Bharat Small Reactors

A Story of India's Nuclear Self-Reliance

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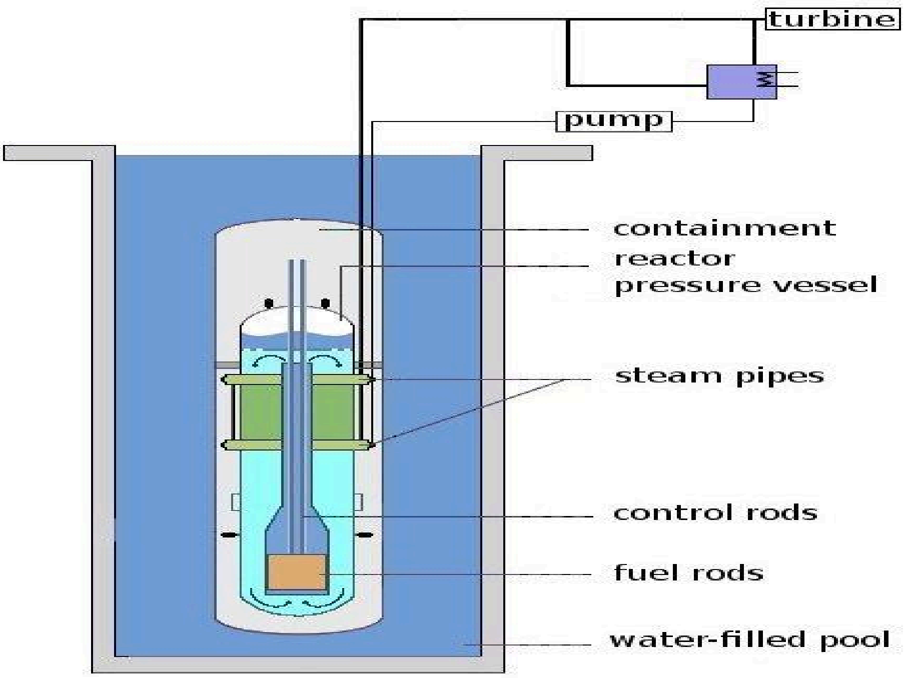
The Bharat Small Reactors are dense, 220 MWe Pressurized Heavy Water Reactors (PHWRs) which are based on India's proven nuclear technology. They are efficient, low-carbon, and flexible power generation systems, mainly used for nuclear industries or remote locations. They matter for India's energy goals to meet the clean energy targets and increase energy security. These goals include various aspects such as decarbonization and net-zero goals, reliable baseload power, industrial applications, fixed deployment, involvement of the private sector, and energy security and independence. The document outlines all the essential fundamental concepts of Bharat Small Reactors including their philosophy, development, importance, social and environmental significance, safety systems, fundamental process, advantages, applications, and brief understanding of future outlook, to give a comprehensive view of the crucial role of Bharat Small Reactors in India and globally.

Background of Nuclear Energy in India

The Bharat Nuclear Program was introduced by the remarkable scientist Homi J. Bhabha in the 1950s for India's self-reliance in nuclear energy. The Bharat Nuclear Program follows a three-stage plan which is used for long-term energy security by making use of the abundant thorium resources. The Bharat Nuclear Program advances from Pressurized Heavy Water Reactors (PHWRs) by using natural uranium to Fast Breeder Reactors (FBRs) that use plutonium to produce more fuel. Finally, advanced systems use thorium to generate fuel for the third stage. The Department of Atomic Energy (DAE) looks after this program whereas the Bhabha Atomic Research Centre (BARC) conducts the research, development, and training. The first PHWR was the Rajasthan 1, built in collaboration with Canada and started up in 1972. The second stage is the most important for maximizing energy output and making more use of thorium resources. The Prototype Fast Breeder Reactor (PFBR) is an essential part of this stage, with the Bhabha Atomic Research Centre (BARC)'s Fuel Fabrication Facility manufacturing its fuel elements. Lastly, the third stage is for the long-term goal which uses the abundance of thorium resources of India, implementing the advanced nuclear systems that are being developed by the Department of Atomic Energy (DAE) to produce fuel for the third generation of reactors. The DAE is responsible for the overall administration and execution of India's nuclear energy program, the parent body for organizations like BARC that guide the three-stages plan for energy security. The Bhabha Atomic Research Centre (BARC) was established by Bhabha in 1954 as named Atomic Energy Establishment, Trombay (AEET), later renamed BARC after his death in 1966, the main R&D hub for nuclear program, training school for developing experts for the program, and fuel and technology.

Emergence of Small Modular Reactors (SMRs)

The world is rapidly moving towards Small Modular Reactors (SMRs), mainly because of their potential to provide a flexible, cost-effective, and safe low-carbon energy source that complements intermittent renewables and aids global decarbonization efforts. India is constantly implementing this technology with the Bharat Small Reactor (BSR) project by the Bhabha Atomic Research Centre (BARC). The Small Modular Reactors are advanced nuclear fission reactors that typically have a power capacity of up to 300 MWe (megawatts electric) per unit, which is one-third of the capacity of traditional large-scale nuclear power plants. Their characteristics include the small size, factory production, safety enhancements, flexibility and scalability, and versatile applications. The world is shifting towards Small Modular Reactors (SMRs) because of several factors such as climate change mitigation, economic viability, energy security and stability, and serving a niche market. India's SMR technology is created to meet growing energy demands and achieve its clean energy transition goals with its commitment to achieve carbon neutrality by 2070. This includes the Bharat Small Reactor (BSR) project by the Bhabha Atomic Research Centre (BARC), whose design and development includes principles such as technology, application focus, and development model. India plans to develop five operational SMRs by the year 2033 as part of its Nuclear Energy Mission.



Concept of Bharat Small Reactors

The concept of India's indigenous initiative to use 220 MWe Pressurised Heavy Water Reactor (PHWR) technology for smaller, flexible, and industrial power generation, which aligns with the "Atmanirbhar Bharat" vision. This differs from the global Small Modular Reactor (SMR) trend, which mostly involves completely new designs.

Definition and Philosophy

The definition and design philosophy of Bharat Small Reactors are to differ from conventional nuclear plants, while global SMRs often have new designs (e.g. Pressurised Water Reactors). The BSRs are primarily based on India's created 220 MWe PHWR technology, which currently uses 16 operational reactors, increasing the decades of operational experience and an existing domestic supply chain. The focus is on targeted applications such as large, conventional plants that are not suited for certain purposes, like providing captive power to energy-intensive industries (e.g. steel, aluminum, cement) or supply of electricity to remote locations. Bharat Small Reactor can also be deployed at brownfield sites, for example to retired coal power plants or to repurpose existing infrastructure. The modular design concept includes faster construction and deployment in about 3-5 years compared to the long timelines which have 6-12 years of large plants. However, it is crucial to highlight that BSRs are not "factory-built and transportable" in the same way as some of the global SMRs. They are designed to be standardized for quicker assembly on-site using the domestic engineering and manufacturing base. The BSRs enhance the safety features that can cool during station blackouts without active power input, mostly requiring a smaller emergency planning (exclusion) zone than conventional large reactors.

Capacity and Scale

Output Range: BSR model has an electrical output of 220 MWe per unit.

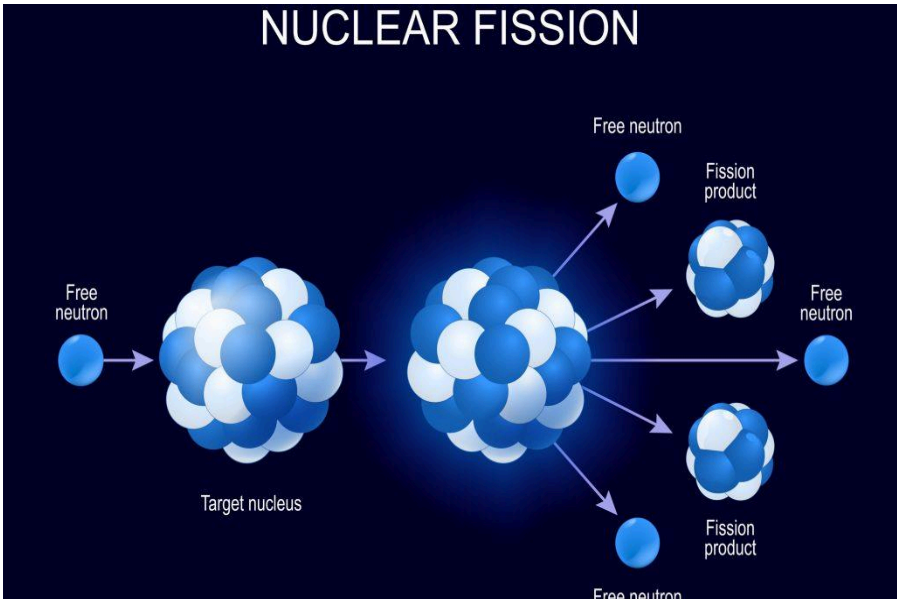
The Bhabha Atomic Research Centre (BARC) is also researching is also other SMR designs and technology with capacities of 55 MWe and a 200 MWe Bharat Small Modular Reactor (BSMR-200) based on PWR technology. Mostly India's standard large reactors are typically 700 MWe such as PHWRs (e.g., at Kakrapar and Rajasthan) or 1000 MWe+ imported Light Water Reactors (e.g., Kudankulam).

The Overview of Bharat Small Reactors' Working Principle

The working principle of a nuclear reactor includes the controlled nuclear fission chain reaction to generate heat, which is used to produce steam and electricity.

Fundamental Nuclear Fission Process

Nuclear fission is the process where a heavy atomic nucleus, such as uranium-235 or plutonium-239 splits into two smaller and lighter nuclei when it absorbs a neutron as a product. This process releases an intense amount of energy with gamma radiation and two or three high-speed neutrons. There starts a chain reaction, where the neutrons released from that fission strikes other fissile nuclei, which causes further fissions and a self-sustaining chain reaction. Additionally, the high-speed neutrons produced by those fissions are not efficient at causing further fission in the low-enriched uranium fuel used in commercial reactors, for this a neutron moderator such as light water is used to slow these neutrons down into "thermal neutrons", that increases its probability of being absorbed by fuel nuclei to continue the chain reaction effectively. Lastly the control rods which are made up of neutron-absorbing materials such as boron, cadmium, or hafnium are inserted into the reactor core to control the rate of the chain reaction and stop it from being uncontrolled.



Reactor Core and Coolant System

The core is the heart of the reactor which contains thousands of fuel rods bundled into assemblies with control rods and that is surrounded by the coolant or moderator. The fission reactions occur here which generates massive amounts of heat. A coolant such as light water, heavy water, or liquid metal is mainly circulated through the core to absorb the heat. In the Pressurized Water Reactor (PWR), the moderator is placed under very high pressure to spot it from boiling, and to transfer heat to a separate secondary water loop through a steam generator. Whereas, in the Boiling Water Reactor (BWR), the main moderator, water is allowed to boil within the core which directly produces steam. The produced steam is channeled to spin a large turbine generator, where the mechanical energy is converted into electrical energy with the generator, after that the cooled back and pump back into the system, to repeat the cycle.

Safety Systems

The nuclear reactors have multiple layers of safety systems to avoid accidents and contain radioactive materials safely.

Passive Safety Features

The passive safety features include safety systems that rely on natural forces such as gravity, natural circulation, or convection, which are often incorporated in modern designs.

Active Safety Features

The active safety features include powered pumps or human intervention systems such as automatic shutdown often by control rods that are typically held up by electromagnets; the power failure automatically causes them to shut down the fission chain reaction. The decay heat removal helps automatically inject heavy amounts of water into the reactor vessel to keep the fuel covered and cool, stopping from damage or melting, with the Emergency Core Cooling System (ECCS) because even after the automatic shutdown the radioactive decay continues to produce heat. Lastly the containment is used to prevent the release of radioactive materials into the environment in the event of an accident.

Applications

Civilian Applications

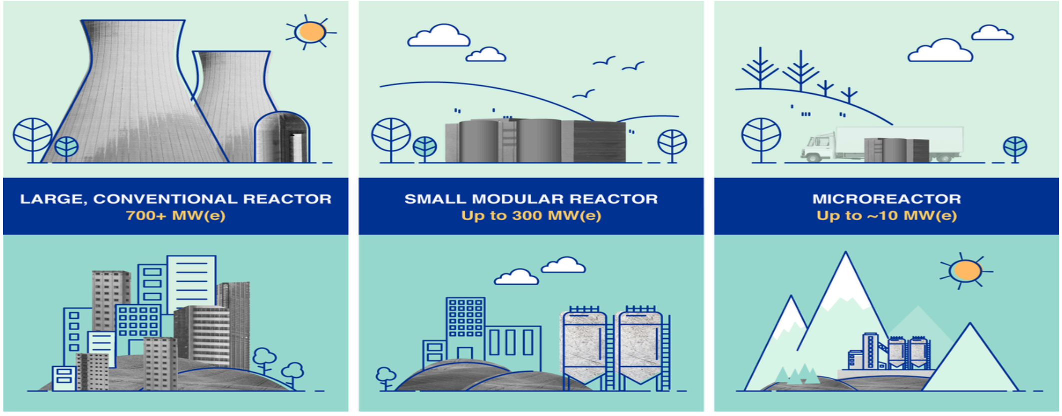
The SMRs offer a complete and flexible solution for providing reliable, low-carbon energy to areas that are difficult to connect to traditional large power grids such as power generation for rural and remote areas to provide consistent electricity supply in isolated communities, industrial sites, or islands, which decrease the dependency on fossil fuels. Industrial heat supply and desalination to provide high-temperature process heat for various industrial applications (e.g., chemical production, hydrogen production). The heat can also be used as a water purification process like desalination in water-scarce regions.

Defense and Strategic Applications

The complete and flexible nature of SMRs makes them highly relevant for various needs, especially in locations requiring durable, independent power sources such as potential use in naval propulsion (e.g. submarines) the nuclear reactors have powered submarines for decades. SMR technology could be adapted for advanced naval propulsion systems, providing long endurance without frequent refueling needs. Powering isolated military installations SMRs can offer a secure and reliable power source for forward operating bases or remote military installations, reducing the logistical challenges and vulnerabilities associated with transporting large volumes of fuel.

Research and Technological Applications

SMRs play an important role in advancing nuclear science and technology, serving as crucial tools for research and development such as SMRs can be used as training facilities for nuclear engineers, operators, and technicians. Some SMR designs can be used to produce medical or industrial isotopes. These smaller-scale, mostly more rapidly deployable reactors serve as testbeds for new materials, fuels, and innovative safety systems that could eventually be scaled up for larger reactors or next-generation designs.



Conclusion

In conclusion, the Bharat Small Reactors is the project introduced by brilliant scientist Homi J. Bhabha used to increase India's energy self-reliance and security which is the goal of "Atmanirbhar Bharat", the small reactors are not even being incorporated in India but globally. The uses of Small Modular Reactors (SMRs) can be in rural and remote locations as well as in defence and research technologies. The SMRs undergo three-stages of nuclear energy missions. The BSRs have a nuclear fission process following the chain rule and reactor core and coolant system that has some safety systems to avoid accidents and radioactive disasters. The program is incorporated smartly to avoid failures and implement technological advances for future outlooks.

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