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A Review For Use Of AI and ML Techniques On Nuclear Power Technologies For The Last Decade

Veda Duman Kantarcıoğlu[1*]

[1]**Nuclear Engineering Department, Hacettepe University, ORCID: 0000-0001-6193-8359**

REVIEW

Abstract

Research in the field of nuclear technology increasingly focus on artificial intelligence (AI) and machine learning (ML) techniques to make nuclear power plants easier to operate safer, and more reliable. This review investigates the integration of AI and ML in nuclear power technologies over the past decade. We collected 725 research articles from five leading journals related to nuclear technology, categorizing them into five distinct groups identified by the International Atomic Energy Agency (IAEA) based on their focus research areas. This study aims to investigate the evolution of research topics over the years. We also examined the keywords used within these studies to obtain insights into prevailing trends. Furthermore, we summarized the AI and ML techniques employed across these articles to understand their applications in the nuclear sector. This study demonstrates experience using artificial intelligence-supported methodologies to improve various aspects of nuclear technology and promote innovation in the nuclear industry. Over the last decade, the use of AI and ML in research on nuclear power reactors has significantly increased. In 2018, there was a rapid increase in research articles on AI and ML applications; this trend has increased linearly over the last five years. The groups with the largest share in the published articles are prediction and prognosis, analytics, and optimization, respectively. However, research articles about automation for nuclear power have been increasing significantly in the last five years.

Keywords: artificial intelligence, machine learning, nuclear power plants

1 Introduction

In recent years, nuclear energy has begun to attract attention again as a low-carbon and reliable energy source. On the other hand, the rapid development of artificial intelligence (AI) technologies in recent years and the development of tools that enable the fastest integration of these technologies into different industries have opened the door to new capabilities that researchers can greatly benefit from in their research on nuclear power technologies. By adding new AI capabilities to the point reached so far in the field of nuclear engineering, the opportunity has arisen to optimize reactor design, performance and safety, and to achieve high efficiency and lower maintenance costs. Machine learning (ML) techniques are used to automate routine procedures and tasks. This increases reliability and reduces human or system errors. Predictive applications of AI are increasingly helping to monitor operations and detect anomalies [1].

Nuclear power technology has played a significant role in providing carbon-free energy for decades and has made significant contributions to global efforts to reduce greenhouse gas emissions. Reducing the greenhouse gas emissions globally to reduce the effects of climate change is now a requirement that is accepted all over the world. With the Paris climate agreement, countries have declared their goals and determination in this regard to the whole world. One of the most effective ways to reduce carbon emissions is to reduce the use of fossil fuels in electricity generation. Plans for this goal have also strongly highlighted nuclear power plants in recent years. Nuclear energy offers a low-carbon solution that can be implemented on a large scale within the required time frame and provides clean, reliable, and affordable electricity globally. According to the International Atomic Energy Agency (IAEA), by 2023, nuclear energy will account for approximately 10 percent of global electricity production and a quarter of all low-carbon electricity [2]. Nuclear power reactors with a capacity of approximately 413 gigawatts (GW) operating in 32 countries prevent global emissions of 1.5 gigatonnes (Gt) per year and global gas demand of 180 billion cubic meters (bcm) [3].

Concerns about climate change have accelerated the development of small and modular nuclear reactor

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***Corresponding author**
veda.duman@hacettepe.edu.tr

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(SMR) designs in recent years. SMRs are nuclear fission reactors with an electrical power output of less than 300 megawatts (MWe). SMRs provide modular production, factor production, portability, and scalable sustainability [4]. SMRs offer enhanced safety features, simplified installation, and flexibility in operation. They can be built in a factory environment, transported to the field, and installed on-site. This reduces construction times and costs. With the lower accident risks and minimal radiological consequences, SMRs are good choices for carbon free electricity production. AI and ML technologies are frequently used for the development of SMRs.

The nuclear power industry has begun to leverage AI in areas such as automation, design optimization, data analytics, prediction, and insight extraction. According to the IAEA, today AI in Nuclear efforts aim to expand AI technologies from pilot studies to broader applications today [5]. AI applications enable precise monitoring and control of operating nuclear reactors and ML models are widely used to simulate reactor behavior. AI and ML constitute important areas of development in predictive maintenance and monitoring. ML algorithms are used especially in predicting failures. The aim is to analyze sensor data from various components of the nuclear reactor and ensure that maintenance is carried out without experiencing any accidents. These applications reduce operating costs. In addition, AI-supported optimization algorithms are used to improve reactor core design to increase fuel efficiency. Moreover, AI applications are integrated into real-time monitoring and control systems to develop automatic responses to detect anomalies and maintain reactor stability. Techniques such as neural networks and fuzzy logic also excel in managing uncertainties, which are among the most important issues in nuclear engineering calculations. In addition, AI-supported digital twins and virtual simulations provide valuable information for design, testing, and training, while AI-supported models optimize the management and disposal of nuclear waste. As AI and ML continue to develop, their applications in nuclear reactor technologies will also increase.

As AI technologies develop and their use becomes widespread, energy consumption levels are also increasing. New generation nuclear power reactors are seen as an important opportunity to meet these rising energy demands. Today, large technology companies are trying to purchase electricity directly from nuclear power plants [6]. As industries and societies move towards AI-driven systems, the demand for clean, reliable and continuous power sources will increase. With its high energy density and ability to operate independently of weather conditions, nuclear power is in a unique position to meet these needs [7].

This study examined the research articles of the last ten years that applied AI and ML techniques in the field of nuclear energy. Five journals directly related to nuclear technology were selected and 758 research articles were obtained online. Articles related to public perception, public opinion, optimization of electric power generation, and power forecasting were excluded. As a result, 725 research articles on nuclear energy reactors were included in the study. The abstracts of these articles were examined, and the articles were classified into five main groups defined by the IAEA for AI applications in nuclear energy. This analysis identified changes in the focus areas under these categories, and keyword analysis highlighted the most emphasized techniques and the nuclear reactor technologies to which these techniques are related.

1.1 The Evolution of AI and ML Applications in Nuclear Technology

The use of AI and ML in nuclear technology began in the early years of the development of these technologies. The chronological development of the integration of technologies can be summarized as follows [5]:

- 1960-1980: Monitoring reactor operating conditions
- 1980-1990: Expert systems for diagnose anomalies and prediction of failures (Following the Three Mile Island nuclear power plant accident in 1979, many methods, especially safety analyses, began to be developed to systematically structure nuclear safety)
- 1990-2000: ML for predictive maintenance and neural networks to model complex processes.
- 2000-2010: Reactor design and risk management
- 2010-2020: Control systems, operational efficiency, and fuel cycle optimization.
- 2020-: Advanced reactors and fusion power, optimizing operations,improving grid management, and improving cybersecurity, revolutionizing maintenance and safety procedures

Future AI-enabled autonomous systems are likely to revolutionize maintenance, inspection, and overall safety in nuclear operations [8]. As AI technologies develop, their impact on nuclear technology also increases.

1.2 IAEA's Grouping of AI Applications in Nuclear Power

AI falls into logic- or knowledge-based AI and data-driven AI. AI refers to a collection of technologies that produce systems capable of tracking complex problems in ways similar to human logic and reasoning. ML technologies learn how to complete a particular task based on large amounts of data. According to the report of IAEA, the main opportunities for AI to achieve a positive impact on the nuclear power industry can be grouped into the 5 areas: Automation, Optimization, Analytics, Prediction and prognostics and Insights [5].

Studies on automation are basically investigating new system innovations to increase reliability and efficiency by minimizing human intervention in routine tasks. Automating repetitive processes provides easier traceability and faster detection of system errors, as well as leading to the reduction of human errors. Thus, it is possible to speed up the processes during the operation of nuclear power plants. All these developments can provide cost savings as well as increased productivity and more efficient and effective use of human resources. The summary of content for studies on automation as described by IAEA is given below:

- High-pressure tasks in nuclear plants increase human error; data science can automate these processes.
- ML improves complex data analysis and defect detection in inspections.
- ML detects anomalies in control rod drive mechanisms (CRDMs), reducing human evaluation needs.
- Anomaly detection and operator awareness are enhanced with ML and physics-based models.
- Drones and natural language processing (NLP) streamline inspections and decision-making.

Optimization focuses on improving the efficiency and effectiveness of complex operations in all processes from the design, installation, operation and dismantling of nuclear power plants. The main focuses of research in this area are to find the best possible solution within physical and economic constraints by maximizing output, increasing efficiency, minimizing costs, or improving overall performance. Optimization techniques are generally developed to ensure that complex processes in the operation of nuclear power plants continue as smoothly and efficiently as possible. The summary of content for studies on optimization as described by IAEA is given below:

- Data science optimizes inventory management and outage scheduling in nuclear power.
- ML enhances scheduling and radiation mitigation.
- AI improves design processes, safety, and cost efficiency.
- AI balances multiple goals in reactor control.
- AI addresses optimization in in-core fuel management.

Research in the field of analytics aims to improve the quality of existing models and deepen the understanding of the analyzed systems. The importance of both theoretical and experimental studies in the development of nuclear reactor technologies is very great. Since the early years of commercial use of nuclear power reactors, important physical phenomena have been simulated with simulations and experiments that are physically impossible or too costly to be carried out in a computer environment. In this way, data can be produced for neutronic and thermal hydraulic calculations, and again, with sector-specific calculation tools, the behaviors of reactors and all components of the power plant under different conditions are tried to be predicted. All developed analytical tools and techniques help to identify patterns, trends and insights that can be used to improve analytics, decision-making, improve models and optimize system performance by collecting, processing and interpreting data. Hence, predictions can become more accurate to develop better strategies. The summary of content for studies on analytics as described by IAEA is given below:

- AI techniques support long-term research benefits.
- Expedite characterization and validation of materials for new designs.
- Develop quality assurance practices for additively manufactured components.
- Create complex models for improved accuracy in decision-making.
- Enhance model validation and support digital twin applications.

Prediction and prognosis focus on predicting the behavior of systems and their components under different conditions or possible failures, thus improving the planning and execution of maintenance activities. Predicting failures in advance is important for preventing serious nuclear power plant accidents, managing accidents in the most effective way, and mitigating their consequences. By using data-driven models and algorithms, proactive maintenance systems can be established as potential problems can be predicted before they occur. The summary of content for studies on prediction and prognosis as described by IAEA is given below:

- Data science for predicting events and assessing asset conditions.

- Tools for planning maintenance and reducing unexpected downtimes.
- Monitoring operation data for abnormal conditions and timing of inspections.
- Advanced simulation tools not fully utilized by end-users.
- AI addresses prediction challenges with mathematically rigorous algorithms.

Data from operating experience and experiments are used to generate insights. For this purpose, experience from a single reactor can be used, as can data from various reactors around the world. This data is evaluated, and important lessons are learned, and these conclusions are shared with nuclear reactor operators around the world. In this way, it is possible to gain insight into the possible outcomes of some operating processes, examples of good practice, and actions that may have negative consequences. These insights are used to improve operating conditions and reduce errors. The summary of content for studies on insights as described by IAEA is given below:

- Thousands of reactor years of operational experience.
- Extensive libraries of validation experiments.
- Data science technologies for best practices and decision-making.
- AI applications for maintenance record assessments.
- Challenges with language and jargon specificity.

2 Material and Methods

This study investigates the areas of focus and the trend of change in research articles published by researchers in the field of nuclear power in the last ten years. The research articles published in the last ten years by five important journals in which research articles in the field of nuclear energy and nuclear technology are published were included in the scope of the study. The following two search terms were used in the searches: "nuclear power" + "AI", "nuclear power" + "machine learning". A total of 758 research articles were found. Articles related to public perception, public opinion, optimization of electrical power generation, and power forecasting were excluded.725 of research papers on nuclear power reactors were included in the analysis.

Table 1. Number of Reviewed Research Articles

Journal Name	Number of Papers Accessed	Number of Papers Reviewed
Nuclear Engineering and Technology	142	126
Annals of Nuclear Energy	241	232
Nuclear Engineering and Design	184	179
Progress in Nuclear Energy	139	138
Journal of Nuclear Science and Technology	52	50
TOTAL	758	725

The selected research articles were classified according to the IAEA grouping explained in previous section. In this way, it was tried to determine the trends in the subjects of the researchers' research in the last 10 years. In the second part of the study, the keywords used by the researchers in the articles were analyzed and a second data was tried to be obtained for the areas where the researchers focused. The second information obtained from the keywords is the AI and ML techniques used. In addition, the articles were examined and the tools used were determined. The techniques and tools determined to be used are given in the following section.

3 RESULTS

3.1 The Outstanding AI And ML Applications in Nuclear Power Research For The Last Decade

As a result of keyword analysis of the research articles included in this review, the word cloud given in Figure 1 was created. This cloud is an important visual in terms of seeing the most common purposes for which AI and ML applications are used in nuclear power plants. A significant portion of the reviewed articles focused on fault diagnosis, and topics such as accident analysis, error analysis to prevent accidents, fault detection, anomaly detection, and control systems also came to the fore. As a result, it can be said that analyses related to nuclear safety are clearly visible in the studies. Analyses such as uncertainty and sensitivity analyses also clearly show themselves in the studies.

Figure 1. Word-cloud of nuclear research areas for which AI and ML techniques are used

Among the reactor types that stand out in the reviewed articles regarding the use of AI and ML techniques in the development of nuclear power technologies are Pressurized Water Reactor (PWR), Boiling Water Reactor (BWR), High-Temperature Gas-Cooled Reactor (HTGR), Sodium Fast Reactor, Fast Breeder Reactor, Small Modular Reactor (SMR), Advanced Gas-Cooled Reactor (AGR), Pressurized Heavy Water Reactor (PHWR) [9] [10] [11] [12] [13] [14] [15] [16]. Important components of nuclear power reactors, Steam Generators, Reactor Core, Fuel Assemblies, Containment Structures and Cooling Systems, take up an important place among the reviewed studies. [17] [18] [19] [20]

Studies on fuel types, core array optimization, fuel lattice design, fuel performance modeling, spent fuel, etc. are among the studies conducted on nuclear fuels. [21] [22] [23] [24]

Another important area where AI and ML techniques are used is nuclear safety and risk management. In the reviewed articles, it was observed that they focused on Probabilistic Risk Assessment (PRA), Safety Analysis, Accident Diagnosis, Fault Diagnosis and Identification, Safety Margin Analysis, Uncertainty Quantification, Risk-Based Approach, Safety Critical Systems. Fault diagnosis has been the most focused area in the last 5 years. [25] [26] [27] [28] [29] [30] [31] [32]

Many topics such as Loss of Coolant Accident (LOCA), Large-Break Loss-of-Coolant Accident (LBLOCA), Station Blackout, Severe Accident Analysis, Post-CHF Analysis are the topics that researchers focus on regarding accident situations in nuclear power plants [33] [34][35] [36]. In addition, many studies have been encountered regarding the safety systems of nuclear reactors. Some of these systems are Reactor Core Isolation Cooling (RCIC) System, Passive Systems, Emergency Response Systems [37] [38]. Many topics related to nuclear safety such as effective management of emergencies, radiation protection, Dosimetry, Environmental Radioactivity, Radiation Shielding, Radioactive Effluents, Atmospheric Dispersion attract the attention of researchers. [39] [40] [41]

Numerous studies have been encountered regarding the Thermal Hydraulics field, which is an important component in the efficient and safe operation of nuclear reactors. It has been observed that the areas of particular focus in this regard are Critical Heat Flux (CHF), Thermal Stratification, Flow Regime, Heat Transfer and Flow Correlations, Thermal Mixing and Stratification, Heat Exchange Coefficient. [42] [43] [44] [45]

It is understood that AI and ML applications have also begun to be widely used in Decommissioning and Waste Management. It is seen that the research in this field focuses on topics such as Decommissioning and Dismantling Processes, Waste Management, Radioactive Waste Disposal, Radioactive Waste Repackaged Drums and In-Situ Decommissioning. [46] [47] [48] [49]

One of the areas where AI and ML applications are most widely used in nuclear power technologies is Instrumentation and Control. In this study, topics such as Digital Instrumentation and Control (I and C), Control Room Radiological Habitability, Automatic Control Systems, Feedback Control, Voltage Regulator and Turbine Speed Control are among the research topics. [50] [51] [52]

Modeling and simulation are of vital importance in the development of nuclear power technologies. Important decisions in processes such as reactor designs, approval of designs, and licensing are made based on the results of analyses made with modeling and simulation tools. In the analyses conducted, it was seen that AI and ML applications were frequently used in this field in studies conducted in the last 10 years. Topics such as Computational Fluid Dynamics (CFD), System-Level Modeling and Simulation, Multi-Physics Simulations, Physics-Based Modeling and Data-Driven Modeling have come to the fore [53] [54] [55]. The increasing interest in new technologies such as Digital Twin Technology, High Fidelity Simulation, Exascale Computing and Augmented Reality for Educational Purposes is also evident in the reviewed papers. [56] [57] [58]

3.2 The Outstanding AI And ML Techniques In Nuclear Power Research For The Last Decade

As a result of keyword analysis for AI and ML techniques in nuclear power research, the word cloud given in Figure 2 was obtained. This cloud shows the most common AI and ML techniques used for research in nuclear power plants. The most prominent techniques in the cloud include neural networks and their varieties. Deep neural networks, convolutional neural networks (CNNs), and recurrent neural networks (RNNs) are some of them. Neural networks are widely used for fault diagnosis, predictive maintenance, and real-time monitoring in nuclear systems [59] [60] [61] [62]. Generative Models and Deep Belief Networks are applied to develop predictive maintenance systems and improve fault diagnosis [63]. In addition to experimental data, they can generate new data samples to work with larger data sets. They can learn complex representations from large data sets. Hybrid and Ensemble Methods such as CFD-ANN in the cloud are also prominent. These are developed by combining the strengths of different models to improve the prediction performance. [64]. Time Series Analysis Techniques such as LSTM (Long Short-Term Memory) networks and time series deep learning are used to analyze dynamic data that are of great importance in critical processes such as reactor transitions and safety analysis scenarios [65]. They help in predicting and diagnosing time-dependent events.

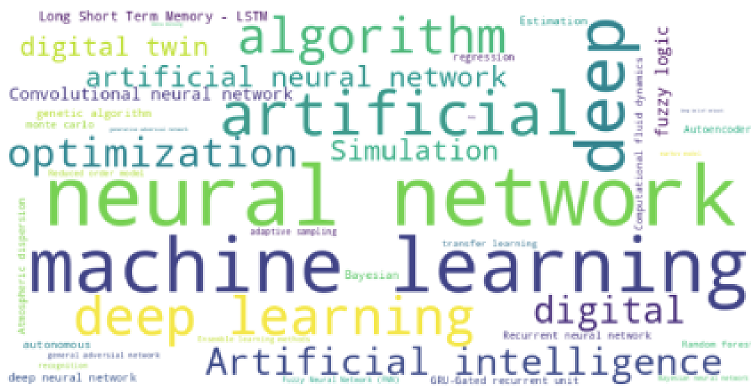

Figure 2. Word-cloud of nuclear research areas for which AI and ML techniques are used.

These techniques facilitate anomaly detection, system prognosis, and improved decision-making by leveraging large datasets and complex patterns. Techniques such as random forests, support vector machines (SVM), and genetic algorithms are applied for tasks like fault detection, optimization of reactor designs, and analysis of reactor behavior [66] [67] [68]. These algorithms are utilized for handling imbalanced datasets, feature selection, and predictive modeling. Genetic algorithms, ant colony optimization, and other optimization techniques are applied for reactor fuel design, control system optimization, and multi-objective problem-solving. These algorithms help in finding optimal solutions for complex reactor configurations and operations. Reinforcement Learning and Deep Reinforcement Learning techniques are used for operator support, diagnosis, and control automation [69] [70]. They help in optimizing reactor operations and improving safety functions by learning from interactions with the environment and adapting control strategies accordingly. Algorithms for pattern recognition are employed in digital neutron spectroscopy and signal processing [71] [72]. These methods help in identifying and analyzing complex patterns within nuclear data, enhancing safety and security measures and monitoring capabilities. Bayesian Networks and Bayesian Machine Learning techniques are used for probabilistic risk assessment, safety analysis, and updating models with new data [73] [74] [75] [76].

AI methodologies such as Principal Component Analysis (PCA), Autocoders, and Graph Convolutional Networks are used for data dimensionality reduction, feature extraction, and pattern recognition. [77] [78] [79] [80] [81] [82]. Deep learning models and reinforcement learning are used to optimize and improve system performance and fault detection. [83] [84] [85] [86][87]. Various optimization methods, including genetic algorithms, ant colony systems, and multi-objective optimization, are applied to improve reactor designs, fuel management, and operational efficiencies [88] [89] [90] [91]. These techniques help improve processes and system configurations for better performance and safety. Dimensionality Reduction and Data Visualization Methods like principal component analysis (PCA), autoencoders, and singular value decomposition (SVD) are used for reducing the complexity of data, enhancing feature extraction, and visualizing high-dimensional data for better analysis and interpretation [92].

Studies investigating the use of automated systems for automation, monitoring, control, and diagnosis in nuclear power plants are increasingly concentrated. Tools such as Hardware in the Loop (HIL) simulations and programmable logic controllers (PLCs) are increasingly important to automate processes and increase operational reliability [93] [94].Analytical tools and methods are used to extract actionable insights from large data sets. Techniques such as statistical analysis, data visualization, and pattern recognition help understand system behavior and predict potential problems. [95] [96] [97] [71].

In recent years, predictive maintenance and prognostics have been key areas where analytics provide insights into equipment health and system reliability. Techniques such as Bayesian Neural Networks and time series analysis help predict failures and plan maintenance. Safety-related studies are also among the main areas of interest for applications in the field of AI and ML. These studies generally focus on probabilistic risk assessments, accident analysis, and fault diagnosis to improve nuclear power plant safety. Tools such as MELCOR and RELAP5/SCDAPSIM are widely used nuclear engineering software for safety analysis and uncertainty quantification [98] [99]. Methods such as risk-based analysis, sensitivity analysis, and hazard analysis are used to assess and reduce risks associated with the operation of nuclear power plants and radioactive waste management [100].

The research articles reviewed focus on innovative technologies such as digital twin technology and augmented reality to simulate and visualize complex systems, improve understanding, and increase operational control [101] [102].These technologies provide a virtual representation of physical systems for better monitoring and decision-making. Studies on AI and ML applications have also focused on radiation protection, radioactive waste management, and environmental impact assessments. It is understood that radiation dose, distribution, and waste processing assessment techniques are considered crucial to ensure safety and compliance [103] [104] [105].

3.3 Trends In Focus Of AI And ML Use In Nuclear Power Research For The Last Decade

In this study, a total of 725 articles were distributed into groups using the grouping approach made by the IAEA on the use of AI and ML in the nuclear power field. As a result of this study, the distribution given in Table 2 was obtained. Between 2014 and 2024, the annual number of published research papers in this field has increased by 13 times. Additionally, in parallel with the rapid advancements in AI technologies worldwide over the past five years, the use of AI and ML techniques in nuclear power research has also become more widespread.

Table 2. Grouping of the Reviewed Articles

GROUP	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	TOTAL
AUTOMATION	0	0	0	2	3	4	13	9	10	16	12	69
OPTIMIZATION	3	4	3	2	6	11	13	24	28	27	40	161
ANALYTICS	6	5	5	4	12	11	18	22	24	32	36	175
PREDICTION and PROGNOSTICS	1	2	4	4	9	7	21	32	34	63	55	232
INSIGHTS	2	3	3	4	7	4	6	9	12	20	18	88
TOTAL	12	14	15	16	37	37	71	96	108	158	161	725

According to Figure 3, 32 percent of the research in the last 10 years is in the field of prediction and prognostics, 24 percent in analytics, 22 percent in optimization, 12 percent in insights and 10 percent in automation.

In the graph given in Figure 4, it can be observed in which groups researchers use AI and ML techniques more in nuclear power technologies and the change in this focus point according to the years. A significant increase is observed in the number of articles using AI and ML techniques in 2018 and after. 668 of the 725 articles examined were published in 2018 and after. The total number of articles has increased significantly over the years and second sharp rise was in 2020 and onwards.

This trend indicates a growing interest and emphasis on AI and ML techniques in the field, likely driven by technological advancements and increased computational capabilities. The peak in 2023 and 2024 shows the highest level of research activity, suggesting that these technologies are becoming increasingly critical in recent applications.

Automation stands out with a notable increase, especially from 2018 onwards. This surge reflects the industry's focus on automating processes to enhance efficiency and safety, particularly in complex environments such as nuclear power plants. The consistent rise indicates that automation remains a priority area for research and development. Prediction and Prognostics is the dominant group as an emerging focus

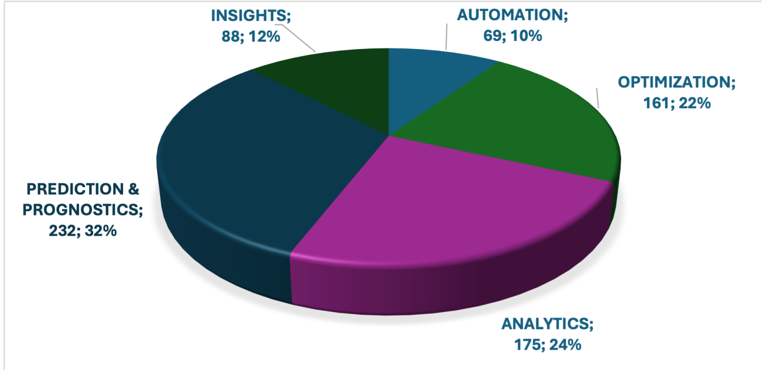

Figure 3. Distribution of Articles Due to the Groups.

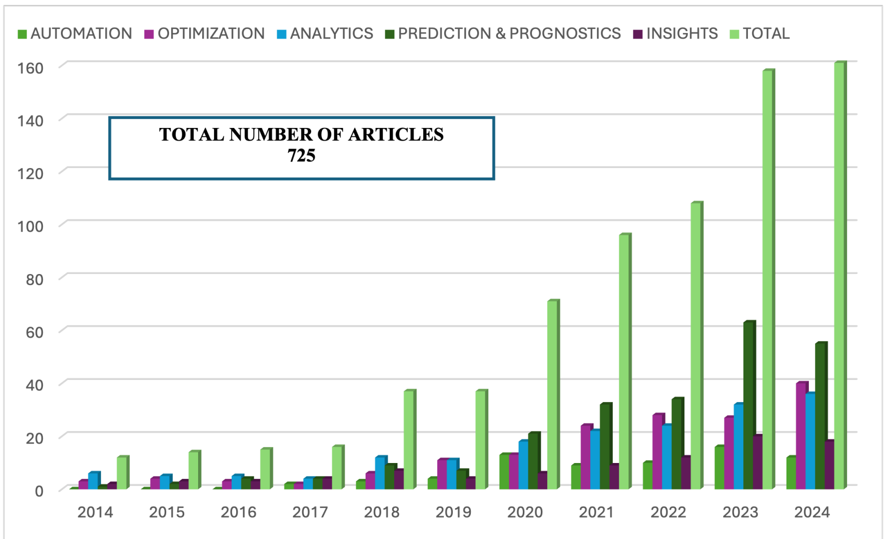

Figure 4. Evolving Research Trends in AI and ML Applications in Nuclear Technology.

area. Prediction and Prognostics and Optimization have seen marked growth since 2020, indicating a shift towards more sophisticated and predictive maintenance strategies. This trend suggests that researchers are increasingly exploring ways to predict equipment failures and optimize operations to prevent unplanned downtime and enhance safety protocols. The categories of Analytics and Insights have shown steady growth over the years, underscoring their importance in data interpretation and decision-making. The gradual increase in articles highlights a consistent effort to extract actionable insights from data, supporting informed decisions in complex systems. The sharp increases in recent years, particularly in advanced techniques like Prognostics and Optimization, reflect a maturation of AI and ML applications. This growth is likely driven by the successful implementation of these technologies in real-world scenarios, leading to increased confidence and further exploration in the field. Overall, the trends suggest a dynamic evolution in research priorities, with a clear shift towards automation, predictive analysis, and optimization, indicating that AI and ML are becoming integral to the future of the nuclear power industry.

4 CONCLUSION

This study provides a comprehensive review on the application of Artificial Intelligence (AI) and Machine Learning (ML) in nuclear power technologies over the past decade. By analyzing 725 research articles from five leading nuclear technology journals, key trends and developments were identified in automation, optimization, analytics, prediction and prognosis, and insights. The findings show that AI and ML are increasingly integrated into various aspects of nuclear power: A graphical analysis of the growth in publications over time highlights the increasing importance of AI and ML in nuclear power. The significant increase in research output since 2018 demonstrates the rapid adoption of these technologies, particularly in areas such as forecasting and prognosis, automation, analytics, and optimization; collectively, these constitute a significant portion of the reviewed literature. The summary of this review is as follows:

- Over the years, the use of AI and ML in research on nuclear power reactors has increased.
- In 2018, there was a significant increase in research articles with AI and ML applications. This trend has increased linearly over the last 5 years.
- The groups with the largest share in the published articles in the last 10 years are prediction and prognosis, analytics and optimization, respectively.
- On the other hand, a significant increase in automation research has been observed in the last 5 years.

As a result, AI and ML are becoming an integral part of the advancement of nuclear energy technologies and providing innovative solutions to complex challenges. However, the review also highlighted the lack of standardized benchmarking practices that limit the wider adoption and validation of AI and ML applications in nuclear engineering. Defining these benchmarks is of great importance to ensure the practical application of AI models in real-world nuclear scenarios. Continued research and development, along with the establishment of standardized benchmarks, will be essential to safely and effectively integrate these technologies and drive the future of the nuclear industry towards greater safety, efficiency and innovation.

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