No power is as expensive as
no power...
Hyman G. Rickover

FORWARDING

Beams

Excellence in Lasers, Plasma, Electromagnetics & Quantum

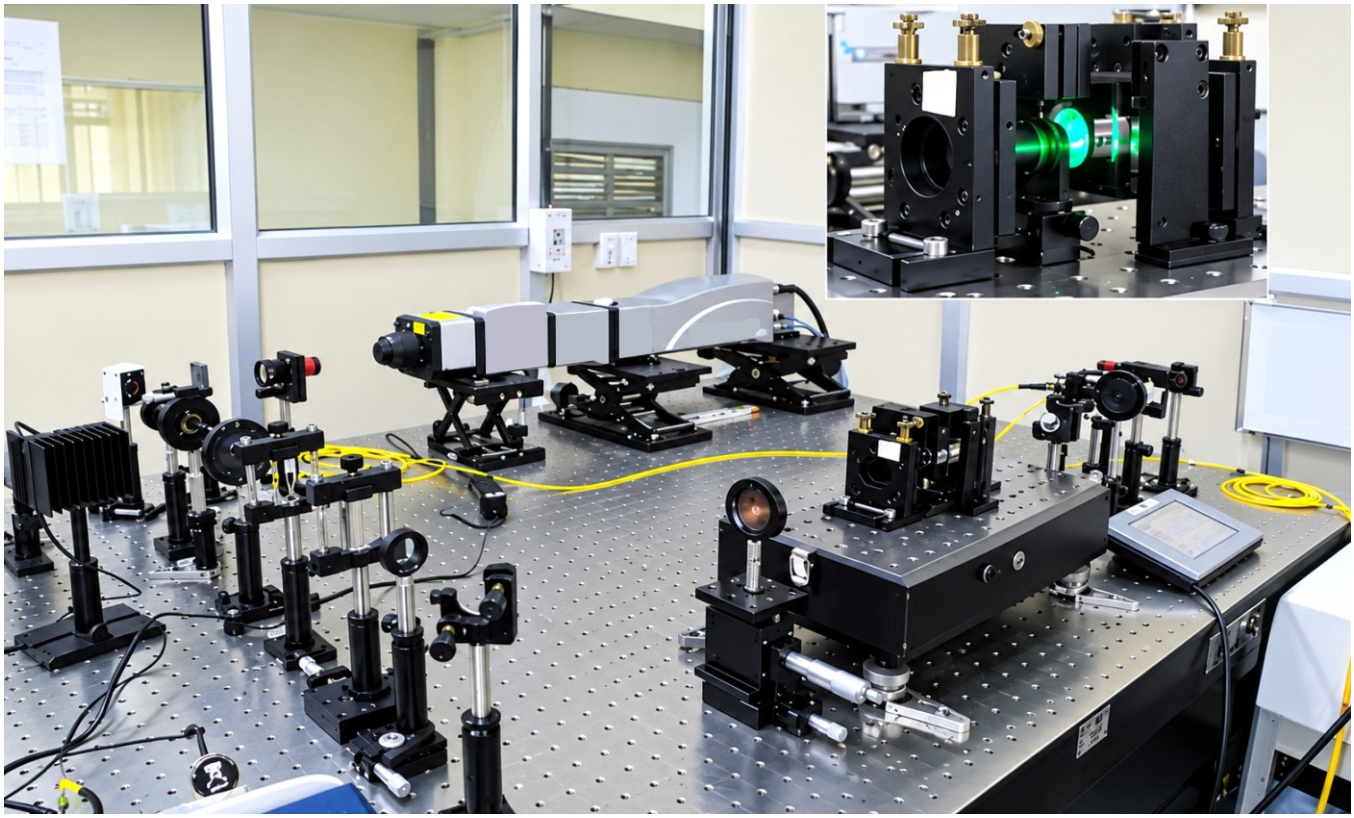
अग्रेषित किरणपुंज: लेसर, प्लाज़्मा, विद्युत चुंबक एवं क्वांटम में उत्कृष्टता

The development of enabling technologies in lasers, plasmas, and electron beams is an important research area at BARC, with applications spanning the front end and back end of the nuclear fuel cycle, as well as industrial and societal needs. Research in lasers focuses on the indigenization of widely tunable laser systems and their application in selective excitation schemes. Laser-based instrumentation is also being developed for reactor operations, security, and medical applications.

Plasma research emphasizes the development of industrial-grade torches for active waste incineration. Thermal plasma technologies for corrosion-resistant spray coatings and aerosol generation have attained maturity, while non-thermal plasma research addresses surface functionalization, NO_x generation, etching, and medical applications.

Electron beam activities include the development of electron accelerators, electron beam welding and melting systems, and non-thermal electron beam applications for sterilization, mutation, and wastewater treatment.

The scientific and R&D activities are organized under five major areas: Accelerator and Pulse Power, Advanced Tunable Laser Applications, Laser and Plasma Technologies, Pulsed

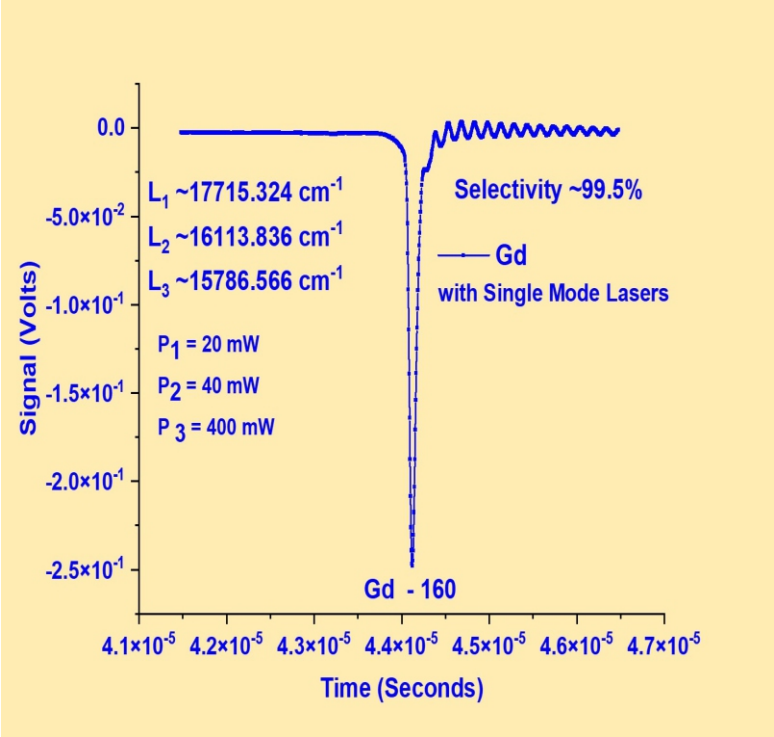


Tunable OPO set-up.

Power and Electromagnetics, and Trapped Ion Quantum Technology. Selected achievements are outlined below.

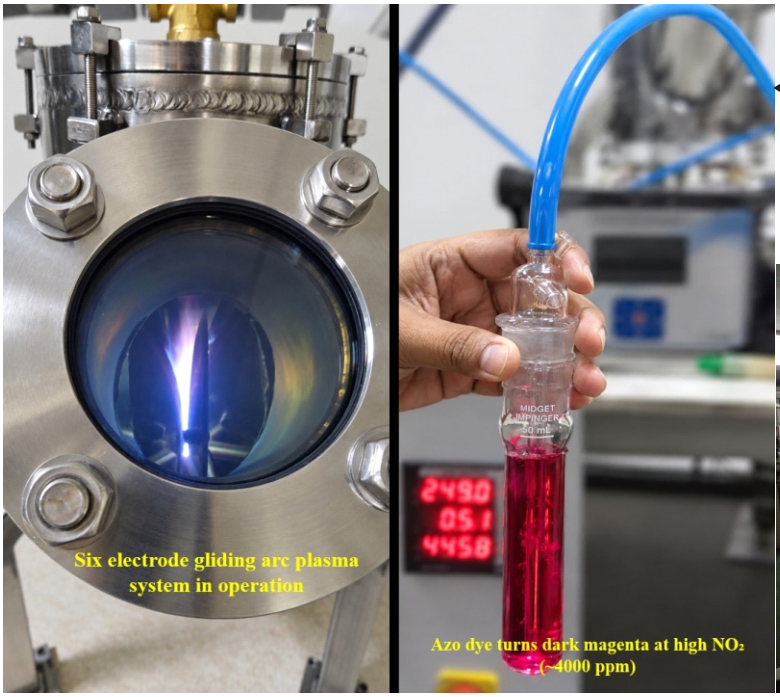
Advanced Tunable Laser Applications: Research focuses on developing technologies for producing enriched stable isotopes for medical and R&D applications. The production capacity of enriched Lu-176 was doubled to 10 mg/month. Approximately 100 mg of enriched lutetium, containing over 85% Lu-176, was produced and used to prepare 1200 Ci of Lu-177-based radiopharmaceuticals, contributing to the treatment of approximately 4800 patients across India. Ytterbium-176 (Yb-176) enrichment exceeding 99% isotopic purity was consistently achieved, surpassing the 95% requirement for producing Lu-177 through the no-carrier-added (NCA) route. Gadolinium-160 (Gd-160) feasibility studies demonstrated enrichment with over 99.5% spectroscopic selectivity using time-of-flight mass spectrometry (TOFMS), supporting future theranostic applications.

Laser and Plasma: Research in this area develops advanced laser and plasma-based technologies relevant to DAE programmes and relevant industrial and societal applications. For Tunable laser sources, an all-solid-state pulsed optical parametric oscillator, tunable across 400-700 nm with a spectral emission width as narrow as 170 MHz, was demonstrated for spectroscopy. A two-step picosecond laser



Gadolinium-160 (Gd-160) Spectrum SLM.

process for fabricating surface-enhanced Raman spectroscopy (SERS) substrates enabled detection limits of 10^{-10} M for rhodamine B and 10^{-7} M for crystal violet. Collaborative development within BARC resulted in fluorescence-based tabletop analysers for heparin and albumin, offering high sensitivity, good linearity, and response times of 1-2 minutes, advancing medical diagnostics. A yttria coating on graphite, incorporating a reactive silicon interlayer, demonstrated strong adhesion through repeated thermal cycles, indicating its suitability for nuclear applications. A cold atmospheric-pressure plasma system was developed for single-step synthesis of MXenes, two-dimensional advanced materials with potential applications in sensing and energy storage.



◀ *NO_x generation using gliding arc plasma torch.*

Laser surface modification using nano second pulsed laser in BARC.

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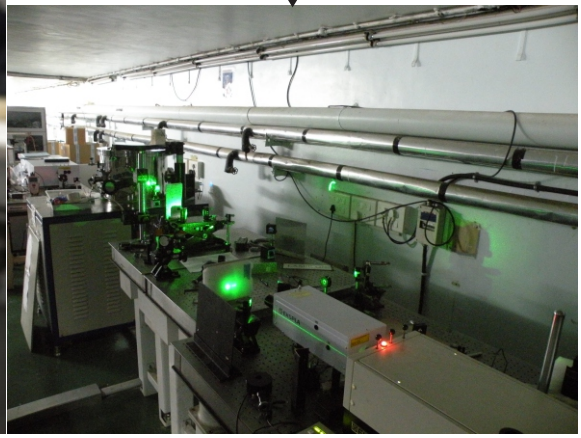

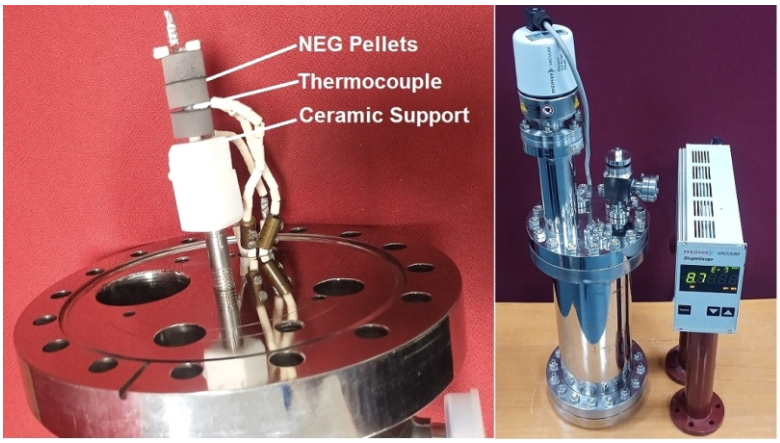

NEG pump and Sealed-off Vacuum Chamber.

An indigenous six-electrode gliding arc plasma system demonstrated on-demand production of NO_x-rich gas from compressed air. NO_2 concentrations exceeding 4000 ppm were achieved and independently validated using an electrochemical sensor and the Saltzman UV-V is spectroscopic method. The technology offers a potential alternative for NO-mediated plutonium valency adjustment in nuclear fuel reprocessing.

Pulsed Power and Electromagnetics: Key developments demonstrate the application of pulsed power and electromagnetic technologies to nuclear safeguards, accelerator systems, resource recovery, and advanced materials processing. An indigenously developed, compact plasma-focus neutron generator (10^8 neutrons/pulse) successfully demonstrated real-time active interrogation of plutonium at PREFRE-2, NRB Tarapur, with a linear response to plutonium mass. An in-house fabricated deuterated titanium target sustained a neutron yield of approximately 3 times 10^6 n/s for over 100 hours at 120 kV and 100 µA, establishing a potential indigenous substitute for imported targets. A non-evaporable getter (NEG) pump using ZrCo sintered pellets achieved approximately 10^{-7} mbar in a prototype non-baked vacuum system and maintained the vacuum for several months. An indigenous 6 kW repetitive pulsed electro-hydraulic discharge system was developed for shockwave-assisted leaching to enhance rare earth element recovery from incinerated radioactive ash. Preliminary extraction trials were conducted at a BARC materials facility in Hyderabad. Magnetic pulse compaction achieved green densities exceeding 90%, demonstrating potential for high-density powder consolidation. Indigenous pulsed power techniques successfully demonstrated nanopowder generation of high-density materials, including tungsten and niobium.

The ultra-high-vacuum chamber.

Trapped Ion Quantum Technology: Development of a five-qubit trapped-ion quantum computer is in works in BARC. An ultra-high-vacuum chamber and a Paul-type linear ion trap have been designed, fabricated, and installed. The trap employs quadrupolar electrodes for radial confinement and ring electrodes for axial confinement. Four laser systems operating at 423, 375, 397, and 866 nm have been installed and commissioned for isotope-selective calcium photoionization and Doppler cooling. The experimental setup is designed to cool trapped ions to approximately 600 µK. Experiments on laser cooling are currently in progress, advancing the development of indigenous trapped-ion quantum computing capabilities.