Федеральное государственное автономное
образовательное учреждение высшего образования
«РОССИЙСКИЙ УНИВЕРСИТЕТ ДРУЖБЫ НАРОДОВ
ИМЕНИ ПАТРИСА ЛУМУМБЫ»

International Youth Forum

«RUSSIA-ASIA: HUMAN RESOURCES POTENTIAL OF THE NUCLEAR INDUSTRY OF THE REGION»

Conference proceedings

Международный молодежный форум

«РОССИЯ-АЗИЯ: КАДРОВЫЙ ПОТЕНЦИАЛ АТОМНОЙ ОТРАСЛИ РЕГИОНА»

Сборник материалов

Научная библиотека
издательский дом
Москва – 2025

УДК 621.039
ББК 31.4
М43

У т в е р ж д е н о
РИС Ученого совета
Российского университета
дружбы народов

М43 **Международный молодежный форум «Россия-Азия: кадровый потенциал атомной отрасли региона»:** сборник материалов = International Youth Forum “Russia-Asia: Human Resources Potential of the Nuclear Industry of the Region” : Conference proceedings. – Москва : РУДН, 2025. – 112 с. : ил.

ISBN 978-5-907954-56-4

В сборник материалов Международного молодежного форума «Россия-Азия: кадровый потенциал атомной отрасли региона» вошли статьи спикеров Форума, в которых отражены результаты научно-исследовательских работ обучающихся российских вузов и вузов из стран Азии по вопросам безопасности атомных реакторов и обеспечения безаварийной работы атомных электростанций, повышения радиационной защиты населения регионов. Авторы статей также рассматривают вопросы топливного цикла, технико-экономические аспекты опреснения морской воды, а также вопросы надежного функционирования системы аварийной защиты АЭС. Обсуждаются вопросы наработке на ядерных реактора изотопной продукции для различных целей, а также рассматривается возможность применения специализированных программных комплексов для поисковых решений повышения надежности АЭС.

В статьях, представленных в сборнике, материалы содержат информацию о роли атомных электрических станций в устойчивом развитии стран Азии и их толь в обеспечении надежной и дешевой электрической энергией регионов размещения на долгие годы вперед. Авторами отражены данные технико-экономического анализа процесса ядерного опреснения морской воды на малых модульных реакторных электростанциях для Шри-Ланки, описаны экологически чистые технологии, безопасное управление ядерными энергетическими установками, методы оценки эффективности систем безопасности, ядерное образование в контексте устойчивого развития стран Азии.

Articles by speakers of the Forum of the International Youth Forum “Russia-Asia: Human Resources Potential of the Regional Nuclear Industry” were included in a collection of materials that reflect the results of research work by students of Russian universities and universities from Asian countries on issues of nuclear reactor safety and ensuring the safe operation of nuclear power plants, increasing radiation protection for the population of the regions. The authors describe issues of the fuel cycle, technical and economic aspects of seawater desalination, as well as issues of reliable operation of the emergency protection system of nuclear power plants. The issues of producing isotope products for various purposes at nuclear reactors are discussed, and the possibility of using specialized software packages for searching for solutions to improve the reliability of nuclear power plants is also considered.

The articles presented in the collection contain information about the role of nuclear power plants in the sustainable development of Asian countries and their role in providing reliable and cheap electrical energy to the regions where they are located for many years to come. The authors present data from a technical and economic analysis of the process of nuclear desalination of seawater at small modular reactor power plants for Sri Lanka, describe environmentally friendly technologies, safe management of nuclear power plants, methods for assessing the effectiveness of safety systems, and nuclear education in the context of sustainable development in Asian countries.

УДК 621.039
ББК 31.4

ISBN 978-5-907954-56-4

СОДЕРЖАНИЕ

ECOLOGY

AGROTECHNOLOGIES

NUCLEAR REACTORS

TO ESTIMATE RELIABILITY OF HYDROACCUMULATOR SYSTEM OF NUCLEAR POWER PLANTS AND IMPROVE ITS DESIGN, RELIABILITY

Abdul Awal

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Abstract. Nuclear Power Plant is one of the most popular plants to produce electricity in the world these days due to its requirement of less space to produce huge amount of electricity and very friendly to the environment. One of the drawbacks of this plant is high maintenance cost as its working substance is ‘nuclear reaction’ that deals with radiation. That is why safety comes first when considering an NPP to be constructed. Goal of this research work is to estimate reliability of a mechanical system which is chosen as Hydroaccumulator System of VVER type reactor, made adjustment to its design to improve its operation and reliability. Research proposal on Figure 1.

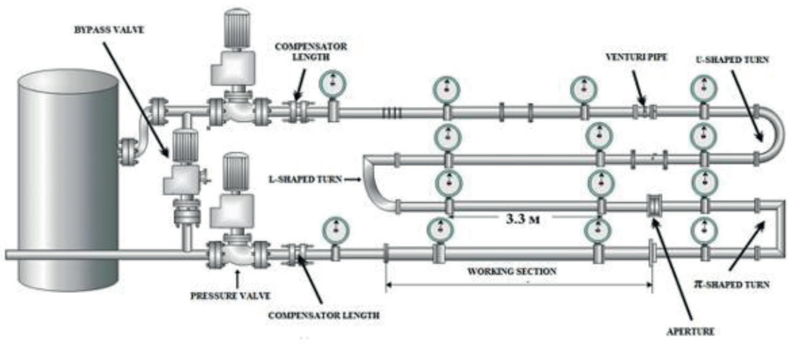

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Figure 1. Scheme of the stand “Circulation loop” of Prototype Reactor

Here, 1.bypass valve 2. Compensator length 3. venturi pipe 4. U-shaped turn 5. L-shaped turn 6. Pressure valve 7. Compensator length 8. Working section 9. Aperture 10. Π-shaped turn

Reliability Calculation for Prototype Fast Reactor: Reliability of prototype 'fast reactor' is: Failure rate of Pressure Valve: $F=\lambda_0 a_1 \sqrt{n}$

a_1 is the coefficient and the value of a1 is: $a_1= k_{11}k_{12}k_{13}k_{14}k_{15}$; k_{11}= Constant due to vibration, k_{12}= Constant due to Crushing/grinding/Shock loads, k_{13}= Constant due to climate of the room, k_{14}= Constant due to quality of service, k_{15}= Constant due to workmanship.

$\boldsymbol{\lambda_0}$ = Failure constant and **n** is the number of rivets, spring, impellers etc. After calculation, Failure rate is: F= 1.0×10-06; And, Reliability of Pressure Valve, R= 1- F Or, R= 0.999999

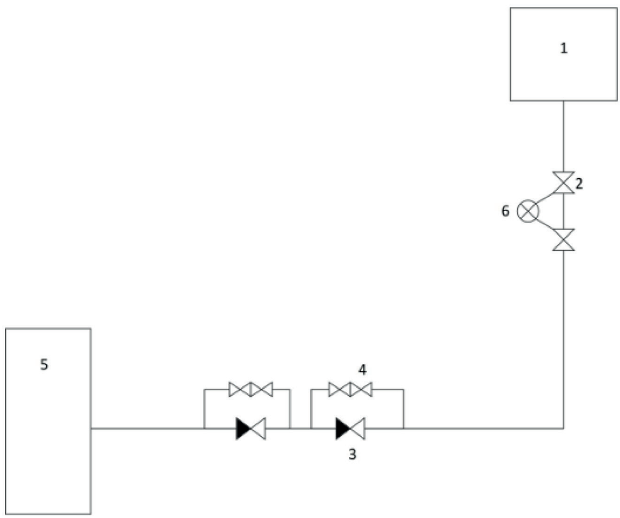

Figure 2. Schematic diagram of the connections of Hydroaccumulator system (one loop)

1. Accumulator Tank 2. Quick Acting Gate Valve 3. One Way Gate Valve 4. Check Valve 5. Reactor 6. Controller

Reliability calculation of components of HA: R= 1- F and F = $= \lambda_0\ a_1\ a_k\ a_m$ (Figure 2)

Where, $a_{k\,=}$ Coefficient for design of the equipment; $a_{m\,=}$ Coefficient for the construction of the materials (table 1).

Table 1

Reliability of different valves used in Hydroaccumulator

No.	Name of the valve	Reliability during one year
01.	Check Valve	0.9914
02.	One Way Gate Valve	0.9655
03.	Quick Operating Gate Valve	0.9655

To Increase the Reliability, Our Proposed Design: From the above calculation, it is clear that during one year, Hydroaccumulator system will be losing 0.06891 or 6.89% of its reliability. For a VVER 1200 type of reactor, the power unit has sixty years of lifetime. So, Hydroaccumulator system should be standby to operate the whole lifetime to ensure its safety. But losing reliability of Hydroaccumulator in this percentage is not likely to be. Again, the current design uses two one way gate valves and two quick operating gate valve that are connected to each other in a serial connection. In the point of safety and reliability view, serial connections of same equipment will cause the system less reliable. As the accumulator is connected directly to the reactor that has very high pressure (15.7 MPa), it is recommended to use serial connection to the valves so that it can resist the reactor coolant from entering to the system. This system has the following disadvantages:

- If one valve of the two has a defect, other valve cannot help to run the system by itself which a parallel system can.
- Unlike parallel connection, it does not increase but decrease the reliability of the system.
- According to the safety rules of IAEA, any defect in the Hydroaccumulator system at the operation of the plant causes complete shutdown unless it is solved within thirty minutes.
- Nuclear reactor outage costs are estimated at $1 million per day and unexpected Downtime can be financially and environmentally devastating (Figure 3).

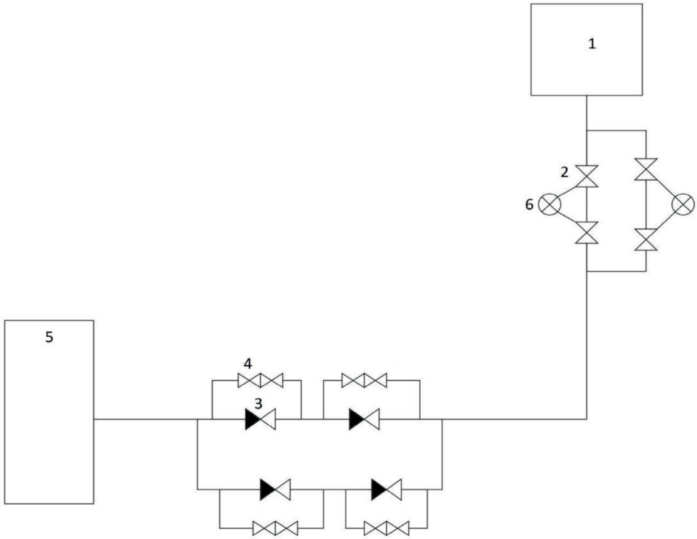

Figure 3. Schematic diagram showing new addition to the original system
Where, 1. Accumulator Tank, 2.Quick Acting Gate Valve, 3.One Way Gate Valve, 4. Check Valve, 5. Reactor, 6. Controller

To solve the mentioned problems, we have proposed few additions to the system that will not only solve these troubles but also increase the reliability as well as save the constriction cost. So, the proposed system is shown in Figure 1 which has new addition:

Using those additional valves and connections, new reliability of the Hydroaccumulator system is: 0.99515. Thus, if any problem arises to any of the valves in the system, there will be a parallel connection that can operate in the case of emergency. So, safety is increased along with reliability. On the other hand, if a valve needs to be repair, it is easier in the new design to fix as we have an additional supply line with valves that can operate and there won't have any time limit as for current design do. In this way, the time limit which is thirty minutes to repair is no longer necessary and to fix the valve, the plant will not have to shut down as there is a backup line to operate (table 2).

Table 2

Comparison Original and Proposed design.

No.	Original Design	Proposed Design
01.	In the original Hydroaccumulator system, there are four channels.	In the proposed design, it is suggested to use three channels instead of four.
02.	Four channels cause four holes in the reactor vessel that decreased its reliability.	In this design, one hole is less required than the original one which means it will increase reliability.
03.	If any valve of this system has trouble, it has to be repaired within thirty minutes to ensure safety.	In this proposed design, there is no time limit unless parallel connection has problem too.
04.	In case of failure of the component, reactor has to be shutdown if cannot repair within thirty minutes.	Reactor won't have to be shutdown as it has a parallel connection that can operate in case of failure.
05.	Construction cost is higher than the proposed design.	It is cheaper than the original system.
06.	It will require much space in the primary circuit as this system consists of four channel.	This proposed system includes three channels that require less space than the original system.
07.	Reliability of this design is 0.93109	Reliability of this design is 0.99515.

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PROLIFERATION-RESISTANT FUEL CYCLE STRATEGIES FOR PU-238 PRODUCTION IN PELUIT-40 HTGR

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Abstract. The PeLUIt-40 High-Temperature Gas-Cooled Reactor (HTGR), a 40 MW pebble-bed reactor utilizing TRISO fuel, speaks to Indonesia's inventive approach to secure atomic vitality and isotope generation. Outlined for characteristic security and dual-purpose applications—electricity era and mechanical heat—it moreover offers a proliferation-resistant pathway to create plutonium-238 (Pu-238), a basic isotope for space investigation (e.g., RTGs) and restorative innovations. Whereas conventional plutonium generation postures multiplication dangers, PeLUIt-40's plan intrinsically mitigates these through TRISO fuel's physical versatility, online refueling complexities, and neutron range optimization. A closed fuel cycle joining minor actinides (Np-237, Am-241) improves Pu-238 surrender whereas minimizing weapons-grade Pu-239. Computational reenactments (OpenMC) illustrate >90% Pu-238 immaculateness, hindering weaponization due to its seriously rotting warm (560 W/kg) and alpha radiation.

To support shields, blockchain-based fuel following and real-time neutron flux checking are proposed, adjusting with IAEA non-proliferation guidelines. These techniques, combined with Pu-238's natural taking care of challenges, guarantee compliance with worldwide security systems. Indonesia's integration of progressed neutronics and advanced shields into PeLUIt-40 underscores its commitment to serene atomic innovation, situating the reactor as a show for feasible, secure isotope generation. This approach not as it were progresses Indonesia's vitality guide but too underpins worldwide needs in space and therapeutic segments, adjusting innovative advance with non-proliferation goals

Keywords: *PeLUIt-40 HTGR, plutonium-238, proliferation resistance, IAEA safeguards.*

Introduction. The PeLUIt-40 (*Pembangkit Listrik dan Uap-panas Industri*), Indonesia's 40 MWt High-Temperature Gas-cooled Reactor (HTGR), is designed for cogeneration of electricity and industrial heat. Its Electricity and Industrial Steam Plant (PeLUIt-40) technology incorporates TRISO-fueled pebble beds for enhanced safety and non-proliferation resistance, a 40 MW reactor developed in Indonesia, represents a major advancement in nuclear energy technology. This reactor utilizes TRISO fuel within a pebble-bed configuration, ensuring high inherent safety due to its negative temperature reactivity coefficient and the ability of its fuel to endure extreme temperatures up to 1,600°C [1]. In addition to electricity generation and industrial heat applications, PeLUIt-40 provides a promising pathway for producing plutonium-238 (Pu-238), a crucial isotope for Radioisotope Thermoelectric Generators (RTGs) used in space exploration and select medical applications [2, 3].

Addressing Proliferation Risks in HTGR Fuel Cycles. The production of plutonium in nuclear reactors presents proliferation risks, particularly concerning the potential diversion of fissile material such as Pu-239 for unauthorized use [4]. HTGRs, however, exhibit intrinsic proliferation resistance due to their design attributes. TRISO fuel particles, encapsulated in a graphite matrix, significantly impede unauthorized material extraction. Additionally, the online refueling mechanism in pebble-bed reactors complicates any diversion of nuclear material without detection [5]. Nonetheless, a comprehensive fuel cycle strategy is necessary to ensure that Pu-238 production adheres to International Atomic Energy Agency (IAEA) non-proliferation guidelines [6].

Strategies for Optimizing Pu-238 Production in PeLUIt-40. Research suggests that a closed fuel cycle, combined with neutron spectrum optimization, can enhance Pu-238 yield while minimizing Pu-239 accumulation [7]. One effective method involves incorporating minor actinides such as neptunium-237 (Np-237) and americium-241 (Am-241) into TRISO fuel. When subjected to neutron bombardment, these elements undergo nuclear reactions that favor Pu-238 formation [8]. Furthermore, utilizing graphite or beryllium reflectors around the reactor core can increase thermal neutron flux, thereby improving the efficiency of Pu-238 production [9] (Figure 1).

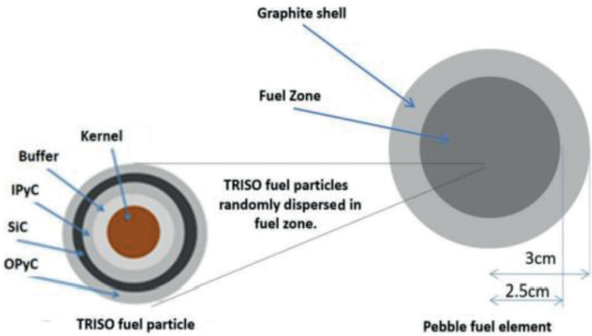

Figure 1. The schematic view of fuel pebbles

Computational simulations using advanced neutron transport codes such as OpenMC confirm the viability of these optimization strategies [10]. Over a five-year operational cycle, isotopic separation can be optimized to yield Pu-238 with a purity exceeding 90%, making it impractical for weaponization due to excessive heat generation and intense radiation emission [11]. This approach aligns with the IAEA's "Attractiveness Level" framework, which evaluates nuclear materials based on isotopic composition to mitigate proliferation risks [12].

Table 1

Specific power and radioactive decay half-life for plutonium and 241Am isotopes

Isotope	Specific power/mW/g*	Half life, $T_{1/2}$/years*
^{238}Pu	567.57 ± 0.26	87.74 ± 0.04
^{239}Pu	1.9288 ± 0.0003	24119 ± 26
^{240}Pu	7.0824 ± 0.0020	6564 ± 11
^{241}Pu	3.412 ± 0.002	14.348 ± 0.022
^{242}Pu	0.1159 ± 0.0003	376300 ± 900
^{241}Am	114.2 ± 0.42	433.6 ± 1.4

Enhanced Safeguard Mechanisms for PeLUIt-40. Despite HTGRs' inherent proliferation resistance, additional safeguards are essential to ensure the integrity of PeLUIt-40's fuel cycle. One challenge arises from its online refueling system, which allows continuous fuel replenishment. To enhance transparency and accountability, blockchain-based tracking systems can be integrated to monitor the movement of each fuel pebble throughout its lifecycle, effectively preventing tampering or unauthorized diversion [13, 14].

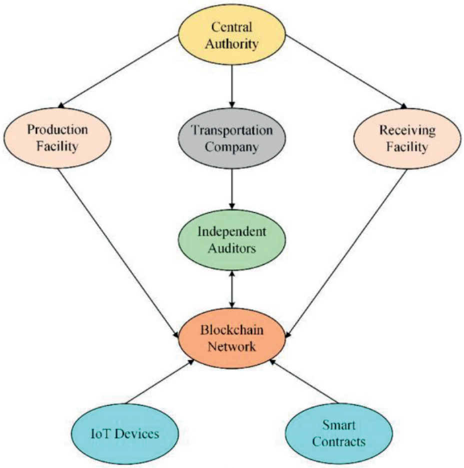

Figure 2. Organizational diagram for nuclear material tracking using blockchain

Another critical safeguard involves real-time neutron flux monitoring. Advanced neutron detectors installed around the reactor core can detect abnormal flux patterns, which may indicate unauthorized material handling [15]. This approach has been successfully tested in international research facilities, demonstrating its efficacy in enforcing nuclear safeguards [16] (Figure 2).

The Intrinsic Proliferation Resistance of Pu-238. Beyond external safeguards, the physical properties of Pu-238 provide additional deterrents against proliferation. This isotope generates approximately 560 W/kg of decay heat, significantly higher than

Pu-239, making unauthorized handling highly challenging without specialized equipment [17]. Additionally, its intense alpha radiation presents further technical barriers to weaponization, reinforcing its classification as a proliferation-resistant material [18, 19].

Policy Implications and Indonesia's Nuclear Strategy. From a policy perspective, this research aligns with Indonesia's nuclear energy roadmap by proactively addressing non-proliferation concerns [20]. By integrating neutron optimization techniques with digital safeguards, PeLUIt-40 can serve as a model for secure and sustainable next-generation reactors [21]. Furthermore, this strategy strengthens Indonesia's position in the international nuclear sector by demonstrating its commitment to peaceful nuclear technology development [22].

Conclusion. PeLUIt-40 offers a viable framework for Pu-238 production while ensuring high proliferation resistance. Through the application of advanced nuclear technologies and stringent safeguards, this reactor contributes to Indonesia's energy and technological progress while supporting global advancements in space exploration and medical isotope applications [23, 24].

REFERENCES

1. **Campbell, D.O., & Gift, E.H.** (1977). *Proliferation-Resistant Nuclear Fuel Cycles*. OSTI.GOV.
2. **Abd Alaziz, R.O., et al.** (2020). *Optimization of Material Test Research Reactor Core for Isotope Production*. IAEA TECDOC-1645.
3. **Gao, Y., et al.** (2018). *Neutronic Design Optimization for Pebble Bed Reactors*. Annals of Nuclear Energy.
4. **Trianti, N., et al.** (2023). *Optimum Power Analysis of PeLUIt-40 HTGR*. Nuclear Engineering and Design.
5. **Baghdasaryan, N., et al.** (2019). *Review of Progress in Coated Fuel Particle Performance Analysis*. Nuclear Science and Engineering.
6. **Kulikov, E.G., et al.** (2022). *Minor Actinide Transmutation in Thermal Reactors*. Journal of Nuclear Materials.

7. **Yamamoto, T., & Nishihara, K.** (2018). *Transmutation of Minor Actinides in High-Temperature Gas-Cooled Reactors*. Annals of Nuclear Energy, 120, 74-82.
8. **Zhang, Z., & Sun, Y.** (2019). *Enhancement of Thermal Neutron Flux in HTGRs Using Graphite Reflectors*. Nuclear Engineering and Design, 351, 1-8.
9. **Leppänen, J., Pusa, M., & Viitanen, T.** (2015). *The Serpent Monte Carlo Code: Status, Development and Applications in 2013*. Annals of Nuclear Energy, 82, 142-150.
10. **Koning, A.J., & Rochman, D.** (2012). *Modern Nuclear Data Evaluation with the TALYS Code System*. Nuclear Data Sheets, 113(12), 2841-2934. DOI: 10.1016/j.nds.2012.11.002.
11. **IAEA**. (2010). *Nuclear Security Recommendations on Physical Protection of Nuclear Material and Nuclear Facilities (INFCIRC/225/Revision 5)*. IAEA Nuclear Security Series No. 13
12. **Petrov, Y.V., & Zvonarev, M.V.** (2017). *Challenges in Safeguarding Online Refueling Systems of HTGRs*. Atomic Energy, 122(4), 241-247.
13. **Englert, M., & Vestergaard, C.** (2020). *Blockchain Technology for Safeguards Information Management*. Journal of Nuclear Materials Management, 48(3), 20-28.
14. **Menlove, H.O., & Swinhoe, M.T.** (2014). *Neutron Detection for Nuclear Safeguards*. In R. Kouzes (Ed.), *The Physics of Neutron Detection* (pp. 345-372). Springer.
15. **Kang, J., & von Hippel, F.N.** (2001). *U-232 and the Proliferation-Resistance of U-233 in Spent Fuel*. Science & Global Security, 9(1), 1-32.
16. **Ougouag, A.M., & Gougar, H.D.** (2009). *Decay Heat Characteristics of Plutonium Isotopes in Nuclear Reactors*. Nuclear Technology, 168(3), 689-695.
17. **Mason, C., & Glaser, A.** (2010). *Proliferation Risks Associated with Pu-238 Production*. Science & Global Security, 18(3), 165-185.
18. **ark, J.C.** (1993). *Explosive Properties of Reactor-Grade Plutonium*. Science & Global Security, 4(1), 111-128.
19. **BATAN (National Nuclear Energy Agency of Indonesia)**. (2015). *Indonesia's Nuclear Energy Development Plan 2015-2025*. BATAN Report No. NEP-2015-01.
20. **IAEA**. (2018). *Guidance on Nuclear Energy Systems Assessments for Long-Term Sustainability*. IAEA Nuclear Energy Series No. NG-T-3.12.
21. **Sagara, H., et al.** (2011). *Double Strata Fuel Cycle Strategy for Transmutation of Minor Actinides*. Progress in Nuclear Energy, 53(7), 802-807.
22. **Cochran, R.G., & Tsoulfanidis, N.** (1999). *The Nuclear Fuel Cycle: Analysis and Management*. 2nd Ed. American Nuclear Society. ISBN: 978-0894484585.

23. **World Nuclear Association (WNA)**. (2021). *Plutonium and Proliferation-Resistance in Nuclear Fuel Cycles*.
24. **National Academies of Sciences, Engineering, and Medicine**. (2018). *Proliferation Risks of Nuclear Fuel Cycles*. National Academies Press.

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METHODOLOGY FOR ESTIMATING THE THERMAL CONDUCTIVITY COEFFICIENTS OF FUEL ROD WITH GADOLINIUM PELLETS FOR CONDUCTING A LINKED CALCULATION OF THE VVER-1200 FUEL ASSEMBLY

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Аннотация. Большую роль в обеспечении надёжной работы твэл играют температурные градиенты, возникающие в оболочке топливного стержня, и, как следствие, создающие температурные напряжения.

В рамках настоящей работы предлагается методика для оценки коэффициентов теплопроводности уран-гадолиневого топлива с целью проведения связанного нейтронно-физического и теплогидравлического расчета твэг с аксиальным профилированием. На данном этапе необходимо выявить влияние содержания гадолиния на температуру оболочки и теплоносителя.

Исследование проводится для профилированного твэг реактора ВВЭР-1200, который планируется эксплуатировать на АЭС “Сюйдапу” (Китай), АЭС “Руппур” (Бангладеш) и может быть, в перспективе, эксплуатироваться в ряде других стран Азии.

Ключевые слова: ВВЭР-1200, аксиальное профилирование, теплогидравлический расчет, теплопроводность, твэг.

Abstract. An important role in ensuring reliable operation of fuel rods is played by temperature gradients that occur in the shell of the fuel rod, and, as a result, create temperature stresses.

As for the main purpose of this work, a methodology is proposed for estimating the thermal conductivity coefficients of uranium-gadolinium fuel in order to perform related neutron physics and thermohydraulic calculation of fuel elements with gadolinium with axial profiling. At this stage, it is necessary to identify the effect of the gadolinium content on the temperature of the shell and coolant.

The study is being conducted for the VVER-1200 profiled fuel elements with gadolinium reactor, which is planned to be operated at the Xudapu NPP (China), the Rooppur NPP (Bangladesh) and may, in the future, be operated in a number of other Asian countries.

Keywords: VVER-1200, axial profiling, thermohydraulic calculation, thermal conductivity, fuel elements with gadolinium.

INTRODUCTION. There are few tables with the thermophysical properties of pure gadolinium or its other chemical compounds, such as silicates or an alloy with zirconium [1], however, to a first approximation, we can say that the thermophysical properties of the oxide will differ from the properties of the mentioned compounds. This conclusion was made based on a comparison of λ for metallic uranium and uranium oxide. For this reason, it was decided to estimate the distribution of λ(T) for Gd_2O_3 using data for metallic Gd [2].

Next, a part of fuel elements with gadolinium (40 cm) was taken, divided into two profiling zones, in which the gadolinium content varied from calculation to calculation. Thus, data were obtained on the amount of energy release in tablets with different gadolinium content.

Using data on the gadolinium thermal conductivity coefficient and the amount of energy release in the zone, a thermohydraulic calculation was performed to determine the temperatures of the shell and coolant.

TOOLS AND MODELS. The thermal conductivity of Gd_2O_3 was evaluated as follows: the coefficient h was introduced, which was taken as a correction for the content of oxygen atoms in the molecule:

$$h(T) = \frac{\lambda_{UO_2}(T)}{\lambda_U(T)} \tag{1}$$

Due to this correction, we can estimate the thermal conductivity of gadolinium oxide:

$$\lambda_{Gd_2O_3}(T) = \lambda_{Gd}(T) \cdot h(T) \left(\frac{W}{m \cdot K}\right) \tag{2}$$

Further, when the thermal conductivity coefficients for uranium oxide and gadolinium oxide are known, it is possible to estimate the distribution of λ(T) for compositions with different Gd_2O3 and

UO_2 contents. For this it is necessary to apply the Maxwell-Aiken formula [3], which makes it possible to calculate the average coefficient of thermal conductivity for a ceramic composition of two components (3). The results are shown in Table 2. This table also shows the thermal conductivity coefficients for the different gadolinium content in a gadolinium fuel rod pellet. The designation 10/90 means that the upper profiling zone contains 10% gadolinium, and the lower zone contains 90% gadolinium. The rest is uranium oxide with an enrichment 4.95%.

$$\lambda_{U+Gd} = \lambda_{UO_2} \cdot \left[\frac{1 + 2 \cdot V_{Gd_2O_3} \left(\dfrac{\lambda_{Gd_2O_3} - \lambda_{UO_2}}{2 \cdot \lambda_{UO_2} + \lambda_{Gd_2O_3}} \right)}{1 - V_{Gd_2O_3} \left(\dfrac{\lambda_{Gd_2O_3} - \lambda_{UO_2}}{\lambda_{UO_2} + \lambda_{Gd_2O_3}} \right)} \right] \left(\frac{W}{m \cdot K} \right). \quad (3)$$

Table 1

Estimated thermal conductivity of Gd_2O_3

T, K	$\lambda_U, \frac{W}{m \cdot K}$	$\lambda_{UO_2}, \frac{W}{m \cdot K}$	$\lambda_{Gd}, \frac{W}{m \cdot K}$	$\lambda_{Gd_2O_3}, \frac{W}{m \cdot K}$
300	22.864	7.591	8.0	1.326
350	24.464	7.054	8.10	1.208
400	26.064	6.581	8.60	1.195
600	32.464	5.140	10.90	1.164
800	38.864	4.165	12.70	1.109
1000	45.264	3.467	14.40	1.058
1200	51.664	2.948	15.50	0.997
1300	54.864	2.740	16.60	0.965
1400	58.064	2.562	17.70	0.899
1500	61.264	2.412	18.80	0.841

Source: Own Development

Table 2

Estimated thermal conductivity of uranium-gadolinium fuel

T, K	$\lambda_{U+Gd}, \frac{W}{m \cdot K}$				
	10/90	**20/80**	**30/70**	**40/60**	**50/50**
300	6.554	5.645	4.842	4.126	3.485
350	6.085	5.236	4.486	3.819	3.222
400	5.693	4.913	4.222	3.607	3.054
600	4.499	3.930	3.421	2.964	2.550
800	3.682	3.249	2.859	2.506	2.184
1000	3.093	2.756	2.449	2.169	1.913
1200	2.650	2.379	2.131	1.904	1.695
1300	2.471	2.225	2.0	1.793	1.602
1400	2.309	2.079	1.868	1.674	1.495
1500	2.173	1.955	1.756	1.573	1.404

Source: Own Development

RESULTS AND DISSCUSSION. To carry out a linked calculation of the fuel elements with gadolinium model, energy releases in zones with different gadolinium content in the fuel were first calculated. A program implementing the Monte-Carlo method was used for the calculation. The results are shown in table 3.

Using the data obtained, as well as the estimated thermal conductivity coefficients, using the ANSYS program, it is possible to calculate the maximal temperatures of the shell (Tsh.in) and the coolant (Tc). The results are shown in table 4 and figures 1-2.

Table 3

Energy releases (W/m^3) in profiling zones of the fuel elements with gadolinium

	10/90	**20/80**	**30/70**	**40/60**	**50/50**
Upper zone	$1.820 \cdot 10^7$	$4.560 \cdot 10^7$	$8.680 \cdot 10^7$	$1.490 \cdot 10^8$	$2.30 \cdot 10^8$

	10/90	20/80	30/70	40/60	50/50
Lower zone	$4.680 \cdot 10^8$	$4.290 \cdot 10^8$	$3.800 \cdot 10^8$	$3.130 \cdot 10^8$	$2.310 \cdot 10^8$

Source: Own Development

Table 4

Maximal temperatures of coolant and inner side of the shell

№	Model	Tc, K	Tsh.in, K
1	10/90	604.550	629.350
2	20/80	602.850	625.550
3	30/70	600.950	621.150
4	40/60	598.350	615.050
5	50/50	595.850	608.150

Source: Own Development

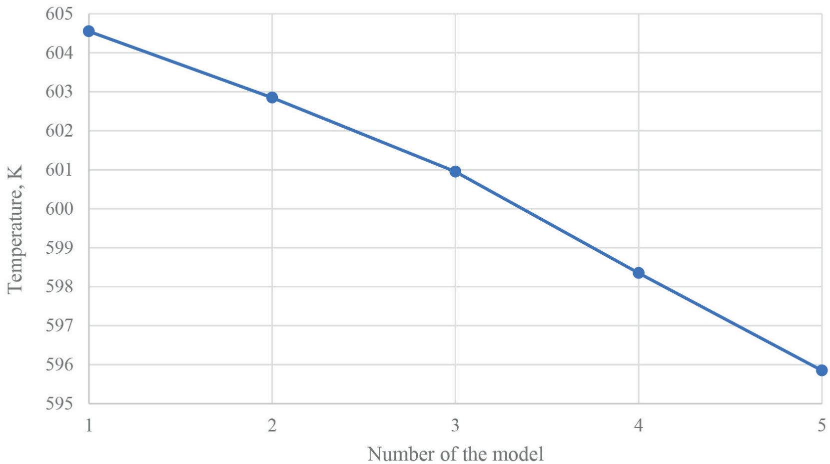

Figure 1. Dependence of the maximum temperature of the coolant on the distribution of gadolinium

Source: Own Development

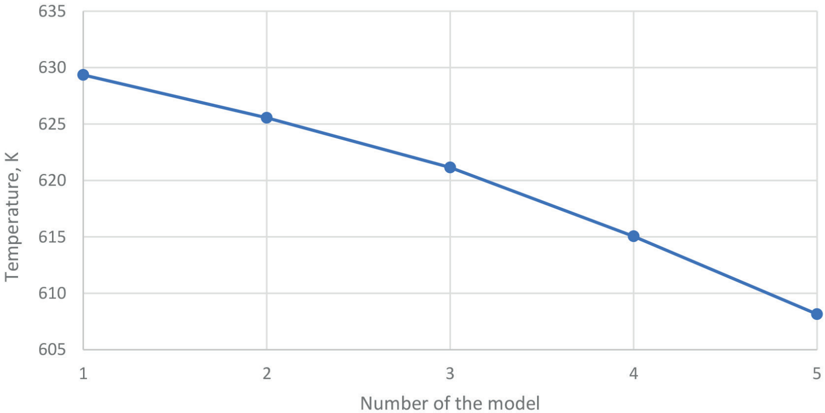

Figure 2. Dependence of the maximum temperature of the inner side of the shell on the distribution of gadolinium

Source: Own Development

CONCLUSION. As a result of the linked calculation, it was shown that the uneven distribution of gadolinium has a strong effect on the uneven energy release at the interface of the profiling zones. This aspect has a strong influence on the temperature distribution in the cell.

The results obtained can be attributed to the fact that uranium oxide has a higher thermal conductivity than gadolinium oxide. When gadolinium is redistributed into zones, the difference between the thermal conductivity of the upper zone and the lower zone decreases. Consequently, the intensity of heat transfer from zone to zone increases.

REFERENCES

1. Luguyev, S. M. Temperature and concentration dependences of thermal conductivity of solid solutions of gadolinium and dysprosium sulfides / S. M. Luguyev, N. V. Luguyeva, V. V. Sokolov // Thermophysics and aeromechanics. – 2012. – VOL. 19, No. 3. – pp. 375-380.
2. K. A. Gschneidner, Jr., *Rare Earth Alloys* (D. Van Nostrand Company, Inc., Princeton, New Jersey, 1961), p. 60.

3. Kingeri, U.D. Introduction to ceramics [Electronic resource] Access mode: https://libcats.org/book/487994 (Access data: 8.03.2025).

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IMPROVING THE METHOD OF FINDING SOLUTIONS TO THE SYSTEM OF EQUATIONS IN THE PROBLEM OF THE FUEL ELEMENT OF A NUCLEAR REACTOR

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Abstract. When modeling the behavior of the fuel element (fuel element) of a nuclear reactor operating on both fast and thermal neutrons, it is necessary to take into account not only thermal processes, but also the stress-strain state of the fuel pellet and the fuel element shell. The system of equations describing the mechanical behavior of a fuel element includes various types of deformations: elastic, thermal, radiation swelling, and creep, both thermal and radiation. This makes the system nonlinear with respect to variable interlayer and axial pressures. Effective iterative methods are required to solve such systems of equations. In this work, the algorithm for finding a solution for a system of nonlinear equations of mechanics of a fuel element of a nuclear reactor has been improved. The Gauss method was replaced by a run-through method adapted to the type of matrix of the linearized system. Optimization has significantly accelerated the process of solving the system of linear equations that arise in the problem. When sampling

Keywords: heat-generating element, equations of mechanics, run-through method, nuclear power plant.

Improving the algorithms of computational codes is an important stage in their creation. This is especially true for modules that are accessed repeatedly during the calculation process. If you use a more advanced algorithm that allows you to get results faster, the total calculation time can be significantly reduced [1]. Optimization in solving systems of linear algebraic equations includes replacing the Gauss method with methods based on the run type. A classic example is a finite-difference approximation of a one-dimensional heat equation. The computational complexity of the Gauss method is O(M2), where M is the size of the matrix. Run-through methods give a linear dependence on the size of the matrix, that is, O(M). If the type of matrix in the problem being solved allows you to use the run-through method instead of the

Gauss method, then the effort spent on developing the algorithm will be justified, as this will significantly speed up calculations [2].

The paper considers the dependence of the solution time on the number of radial layers m. For each fixed value of m, 100 calculations were performed, after which the average calculation time was determined. For small values of m, using an algorithm based on the run-through method is inefficient. However, as the number of layers increases, the time gain becomes noticeable, reaching approximately a twofold increase at m = 20. Usually, to simulate the stress-strain state of a fuel element (fuel element), the fuel pellet is discretized into 20 layers, and the shell into 10. The paper analyzes the time it takes to find a solution to a nonlinear system of equations, where the solution of a linearized system of equations at each iteration is carried out either by the Gauss method or by a run-through method. For the test task, the stress-strain state of the shell made of zirconium alloy E110 is calculated with a time step of 1 hour at a pressure in the gap between the fuel and the shell of 2 MPa and a coolant pressure of 16 MPa [3].

Under these conditions, Newton's method converges in 4 iterations. 300 calculations were performed for each fixed value of m, after which the average time was calculated.

The study of the matrix structure corresponding to the linearized system of equations, which is obtained by solving a nonlinear system of equations for determining the stress-strain state of a fuel element (fuel element), allowed us to create an algorithm based on the run-through method.

REFERENCES

1. Filimonov, A. A. Modernization of nuclear power plants: new technologies for safety and efficiency / A. A. Filimonov // Concepts, tools and technologies for the development of modern science and technology : Proceedings of the XI All-Russian Scientific and Practical Conference, Stavropol, May 24, 2023. Stavropol: Stavropol Paragraph Publishing House Limited Liability Company, 2023. pp. 244-245. EDN FSQUNW.

2. Zalaev, A. E. Introduction of nuclear power plants with supercritical steam parameters / A. E. Zalaev // XXVII All-Russian Postgraduate and Master's Scientific Seminar dedicated to the Day of the Power Engineer and the 55th anniversary of the KGEU : materials of reports, Kazan, 05-06 December 2023. Kazan: Kazan State Power Engineering University, 2023, pp. 38-40. – EDN EJZPJH.
3. Filimonova, A. A. Atomic-hydrogen hybrid energy systems and installations of a new generation: an introduction to the problem / A. A. Filimonova, E. G. Gasho, N. D. Chichirova. Kazan : Kazan State Power Engineering University, 2023. 170 p. ISBN 978-5-89873-647-7. EDN CWKYOH.

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PRODUCTION OF MOLYBDENUM-99 IN FAST NEUTRON REACTORS THROUGH FISSION

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Abstract. This article analyses the ability of utilizing the BN-600 fast neutron reactor prototype to produce Molybdenum-99 (Mo-99), which is an important medical isotope for the production of Technetium-99m (Tc-99m) for imaging diagnostics. Fast neutron reactors provide benefits for isotope production thanks to the high neutron flux and special fuel cycle. A Serpent Monte Carlo code simulation was created to model neutron interaction and calculate Mo-99 production efficiency. Two target designs of 26% enriched uranium rods with 4 cm and 2 cm radii were experimented. Results showed that the 4 cm target produced 2526 Ci of Mo-99 and the 2 cm target produced 616 Ci with a decrease in efficiency by only 2,38% per unit mass. These results verify that bigger target designs make Mo-99 production more efficient in BN-600.

Introduction. Fast neutron reactors (FNRs) are important to nuclear power generation and radioisotope production because they have the ability to cause fission by fast neutrons and thus attain improved fuel economy along with special breeding features [2]. FNRs do not need the employment of a moderator, as thermal reactors do, and have a tendency to employ liquid metals like sodium or lead for cooling [1]. BN-600, a sodium-cooled fast breeder reactor (FBR), is well-suited for radioisotope production due to its high neutron flux and fast neutron spectrum [3]. The flux ensures optimal conditions for uranium fission route of Mo-99 production, which consequentially decays into Tc-99m – valuable diagnostic isotope. BN-600 Mo-99 production feasibility is examined by Monte Carlo simulation using the Serpent code in this study. By examination of different target geometries changing radius, this project will optimize isotope production efficiency, contributing to an evaluation of the potential contribution of fast reactors to meeting global medical isotope demand.

Serpent Monte Carlo Neutron Transport Code. Serpent is a Monte Carlo neutron transport code that has been written for continuous-energy simulation at VTT Technical Research Centre of Finland. It has been used extensively in reactor physics applications such as fuel cycle studies, core modelling, and isotope production simulations. The Serpent geometry description is capable of detailed three-dimensional reactor modelling and is thus well suited for fine neutron transport and burnup calculations [5]. Serpent also features automated burnup calculation with accurate transmutation chain treatment and neutron interactions. It can handle a variety of nuclear data libraries and is designed to achieve high parallel computation efficiency, saving the simulation time for the general-purpose Monte Carlo codes. It is also applicable for research reactors, fusion neutronics, and radiation shielding [6].

Molybdenum-99. Mo-99 is a useful medical isotope for the manufacture of the widely used medical scan agent Tc-99m. The short half-life (6 hours) and high level of gamma emission make Tc-99m suitable for medical scanning with low radiation dosage [7]. Mo-99 is nowadays manufactured predominantly from the fission process of Uranium-235 (U-235) or neutron activation of Molybdenum-98 (Mo-98). Fission produces Mo-99 with higher activity and thus is the preferred method [4]. Mo-99 global supply is faced with the challenge of aging research reactors and the use of highly enriched uranium (HEU). BN-600-type fast neutron reactors are a potential alternative route for Mo-99 production with the advantage of high neutron flux and ability for isotopic production with high yield [10]. Mo-99 production within BN-600 is evaluated here and the target configurations are optimized for maximum yield and a viable medical supply.

Methodology. The following details were used to model a part of BN-600 reactor core. The full core was made by mirroring the arrangement. The core consists of 8 types of assemblies also known as subassemblies. The subassemblies are arranged in the following pattern as in figure 1.

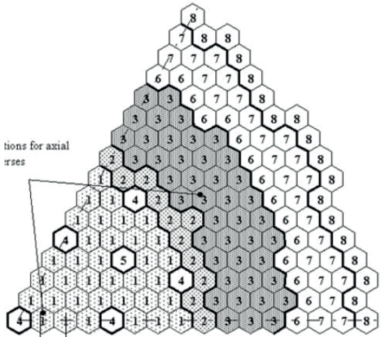

Figure 1. Arrangement of assemblies in the core for 60 degree

Source: [8]

Among these, 1, 2 and 3 are fuel assemblies, 4 and 5 are assemblies with control rods and 6, 7 and 8 are shielding and reflective zones. The parameters for the fuel rods for above zones are mentioned in table 1 [8].

Table 1

Details of fuel rods in BN-600

Category	Parameter	1	2	3	6	7
Fuel	Enrichment	17%	21%	26%	0,3%	0,3%
	Fuel used	Uranium Oxide (UO_2)				
	Density	10,4 gcm^{-3}				
Dimensions	Outer radius	3,45 mm			7,1 mm	
	Cladding thickness	0,4 mm			0,4 mm	
	Rod pitch	3,975 mm			14,725 mm	

Source: [8]

First the core was simulated in order to verify the high the neutron flux within the core. Considering the half-life of Mo-99 (65.9h) we chose to irradiate the sample for five days [7]. Therefore, only the first seven days were considered (figure 2).

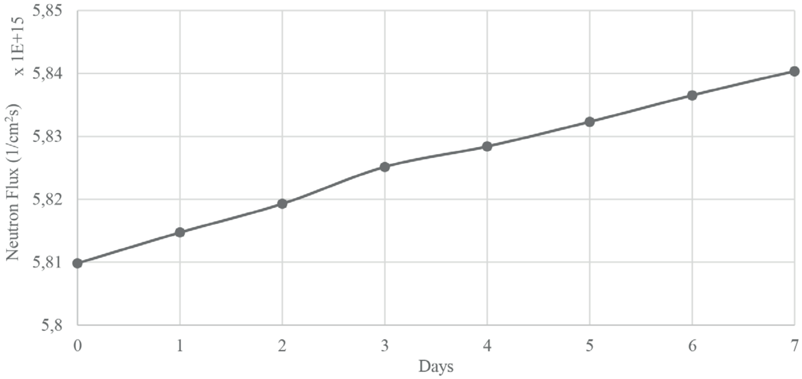

Figure 2. Flux graph vs days

Source: Own development

Then a fuel assembly was modified into one fuel element in order to make the extraction of molybdenum feasible. The modified fuel element was made into 4 cm and 2 cm radii cylinders to find out the most efficient one (figure 3).

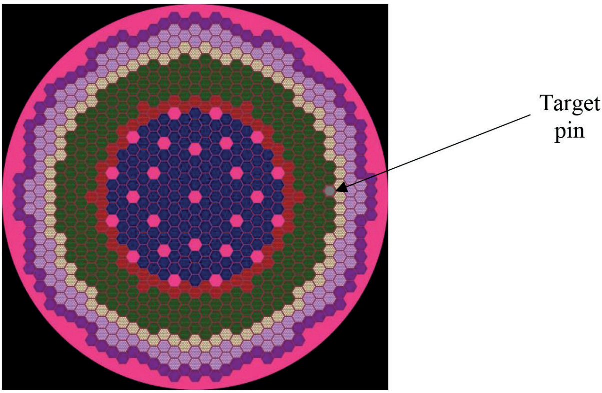

Figure 3. Geometry for target with 4cm diameter

Source: Own development

The modified core was simulated for six days, five days of irradiation and one day cool down to make sure the activity of short lived high radioactive isotopes has reduced.

Results. The results of the simulation were obtained and processed [9]. Then the activity of Mo-99 from the both targets were plotted against the time as in figure 4.

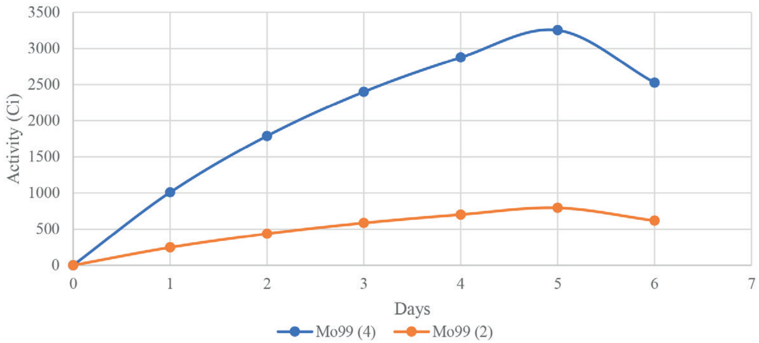

Figure 4. Activities of Mo-99 produced

Source: Own development

The activity per initial mass is calculated and mentioned in the table 2.

Table 2

Comparison of Mo-99 production with different radius of target

	Rod with 4 cm radius	**Rod with 2 cm radius**
Mass of U-235 per unit length of rod (kg)	52,28	13,07
Final activity (Ci)	2526	616
Activity per unit initial mass (Ci/kg)	48,3	47,2

Source: Own development

The activity of the target with smaller radius is 2,34% less than that of the bigger one. So, we can conclude that use of target bigger radius is more effective than smaller one in BN-600 to produce Mo-99.

Conclusion. The study demonstrates the capability for the BN-600 fast neutron reactor's use for Mo-99 production. The neutron interaction and isotope production were investigated for different target configurations using Monte Carlo simulations through the Serpent code. Mo-99 production was found to be enhanced with the increase in the target radius. 616 Ci from the 2 cm radius target against 2526 Ci from the 4 cm radius target. The BN-600 reactor's high neutron flux and fast neutron spectrum make the reactor a good potential candidate for medical isotope production with a good alternative to the conventional research reactor. The observation confirms the Mo-99 production through fission in BN-600 as efficient with the increasing global demand for the predecessor of the vital medical isotope.

REFERENCES

1. Fast Neutron Reactors [Electronic resource]. URL: https://world-nuclear.org/information-library/current-and-future-generation/fast-neutron-reactors.aspx
2. Breeder Reactor [Electronic resource]. URL: https://www.britannica.com/technology/breeder-reactor
3. Реактор на быстрых нейтронах [Electronic resource]. URL: http://nuclphys.sinp.msu.ru/ne/ne6.htm
4. What is molybdenum-99 (MO-99) SHINE Technologies [Electronic resource]. URL: https://www.shinefusion.com/blog/what-is-molybdenum-99-mo-99
5. A continuous-energy Monte Carlo Neutron and photon transport code Serpent [Electronic resource]. URL: https://serpent.vtt.fi/serpent
6. SERPENT MANUAL [Electronic resource]. URL: http://montecarlo.vtt.fi/download/Serpent_manual.pdf
7. G. Audi, O. Bersillon, J. Blachot, A.H. Wapstra, The Nubase evaluation of nuclear and decay properties, Nuclear Physics A, Volume 729, Issue 1, 2003
8. BN-600 MOX Core Benchmark Analysis | IAEA [Electronic resource]. URL: https://www-pub.iaea.org/MTCD/Publications/PDF/TE-1700_web.pdf
9. Description of output files [Electronic resource]. URL: https://serpent.vtt.fi/mediawiki/index.php/Description_of_output_files

10. Molybdenum-99 Production Processes [Electronic resource]. URL: https://www.ncbi.nlm.nih.gov/books/NBK215146/

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RELIABILITY ANALYSIS OF MECHANICAL EQUIPMENT USED IN NUCLEAR POWER PLANTS

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Abstract. Reliability analysis of mechanical products used at nuclear power plants is a critical aspect of ensuring the safe and efficient operation of these facilities.

The reliability of mechanical products in nuclear power plants is assessed using various methodologies, including probabilistic safety assessments (PSA) and deterministic safety analyses. PSA is a regulatory requirement for nuclear power plant construction licensing, providing vital input regarding the reliability of plant equipment and safety systems. These assessments help identify potential failure modes and their impacts on the overall system, ensuring that safety-critical components meet the required performance standards.

Mechanical systems in nuclear power plants consist of multiple units or subsystems, each of which must be analyzed for reliability. The reliability of the entire system depends on the reliability of its individual components and their interactions. This analysis involves studying the structure of the system and the reliability of each component over time.

Moreover, the manufacturing quality assurance process plays a significant role in the reliability of nuclear power plant equipment. Deviations from design specifications during manufacturing can occur due to various factors, such as human errors or material defects. Ensuring high-quality manufacturing processes is essential for maintaining the reliability and safety of mechanical products used in nuclear power plants.

In summary, the reliability analysis of mechanical products used at nuclear power plants involves a comprehensive evaluation of individual components and systems, considering their interactions and potential failure modes. This analysis is crucial for ensuring the safe and continuous operation of nuclear power plants, minimizing the risk of accidents, and protecting public health and the environment.

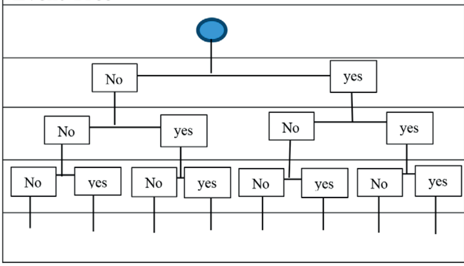
Keywords: Reliability analysis, mechanical products for nuclear power plants, Safety, Probabilistic Safety Analysis.

INTRODUCTION. The main task of the probabilistic safety analysis (PSA) for accident assessment is the development of probabilistic models including accident sequences (event trees) for each accident initial event (AE). The operational states (OS) of the power unit, the characteristics of the AE, the configuration of the safety systems, and their ability to perform safety functions are taken into account. The "safe state" is understood as a stable state of the reactor installation with a subcritical state of nuclear fuel and non-exceedance of the established safety criteria. PSA is a system analysis of the causes of occurrence, all possible paths of development and consequences of accidents at NPPs using a wide range of physical, thermal engineering methods, fracture mechanics and a number of others, supplemented by an analysis of the reliability of safety equipment, as well as the latest achievements in probability theory, mathematical statistics, the theory of random processes, Boolean algebra and others.

Table 1 shows an example of an event tree (Primary circuit pipeline rupture).

Table 1

Example of an event tree (Primary circuit pipeline rupture)



Event Tree	Event Name	Level No.
	Leak in the first loop	1
	Emergency reactor shutdown	2
	Emergency cooling of core	3
	Sealing of rooms	4
	Exceeding permissible emission limits	End event

TOOLS AND MODELS. The failure rate of connections, mechanical parts, units and devices is determined by the formulas given in Table 1, λ_0 – is the failure rate of a connection, part or component in nominal mode and normal conditions (ambient temperature 20±10 °C; relative humidity 30...70%; atmospheric pressure 0,825...1,06 $* 10^5$ Pa; no vibration or impact); n is the number of rivets; l is the length of a soldered, welded or glued seam, m; p is the mass of the glued part, r,s is the area of the glued surface, cm^2. The values of the coefficients K_{11} ,K_{12} ,K_{13} ,K_{14} ,K_{15}, for detachable and permanent connections. Failure rate of connections, mechanical parts, units and devices (table 2).

Table 2

Example of an event tree (Primary circuit pipeline rupture)

Connections, parts, components, sensors, devices	**Failure rate in the state:**	
	working	**non-working**
Non-detachable connections:		
riveted seams	$\lambda_0 a_1 \sqrt{n}$	$\lambda_0 a_1 a_2 \sqrt{n}$
welded, soldered, glued seams	$\lambda_0 a_1 l$	$\lambda_0 a_1 a_2 l$
"housing-compound" seams	$\lambda_0 a_1 a_m l$	$\lambda_0 a_1 a_2 a_m l$
surface adhesives	$\lambda_0 a_1 p / s$	$\lambda_0 a_1 a_2 p / s$
Detachable threaded connections:		
fastening	$\lambda_0 a_1 a_k$	$\lambda_0 a_1 a_2 a_k$
sealed	$\lambda_0 a_1 a_k a_m$	$\lambda_0 a_1 a_2 a_k$
transmitting motion	$\lambda_0 a_1$	$\lambda_0 a_1 a_2$
Detachable connections: wedge, pin, spline	$\lambda_0 a_1$	$\lambda_0 a_1 a_2$
Motion transmission units:		
belt	$\lambda_0 a_1 a_{k1} a_{k2} a_{k3} a_m$	$\lambda_0 a_1 a_2$
friction	$\lambda_0 a_1 a_k$	$\lambda_0 a_1 a_2$
toothed	$\lambda_0 a_1 a_k$	$\lambda_0 a_1 a_2$
Axles, shafts, brackets	$\lambda_0 a_1 a_k$	$\lambda_0 a_1 a_2$
Bearings	$\lambda_0 a_1 a_k$	$\lambda_0 a_1 a_2$
Gaskets	$\lambda_0 a_1 a_k$	$\lambda_0 a_1 a_2 a_m$
Bellows and tubular springs	$\lambda_0 a_1 a_g a_h a_n$	$\lambda_0 a_1 a_2$
Flow sensor impellers	$\lambda_0 a_1 a_m$	$\lambda_0 a_1 a_2$

Connections, parts, components, sensors, devices	Failure rate in the state:	
	working	**non-working**
Diaphragms	$\lambda_0 a_1 a_m a_h$	$\lambda_0 a_1 a_2$
Manometers, vacuum gauges with tubular springs	$\lambda_0 a_1 a_g a_h$	$\lambda_0 a_1 a_2$
Springs, couplings, clock devices	$\lambda_0 a_1$	$\lambda_0 a_1 a_2$

The material reviewed will allow for a more complete assessment of the reliability indicators of instruments, sensors and control system devices.

For example the reliability of main circulation pumps (MCP) equipment will be based on the calculation of equipment arranged in series and/or parallel, equations (2) and (3) are used, respectively.

$$R_i(t) = e^{-\lambda_j t} \tag{1}$$

$$R_s = R_1 R_2 \ldots\ldots R_j = \prod_{j=1}^{N} R_j \tag{2}$$

$$\mathrm{R_P}(\mathrm{t}) = 1 - \prod_{\mathrm{j=1}}^{\mathrm{N}} (1 - \mathrm{e}^{-»_{\mathrm{j}}\mathrm{t}}) \tag{3}$$

RESULTS AND DISSCUSSION. Table 3 below contains the reliability information of equipment for MCN, it's updated failure rate. The updated failure rate was calculated based on the scientific and technical document, providing a foundation for assessing device and system reliability with adjustable accuracy.

Table 3

Reliability of different equipment MCN

Name of equipment	Failure rate, per hr.	Reliability
sealed joints on the working MCP	$0.9 * 10^{-8}$	0.99984
shafts on the working MCP	$0.18 * 10^{-6}$	0.99684
couplings on the working MCP	$0.27 * 10^{-6}$	0.99534

Name of equipment	Failure rate, per hr.	Reliability
bearings on the working MCP	$0.13*10^{-6}$	0.99775
the input and output of the working MCP	$0.45*10^{-6}$	0.99225

Table 4

Result comparison of hand calculation

Notations	Hand calculation	
	Reliability	Errors
R_p	0.99634	$\pm 0,0005$

Table 4 contains the result comparison of hand calculation.

CONCLUSION. To analyze the reliability of mechanical elements, it is necessary to conduct a comprehensive assessment of the probability of element failure under various operating conditions, taking into account its design, manufacture and environmental factors. This can be achieved by using reliability analysis methods, such as failure mode and effect analysis, which allow us to estimate the probability of failure, identify critical failure modes and prioritize actions to improve reliability.

REFERENCES

1. ASSESSMENT OF RELIABILITY INDICATORS OF MECHANICAL ELEMENTS OF INSTRUMENT-MAKING PRODUCTS, N. A. Shavykin, B. P. Petrukhin.
2. NUCLEAR ENERGY SAFETY GUIDE "RECOMMENDATIONS ON THE PROCEDURE FOR PERFORMING RELIABILITY ANALYSIS OF SYSTEMS AND ELEMENTS OF NUCLEAR POWER PLANTS IMPORTANT TO SAFETY AND THEIR FUNCTIONS" (RB-100-15).
3. Y.V. Volkov, O.B. Duginov, D.A. Klinov Reliability and safety of nuclear power plants.
4. A.D. Swain & H.E. Guttman, Handbook of Human Reliability Analysis with Emphasis on Nuclear Power Plant Application, NUREG/CR-1278, US NRC, USA, 1983.

5. G.W. Hannaman et.al. Human Cognitive Reliability Model for PRA Analysis, NNUS-4531 (EPRI), Nuclear Utility Service Corp., 1984.

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RADIATION SAFETY

HUMAN HEALTH RISK ASSESSMENT FROM RADON AND ARSENIC EXPOSURE IN DRINKING WATER IN BANGLADESH

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Abstract. Sustainable Development Goal (SDG) 6 (Clean water and sanitation), followed by the United Nations and its partners in Bangladesh, emphasizes that access to clean water is essential for life. The study assesses human health risks from radon (222Rn) and its progeny in drinking water throughout Bangladesh, including the Rooppur Nuclear Power Plant (RNPP) area. The outcomes are contrasted with health risks from arsenic (As) in drinking water. 222Rn's annual effective dose by ingestion, and excess lifetime cancer risk are calculated for adults using the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) methods. Annual dose and risk results are one order of magnitude below the allowed limits (0.1 mSv/y) and global average (0.29×10−3), respectively, with excess lifetime cancer risk at RNPP site notably below the global mean. As-related health risks on adults via ingestion route are estimated using United States Environmental Protection Agency (USEPA) models. Barishal district, having the least amount of As in drinking water, has carcinogenic risk 4.3 times the permissible limit (1×10-4). At RNPP site, cancer risk from As is 21.4 times the tolerable level. Therefore, 222Rn exposure poses minimal risk, but As-contaminated ground water presents significant human health risks.

Introduction. The environment is indispensable to human existence, but accumulation of certain elements or compounds can seriously harm people's health. The primary causes of these risks are heavy metal biochemical interactions and radiologic reactions between energetic particles and photons with living cells [1]. To lessen potential health hazards, it is crucial to ascertain background radiation levels and the amount of heavy metal build-up in the environment [2].

An important factor in environmental research is water quality. Roughly 97% of Bangladesh's population gets safe drinking water from ground water. Radium (^{226}Ra) and radon (^{222}Rn) are the two most common naturally occurring radionuclides in groundwater [3]. Prolonged contact with high levels of ^{222}Rn and its progeny in drinking water can cause cancers of the stomach, digestive tract, and respiratory system. The issue of drinking water contaminated by heavy metals prevents the United Nation's SDG Goal 6 (Clean water and sanitation) from meeting water targets. Out of many heavy metals in drinking water, arsenic (As) is a non-radioactive heavy metalloid with carcinogenic effects like that of ^{222}Rn. Sustained ingestion of As, even at low concentrations, is thought to cause carcinogenic changes in various human organs and tissues.

A literature review showed lack of nationwide study of human health risks from ^{222}Rn and As prevalence in ground water in Bangladesh. Thus, the study's main aim is to estimate and compare health risks from ^{222}Rn and As in ground water across Bangladesh, including RNPP site.

Materials and Methods. About 20.57º N to 26.63º N and 88.02º E to 92.68 E, Bangladesh is a Southeast Asian nation. RNPP (2-units) is under construction in the Rooppur village, ~160km NW of Dhaka [4].

Human Health Risks Assessment of ^{222}Rn and its Progeny in Drinking Water. Annual Effective Dose (AED) for adults (age>17y) via ingestion pathway is computed using mean ^{222}Rn levels in ground water obtained from literature review. UNSCEAR documentation is utilized to compute AED using formula (1):

$$AED = C_{RnW} \times C_W \times EDC \times 10^{-3} \quad (1)$$

Lifetime exposure to ^{222}Rn and its decay products increases an individual's cancer risk. Excess Lifetime Cancer Risk (ELCR) is determined by applying equation (2):

$$ELCR = AED \times D_f \times R_f, \quad (2)$$

where C_{RnW}=^{222}Rn concentration in water (Bq/L), C_W=annual water consumption=730 L, EDC=coefficient for effective dose for oral intake of ^{222}Rn=3.5 nSv/Bq, D_f=estimated avg. life expectancy=70 years, and R_f=deadly cancer risk per Sievert=5.5×10^{-2} Sv^{-1}.

Human Health Risks Assessment of As in Drinking Water

Human health risks of As accumulation in ground water were examined using USEPA's methodology. Average Daily Dose (ADD) through ingestion was computed using equation (3):

$$ADD(\text{for ingestion pathway}) = \frac{C \times IR \times ED \times EF}{BW \times AT} \quad (3)$$

Equation (4) calculates the Hazard Quotient (HQ) which describes non-cancerous dangers:

$$HQ = \frac{ADD}{RfD} \quad (4)$$

Carcinogenic Risk (CR) from As in groundwater were estimated using equation (5):

$$CR = ADD \times CSF \quad (5)$$

where: C=As conc. (mg/L), IR=Water ingestion rate=2L/day, ED=Exposure duration=70y, EF=Exposure frequency=365days/y, BW=Body weight=70kg, AT=Avg. lifetime=25,550days, RfD=oral reference dose=3×10^{-4}mg/kg/day, CSF=cancer slope factor=1.5 $(mg/kg/day)^{-1}$.

Any non-carcinogenic consequences can cause worry if the HQ>1. The level at which carcinogenic hazards are safe must be below 1×10^{-6}. According to the USEPA, hazards should not exceed 1×10^{-4} but instead fall between 1×10^{-4} and 1×10^{-6}.

Results and Discussion. Human Health Risks Assessment of ^{222}Rn and its Progeny in Drinking Water. Table 1 shows that the mean ^{222}Rn content in ground water across Bangladesh are below the maximum contaminant levels (MCL) of 11 Bq/L (USEPA) and 100 Bq/L (WHO-World Health Organization and EU-European Union). Estimated AED varies from 5.95 to 18.22 µSv/y; one order of magnitude lower than the 0.1 mSv/y safety level (WHO and EU). The calculated ELCR is one order of magnitude smaller than the global average (0.29×10^{-3}) [5]. Thus, ^{222}Rn and its progeny provide no significant health danger to Bangladeshis who consume ground water.

Table 1

Estimated AED and ELCR (adult) of ^{222}Rn and its progeny in ground water

Region	^{222}Rn conc. (Bq/L)	AED (µSv/y)	ELCR×10^{-5}
South-east coastal	4.56±0.70 [6]	11.65	4.49
West coastal	2.33±0.50 [7]	5.95	2.29
Central	7.13±0.71 [8]	18.22	7.10
RNPP site	4.42±2.00 [9]	11.29	4.35

Source: Created by the author

Mean activity concentration at the RNPP site (Table 1) is below the safety limits of WHO, EU, and USEPA. AED is 11.29 µSv/y which is ~9 times less than the 0.1 mSv/y safety level. The calculated ELCR value (4.35×10^{-5}) is notably below the global mean (0.29×10^{-3}) [5].

Human Health Risks Assessment of As in Drinking Water. Estimated human health risks (adult) from As in ground water around Bangladesh are given in Table 2.

Table 2 shows that Barishal district has the lowest mean As concentration (10µg/L). In this region, ADD is 0.29 µg/kg-day and HQ equals the limit value of 1. CR was 4.3 times higher than the permissible limit value of 1×10^{-4}. As a result, the extent of As pollution in ground water throughout Bangladesh is highly alarming and presents significant carcinogenic and non-carcinogenic health risks. At the RNPP site, exposure to As through ingestion of groundwater poses a cancer risk (2.14×10^{-3}), that is 21.4 times the acceptable level.

Table 2

Estimated human health risks (adult) from As in ground water

Region	As conc. (µg/L)	ADD (µg/kg-day)	HQ	$CR\times10^{-3}$
Faridpur, south-central	95.9 [10]	2.74	9.1	4.11
Barishal, south-central	10 [11]	0.29	1.0	0.43
Jashore, south-western	90 [12]	2.57	8.6	3.86
8 districts, north-western	44 [13]	1.26	4.2	1.89
RNPP site	49.9 [14]	1.43	4.8	2.14

Source: Created by the author

Conclusion. ^{222}Rn and its progeny do not provide a significant cancer risk to the drinking water supply in Bangladesh. But, groundwater poisoning by As possesses significant health risk. At the RNPP site, ELCR (4.35×10^{-5}) from ^{222}Rn in ground water is notably below the global mean (0.29×10^{-3}) while As-related cancer risk is 21.4 times the acceptable level. The study's findings may be used to establish a baseline for future sustainable groundwater management in Bangladesh.

REFERENCES

1. Sadhukhan, R.K., Synzynys, B.I. Natural radioactivity around Rooppur nuclear power plant before commissioning // Journal of Physics: Conference Series. IOP Publishing Ltd. 2020. doi.org/10.1088/1742-6596/1701/1/012009
2. Karahan, G., Taşkin, H., Oldag, N.B. et al. Environmental impact assessment of natural radioactivity and heavy metals in drinking water around Akkuyu Nuclear Power Plant in Mersin Province // Turkish Journal of Chemistry. 2018. V. 42. P. 735–747. doi.org/10.3906/kim-1710-83

3. Nalukudiparambil, J., Gopinath, G., Ramakrishnan, R.T., Surendran, A.K. Groundwater radon (222Rn) assessment of a coastal city in the high background radiation area (HBRA), India // Arabian Journal of Geosciences. 2021. V. 14. P. 1–7. doi.org/10.1007/S12517-021-07082-7/TABLES/2
4. Sadhukhan, R.K., Synzynys, B.I. Comprehensive assessment of radiation impact from natural radioactivity and tritium around Rooppur NPP before commissioning and predicted exposures of NPP operation // Progress in Nuclear Energy. 2023. V. 164. doi.org/10.1016/j.pnucene.2023.104872
5. Divya, P. V, Prakash, V. Investigation on radon concentration in drinking water to assess the whole body dose and excess lifetime cancer risk along coastal Kerala, India. // Journal of Radioanalytical and Nuclear Chemistry. 2019. V. 322. P. 37–42. doi.org/10.1007/s10967-019-06518-5
6. Deeba, F., Rahman, S.H., Kabir, M.Z. Assessment of Annual Effective Dose Due to Inhalation and Ingestion of Radon From Groundwater at the Southeast Coastal Area , Bangladesh // Radiation Protection Dosimetry. 2021. V. 194. No. 2-3. P. 169–177. doi.org/10.1093/rpd/ncab096
7. Deeba, F., Rahman, S.H., Kabir, M.Z. Radon Concentration in Soil and Groundwater of West Coastal Area, Bangladesh // Radiation Protection Dosimetry. 2020. V. 191. No. 3. P. 341–348. doi.org/10.1093/rpd/ncaa134
8. Pervin, S., Yeasmin, S., Ferdous, J., Begum, A. Radon Concentration in Ground Water of Dhaka City // International Journal of Engineering Technologies and Management Research. 2020. V. 5. P. 61–70. doi.org/10.29121/ijetmr.v5.i11.2018.318
9. Pervin, S., Banik, S., Sultana, N. et al. Measurement of 222Rn in ground water and NORMs in top soil in the environs of Rooppur Nuclear Power Plant site and associated health hazard // Journal of Radioanalytical and Nuclear Chemistry. 2024. V. 333. P. 1497–1505. doi.org/10.1007/s10967-023-09083-0
10. Saha, N., Islam, A.R.M.T., Begum, B.A., Rahman, M.S. Hydrogeochemical evolution of shallow and deeper aquifers in central Bangladesh: arsenic mobilization process and health risk implications from the potable use of groundwater // Environmental Earth Sciences. 2021. V. 79. 477. doi.org/10.1007/s12665-020-09228-4
11. Yasmin, G., Islam, D., Islam, T. et al. Evaluation of groundwater quality for irrigation and drinking purposes in Barishal district of Bangladesh // Fundamental and Applied Agriculture. 2019. V. 4. No. 1. P. 632-641. doi.org/10.5455/faa.301258
12. Chakraborty, T.K., Ghosh, G.C., Ghosh, P. et al. Arsenic, iron, and manganese in groundwater and its associated human health risk assessment in the rural area of Jashore, Bangladesh // Journal of Water & Health. 2022. V. 20. No. 6. P. 888–902. doi.org/10.2166/wh.2022.284

13. Rana, S., Alam, J., Musa, A., Kumar, S. Groundwater arsenic poisoning in a primary educational institution : health risks to school-going children // Acta Geochimica. 2022. V. 41. P. 1069–1082. doi.org/10.1007/s11631-022-00563-w
14. Uddin, M.G., Moniruzzaman, M., Quader, M.A., Hasan, M.A. Spatial variability in the distribution of trace metals in groundwater around the Rooppur nuclear power plant in Ishwardi, Bangladesh // Groundwater for Sustainable Development. 2018. V. 7. P. 220–231. doi.org/10.1016/J.GSD.2018.06.002

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RADIATION SAFETY ASSESSMENT IN THYROID CANCER TREATMENT

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Abstract. Staff involved in medical settings need to prioritize radiation safety since it proves crucial for thyroid cancer treatments that use radioiodine ^{131}I therapy and ^{124}I medical imaging modalities. These diagnostic and therapeutic methods show high accuracy but patients together with healthcare team members and surrounding public face potential radiation risks. The assessment looks into current protocols and patient preparation procedures and post-therapy care guidelines and radiation risk assessment methods. Quality enhancement programs alongside technological advancements are examined within the study to determine their effectiveness in protecting patients from radiation. This review links contemporary research outcomes with international guidelines to deliver complete information about proven practices that protect patients from radiation harm as well as the delivery of effective treatment. The focus of this review emphasizes on dose optimization together with shielding techniques and regulatory compliance to patients receiving treatment & healthcare providers handling radioactive materials. The review aims to contribute to safer, more effective thyroid cancer management through strengthened radiation safety measures.

Introduction. Differentiated thyroid cancer (DTC) stands as the main subtype of endocrine malignancies which exist as one of the most common types of thyroid cancer. Radioiodine therapy that administers ^{131}I represents an established treatment plan for DTC following thyroidectomy procedures. The radiation safety risks are major complications of ^{131}I therapy because of its beta and gamma radiation emission properties. Patients and healthcare workers and the community need to follow strict radiation safety procedures for maintaining their protection from health risks. The article presents insights into thyroid cancer treatment radiation safety evaluations by examining standards and patient care practices and quality assurance methods.

Regulatory Framework. The International Commission on Radiological Protection (ICRP) along with the Nuclear Regulatory Commission (NRC) both regulate radiation safety practices for thyroid cancer treatment at the international and national levels. The organizations create guidelines that establish safe practices for administering ^{131}I medicine by using justification and optimization and setting dose limitations [1, 2]. Under recommendations from the ICRP each year family and caregiver members should receive no more than 1 mSv of radiation whereas pregnant individuals and youngsters face tighter exposure limits [3]. Hospital patients can gain release under NRC's "Patient Release Criteria Rule" by meeting radiation exposure limitations set at 5 mSv for adults alongside 1 mSv for both children and pregnant women [4].

Dosimetry. The radioactive substance ^{131}I administered during therapy generates beta along with gamma radiation. Beta radiation destroys thyroid tissue yet gamma radiation presents a danger of exposing other individuals to radiation. Medical staff need to perform accurate dosimetry measurements because they determine the suitable radiation activity while preventing harmful levels of exposure to both patients and their caregivers [5]. The established protocol for pre-therapeutic dosimetry consists of multiple days during which medical staff conduct blood sampling and whole-body counting. Jentzen W. et al. [1] proved that maximum tolerable activity (MTA) measurements from point-based protocols at 1-2, 24 and 96 hours produce results equivalent to the standard reference method. They examined, as reference to Table, simplified MTA blood dosimetry methods for ^{224}I treatment in thyroid cancer patients, Multiple blood sample reduction in combination with fewer whole-body counting stations allowed their methods to maintain accurate results within ±20% of established reference values [1].

The introduced methodology decreases both medical staff exposure to radiation while providing patients better comfort. Simplified protocols assist with achieving both lower costs of operation and better workflow organization in medical facilities.

Table

Comparison of Dosimetry Protocols

Protocol Type	Number of Samples	Accuracy Range	Radiation Exposure
Standard	Multiple (5-7)	±10%	High
Simplified	Reduced (2-3)	±20%	Lower

Source: [1]

Patient Release Criteria and Radiation Protection. Regulations determine the release of patients who receive ^{131}I therapy so that radiation exposure remains below acceptable boundaries for both public and care providers. The Nuclear Regulatory Commission (NRC) within the United States enables patient discharge when retained activity reaches below 33 mCi only if nurses provide detailed guidance to protect others [3]. According to Tenhunen M. et al. [5] patients can receive customized precautions regarding their radiological safety by validating their iodine clearance patterns from the initial day.

Pre-Treatment Preparation. The proper treatment of ^{131}I therapy requires patients to follow multiple essential steps to achieve best results. Before ^{131}I treatment patients need to withdraw thyroid hormones or receive recombinant human Thyroid-Stimulating Hormone to raise Thyroid-Stimulating Hormone levels for improved thyroid tissue ^{131}I uptake [6]. The patient needs to follow a low-iodine diet for ½ weeks before receiving treatment to decrease dietary iodine competition for ^{131}I uptake [7]. Prior to the treatment pregnancy tests are done in women to protect the foetus from fatal exposure [8].

Post-Treatment Radiation Safety. The patients who receive ^{131}I treatment become radioactive and need strict radiation safety measures. The practice of hospital admission follows ^{131}I treatment with activities exceeding 1.1 GBq until the remaining radioactivity reaches levels under 400 MBq. The outpatient treatment for lower administered doses is done when patients demonstrate ability to follow safety guidelines [9]. Patients need to sustain minimum 1m social distance from others and must sleep on a distinctive bed while refraining from long close contact with children and pregnant women for 1-2 weeks [10]. Good hygienic practices enable patients to prevent spreading radioactive body fluids to others [11].

Bonato C.C. et al. studied brief thyroid alterations in children undergoing non-directed radiation therapy [2]; according to their report, 3 months after the scattered doses treatment, no functional thyroid gland changes developed. Long-term monitoring of paediatric thyroid tissue required while their tissues demonstrate increased sensitivity. Personalized dosimetry methods together with safety measures must receive emphasis since younger patients demand special attention. Medical professionals should adjust dose amounts specifically for paediatric patients because children tend to be more radiosensitive.

Risk Assessment of Radiation Exposure. The main danger affecting patients receiving ^{131}I therapy stems from radiation-caused damage that primarily affects bone marrow together with lungs. Blood dosimetry determines organ-specific dose absorption which must stay under the boundary of physiological damage (2 Gy for bone marrow) [12].

Modern technology offers better tools for measuring radiation exposure throughout ^{131}I therapy processes. The collar detection device developed by Santhanam P. et al. enabled real-time recording of radioiodine intake by the thyroid thus helping reduce therapy doses and patient exposure to radiation [7]. A mobile high-resolution gamma camera developed by Trigila C. et al. aims to monitor radionuclide therapy by establishing real-time dose assessment in addition to imaging therapy occurs [8].

Occupational Radiation Safety. Employees who work with $^{131}I/^{124}I$ need to exercise caution since preparing and dispensing radiopharmaceuticals puts them at risk for radiation exposure. They must follow rigorous radiation safety procedures by using protective shields along with personal protective equipment to prevent exposure [13]. Public face exposure to radiation when they care for discharging patients who have undergone medical procedures. Medical studies demonstrate that family members and caregivers remain safely under established regulations when patients adopt guidelines for protection [14].

Continuous Quality Improvement (CQI). The programs for CQI concentrate on maximizing patient readiness and improving dosimetric rules and following safety protocols. The research by Zhou M. et al. [4] proved that CQI approaches which included drug flow chart development and patient education improved healthcare personnel safety together with patient satisfaction while decreasing worker exposure.

Conclusion. The safety of patients against radiation exposure stands as the top priority during ^{131}I treatment of thyroid cancer. To achieve safe levels of radiation exposure, regulatory guidelines must be followed and maintained through patient preparation together with strict post-treatment precautions. Medical procedures becoming simpler and more efficient through new standard dosimetry procedures have demonstrated simultaneous improvements in operational safety. The results of these protocols heavily depend on achieving precise calculations for individual patients. The safety and effectiveness of radioiodine therapy improve as a result of quality and technological improvements. The development of thyroid cancer treatment safety depends on continuous research together with professional collaboration between healthcare providers and regulatory bodies and patients.

REFERENCES

1. Jentzen W., Bockisch A., Ruhlmann M. Assessment of Simplified Blood Dose Protocols for the Estimation of the Maximum Tolerable Activity in Thyroid Cancer Patients Undergoing Radioiodine Therapy Using 124I // Journal of Nuclear Medicine. 2015. V. 56. No. 6. P. 832-838.
2. Bonato C.C., Dias H.B., Alves M.S. et al. Acute effects on the thyroid gland after non-directed radiation therapy in children and adolescents //

Journal of Radiotherapy in Practice. 2014. V. 13. No. 3. P. 310-316. doi.org/10.1017/S1460396913000253
3. Sisson J.C., Freitas J., McDougall I.R. et al. Radiation Safety in the Treatment of Patients with Thyroid Diseases by Radioiodine 131I: Practice Recommendations of the American Thyroid Association // Thyroid. 2011. V. 21. No. 4. doi.org/10.1089/thy.2010.0403
4. Zhou M., Lin Q., Xiong J. et al. Continuous Quality Improvement of Radiation Safety Management for Treatment of Differentiated Thyroid Carcinoma with Iodine-131 // American Journal of Nursing Science. 2020. Vol. 9. No. 3. P. 120-123.
5. Tenhunen M., Lehtonen S., Heikkonen J. et al. First-day iodine kinetics is useful for individualizing radiation safety precautions for thyroid carcinoma patients // Nuclear Medicine Communications. 2013. V. 34. No. 12. P. 1208-1215.
6. Al-Mohammed H.I., Sulieman A., Mayhoub F.H. et al. Occupational exposure and radiobiological risk from thyroid radioiodine therapy in Saudi Arabia // Scientific Reports. 2021. V. 11. 14557. doi.org/10.1038/s41598-021-93342-1
7. Santhanam P., Solnes L., Nath T. et al. Real-time quantitation of thyroidal radioiodine uptake in thyroid disease with monitoring by a collar detection device // Scientific Reports. 2021. V. 11. 18479. doi.org/10.1038/s41598-021-97408-y
8. Wadsley J., Armstrong N., Bassett-Smith V. et al. Patient preparation and radiation protection guidance for adult patients undergoing radioiodine treatment for thyroid cancer in the UK // Clinical Oncology. 2023. V. 35. No. 1. P. 42-56. doi.org/10.1016/j.clon.2022.07.002
9. Trigila C., Verdier M.-A., Pinot L. et al. A mobile high-resolution gamma camera for therapeutic dose control during radionuclide therapy // Physics in Medicine & Biology. 2022. V. 67. No. 3. 035011. doi.org/10.1088/1361-6560/ac4c31
10. Van Velsen E.F.S., Leung A.M., Korevaar T.I.M. et al. Diagnostic and treatment considerations for thyroid cancer in women of reproductive age and the perinatal period // Endocrinology and Metabolism Clinics of North America. 2022. V. 51. No. 2. P. 403-416.
11. Silberstein E.B., Alavi A., Balon H.R. et al. The SNMMI practice guideline for therapy of thyroid disease with 131I 3.0 // Journal of Nuclear Medicine. 2012. V. 53, No. 10. P. 1633-1651. doi.org/10.2967/jnumed.112.105148
12. Luster M., Clarke S.E., Dietlein M. et al. Guidelines for radioiodine therapy of differentiated thyroid cancer // European Journal of Nuclear Medicine and Molecular Imaging. 2008. Vol. 35. P. 1941-1959. doi.org/10.1007/s00259-008-0883-1

13. Yama N., Sakata K., Hyodoh H. et al. A retrospective study on the transition of radiation dose rate and iodine distribution in patients with I-131-treated well-differentiated thyroid cancer to improve bed control and shorten isolation periods // Annals of Nuclear Medicine. 2012. V. 26. P. 390-396. doi.org/10.1007/s12149-012-0586-3
14. Rao V.V.S. P., Sudhakar P., Swamy V.K. et al. Closed system vacuum assisted administration of high dose radioiodine to cancer thyroid patients: NIMS technique // Indian Journal of Nuclear Medicine. 2010. V. 25. No. 1. P. 34-35. doi.org/10.4103/0972-3919.63601

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CFD MODELS OF HYDROGEN RECOMBINATOR RVK500 ON BM-P STAND

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An essential part of the approach is the use of a detailed mechanism of the chemical kinetics of hydrogen and oxygen, which avoids the privately used fitting procedure in determining the parameters of a one-step reaction to describe the hydrogen recombinator performance [1, 2]. This approach makes it possible to calculate the recombinator performance at any regimes in a consistent manner and to determine the threshold of flameless recombination, which is unambiguously necessary in the numerical justification of severe accidents with hydrogen entry. To test the developed methodology of numerical substantiation of recombinator operation in the environment with changing parameters and substantiation of transient (non-stationary) processes, the data obtained in testing of hydrogen recombinator RVK-500 (produced by CJSC "INPC RET") on the BM-P stand were used. In this work, the data of only one test, namely BM-P P13p (natural circulation) and BM-P P19p (forced circulation) were used (2). Figure 1 shows the comparison between the calculated and experimental hydrogen recombination rates, taking into account the experimental errors. A reasonably good agreement is obtained. The calculated performance of the recombinator RVK-500 using the RET formula is also given. As can be seen, the result of calculation by the proposed model (1) significantly better describes the experimental data.

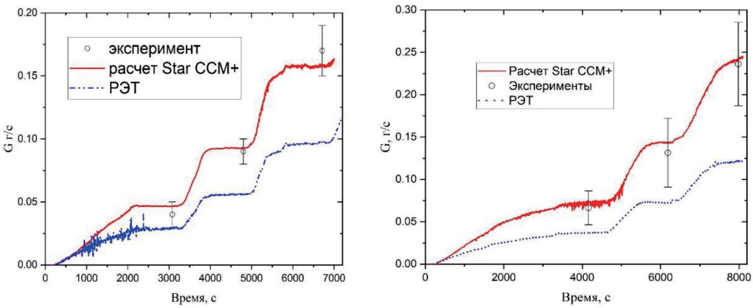

Figure 1. Calculated and experimental performance of recombinator RVK 500 in test P13p (left), P19p (right)

REFERENCES

1. Duong Quang Huong., Avdeenkov A. V., V.V. Ketlerov, Verification of CFD model of hydrogen recombinator RVC-500 using detailed mechanism of recombination reaction // XVI International Conference "NPP Safety and Training. – Obninsk: INPP MEPhI, 2023.- P. 74-76.
2. Validation of the numerical model of the hydrogen recombinator RVC-500 / S. G. Kalyakin, A. V. Koshcheev, M. K. Sedov [et al.] // Teploenergetika : monthly theoretical and scientific-practical journal / founders: Ros. akad. of sciences, Ros. nauchno-technical society of power engineers and electrical engineers. – Moscow. – 2024. – N 3. – C. 5 -17.

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NUCLEAR MEDICINE

POTENTIAL OF NUCLEAR MEDICINE FOR TREATMENT OF GLIOBLASTOMA

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Abstract. This report presents the current status of targeted radionuclide therapy in Glioblastoma, highlighting the commonly used therapeutic radionuclides emitting alpha, beta particles that could induce potent molecular and cellular damage to treat Glioblastoma. The physical property is based on particle–matter interaction differences and results in α particles being highly efficient in killing tumor cells with minimal irradiation of healthy tissues and permits targeting of isolated tumor cells. The clinical trials confirmed this idea and showed good therapeutic efficacy and less side effects, thus opening a new and promising era for glioblastoma medical care using α therapy. The objective of this literature review is focused on the developing field of nuclear medicine and aims to describe the various parameters such as targets, vectors, isotopes, or injection route (systemic and local) in relation to the clinical and preclinical results in glioblastoma pathology..
Keywords: glioblastoma (GBM), nuclear medicine, cancer, radioimmunotherapy (RIT), peptide receptor radiotherapy (PRRT).

Introduction. Glioblastoma is a neoplasm derived from astrocytes, a subtype of brain macroglial cells. Astrocytomas from the most benign to the most aggressive tumors have been classified using four grades: pilocytic astrocytoma (grade I tumors), diffuse astrocytoma (grade II tumors), anaplastic astrocytoma (grade III tumors), and glioblastoma (grade IV tumors). Glioblastoma appears to be the most aggressive and also, unfortunately, the most frequent primary brain tumor. The worldwide incidence of glioblastoma is less than 10 per 100,000 people.

The recent progress in nuclear medicine development has generated a new promising arsenal for glioblastoma therapy. This has been mainly driven by biotechnologies such as radioimmunotherapy, radiopeptide therapy, and radionanoparticles. The four main parameters required for successful radionuclide targeted therapies for glioblastoma are the selection of an appropriate target, the size of the targeting vector, the physical properties of the radionuclide, and the physicochemical properties of the vector.

The objective of this report is focused on the improving field of nuclear medicine and describes the various parameters such as targets, vectors, isotopes, or injection route (systemic and local) in relation to clinical and preclinical results in glioblastoma pathology.

Methodology. This study employed mixed approach by targeting Cadherin5, Integrin αV β3, Somatostatin receptors, neurokinin type1 receptor. These targets were selected because these are responsible for tumor growth and angiogenesis which is crucial for tumor survival.

They were labelled with alpha and beta particles and then introduced into mice. Data was collected by pilot studies and experiment on mice by observing the effectives of radiolabelled particle in regression of tumor growth with increase in life expectancy of patient.

<u>Physical properties of radioisotopes used in glioblastoma therapy</u>

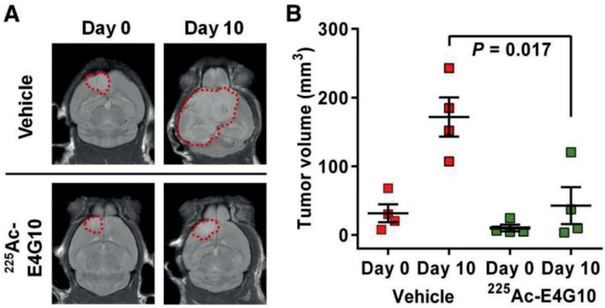
Radionuclide	Emission type	Half-life (h)	E_{max} (keV) of main emission	Maximum range in soft tissues (mm)
Iodine-125	Auger	1426	3.19	Nanometer scale
Iodine-131	β^-	193	606.3	2.9
Yttrium-90	β^-	64	2,280.1	12.0
Lutetium-177	β^-	162	498.3	2.0
Rhenium-186	β^-	89.2	1,069.5	5.0
Rhenium-188	β^-	17	2,120.4	10.8
Astatine-211	α	7.2	5.870 to 7.45	0.055 to 0.080
Bismuth-213	α	0.76	8.4	0.1
Actinium-225	α	240	8.4	0.1

Results. **<u>Cadherin</u>** is responsible for formation of new blood vessels it was targeted by E4G10 is monoclonal antibody which was llabelled with the multiple alpha emitter actinium-225 and intravenously injected into transgenic glioblastoma mice, the E4G10 showed therapeutic efficacy with a significant increase in survival and increased penetration of chemotherapeutic drug.

In the below T2 MRI

(A)is comparison of mice brain before and after 10days of treatment by actinium-225 E4G10 Tumor margins are displayed as dashed red lines.

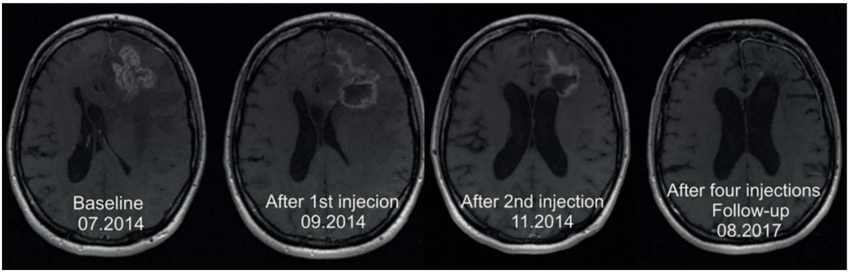
(B) Mean tumor volumes at day 0 and day 10 of vehicle-treated (n = 4) versus 225Ac-E4G10–treated (n = 4) animals. Reported values are mean ± SEM.



Integrin αV β3 is involved in tumor neoangiogenesis and appears to be an oncologic target in various diseases including glioblastoma. Abegrin® is an monoclonal antibody directed against αV β3 and can be used after radiolabeling with yttrium-90. A proof of concept in a mouse glioblastoma xenograft model showed a partial tumor regression as assessed by image monitoring compared with control groups.

Somatostatin Receptor: Three patients with glioblastoma multiform (WHO grade IV) were locally injected via a subcutaneous reservoir system implanted into the resection cavity. Patients received 1,660 to 2,200 MBq of 90Y-DOTATOC in three or four fractions at an interval of 3 to 4 months. There was a complete remission for one patient and partial remission in the other two patients. The Karnofsky performance score increased by 10% to 40% for the three patients, and they reported an improved quality of life.

<u>Neurokinin type 1 Receptor</u>: A pilot study was done on nine patients suffering recurrent glioblastoma were injected with 1.4 to 9.7 GBq of 213Bi-substance P into a resected cavity using a fractionated therapy cycle (one to six). The results supported the pilot study, with a median progression free-survival time of 5.8 months and overall survival time of 16.4 months. The median overall survival time from the first diagnostic was 52.3 months, and two of the nine patients (22.2%) are still alive 39 and 51 months after the Peptide receptor radionuclide therapy (PRRT) initiation.



In above figure is MRI of 32-year-old woman suffering from Glioblastoma multiforme (GBM) manifested 10.6 months after initial diagnosis. Following standard treatment consisting of surgery, radiotherapy, and chemotherapy with temozolomide, four cycles of 213Bi-DOTA-substance P were applied. The total activity injected amounted to 8.0 GBq of the therapeutic isotope. The T1-weighted enhanced MRI examination revealed shrinkage of the tumor by 32%.

Conclusion. Glioblastoma is tumor associated with fatal outcome. Considering the clear need to improve therapeutic strategies, substantial efforts have been made to understand GBM biology. The blood-brain-tumor barriers, the intra-, and inter-tumoral heterogeneity, and the intrinsic resistance to chemo- and radio-therapies are important barriers to the development of effective treatments. Mentioned molecular mechanisms of GBM resistance to therapy were recently reviewed. Low survival rates of GBM are, at least in part, a consequence of the extensive invasion of the brain tissue. This infiltration is notably controlled by the interactions between cancer cells and the surrounding brain microenvironment

Most therapeutic radiopharmaceuticals are labelled with alpha and beta-emitting isotopes. These particles have a tissue penetration of only a few millimetres, which allows cell irradiation in limited radius, causing a cytotoxic effect on tumor cells while sparing surrounding healthy tissue. Many clinical trials demonstrate the efficacy and safety of nuclear medicine approaches, but these have only been assessed in phase I or II clinical trials. These results need to be strengthened, and phase III are trials are necessary to confirm the emerging place of nuclear medicine in the therapeutic arsenal against glioblastoma.

REFERENCES

1. Vascular Targeted Radioimmunotherapy for the Treatment of Glioblastoma Katja Behling, William F. Maguire, José Carlos López Puebla, Shanna R. Sprinkle, Alessandro Ruggiero, Joseph O'Donoghue, Philip H. Gutin, David A. Scheinberg and Michael R. McDevitt
2. Targeted radionuclide therapy for gliomas, neuro-oncology volume 26
3. Basic science of nuclear medicine, 2nd edition 2021.
4. European Association for Neuro-oncology Guidelines.
5. WHO tumor grading.

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RESEARCH ON RADIATION THERAPY PROCESSES USING VIRTUAL VISUALIZATION SYSTEM TOOLS

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Abstract. Currently, radiation therapy is one of the common methods for treating malignant neoplasms. The primary goal of radiation therapy is to deliver localized ionizing radiation to the tumor while minimizing exposure to healthy tissues.

The radiation therapy procedure consists of several stages: pre-radiation preparation, dosimetric planning, verification of the dosimetric plan, and the actual irradiation. Each stage of radiation therapy is critically important, and any error at any of these stages can negatively impact the patient's condition. Therefore, specialists involved in administering radiation therapy must constantly practice their skills. To safely practice all stages of radiation therapy, a virtual radiation therapy visualization system (VRTVS) can be utilized.

In this study, the tools of the VRTVS were examined. Using the system, possible emergency situations were simulated and practiced during radiation therapy procedures.

The results of the study showed that the VRTVS is an effective tool for training professionals in the field of radiation therapy, allowing not only the practice of standard procedures but also the development of skills for solving complex and emergency situations.

Keywords: radiation therapy, therapeutic linear accelerator, quality assurance of radiation therapy.

Introduction. Radiation Therapy (RT) is one of the methods for treating oncological and a number of non-oncological diseases, based on the use of ionizing radiation [3]. The process of preparing and conducting radiation therapy consists of several stages:

Topometric preparation. The patient undergoes tomographic studies such as X-ray computed tomography (CT), magnetic resonance imaging (MRI), and positron emission tomography (PET), which allow for precise determination of the tumor's location and size. During the pre-radiation preparation stage, immobilization methods are used to ensure the patient's comfortable and reproducible position from fraction to fraction and to guarantee the correct delivery of the planned absorbed dose distribution to the tumor.

Dosimetric planning. Based on the results of imaging, contouring, and prescription, an individual dosimetric plan is developed to calculate the absorbed dose in target volumes and organs at risk. This process involves the use of specialized software, a treatment planning system (TPS), to create the geometry of dose delivery and calculate the distribution of the absorbed dose.

Quality assurance (verification) and clinical dosimetry. A check is performed to ensure the conformity of the calculated absorbed dose distribution in the TPS and the measured absorbed dose distribution obtained during the implementation of the dosimetric plan on the therapeutic machine using various dosimetric phantoms. This procedure allows for the verification of the reproducibility of the calculated dosimetric plan on the corresponding machine.

Treatment delivery. The patient undergoes a course of RT, consisting of one or several irradiation sessions on the therapeutic machine to deliver the absorbed dose to the tumor.

The success of radiation therapy hinges on the precision of each step, as a mistake at any point can have adverse effects on the patient's health. Given this, professionals involved in radiation therapy must continuously hone their practical skills. One effective way to achieve this is by utilizing a Virtual Radiation Therapy Visualization System (VRTVS).

The VRTVS system allows for practicing and refining skills in a safe and controlled virtual environment. With its toolkit, users can develop skills such as patient positioning on the radiotherapy complex, conducting visualization of diagnostic images, reproducing individually developed dosimetric plans, and performing quality assurance steps on modern equipment. Figure 1 shows the main instruments for conducting radiation therapy sessions in the system.

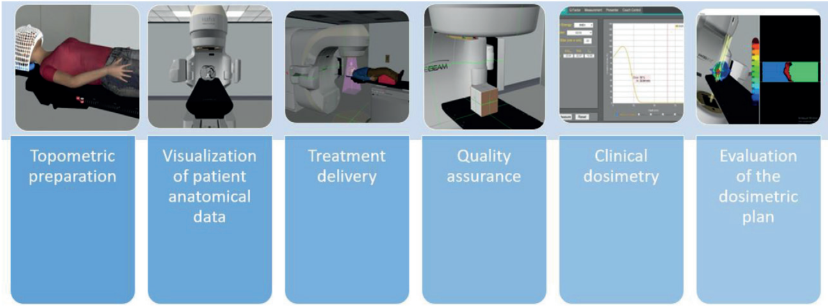

Figure 1. Possibilities of the VRTVS for practicing practical skills in conducting radiation therapy sessions

Using the system's possibilities, users can simulate various scenarios of radiation therapy procedures, without the risks associated with real interaction with patients. These scenarios can consider all possible collisions.

Conclusion. In conclusion, the integration of VRTVS into radiation therapy training programs represents a significant advancement in the field. It supports the continuous professional development of specialists, reduces the risk of errors, and contributes to better patient outcomes.

REFERENCES

1. Podgorsak E. Radiation Oncology Physics: A Handbook for Teachers and Students. – Medical Physics. – 2006. – vol. 33. – P. 1920. – DOI: 10.1118/1.2201870.
2. Sukhikh E.S., Vertinsky A.V., Stakhova O.M. Methodological Recommendations for Ensuring the Quality of Electron Linear Accelerators for External Beam Radiation Therapy (Quality Assurance). – Tomsk: Publishing House of Tomsk Polytechnic University, 2022. – 46 p.
3. Khan F.M. Physics of Radiation Therapy. – 3rd ed. – Philadelphia: Lippincott Williams & Wilkins, 2003.

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NUCLEAR ENERGY-POWERED REHABILITATION CENTERS

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Abstract. Inspired by the success of nuclear-powered submarines and data centers, this paper proposes nuclear energy-powered rehabilitation centers, a groundbreaking solution using small modular reactors (SMRs) to provide clean, reliable energy for advanced medical technologies like Nuclear-Powered Pacemakers, pediatric gait robots and prosthetics. These centers can operate 24/7 to ensuring eco-friendly uninterrupted care for children with cerebral palsy (CP), injured military personnel and others in need.

Nuclear-Powered Rehabilitation Center combines nuclear medicine and healthcare, offering a unique opportunity to make a meaningful impact in patient care and rehabilitation. It can significantly reduce carbon emissions, contributing to global efforts to combat climate change while improving the quality of care for millions. Through Russia-Asia collaboration, we can bring this vision to life, leveraging expertise in nuclear technology and healthcare innovation. Join us in reimagining rehabilitation powered by the limitless potential of nuclear energy.

Keywords: Nuclear-powered rehabilitation centers, Small modular reactors (SMRs), Pediatric gait robots, pacemakers, Cerebral palsy, injured military personnel, Sustainable, healthcare, Russia-Asia collaboration, Nuclear energy, Advanced medical technologies..

Introduction. Nuclear medicine facilities in hospitals provide diagnostic and therapeutic services using radionuclides, including in-vivo and in-vitro procedures, internal radiation monitoring, and targeted therapies [1]. This study aims to propose nuclear-powered rehabilitation centers as a sustainable and innovative solution to address the energy challenges faced by healthcare facilities. Rehabilitation aims to help individuals, including those with disabilities like cerebral palsy or injured military personnel, prosthetics achieve their highest level of function, independence, and quality of life by providing better treatment and restoring optimal health. Worldwide, an estimated one in three people live with a health condition that could significantly improve through rehabilitation

[2]. By small modular reactors (SMRs), the study demonstrates how nuclear energy can provide clean, reliable, and cost-effective power for advanced medical technologies like pediatric gait rehabilitation robots and prosthetics.

According to the Cerebral Palsy Alliance Research Foundation (CPARF) in globally about 18 million people have some form of cerebral palsy. In Asia, cerebral palsy (CP) affects 2.19 in every 1,000 individuals, with a higher incidence observed in children from economically disadvantaged backgrounds [3]. Spastic CP, the most common type, often requires long-term rehabilitation and advanced medical care. However, many children lack access to proper treatment due to limited healthcare infrastructure and unreliable energy sources in village or underserved areas.

Methodology. The nuclear medicine facility, spanning 473 square meters (about 5,090 square feet), can be repurposed as a spacious and adaptable rehabilitation center [4]. This generous area allows for a variety of therapy rooms, exercise spaces, and treatment areas, creating a comfortable and healing environment for patients on their journey to recovery. Using data from the World Nuclear Association (2023) Nuclear energy reduces CO_2 emissions by 1,911,082 kg CO_2/year compared to coal.

This study provides strong evidence for the feasibility and benefits of nuclear-powered healthcare infrastructure, improving accessibility to rehabilitation services, reducing carbon emissions, and ensuring uninterrupted care for children with cerebral palsy, injured military personnel, and others in need.

The International Atomic Energy Agency (IAEA), in a publication dated 4 November 2021, defines Small Modular Reactors (SMRs) as nuclear reactors with a capacity of up to 300 MW(e) per unit [5]. The average annual energy consumption of a healthcare center is 86.01 kWh/m² [4]. This observation can be used as a basis for estimating energy consumption in rehabilitation centers.

Power Requirements and Calculations. Assume a medium-sized rehabilitation center has a floor area of 3,000 m².

Calculate energy consumption = 86.01 kWh/m²/year × 3000 m² = 258,030 kWh/year.

$$Average\ power\ requirement = \frac{258{,}030\, kWh\ /\ year}{8{,}760\, hours\ /\ year} = 29.5\text{ kW}$$

Peak Power Requirement = 29.5 kW × 3 = 88.5 kW.

The number of centers powered by one SMR is calculated as:

$$Number\ of\ Centers = \frac{SMR\ Output}{Center\ Requirement} = \frac{10{,}000\, kW}{88.5\, kW} = 113\, centers$$

Benefits of Nuclear-Powered Rehabilitation Centers:

Uninterrupted power ensures 24/7 operation of critical medical equipment. Low-carbon energy reduces environmental impact. Centers can be deployed in rural or underserved areas. Long-term energy savings make healthcare more affordable. Collaboration of nuclear energy with advanced medical technologies drives progress in both fields. A Rehabilitation in village areas is a planning concept that goes beyond a single structure, incorporating urban design elements to create a nature-friendly community [6]. It combines multi-complexes, sanatoriums, and recreational spaces, with a Nuclear-Powered Rehabilitation Center offering sustainable energy, cost savings, and a healing environment, while improving healthcare access and supporting local development [6].

Vision for a Nuclear-Powered Rehabilitation Center

We hope a Nuclear-Powered Rehabilitation Center to promise the unique needs of individuals with conditions like Cerebral Palsy, injured military personnel, and other disabilities, while leveraging the potential of nuclear medicine and advanced technology. By utilizing Small Modular Reactors (SMRs), the center ensures a sustainable and reliable energy source to power cutting-edge medical devices and therapies.

This innovative approach not only supports long-term rehabilitation and care but also reduces operational costs and environmental impact. Integrating nuclear medicine into treatment plans allows for precise diagnostics and therapies, enhancing patient outcomes. The center's design fosters a healing environment, combining advanced medical care with eco-friendly energy solutions, making it a transformative model for rehabilitation and healthcare accessibility.

The Challenges:

– Public perception of nuclear energy, particularly regarding safety.

– Lack of regulatory maintain for nuclear-powered healthcare facilities.

– High initial investment costs for nuclear infrastructure.

Solutions:

– Build trust through education and transparent communication, highlighting the advanced safety features of SMRs and RTGs.

– Collaborate with organizations like the International Atomic Energy Agency (IAEA) to develop guidelines and standards.

– Secure funding from governments, private investors, and international organizations to offset costs and ensure long-term viability.

Conclusion. A Sustainable Future in Rehabilitation with Nuclear-Powered offer a sustainable, reliable, and innovative solution for pediatric gait rehabilitation, injured military personnel, and others in need. By nuclear technology, we can create healthcare infrastructure that is both eco-friendly and improved quality of life for vulnerable populations while setting a global standard for future healthcare facilities. Collaboration between Russia and Asia, this vision can become a reality, transforming lives and building a brighter nucleo-healthcare future.

REFERENCES

1. Anita Nur Mayani and Basari, "Evaluation on Requirements of Nuclear Medicine Facility Building" (THE 4TH BIOMEDICAL ENGINEERING'S RECENT PROGRESS IN BIOMATERIALS, DRUGS DEVELOPMENT, HEALTH, AND MEDICAL DEVICES: Proceedings of the International Symposium of Biomedical Engineering (ISBE) 2019, Padang, Indonesia, 2019), 020049, https://doi.org/10.1063/1.5135558.

2. World Health Organization. Health-topics/rehabilitation.
3. Andromeda, Nurul Hartini and Suryanto "Reassuring The Prevalence of Cerebral Palsy in Asian Children and Adolescents."
4. Justo García-Sanz-Calcedo, "Analysis on Energy Efficiency in Healthcare Buildings," Journal of Healthcare Engineering 5, no. 3 (January 2014): 361–74, https://doi.org/10.1260/2040-2295.5.3.361.
5. International Atomic Energy Agency, https://www.iaea.org/newscenter/news/what-are-small-modular-reactors-smrs.
6. Marina Zvyagintseva, Julia Skripkina, and Natalia Fedorchenko, "Principles and Examples of Design of Rehabilitation Centers in Russia and Abroad," Journal of Applied Engineering Science 17, no. 4 (2019): 567–70, https://doi.org/10.5937/jaes17-23722.

THE ROLE OF RADIOPHARMACEUTICALS IN THE CENTER FOR NUCLEAR SCIENCE AND TECHNOLOGY OF VIETNAM SUPPORTED BY ROSATOM

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Abstract. Nuclear medicine plays a crucial role in diagnosing and treating oncological diseases in Vietnam, where 180,480 new cases were registered in 2022. Domestic radiopharmaceutical production meets only about 60% of the national demand, primarily due to the aging research reactor in Dalat, owned by the Dalat Nuclear Research Institute (DNRI) – a branch of Vietnam Atomic Energy Institute (VINATOM). The geographical distance between medical institutions and the reactor further exacerbates reliance on radiopharmaceutical imports. The Center for Nuclear Science and Technology (CNST) in Long Khanh, equipped with a modern 10 MW reactor supported by Rosatom, is expected to significantly enhance radiopharmaceutical production. This study assesses the potential impact of CNST on the development of radiopharmaceuticals in Vietnam.

Keywords: Radiopharmaceuticals, nuclear medicine, medical isotopes,Dalat Nuclear Research Reactor, Dalat Nuclear Research Institute, The Center for Nuclear Science and Technology.

INTRODUCTION. Oncological diseases are among the leading causes of mortality in Vietnam, with a fatality rate of 66.6% [1]. Radiopharmaceuticals such as Tc-99m and I-131 play a crucial role in diagnosis and treatment. However, domestic production remains limited, resulting in shortages and dependence on imports [2,3]. Even in Ho Chi Minh City, the second-largest city in Vietnam, patients are forced to seek treatment abroad due to the lack of radiopharmaceuticals [3]. Expanding domestic production of new radionuclides is essential for the advancement of nuclear medicine in the country. With over 40 years of operation, the research reactor in Dalat can no longer fully meet the increasing demand for radiopharmaceuticals in modern healthcare. Addressing this challenge, the CNST, supported by Rosatom, presents a promising opportunity to expand domestic radiopharmaceutical production. This advancement is expected to enhance the availability of critical medical isotopes, reduce reliance on imports, lower costs, and ultimately strengthen the development of nuclear medicine in Vietnam.

METHODS AND MATERIALS. The study is based on official reports from the Vietnam Atomic Energy Institute (VINATOM), the Ministry of Science and Technology of Vietnam, and the Government of the Socialist Republic of Vietnam.

RESULTS AND DISCUSSION. The Dalat Research Reactor (DRR) has undergone significant transformations since its commissioning in 1963 as the TRIGA Mark II reactor (250 kW) with U.S. support. Following an operational period (1963–1968), it was shut down, and its fuel was returned to the U.S. in 1975. In 1979, Vietnam collaborated with the Soviet Union to reconstruct and upgrade the reactor to 500 kW, renamed IVV-9 [4,5]. The upgraded reactor achieved first criticality in 1983 and resumed operation in 1984, focusing on radioisotope production, neutron activation analysis, reactor physics, and personnel training. Between 2007 and 2011, DRR transitioned from Highly Enriched Uranium (HEU, 36% U-235) to Low Enriched Uranium (LEU, 19.75% U-235), achieving first criticality with a full LEU core in 2011. In 2013, all spent HEU fuel was repatriated to Russia under the Russian Research Reactor Fuel Return Program, supported by the IAEA and the U.S. Today, DRR remains a key facility for nuclear research and radiopharmaceutical production in Vietnam [6].

On the other hand, the CNST in Long Khanh, Vietnam, is being developed with the support of Rosatom as part of an intergovernmental agreement between Vietnam and Russia. The project was initiated in 2011, and in 2018, it received approval from the Vietnamese government [7]. In 2024, a memorandum of understanding was signed between Rosatom and the Vietnamese Ministry of Science and Technology to cooperate in peaceful nuclear research [8]. In addition to its technical advancements, the CNST will train specialists under Rosatom's educational programs, and VINATOM is actively sending personnel to the Joint Institute for Nuclear Research (Dubna, Russia) to train key staff for the project, further enhancing Vietnam's nuclear capabilities [9]. The center's proximity to Ho Chi Minh City will facilitate the distribution of radiopharmaceuticals, reducing dependency on imports.

Table 1

Comparison of the Dalat Nuclear Research Institute (DNRI) and the Center for Nuclear Science and Technology (CNST)

Criterion	DNRI [6]	CNST [7,8,9,10]
Location	Dalat, located far from major medical centers	Long Khanh, approximately 80 km from Ho Chi Minh City
Reactor power	0.5 MW	10 MW
Year of establishment	1984	Planned construction start: 2027–2028, Expected completion: 2031
Main products	Tc-99m, I-131, P-32, S-35, etc.	11 isotopes
Technology	TRIGA Mark II (USSR)	Modern reactor (Rosatom)
Production capacity	1,300 Ci (2020), partial demand coverage	Full domestic demand coverage
Radiopharmaceutical production	Limited (Tc-99m, I-131)	Expected production of 50–70 radiopharmaceuticals
Project scale	21 ha	100 ha

CONCLUSION. The commissioning of CNST will ensure Vietnam's independence in radiopharmaceutical production, reduce reliance on imports, and support the development of medicine, industry (silicon irradiation), and research. The center will become a key hub for nuclear medicine alongside the Dalat research reactor, strengthening Vietnam's position in this field.

REFERENCES

1. GLOBOCAN 2022. Global Cancer Observatory. International Agency for Research on Cancer. Available at:
2. https://gco.iarc.who.int/media/globocan/factsheets/populations/704-viet-nam-fact-sheet.pdf (accessed: 10.03.2025).
3. VnExpress. How Vietnam's radiopharmaceuticals are synthesized. Available at: https://vnexpress.net/thuoc-phong-xa-cua-viet-nam-duoc-dieu-che-the-nao-4744922.html (accessed: 10.03.2025).
4. Ministry of Science and Technology of Vietnam. Removing obstacles in radiopharmaceutical production for cancer diagnosis. Available at: https://www.most.gov.vn/vn/tin-tuc/25135/go-vuong-cho-viec-san-xuat-thuoc-phong-xa-chan-doan-ung-thu.aspx (accessed: 10.03.2025).
5. Nguyen N. D., Luong B. V., Le V. V., Duong V. D., Nguyen X. H., Pham N. S., Cao D. V. Results of Operation and Utilization of the Dalat Nuclear Research Reactor // Nuclear Science and Technology. – 2014. – Vol. 4, No. 1. – P. 1–9. DOI: 10.53747/jnst.v4i1.208.
6. Nguyen N. D., Nguyen T. S., Luong B. V., et al. Overview of the Dalat Nuclear Research Reactor. – Science and Technics Publishing House, 2016. – 29 p.
7. Dalat Nuclear Research Institute, Vietnam Atomic Energy Institute (VINATOM). History of the Institute. Available at: https://nri.gov.vn/en/history.html (accessed: 10.03.2025).
8. Vietnam Atomic Energy Institute (VINATOM). Geological survey of the proposed site for the new research reactor in Dong Nai. Available at: https://vinatom.gov.vn/khao-sat-dia-chat-khu-vuc-xay-lo-nghien-cuu-hat-nhan-tai-dong-nai/ (accessed: 10.03.2025).
9. Online newspaper of the Government of the Socialist Republic of Vietnam. Cooperation with Rosatom on the implementation of the Nuclear Science and Technology Center project. Available at: https://baochinhphu.vn/hop-tac-voi-rosatom-trien-khai-du-an-trung-tam-nghien-cuu-khoa-hoc-cong-nghe-hat-nhan-102240925085757815.htm (accessed: 10.03.2025).
10. Online newspaper of the Government of the Socialist Republic of Vietnam. Developing strong research groups in nuclear energy for Vietnam. Available at: https://baochinhphu.vn/hop-tac-phat-trien-cac-nhom-nghien-cuu-manh-ve-nang-luong-nguyen-tu-cho-viet-nam-102240927125440242.htm (accessed: 10.03.2025).

11. Ministry of Science and Technology of Vietnam. Rosatom to support Vietnam in building a research reactor tailored to practical needs. Available at: https://www.most.gov.vn/vn/tin-tuc/25209/rosatom-se-ho-tro-viet-nam-xay-dung-lo-phan-ung-hat-nhan-phu-hop-voi-yeu-cau-thuc-tien.aspx (accessed: 10.03.2025).

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ECOLOGY

SYNTHESIS OF FUNCTIONALIZED BIOCHAR FOR PHOSPHATE RECOVERY FROM EUTROPHIC WATER AND ITS SUBSEQUENT UTILIZATION AS A P-BASED FERTILIZER FOR PLANT GROWTH

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Abstract. The present study addresses the phosphates' recovery from eutrophic water using iron-functionalized biochar derived from sugarcane bagasse. The biochar, modified with iron, demonstrated high phosphate adsorption efficiency (98.5% under optimal conditions) and was subsequently used as a phosphorus-based fertilizer. Batch experiments optimized parameters like dosage, pH, and contact time, while characterization (SEM-EDS, BET) confirmed iron integration. The adsorption followed the Freundlich isotherm and Pseudo-Second-Order kinetics, indicating multilayer adsorption and chemisorption. A pot test showed enhanced mustard plant growth, confirming the biochar's potential as a sustainable fertilizer. This research offers an eco-friendly solution for phosphate recovery and reuse, addressing water pollution and promoting sustainable agriculture.

Keywords: water treatment, biochar, pyrolysis, sugarcane bagasse.

Introduction. Eutrophication, caused by excessive phosphorus (P) release into aquatic ecosystems, is a significant environmental challenge [1]. This study addresses the issue by developing a novel approach to recover phosphates from eutrophic water using functionalized biochar derived from sugarcane bagasse. The recovered phosphate is then utilized as a phosphorus-based fertilizer for plant growth. The research focuses on modifying biochar with iron (Fe) to enhance its phosphate adsorption capacity and subsequent use in agriculture.

The present study aims to: 1) Synthesize and characterize iron-functionalized biochar for phosphate recovery from water. 2) Evaluate the impact of water chemistry parameters on phosphate removal efficiency. 3) Utilize phosphate-loaded biochar as a P-based fertilizer for mustard plant growth.

Methodology. The raw sugarcane bagasse was collected, cleaned, dried, ground, sieved, chemically treated, and stored for further use. The bagasse was pyrolyzed at 500°C in the pyrolysis reactor (Figure 1) under nitrogen gas to produce biochar, bio-oil, and syngas [2]. The biochar was collected and analyzed using techniques like SEM, BET, and FTIR. The biochar was activated with iron by treating it with $FeCl_3 \cdot 6H_2O$ solution, adjusting the pH to 11, and heating at 60°C. The activated biochar was then neutralized, washed, and dried.

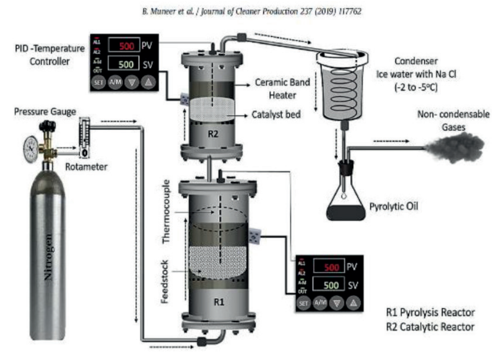
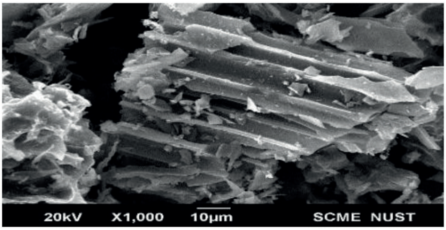


Figure 1. Pyrolysis Reactor [3]

A method using Ammonium Molybdate and Ammonium Metavanadate was developed to detect phosphate concentrations in water samples [4]. Batch experiments were conducted to study the effects of biochar dosage, pH, contact time, initial phosphate concentration, and temperature on phosphate adsorption [5]. The phosphate-loaded biochar was used as a fertilizer in a pot test with mustard plants. Root and shoot lengths were measured to evaluate plant growth [6].

Results and Discussion. As a result, it was established that the optimal dosage for phosphate removal was 4 g/L, achieving 80.25% removal efficiency. Acidic conditions (pH 2) yielded the highest removal efficiency (98.5%). The adsorption capacity increased with contact time, reaching equilibrium at 2 hours. Higher initial concentrations led to increased adsorption capacity but reduced removal efficiency. Adsorption capacity decreased at higher temperatures, with optimal performance at 25°C.

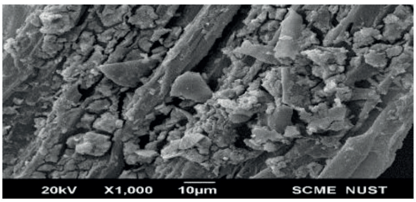
The surface morphology of raw and iron-activated biochar was analyzed, showing iron integration into the biochar structure, further demonstrated in Figure 2 & 3.



eZAF Quant Result - Analysis Uncertainty: 14.48 %

Element	Weight %	MDL	Atomic %	Error %
C K	77.1	1.02	85.9	10.0
O K	13.0	0.30	10.9	12.6
Mg K	0.8	0.09	0.5	10.8
P K	3.0	0.08	1.3	3.7
K K	1.4	0.10	0.5	5.3
Cu K	2.5	0.29	0.5	9.0
Zn K	2.2	0.35	0.4	4.8

Figure 2. SEM-EDS of Raw Biochar created (designed) by author



eZAF Quant Result - Analysis Uncertainty: 11.29 %

Element	Weight %	MDL	Atomic %	Error %
C K	40.7	1.32	59.7	11.0
O K	27.6	0.37	30.4	10.8
K K	0.4	0.13	0.2	18.0
Fe K	27.4	0.28	8.6	2.5
Cu K	2.2	0.42	0.6	16.7
Zn K	1.6	0.50	0.4	6.6

Figure 3. SEM-EDS of Activated Biochar created (designed) by author

It was revealed that iron activation reduced the surface area and pore volume of the biochar due to pore blockage. Volatile matter decreased, and fixed carbon increased after iron activation, and the results are presented in Table 1.

It was observed that the adsorption process followed the Freundlich isotherm model, indicating multilayer adsorption. The Pseudo-Second-Order (PSO) kinetic model best described the adsorption process, suggesting chemisorption as the rate-limiting step.

Table 1

BET and Proximate Analysis created (designed) by author

Characteristics	Raw Biochar	Iron-Biochar		Moisture Content	Volatile Combustible Matter	Fixed Carbon	Ash Content
Pore volume (cm^3/g)	0.05	1	**Raw Sugarcane Bagasse Powder**	12.7 %	67.9 %	16.1 %	3.3%
Pore diameter (nm)	1.7	1.2	**Raw Biochar**	7.6 %	49.4 %	40 %	3 %
Surface area (m^2/g)	31.6	27.2	**Fe-Biochar**	11.6 %	32.8 %	%	2 %

The adsorption process was exothermic and thermodynamically favorable, with a negative Gibbs free energy (ΔG). The modelled data is given below in Figure 4.

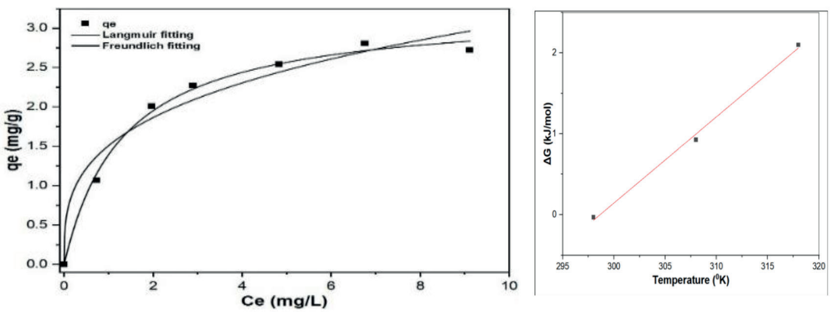


Figure 4. Isotherm Modelling & Gibbs Free Energy created (designed) by author

Experiments show that the addition of iron-activated biochar significantly improved the root and shoot lengths of mustard plants, demonstrating its potential as a sustainable fertilizer. The pot test results are shown in Figure 5 below.

The calculations of cost and benefit analysis were performed. It was established biochar production costs:

– Sugarcane bagasse: 2,200–2,500 PKR/ton.

– Rice straw: 3,500 PKR/ton.

Maximum phosphate removal efficiency of 98.5% under optimal conditions.

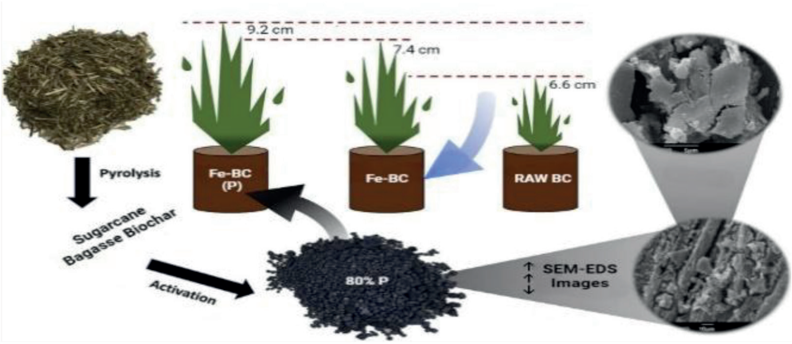


Figure 5. Pot Test Results created (designed) by author

Conclusion. The study demonstrated that iron-functionalized biochar is an effective and sustainable solution for phosphate recovery from eutrophic water. Under optimal conditions, a removal efficiency of 98.3% was achieved. The biochar also showed promise as a P-based fertilizer, enhancing plant growth. The research highlights the potential of biochar in addressing water pollution and promoting sustainable agriculture.

REFERENCES

1. Manyatshe A. et al. Chitosan modified sugarcane bagasse biochar for the adsorption of inorganic phosphate ions from aqueous solution //Journal of Environmental Chemical Engineering. – 2022. – Vol. 10. – №. 5. – P. 108243.

2. Palansooriya K. N. et al. Fe (III) loaded chitosan-biochar composite fibers for the removal of phosphate from water //Journal of hazardous materials. – 2021. – Vol. 415. – P. 125464.
3. Bushra M. et al., Influence of in-situ and ex-situ HZSM-5 catalyst on co-pyrolysis of corn stalk and polystyrene with a focus on liquid yield and quality, Journal of Cleaner Production, Volume 237, 2019, 117762, ISSN 0959-6526.
4. Zhang X. et al. Removal of phosphate from aqueous solution by chitosan coated and lanthanum loaded biochar derived from urban dewatered sewage sludge: adsorption mechanism and application to lab-scale columns // Water Science and Technology. – 2021. – Vol. 84. – №. 12. – P. 3891-3906.
5. Choi Y. K. et al. Adsorption of phosphate in water on a novel calcium hydroxide-coated dairy manure-derived biochar //Environmental Engineering Research. – 2019. – Vol. 24. – №. 3. – P. 434-442.
6. Vikrant K. et al. Engineered/designer biochar for the removal of phosphate in water and wastewater //Science of the Total Environment. – 2018. – Vol. 616. – P. 1242-1260.

DIGITAL TOOLS FOR ENVIRONMENTAL EDUCATION: ENGAGING THE NEXT GENERATION IN SUSTAINABILITY

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Abstract. Environmental education is a critical component of sustainable development, equipping individuals with the knowledge and skills necessary to protect natural ecosystems. Traditional teaching methods, while effective, often fail to fully engage young learners in an era dominated by digital technology. The integration of digital tools such as interactive websites, mobile applications, virtual and augmented reality, online courses, and gamified learning has transformed the way environmental education is delivered. These tools enhance accessibility, interactivity, and engagement while providing real-world connections through live data and citizen science projects. However, challenges such as unequal access to technology, misinformation, and screen fatigue must be addressed to maximize the impact of digital education. The future of environmental education lies in leveraging artificial intelligence, blockchain, and immersive experiences to create adaptive and personalized learning solutions. This paper explores the significance of digital tools in fostering environmental awareness and outlines how educators, students, and organizations can contribute to a more sustainable future.

Keywords: Digital education, sustainability, gamification, virtual reality, augmented reality, citizen science, environmental awareness, artificial intelligence in education, e-learning

Introduction. Environmental education goes beyond traditional classroom instruction; it fosters an ecological mindset that encourages responsible decision-making and sustainability practices. In today's digital age, engaging young learners requires more than textbooks and lectures. Digital tools provide an innovative approach to environmental education, making complex ecological concepts more accessible and engaging [1].

By utilizing interactive platforms, mobile applications, augmented and virtual reality experiences, and gamified learning strategies, educators can transform how students perceive environmental issues. These tools not only enhance understanding but also inspire students to take meaningful action. This paper explores the role of digital tools in environmental education, highlighting their benefits, challenges, and future potential in shaping a new generation of sustainability advocates.

The importance of digital tools in environmental education. The use of digital tools in environmental education is essential for several reasons. First, digital learning resources provide accessibility, allowing students from various geographical locations to engage with environmental content. This is particularly important in remote or underserved regions where traditional educational resources may be limited.

Another key advantage is interactivity. Augmented reality (AR) and virtual reality (VR) offer hands-on experiences that make learning about the environment more immersive. Gamification and storytelling add an additional layer of engagement, making complex ecological concepts easier to grasp. Furthermore, real-world connections are fostered through digital tools that provide access to live environmental data, citizen science initiatives, and virtual field trips.

Key digital tools for environmental education. A variety of digital tools enhance environmental education by providing interactive, engaging, and impactful learning experiences. These include [2]:

– Interactive websites and platforms;
– Mobile applications for sustainability;
– Virtual and augmented reality in environmental education;
– Gamification and serious games;
– Citizen science and community engagement.

Challenges in implementing digital environmental education. Despite the numerous benefits of digital tools, several challenges must be addressed to ensure their effective implementation in environmental education.

One of the primary issues is unequal access to technology. Many students, particularly in low-income communities, do not have reliable internet access or digital devices. This digital divide limits the reach of online environmental education resources.

Another challenge is the spread of misinformation. Digital platforms must ensure that the content provided is scientifically accurate and sourced from credible institutions. Teachers and educators play a crucial role in guiding students toward reliable resources.

Screen time fatigue is also a growing concern. While digital tools can enhance learning, excessive screen exposure can lead to disengagement and physical strain. A balanced approach that combines digital learning with outdoor activities is necessary to maintain student engagement.

Finally, scalability and cost are barriers to widespread adoption. High-quality digital tools, particularly VR and AR applications, require significant investment, making them less accessible to schools with limited funding. Governments and educational organizations must work together to make these technologies affordable and widely available.

The future of digital environmental education. Looking ahead, the integration of artificial intelligence (AI), blockchain, and immersive learning technologies will shape the future of digital environmental education. AI-powered platforms will personalize learning experiences, adapting content to individual students' progress and preferences. Blockchain technology will enhance sustainability tracking, ensuring transparency in environmental efforts. The expansion of VR and AR field trips will further revolutionize how students interact with environmental topics, making learning more immersive than ever before.

As digital tools continue to evolve, the goal should be to create an inclusive and engaging learning environment that empowers individuals to take action for a more sustainable future.

Conclusions. Digital tools have revolutionized environmental education by making learning more accessible, interactive, and engaging. From mobile apps and virtual reality to gamification and citizen science projects, these tools are equipping the next generation with the knowledge and motivation to take action for sustainability. However, addressing challenges such as the digital divide, misinformation, and cost barriers will be essential for maximizing the impact of these innovations.

The future of environmental education lies in innovation, accessibility, and global collaboration. By integrating digital tools effectively, educators, students, and organizations can contribute to a more sustainable world. Now, more than ever, leveraging technology for environmental education is not just an opportunity – it is a necessity for creating a greener, more informed future.

REFERENCES

1. Degteva A., Pange J., Christou P. The use of ICTs for teaching environmental courses in Greece and Russia // Norwegian Journal of Development of the International Science. 2020. №43-3. URL: https://cyberleninka.ru/article/n/the-use-of-icts-for-teaching-environmental-courses-in-greece-and-russia (10.03.2025).
2. Degteva, A., Pange, J., Christou, P. Distance Learning and Internet Use during the Covid-19 Pandemic – The Russian Student Community Opinion // Enhancing the Human Experience of Learning with Technology: New challenges for research into digital, open, distance & networked education. Short Paper Book of the European Distance and E-Learning Network (EDEN) 2020 Research Workshop | Lisbon, 21-23 October, 2020 ISBN 978-615-5511-29-5 (10.03.2025).

ENVIRONMENTAL EFFICIENCY ASSESSMENT OF CHEMICAL PROCESSES BASED ON THE 12 PRINCIPLES OF GREEN CHEMISTRY

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Abstract. The rapid growth of the chemical industry necessitates the development of innovative methods for assessing the safety and environmental efficiency of chemical processes. This paper presents a model for the comparative analysis of chemical processes based on the 12 principles of green chemistry. The model incorporates an informational block, a functional block, and a report output block to streamline assessment. A quantitative evaluation framework was developed using mathematical formulas and specific coefficients, which consider mass indicators and physicochemical parameters of processes producing the same chemical product. This approach enables a systematic comparison of environmental efficiency, contributing to the advancement of sustainable industrial practices.

Keywords: green chemistry, environmental efficiency,chemical processes.

One of the main challenges of modern chemistry is the assessment of the environmental parameters of chemical processes [1] and the integration of this data into a broader context for analyzing the life cycle of chemical products, for which numerous tools are available. Various approaches and criteria are applied for the quantitative evaluation of the environmental performance of chemical processes. The choice of assessment method largely depends on the specific objectives of process optimization and the area of application, making it difficult to develop a universal algorithm suitable for different sectors of the chemical industry and scientific-educational activities [2].

Nevertheless, various methods and tools have been developed to meet specific user needs. These tools utilize well-known indicators, such as Process Mass Intensity (PMI), Environmental Factor (E-factor), and target product yield, to evaluate the efficiency of chemical processes, ensure the safety of reagents, and minimize the use of toxic substances. Furthermore, new indicators are being introduced, such as Eco-Scale, GAPI (Green Analytical Procedure Index), and AGREE (Analytical Greenness Metric Calculator) in analytical chemistry, as well as iGAL (Innovation Green Aspiration Level), AMGS (Analytical Method Greenness Score), and eco-labeling in pharmaceutical chemistry [3].

The Green Chemistry Metrics (GCM) toolkit is successfully used to raise awareness of the concept of green chemistry in educational processes [4]. Additionally, active efforts are being made to develop automated algorithms based on this method, which can be utilized by chemical raw material manufacturers and researchers in the planning of chemical synthesis. This methodology for assessing the compliance of chemical processes with the principles of green chemistry was developed by a team of scientists from the American Chemical Society. The approach includes specific algorithms for each of the 12 principles of green chemistry, based on chemical data available from various sources, including the Globally Harmonized System of Classification and Labeling of Chemicals (GHS) database.

In this study, this method is utilized to develop a new algorithm aimed at improving the assessment and optimization of chemical processes in accordance with green chemistry principles. The scores calculated for each principle are used to evaluate alternative processes, and a ranking strategy is applied to eliminate uncertainty when comparing aggregated data due to different measurement scales [5].

The design stage includes the development of the software architecture and the creation of mathematical algorithms with a focus on the efficient use of computational resources. The user interface is designed with particular attention to intuitiveness and high-quality data visualization. During the implementation of this stage, a flowchart of the program's conceptual framework was developed (Figure 1), incorporating architectural blocks as well as blocks for data output and visual interpretation [6].

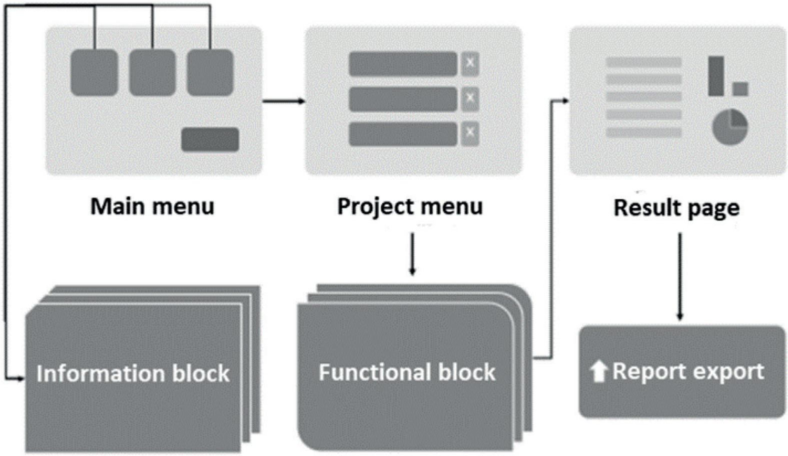

Figure 1. Block diagram of the software functionality (developed by the author)

The "Green Chemistry Metrics" methodology was used as the basis for developing mathematical algorithms to assess the compliance of chemical processes with the principles of green chemistry. This methodology considers mass indicators, substance hazard factors for humans and the environment, as well as energy consumption parameters. The original formulas of this methodology were modified and adapted to enable the use of data from regulatory documents of the Russian Federation, including GOST 32419-2022: Hazard Classification of Chemical Products. General Requirements. For example, the formula for Principle 1, "Waste Prevention," is as follows:

$$\frac{\sum_i^n (m_{waste} \times HC_{waste})}{m_{product.}}, \text{ where}$$

m_{waste} – mass of substances produced during the synthesis process that are not desired for the specific process (excluding water);

HC_{waste} – hazard coefficient of the waste;

$m_{product}$ – mass of the desired substance that the process aims to produce.

REFERENCES

1. Sajid M, Płotka-Wasylka J. Green analytical chemistry metrics: a review. // Talanta 2022, 238:123046. DOI: https://doi.org/10.1016/j.talanta.2021.123046 (10.03.2025).
2. Rogers L, Jensen KF: Continuous manufacturing – the green chemistry promise. // Green Chem. – 2019. – 21:3481–3498. https:// doi.org/10.1039/C9GC00773C (10.03.2025).
3. Sheldon R.A.: Metrics of green chemistry and sustainability: past, present, and future // ACS Sustain Chem Eng. – 2018, – V.6. – Is.1. pp. 32–48. DOI: https://doi.org/10.1021/acssuschemeng.7b03505 (10.03.2025).
4. Kyle M. D. Reyes, Kyla Bruce, Shegufta Shetranjiwalla. Green Chemistry, Life Cycle Assessment, and Systems Thinking: An Integrated Comparative-Complementary Chemical Decision-Making Approach // Journal of Chemical Education. – 2023. – V. 100 (1). pp. 209-220. DOI: 10.1021/acs.jchemed.2c00647 (10.03.2025).
5. Tolstov M.A., Zanin A.A. Computational approach for assessing chemical processes according to the principles of green chemistry // Proceedings of the XVI International Scientific and Practical Conference dedicated to the 300th anniversary of the Russian Academy of Sciences. In 2 parts. Part 1: Sections “Materials for Energy Production, Conversion and Storage”. “Green Chemistry for Sustainable Development: from Fundamental Principles to New Materials”. – 2024. – pp. 250-253.
6. Tolstov M.A., Zanin A.A. Computational approach to assessing compliance of chemical processes with principles of green chemistry. // XXII Mendeleev congress on general and applied chemistry dedicated to the 190th anniversary of D.I. Mendeleev and the 300th anniversary of the Russian Academy of Sciences. Book of abstracts. – 2024. – V.2. – P. 220.

METHODS FOR THE ANALYSIS OF POLYMERIC SULFUR SYNTHESIZED USING HIGH ENERGY CHEMISTRY

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Abstract. The current stage of development of chemistry tends to use green chemistry methods in laboratory and industrial processes. As a result, improving the safety of the substances used and the processes implemented should contribute to the achievement of the Sustainable Development Goals, which is a global task for the entire world community. The paper considers a method for obtaining polymeric sulfur (sulfur-containing polymers) using high-energy chemistry, namely the effect of accelerated electrons. The paper also considers various methods of physicochemical analysis that can be used to study the obtained sulfur-containing polymers.

Keywords: sulfur, green chemistry, energy efficiency, Sustainable Development Goals.

The concept of sustainable development aims to meet the needs of the present without compromising the ability of future generations to meet their own needs. In 2015, the United Nations adopted 17 Sustainable Development Goals (Figure 1), including Goal 12: Ensure sustainable consumption and production patterns. Green chemistry, aimed at developing chemical processes and products that minimize the use and formation of harmful substances, reduce the negative impact on the environment and promote sustainable development, can act as an effective tool for achieving the Sustainable Development Goals [1].

Among the principles of green chemistry, one can mention the principle of energy efficiency (preference for reactions at room temperature and pressure), the principle of safety (use of substances that are safe for humans and the environment). Based on these principles, it was proposed to use such a method of high-energy chemistry as irradiation with accelerated electrons for the polymerization of elemental sulfur, which is safer than the use of radionuclides as radiation sources [2]. High-energy chemistry plays an important role in various scientific and industrial fields, including materials science, nuclear energy, aerospace industry, etc.

Accelerated electron irradiation does not require high temperatures and pressures, and does not involve the use of radionuclides as sources of high-energy radiation, which increases the safety of the process.

Electron accelerators are based on the principle of using electric fields to increase the speed of electrons, which can then be used in scientific research, medical diagnostics, material processing, and other areas. Electron accelerators can be of various types, including linear accelerators and cyclic accelerators [3]. Electron accelerators are used to polymerize coatings on the surface of materials, create durable and lightweight materials for the aerospace and automotive industries, sterilize biocompatible materials, and manufacture thin films and insulating materials. This approach is highly environmentally friendly due to the absence of harmful chemicals.

Figure 1. Sustainable Development Goals

Polymer sulfur is of great importance in chemistry, materials science and industry because polymer sulfur has unique properties such as high strength and heat resistance.

Elemental sulfur samples were irradiated on the electron accelerator “Elektronika” UELV-10-10-S-70 with a magnetron MI-470 (CJSC “INTECH”, Novovoronezh), the electron energy was 7 MeV [4]. To increase the efficiency of polymerization, various cross-linking agents were also used. The complex composition of the resulting substances requires that considerable attention be paid to various methods of physicochemical analysis to determine the composition and properties of the polymerization products.

Let us consider these methods, which allow us to study the structure, composition and properties of sulfur at different stages of polymerization [5].

One important research method could be differential scanning calorimetry (DSC), that is, measuring thermal effects (heat absorption or release) during sulfur polymerization, but conducting such studies under accelerated electron irradiation conditions can be technically difficult.

X-ray diffraction (XRD) allows the structure of sulfur to be investigated at different stages of polymerization, identifying different phases (e.g. S_8, S_6, polymer chains) and their changes.

The composition of the obtained sulfur-containing polymers can be determined using infrared spectroscopy (IR spectroscopy), Raman spectroscopy and mass spectroscopy, which allows studying its molecular structure. Nuclear magnetic resonance (NMR) allows studying the local environment of sulfur atoms, which shows the possibility of incorporating other elements into the polymer structure. The use of scanning and transmission electron microscopy (SEM, TEM) allows visualizing the morphology of sulfur at the micro- and nanolevel, shows the formation of fibers or films of polymer sulfur.

Rheological analysis, including determination of viscosity and study of the mechanical properties of sulfur during polymerization, allows us to evaluate the change in the properties of the material during the transition to the polymer form.

To conduct the listed studies of elemental sulfur, it is proposed to use the equipment of the D. I. Mendeleev Center for Collective Use.

REFERENCES

1. U.P. Ogodo, O.O. Abosede. The Role of Chemistry in Achieving Sustainable Development Goals: Green Chemistry Perspective // International Research Journal of Pure and Applied Chemistry. – 2025. – V.26.– pp. 1–8.
2. N.P. Tarasova, A.A. Zanin, P.S. Sobolev, E.G. Krivoborodov, P.I. Shlyakhov. Green chemistry within planetary boundaries: examples of phosphorus and sulfur polymers // 10th IUPAC International Conference on Green Chemistry Abstracts. Beijing. – 2024. – pp. 202–203.
3. J. Yuan, G. Zhang, S. Pang, T. Chen, J. Huang. Study and Design of an Energy Monitoring Device for an Industrial Electron Accelerator Using Monte Carlo Simulation // Radiation Physics and Chemistry. – 2023. – V. 206. – 110808.
4. S.E. Karavaev, N.A. Ksenofontov, A.A. Zanin, N.P. Tarasova. Synthesis of Polymer Forms of Phosphorus Under the Influence of Accelerated Electrons // XXII Mendeleev Congress on General and Applied Chemistry. – 2024. – P. 404.
5. L. Jiang, R. Kong, Y. Yi, S. Yang, Y. Me, X. Feng, Z. Yao, J. Zhang. Direct Introduction of Elemental Sulfur into Polystyrene: A New Method for Preparing Polymeric Materials // Polymer. – 2019. – V. 180. – 121715.

PLANT GERMINATION AS AN INDICATOR OF SOIL POLLUTION WITH HEAVY METALS

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Abstract. Pollution of natural environments with heavy metals (HMs) is a pressing global issue, with lead, cadmium, copper, and other HMs becoming persistent components of urban and industrial air. These pollutants, emitted from metallurgical plants, thermal power stations, and highways, can travel long distances before settling on soil and vegetation. Soil acts as both a source and a filter for HM pollution, impacting agricultural productivity and public health through dust dispersion. This study explores the use of vegetation as a bioindicator for soil contamination by mobile forms of HMs. A model experiment was conducted using soil from the Upper Bolshaya Sestry River Nature Reserve, uncontaminated by anthropogenic or natural HM sources. HMs (chromium, lead, cadmium) were introduced in concentrations equivalent to 1–50 maximum allowable concentrations (MACs) for acidic loams and clays. Oats, watercress, arugula, barley, and wheat were sown to assess germination rates and HM bioindication potential. The study identified concentration-dependent germination responses and established ranges for effective bioindication. This research contributes to developing methods for monitoring and assessing environmental pollution, supported by the R&D framework of the Russian Hydrometeorological Service.

Keywords: heavy metals, soil pollution, bioindicators, environmental monitoring, agricultural soils, mobile forms of heavy metals, pollution assessment, geochemical barrier.

Plant germination serves as a vital indicator of soil pollution with heavy metals, as the presence of these toxic elements can significantly impair seed viability and growth. Heavy metals such as lead, cadmium, and arsenic can disrupt physiological processes in plants, leading to reduced germination rates, stunted growth, and altered biochemical responses. By assessing the germination success and subsequent development of various plant species in contaminated soils, researchers can gauge the extent of heavy metal pollution and its potential ecological impacts. This bioassay approach not only highlights the toxicity levels of the soil but also provides insights into the broader implications for food safety and ecosystem health, underscoring the need for effective soil management and remediation strategies.

Pollution of natural environments with heavy metals (HM) is one of the main problems of our time. Lead, cadmium, copper, nickel, zinc, chromium, vanadium, etc. have become almost constant components of the air of industrial centers and urban agglomerations [1]. Dispersed with emissions and dust from metallurgical and mining enterprises, thermal power plants, highways, etc., HM can be transported over significant distances, after which they settle on vegetation and soil [2].

Soil in the context of HM can be both a primary or secondary source of pollution, and a filter or geochemical barrier capable of accumulating HM [1]. Pollution of agricultural soils with HM is often accompanied by a redistribution of their forms of occurrence and accumulation of vegetation, and pollution of soils of urban agglomerations affects the health of the population due to the rise of soil dust [3].

In this work, the possibility of using various types of vegetation as a bioindicator of soil pollution with mobile forms of heavy metals was considered. For this purpose, a model experiment was conducted.

The model experiment was conducted using soil sampled in the territory of the Upper Bolshaya Sestry River Nature Reserve, located far from both anthropogenic and natural sources of heavy metal pollution. Heavy metals were added to the soil in the form of aqueous solutions of their salts (chromium sulfate (III), lead nitrate (II), cadmium chloride (II)) in quantities equivalent to 1, 2, 5, 10, 25 and 50 MACs of these heavy metals in pure form for acidic loams and clays (in accordance with SanPiN 1.2.3685-21). After introducing HM into the soil, oat (*Avena sativa L.*), watercress (*Lepidium sativum L.*), arugula (*Eruca sativa Mill.*), barley (*Hordeum vulgare L.*) and wheat *(Triticum aestivum L.*) seeds were sown into it (Fig. 1).

Figure. 1. Wheat (*Triticum aestivum L.*)

The experiment helped to establish specific dependencies of the germination parameter of the plants used on the concentrations of mobile forms of HM, as well as to determine the range of concentrations in which the proposed plants can be used for bioindication. Data on the germination of wheat seeds were obtained Fig. 2.

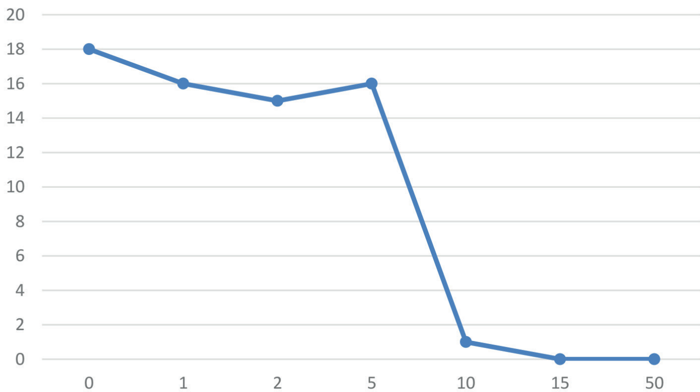

Figure. 2. On the vertical axis, the number of germinated wheat seeds on the horizontal axis, the MPC values

The research was partially carried out within the framework of the R&D topic “Development and modernization of methods and technologies for integrated background monitoring and integrated assessment of the state and pollution of the environment of the Russian Federation and its dynamics (based on integrated results of monitoring networks of the Russian Hydrometeorological Service)”.

REFERENCES

1. Bekuzarova S. A. Plants-indicators of soil pollution with heavy metals // Advances in modern science. – 2017. – Vol. 1. – No. 9. – P. 111-115.
2. Kizilov O. A., Baikin Yu. L., Ovchinnikov P. Yu. Application of mineral sorbents for soil pollution with heavy metals// Bulletin of biotechnology. – 2017. – No. 1 (11). – P. 16.
3. Mazhaisky Yu. A., Evtyukhin V. F., Guseva T. M. Effect of heavy metal pollution of soil on its properties and environmental indicators // Sergeev readings: Anniversary conference dedicated to the 100th anniversary of the birth of Academician E. M. Sergeev. Proceedings of the annual session of the Scientific Council of the Russian Academy of Sciences on the Problems of Geoecology, Engineering Geology and Hydrogeology, Moscow, March 21, 2014. – Moscow: Peoples’ Friendship University of Russia. – 2014. – V. 16. – P. 438-442.

ASSESSMENT OF THE LEVEL OF METAL POLLUTION BY THE WATERS OF THE MOSCOW RIVER: ENVIRONMENTAL RISKS AND SOURCES OF POLLUTION

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Abstract. River pollution can be classified into several types, each with its own sources and consequences. The first type is chemical pollution caused by the discharge of wastewater from industrial enterprises such as factories and plants, which often discharge heavy metals, oil products and chemicals into the river, which leads to deterioration of water quality. The second type is biological pollution caused by the discharge of untreated or insufficiently treated wastewater containing pathogenic microorganisms, which poses a threat to human health and the ecosystem. The third type is physical pollution, including the presence of garbage and plastic waste that accumulate in the riverbed and impede the movement of water, as well as negatively affect flora and fauna. Finally, an important aspect is noise pollution caused by transport and construction along the banks, which also affects the river ecosystem. All these types of pollution require a comprehensive approach to solving the problem and active measures to protect water resources.

Keywords: heavy metals, sources of pollution, the Moscow River.

The UNESCO Department of "Green Chemistry for Sustainable Development" of the Mendeleev Russian State Technical University has long been investigating the sources of pollution of urban areas and, in particular, water resources [1]. Pollution of the Moscow River is a serious environmental problem caused by a combination of factors such as wastewater discharge, industrial pollution and illegal dumping. For many years, the river has suffered from pollution by chemicals, heavy metals and organic waste, which negatively affects the ecosystem and public health. Despite efforts to clean and restore the water bodies, including projects to modernize treatment facilities and improve water quality, the river still needs a comprehensive approach to solving the problem, including raising public awareness and monitoring compliance with environmental standards.

Monitoring river water pollution is an important task for ensuring environmental safety and sustainable use of water resources. Heavy metals (HM) play a special role among other water pollutants due to their unique properties and potential danger to living organisms and the ecosystem as a whole. In view of this, it is necessary to determine the degree of river water pollution and assess potential sources of pollution.

To assess the content of heavy metals, field studies were conducted at several sections of the river. For this purpose, 3 sampling points were selected (Fig. 1). Water samples were collected in different seasons of the year in sterile plastic tubes, after which they were subjected to laboratory analysis using atomic absorption spectrometry.

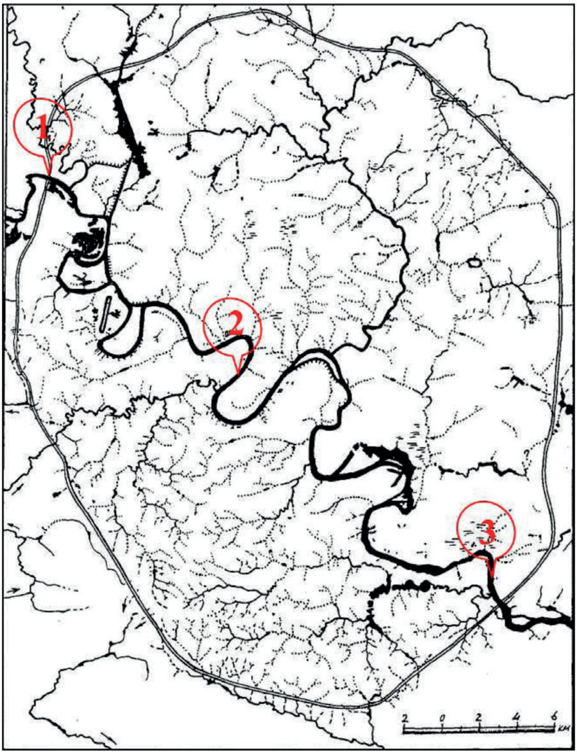

Figure. 1. Sampling points on the Moscow River [2]

The analysis showed a slight excess of permissible concentrations of a number of heavy metals, such as copper and manganese, especially in the area of large industrial enterprises and transport hubs. Wastewater in urban conditions contains a wide range of pollutants, among which may be copper compounds, for example, household chemicals, paints – all this can contain traces of copper and manganese, the second is contained in minerals and rocks that are found in the geological layers of the Moscow River basin [3]. Sewage systems and treatment facilities are not always able to effectively remove these pollutants, which is confirmed by the city administration. It is also worth noting the high wear of treatment facilities, most of which were built in the 60-70s of the last century. Under the influence of the environment, copper gradually dissolves and enters the reservoir through rainwater and groundwater (Table 1.). Thus, the study emphasizes the need for further ongoing control and monitoring of the content of heavy metals in the Moscow River.

Table 1

HM content (mg/l) in the Moscow River

Sampling point / date	Cu	Mn	Fe	Zn
1 / 05.04.24	0,0008	**0,0281**	0,0485	0,0019
2 / 03.04.24	0,0013	0,0073	0,0263	0,0025
3 / 10.04.24	**0,0024**	<0,0034	<0,0062	0,0049
1 / 30.07.24	<0,0005	0,0099	0,0158	0,0013
2 / 31.07.24	<0,0005	0,0090	0,0128	<0,0005
3 / 02.08.24	0,0019	0,0056	0,0175	0,0040
1 / 08.10.24	<0,0005	0,0056	0,0194	0,0008
2 / 10.10.24	<0,0005	0,0055	0,0089	<0,0005
3 / 10.10.24	**0,0026**	0,0088	0,0262	0,0036

REFERENCES

1. Muradyan S.A., Kuznetsov V.A. Assessment of the danger of soil salinization in urbanized areas based on the analysis of snow cover. XIII Russian Scientific and Practical Conference «Education and Science for Sustainable Development», Moscow. Mendeleev University of Chemical Technology of Russia. – 2021. – V. 1. – P. 73-78.
2. Nasimovich Yu.A. Annotated list of names of rivers, streams and ravines of Moscow. Russian Research Institute for Nature Conservation of the Ministry of Natural Resources of the Russian Federation. – Moscow. – 996. – 114 p.
3. Evseev A.A. Atlas for the mineralogist. Russia and the former USSR. – M.: Association Ecost. – 2011. – 284 p.

DETERMINATION OF THE ACTIVITY OF CHEMICAL COMPOUNDS OF THE AQUEOUS EXTRACT OF SUMAC (*RHUS CORIARIA L.*)

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Abstract. The aim of the study is to evaluate the efficacy of aqueous sumac (Rhus coriaria) seed extract in the growth and inhibition of some pathogenic fungi and identify the chemical compounds contained in the extract by analyzing the extract. Plants are a major source in many industrial, medicinal and agricultural applications due to the production of many chemical compounds which are secondary metabolites of plants, as opposed to those found in pharmaceutical compounds and chemical pesticides. The objective of this study is to determine the phytochemical separation of Rhus coriaria seed extract using GC-Mass technology and the role of these compounds as biological control agents in inhibiting the growth of some fungi that infect plants, especially field crops. GC-Mass analysis showed the presence of many chemical compounds such as eneicosane, ethyl phthalate, docosane, tetratriacontane, eicosane, docosane, heptacosane, 5,6-benzoquinoline, silicic acid, diethylbis(trimethylsilyl)ester, oxasiloxane and hexadecamethyl. This study investigated the effect of different concentrations of aqueous extract of Rhus coriaria sumac seeds. plant on the growth of phytopathogenic fungi.

Keywords: Sumac, GC-mass analysis, chemical compounds, phytopathogens.

Introduction. *Rhus coriaria.L.* belongs to the plant family (Anacardiaceae), commonly called sumac due to its strong antibacterial activity. *Rhus coriaria* is an edible medicinal herb endemic to Journal Pre-proof 6 Mediterranean regions, widely known and used as a spice in cooking. The fruits are the main part of the sumac plant consumed by humans [1]. Sumac (*Rhus coriaria* L.) is the only native species of the genus Rhus in Iraq. The natural distribution of the genus is in the Mediterranean and North Africa, as well as Iran, the Caucasus and Central Asia [2]. As for the root of the word, some believe that it is derived from "Sumaga" in Syriac, which often means "red" [3]. More than 200 compounds have been identified and labeled from the plant *Rush coriaria*, most of which are associated with medicinal activity [4]. Sumac contains many chemical compounds including a number of Some of these compounds are of medicinal importance including phenolic compounds as sumac contains approximately 15–20% polyphenolic compounds most of which are classified as tannins. In addition to the presence of gallic acid in small amounts which is one of the simple phenolic compounds [5], Among the phenolic compounds that sumac also contains are 4-methoxy-3,5- and methyl gallate dihydrobenzoic acid [6]. The toxicity of a phenolic compound to microorganisms depends on the location and amount of this group or hydroxyl groups attached to the aromatic ring. The greater the number of hydroxyl groups, the higher its toxicity. Phenolic compound for microorganisms [7]. Sumac has been known on the surface of the globe since ancient times, so that its fruits have been preserved as fossils since the Middle Dialogue period, but in our modern era, about 120 species of sumac have been discovered, spontaneously distributed in dry calcareous earths or calcareous silts, and sandy-calcareous, from hot, subtropical and temperate regions surrounding the Mediterranean basin, southern France (lower and central part of the coastal Alps), southern Italy (Sicily), northern Africa (Egypt and Algeria), western Asia (Sinaia, Palestine) and especially in the Salfit region, southern Lebanon and Syria, northern Iraq. Sumac contains many antioxidants that help reduce damage caused by oxidative stress in the body and protect cells from damage. Below are some of the antioxidants and bioactive compounds found in sumac that are responsible for its beneficial properties [8].

Materials and Methods. Followed method of Harbon (1984) for the preparation of aqueous extracts of sumac seeds. 20 grams of dry weight of the plant (sumac seeds) were sterilized with 1% sodium hypochlorite solution, dried with filter paper, then dried by placing them in an electric oven at 50 degrees Celsius and ground with an electric mill. The resulting powder was stored in sterile glass jars until used in the preparation of the aqueous extract. and placed in a 500 ml glass beaker containing 200 ml of distilled water. The plant material was then stirred with an electric mixer on a hot plate for 30 minutes and the solution was left for 30 minutes. After that, it was filtered with filter paper to separate large plankton and the filtrate was transferred to a centrifuge. A Hera-type centralizer at a speed of 3000 rpm for 10 minutes to precipitate the smallest phytoplankton and obtain a finely dispersed plant extract [9].

Results and Discussion. The present results revealed the bioactive components present in sumac seed extract using gas chromatography-mass spectrometry (GC-MS). Table 1 and Figure 1, expressed in terms of retention time (RT) and concentration (percentage of peak area), show the presence of 10 bioactive phytochemical compounds in sumac seed extract belonging to specific compound groups. Among the identified phytochemicals were: a white, waxy, saturated crystalline hydrocarbon solid, a teratogenic agent, alkane 87, a long-chain alkane, a hydrocarbon used in the petrochemical industry, alkane 91, heptocosan 91, 5,6-benzoquinoline, silicic acid, and octasiloxane (hexadecamethyl). The analysis results were similar to those of the 10 chemical compounds identified by GC-MS. Several chemical compounds were identified. [10].

Table 1 shows the chemical components of sumac seed extract, which were identified by mass spectrometry and gas chromatography in terms of specificity, peak area, peak time, and percentage, as detailed in the table below, also appeared in the spectroscopic analysis. The results of this analysis are also consistent with Al-Kabaili [11].and Saba Shahrivari [12].

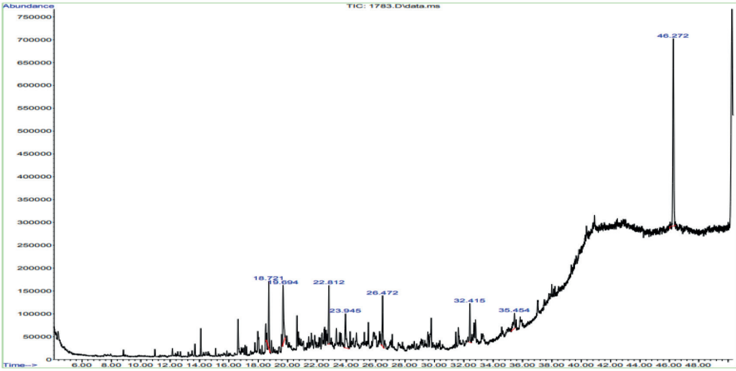

Figure 1. GC-MS chromatogram of aqueous extract of Rhus coriaria seeds

Table 1

Results of spectral analysis using GC-MS chromatogram of aqueous extract of Sumac seeds

No	RT (min)	Area (Ab*s)	Area %	Name of Chemical compounds	Qua-lity	CAS Number
1	18.791	2865297	9.58	Heneicosane	91	000629-94-7
2	19.946	3323938	11.34	Ethyl phthalate	96	000084-66-2
3	22.831	4038663	13.98	Docosane	87	000629-97-0
4	23.556	2440268	8.93	Tetratriacontane	90	014167-59-0
5	26.467	3673402	14.02	Eicosane	93	000112-95-8
6	27.31	2017958	6.49	Docosane	91	000629-97-0
7	29.768	2109716	10.03	Heptacosane	91	000593-49-7
8	32.471	2486251	8.55	5,6-Benzoquinoline	38	000085-02-9
9	39.526	2202990	7.85	Silicic acid, diethyl bis(trimethylsilyl) ester	43	003555-45-1
10	46.72	3920045	3.80	Octasiloxane, hexa-decamethyl	72	019095-24-0

Conclusion/ We conclude that it is possible to use the aqueous extract as an alternative or auxiliary biopesticide to control pathogens affecting plants and field crops because it contains chemical compounds that have an effective antifungal function. According to the above analysis to determine the chemical compounds of the extract, sumac is also considered to be an inexpensive and environmentally friendly plant compared to commercial chemical pesticides used to control pathogens.

REFERENCES

1. Abdul-Jalil, T.Z., 2020. *Rhus coriaria* (Sumac): The magical spice, in: Akram, M., Ahmad, R.S. (eds.), Herbs and Spices. IntechOpen, pp. 39–52. https://doi.org/10.5772/intechopen. 92676".
2. Sahr. K., S. El-Khatib., 2020. Physicochemical properties and medicinal, food and industrial applications of Lebanese sumac (Syrian sumac – *Rhus coriaria*): a review Heliyon, 6 (1), article e03207, 10.1016/ j. heliyon. e03207.
3. Nasar-Abbas, S. M., Halkman, A. K. and Al-Haq, M. I. Inhibition of some food bacteria by ethanol extract of sumac (Rhus coriaria L.). J. Food Saf. 24, 2004. 257–267
4. Abu-Reida, I. M., Jamous, R. M. and Ali-Shtaeh, M. S., 2014. Phytochemistry, pharmacological properties and industrial applications of *Rhus coriaria* L. (Sumac). Jordan J. Biol. Sci. 7, 233–244
5. Van Loo P., De Bruijn A., 1988. On the liquid chromatographic identification of flavonoids present in "sumac tannic acid" extracted from *Rhus coriaria*, 25(1).
6. Raine S., Mazza G., 2007. Plant Foods from Human Nutrition, 62(4), 165.
7. Ghazwan TN., 2008. Antibacterial Activity of Extracts of Two Phenolic Compounds from Sumac Plant, Department of Life Sciences/College of Education – University of Basra – Issue 34 Vol 2., Iraq. 2695– 1817– ISSN
8. Farzad S., Seyedeh TR, Asadollah R., et al., 2014. "Effect of sumac (*Rhus coriaria* L.) powder on serum glycemic status, ApoB, ApoA-I and total antioxidant capacity in type 2 diabetes patients", Iranian Journal of Pharmaceutical Research, Issue 4, Vol.13, Page 1249-1255
9. Harbon JB., 1984. Phytochemical Methods. Handbook of Modern Plant Analysis Methods. 2nd. Ed. London, New York, Press., New York, San Francisco.
10. Nafiseh F., F Sotoudegan, A. A. Sepahy, M. R.Fazeli., 2024. Antibacterial and antioxidant properties of sumac aqueous extract on methicillin-resistant *Staphylococcus aureus*. Research square. DOI: 10.21203/ rs.3.rs-3980124/v1

11. Al-Kabaili. M, Muhammad. T, and S. Al-Maghribi., 2017. Isolation of tomato wilt fungus *Fusarium oxysporum* and the effect of some of its isolates on tomato plant growth. Journal of Al-Baath University, 39:11.
12. Saba Shahrivari, Saeed M. Saeed Zebari, Saeed Alizadeh-Salteh, Hadar S. Feizi ,Mohammad Reza Morshedloo., 2014. Phytochemical variations in antioxidant and antibacterial activities among Zebaria sumac (*Rhus coriaria* var. zebaria) populations in Iraq., Published online doi: 10.1038/s41598-024-53635-7.

GENETIC MARKERS OF WHEAT QUALITY: THE ROLE OF GLU AND GLI GENES IN ENHANCING SPRING SOFT WHEAT BREEDING IN KAZAKHSTAN

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Abstract. The quality of wheat grain is a key priority for Kazakhstan's agricultural sector, as the country is one of the active producers and exporters of strong wheat. The protein-gluten structure of the grain, which determines the baking properties of flour, largely depends on the Gli (gliadins) and Glu (glutenins) genes. The introduction of molecular genetic marker-assisted selection methods, in turn, opens new opportunities for wheat breeding in this direction, allowing for precise identification of beneficial gene alleles responsible for high grain quality.

However, in Kazakhstan, the application of these technologies faces several large-scale implementation limitations, including the introduction of comprehensive genetic research at the regional level, a shortage of specialists in this field within the country's breeding centers, and the need for more extensive technical support. Despite the extensive study of these wheat quality genes, breeding material must be continuously expanded, including through the introduction of foreign genotypes, necessitating their screening and the search for donor varieties carrying the desired genetic information.

This review examines the significance of Gli and Glu genes for the quality of spring soft wheat, as well as the still relevant prospects for their use in Kazakhstan's breeding practices. It analyzes key issues in the country's agricultural sector related to grain quality and discusses the potential of molecular marker-assisted selection as a tool for targeted breeding. The use of molecular markers in wheat breeding enhances selection efficiency, enabling the development of varieties with the most successful combinations of target genes that meet the high standards of the global market, ultimately increasing Kazakhstan's export potential as a supplier of high-quality grain.

Keywords: wheat, grain quality, Glu and Gli genes, molecular markers, breeding, Kazakhstan.

Introduction. Wheat is a strategically important crop for Kazakhstan, which ranks among the world's leading grain exporters.

The dynamics of grain exports show a stable growth in the period 2019-2023: in 2019, more than 5.2 million tons of grain were exported to 26 countries, in 2021 the export volume increased to 5.7 million tons, and in 2023 reached a peak of 7.2 million tons. At the same time, there is a temporary decline in exports in 2024 – in eight months, they amounted to only 3.1 million tons, which is 1.6 times less than in the same period of the previous year (see Figure). The number of importing countries has also decreased to 12 [1].

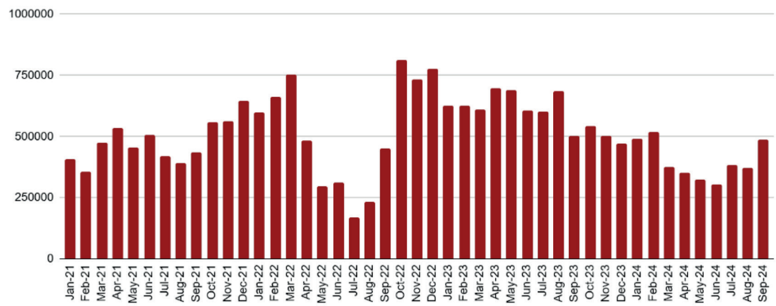

Figure. Wheat exports in tons

The decline in export performance is due to several factors. In 2023, Kazakhstan's agricultural producers faced unfavorable weather conditions that resulted in lower grain yields and quality. Of the total harvest of 12.1 million tons, about 40% did not meet quality standards, and 35% was classified only as Class 3 grain. But in general, Kazakh wheat remains competitive in the international market, although it needs breeding improvement to meet the requirements of production and climate change [2].

So, the quality of flour is directly related to the protein and gluten structure of the grain, the main components of which are glutenins and gliadins [3,4]. These proteins form gluten, which has a determining influence on the rheological properties of dough and the final characteristics of baked goods. High gluten content and an optimal ratio of gliadins and glutenins improve the elasticity and flexibility of dough, which is especially important for baking and pasta production.

The role of Gli and Glu genes in the formation of grain quality. Modern methods of molecular genetic labeling make it possible to significantly increase the efficiency of the breeding process by identifying genetic determinants of grain quality at early stages of selection. The Glu and Gli genes are of particular importance here [5–7]:

• Glu – encodes the high molecular weight glutenin subunits responsible for the structure and elasticity of gluten. These proteins are critical to the elasticity of dough, its ability to retain gases during fermentation and to create an optimal structure during baking.

• Gli – encodes gliadins, which ensure the extensibility of gluten. Gliadins play a key role in improving the texture of the dough, giving it the necessary softness and extensibility, which is of paramount importance for the production of high-quality bakery and pasta products.

Allelic variants of these genes affect baking properties. For example, allelic variants of *Glu-1* and *Glu-3* are associated with dough properties and bread baking quality [8], while *Gli-A2* genes affect gluten extensibility [9]. The optimal combination of these alleles provides the balanced rheological characteristics necessary to produce high-quality products.

Prospects for application of molecular markers in wheat breeding in Kazakhstan. Application of marker-assisted selection (MAS) is a promising approach to accelerate the development of new varieties of spring soft wheat with improved quality characteristics. This method allows:

1. Identify genotypes with favorable combinations of alleles of Gli and Glu genes at early stages of the breeding process.
2. Reduce the time and material costs of traditional phenotypic testing.
3. Improve the accuracy of selection by a complex of grain quality traits.
4. Targeted combination of alleles determining high baking properties with genes for resistance to abiotic and biotic stresses [10].

The introduction of molecular genetic approaches will make it possible to create competitive varieties that meet the high requirements of the world market.

Conclusion. Identification of Gli and Glu genes in the creation of new wheat source material accumulating in its genetic composition qualitative characteristics of grain is an actual direction of research that can increase the accuracy of selection. The development of domestic breeding on the basis of molecular genetic markers will allow not only to ensure consistently high quality of grain, but also to strengthen the position of Kazakhstan in the world market as a supplier of high quality wheat.

REFERENCES

1. Shamsutdinova Zh. Golden grain: what is happening to Kazakhstan wheat export. Infographics // LSM.KZ. – 2024. C. 1-2 [in Russian]
2. Smailov A. The year was very difficult: Smailov on the decline in yields // Tengrinews.kz. – 2023. C. 1-2 [in Russian]
3. Orlovskaya O.A. et al. Grain quality in bread wheat lines T. aestivum with introgression of genetic material T. dicoccoides and T. dicoccum // Dokl. Akad. nauk. 2019. Vol. 62, № 6. P. 712-718.
4. Delcour J.A. et al. Wheat Gluten Functionality as a Quality Determinant in Cereal-Based Food Products // Annu. Rev. Food Sci. Technol. 2012. Vol. 3, № 1. P. 469-492.
5. Li Y. et al. High-Molecular-Weight Glutenin Subunits: Genetics, Structures, and Relation to End Use Qualities // IJMS. 2020. Vol. 22, № 1. P. 184.
6. Anjum F.M. et al. Wheat Gluten: High Molecular Weight Glutenin Subunits-Structure, Genetics, and Relation to Dough Elasticity // Journal of Food Science. 2007. Vol. 72, № 3.
7. Pourmohammadi K., Abedi E., Hashemi S.M.B.. Gliadin and glutenin genomes and their effects on the technological aspect of wheat-based products // Current Research in Food Science. 2023. Vol. 7. P. 100622.
8. Guzmán C. et al. Effects of glutenins (Glu-1 and Glu-3) allelic variation on dough properties and bread-making quality of CIMMYT bread wheat breeding lines // Field Crops Research. 2022. Vol. 284. P. 108585.
9. Noma S. et al. Contribution of α-gliadin alleles to the extensibility of flour dough in Japanese wheat cultivars // Journal of Cereal Science. 2019. Vol. 86. P. 15–21.

10. Khlestkina E.K., Wheatnikova T.A., Usenko N.I., Otmakhova Y.S. Prospective opportunities for the use of molecular genetic approaches in wheat breeding // Vavilov Journal of Genetics and Breeding. – 2016. – T. 20, № 1. – C. 10-17. [in Russian]

Научное издание

Международный молодежный форум
«РОССИЯ-АЗИЯ: КАДРОВЫЙ ПОТЕНЦИАЛ АТОМНОЙ ОТРАСЛИ РЕГИОНА»

На английском языке

Издание подготовлено в авторской редакции

Главный редактор Д. В. Дерновой
Компьютерная верстка С. С. Ламан
Корректор О. В. Якубова

Подписано в печать 13.03.2025. Формат 60/90 1/16.
Бумага офсетная. Печать офсетная.
Объем 7 п.л. Тираж 1000 экз. Заказ № 1151.

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