Bölüm 1

A New Era in Nuclear Energy: Small Modular Reactors and Türkiye's Approach

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Abstract

Energy is one of the major issues of today and with the advancement of technology, it will become an even more significant challenge in the future. Obtaining energy from clean sources is of great importance in minimizing global warming and other environmental impacts. At this point, the use of nuclear power plants, which operate with zero carbon emissions, comes into play. Nuclear power plants are generally facilities that produce large amounts of electricity. In recent years, small modular reactors (SMRs) have begun to be developed as an alternative to conventional high-power nuclear power plants, characterized by smaller sizes, modular designs, and shorter construction times. Small modular reactors can serve not only as electricity sources for residential areas and industrial zones, but also for purposes such as seawater desalination and powering icebreaker ships. In this study, the fundamental characteristics, current design approaches, and application areas of small modular reactors which are considered the energy of the future are examined.

1. INTRODUCTION

Sustainability and security of supply in energy have become crucial issues today due to the increasing energy demand. Nuclear energy emerges as a clean and sustainable energy source thanks to its zero carbon emissions and long-term continuous operating regime. With advancing technology, nuclear

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power plants have become safer, equipped with passive safety systems that prevent accidents caused by human error(Kemah, 2017; Nogay, 2016).

High-power nuclear power plants have long and costly construction processes. Therefore, it is difficult for governments and private companies to invest in this area. Small modular reactors (SMR), developed as a solution to this problem, are advancing towards becoming the energy of the future with their low construction costs and short construction times(Topal, 2019).

In addition to power plants that generate electricity for cities and industrial facilities, small modular reactors can be used in icebreaker ships, seawater desalination plants, and mobile nuclear power plants. Today, there are nuclear power plants and icebreakers with small modular reactors in operation. Small modular reactors in operation serve as references for modular reactors in the project phase.

This study examines the technical characteristics, construction advantages and disadvantages, and construction processes of small modular reactors that are under construction and in operation. In addition, the progress of modular reactors in the project phase is evaluated, and our country's perspective on small modular reactors is discussed.

To select the right reactors for the small modular nuclear power plants planned to be built in Türkiye, it is important to examine small modular reactors that are in operation and under construction.

2. LITERATURE REVIEW

(Yurt, 2021), researched the operating principles and construction processes of nuclear reactors and classified them according to their areas of use and technical characteristics. He examined the operating principle and safety systems of the VVER-1200 reactor to be used in the nuclear power plant to be built in our country.

(Öngü, 2014), examined the types of fuel used in nuclear reactors, specified the types of radioactive waste produced as a result of energy production in the reactor, classified the waste according to their radioactivity levels, and discussed disposal methods.

(Topal, 2019), examined nuclear reactors according to their coolant type, evaluated the use of different secondary coolants for a modular reactor, and performed energy and exergy analyses of the reactor.

(İbiş, 2020), stated that fossil fuels other than lignite coal are imported into Türkiye and that the use of lignite coal as an energy source has negative environmental impacts. He noted that nuclear power plants play a key role in reducing energy dependence on foreign sources.

(Sever, 2019), emphasized the necessity of establishing nuclear power plants to ensure Türkiye's sustainable energy future and discussed the importance of nuclear power plants in terms of energy security and strategy. He stated that nuclear power plants to be established in Türkiye should be equipped with the most modern systems in terms of technology and safety.

(Abdulla, 2014), has researched the potential for the widespread adoption of small modular reactors, evaluated them in terms of cost and construction time, and analyzed the economic feasibility of light water-cooled modular reactors.

(Taso, 2011), in the first section of his study on the current role of small modular reactors, discusses the history of nuclear energy and explains its technical details. In the second section, he addresses small modular reactor projects proposed in the United States and other countries. In the third section, he emphasizes the importance of establishing small modular reactors in countries' energy and economic policies.

(Asuega-Souza, 2022), evaluated small modular reactors in terms of cost, conducted a detailed economic assessment of gas-cooled, light water-cooled, and molten salt small modular reactors, and compared them with natural gas combined cycle power plants.

(Fernández-Arias et al., 2023), examined modular plants with pressurized water reactors (PWR), compared their safety systems, and indicated the current status of planned PWR-type small modular reactors.

(Boening, 2020), researched small modular reactor strategies in developing countries and compared Canada and Kenya, which plan to install small modular reactors in rural areas, in terms of public perception of nuclear energy and safety.

(Franco, 2021), researched the economic sustainability of micro nuclear reactors and small modular reactors, comparing micro reactors, modular reactors, and high-power reactors in terms of electricity generation and cost.

(Godsey, 2019), conducted a life cycle analysis of small modular reactors, evaluating the process from fuel mining to waste disposal, analyzing mining, purification, conversion, enrichment, fuel manufacturing, and waste management processes.

(Lulik, 2020), analyzed how much a small modular reactor would affect the surrounding area in the event of an accident and examined the change in radiation dose according to distance. His work also included a review describing the technical characteristics of small modular reactors.

(Hussein, 2020), conducted a critical review of developing small modular reactors, evaluating them under the headings of small size, modularity, and design, and classifying them technically.

3. NUCLEAR ENERGY

Nuclear energy is a type of energy obtained by the controlled release of the binding energy in the atomic nucleus. This energy is released through the splitting (fission) or merging (fusion) of atomic nuclei. The most widely used method today is the fission of heavy atoms, particularly uranium or plutonium(Бартоломей et al., 1989).

In the fission process, when an atomic nucleus is bombarded by a neutron, it splits, releasing new elements, neutrons, radiation, and energy. The newly formed neutrons strike heavy atoms, causing the fission to continue in a chain reaction, while the energy released heats the coolant (water, heavy water, sodium, etc.), enabling steam production. This steam turns turbines, converting thermal energy into mechanical energy, and mechanical energy into electrical energy(Raymond L. Murray, 2001).

$$ {}_{0}n^{1} + {}_{92}U^{235} \longrightarrow {}_{56}Ba^{144} + {}_{36}Kr^{89} + {}_{0}n^{1} + 210\ \text{MeV} $$

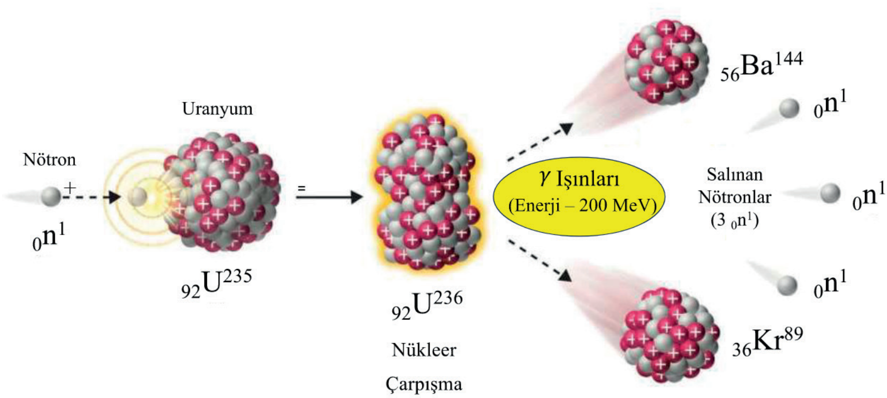

Figure 1 Fission reaction illustration (Alahmad & Taskesen, 2024)

In a chain reaction, there is no carbon emission during the splitting of atoms. In this respect, nuclear energy provides a significant advantage in terms of environmental sustainability. However, due to its radioactivity, it brings with it important challenges such as the safe disposal of nuclear waste and the prevention of accidents. For this reason, the use of nuclear energy must be carefully considered in terms of its economic, environmental, and safety dimensions(Igor Pioro, 2016).

3.1. Nuclear Power Plants

Nuclear power plants are facilities that generate electricity using the energy released by the splitting of atomic nuclei (fission). Most of these plants use enriched uranium as fuel. Enrichment levels vary depending on the coolant and moderator used(Rubinsteyn & Sepetilnikov, 1982).

The heat generated by fission is transferred to the steam boiler via the coolant. Steam is produced in the steam boiler. The steam enters the turbine and causes it to rotate. During this rotation, electricity is generated by the generators. The steam used in the turbines condenses with the help of a condenser and returns to the steam boiler as water. This creates a closed cycle(Курчатовский, 2015).

The moderator, fuel, coolant, and cycle type used in a nuclear power plant are the factors that determine the basic structure of the plant. The moderator helps the chain reaction occur in a controlled manner. The choice of moderator depends on the fuel used and the enrichment ratio. The type of cycle is selected based on the coolant used and cost considerations. In plants with two or more cycles, the coolant is safer because it is not exposed to radiation in the second cycle and beyond. However, costs increase due to the additional equipment required(Андрушечко et al., 2010).

Pressurized water reactors (PWR) are the most widely used reactor type worldwide. PWRs use light water as both the coolant and moderator. In reactors that use light water as a moderator, the enrichment ratio of the fuel is higher than in heavy water reactors(Canada deuterium uranium- CANDU)(Kemah, 2017). Economic criteria and available reserves are evaluated when selecting the moderator and fuel.

3.1.1. Classification of Nuclear Power Plants

Nuclear reactors are classified according to their purpose of use as research reactors, commercial reactors, and military reactors. Research reactors are used for nuclear testing rather than for electricity generation. Commercial reactors are used for purposes such as electricity and heat generation, water purification, and providing propulsion power to icebreakers and submarines(Ahmet Ege, 2019).

Based on installed power, they are classified as micro, small, medium, and high-power reactors. Microreactors are generally reactors with an installed electrical power not exceeding 20 MWe. Small modular reactors are reactors with an installed electrical power of to 300 MWe. Medium-power reactors are reactors with an electrical power between 300 MWe and 700 MWe. Reactors with an electrical power output exceeding 700 MWe are classified as high-power reactors(IAEA, 2024c; Liou, 2023; Rowinski et al., 2015).

One of the criteria determining safety in nuclear reactors is the generation to which the reactor belongs. Reactors produced between 1950 and 1970 are referred to as first-generation reactors, those between 1970 and 1995 as second-generation, those between 1995 and 2030 as third-generation, and new-generation reactor projects as fourth-generation reactors. Lessons have been learned from past accidents in new generation reactors, and passive safety systems have been enhanced(Rowinski et al., 2015).

Nuclear reactors go through the following stages from the project phase to commissioning: preliminary design, basic design, conceptual design, detailed design, licensing, equipment manufacturing, and construction(IAEA, 2024a).

4. SMALL MODULAR REACTORS IN THE CONSTRUCTION PHASE AND IN OPERATION

4.1. CAREM

CAREM (Central Argentina de Elementos Modulares) is a small modular reactor of the pressurized water reactor (PWR) type. Developed and manufactured in Argentina, CAREM is designed to meet the electricity needs of small regions. In addition to electricity generation, also planned for use for desalination of seawater(Magan et al., 2011).

The Argentine National Atomic Energy Commission (CNEA) has granted a construction license for CAREM-25, which was initially designed as a prototype. The construction license for CAREM-25 was obtained in 2013, and construction began in 2014. CAREM-25 is planned to pioneer Argentina's future SMR projects and serve as a model for production and licensing processes. Construction of CAREM-25 was suspended for two years in November 2019 and resumed in 2021. The target date for first criticality is 2027(WNN, 2024a).

Table 1 CAREM-25 Technical Specifications(Marcel et al., 2013; Tashakor et al., 2017)

Country	Argentina
Electric Power	32 MWe
Reactor Type	Pressurized Water Reactor (PWR)
Coolant and Moderator	Water
Primary/Secondary Cycle Pressures	12.25 MPa / 4.7 MPa
Reactor Length / Width	11 m / 3.2 m
Fuel Type	UO_2 (3.1% enrichment rate)
Fuel Cycle	14 months
Reactor Lifespan	40 Years

The CAREM-25 reactor core is cooled by natural circulation of water. Natural circulation is a convective cooling method that does not require pumps. This minimizes equipment and maintenance costs while ensuring natural cooling under all conditions. As shown in Figure 2, the steam generators are mounted on the reactor vessel. Coolant water and moderators absorb heat from the core, rise, and reach the steam generator. The water transfers its heat to the steam generator and moves downward. This creates natural circulation(Ganjaroodi et al., 2024).

The CAREM-25 reactor is considered a prototype for small modular reactors with an electrical power output between 100 MWe and 300 MWe. It is intended that the data obtained from CAREM-25 and the operational experience gained will be used in future planned small modular reactor projects(Tashakor et al., 2017).

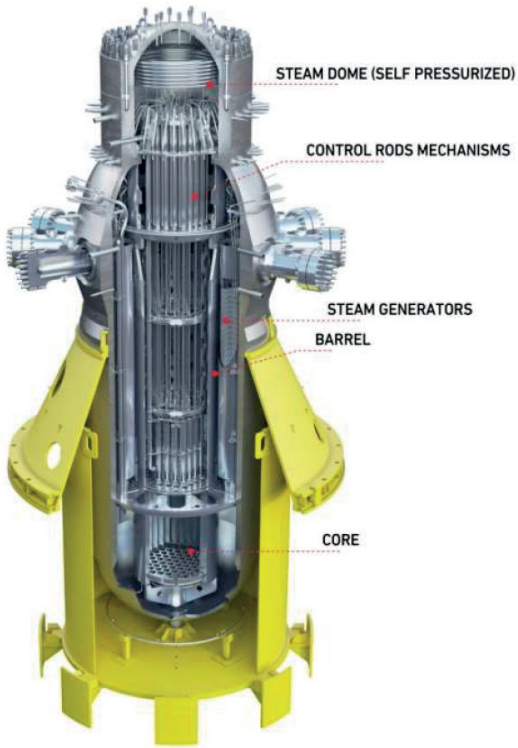

Figure 2 CAREM-25 Reactor Vessel (IAEA, 2022)

4.2. ACP-100

The ACP-100 reactor is a PWR-type small modular reactor designed by the China National Nuclear Corporation (CNNC). Its intended uses are for electricity generation, heat production, and seawater desalination(Ishraq, Rohan, et al., 2024).

The ACP-100 reactor was the first small modular reactor to pass the safety review by the International Atomic Energy Agency (IAEA) in 2016. The China National Nuclear Corporation (CNNC) announced the start of construction of the ACP-100 reactor in 2019, with the first concrete pouring taking place in July 2021. Construction of the reactor building was completed in 2023. The reactor is scheduled to enter commercial operation in 2026(WNN, 2024b).

Table 2 ACP-100 Technical Specifications (Ishraq, Kruglikov, et al., 2024)

Country	China
Electric Power	125 MWe
Reactor Type	Pressurized Water Reactor (PWR)
Coolant and Moderator	Water
Primary/Secondary Cycle Pressures	15 MPa / 4.6 MPa
Reactor Length / Width	10 m / 3.35 m
Fuel Type	UO_2 (enrichment ratio 1.9-4.95%)
Fuel Cycle	24 Months
Reactor Life	60 Years

In the ACP-100 reactor, the circulation of cooling water between the reactor core and the steam generator is provided by a pump. Unlike classic high-power PWR reactor designs, the main circulation pumps and steam generator are integrated into the reactor vessel. The ACP-100 reactor has a passive cooling system in addition to the active cooling system. The passive cooling system allows the reactor to cool itself by natural circulation under all conditions(Deng et al., 2020; Xiong et al., 2023).

Mounting the main components to the reactor vessel ensures the reactor's compactness, thereby enabling its use in various types of projects.

Figure 3 ACP-100 Reactor Vessel (Deng et al., 2020)

4.3. HTR-PM

The HTR-PM reactor is a fourth-generation gas-cooled reactor operating at high temperatures. Its initial design was developed by Tsinghua University in 1992 as the HTR-10 with a 10 MWe electrical power capacity. The HTR-10 was operated at full capacity in 2003 and served as a reference for the HTR-PM, which received its construction license in 2012. HTR-PM reached criticality in 2021 and was operated at full power (210 MWe) in 2022(IAEA, 2022; J. Zhang et al., 2018).

Table 3 HTR-PM Technical Specifications(S. Wu et al., 2023; Z. Zhang et al., 2006)

Country	China
Electrical Power	210 MWe
Reactor Type	High-Temperature Gas-Cooled Reactor (HTGR)
Coolant / Moderator	Helium / Graphite
Primary / Secondary Cycle Pressures	7 MPa / 13.25 MPa
Reactor Length / Width	25 m / 5.7 m
Fuel Type	Pebble bed (spherical, 7 grams) UO_2 (8.5% enrichment)
Fuel Cycle	Continuous (Used fuel can be taken out for interim storage, new fuel can be added)
Reactor Lifespan	40 Years

In the HTR-PM reactor, the fuel consists of five-layered spheres weighing 7 grams. At the center of the sphere is UO_2(Uranium dioxide), while the outer layers consist of pyrocarbon and silicon-carbon carbide coatings of low, medium, and high densities. This allows the high temperature generated at the center of the sphere to be transferred to the coolant in a balanced manner, while limiting the radiation escaping from the sphere's center (Knol et al., 2018).

Fuel spheres can be removed from and added to the reactor as they are used (B. Wu et al., 2022). The ability to change fuel without stopping the reactor ensures continuity in electricity production.

The HTR-PM reactor has two reactor modules and two steam boilers. The heat generated by the fuel is transferred to the steam boiler via helium gas. Helium gas entering the reactor at a temperature of 250 °C heats up to 750 °C, exits the reactor, and enters the steam boiler. The helium gas is returned to the reactor by a compressor. The feed water entering the steam generator is converted into steam at a temperature of 567 °C and enters the turbine(S. Wu et al., 2023).

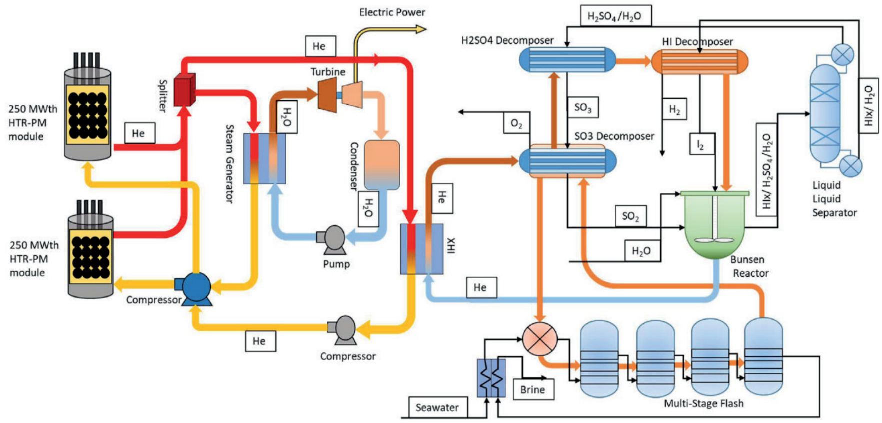

Figure 4 HTR-PM Cycle Diagram(González Rodríguez et al., 2023)

4.4. KLT-40S

The KLT-40S reactor is the first floating nuclear power plant project designed by the Afrikantov OKBM company. The aim of the project is to make the nuclear power plant mobile and deliver electrical energy to regions in need. The construction process of nuclear power plants is long and complex. Building a nuclear power plant in areas where land transportation is difficult is quite costly and complex. The KLT-40S reactor, together with the ship named Akademik Lomonosov, has solved this problem by operating as a floating power station(Макеев, 2015).

The KLT-40S reactor reached criticality in 2018, was shipped to the city of Pevek in the far north of Russia in 2019, and began generating electricity in 2020(Maksimov & Mazjarkin, 2023).

Table 4 KLT-40S Technical Specifications (Bagus Awienandra et al., 2020; Beliavskii et al., 2023)

Country	Russia
Electrical Power	35 MWe
Reactor Type	Pressurized Water Reactor (PWR), Ship-mounted reactor vessel
Coolant and Moderator	Water
Primary/Secondary Cycle Pressures	12.7 MPa
Reactor Length / Width	4.8 m / 2 m
Fuel Type	UO_2 (14.1-18.6% enrichment)
Fuel Cycle	28-36 months
Reactor Lifespan	40 Years

The Akademik Lomonosov ship consists of two KLT-40S reactors, each with a capacity of 35 MWe. The heat generated in the reactor core is transferred to the steam boiler via circulation pumps. The steam generated in the steam boiler drives the turbines to produce electrical energy. The electrical energy is transferred from the port where the ship docks to the region's electrical grid(Зверев et al., 2018).

The KLT-40S reactor is used for city heating when needed, in addition to the electricity it produces. The Akademik Lomonosov ship provides electricity to the city of Pevek with the energy it produces, while also playing a role in heating the city(Макеев, 2015).

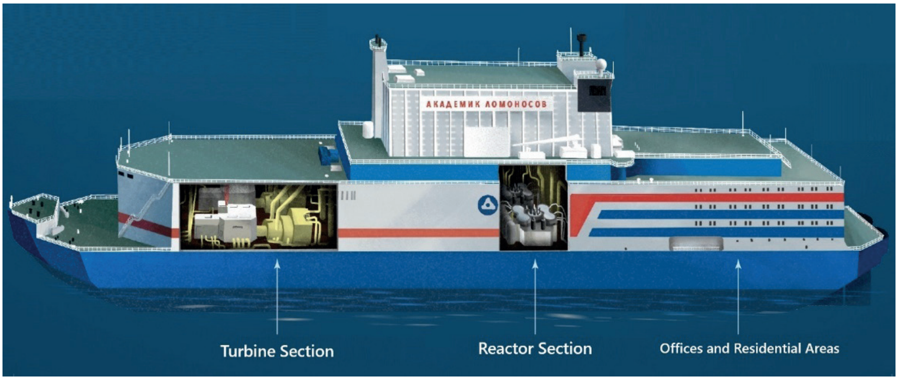

Figure 5 Akademik Lomonosov Ship(TACC, 2022)

4.5. RITM-200

The RITM-200 reactor was designed by Russia to power icebreaker ships. It was first installed on the Arktika icebreaker in 2016, and the ship entered service in 2020. Subsequently, the Sibir icebreaker in 2021 and the Ural icebreaker in 2022 were commissioned with the RITM-200 reactor. The Yakutiya icebreaker is expected to be commissioned with the RITM-200 reactor in 2025, followed by the Chukotka icebreaker in 2026(Атомная, 2024).

Afrikantov OKBM, which designed the RITM-200 reactor, also designed the nuclear power plant version of the reactor, RITM-200N, in 2018 for installation in the Yakutsk region. Construction of the Yakutsk Nuclear Power Plant, for which a license was obtained in 2023, is scheduled to be commissioned in 2027(Базин & Гиниятуллин, 2022).

Table 5 RITM-200 Technical Specifications (Petrunin et al., 2019)

Country	Russia
Electrical Power	55 MWe
Reactor Type	Pressurized Water Reactor (PWR),
Coolant and Moderator	Water
Primary/Secondary Cycle Pressures	15.7 MPa / 3.83 MPa
Reactor Length / Width	7.5 m / 3.4 m
Fuel Type	UO_2 (up to 20% enrichment rate)
Fuel Cycle	5-7 years
Reactor Life	60 Years

The RITM-200 reactor vessel is compactly designed to minimize the risk of damage to pipe and equipment connection points during ship motion. The steam generator, circulation pumps, and reactor vessel are integrated into a single unit. This design minimizes the installation volume while enabling the simultaneous use of multiple reactor vessels, thereby allowing for higher power outputs(Zverev et al., 2013, 2019).

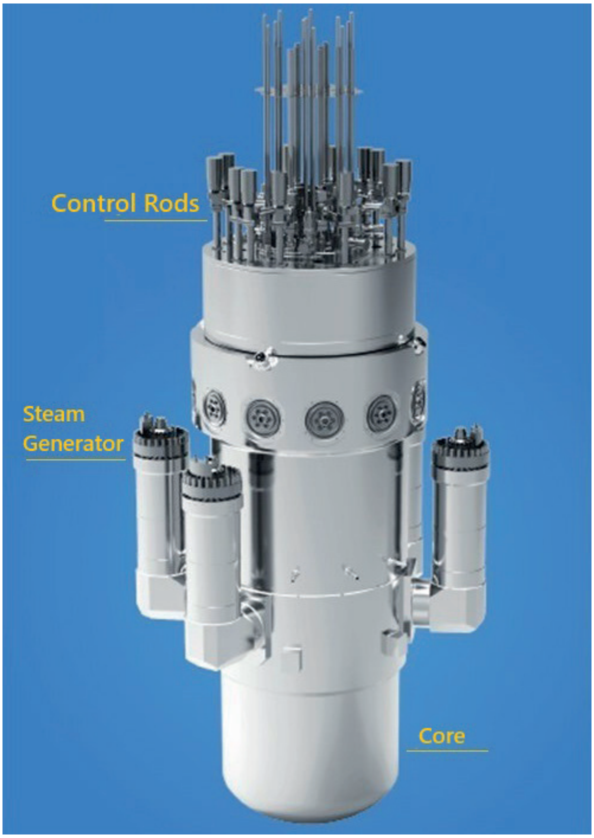

Figure 6 RITM-200 Reactor Vessel(Zavodfoto, 2022)

4.6. BREST-300

BREST-300 is a lead-cooled fast neutron reactor. The BREST-300 reactor was designed by Russia in 2016, and construction began in the city of Seversk in 2021. The reactor is scheduled to be commissioned between 2028 and 2029. Once commissioned, the BREST-300 reactor will also play a role in city heating in addition to electricity generation(Interfax, 2024).

The BREST-300 reactor uses a mixed fuel derived from spent nuclear fuel from other power plants. This allows for the recycling of spent nuclear fuel while generating electricity(ФЭИ, 2024).

Table 6 BREST-300 Technical Specifications(Makarov, 2023; Novoselov et al., 2014)

Country	Russia
Electrical Power	300 MWe
Reactor Type	Lead-Cooled Fast Neutron Reactor (BREST)
Coolant and Moderator	Lead
Primary/Secondar Cycle Pressures	Atmospheric Pressure / 18.5 MPa
Reactor Length / Width	17.5 m / 26 m
Fuel Type	Uranium, Plutonium, Nitride Mixture (MOX-Mixed Oxide Fuel)
Fuel Cycle	5-7 Years
Reactor Lifespan	30 Years

The core coolant of the BREST-300 reactor is liquid lead, which reaches its boiling point at 1727 °C. When the reactor is in operation, the coolant reaches a maximum temperature of 420 °C, allowing the reactor vessel to operate at atmospheric pressure. This reduces material costs and eliminates safety risks associated with pressure. Thanks to the fuel mixture used, the reactor can reduce its own reactivity in the event of reactivity increases(Gol'din & Pestryakova, 2014; ФЭИ, 2024).

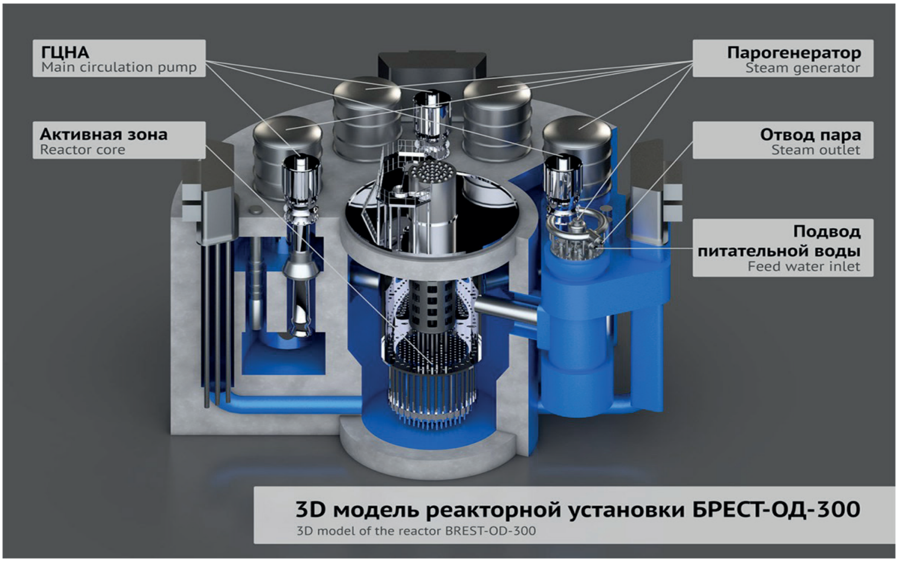

Figure 7 BREST-300 Reactor Vessel(Orlov & Gabaraev, 2023)

4.7. KP-FHR

The KP-FHR reactor is a fourth-generation molten salt-cooled pebble-bed reactor. This advanced reactor technology was designed by the American company Kairos Power with the aim of reducing production and maintenance costs without compromising safety. The conceptual design of the KP-FHR reactor was completed in 2018, and construction of the first engineering test unit (ETU 1.0) began in 2021 and was completed in 2023. In 2024, construction of the Hermes test reactor began in Tennessee, with commissioning expected in 2026(IAEA, 2024b).

Table 7 KP-FHR Technical Specifications(Kairos, 2024; Zhao et al., 2023)

Country	United States
Electrical Power	140 MWe
Reactor Type	Pebble Bed Molten Salt Reactor
Coolant / Moderator	Li_2BeF_4 (Flibe) / Graphite
Primary / Secondary Cycle Pressures	Atmospheric Pressure
Reactor Length / Width	7.2 m / 3.9 m
Fuel Type	TRISO Pebble Bed (up to 19.75% enriched)
Fuel Cycle	Continuous (Used fuel can be taken out for storage, new fuel can be added)
Reactor Lifespan	80 Years

The KP-FHR reactor is a state-of-the-art, innovative, fourth-generation reactor that uses fluoride salt for cooling in its first cycle and gravel-bed fuel in its core. Using fluoride salt for core cooling, the first cycle can reach temperatures up to 650 °C at atmospheric pressure. The absence of high pressure in the reactor vessel enhances safety by preventing pressure-induced explosions. It also significantly reduces the cost of the equipment used(Zhao et al., 2023).

The heat generated in the reactor core is transferred to the intermediate heat exchanger via a fluoride salt coolant. In the intermediate heat exchanger, the second-cycle water heats up and enters the steam boiler. In the steam boiler, the third-cycle water vaporizes and drives the turbines. The steam used is condensed in the condenser and converted back into water. This completes the cycle(Łukasz Bartela et al., 2021).

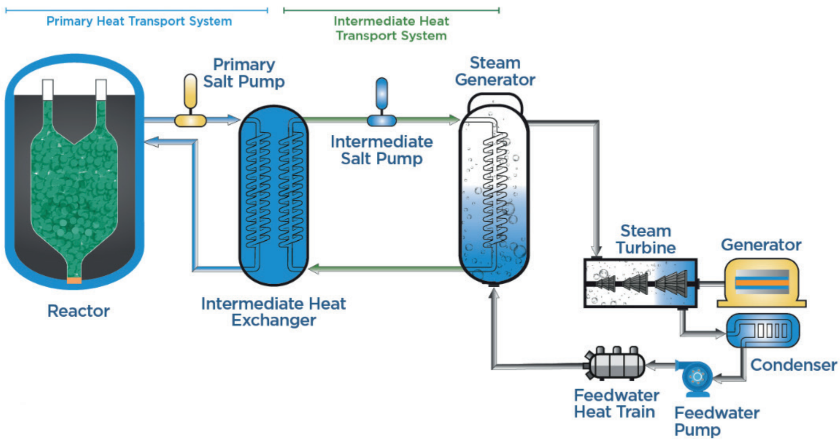

Figure 8 KP-FHR Cycle Diagram(Kairos, 2024)

4.8. Small Modular Reactors in the Design Phase

Small modular reactors have become quite popular as an energy solution in the energy race between countries. Countries have begun to create numerous designs to produce their own small modular reactors. This article examines small modular reactors that are under construction and in operation; reactors in the design phase are classified in Table 8 according to International Atomic Energy Agency records.

Table 8 Small modular reactors under design(IAEA, 2024b, 2024a)

Design Name	Electrical Power MWe	Designer Country	Status
Water-Cooled Reactors (Pressurized, Boiling)			
AP300	330	USA	Basic design
BWRX-300	300	USA, Japan	Detailed design
HAPPY200	200	China	Detailed design
i-SMR	170	South Korea	Conceptual design
NuScale	77	United States	Detailed design
PWR-20	20	USA	Detailed design
NUWARD	170	France	Detailed design
STAR	10	Switzerland	Basic design
VBER-300	325	Russia	Detailed design
ABV-6E	9	Russia	Detailed design
BANDI	60	South Korea	Conceptual design
High-Temperature Gas-Cooled Reactors			
EM2	265	USA	Conceptual design
FMR	50	USA	Conceptual design
GTHTR300	300	Japan	Basic design
GT-MHR	288	Russia	Basic design
HTMR-100	35	South Africa	Basic design
MHR-100	87	Russia	Conceptual design
HTGR-POLA	11.5	Poland	Basic design
PeLUIt-40	10	Indonesia	Conceptual design
Fast Neutron Reactors			
4S	10	Japan	Detailed design
ARC-100	100	Canada	Conceptual design
HEXANA	150	France	Conceptual design
LFR-AS-200	200	Italy / France	Conceptual design
OTRERA 300	110	France	Conceptual design
SEALER-55	55	Sweden	Conceptual design
SVBR-100	100	Russia	Detailed design
Natrium	345	USA	Conceptual design
Molten Salt Reactors			
CA Waste Burner	100	Denmark	Detailed design
CMSR	110	Denmark	Conceptual design
Flex Reactor	24	United Kingdom	Basic design
FUJI	200	Japan	Conceptual design
IMSR 400	195	Canada	Detailed design
Stellarium	110	France	Conceptual design
ThorCon	250	Indonesia / USA	Conceptual design
Thorizon	100	Netherlands / France	Conceptual design
XAMR	40	France	Conceptual design

5. TÜRKIYE'S STRATEGY AND POSITION ON SMALL MODULAR REACTORS

Türkiye imports a large portion of the energy sources it uses. Dependence on foreign energy threatens energy security. In this context, nuclear power plants increase countries' energy security thanks to their continuity and high power production(Furuncu, 2016).

Türkiye has not yet joined the ranks of countries that generate electricity from nuclear power plants. The Akkuyu Nuclear Power Plant, whose construction began in 2018, will be Türkiye's first nuclear power plant. The Akkuyu Nuclear Power Plant will have an electrical capacity of 4800 MWe and will consist of four high-power reactors. Secondly, a high-power nuclear power plant is planned to be built in Sinop province in Türkiye. The third high-power nuclear power plant is planned to be built in the Thrace region(Karataşlı, 2020; NDK, 2024; Polatoğlu, 2024).

The Ministry of Energy and Natural Resources stated that Türkiye signed the "Tripling Nuclear Energy" declaration, which includes 31 countries, at the 29th Conference of the Parties (COP29) to the United Nations Framework Convention on Climate Change held in Baku. It was stated that within this scope, the goal is to increase the installed electricity capacity to 20GWe from nuclear energy, by 2050. The statement indicated that, following the Akkuyu Nuclear Power Plant, two more high-power nuclear power plants are planned, and in addition to high-power plants, new generation modular reactor projects are also planned. The planned projects will contribute to a significant reduction in carbon emissions by 2050(ETKB, 2024).

Energy and Natural Resources Minister Alparslan Bayraktar stated that they were open to cooperation with the Chinese nuclear energy company CNOS for new generation modular reactors. In the United States Minister Bayraktar announced that small modular reactors have an important place in Türkiye's energy planning and invited American nuclear energy companies to invest in small modular reactor projects planned in Türkiye(CNBC-e, 2024; Okay & Gökkoyun, 2024).

President Recep Tayyip Erdoğan announced on March 26, 2025, that Türkiye would begin developing its own Small Modular Reactor (SMR) design as part of its 2030 Industry and Technology Strategy and that a nuclear technology park would be established for this purpose. This officially marked the beginning of the "domestic SMR era" in Türkiye's energy and industrial policies. The program's financing model has been structured in phases: State-guaranteed purchase agreements will be implemented for the first two or three modules to be constructed, while new modules in subsequent phases are expected to be supported by low-interest green bonds and export credits.

In terms of industry, maintaining a high domestic contribution share has been designated a strategic priority. The goal is for at least 40–50% of large-scale equipment, such as reactor pressure vessels and heat exchangers, to be produced domestically, while support will be provided to companies operating in the nuclear technology park for the production of the remaining parts. This approach will ensure that a large portion of the project value remains within the country while also increasing technology transfer and skilled employment. In this way, Türkiye will take a step that will increase its global competitiveness not only in terms of energy supply security but also in terms of advanced technology production and export potential(Anadolu Ajansı, 2025b, 2025a).

The "Nuclear Energy Technologies Design Competition" organized by TEKNOFEST aims to develop innovative solutions in the areas of innovation, safety, efficiency, and sustainability, focusing particularly on Small Modular Reactor (SMR) designs. This competition will increase focus on SMR among universities, academics, and industry professionals, thereby encouraging young and competent designers to enter this field. Therefore, the academic and technical awareness provided by the competition will directly contribute to both an increase in the number of SMRs and the development of the modular reactor sector equipped with domestic technologies(TEKNOFEST, 2025).

Within the scope of its defense industry vision, Türkiye has also included preparations for nuclear propulsion technologies in its National Aircraft Carrier and National Nuclear Submarine projects. The experience gained at Akkuyu, the new nuclear power plant projects planned in Sinop and Thrace, and small modular reactor (SMR) research are considered strategic steps that will also form the infrastructure for future defense-oriented nuclear power systems. Thus, Türkiye aims to increase its nuclear competence in both energy supply security and defense technologies(Hürriyet, 2025).

6. METHOD

This study was conducted to conduct a technical examination of small modular reactors under construction and in operation and to evaluate their current construction stages. The study employed a literature review and used secondary data studies as its methodology.

A literature review was conducted using the Web of Science, Springer, ScienceDirect, ProQuest, YÖK Tez, ResearchGate, EBSCO, Google Scholar, Taylor & Francis, and ELibraryRu databases. The keywords "Small Modular Reactor," "Nuclear Power Plants," "SMR Technology," and "Nuclear Energy Innovations" were used during the searches.

Publications on the applications and technical characteristics of small modular reactors in the energy sector were included in the study content, repetitive or off-topic data were excluded.

7. CONCLUSION, DISCUSSION, AND RECOMMENDATION

While nuclear energy offers an important solution to meet the growing energy demand, new generation small modular reactors are becoming an attractive energy source for countries due to their safety and applicability compared to traditional high-power reactors.

The technical specifications examined in the article show that small modular reactors have roles beyond electricity generation, such as water purification and propulsion power generation. The use and proliferation of modular reactors in different fields will lead to an overall reduction in carbon emissions. The safety standards and operational successes of existing reactors serve as a model for new-generation modular reactors.

From Türkiye's perspective, within the framework of its 2050 targets, the establishment of nuclear power plants is important in order to increase energy supply security, reduce external dependency, and lower carbon emissions in energy production. The establishment of nuclear power plants will enable the transfer of existing technology to local engineers and the planning of national projects. When selecting the small modular reactor project planned by Türkiye within the framework of its 2050 perspective, it is important to use reactor models that have operational experience, tested safety systems, and completed standards and regulations. In this context, pressurized water reactors can be considered a sound choice, as they have been in operation for many years in nuclear power plants of varying capacities.

In conclusion, new generation small modular reactors offer solutions for both the global energy transition and Türkiye's future energy strategy. The development and widespread adoption of small modular reactors will open a new door in energy policies and offer hope for a clean energy future.

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