Volume 9, Issue 12, December – 2024 International Journal of Innovative Science and Research Technology
ISSN No:-2456-2165 https://doi.org/10.5281/zenodo.14631782

The Possibilities of Using Computer Programmes in the Study of Nuclear Processes in the Science of Nuclear Power Engineering

Ramazanov Asror Khamroevich
National University of Uzbekistan Named after Mirzo Ulugbek.
University Street, 4, 100174, Tashkent

Abstract:- In the article, the rapid development of computer technology has significantly transformed various fields of science, including nuclear energy. In the study of nuclear processes, computer programs offer powerful tools for simulating, modeling, and analyzing complex phenomena that are otherwise difficult or impossible to observe directly. This paper explores the various applications of computational techniques in nuclear energy research, highlighting their role in the design, optimization, and safety analysis of nuclear reactors, as well as in the understanding of nuclear reactions and radiation interactions. Key technologies such as Monte Carlo simulations, finite element analysis, and molecular dynamics are utilized to investigate particle behavior, energy transfer, and material properties under extreme conditions. Additionally, computer programs aid in predicting reactor performance, managing waste disposal, and ensuring compliance with safety standards. The integration of artificial intelligence and machine learning further enhances the accuracy and efficiency of nuclear process studies. As the complexity of nuclear systems continues to grow, the use of advanced computational tools will be essential in driving innovation, improving safety, and ensuring the sustainable development of nuclear energy.

Keywords:- *Simulation, Modeling, Monte Carlo Methods, Finite Element Analysis (FEA), Data Analysis, Visualization, Machine Learning, Predictive Maintenance, Control Systems, Real-Time Monitoring, Nuclear Safety, Risk Assessment, Emergency Response, Interactive Learning, Virtual Labs, Reactor Design, Material Science, Computational Physics, Neutron Transport, Fuel Optimization.*

I. INTRODUCTION

Today, as we know, Nuclear power is one of the main areas of modern energy and requires in-depth analyses of nuclear processes. This field is characterised by its complexity and safety, as there is a need to control, model and analyse nuclear processes. The role of computer technology in the study of nuclear processes is increasing. Today, computer programs are used as one of the main tools for modelling, simulation and analysis of complex physical and chemical processes in nuclear power engineering.

Nuclear processes are limited by conventional experiments and theoretical calculations due to their uncertainty, high energy and strong electromagnetic fields. Therefore, computer simulations and models have become an indispensable tool in solving various problems in nuclear physics and nuclear power engineering. Computer technologies are particularly important in modelling the operation of nuclear reactors, nuclear reactions and material properties. They are also effectively used to address issues such as nuclear power safety, environmental impact assessment, nuclear waste management and energy production efficiency.

In addition, advanced computing technologies, such as artificial intelligence and machine learning, are helping to predict nuclear processes more accurately and are creating new opportunities for effective problem solving in the field of nuclear energy. This article reviews the role and potential of computational technologies and programmes in nuclear energy research and analyses their role in ensuring the efficient and safe operation of nuclear reactors.

- *The level of Knowledge of the Topic.*

Many scientific works and dissertations are devoted to the introduction of innovative technologies in the educational process, and most of them are devoted to virtual methods for conducting physical laboratories.[1]Early history of the study of computer technology in nuclear power engineering:

The first use of computer technology in nuclear power began in the mid-20th century. The first methods of mathematical modelling of nuclear physics and reactor design were associated with the development of computer hardware and software. The main importance in this was, for example, Monte Carlo simulation programs and programs allowing to calculate thermal and mechanical properties of nuclear reactors.

[1] Mitrofanov K.G., Zaitseva O.V. (2009). Application of innovative computer technology in the field of education: basic aspects and trends // Vestnik, issue 10(88), p.64-68.

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- *Methods of Modelling and Simulation of Nuclear Processes:*

Monte Carlo simulation: is widely used in modelling nuclear processes and particle transport. This method is characterised by its efficiency and high accuracy, but because it requires computer resources, its development and use has increased in recent years. Many new methods and algorithms have been developed as a result of the study of this technology in the field of nuclear engineering.

Thermo-hydrodynamic modelling: another important method used to simulate the operation and safety of nuclear reactors. This has been able to calculate the heat and water flow processes of the reactor, the effect of materials and other mechanical properties[2].

- *The Role of Computer Technology in Reactor Design Optimisation:*

Computer technology plays an important role in the development of new reactor designs to ensure efficient operation of nuclear reactors and to improve safety. To date, many research studies have been conducted to optimise reactor efficiency, determine the effect of materials and to ensure efficient operation of nuclear power using several computer programs.

Programmes such as RELAP5, TRACE and ANSYS allow the reactor safety, thermal and hydrodynamic properties to be verified. With the help of these programs, the reactor response under different operating conditions can be modelled.

- *Application of Computer Technology in Advanced Nuclear Research:*

Artificial intelligence and machine learning. One of the most advanced forms of computer technology in nuclear power is the increasing use of artificial intelligence and machine learning (ML) techniques for nuclear process prediction and hazard detection. These technologies are widely used in real-time monitoring of nuclear reactor operations, improving safety and optimising design.

Big Data. New approaches to analysing large amounts of data in the nuclear power industry have emerged with the help of computer technology. Big data from nuclear reactors and other power systems are being used to improve safety and efficiency through machine learning and statistical analysis.

- *Research and Learning Levels:*

The use of computer technology in the study of nuclear processes has great scientific potential. Currently, the world's leading research institutions such as Los Alamos National Laboratory, Oak Ridge National Laboratory, and Argonne National Laboratory are conducting extensive nuclear modelling and simulation research.

The results obtained from computer programs help not only to improve the operation of nuclear reactors, but also to ensure safety, manage waste, and minimise environmental impact.

- *New Approaches Currently being Explored:*

Quantum computing: creating new capabilities that require deep and accurate modelling of nuclear processes. New approaches to modelling patterns and changes in nuclear processes at the microscopic level are being developed using quantum computing technologies.

Nuclear waste management: New methods for long-term storage and safety of nuclear waste are being developed using computer technology.

The research of computer technology in the nuclear power industry is very advanced today. Research and new technologies in this field, in particular computer modelling, have helped to make great progress in improving the safety of nuclear reactors, optimising energy production and reducing environmental impact. However, there are still many unexplored areas in this field, and future opportunities are expected to open up in the development and improvement of new core systems using computer technology.

This level of research shows how computer technology is being utilised in nuclear power and what research is being done in this area. There are many more scientific and practical studies within the topic.

➢ *Statement of the Research Problem.*

The study of nuclear processes, particularly in the field of nuclear energy, presents significant challenges due to the inherent complexity and high-risk nature of nuclear phenomena. Traditional methods of understanding nuclear processes—such as experimental measurements and theoretical models—have limitations in terms of precision, scope, and safety, especially when it comes to simulating extreme conditions like those within a nuclear reactor. As a result, there is a growing need for advanced computational tools to aid in the analysis, modeling, and optimization of nuclear energy systems.

The problem lies in effectively utilizing computer technology programs to enhance the understanding and management of nuclear processes. While computational methods have shown great potential in simulating various nuclear phenomena, their application in the study of nuclear energy systems is still evolving. Specifically, there is a need for more precise simulations of nuclear reactions, heat transfer, radiation effects, and material behavior under extreme conditions. Additionally, integrating artificial intelligence (AI) and machine learning (ML) into nuclear simulations to improve accuracy, efficiency, and real-time decision-making remains an underexplored area.

➢ *Aim of the Study.*

The aim of this study is to explore and evaluate the potential of using computer technology programs in the

[2] Мастропас З.П., Синдеев Ю.Г. Физика: Методика и практика преподавания. Р-нД: Феникс, 2002. С 11-32.

ISSN No:-2456-2165 https://doi.org/10.5281/zenodo.14631782

study of nuclear processes within the field of nuclear energy. Specifically, the research aims to investigate how advanced computational tools, including simulation software, modeling techniques, and artificial intelligence (AI), can enhance the understanding, optimization, and safety of nuclear energy systems. this study seeks to demonstrate the crucial role that computer technology programs can play in advancing the science of nuclear energy by providing innovative solutions to the challenges of modeling and managing complex nuclear processes, enhancing the safety and efficiency of nuclear systems, and fostering the sustainable development of nuclear energy.

➢ *Tasks of the Research.*

In order to achieve this objective, it is important to carry out the following tasks.

- To create mathematical models to simulate the behavior of nuclear reactors;
- To simulate neutron interactions with reactor materials to understand how neutrons are distributed and how they interact with the reactor core;
- To simulate heat transfer and fluid flow within the reactor to ensure safe and efficient cooling of the reactor core;
- To Analyze the nuclear fuel cycle, including fuel consumption, waste generation, and isotopic composition changes over time;
- To optimize the design and operation of the reactor core to maximize energy output while ensuring safety;
- To analyze the environmental impact of nuclear power plants, including potential radioactive release, thermal pollution, and ecosystem disruption;
- To analyze experimental data and operational data from nuclear reactors to support decision-making and optimize plant performance.

II. METHODS OF THE RESEARCH

Research methods include conduct a systematic review of existing literature including academic papers, technical reports, case studies, and industry publications related to the use of computational tools in nuclear energy. Mathematical models form the foundation of any computer-based analysis in nuclear power engineering. These models describe the physical processes that occur in a nuclear reactor, including neutron transport, heat transfer, fluid dynamics, and material interactions.[3] The research will employ a multi-method approach, combining literature review, computational simulations, AI/ML applications, uncertainty quantification, HPC techniques, and expert input to comprehensively assess the possibilities and limitations of using computer technology programs in the study of nuclear processes. Neutron transport is a critical process in nuclear reactors. Computer programs are used to model the behavior of neutrons as they interact with materials within the reactor, thereby influencing the reactor's power generation, fuel usage, and safety. Reactor cooling systems and heat dissipation are vital to reactor safety. Computer programs simulate the thermal and fluid dynamics inside nuclear reactors to ensure that the reactor core stays within safe operating temperatures. Fuel burnup and fuel cycle analysis are essential for understanding how fuel is used in a reactor, how long it lasts, and how waste products are produced. The study of nuclear processes using computer programs involves a wide range of methods, from mathematical modeling and neutron transport simulations to AI and machine learning. These computational methods allow for a deeper understanding of nuclear reactors' behaviors, optimization of their designs, and improvement of safety protocols. By using advanced simulation techniques, optimization algorithms, and predictive modeling, the efficiency, safety, and environmental impact of nuclear power generation can be significantly enhanced.

These methods contribute to the development of next-generation reactors, improved nuclear fuel cycles, and more effective risk management strategies, making nuclear power more sustainable and safer for the future.

➢ *The main Part of the Research*

Modern computer modelling is one of effective methods for studying complex systems. Logicality and formalization of models makes it possible to identify the main factors, determining the properties of the studied object, models help to understand the process, establishing qualitative and quantitative characteristics of its state, and predict the behavior of interesting, 'leading' in this process characteristics. The application of mathematical modelling is necessary for the power industry, and for NPPs in particular. Objects power engineering facilities need management, which implies constant observation in operation of intensive and dynamic processes of energy conversion and movements of working media. This, in turn, is inevitably connected with the need to study the acceptability of different operating modes, assessment and forecasting of technical condition, etc., which is inevitably connected with the necessity to study the permissibility of various operating modes, assessment and forecasting of technical condition, etc. It is expedient to perform with the help of specially created models[4].

The processes occurring in reactors are so complex that it is impossible to to build a single mathematical model of all processes. At present modelling of these processes is based on the development of models of different level of description, which is determined by the nature of specific tasks to be solved, including educational ones. We can talk about a hierarchy of descriptions, differing in the degree of detail, in other words, the level of completeness.

In the case of neutron-physical processes, their complete (detailed) description can be given only at the level of description can be given only at the level of kinetic

[3] A.Kh.Ramazanov, S.R.Polvonov, E.Kh.Bozorov. Oliy ta`lim muassasalarida "yadro energetikasi" mavzusini o`qitishda interfaol usullardan foydalanish uslublari. O'zMU xabarlari, 2022, [3/2], Pp. 487-489.

[4] Briesmeister, J. F. (Ed.). (2013). *Monte Carlo methods in nuclear engineering*. American Nuclear Society

ISSN No:-2456-2165 https://doi.org/10.5281/zenodo.14631782

equations constructed on the basis of fundamental equations, which describe microscopic processes. In such a description, the process is characterised by a distribution function, or, equivalently, by moments of different orders of random variables defined by the distribution function. Such a description, which allows a detailed calculation of the core, is the basis of powerful calculation codes.

The field of application of such codes is the calculation of reactor cores at the stage of design, including in the justification of reactor cores.

At the same time, in practice, in a great number of cases, knowledge of only some quantities characterizing the process is required. Accordingly, a phenomenological description is introduced, which is satisfied with knowledge of a small number of quantities. In such a description, the reactor core is represented as a continuous medium, which suggests the use of the apparatus of partial differential equations as a description tool. In turn, in the phenomenological description, multilevel models are used. Thus, in less detailed calculations of active zones compared to the above, multigroup diffusion equations are used, in particular, two-group equations. With this approach to calculating the neutron field, the neutron flux density is represented as a product of a rapidly changing amplitude function in time and a form function that weakly depends on time. The two-group approach with improved quasi-statics, combining sufficient accuracy and speed, is used in the construction of simulators based on real-time modeling with a strict limitation on the calculation time. In recent years, a number of companies have been developing full-scale and analytical (computer) simulators of power units in parallel. Analytical simulators implemented on a personal computer do not contain equipment that requires constant maintenance. They provide an opportunity to experiment when modeling various transient processes and can be used in emergency planning, training of NPP personnel, in the preparation of research personnel, as well as in the educational process of universities. It is worth noting that such a simulator is only a mathematical model of an object, which, depending on the detail of the description, only approximately reflects certain features of the simulated object, and this is both its advantages and disadvantages. On the one hand, the simulator allows experiments to be carried out that cannot be carried out in full-scale tests. But, on the other hand, it is only a model of the object describing its behavior with a varying degree of approximation. To use all the capabilities of the simulator, it is necessary to develop methodological support, the basis of which should be the current guidelines and instructions, but since this is a different device, they must be adapted and revised for it. This concerns not only the simulation of experiments, but also the methods of processing the obtained results. In turn, the methods developed for the simulator concern only the simulator, and, due to the above, cannot be transferred to real installations and pursue another goal - the study of the physics of processes[5].

Analysis of the existing system of training operational personnel shows that between theoretical training in the physics of interrelated technological processes, most of which is carried out at the university, and practical training at the UTP, there is no connecting link that would allow projecting the theoretical knowledge obtained at the university onto practical activities in managing the unit. In addition, over time, the theory is "forgotten", and in the process of advanced training and retraining, due to the short duration of this process, it may be problematic to restore and expand theoretical knowledge to the extent necessary for making the right decisions in non-standard situations. To maintain and constantly improve the required level of readiness, constant training is necessary in the form of independent research of mathematical models of processes that may have to be encountered in practical activities. Such an opportunity is provided by the wide use of computer modeling. Therefore, in order to organize a link between theoretical and practical training and to increase the efficiency of the personnel training system as a whole, it is advisable to supplement the current personnel training system with elements of computer modeling of neutron-physical and thermal-hydraulic processes.

III. THE RESULT OF EXPERIMENTS AND DISCUSSIONS

First of all, Modern computer modeling is one of the effective methods for studying complex systems. The logicality and formalization of models allows us to identify the main factors that determine the properties of the object under study, models help to understand the process, establishing the qualitative and quantitative characteristics of its state, and predict the behavior of the characteristics of interest, "leading" in this process. The use of mathematical modeling is necessary for the energy industry, and for nuclear power plants in particular. Energy facilities require management, which involves constant monitoring during operation of intensive and dynamic processes of energy conversion and movements of working media. This, in turn, is inevitably associated with the need to study the admissibility of various operating modes, assess and predict the technical condition, etc., which is advisable to perform using specially created models.

The processes occurring in reactors are so complex that it is impossible to build a single mathematical model of all processes. Currently, modeling of these processes is based on the development of models of different levels of description, which is determined by the nature of the specific problems being solved, including training ones. We can talk about a hierarchy of descriptions, differing in the degree of detail, in other words, the level of completeness. With regard to neutron-physical processes, their full (detailed) description can only be given at the level of kinetic equations constructed on the basis of fundamental equations that describe microscopic processes. In such a

[5] Qo’chqarov X.O., Yusupov D.A Fundamental fanlarni o’qitish samaradorligini oshirishning dolzarb muammolari va yechimlari : Academic Research in Educational Sciences. Volume 2. Uzbekistan 2021. p. 448-455.

ISSN No:-2456-2165 https://doi.org/10.5281/zenodo.14631782

description, the process is characterized by a distribution function, or, equivalently, by moments of different orders of random variables determined by the distribution function. Such a description, which allows for a detailed calculation of the active zone, is the basis for powerful calculation codes.

The scope of such codes is the calculation of reactor active zones at the design stage, including when justifying their safety, as well as support, but not in terms of personnel training. At the same time, in practice, in a great number of cases, knowledge of only some quantities characterizing the process is required. Accordingly, a phenomenological description is introduced, which is satisfied with knowledge of a small number of quantities. In such a description, the reactor core is represented as a continuous medium, which implies the use of the apparatus of partial differential equations as a description tool. In turn, in the phenomenological description, multilevel models are used. Thus, in less detailed calculations of active zones compared to the above, multigroup diffusion equations are used, in particular, two-group equations. With this approach to calculating the neutron field, the neutron flux density is represented as a product of a rapidly changing amplitude function in time and forms of a function that weakly depends on time. A two-group approach with improved quasi-statics, combining sufficient accuracy and speed, is used in the construction of simulators based on real-time modeling with a strict limitation on the calculation time. In recent years, a number of companies have been developing full-scale and analytical (computer) simulators of power units in parallel.

Analytical simulators implemented on a personal computer do not contain equipment that requires constant maintenance. They provide an opportunity to experiment when modeling various transient processes and can be used in emergency planning, training of NPP personnel, in the preparation of research personnel, as well as in the educational process of universities. It is worth noting that such a simulator is only a mathematical model of an object, which, depending on the detail of the description, only approximately reflects certain features of the simulated object, and this is both its advantages and disadvantages. On the one hand, the simulator allows you to conduct experiments that are impossible to conduct in full-scale tests. But, on the other hand, it is only a model of an object that describes its behavior with a certain degree of approximation. To use all the capabilities of the simulator, it is necessary to develop methodological support, the basis of which should be the current guidelines and instructions, but since this is a different device, they must be adapted and revised for it. This applies not only to the simulation of experiments, but also to the methods for processing the results obtained. In turn, the methods developed for the simulator concern only the simulator, and, due to the above, cannot be transferred to real installations and pursue another goal - studying the physics of processes. If the spatial distribution of the neutron flux density does not change during the transient process, then we speak of the kinetics of a point reactor. In this case, the parameters included in the equations for the point kinetics of the reactor can be calculated based on form functions. However, more often the parameters are not calculated using form functions, but are postulated, which can be done, for example, based on experimental studies. Therefore, the equations of point kinetics are the basis for processing the results of neutron-physical experiments. The use of point kinetics equations developed at an early stage of development of reactor physics issues, when an intuitive understanding of processes was required. The point kinetics model is not only still widely used in the educational process, which is reflected in the works of NRNU MEPhI, VNIIAES, IGEU, etc., but is also the basis for methods of processing the results of neutron-physical reactor measurements. The training and practical activities of unit operators are largely based on this model, so it should be used in training operating personnel.

IV. CONCLUSION

To sum up, Within the framework of the set tasks, the mathematical model of reactor dynamics was substantiated and refined. The method of integral relations was used to analytically solve the problem of calculating the coolant temperature field and establish a relationship between the average coolant temperature and the temperatures at the reactor inlet and outlet. By switching to dimensionless variables, the similarity criteria of the problem were formulated, allowing all similar fuel loads to be considered, and the hypothesis of closing the system of differential equations was discussed and numerically substantiated. A set of problem-oriented computer programs was developed and numerical experiments were performed to model transient processes affecting safety, including: starting a cold reactor, poisoning the reactor with xenon, malfunctions in the mechanical control and safety system, and the possibility of self-starting the reactor during emergency cooldown of the primary circuit. The developed software package makes it possible to continue modeling in various directions with the expansion of the modeled processes. A mathematical model of axial xenon oscillations is proposed, which, unlike the accepted approaches based on perturbation theory, allows one to study the xenon stability of a reactor under nonlinear problem conditions. The region of xenon stability of a reactor in the coordinates of temperature coefficients of reactivity – reactor power is constructed using the method of numerical experiments.

Furthermore, for the analytical simulator of a power unit with a WWER-1000 reactor, based on the adaptation of the guidelines and current operating instructions to the analytical simulator, a methodological support was developed for the simulation of unit startup and shutdown operations, the action of the main protections and primary circuit interlocks during the simulation of violations of normal operating conditions and neutron-physical reactor measurements. Computer programs were developed for processing the results of reactor measurement simulation, which were tested both on the analytical simulator and on the PMT of Unit No. 3 of the Kalinin NPP.

ISSN No:-2456-2165 https://doi.org/10.5281/zenodo.14631782

Based on the analysis of inverted solutions of reactor dynamics equations, a new approach was proposed, new methods of neutron-physical reactor measurements for the analytical simulator were developed and implemented, concerning the determination of the barometric and temperature reactivity coefficients for the fuel and coolant, as well as the construction of the integral and differential characteristics of the groups of control elements. Unlike the accepted methods, the basis is the analysis of the dynamic process, during which compensation of the reactivity introduced by the absorbers is carried out by temperature effects of reactivity. The obtained results are consistent with the results of standard methods.

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