregnation with urea (a source of nitrogen groups) and Prussian blue (a selective agent for the removal of caesium). - urea-modified sorbents have demonstrated improved sorption characteristics due to targeted nitrogen doping (~ 1%), they are especially effective in meso-/macroporous matrices, improving the absorption of triiodide (I_3^-) ions. - confirmed high selectivity of ferro cyanide-modified sorbents for the extraction of Cs^+ in the presence of competing ions (Sr^{2+}, Ca^{2+}, Na^+), reducing total radioactivity below regulatory limits. - confirmed sorbent characteristics on real samples of radioactive water from the Semipalatinsk nuclear test site (Degelen test site) and applied molecular modeling (Gaussian) to identify interaction mechanisms at the atomic level. Thus, all the results are confirmed by experimental verification and theoretical substantiation, which confirms their novelty and reliability.
		5.2 Are the conclusions of the dissertation new? **1) Completely new;** 2) partially new (25-75% are new); 3) not new (less than 25% are new).	The conclusions of the thesis are based on the development of a technical protocol for the synthesis of sorbents and experimental verification of modified sorbents for water purification from radionuclides. The novelty is confirmed by the results of comparative tests to determine the sorption capacity relative to target ions in laboratory conditions on stable non-radioactive isotopes and laboratory tests on radioactive isotopes (UMSC, Poland) and radioactive isotopes of real contaminated natural groundwater at the Degelen site, which confirms their applied nature. All the presented conclusions are based on experimental data and calculations performed.
		5.3 Technical, technological, economic or managerial decisions are new and justified: 1) Completely new; **2) partially new (25-75% are new);** 3) not new (less than 25% are new).	Technical, technological, economic, or managerial decisions are characterized by novelty and a high degree of validity. Doctoral student M.S. Kunarbekova has developed an intelligent method for the production of modified sorbents for the selective extraction of caesium and triiodide ions. Technological developments are implemented in the form of a technological protocol for the synthesis of sorbents and their testing in a heterogeneous environment, which confirms their practical significance and applicability. All the presented solutions are based on theoretical calculations and confirmed by experimental data.
6.	Validity of the main conclusions	All the main conclusions are based/not based on scientifically	All conclusions of the thesis are scientifically substantiated, supported by theoretical data and confirmed by experimental results and computer calculations. In the course of the study, comparative testing of

		significant evidence or are well-founded enough (qualitative research) and areas of study in the arts and humanities.	sorbents obtained by physical, chemical activation and further modification of the surface with nitrogen-containing or ferro cyanide-containing groups, as well as a commercial sorbent, was carried out. The results fully confirm the positions put forward for protection, demonstrating both the scientific novelty and the high practical significance of the work performed.
7.	Основные положения, выносимые на защиту	It is necessary to answer the following questions for each provision separately: 7.1 Has the position been proven? **1) Has it been proven;** 2) rather proven; 3) rather not proven; 4) not proven; 5) in the current formulation, it is impossible to verify the validity of the provision. 7.2 Is it trivial? 1) yes; **2) no;** 3) in the current formulation, it is impossible to verify the triviality of the position. 7.3 Is it new? **1) yes;** 2) no; 3) in the current formulation, it is impossible to verify the novelty of the provision. 7.4 Application level: 1) narrow; **2) Average;** 3) Wide; 4) in the current wording, it is impossible to verify the level of application of the provision. 7.5 Is it proved in the article? **1) yes;** 2) no; 3) in the current formulation, it is impossible to verify the evidence of the provision in the article.	There are no elements of triviality in this thesis. There are 3 provisions for the defense: 1. Activated carbons obtained from biomass that have undergone hydrothermal modification (surface area: 1600-2200 m2/g) are enriched with nitrogen groups. Increased sorption capacity of I3- up to 35% of modified carbamide compared to the best non-modified activated carbons. - the position is proven; - the position is original; - The provision is applicable for the purification of drinking and wastewater contaminated with radioactive forms of iodine (especially I_3^-, formed in an oxidizing environment). Decontamination of water in emergency situations at nuclear power plants. Pretreatment of water before membrane or chemical post-treatment methods. Protection of the population in the area of potential radioactive contamination. - the situation is disclosed in an article published in the Journal Of Water Process Engineering (Q1, 92% percentile) – 2024 in a paper on the topic: "Carbon adsorbents for the uptake of radioactive iodine from contaminated water effluents: A systematic review", and 2 articles in the journal Combustion and plasmochemistry journal on the topic: "Synthesis of nanofiber composite doped with nitrogen groups from biomass by chemical activation" and "Synthesis and characterization of activated carbon from biomass for the sorption of radioactive iodine". 2. Activated carbons modified with Prussian blue demonstrate high selectivity for Cs^+ adsorption, reducing the total activity from 120 to < 5 Bq/L in multiionic systems ($90Sr2^+$, $Ca2^+$, Na^+) from real groundwater contaminated with radionuclides. - the position is proven; - the position is original; - provision – applicable for the treatment of real groundwater and groundwater contaminated with radioactive cesium (Cs+) This was carried out on the territory of the former Semipallatinsk test site at the Degelen test site of the National Nuclear Center of the Republic of Kazakhstan. The radiation level after cleaning the contaminated outlet water was lower than recommended by the World Health Organization for drinking water. - the provision is disclosed in the chapter of the book "Innovative materials for industrial application: Book Chapter 11-2025" and utility model patent No. 9470 "Method for obtaining sorption material for water purification from radionuclides". 3. Sorption mechanisms were formulated on the basis of carbon atoms of different pore structures and function using analytical methods. Typical fragment structures and the contribution of physico-sorption, chemosorption, and electrostatic interaction were discussed. - the position is proven;

			- the position is original; The formulated sorption mechanisms make it possible to purposefully develop carbon materials with optimal porous structures and functional groups for effective removal of various ions from water. Understanding the contribution of physical sorption, chemisorption, and electrostatic interaction makes it possible to predict sorption efficiency depending on the nature of the contaminant. This knowledge can be applied to the design of selective sorbents adapted to specific conditions, including complex multi-ion and radioactive environments. - the position is promising for the application of computer modeling for the processes of sorbent-pollutant interaction.
8.	The principle of reliability. Reliability of sources and information provided	8.1 The choice of methodology is justified or the methodology is described in sufficient detail: **1) yes;** 2) No.	To fulfill the tasks in the thesis, an analysis of more than 195 literary sources was carried out. The choice of methodology is reasonable and consistent with the objectives of the study. The work describes in detail the stages of activated carbon modification, the analytical methods used (BET, FAIR, SEM-EDX, etc.), as well as approaches to determining sorption mechanisms, including interaction modeling. This integrated approach ensures the reliability of the results obtained and their reproducibility.
		8.2 The results of the dissertation work were obtained using modern scientific research methods and methods of data processing and interpretation using computer technology: **1) yes;** 2) No.	The results of the dissertation work were obtained using modern methods of scientific research and data processing using high-performance computing tools: Gaussian 16W software and Tianhe-2 supercomputer based on K.I. Satpayev KazNTU. Calculations based on the experimental results were performed using Origin 2018 software.
		8.3 Theoretical conclusions, models, identified relationships and patterns have been proven and confirmed by experimental research (for areas of training in pedagogical sciences, the results have been proven on the basis of a pedagogical experiment): **1) yes;** 2) No.	The theoretical positions and models proposed in the work are confirmed by the results of experimental studies. The relationships between the structural characteristics of modified sorbents and their sorption activity have been substantiated using physico-chemical analysis and compared with model calculations. The reliability of the revealed patterns is confirmed by the coincidence of experimental data with theoretical forecasts. For example, computer modeling confirms that Cs^{+} forms a more stable complex (~434.73 kJ/mol) with a Prussian blue matrix compared to $Sr2^{+}$, which was confirmed when testing on real groundwater at the Degelen site, where selective cesium sorption was shown.
		8.4 Important statements are **confirmed**/partially confirmed/not confirmed by references to relevant and reliable scientific literature.	The most important scientific statements in the work are confirmed by references to relevant and peer-reviewed sources, including publications in international journals indexed in Scopus and Web of Science. The literature covers both fundamental aspects of sorption and modification of activated carbons, as well as modern research on the removal of radionuclides. This ensures the scientific validity and credibility of the results obtained.
		8.5 The literature sources used are **sufficient**/not sufficient for a literary review.	The doctoral student conducted a review of a sufficient number of literary sources. The dissertation analyzed 199 titles of domestic and foreign publications, which provided a reliable theoretical basis for the

			research. The sources presented cover both fundamental works and modern articles on the topic of the dissertation.
9	The principle of practical value	9.1 The thesis has theoretical significance: **1) yes;** 2) No.	The dissertation has significant theoretical significance, since it reveals the mechanisms of sorption of radionuclides on modified carbon materials, substantiates the role of the sorbent's structural and functional parameters, and suggests models of interaction that have been confirmed experimentally. The obtained scientific provisions expand the fundamental understanding of the processes of selective adsorption and can serve as a basis for further research in the field of purification of aqueous media from radioactive ions.
		9.2 The thesis is of practical importance and there is a high probability of applying the results obtained in practice: **1) yes;** 2) No.	The dissertation has high practical significance, since the developed modified sorbents have demonstrated effectiveness in removing radionuclides from real contaminated waters, including multi-ion systems. The results obtained can be used in the creation of filtration materials for environmental purification, reclamation of territories and protection of drinking water sources. The high selectivity and stability of sorbents create prerequisites for their introduction into industrial and field practice. *To further enhance the scientific and applied value of the work, it is recommended:* *- expand the comparative analysis with other types of sorbents (zeolites, oxides, resins) in order to more clearly show the advantages of the proposed materials;* *- to conduct additional research on the regeneration and reuse of modified sorbents, which is important to assess their practical sustainability and cost-effectiveness.;* *- to deepen the thermodynamic or kinetic analysis of sorption processes using mathematical modeling or DFT calculations;* *- add more data on the influence of natural factors (pH, temperature, organic substances) on sorption efficiency in real conditions.* *This remark is not essential and does not require amendments to the completed dissertation.*
		9.3 Suggestions for practice are new: 1) Completely new; **2) partially new (25-75% are new);** 3) not new (less than 25% are new).	The proposals presented in the dissertation are new and scientifically sound. The development of sorbents based on activated carbon modified with Prussian blue and nitrogen-containing groups was proposed for the first time in the context of the purification of real radioactively contaminated waters with a complex ionic composition. The novelty lies in the combination of a highly developed porous structure with targeted surface functionalization, which ensures high selectivity and sorption efficiency. The practical significance of the work is also confirmed by the utility model patent.
10.	Quality of writing and design	The quality of academic writing: **1) High;** 2) Average; 3) below average; 4) Low.	Kunarbekova Mahabbat Site-Zadaevna's dissertation, is written in a literate scientific and technical, readable language. The presentation is logical and consistent. The formulation of the main provisions and conclusions are logical, clearly formulated and reflect the completeness of the conducted research.
11.	Review comments on the dissertation	1. 1. When further developing the topic and preparing scientific publications, it is recommended to take into account current regulatory documents and state strategic priorities of the Republic of Kazakhstan, including, for example, the results of the referendum on the use of atomic energy dated October 6, 2024. This note is intended as a recommendation and does not detract from the scientific value and completeness of the presented research. 2. 2. In substantiating the relevance of the dissertation, it would be desirable to distinguish between scientific and applied significance.	

		3. 3. An analysis of the method of obtaining and properties of available analogues has been carried out, however, an approximate economic calculation of the cost of sorbent synthesis or the cost of water purification has not been presented. The above remark is not essential and does not require making edits to the completed dissertation. 4. 4. To further enhance the scientific and applied value of the work, it is recommended: 5. - expand the comparative analysis with other types of sorbents (zeolites, oxides, resins) in order to more clearly show the advantages of the proposed materials; 6. - to conduct additional research on the regeneration and reuse of modified sorbents, which is important to assess their practical sustainability and cost-effectiveness.; 7. - to deepen the thermodynamic or kinetic analysis of sorption processes using mathematical modeling or DFT calculations; 8. - add more data on the influence of natural factors (pH, temperature, organic substances) on sorption efficiency in real conditions. These remarks are not critical and do not reduce the scientific significance of the study.
12.	The scientific level of the doctoral student's articles on the research topic (in the case of a dissertation defense in the form of a series of articles, official reviewers comment on the scientific level of each doctoral student's article on the research topic)	The main results of the study have been published in scientific publications confirming the scientific level of the work performed. In the Scopus database https://www.scopus.com/authid/detail.uri?authorId=58150666700 , the doctor has an h-index of 4. At the time of the doctoral student's defense, he published: 1 review in the Journal Of Water Process Engineering-Q1, 92% percentile, 2 articles in journals recommended by the Committee for Quality Assurance in Education and Science of the Ministry of Science and Higher Education of the Republic of Kazakhstan, one chapter in a book published by IGI Global Scientific, one utility model patent.
13.	The decision of the official reviewer (according to paragraph 28 of this Model Provision)	Thus, I believe that Kunarbekova Mahabbat Seit-Zadaevna's dissertation meets the requirements of the Rules for Awarding Degrees approved by the Order of the Ministry of Science and Higher Education of the Republic of Kazakhstan dated March 31, 2011 No. 127 (with amendments and additions as of July 18, 2024 No. 352), and its author Kunarbekova Mahabbat Seit-Zadaevna deserves awarded the degree of Doctor of Philosophy (PhD) in the specialty 8D07109 - Innovative technologies and new inorganic materials.

Official reviewer:
Scientific and Production Enterprise Antigen LLP,
PhD, Senior Researcher

Issayeva Assem