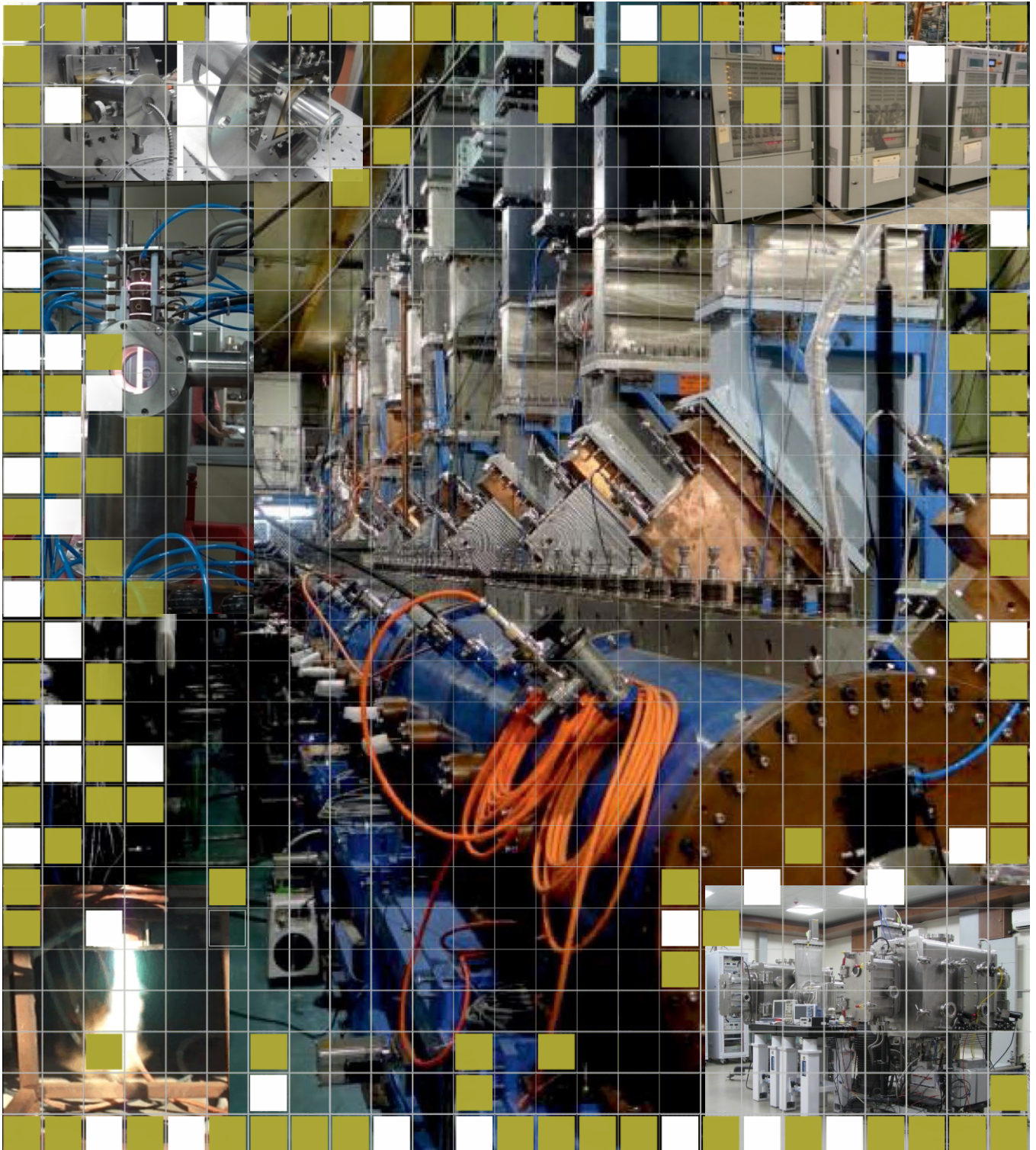


ACCELERATORS & LASER PROGRAMMES



THE ACCELERATORS AND LASER PROGRAMMES

vertical of DAE's Vision Programme outlines India's advancements in particle accelerator and laser technology for scientific, medical, and industrial applications. The accelerator segment highlights the development of indigenous high-intensity linear proton accelerators (such as MEHIPA and HEHIPA) in tandem with the development of Solid State Amplifier Systems as klystron substitute for accelerators among others. In parallel, the programme advances linear and electron beam accelerators for industrial irradiation of food and medical products. The segment on laser development enlists future plans for advanced laser facilities for applications ranging from material processing to high-energy physics. The range of multi-disciplinary activities underscore the shift towards self-reliance in high-technology materials.

Lasers, Plasma, Pulsed Power & Electron Beams

Laser and Plasma: Notable progress has been achieved in the area of laser and plasma technologies through the following developments. A 25 kW hollow-electrode (Cu), reverse-polarity thermal air plasma torch has been successfully simulated, designed, and fabricated. The torch employs an electromagnet-assisted vortex stabilization technique for arc stabilization. Endurance testing demonstrated a cumulative electrode life exceeding 150 hours under continuous 25 kW operation, confirming its reliability for sustained high-power plasma applications. A 13.56

MHZ RF-plasma system in a capacitively coupled configuration has been designed, fabricated, and commissioned to study enhancements in the etching process of CR-39 detectors used for neutron dosimetry through an interdivisional joint effort. Systematic variation of operating parameters enabled process optimization. Post-etching characterization revealed neutron track enlargement ranging from 3–30 μm , an average track density of 7984 ± 3171 tracks/ cm^2 , and a signal-to-noise ratio of approximately 3. These results demonstrate the promising potential of plasma-assisted etching for precise neutron track analysis in CR-39. A highly stable, low-divergence helium thermal plasma source that functions without the need for external magnetic fields to shape the plasma beam has been developed and successfully demonstrated. This innovation holds significant importance for plasma-material interaction studies under fusion-relevant conditions, particularly in the development of advanced diverter wall materials. The design and development of a laser-based end-shield alignment verification system has been completed. The system is capable of measuring radial offsets between end shields with an accuracy of 200 μm across a ± 2 mm range. The tool has been successfully tested on a mock-up facility at NPCIL's Kaiga Generation Station-1, and is currently being modified for enhanced site adaptability.

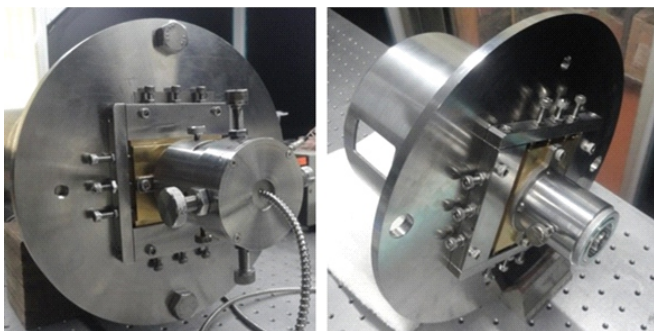
Advanced Tunable Laser: Advanced tunable lasers were utilized for cutting-edge research and development in emerging technologies, as well as for the production and analysis of medical isotopes with emerging applications in nano-scale brachytherapy, with a focus on enhancing indigenization. Efforts are also directed toward the development of advanced laser systems, alongside research initiatives in quantum computing.

Accelerator, Pulse Power & Electromagnetics: In alignment with its mandate to develop electron beam accelerators for societal applications, alongside electron beam and magnetic pulse systems for industrial purposes, a dual-energy S-band electron linear accelerator (Linac) based X-ray source suitable for cargo inspection has been successfully developed and characterized at a beam repetition rate of 400 Hz. This system will be installed at the Jawaharlal Nehru Port Trust (JNPT) site for field trials, where the necessary civil infrastructure development has already been initiated.

A compact X-band Linac developed for medical therapy has been fully characterized and is currently being integrated with a gantry system in collaboration with a private vendor.



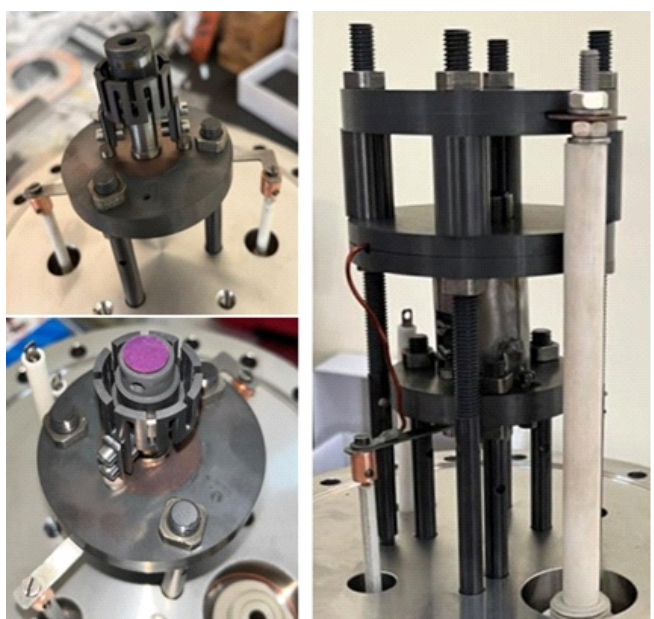
Non-divergent stable Helium thermal plasma.



Laser based end shield alignment verification system.



LESIMA laboratory in BARC for medical isotope production.



Graphite heater based 40 kV electron gun.

A 30 MeV Linac, comprising two cascaded 15 MeV Linacs, is under development for applications in radioactive ion beam generation and neutron radiography. The pre-buncher unit for this 15 MeV Linac has been successfully developed and tested. Additionally, a 100 kV, 20 kW electron beam welding gun has been designed and developed for joining thick refractory metals. The gun has been characterized, and preliminary weld trials were successfully conducted at reduced beam power.

Magnetic pulse welding (MPW) of a dissimilar tube assembly was also demonstrated using an indigenously developed MPW machine, with the joint successfully passing leak-tightness qualification tests.

The installation and commissioning of the capacitor bank system and power supply for the 1 MW plasma explosion setup at UCIL Narwapahar, intended for deployment in uranium mining operations, have been successfully completed at a depth level of 140 m. Site trials incorporating a 20 MJ chemical energy augmentation through Al-CuO thermite ignition were conducted successfully to optimize yield. Activities related to the design, fabrication, development, and testing of deuterated titanium targets for neutron generation have been initiated. In addition, the development of a graphite-heater-based 40 kV electron gun, offering several advantages over conventional tungsten-based heaters, has been successfully accomplished.

Indigenous SSPA Technology Roadmap for Accelerators

Indigenous Solid-State Power Amplifier Systems as Klystron Substitutes for Accelerators: BARC has embarked on the development of major particle accelerator projects, including those for Accelerator Driven Subcritical Reactor (ADS) systems. These accelerators impart energy to particle beams using radio-frequency (RF) power. For decades, klystrons (megawatt-level RF power generation devices used in high-power RF (HPRF) systems) have been the undisputed choice, sourced through imports. As part of the national drive toward self-reliance, BARC has undertaken the indigenous development of solid-state power amplifier (SSPA) systems.

Globally, leading particle accelerator laboratories have transitioned from klystrons to solid-state power amplifier systems. Although klystrons still provide very high peak power and efficiency at certain frequencies, ongoing research and development aim to address the challenges of SSPAs through advanced power-combining techniques and improved semiconductor technologies.

BARC is advancing indigenous SSPA technology through a coordinated focus on in-house innovation and by fostering a vibrant ecosystem that brings together research and development activities with active participation from small and medium enterprises (SMEs) and micro, small, and medium enterprises (MSMEs). These collective efforts are driving the pursuit of Aatmanirbhar Bharat (self-reliance) in solid-state power amplifier systems.

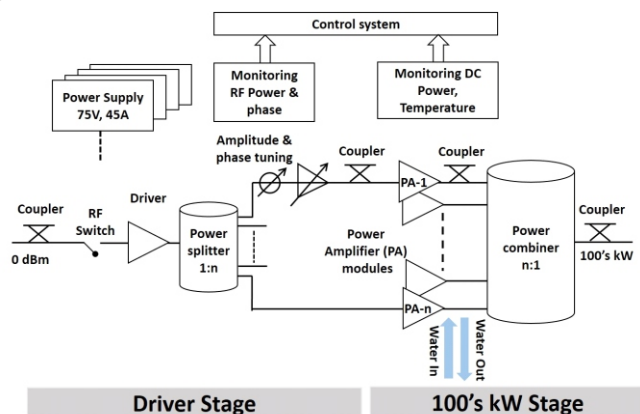
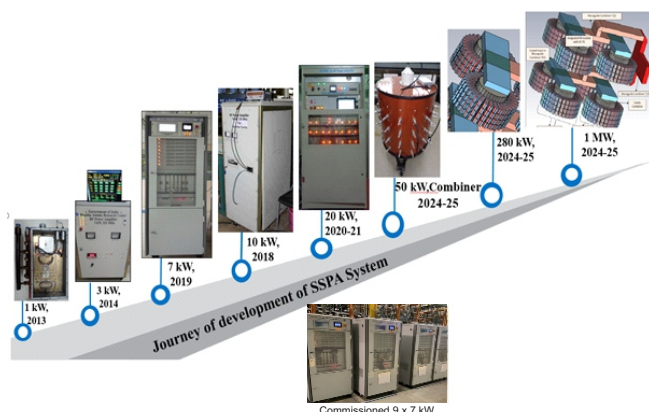
Roadmap Towards Indigenous SSPAs for Accelerators: Indigenous SSPA systems have been designed, developed, and deployed up to 20 kW capacity, including nine 7 kW SSPAs commissioned at the US-headquartered research laboratory Fermilab. As part of its strategic vision, BARC aims to extend these developments to 100 kW, 300 kW, and ultimately 1000 kW systems. These SSPAs are poised to replace the existing klystron-based RF systems across various accelerator platforms. The LDMOSFET-based SSPAs for accelerator applications offer significant advantages, including modularity, high power-added efficiency, reliability, low maintenance, and upward scalability. Their development integrates multidisciplinary expertise in high-voltage

engineering, RF, thermal management, applied physics, and innovative design, supported by experimental validation and stringent qualification protocols to ensure performance reliability in accelerator operations.

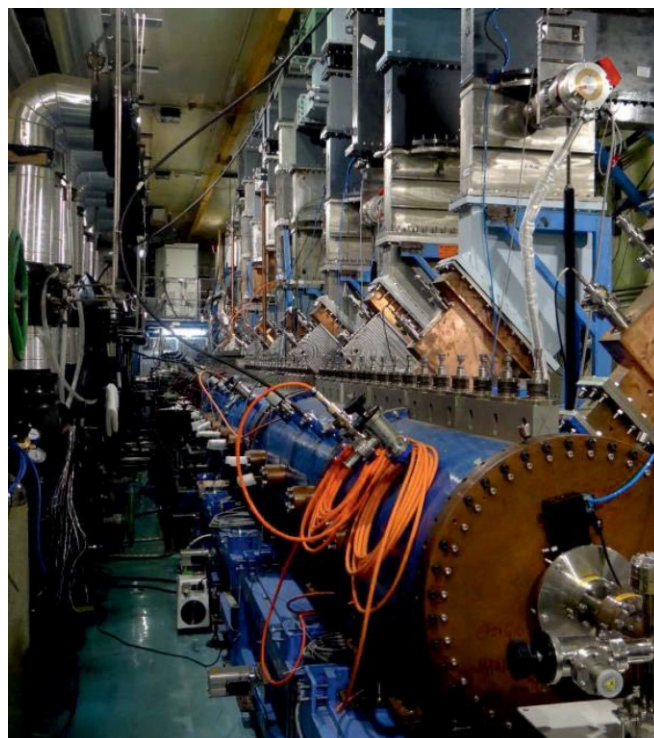
Proton Accelerators

Linear High Intensity Proton Accelerator: The accelerator technology primarily involves proton linear accelerators operating with high reliability and stability at high beam power, utilizing a series of electromagnetic cavities powered by RF amplifiers to incrementally boost beam energy. BARC demonstrated proton acceleration up to 20 MeV with a peak current of 2 mA. R&D effort is underway for reliable operation at high power levels.

Future Roadmap: The overall plan includes a phased development of a 1 GeV, 1 mA average beam current proton accelerator, designed to meet rigorous requirements for delivering high-current CW beams efficiently and reliably. The phased approach includes four key stages: MEHIPA-Phase I, which involves a front-end with an ion source and acceleration to 40 MeV; MEHIPA-Phase II, accelerating the beam to 200 MeV; HEHIPA-Phase I, raising the energy to 400 MeV; and HEHIPA-Phase II, culminating in an acceleration to 1 GeV for coupling to the ADS target. All these stages will utilize superconducting cavities and solid-state RF amplifiers.



Roadmap ahead of Indigenous SSPA systems' development & Architecture of 100's kW SSPA.



LEHIPA facility in BARC.