



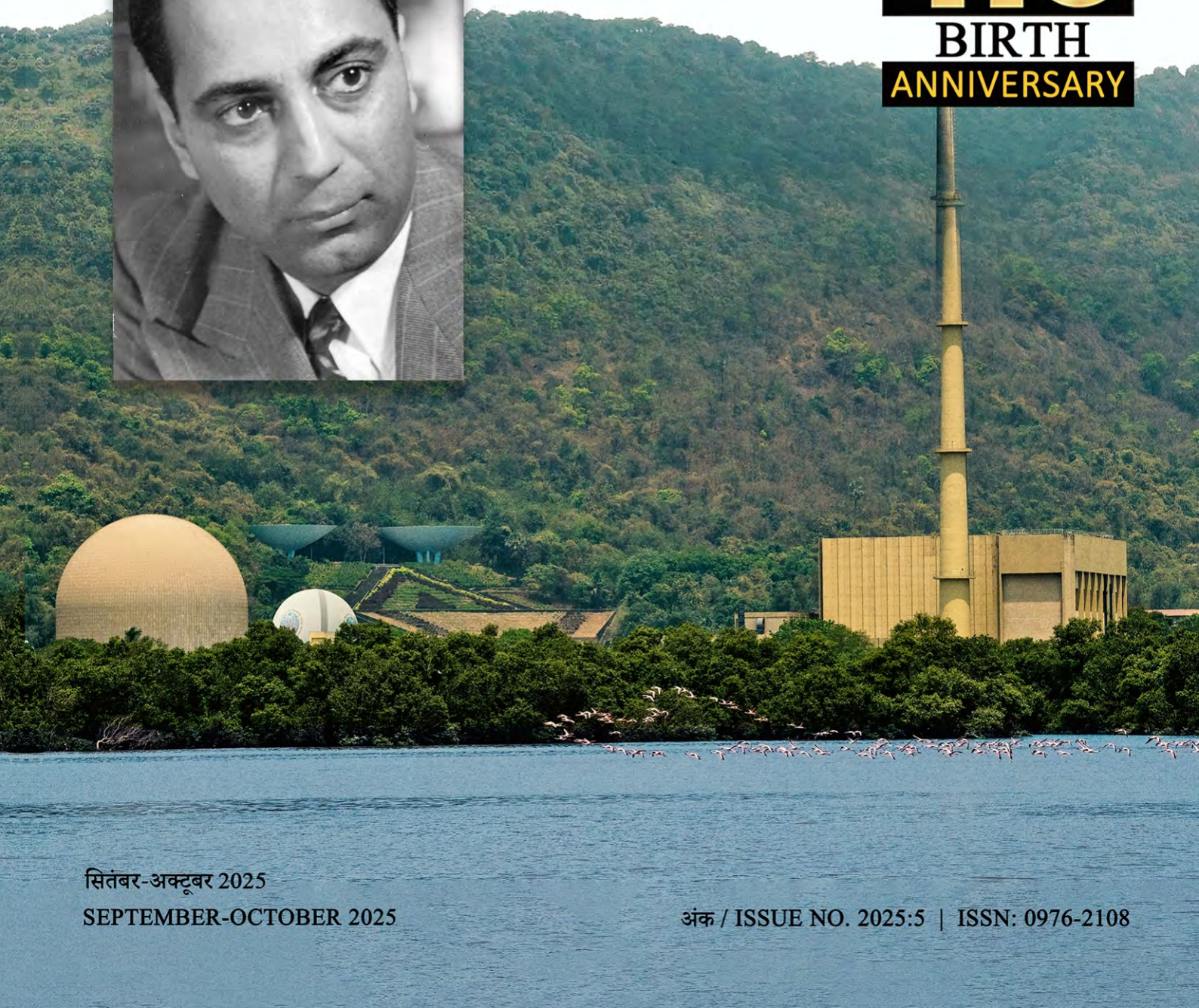
भा.प्र.अ.कें. न्यूज लेटर BARC NEWSLETTER

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अध्यक्ष, परमाणु ऊर्जा आयोग
व

सचिव, परमाणु ऊर्जा विभाग

Chairman, Atomic Energy Commission
&
Secretary, Department of Atomic Energy

डॉ. अजित कुमार मोहान्ती
Dr. Ajit Kumar Mohanty



विकसित भारत के मार्ग को प्रशस्त करती नाभिकीय ऊर्जा

परमाणु ऊर्जा विभाग (पऊवि) विकसित भारत 2047 मिशन के अंतर्गत विकसित अर्थव्यवस्था प्राप्त करने के भारत के दृष्टिकोण के लिए महत्वपूर्ण है। नाभिकीय ऊर्जा इस विजन का आधार है, जो सतत विकास, ऊर्जा सुरक्षा और प्रौद्योगिकीय नवोन्मेषण एवं प्रगति को बढ़ावा देती है।

पऊवि का उद्देश्य स्वदेशी अनुसंधान एवं विकास, नीतिगत सुधारों और मजबूत घरेलू तथा वैश्विक साझेदारी के माध्यम से भारत की नाभिकीय ऊर्जा की वर्तमान क्षमता लगभग 8.8 गीगावाट में दस गुणा से अधिक विस्तार देना है। एक प्रमुख पहल-विकसित भारत हेतु नाभिकीय ऊर्जा मिशन भापअ केंद्र द्वारा अभिकल्पित लघु मॉड्यूलर रिएक्टरों (एसएमआरएस) को विकसित करने के लिए रुपये 20,000 करोड़ आबंटित किया जाना है, जिसमें 200 मेगावाट के भारत एसएमआर, 50 मेगावाट संस्करण और हाइड्रोजन उत्पादन के लिए उच्च तापमान के 5 मेगावाट वाले गैस शीतित रिएक्टर शामिल हैं, जो नाभिकीय ऊर्जा को हरित हाइड्रोजन अर्थव्यवस्था से जोड़ते हैं।

विस्तार की अन्य योजनाओं में औद्योगिक केंद्रों के पास परिनियोजन के लिए, बढ़ी हुई संरक्षा सुविधाओं के साथ पीएचडब्ल्यूआर को भारत लघु रिएक्टरों (बीएसआर) में अपग्रेड करना, यूरेनियम अन्वेषण, अंतरराष्ट्रीय ईंधन साझेदारी के माध्यम से नाभिकीय ईंधन सुरक्षा को मजबूत करने के भारत के वर्ष 2070 तक शून्य-कार्बन उत्सर्जन के लक्ष्य का समर्थन करना और प्लूटोनियम तथा थोरियम का उपयोग करके संवृत ईंधन चक्र प्रौद्योगिकियों का उपयोग करना शामिल है।

पऊवि के आधारभूत विज्ञान कार्यक्रम ने भौतिकी, रसायन विज्ञान, पदार्थ विज्ञान और गणना में प्रगति के माध्यम से रिएक्टर अभिकल्पन, ईंधन चक्र तथा संरक्षा प्रणालियों में नवाचारों को जारी रखा है। शिक्षा में समानांतर प्रयास, भापअ केंद्र जैसे संस्थानों में कौशल विकास, और सार्वजनिक भागीदारी एक कुशल कार्यबल और सूचित सार्वजनिक समर्थन सुनिश्चित करती है।

कुल मिलाकर, पऊवि की प्रौद्योगिकी, सुधार, साझेदारी और मानव संपदा विकास का रोडमैप आत्मनिर्भर भारत और विकसित भारत 2047 के लक्ष्यों के लिए भारत के स्वच्छ ऊर्जा भविष्य में परमाणु ऊर्जा की महत्वपूर्ण भूमिका को मजबूत करता है।

हमारे प्रमुख अनुसंधान एवं विकास केंद्र - भापअ केंद्र की कुछ उल्लेखनीय उपलब्धियों की एक झलक इस संस्थापक दिवस 2025 के अंक में आकर्षक रूप से प्रदर्शित की गई है, जिसके माध्यम से पाठकों के बड़े वर्ग को प्रेरित करने और उन तक पहुंच बनाने का प्रयास है।

अजित कुमार मोहान्ती

अजित कुमार मोहान्ती

सचिव, डीई एवं अध्यक्ष, आईसी



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सचिव, परमाणु ऊर्जा विभाग

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Dr. Ajit Kumar Mohanty



Nuclear Energy facilitating Viksit Bharat

The Department of Atomic Energy (DAE) is pivotal to India's vision of achieving a developed economy by 2047 under the *Viksit Bharat 2047* mission. Nuclear energy forms the backbone of this vision, driving sustainable development, energy security and technological innovations & advancement.

DAE aims to expand India's nuclear power capacity more than tenfold from the current 8.8 GWe through indigenous R&D, policy reforms, and strong domestic & global partnerships. A key initiative - the *Nuclear Energy Mission for Viksit Bharat* - allocates ₹ 20,000 crore for developing Small Modular Reactors (SMRs) designed by BARC, including the 200 MWe *Bharat SMR*, a 50 MWe variant, and a 5 MWt *High Temperature Gas-Cooled Reactor* for hydrogen production, linking nuclear energy with the green hydrogen economy.

Future plans for expansion include upgrading PHWRs to *Bharat Small Reactors* (BSRs) with enhanced safety features for deployment near industrial hubs, supporting India's 2070 net-zero goal. Strengthening nuclear fuel security through uranium exploration, international fuel partnerships, and closed fuel cycle technologies using plutonium and thorium remains central to India's multi-stage programme.

DAE's Basic Sciences program continues to drive innovations in reactor design, fuel cycles, and safety systems through advances in physics, chemistry, materials science, and computation. Parallel efforts in education, skill development at institutions like BARC, and public engagement ensure a skilled workforce and informed public support.

Together, DAE's roadmap of technology, reforms, partnerships, and human capital development reinforces nuclear power's vital role in India's clean energy future for *Atmanirbhar Bharat and Viksit Bharat 2047* goals.

A glimpse of some of the noteworthy achievements from our premier R&D centre, BARC, is elegantly featured in this Founder's Day issue, created to inspire and reach wider audience.

Ajit Kumar Mohanty

Ajit Kumar Mohanty
Secretary, DAE & Chairman, AEC



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विवेक भसीन
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Director, Bhabha Atomic Research Centre
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Member, Atomic Energy Commission



भारत के उज्ज्वल भविष्य को सशक्त बनाता नाभिकीय अनुसंधान एवं विकास

भारत के सतत एवं आत्मनिर्भर भविष्य को आकार देने में नाभिकीय ऊर्जा अग्रणी है। भाभा परमाणु अनुसंधान केंद्र (भापअ केंद्र) दूरदर्शी परियोजनाओं के माध्यम से इस परिवर्तनकारी यात्रा का नेतृत्व करना जारी रखे हुए है जो आने वाले दशकों में जीवन के हर पहलू को प्रभावित करेगी। रिएक्टर प्रौद्योगिकियों में नए नवाचारों को स्वच्छ विद्युत उत्पादन का विस्तार करने और किफायती चिकित्सा आइसोटोप का उत्पादन करने के लिए अभिकल्पित किया गया है, जिससे देश भर में कैंसर के उन्नत निदान एवं सस्ते उपचार तक पहुंच बढ़ जाती है।

भापअ केंद्र अगली पीढ़ी के नाभिकीय ईंधनों में नवाचार, विशेष रूप से भारत के स्वदेशी थोरियम संसाधनों के उपयोग के माध्यम से और एक स्वच्छ, सुरक्षित पर्यावरण के लिए नाभिकीय अपशिष्ट प्रबंधन को आगे बढ़ाने के प्रति गंभीरता से प्रतिबद्ध है। भापअ केंद्र के नवाचार संरक्षा, गुणवत्ता और वैज्ञानिक उत्कृष्टता के उच्चतम मानकों को बनाए रखते हुए नाभिकीय प्रौद्योगिकी की सामाजिक पहुंच को जल शोधन, अपशिष्ट प्रबंधन और विकिरण सुरक्षा तक विस्तार दिया जा रहा है।

केंद्र ने अग्रणी अनुसंधान के माध्यम से, खाद्य संरक्षण के लिए बेहतर फसल किस्मों और विकिरण-आधारित प्रौद्योगिकियों को विकसित करना जारी रखा ताकि भारत के कृषि समुदाय को सशक्त बनाने और देश की स्थायी हरित क्रांति का समर्थन किया जा सके।

भापअ केंद्र का जीवंत वैज्ञानिक समुदाय क्वांटम कंप्यूटिंग, प्रगत संवेदन प्रौद्योगिकियों और बड़े पैमाने पर अनुसंधान सुविधाओं की स्थापना में महत्वाकांक्षी कार्यक्रमों को आगे बढ़ाते हुए भौतिकी, रसायन विज्ञान, पदार्थ विज्ञान और जैव प्रौद्योगिकी में भी आगे बढ़ रहा है। भापअ केंद्र युवा वैज्ञानिक प्रतिभा को पोषित करने और नाभिकीय विज्ञान में देश के मानव संसाधन आधार को मजबूत करने के लिए समर्पित है और इस प्रगति के कारण, केंद्र शोध लेखों के मुक्त प्रकाशन और इसके पाठकों और उद्धरणों को बढ़ाने के लिए भी प्रोत्साहित करता है।

जैसा कि डॉ. होमी जे. भाभा ने सही ही कहा है कि, "देश के भविष्य के औद्योगिक विकास के लिए नाभिकीय ऊर्जा का विकास महत्वपूर्ण है, क्योंकि विद्युत एवं ऊर्जा के उपलब्ध स्रोत सीमित हैं।" उनके दूरदर्शी शब्द भारत की बढ़ती औद्योगिक और सामाजिक आकांक्षाओं का समर्थन करने हेतु स्वच्छ, विश्वसनीय एवं टिकाऊ नाभिकीय ऊर्जा की भापअ केंद्र की खोज का मार्गदर्शन करते हैं।

हमारे 116वें संस्थापक दिवस के अवसर पर, मैं एसआईआरडी और पूरे भापअ केंद्र वैज्ञानिक समुदाय को भापअ केंद्र समाचार पत्र प्रकाशन के इस विशेष अंक को प्रकाशित करने के उनके प्रयासों के लिए हार्दिक बधाई देता हूं। यह अंक अमृत काल विज्ञान लक्ष्यों (वॉल्यूम 1 से वॉल्यूम 8) के साथ संरेखित भापअ केंद्र की महत्वपूर्ण उपलब्धियों को दर्शाता है, होमी भाभा विज्ञान एवं प्रौद्योगिकी मानपात्र पुरस्कारों के प्राप्तकर्ताओं की प्रोफाइल, और हमारे केंद्र का दौरा करने वाले विशिष्ट अतिथियों की मात्रा की झलकियां प्रदान करता है, जो विज्ञान, प्रौद्योगिकी और राष्ट्र की सेवा में उत्कृष्टता की हमारी निरंतरता को प्रतिबिंबित करता है।

विवेक भसीन

विवेक भसीन

निदेशक, भाभा परमाणु अनुसंधान केंद्र



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Nuclear R&D Powering India's Bright Future

Nuclear energy stands at the forefront of shaping India's sustainable and self-reliant future. The Bhabha Atomic Research Centre (BARC), continues to lead this transformative journey through visionary projects that will influence every aspect of life in the coming decades. The new innovations in reactor technologies are designed to expand clean power generation and produce affordable medical isotopes, thereby enhancing access to advanced cancer diagnostics and inexpensive treatment across the country.

BARC remains deeply committed to innovation in next-generation nuclear fuels, particularly through the utilization of India's indigenous thorium resources and to advancing nuclear waste management for a cleaner, safer environment. BARC's innovations in water purification, waste management, and radiation safety further extend the societal reach of nuclear technology, while maintaining the highest standards of safety, quality, and scientific excellence.

Through pioneering research, the Centre continues to develop improved crop varieties and radiation-based technologies for food preservation, empowering India's agricultural community and supporting the nation's enduring *Ever Green Revolution*.

BARC's vibrant scientific community is also advancing frontiers in physics, chemistry, materials science, and biotechnology, while pursuing ambitious programs in quantum computing, advanced sensing technologies, and the establishment of large-scale research facilities. BARC remains devoted to nurturing young scientific talent and strengthening the nation's human resource base in nuclear science and engineering. Alongside these advancements, BARC also encourages Open Access publishing of research articles and increase its readership & citations.

As Dr. Homi J. Bhabha rightly emphasized, "The development of nuclear energy is crucial for the future industrial growth of the country, as the available sources of power and energy are limited." His visionary words continue to guide BARC's pursuit of clean, reliable, and sustainable nuclear energy to support India's expanding industrial and societal aspirations.

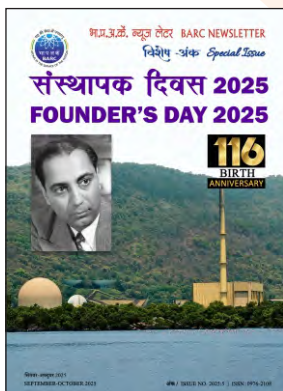
On the occasion of our 116th Founder's Day, I extend my heartfelt congratulations to SIRD and the entire BARC scientific community for their efforts in bringing out this special issue of BARC Newsletter. This issue showcases BARC's significant achievements aligned with the *Amrit Kaal Vision* targets (V1 to V8), profiles of the recipients of the *Homi Bhabha Science and Technology Maanpatra Awards*, and provides a glimpse of distinguished visits to our Centre, reflecting our continued pursuit of excellence in science, technology, and service to the nation.

Vivek Bhasin

Director, Bhabha Atomic Research Centre



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Vision to Reality...

Leaders of Bhabha Atomic Research Centre

Dr. Homi J. Bhabha [Tenure: 1954-66]

A visionary physicist. Founded India's nuclear energy programme and established Atomic Energy Establishment Trombay (now BARC). Renowned globally for his pioneering work in cosmic rays and particle physics, including Bhabha Scattering, Bhabha-Heitler Cascade theory. A master institution builder who



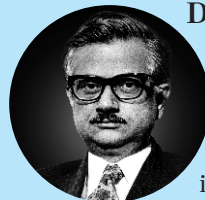
shaped India's nuclear future and championed peaceful applications of nuclear energy worldwide. Mentored future generations of scientists.

Awarded the Padma Bhushan (1954), elected FRS (1941), won the Adams Prize (1942) and was nominated for the Nobel Prize multiple times.



Dr. Homi Nusserwanji Sethna

[Tenure: 1966-72] A pioneering chemical engineer. Instrumental in developing India's nuclear fuel cycle. Led the establishment of key facilities for uranium production and thorium processing. Oversaw major projects - CIRUS reactor, Heavy water and isotopic separation units. Honored with the Padma Shri (1959), Padma Bhushan (1966), Padma Vibhushan (1975) and the Shanti Swarup Bhatnagar Prize (1960). Played key roles in shaping India's S&T policy.



Dr. Raja Ramanna [Tenure: 1972-78

& 1981-84] A pioneer in nuclear physics and reactor design, led landmark projects like the Apsara and Dhruva reactors. Advanced fission research, oversaw the creation of Training School in Mumbai. Guided setting up of key institutions - RRCAT. Played a vital role in India's strategic ambitions. Awarded Padma Shri (1968), Padma Bhushan (1973), and Padma Vibhushan (1975). Remains a towering figure in the world of nuclear science.



Dr. Padmanabhan Krishnagopalan

Iyengar [Tenure: 1984-90] A visionary nuclear physicist. Renowned for his work in neutron scattering, condensed matter, and reactor physics. Led the construction of the Dhruva reactor, advanced accelerator and neutron beam research. Explored bold frontiers like cold fusion, blending basic science with applied innovation. Honoured with the Padma Bhushan (1975) and Shanti Swarup Bhatnagar Award (1971). Recipient of the Raman Centenary Medal, Bhabha Medal, and R.D. Birla Award.



Dr. Rajagopala Chidambaram

[Tenure: 1990-93] A world-class physicist. Made pioneering contributions to high-pressure physics, crystallography, and materials science. Advanced supercomputing at BARC. Played a vital role in India's strategic and scientific future. Honoured with the Padma Shri (1975) and Padma Vibhushan (1999). Has 20+ honorary D.Sc. degrees, global fellowships, C.V. Raman Award and Meghnad Saha Medal.



Dr. A. N. Prasad [Tenure: 1993-96]

A specialist in the nuclear fuel cycle, focusing on back-end processes and safeguards. Expertised in reprocessing plant operations. He was instrumental in establishing India's maiden Fuel Reprocessing Plant in Trombay in 1964. Spearheaded efficient and secure management of nuclear materials. Chaired the highly important DAE's Safeguards Committee.



Dr. Anil Kakodkar [Tenure: 1996-

2001] A visionary nuclear scientist. Instrumental in India's landmark Pokhran-II tests. Advanced India's reactor and power programmes. Championed thorium-based technologies to ensure energy sustainability. Shaped India's modern nuclear journey. Honoured with the Padma Shri (1998), Padma Bhushan (1999), and Padma Vibhushan (2009). Other accolades include the Maharashtra Bhushan, Gomant Vibhushan, Homi Bhabha Lifetime Achievement Award, and several national and international honours.

...Excellence in Nuclear R&D

Leaders of Bhabha Atomic Research Centre



Mr. Bisweswar Bhattacharjee

[Tenure: 2001-04] A pioneering chemical engineer. Instrumental in developing India's uranium and enrichment capabilities. Championed nuclear-powered desalination, leading projects such as Kalpakkam facility for ensuring sustainable water and energy solutions.

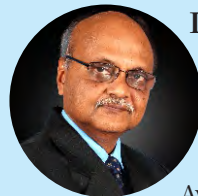
He also made significant contributions to chemical metallurgy. He's a Padma Shri awardee (2001) and a Fellow of the Indian National Academy of Engineering. Member of NDMA.



Dr. Srikumar Banerjee [Tenure:

2004-10] An internationally acclaimed metallurgist. Made pioneering contributions to zirconium and titanium alloys. His research on radiation stability and shape memory alloys led to innovative applications like heat-shrinkable couplings for India's home-grown LCA fighter Tejas.

Received Padma Shri (2005), Shanti Swarup Bhatnagar Award (1989), G.D. Birla Gold Medal, and INSA Prize. Internationally acclaimed with the Acta Metallurgica. He's a fellow of India's leading science and engineering academies.



Dr. Ratan Kumar Sinha [Tenure:

2010-12] A distinguished mechanical and nuclear engineer. Renowned for his pioneering work on thorium-based advanced reactors with passive safety features. Led key projects - AHWR and Dhruva reactor core design. Awarded the inaugural Homi Bhabha Science and

Technology Award, Indian Nuclear Society Award, DAE Special Contributions Award. He is a Fellow of INAE. Received Honorary D.Sc. from the University of Mysore.



Dr. Sekhar Basu [Tenure: 2012-16]

A visionary nuclear engineer. Shaped India's reactor technology and nuclear waste management. Led the Nuclear Recycle Board. Pioneered safe nuclear waste disposal. Designed key reprocessing plants. Advanced India's first Integrated

Nuclear Recycle Plant. Honoured with the Padma Shri (2014). Indian Nuclear Society Award, DAE Group Achievement Award, and DAE Special Achievement Award. He's a Fellow of the Indian National Academy of Engineering.



Mr. Kamlesh Nilkanth Vyas [Tenure:

2016-19] A distinguished mechanical engineer. Renowned for pioneering nuclear fuel design, reactor component development, and thermal hydraulics. Expertised in stress analysis of reactor core components. Spearheaded India's participation in the ITER Test Blanket Module,

strengthening global nuclear collaboration. Awarded Indian Nuclear Society Outstanding Service Award (2011). Homi Bhabha Science and Technology Award (2006). He's a Fellow of INAE.



Dr. Ajit Kumar Mohanty [Tenure:

2019-23] A distinguished nuclear physicist. Regarded for his pioneering experimental research across collision energies and leading India's role in global projects like PHENIX and CMS at CERN. A two-time CERN Scientific Associate. Held

key leadership positions at SINP and the Indian Physics Association. Honored with the Indian Physical Society's Young Physicist Award (1988), INSA Young Scientist Award (1991), DAE's Homi Bhabha Science and Technology Award (2001). He also received an Honorary D.Litt. from Utkal University.



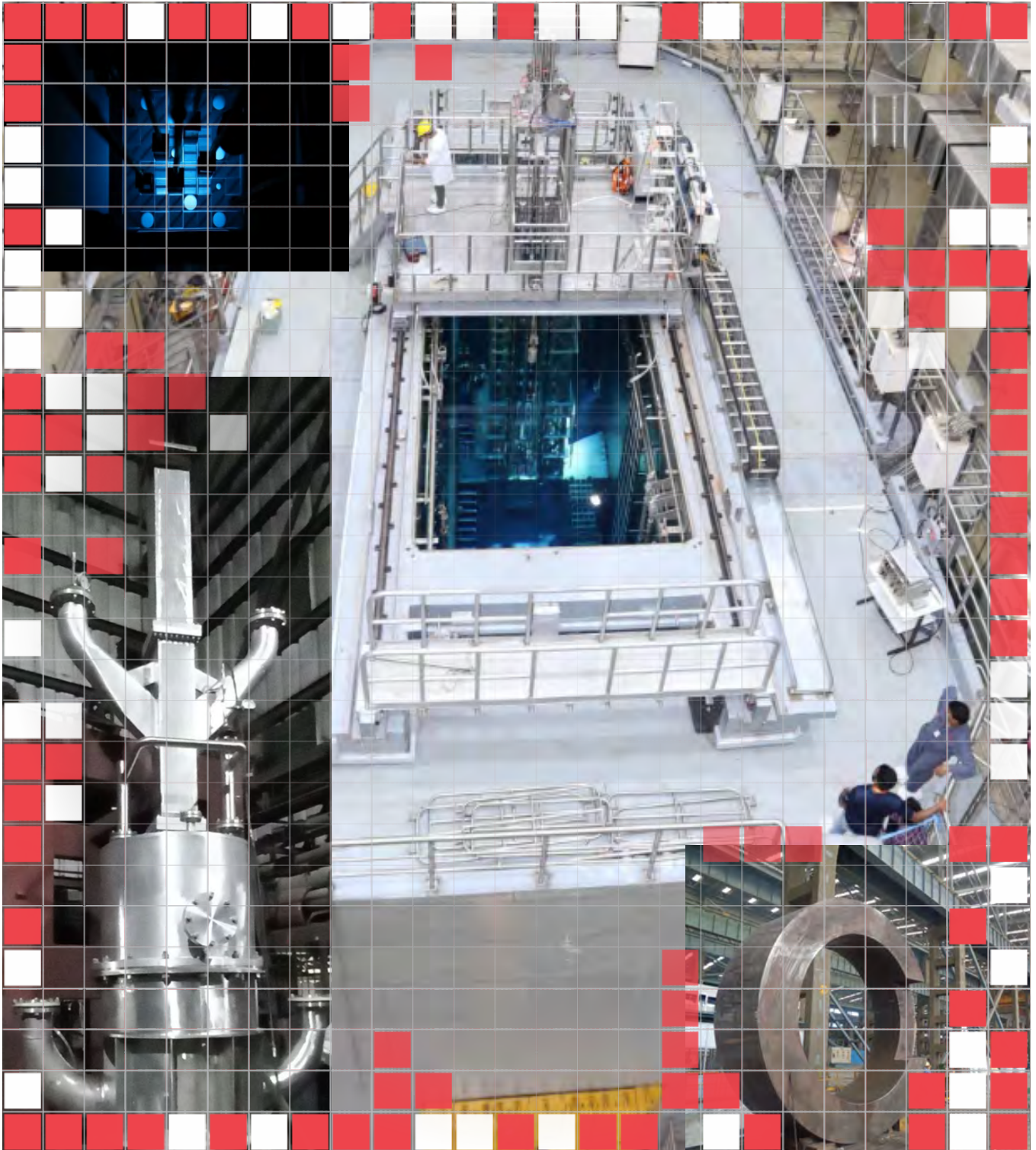
Mr. Vivek Bhasin [Tenure: 2023-Present]

A distinguished advanced nuclear engineer. Expertises in advanced nuclear fuel development, reactor design, and structural integrity assessment for India's power reactors. He immensely contributed for enhancement in reactor safety and longevity across multiple sites and pioneered key facilities like APSARA-U fuel fabrication and the Fission-Moly production plant. Awarded the Indian Nuclear Society Medal (2002), DAE Science & Technology Award (2006), and

Homi Bhabha Science & Technology Award (2014). He's a Fellow of the Indian National Academy of Engineering.

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REACTORS PROGRAMME



THE REACTORS PROGRAMME

is the core mission of the DAE's 'Vision 2047', advancing India's self-reliance in critical technologies, and energy security while augmenting its leadership in global nuclear technology landscape. Its flagship initiatives encompass the design, development, construction, and commissioning of research and developmental reactors, aligned with the multi-stage nuclear power programme. In the run up to the Amrit Kaal (Year 2047), the programme emphasizes greater indigenization, advanced R&D, and sustainability, with major developmental activities planned at premier research centres.

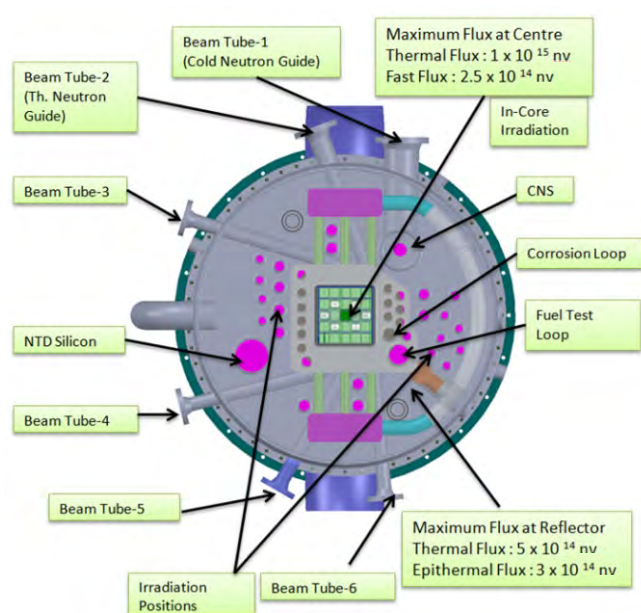
New Reactors

High Flux Research Reactor: A standout activity in the domain of reactors is the High Flux Research Reactor (HFRR) - a pool-type compact research reactor coming up at BARC Visakhapatnam. It is designed to yield high neutron flux in the order of 10^{15} n/cm²/s (peak) and operates at a nominal power of 40 MWth. The advanced nuclear research facilities planned at HFRR include cold neutron sources, corrosion studies, radioisotope production, and advanced testing of nuclear fuels and materials, which are considered a boon to both academia and industry. Envisioned as a centralized national facility for neutron beam research and neutron transmutation doping (NTD) of silicon, feasibility studies for commercial-scale NTD production of silicon is under

active evaluation. Once fully operational, HFRR will serve as a national facility for neutron beam research with advanced facilities and instruments for both DAE and non-DAE users.

High Temperature Gas Cooled Reactor: India's pioneering development of High Temperature Reactor technology represents a major milestone toward realizing the national vision of 'Atmanirbhar Bharat' (self-reliant India). It advances energy independence, industrial competitiveness, and environmental sustainability through indigenous nuclear innovation. As a lead step, the 5 MWth High Temperature Gas Cooled Reactor (HTGCR), developed indigenously by BARC, is designed to deliver high-grade process heat suitable for clean hydrogen production - a decisive step in decarbonizing core industrial sectors and reducing dependence on imported fossil fuels.

The High Flux Research Reactor will have advanced research facilities such as cold neutron source and corrosion test loop, a first-of-a-kind facilities in India's research reactor landscape. It will also have a provision for production of neutron transmutation doped (NTD) silicon; supports development of new nuclear materials for advanced reactors.



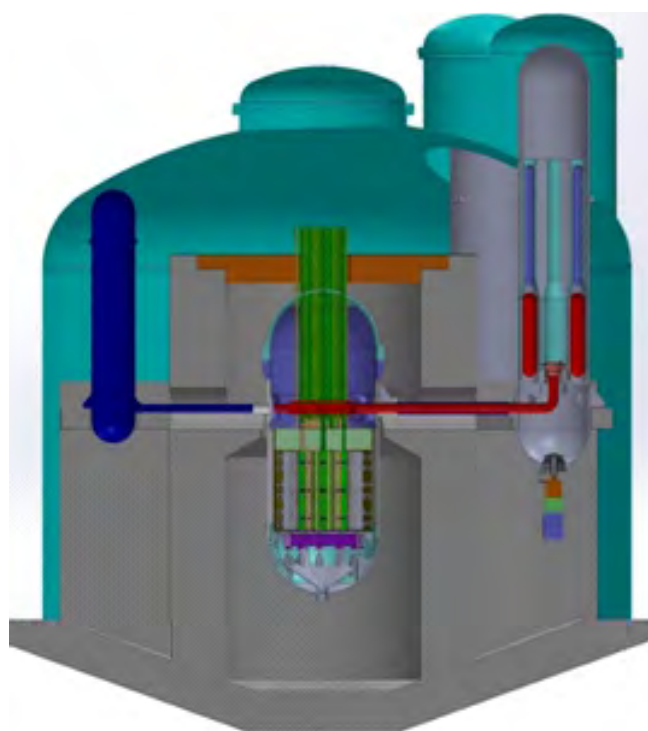
Salient features of HFRR.

India's HTGCR, being developed by BARC, uses advanced physics simulation tools combining Monte Carlo (PATMOC) and deterministic (ARCH) codes. These provide co-dependent optimization of fuel cluster configuration, thermal-hydraulic feedback, and neutron economy. The design ensures extended core life - approximately 4 full power years - with adequate excess reactivity and redundant safety systems. The compact core, about 2 meters in diameter, contains 21 fuel channels and 28 reactivity control devices comprising three types of control rods and two diverse, fast-acting shutdown systems. This configuration provides strong reactivity management and operational reliability. Slightly enriched uranium dioxide (UO₂) serves as fuel, moderated and reflected by high-density, near-isotropic graphite. The average thermal neutron flux is approximately 1.44×10^{13} n/cm²/s, producing a core power density of 1.1 kW/litre. The reactor's inherent safety is reinforced by negative reactivity coefficients, ensuring self-stabilizing performance across its operational life. Control rod worth is stringently managed to guarantee safe reactivity control under all conditions.

The fuel cluster design follows a physics-thermal hydraulics coupled methodology. It uses pin-type fuel assemblies consisting of cylindrical UO_2 pellets clad in austenitic steel for corrosion resistance and mechanical strength. The pellets measure 12.2 mm in diameter with a 1:1 length-to-diameter ratio, while the pellet-clad radial gap is precisely maintained at 0.12 mm to accommodate differential thermal expansion. Each cluster hosts 24 pins - nine in the inner ring and fifteen in the outer - secured centrally to prevent bowing (or stress deformation). Vertically arranged assemblies are linked via tie rods and enclosed within double graphite sleeves and static gas gaps that limit both heat loss and neutron leakage. To ensure structural soundness and thermal performance, engineering test loops are planned for fuel experimentation, focusing on thermomechanical reliability, flow-induced vibration effects, and endurance under full-spectrum service conditions. These validation programs are integral to qualifying the fuel design for long-term, high-temperature operation.

The HTGCR core comprises precision-machined graphite blocks - octagonal and rectangular - designed to securely accommodate fuel channels and reactivity control devices. The blocks are assembled using spigot rings and dowel pins, with interlocking keys preventing rotational displacement. To withstand both seismic loads and irradiation-driven dimensional changes, a temperature-compensated core restraint mechanism maintains geometric stability under dynamic conditions. The re-entrant flow core configuration enhances cooling efficiency by circulating the primary coolant through annular passages that lower graphite temperature before re-entering the fuel channels. The cooled graphite contributes to efficient moderation and structural longevity. Hot coolant emerges from the core at 650°C , transferring energy to the heat utilization system for process applications. The graphite assembly is housed within a robust core barrel supported on a diagrid, enclosed by thermal and neutron shields made from low-alloy steel for durability and radiation protection.

The HTGCR focuses on efficient process heat delivery for hydrogen generation. The Heat Utilization System (HUS) integrates chemical reactors within primary heat exchangers, optimizing the Copper-Chlorine (Cu-Cl) thermochemical cycle. The Primary Heat Transport (PHT) system has two redundant CO_2 -cooled loops, each capable of removing up to 2.5 MW of thermal energy. During operation, most heat supports hydrogen production, while the Secondary Cooling System (SCS) handles surplus heat through



The Engineered Safety Features placed inside a metal containment of HTGCR.

A first-of-a-kind coupling technology is being evolved for HTGCR which integrates the nuclear reactor with a chemical plant employing Copper-Chlorine cycle for H_2 production. Successful demonstration of clean H_2 production using nuclear energy will be an important step towards industry decarbonisation.

atmospheric cooling towers. The system operates within metallic containment, ensuring radiation-tight boundaries, and exhaust air is filtered using HEPA systems for environmental protection. Passive and active safety mechanisms reinforce reliability: the Passive Decay Heat Removal System (PDHRS) disperses residual heat via natural circulation, and the Emergency Core Cooling System (ECCS) addresses loss-of-coolant conditions. Dual, fast-acting reactor protection systems respond automatically to abnormal reactivity changes, ensuring defense-in-depth safety.

Isotope Production Reactor: The Isotope Production Reactor (IR) is a high-flux, 40 MW open-pool type reactor designed primarily for large-scale radioisotope production, especially for

nuclear medicine. Planned for commissioning at BARC Visakhapatnam, it will be built in Engineering, Procurement and Construction mode, beginning in 2027 and expected to commence operations by 2034. The project supports India's goal of self-reliance in medical isotope supply, unlocking exports, and advanced healthcare infrastructure.

The facility will produce high-specific-activity isotopes such as ^{192}Ir , ^{99}Mo , ^{60}Co , ^{177}Lu , ^{131}I , ^{153}Sm , ^{166}Ho , ^{188}W and ^{90}Y in addition to production of specialized isotopes, such as Pu-238 , Ni-63 and NTD-Si , for deployment in programmes of high national importance. With an estimated annual output of 0.8 million curies (MCi). Besides medical use, some isotopes will serve strategic national programs.

The reactor uses low-enriched uranium (LEU) in the form of U_3Si_2 fuel and employs light water as coolant and moderator. The core houses 28 plate-type fuel assemblies surrounded by beryllium reflectors and a central beryllium trap to enhance neutron flux. Around the core is a heavy-water reflector tank, supported by a cylindrical inlet plenum that distributes coolant water evenly. The coolant flows upward through the core, carrying away fission heat, and exits through outlet nozzles to the heat-removal systems.

Most irradiation positions are located in the reflector region, providing large irradiation volumes. Target materials are sealed in aluminum capsules and irradiated in tray rods inserted into these locations. After irradiation, manipulators in hot cells retrieve the

capsules and transfer them in shielded casks to the isotope processing facility.

The nuclear island consists of the reactor building, auxiliary buildings, service structures, and a 75 m exhaust stack for safely venting gaseous effluents. The reactor operates roughly 280 days per year, with refueling performed during shutdowns; about one-third of the core is replaced per cycle. Spent fuel is stored underwater in a connected storage bay.

Heat is removed via the Primary Heat Transport System, which maintains sufficient flow to prevent boiling. Backup shutdown cooling pumps ensure core cooling during loss-of-coolant accidents. In blackout scenarios, natural circulation through dedicated valves sustains passive heat removal. Long-term cooling is provided by diesel-backed pool-water systems.

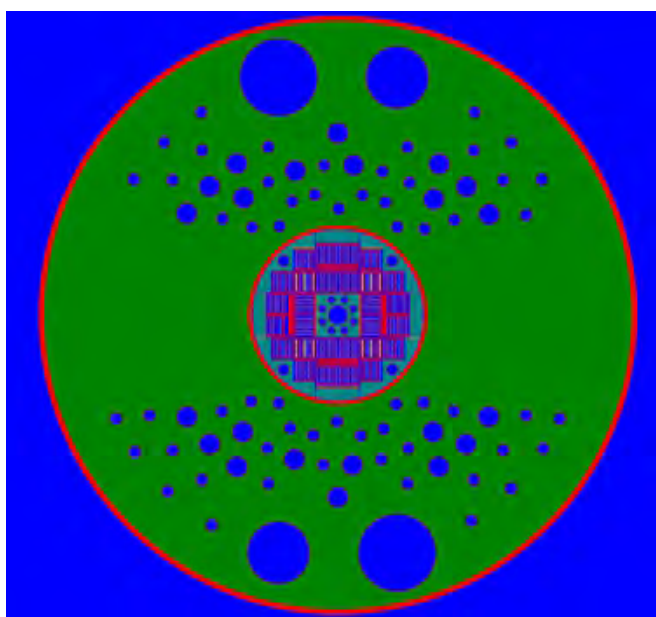
The Isotope Production Reactor is designed to produce high specific-activity and specialized isotopes such as ^{99}Mo , ^{60}Co , ^{177}Lu , ^{131}I , ^{153}Sm , ^{166}Ho , ^{90}Y with significant healthcare applications.

Two independent shutdown systems guarantee safety: Primary System equipped with six control-cum-shut-off rods operated from above and the Secondary System equipped with four emergency rods with a heavy-water dump component operated from below.

Overall, the Isotope Reactor integrates robust safety, efficient heat removal, and specialized isotope production capabilities to serve both medical and strategic sectors.

Advanced Purified Reactor Vessel Alloy (APURVA): The Pressurised Water Reactor (PWR) based Nuclear Power Plant (NPP) necessitates the development of large, high-purity, low-alloy steel (LAS) forgings for the fabrication of the Reactor Pressure Vessel (RPV) - the plant's most critical component. The RPV for India's PWR program is a ~12 m long vessel with an outer diameter of about 5 m, designed to withstand temperatures around 320°C and pressures of approximately 16 MPa over a 60-year service life under intense radiation exposure.

Developing such robust RPV forgings posed major challenges, including achieving large section thicknesses with uniform mechanical properties, controlling microstructure and chemical composition, ensuring excellent weldability, and preventing



The core of Isotope Production Reactor.

hydrogen-induced micro-cracks. Addressing these challenges required development of indigenous technology through extensive research and industrial collaboration.

To realize this capability, a program was initiated in BARC in partnership with Ranchi based Heavy Engineering Corporation Ltd to develop low alloy steel (LAS) forgings. Subsequently, efforts with L&T Special Steels and Heavy Forging Pvt. Ltd., Hazira, focused on scaling up to industrial production of heavy-section forgings. Metallurgical parameters - melting chemistry, forging practices, and heat-treatment protocols - were optimized through rigorous R&D work. Three prototype shell forgings with internal diameters ranging from 3.8 m to 4.2 m and thicknesses of 340 mm, 550 mm, and 750 mm were produced successively, simulating various RPV sections such as nozzle belts and flanges. Comprehensive metallurgical and mechanical testing confirmed uniform through-thickness properties and structural soundness. Impurity control was achieved at parts per million levels, including hydrogen content below 1 ppm. The developed special-grade steel was designated “Advanced Purified Reactor Vessel Alloy”, or APURVA.

The manufacturing process utilized a controlled melting and refining route to achieve superior purity and chemistry. Specially selected steel scrap and direct reduced iron (DRI) were melted in a 100-ton Electric Arc Furnace (EAF), refined and alloyed in a 110-ton Ladle Furnace (LF), and degassed in a 110-ton Vacuum Degassing (VD) unit under ultra-low vacuum (<1.0 torr) to remove hydrogen. Two 100-ton degassed heats were sequentially cast in a 208-ton mold within a Vacuum Ingot Casting (VIC) setup, also under <1.0 torr conditions. The resulting ingots underwent extensive forging, heat treatment, machining, and inspection.

Key R&D areas focused on: Optimization of chemical composition and process parameters for each forging thickness; Control of impurities and gaseous elements (H, N, O); Determination of optimal quenching rates and validation of heat treatment cycles and Extensive material characterization and qualification testing.

A novel laboratory-scale physical simulation technique developed at BARC enabled fine-tuning of heat-treatment cycles specific to each section. Over 300 trials involving around 3000 test samples were executed before industrial implementation. The validated forgings were then examined for ultrasonic integrity, mechanical strength, fracture toughness, fatigue performance, thermal endurance, and



APURVA replica of 750 mm thick ring forging erected in BARC Trombay.

Development of APURVA signifies the achievement of significant technological milestone in LWR technology. It stands as a testament to BARC's unwavering commitment to achieving self-reliance in critical technologies.

weldability using samples extracted from multiple orientations and elevations.

The qualification included 100% ultrasonic scanning, through-thickness mechanical testing, post-quench and temper (QT) evaluations, directional mechanical tests (axial, tangential, radial), low-cycle fatigue and fracture toughness tests conforming to ASME standards, temper embrittlement (step cooling) tests under ASME Section IIA SA-542 requirements, and weldability assessments via Tekkon Y-Groove and V-restraint methods. All results exceeded acceptance norms with considerable margins.

The project concluded successfully, establishing indigenous expertise in manufacturing high-thickness RPV class forgings. The domestically developed APURVA steel now supports production of RPVs, steam generators, and other pressure-boundary

components for water-cooled reactors operating up to 350°C.

A significant milestone in India's pursuit of nuclear self-reliance was marked by the Atomic Energy Commission's in-principle approval of the Bharat Small Modular Reactor BSMR-200, an entirely indigenous medium-sized PWR project jointly executed by BARC and NPCIL, employing APURVA forgings for its RPV.

The APURVA monument installed at BARC's Trombay campus, created from prototype forgings of 340 mm, 550 mm, and 750 mm thickness, symbolizes India's technological advancement toward Aatmanirbhar Bharat in the Amrit Kaal era.

Operation and Utilization of Research Reactors:

During the year, research reactors Apsara-U and Dhruva operated with high safety and reliability, supporting medical, agricultural, and industrial isotope production, fundamental research, material testing, and studies for future power reactor programs. The Critical Facility (CF) was operated to cater to research community requirements.

The Apsara-U reactor achieved rated 2 Mwth power with ~92% availability, supporting research and radioisotope production. Indigenous uranium silicide dispersion fuel demonstrated robustness beyond 55,000 MWD/Te burn-up.

Sixteen cans in tray rods were irradiated and 78 samples processed via Neutron Activation Analysis (NAA). Preparations for fission molybdenum production progressed, including qualification of tray rod assemblies and safety clearance, with trial irradiation planned. Material characterization samples were routinely irradiated; a single crystal

alignment facility is under commissioning in a beam tube.

Irradiation experiments included natural uranium specimens for fission gas distribution, swelling, and creep studies; Invar alloy used in calandria supports; and dissimilar material joints for cryogenic applications. A facility for Neutron Transmutation Doping (NTD) of silicon ingots (4"–8" diameter, 10" length) is under design for installation in Apsara-U.

The Dhruva reactor operated with ~80% availability. Annual plant radiation dose was the lowest since commissioning. Production included 410 medical and industrial radioisotopes and 44 NAA samples. Fission molybdenum targets were irradiated as required. Seventy-two plates were delivered to the Fission Moly Processing Plant. An on-power irradiation facility was designed and tested, enabling target handling without reactor downtime.

An on-power irradiation facility for fission moly was designed & tested for deployment in the operations of Dhruva. The facility will enhance the production of fission moly as the loading/unloading of targets for irradiation will be done without affecting the reactor's regular operation.

Instrumentation upgrades included differential temperature monitoring of 130 failed-fuel detection tubes, continuous shut-off rod position monitoring, and a new radiation data acquisition system. Seawater supply reliability improved through year-round desilting and design of a new intake system. The Dhruva's coolant header pressure was enhanced via procurement of a fourth auxiliary pump (XCP-4), tested and pending commissioning.

A laser-based positioning system for Fuelling Machine-A was installed, with performance testing in progress. Security enhancements included upgrading the Perimeter Intrusion Detection System (PIDS).

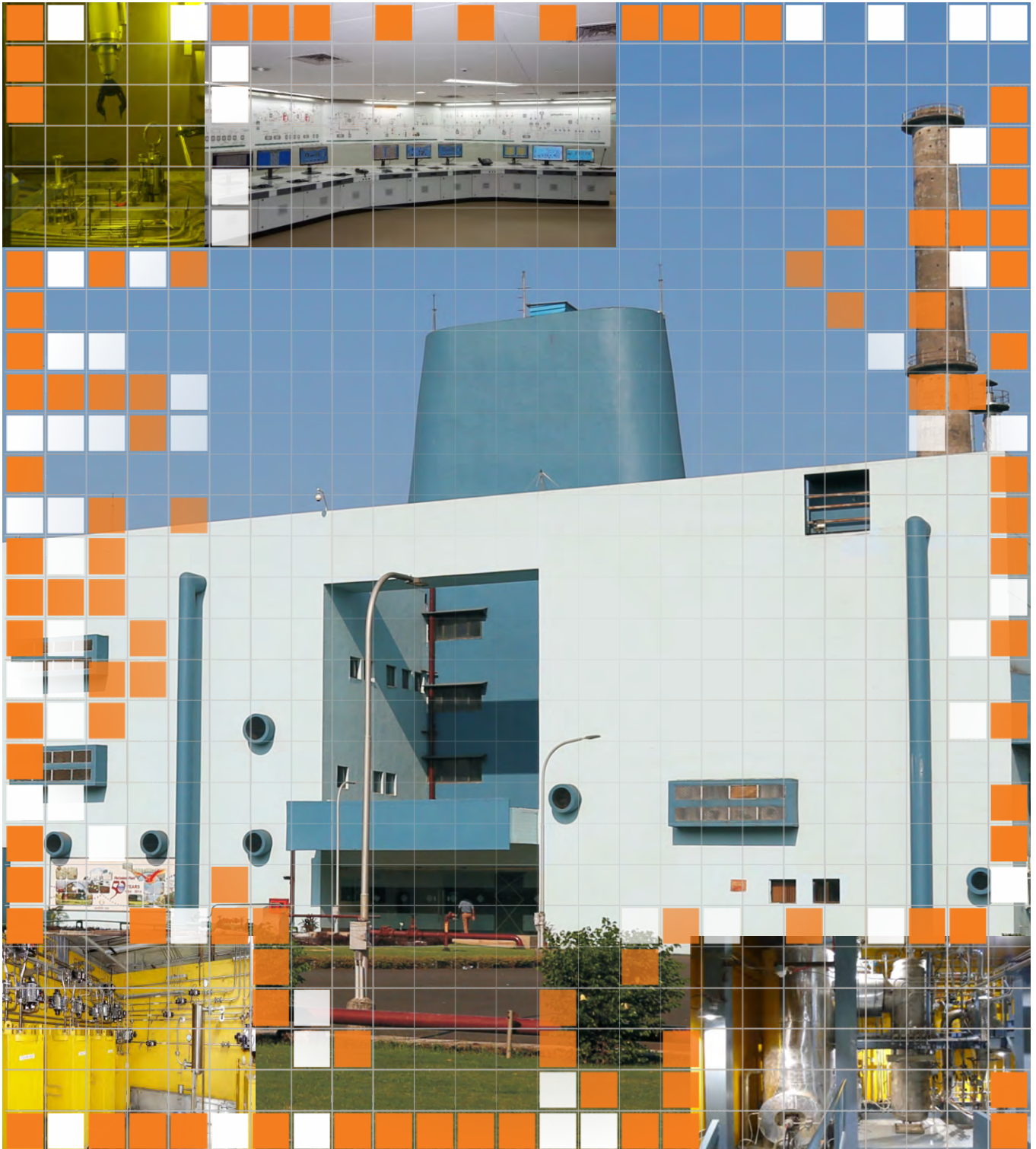
The Critical Facility was operated on 67 occasions, supporting detector testing and activation of large samples for NAA.

Thirty-eight nuclear detectors and 36 samples with 11 foils were activated, matching predicted reactivity values. Integral experiments with molten salt reactor fuel salt at various core locations validated theoretical estimates for MSR development.



Apsara-U Reactor Core.

NUCLEAR FUEL CYCLE



THE NUCLEAR FUEL CYCLE

vertical of the DAE Vision Programme focuses on the exploration and enhancement of uranium, thorium, and rare earth (RE) material reserves in the front end. In the back end, construction and commissioning of integrated fuel reprocessing plants for PHWRs and advanced reactor systems are critical for efficient fuel recycling. These efforts are complemented by the adoption of waste management technologies to ensure safe and sustainable disposal of nuclear waste.

In BARC, comprehensive initiatives are underway to ensure the sustained safe and reliable operation of nuclear facilities, enhance overall plant performance, optimize resource utilization, and maintain environmental releases to minimum.

Research and development efforts are being intensified to develop advanced, future-ready technologies and to recover valuable radioisotopes from nuclear waste, supporting societal applications and promoting the sustainable management of the back-end fuel cycle.

Front end of Fuel Cycle

Recovery and Extraction of Atomic Minerals:

The recovery of uranium and by-products from low-grade Kudada ore of the Singhbhum Shear Zone, containing 0.035% U_3O_8 and 0.2% total rare earth elements (REE), has been successfully achieved. A process flow-sheet for uranium recovery through acid leaching-ion exchange-precipitation route was developed, demonstrating the feasibility of producing yellow cake assaying 82.5% U_3O_8 with an overall uranium recovery efficiency of 92%.

Experimental separation studies further confirmed that uranium can be effectively adsorbed from leach liquor using a strong-base anion exchange resin. The resin's breakthrough and saturation capacities were optimized, and subsequent elution and precipitation yielded uranium peroxide as the final product.

A comprehensive extraction process for the recovery of rare earth elements (REEs) and valuable by-products from Dantala ore of the Siwana Ring Complex (SRC), Rajasthan, has also been developed. The integrated flowsheet comprising flotation, leaching, solvent extraction, and precipitation enabled recovery of approximately 85% of REE values as mixed oxalates. Concurrently, recoveries of around

75% were achieved for niobium (Nb), zirconium (Zr), and hafnium (Hf) in the form of mixed hydroxides.

Chemical analysis of the Ramaniya ore sample from the SRC showed 0.36% total REE content (with 37% heavy rare earth elements), in addition to 0.68% Zr, 0.034% Nb, 0.015% Hf, and trace quantities of thorium and uranium.

Rare Earths Recovery: Preparation of samarium metal has been successfully demonstrated at a batch scale of 120g through the lanthano-thermic reduction of samarium oxide. Calcio-thermic reduction technology for large-scale production of neodymium-praseodymium (Nd-Pr) metals has been validated at kilogram scale. Additionally, pilot-scale production trials of lamp and LED phosphors at a 5kg scale were successfully demonstrated at IREL's RETTP facility in Bhopal.

BARC provided comprehensive technical guidance, including standard operating procedures, for the commissioning of these two technologies.

BARC provided comprehensive technical guidance, including standard operating procedures, for the demonstration followed by commissioning of plants for the preparation of samarium metal and lamp and LED phosphors at IREL's RETTP facility in Bhopal.

A new cathode material, lanthanum hexaboride (LaB_6), has been successfully synthesized as an import substitute for use in electron beam accelerators. By optimizing the processing parameters, fully dense LaB_6 pellets (10mm in diameter) were produced in batches of up to 1kg, marking a significant milestone in indigenous advanced material development.

Back end of Fuel Cycle

Spent Fuel Reprocessing: The Plutonium Plant at Trombay has successfully completed over six decades of spent fuel reprocessing, marking a significant milestone in India's nuclear fuel cycle program. As the country's first reprocessing facility, it played a pivotal role in developing the technology base and operational expertise for recycling Heavy Water Reactor spent fuel.



The Effluent polishing system at WIP Trombay.

Reprocessing of thorium bundles irradiated in Pressurized Heavy Water Reactors (PHWRs) was successfully demonstrated at the WPRTRF facility in Trombay.

To improve process efficiency and product morphology, equipment for converting uranyl nitrate solution to uranium oxide via the ammonium di-uranate route was upgraded. These upgrades include precise pH and temperature control during precipitation, improved filtration through a Nutsche filter system, reduced moisture content using a conical dryer, and enhanced automation.

Radioactive Waste Management: The radioactive waste management facilities at Trombay, including the Waste Immobilization Plant (WIP), Effluent Treatment Plant (ETP), Decontamination Centre (DC), and Radioactive Solid-Waste Management Site (RSMS) - were operated to ensure the safe and effective management of radioactive wastes arising from fuel cycle facilities and radiological laboratories of BARC. These operations focused on recovering valuable radioisotopes for societal applications, minimizing environmental discharges, and reducing secondary waste generation.

Low-level effluents received at the ETP were decontaminated prior to discharge using chemical precipitation and ion exchange methods to minimize environmental impact.

The Decontamination Centre processed protective gear and cut-end rods for reuse, while solid radioactive wastes were compacted or incinerated via a plasma-assisted incinerator to achieve

The operations at several radioactive waste management facilities in Trombay focused on recovering valuable radioisotopes for societal applications, minimizing environmental discharges, and reducing secondary waste generation.

significant volume reduction before disposal in the Near Surface Disposal Facility (NSDF).

Ageing Management of Backend Fuel Cycle Facilities: Effective ageing management is essential for ensuring the long-term safety and reliability of nuclear fuel cycle facilities.

A comprehensive ageing management program has been implemented to sustain backend operations by identifying, evaluating, and mitigating risks associated with the degradation of equipment, systems, and structures.

The strategy combines preventive and corrective measures. Preventive actions include routine inspections, testing, and maintenance to detect early signs of wear or malfunction, while corrective measures involve repair, replacement, or modification of components at the end of their service life.

Continuous ageing management activities are being implemented across reprocessing and waste management facilities at Trombay, extending their operational longevity and maintaining high safety standards.



Upgraded PLC-SCADA System of WIP Trombay.

Recovery of Valuable Radionuclides for Societal Applications: India has developed and deployed advanced technologies for the recovery of valuable radionuclides such as Cs-137, Sr-90, and Ru-106 from high-level liquid waste (HLLW) for beneficial use in healthcare and industry.

Cesium-137 is converted into a non-dispersive cesium-glass matrix for use in blood irradiation devices that prevent transfusion-associated graft-versus-host disease. To date, over 450 kCi of Cs-137 have been recovered, yielding about 250 Cs-glass pencils. A re-designed production system with single-step pouring and an indexing arrangement has improved annual capacity from 40 to 100 pencils.

Strontium-90 is purified for the generation of Yttrium-90 (Y-90), a key isotope in targeted internal radiotherapy, particularly for neuroendocrine tumors.

A di-glycol amide (DGA)-impregnated resin column was developed to enhance Y-90 extraction efficiency. Process validation is underway for regulatory clearance from the Radiation Protection Committee (RPC).

Ruthenium-106 recovered from waste streams is utilized to fabricate RuBy plaques — an indigenous

Ruthenium-106 recovered from waste streams is utilized to fabricate RuBy plaques — an indigenous product for ocular cancer therapy. Currently, fifteen hospitals in India employ RuBy plaques in medical treatments.

product for ocular cancer therapy. Currently, fifteen hospitals in India employ RuBy plaques in medical treatments.

Research and Development for Back end of Fuel Cycle: Research and development activities are underway on the reprocessing of various nuclear fuels envisaged under the departmental programme. A comprehensive roadmap for fuel reprocessing in molten salt reactors (MSRs) and molten salt breeder reactors (MSBRs) has been formulated and is being actively implemented. India's IMSBR initiative aims to utilize thorium resources to enhance long-term energy security, with the commissioning of a 5 MWth demonstration reactor representing an initial milestone.

Ongoing MSR reprocessing research focuses on protactinium recovery, uranium recycling, and efficient removal of fission products to sustain optimal reactor performance. Emphasis is placed on pyrochemical technologies, including fluoride volatility, reductive extraction, vacuum distillation, and electro-refining.

Engineering-scale development of these processes will strengthen the objectives of Aatmanirbhar Bharat by advancing indigenous fuel cycle capabilities and promoting sustainable nuclear energy generation.

A pyrolysis-incineration-based process has been developed for the treatment of alpha-bearing solid wastes comprising cellulose, plastic, and rubber.

A plant-scale system, housed within a series of glove boxes, was operated continuously on an inactive-campaign basis to demonstrate throughput capacity. Parallel research on zircaloy hull management involves developing a chemical dissolution process using sulfur monochloride and thionyl chloride.

Laboratory-scale tests involving 250 g of zircaloy-4 cladding successfully demonstrated complete dissolution and zirconium recovery. Performance



Cesium glass pencil making in progress.



Incinerator (left) & Quencher (right) of Organic Liquid Waste Incineration System (OLWIS).

evaluation of CA-BTPPhen, developed for single-step minor actinide partitioning, is currently in progress.

A Cold Crucible Induction Melter (CCIM), developed by BARC, to address operational and design challenges in high-level liquid waste (HLLW) vitrification, has been installed at WIP, Trombay.

The installation included a high-frequency induction heating power supply, induction coils, and busbar assemblies, which were successfully integrated with the melter.

Given that the current generation of Thermosyphon Evaporators (TSEs) in back end facilities has shown vulnerability to failure due to severe intergranular corrosion (IGC) of SS304L heat exchanger tubes, next-generation heat exchangers have been fabricated using titanium alloy tubes and titanium-clad stainless steel tube sheets.

Fabrication was accompanied by rigorous inspections and stringent acceptance criteria. Five such units were successfully fabricated, comprehensively tested, and are now ready for deployment in back end fuel cycle facilities.

Computational Method for Prediction of Chemical Durability of Nuclear Glass: A computational scheme has been developed to predict the chemical durability of sodium borosilicate (NBS) glass by performing large scale molecular dynamics (MD) simulations.

Cascade evolution profiles for irradiated glass captured the depolymerization of glass and first-time leach rate in irradiated glass was predicted.

Simulations showed that structural damage scaled with total deposited energy rather than recoil energy. Overlapping of structural profiles for PKA energies

A comprehensive roadmap for fuel reprocessing in molten salt reactors (MSRs) and molten salt breeder reactors (MSBRs) has been formulated and is being actively implemented. India's IMSBR initiative aims to utilize thorium resources to enhance long-term energy security, with the commissioning of a 5 MWth demonstration reactor representing an initial milestone. Ongoing MSR reprocessing research focuses on protactinium recovery, uranium recycling, and efficient removal of fission products to sustain optimal reactor performance.

below 10 keV, suggest that structural recovery is feasible at lower recoil energies. The findings suggest that while NBS glass may undergo moderate structural and chemical degradation, it will retain long-term stability under repository conditions.



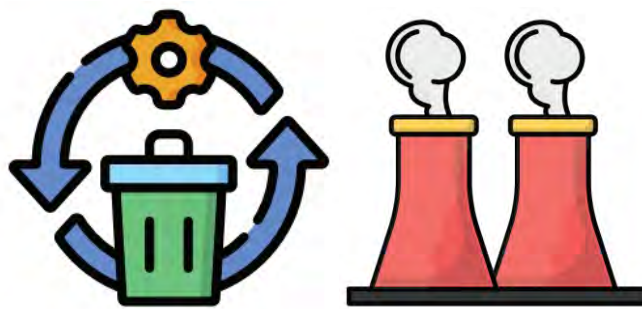
Plutonium Plant in BARC Trombay.

Front end of Fuel Cycle

Recoveries of around 75% were achieved for the atomic minerals niobium (Nb), zirconium (Zr), and hafnium (Hf) in the form of mixed hydroxides.

Uranium recovery through acid leaching–ion exchange–precipitation route was developed, demonstrating the feasibility of producing yellow cake with an overall uranium recovery efficiency of 92%.

A new cathode material, lanthanum hexaboride, has been successfully synthesized as an import substitute for use in electron beam accelerators.

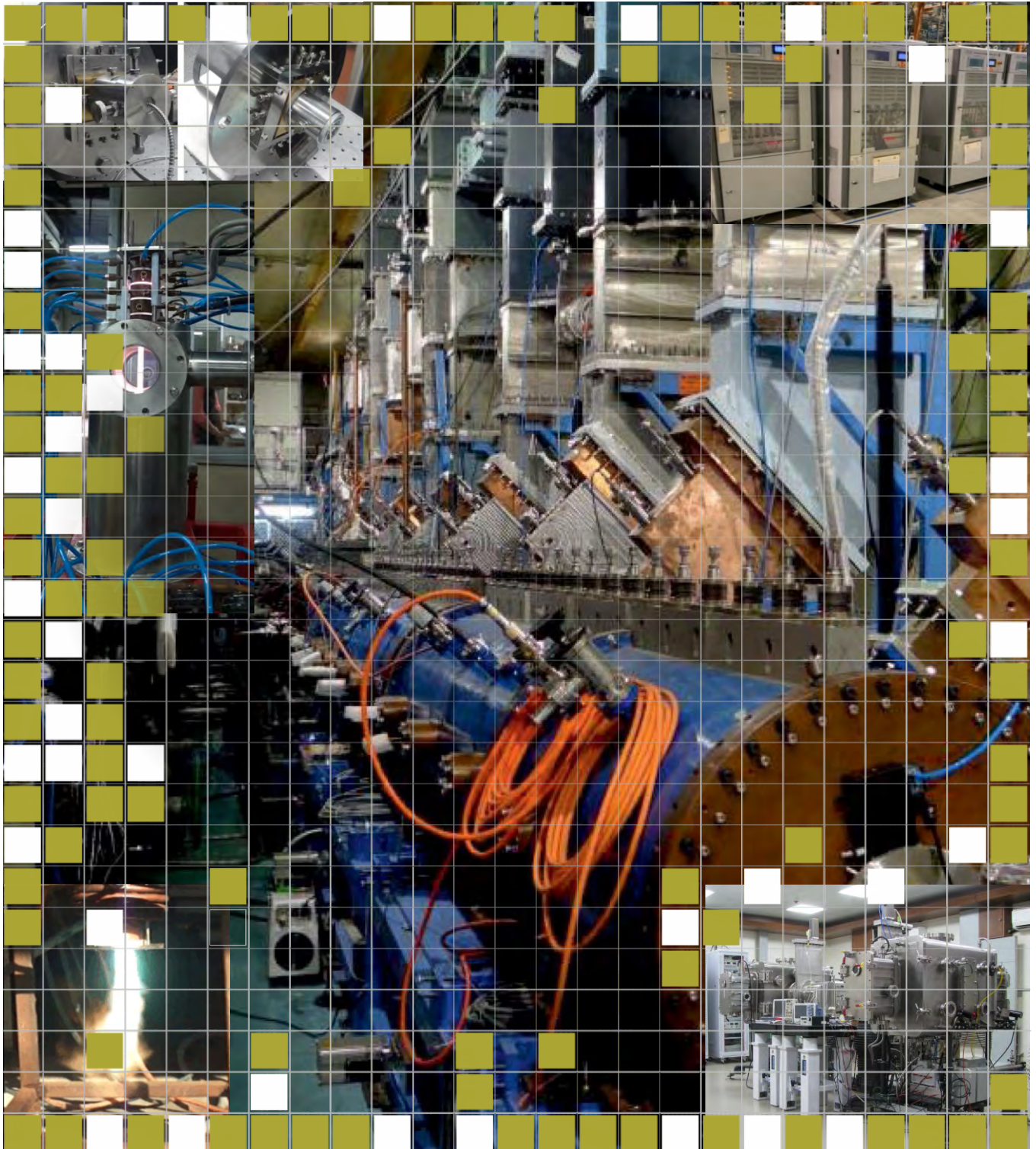


Back end of Fuel Cycle

Reprocessing of thorium bundles irradiated in PHWRs was successfully demonstrated at Trombay.

Radionuclides Cs-137, Sr-90, and Ru-106 are obtained from high-level liquid waste with key applications in healthcare and industry.

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.

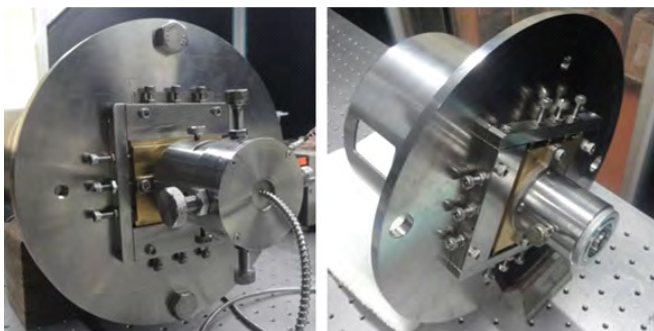
Advanced Tunable Laser: Advanced tunable lasers were utilized for cutting-edge research and development in emerging technologies, as well as for the production and analysis of medical isotopes with emerging applications in nano-scale brachytherapy, with a focus on enhancing indigenization. Efforts are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



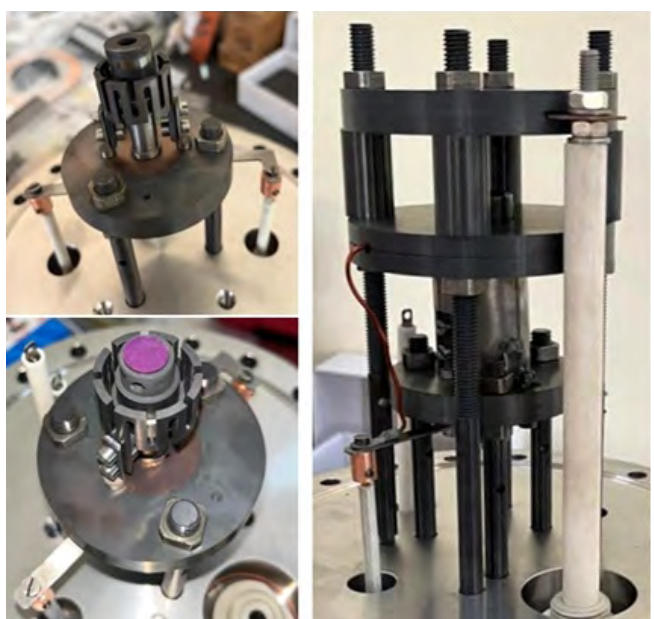
Non-divergent stable Helium thermal plasma.



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.

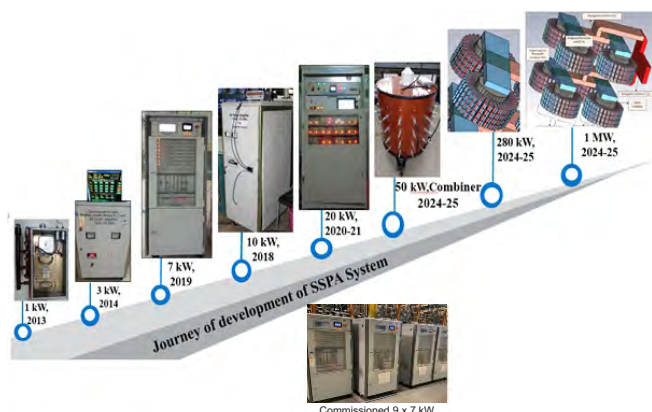
Roadmap Towards Indigenous SSPAs for Accelerators: Indigenous SSPA systems have been designed, developed, and deployed up to 20 kW capacity, including nine 7 kW SSPAs commissioned at the US-headquartered research laboratory Fermilab. As part of its strategic vision, BARC aims to extend these developments 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.

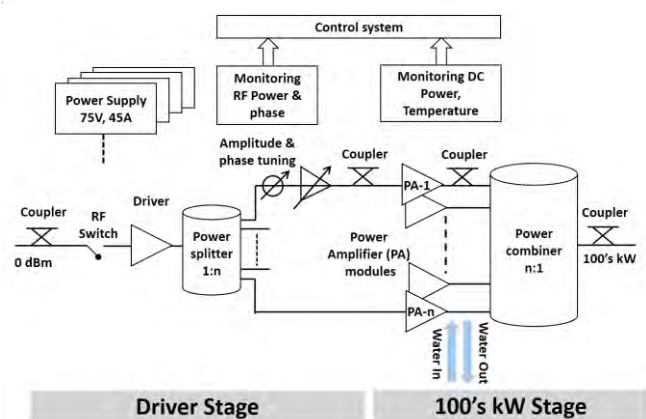
Proton Accelerators

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.

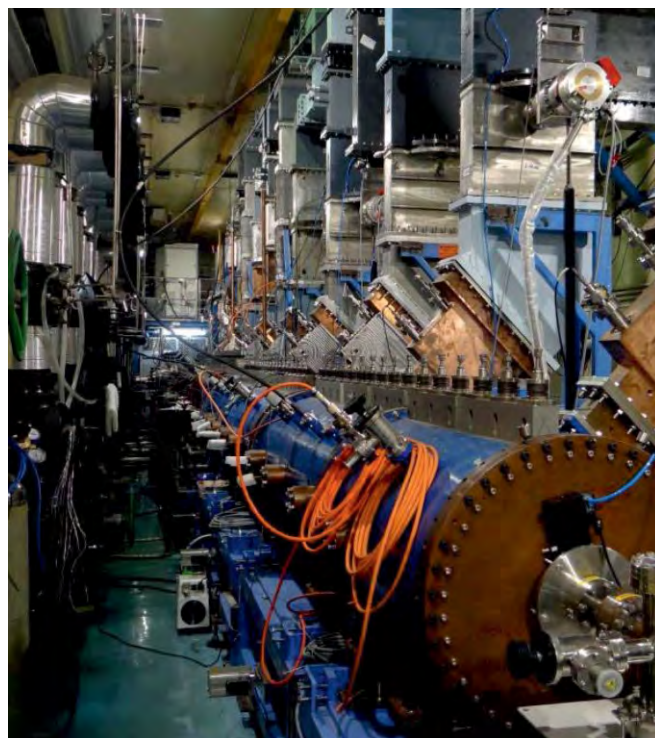
Future Roadmap: The overall plan includes a phased development of a 1 GeV, 1 mA average beam current proton accelerator, designed to meet rigorous requirements for delivering high-current CW beams efficiently and reliably. The phased approach includes four key stages: MEHIPA-Phase I, which involves a 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.



Commissioned 9 x 7 kW



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



LEHIPA facility in BARC.

SOCIETAL APPLICATIONS



THE SOCIETAL APPLICATIONS

vertical of DAE's Vision Programme entails initiatives that encompass agricultural, medical, environmental, and industrial applications of nuclear science and technology to enhance societal and national capacity. Under Crop Variety Development, efforts are being continued in BARC on radiation-induced mutagenesis and speed breeding to create high-yield, climate-resilient crops, while engineering plant-microbe interactions aims to boost nutrient uptake and reduce chemical fertilizer dependence. In Food Preservation by Irradiation, novel accelerator-based and radionuclide irradiator designs are planned to ensure safe, large-scale preservation of food and to strengthen national food security.

In the activities of Nuclear Medicine and Radioisotope emphasis is placed on indigenous production of diagnostic and therapeutic radiometals for advanced imaging and cancer therapy. In research for Cancer Medicine, clinical studies on chlorophyllin and DSePa continue in BARC. Nanoparticle-based targeted therapies, tumour-on-chip prognosis models, and point-of-care optical devices will aid early detection and therapy optimization.

In Water and Waste Management, BARC advances desalination and purification through hybrid MSF-MED-SWRO plants, membrane technologies, electron beam wastewater treatment, and radiation hygienisation of sludge besides isotope hydrology investigations. These will enable water security, zero-liquid discharge, and clean reuse.

Collectively, these programs aim for self-reliance in food and water security, advanced healthcare, sustainable environment management, and technological leadership in the Amrit Kaal.

Crop Variety Development

Oilseeds: To advance the goal of achieving self-reliance in oilseeds, several new and improved Trombay varieties have been developed and released in crops such as mustard, groundnut, and sesame.

In mustard, two high-yielding varieties have been introduced for irrigated conditions in Rajasthan. The breeding line TM 267-3 was released as Trombay Jodhpur Mustard 2 (TJM 2), offering a yield advantage of 10–14%.

Similarly, the previously developed line TM 108-1 initially bred in Maharashtra demonstrated a 12–13% higher seed yield and was released as Trombay

Jodhpur Mustard 1 (TJM 1). TJM 1 is a tall variety with high siliqua density, a maturity period of 112–118 days, and a thousand-seed weight of 3.80 gm. Its brown seeds contain 39.4% oil, comprising 12.6% oleic acid, 19.16% linoleic acid, and 12.29% linolenic acid. The variety has shown field tolerance to aphid infestation and powdery mildew disease. In contrast, TJM 2 is semi-dwarf with constricted pods, 118–128 days to maturity, and a thousand-seed weight of 5.37 gm. Its brown seeds contain 39.0% oil, with 11.68% oleic acid, 18.13% linoleic acid, and 10.26% linolenic acid.

For the first time, BARC has developed a sesame gamma ray mutant, TL 10, released as Trombay Latur Til 10 (TLT-10). This variety is suitable for both rainy and summer cultivation seasons in Maharashtra, and later extended to Telangana. TLT-10 offers 17–24% higher seed yield, 13–16% greater oil yield, and 4–14% more oil content compared to existing varieties. It features bold seeds, medium plant height, 90–95 days maturity, elongated capsules, and moderate resistance to major pests and diseases.

In groundnut, a new mutant derivative, TG 88, has been found suitable for both rainy and summer cultivation seasons due to its 15–20% yield superiority. It has been released as Chhattisgarh Trombay Mungfali (CGTM) for the state of Chhattisgarh. TG 88 is a semi-dwarf variety with 105–110 days maturity, 50–55 gm hundred-seed weight, and a 72% shelling percentage. Nutritionally, it contains 24.5% protein and 49.0% oil, with 48% oleic acid and 33% linoleic acid.

Improved Varieties in Cereals: In rice, a newly developed mutant derivative, BARCKKV 16 has been released as 'Trombay Konkan Khara' for cultivation in coastal saline soils of Maharashtra. This variety exhibits tolerance to soil salinity levels up to 6–7 dS/m and produces about 15% higher grain yield under saline conditions. It is semi-dwarf, non-lodging, and



The plant of TJM1 (Mustard) in the inset; and a field view of Trombay mustard.

matures in 125–130 days. The variety also displays excellent milling and head rice recovery, long slender grains, and resistance to stem borer.

Another gamma-ray-induced mutant derived from the popular soft-cooked rice landrace Luchai of Chhattisgarh has been released as ‘Bauna Luchai-CTLM’. This variety retains the soft-cooking quality of its parent line while exhibiting lodging resistance, early maturity, and higher grain yield.

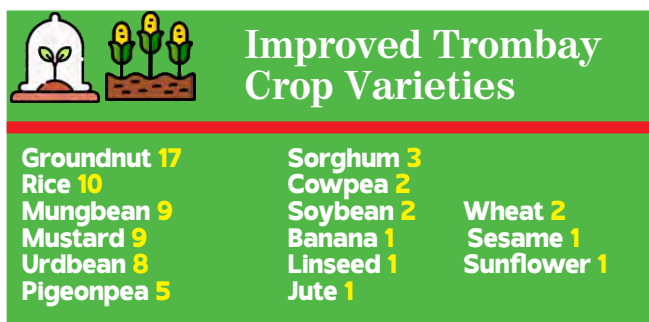
Additionally, a selection from a traditional therapeutic rice landrace of Chhattisgarh has been released as ‘Sanjeevani’. Its slender, scented brown grains are noted for immune-boosting and cancer-suppressive properties. The variety possesses intermediate amylose content, while its bran oil contains moderate levels of gamma oryzanol, contributing to its nutritional and health benefits.

In wheat, two high-yielding breeding lines, TAW 153 and TAW 155, have been developed with multiple disease resistance and good chapati-making quality for irrigated, timely sown conditions. TAW 153, which outyields check varieties by 14%, has been released as ‘Trombay Jodhpur Wheat 153 (TJW 153)’ for cultivation in Rajasthan. It is a medium-tall variety producing amber, semi-hard, bold grains with superior grain quality traits viz., 11% protein content, medium gluten strength, and 39.7 ppm iron. The variety shows resistance to leaf and stem rust, Karnal bunt, loose smut, powdery mildew, and flag smut.

The TAW 155 variety, yielding 11% more grain than the check variety, has been released as ‘Trombay Raj Vijay Wheat 155 (TRVW 155)’ for cultivation in Madhya Pradesh. It is characterized by medium plant height, lodging resistance, a waxy plant type, and dark green foliage that enhances heat stress tolerance. The variety also possesses medium protein content, medium gluten strength, and elevated levels of iron and zinc. It exhibits broad-spectrum resistance to wheat blast, stripe rust, leaf rust, stem rust, Karnal bunt, loose smut, powdery mildew, and foot rot.

Sorghum Mutant Variety: A novel mutant variety of sorghum has been developed through gamma ray-induced mutagenesis at the Bhabha Atomic Research Centre (BARC). F₁ hybrid seeds were irradiated, leading to the development of a new variety designated as Raichur Trombay Sorghum-43 (RTS-43). This variety is recommended for medium to deep black soils of the transitional zone under rainfed conditions of northern Karnataka.

RTS-43 demonstrates a 9–15% increase in grain and fodder yield, coupled with early maturity,



Improved Trombay Crop Varieties

Groundnut 17	Sorghum 3	
Rice 10	Cowpea 2	
Mungbean 9	Soybean 2	Wheat 2
Mustard 9	Banana 1	Sesame 1
Urdbean 8	Linseed 1	Sunflower 1
Pigeonpea 5	Jute 1	

synchronized flowering, a waxy coating on stems and leaves, semi-compact panicles, and bold, straw-colored seeds. The flour produced from RTS-43 yields rotis with superior palatability and consumer acceptability, attributed to its favorable organoleptic, sensory, physical, and functional characteristics. From a nutritional perspective, RTS-43 exhibits enhanced levels of iron, zinc, crude fiber, protein, and fat, making it a nutritionally valuable crop. Additionally, it shows moderate resistance to major diseases such as charcoal rot, blight, and rust.

Through a combined approach of radiation-induced mutagenesis and conventional crossbreeding, BARC in a joint collaboration with several crop research organizations within the country, developed 72 improved crop varieties and more are in the offing. These varieties are now widely cultivated across India, substantially contributing to enhanced agricultural productivity, farmer welfare, and national food security.

Food Preservation by Irradiation

New and Tailor-made Irradiators: Food preservation through irradiation is a vital research initiative aimed at strengthening India's national food security. Currently, 28 food irradiation facilities operate across the country: five managed by the government and twenty-three privately-owned. To address the rising demands of the agricultural produce market, five customised irradiator designs are under development. Research is also focused on evaluating Bismuth-207 (Bi-207) as a potential alternative to the commonly used Cobalt-60 (Co-60) and Cesium-137 (Cs-137) sources for food irradiation. Another major goal is to design and develop novel low-energy electron and X-ray systems, up to 300 keV, for surface food treatment.

Efforts are underway to conceptualise and deploy radionuclide-based irradiators tailored for diverse food products. Additionally, innovative product handling systems will be designed, alongside detailed studies on dosimetry and process control to ensure



Release of AKTOCYTE (Chlorophyllin) Oral Tablets.

precise and safe application of irradiation. The production of Bi-207 will be explored using charged-particle bombardment, specifically by irradiating lead (Pb) targets with a high-power 20 MeV proton beam to generate residual activity.

These accelerator-based systems and customised irradiators are expected to significantly enhance India's capacity for safe and effective food preservation. By enabling long-term storage, reducing food wastage, and maintaining nutritional quality, this programme will play a pivotal role in achieving comprehensive national food security.

Research for Cancer Medicine

Radioprotective and Regenerative Action of Chlorophyllin in Cancer Patients: Pelvic radiotherapy often induces hemorrhagic cystitis due to radiation-mediated tissue, vascular, and inflammatory damage. Chlorophyllin (CHL), recognized for its antioxidant, immune-stimulatory, chemoprotective, and radioprotective functions, was evaluated clinically. In a Phase II trial, CHL tablets resolved hematuria in 83.3% of patients with grade II–IV cystitis. Treatment reduced systemic inflammatory indices (NLR, PLR, SII) and cytokines (IL-1 α , IL-1 β , IP10, IL-6, IL-8, IL-33, MIP-1 α , MIP-1 β). Proteomics and metabolomics analyses confirmed modulation of complement activation, wound repair, and coagulation pathways. Long-term follow-up showed sustained relief and improved quality of life. CHL tablets (AKTOCYTE) are now available as nutraceuticals approved by the Department of Atomic Energy.

Molecular Prognostic Markers in Neuroendocrine Tumors: Peripheral blood RNA sequencing of Neuroendocrine Tumors (NET) patients undergoing ¹⁷⁷Lu-DOTATATE therapy identified 30 dysregulated Cancer Hallmark pathways, 14 overlapping with tumor tissue profiles. Elevated activity in heme metabolism (>0.3) and IL2/STAT5 signaling correlated with early disease progression and significantly shortened progression-free survival, conferring a five-fold higher risk.

Somatic Mutation Profiling via cfDNA in Lung Cancer: Ultra-deep sequencing (10,000X) of plasma cfDNA revealed actionable mutations, including EGFR variants, indels, and gene fusions (ALK, ROS1, RET). Parallel studies developed cfDNA extraction from cell-conditioned media to elucidate release and fragmentation biology. These findings validate cfDNA as a non-invasive, clinically informative biomarker for targeted lung cancer therapy.

Nanobody Development for Thyroglobulin Detection: Two human thyroglobulin-specific nanobodies (KT75, KT76) were developed (BARC-RMC collaboration). Crystal structures at 1.3Å and 1.6Å indicated intrachain disulfide bonds conferring high thermal stability. Binding affinities measured by ITC and SPR yielded KD values of 2 nM for KT75 and 10 nM for KT76, underscoring their diagnostic potential for sensitive Tg assays in thyroid cancer.

CRISPR based Diagnostics for Blood Pathogens and Mycobacterium: A single-pot CRISPR-based assay was designed to simultaneously detect HIV, HCV, Treponema spp., and Plasmodium spp. using conserved nucleic acid targets and optimized guide RNAs. Fluorescent visualization under blue light (~520 nm) enables rapid, eye-visible detection. Extended assays for Mycobacterium demonstrated high sensitivity on synthetic targets. The portable CRISPR-CUBE device facilitates on-site testing and visualization, proposing a unified, sensitive alternative to conventional TTI screening in blood banks.

Nuclear Medicine and Related Radioisotopes

Advanced Diagnostic and Therapeutic Patient Services: In alignment with recent innovations in molecular imaging and targeted radionuclide therapy, RMC Mumbai-BARC Hospital has introduced five advanced diagnostic radiopharmaceutical studies over the past two and a half years. These include four ⁶⁸Ga-labeled PET tracers and one ^{99m}Tc-based SPECT agent, complemented by a novel ¹⁷⁷Lu-labeled FAPI-2286 therapeutic radiopharmaceutical.

These agents have been successfully integrated into patient care protocols for a wide spectrum of clinical indications, including RAI-refractory thyroid carcinoma, parathyroid adenoma, peripheral vascular disease, head and neck squamous cell carcinoma (SCC), medullary thyroid carcinoma, insulinoma, multiple myeloma, adrenal adenoma, Parkinson's disease and other movement disorders, as well as metastatic manifestations of medullary thyroid, breast, and gastric carcinomas.

Production of Advanced Medical Isotopes: During 2025 so far, around 650 Ci of Lu-177-based radiopharmaceuticals were produced using nearly 45 mg of enriched Lu-176 through efforts in BARC, contributing to the treatment of over 2,600 patients across India. Additionally, for the first time, Ytterbium-168 has been enriched from 0.126% to over 30%, producing around 4 mg of material to support the development and pre-clinical evaluation of Yb-169 based radiopharmaceuticals for the emerging application in nano-scale brachytherapy. Further, Yb-176 was isotopically enriched in-house to 96.8% and used as target to make no-carrier Lu-177, which was then utilized in combination with PSMA-617 and DOTA-TATE at TMH for radionuclide therapy of prostate and neuroendocrine cancers, respectively.

Facilities and Treatment Services at RMRC: The Radiation Medicine Research Centre (RMRC) at Kolkata, is a state-of-the-art Nuclear Medicine facility established under the aegis of BARC. The centre aims to provide affordable, cutting-edge diagnostic and therapeutic nuclear medicine services to patients across the country, particularly in the Eastern and North-Eastern regions of India.

In addition to routine PET-CT services, I-131 therapies for thyroid cancer patients have been conducted regularly since July 2025. MD residents and consultant physicians visit the centre regularly to provide clinical patient care. Furthermore, 177Lu-based treatments have recently commenced for metastatic castration-resistant prostate cancer (mCRPC) patients.

To facilitate seamless integration & data sharing, connectivity work with RMC Mumbai is underway in collaboration with the TMH. It will extend EMR of TMH with RMRC Kolkata, enabling both centres to access & review treatment records in real time.

Water and Waste Management

For effective water resources management, the Isotope Hydrological Program in BARC continued its sustained focus on pan-India isotope investigations to identify groundwater recharge sources, supported by rainwater harvesting measures for improving



Prototype CRISPR-CUBE designed by tech transfer partner based on BARC know-how.

groundwater sources. In this pursuit, isotope hydrological activities were carried out by roping in several leading governmental and non-governmental agencies in the country and abroad.

River-Groundwater Interaction Studies: A collaborative study with NOIDA, Uttar Pradesh, examined groundwater recharge dynamics within the Yamuna (YFP) and Hindon (HFP) floodplains. Isotopic analyses indicated that wells between 12 and 30 m bgl receive significant and consistent recharge during both seasons, primarily from rainfall, shallow subsurface flow, and river infiltration. Deeper wells (>30 m bgl) are mainly sustained by older lateral flows. River and rainfall contributions to groundwater in HFP are found to be minimal.

Groundwater Recharge via Defunct Dug Wells: In partnership with WaterAid, isotope hydrological investigations in Gaya (Bihar) and Nuapada (Odisha) revealed that defunct dug wells effectively facilitate rainwater recharge. Stable isotope data ($\delta^2\text{H}$, $\delta^{18}\text{O}$) and End Member Mixing Models estimated rainwater contributions of $39 \pm 7\%$ in Nuapada and $32\text{--}55\%$ in Gaya. These findings highlight the potential of artificial recharge through abandoned wells for economic & sustainable groundwater management.



Field sampling work by BARC at a recharge well of Nuapada in Odisha.



The Seawater reverse osmosis plant established by BARC at OSCOM in Odisha.

Estimation of Natural Rainwater Infiltration:

Under NAQUIM 2.0, a radiotracer (HTO) study in Bengaluru city quantified natural recharge rates across three catchments. Radiotracer injection (50–70 cm depth) before monsoon and tritium activity profiling during post-monsoon yielded recharge estimates of 1.5–13.5%. These results inform quantification of monsoonal recharge critical for aquifer sustainability as well as indicate potential recharge zones for undertaking artificial measures.

Radiation Technology for Remediation & Detection of Water Pollutants:

Different functional materials have been synthesized through radiation induced graft polymerization process and employed for remediation and detection of water pollutants (textile dyes and metal ions) in water streams. Radiation Assisted Adsorbent Technology for Textile Effluent Decoloration, developed for removing ionic dyes from cotton textile wastewater, has been successfully scaled up and validated through a 75 KLD industrial plant installed at Jodhpur, Rajasthan. The system was demonstrated to industry representatives from Surat, Chennai, Hapur, and Balotra, along with BARC tech licensees from Ahmedabad and officials from Pollution Control Boards of Gujarat and Rajasthan. The treated, decolored water was fully reused by the host industry. Following a detailed evaluation, RSPCB, Jaipur granted the 'Consent to Establish' for the technology, which has since led to four additional tech licensees.



Textile Effluent Decoloration treatment plant (75KLD) installed at Jodhpur (Top).

Electron Beam accelerator for wastewater treatment(Right).



For trace detection of Chromium(VI), paper-based analytical devices (PADs) offer a low-cost, portable solution. Acid-free PADs (Af-PADs) incorporating diphenylcarbazine (DPC) were developed via gamma radiation-induced grafting of poly(acrylic acid) onto Whatman filter paper, followed by DPC loading. The grafted acidic groups create localized acidity needed for the chromogenic reaction between Cr(VI) and DPC, eliminating the need for external acid addition and enhancing safety and usability in on-site detection.

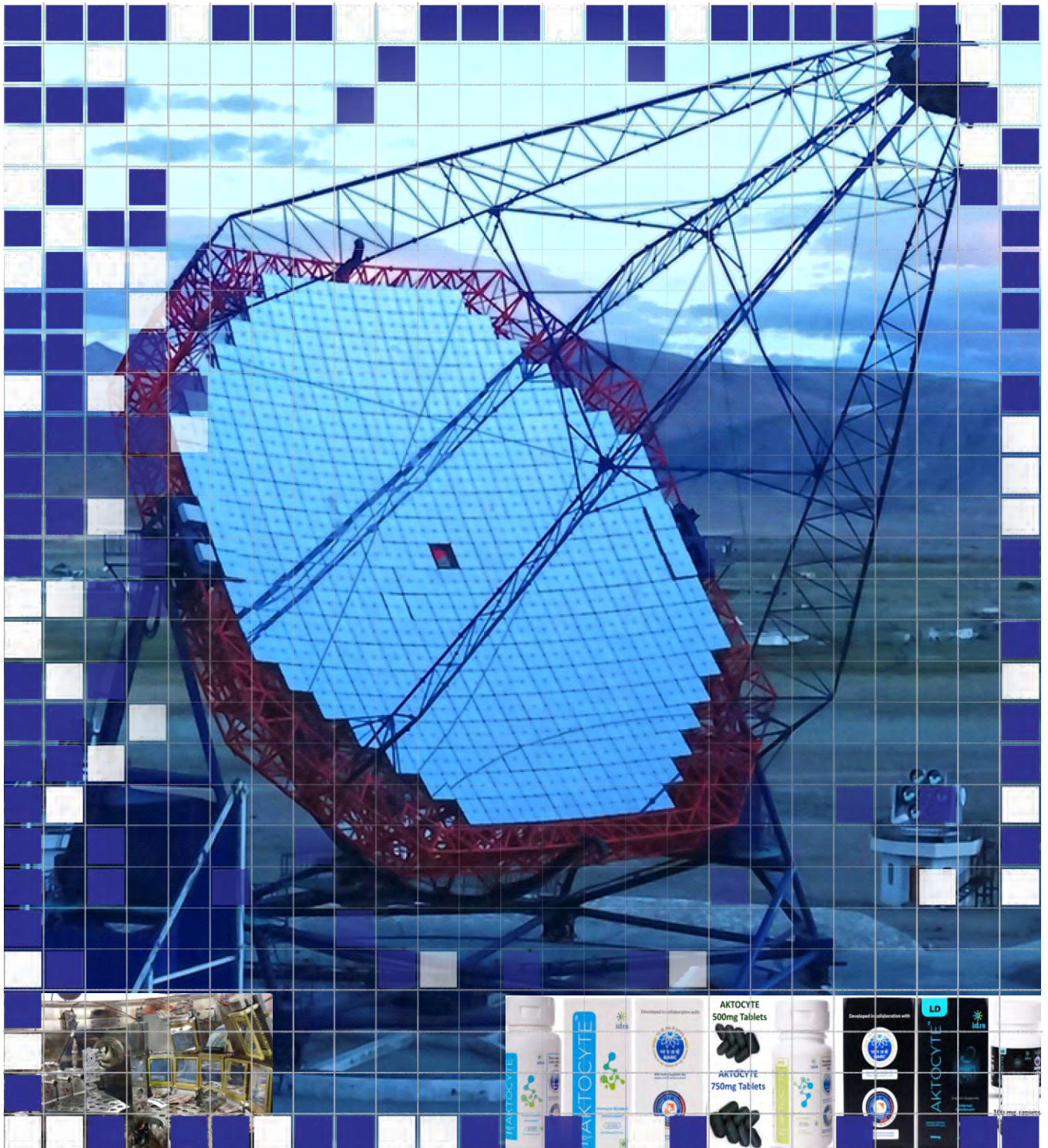
Desalination (Nuclear) and Membrane Technologies:

The Multi-Stage Flash (MSF) distillation plant operated continuously, producing 513.13 million liters of high-quality water with TDS ranging between 5–50 ppm. Of this, 237.86 million liters were supplied to the Madras Atomic Power Station, and the remainder was delivered to the IGCAR/BARC reservoir as potable water. The seawater reverse osmosis (SWRO) plant, employing indigenous membranes, produced 26.78 million liters of potable water for the same reservoir. BARC's 5 MLD seawater reverse osmosis plant at OSCOM, Odisha, achieved stable operation and consistently produced water conforming to IS:10500 standards. Based on its proven reliability, 1.5 MLD of desalinated water is now distributed to Aryapalli and Matikhali villages under a certified public supply program, inaugurated in August 2025 by the Hon'ble Union Minister. A hollow-fiber ultrafiltration (UF) membrane developed at BARC effectively treats turbid, microbiologically contaminated water, reducing turbidity from >100 NTU to <1 NTU and achieving a 5-log E. coli reduction. The technology, suitable for offline and online systems, has been transferred to two Indian industries. Additionally, a lab-scale Air Gap Membrane Distillation (AGMD) unit using hydrophobic membranes was developed and validated through mathematical modeling. It efficiently recovers distilled water from seawater (50 mS/cm) and concentrated brine (120 mS/cm), demonstrating potential for high-recovery desalination applications where conventional methods are limited.

EB Accelerator for Waste Water Treatment:

A 1 MeV, 100 kW Electron Beam (EB) accelerator for wastewater treatment has been tested up to 50 kW. It safely and efficiently reduces chromaticity, COD, and BOD by applying 5–16 kGy radiation to dye effluents. The system pumps effluent from an ETP aeration tank through the beam exit port, circulating until COD ≤ 250 ppm and BOD ≤ 30 ppm, then discharges as a thin water film. Compared to conventional methods, EB enables rapid oxidation of non-biodegradable matter and supports the National Clean Ganga Mission.

FRONTIERS IN BASIC RESEARCH



FRONTIERS IN BASIC RESEARCH

articulates DAE's vision to strengthen India's scientific, technological, and healthcare frontiers through fundamental research across its premier R&D centres. It lays out a multi-disciplinary roadmap encompassing the domains of physics, chemistry, materials science, biology, and health physics to drive significant progress in atomic energy.

In physics, the initiative focuses on establishing advanced national facilities at MACE in Ladakh for gamma-ray astronomy, high-energy heavy-ion accelerators, and a next-generation radioactive ion beam complex at BARC Vizag. It also prioritizes leadership in quantum technologies through the proposed Centre for Advanced Quantum Computing and the indigenous development of scalable multi-qubit systems for quantum computing and information processing.

In chemistry and materials science, thrust areas include the development of innovative nuclear fuels, molten salt reactor materials, advanced fuel cycle technologies, and high-performance materials for laser and accelerator applications. Some of the other initiatives target indigenous helium recovery and eco-friendly, lead-free radiation shielding materials for both nuclear and medical uses.

The life sciences component highlights novel cancer therapies such as boron and gadolinium neutron capture techniques, radiobiology of charged particles, and the proposed Centre of Excellence in Biophotonics for advanced optical diagnostics and therapeutic innovations. Programmes in health physics focus on next-generation dosimetry, optically stimulated luminescence detectors, space radiation effects, and enhanced radiation monitoring systems. Together, these initiatives reflect DAE's commitment to self-reliance and societal advancement through atomic research.

Physics Research

MACE Detection of Blazar OP 313: The MACE telescope covers an energy range of 30 GeV-5 TeV, while TACTIC operates over 1-20 TeV, complementing MACE by extending coverage to higher energies. On 26 January 2025, MACE detected the blazar OP 313, a member of the rare Flat Spectrum Radio Quasar (FSRQ) subclass; only about ten such sources are known in the Very High Energy (VHE; $E > 30$ GeV) gamma-ray band. FSRQs, among the brightest

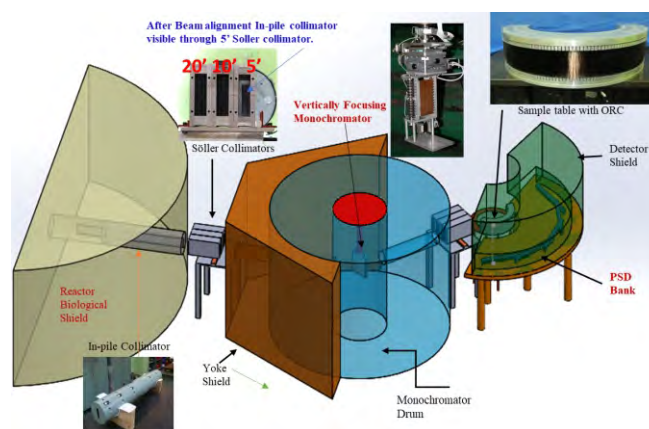
extragalactic objects, are key to probing emission mechanisms underlying Very High Energy gamma rays, whether leptonic or hadronic in origin. Located approximately 8 billion light-years away, OP 313 emitted these photons when the universe was less than half its current age, making it the most distant VHE blazar known and a valuable probe of early cosmic conditions.

Research at NFNBR, Dhruva Reactor: During the past year, NFNBR facilities served about 290 users from across India. Experiments at various beamlines resulted in roughly 145 publications in reputed international journals, with an average impact factor of 4.3. Key highlights are summarized below.

Helical Magnetic Structure at Ni/Gd Interfaces: Studies at the Dhruva reactor using polarized neutron reflectivity (PNR) revealed a twisted magnetic phase at Ni/Gd interfaces due to strong antiferromagnetic coupling between Ni (transition metal) and Gd (rare earth). A 1D spin model confirmed a helical spin structure arising from interfacial intermixing. The observation of this helical phase at room temperature opens new avenues to control magnetic properties for advanced memory storage technologies.

Exotic Magnetic State in $\text{Ca}_3\text{LiRuO}_6$: Investigations using neutron powder diffraction on Powder Diffractometer-I uncovered a canted antiferromagnetic ground state in $\text{Ca}_3\text{LiRuO}_6$. This behavior stems from spin-orbit coupling-induced anisotropic exchange in an orbitally quenched Ru^{5+} system. The results establish $\text{Ca}_3\text{LiRuO}_6$ as an ideal material to study weak ferromagnetism and spin canting driven by spin-orbit and lattice interactions in $4d^3$ oxides.

Upgrades at Dhruva for Probing Local Structure: The High-Momentum Transfer Diffractometer (High-Q) underwent major upgrades, including replacing the



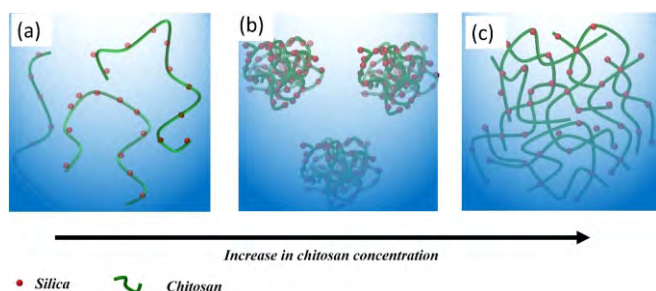
High-momentum Transfer Diffractometer at Dhruva reactor.

in-pile collimator, optimizing beam collimation, upgrading the monochromator, and increasing detector count. These improvements tripled the neutron flux and enhanced resolution threefold. The upgraded instrument now enables faster experiments, partial structure studies through isotopic substitution, high-pressure analyses up to 2 GPa, and time-resolved diffraction, making it a world-class facility for disordered materials research.

Neutron Depth Profiling at APSARA-U: The Neutron Depth Profile (NDP) technique provides quantitative depth concentration profiles up to 5–10 μm with nanometre resolution in solids for selected elements such as He, Li, B, N, and Cl. The NDP system, commissioned at the BT-07 beamline of the APSARA-U reactor, has been used for analyzing B- and Li-containing samples under various reactor power conditions.

Synchrotron-based Research: BARC beamlines at the Indus-1 and Indus-2 synchrotrons operate continuously to support scientific and industrial users. From Sept. '24 to Aug. '25, these facilities catered to approximately 430 users across India, including 20 from industry. The outcome was around 150 peer-reviewed publications and 21 new protein structure depositions in the Protein Data Bank.

AI-Driven Protein Design Pipeline: A generative AI-based protein design pipeline was implemented at BL21 of Indus-2, integrating RFdiffusion, ProteinMPNN, and AlphaFold2. This pipeline combines structure prediction with generative diffusion modelling to design sub-10 kDa protein binders that target pathogen or cancer-associated proteins. Using this approach, mini-protein binders were developed against the SARS-CoV-2 nucleocapsid protein. The crystal structure of one binder, Gpx62, was resolved at 1.8 $\text{\AA}$ (PDB ID: 9UC5), showing close agreement with the design (RMSD 0.48 $\text{\AA}$). Work is ongoing to design binders for cancer surface proteins.



Various intriguing phases of polyelectrolyte-nanoparticles with varying polyelectrolyte concentration, as revealed by SAXS.

Soft Matter Studies via SAXS (BL-18): The Small-Angle X-ray Scattering (SAXS) beamline (BL-18) at Indus-2 enables nanoscale investigations of soft matter, biological systems, and nanomaterials. Recent studies captured electrostatically driven collapse and relaxation of polyelectrolyte-colloid complexes, revealing a multi-step structural transition from intermediate bead-like states to compact domains and stable coacervate-like assemblies. The results elucidate how electrostatic tuning governs the kinetics and morphology of these complexes, guiding researchers in their efforts to design smart drug carriers, adaptive nanocomposites, and bio-responsive materials.

X-ray Absorption of Radioactive Samples (BL-09): A dedicated facility for X-ray Absorption Spectroscopy (XAS) of α - and β -emitting samples has been established at the Scanning EXAFS beamline (BL-09) of Indus-2. Developed through the joint efforts of two scientific groups in BARC, the facility supports both transmission and fluorescence detection modes for dilute and concentrated samples. Custom-designed containment systems ensure sample integrity and maintain radiation exposure below 0.1 mSv h^{-1} during all handling operations. The setup was validated through Pu $L_{2,3}$ -edge XAS measurements on plutonium sulfate, providing Pu–O bond distances consistent with powder XRD data. This facility significantly strengthens synchrotron-based research on actinides and long-lived radioisotopes.

Observation of Scission Proton Emission in Heavy-Ion Fission: Neck rupture in nuclear fission is a turbulent process governed by nuclear viscosity and steep potential gradients, with particle emission near scission offering a sensitive probe of its dynamics. At the BARC–TIFR Pelletron Linac Facility, systematic studies using advanced detection and analysis techniques have examined scission alpha emission, characterized by predominant equatorial emission. For the first time, scission proton emission has also been observed in heavy-ion-induced fission. Unlike alphas, protons show both equatorial and polar emission with nearly equal intensities but an order-of-magnitude lower yield. These observations provide new insights into scission dynamics in heavy nuclei.

Cluster Structure and Reactions of Weakly Bound Light Nuclei: Studies at the BARC–TIFR Pelletron Linac facility, using a large-acceptance silicon strip detector array, explore the cluster structure and reaction mechanisms of weakly bound light nuclei to better understand quantum clustering and stellar nucleosynthesis. Exclusive α – α

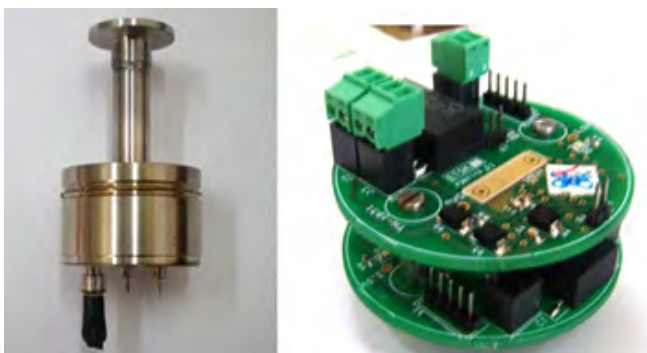


Silicon strip detector array at the BARC-TIFR Pelletron Linac Facility.

coincidence measurements from $^9\text{Be} + ^{124}\text{Sn}$ reactions near the Coulomb barrier have distinguished breakup and transfer channels. Reactions with ^{10}B projectiles on ^{159}Tb , ^{197}Au , and ^{209}Bi targets at 54 MeV revealed dominant alpha production, while neutron transfer cross-sections for the $^7\text{Li} + ^{205}\text{Tl}$ system, analyzed with Coupled Reaction Channel calculations, exhibit universal trends linking neutron transfer and fusion processes in weakly bound systems.

High-Transmittance Beam Splitters (HTBSs) for Photoionization Experiments: HTBSs with $\text{TiO}_2/\text{SiO}_2$ multilayer coatings (450–625 nm) were indigenously developed at ATLAD-BTDG for laser-based isotope-selective photoionization studies. Fabricated via confocal RF sputtering on fused silica substrates, these HTBSs exhibit $T > 98\%$ and $R < 2\%$ at 45° incidence. Deployed in Nd:YAG-pumped dye laser systems, they demonstrate excellent optical stability and durability.

Capacitance Gauge for Corrosive Environments: An Inconel 625-based capacitance gauge capable of absolute pressure measurement from 1000 to 1 mbar with ± 0.1 mbar accuracy was developed for highly corrosive environments (HF , CF_4). Long-term HF exposure tests confirm consistent and repeatable performance.



Capacitance Gauge (left) and its pressure measuring & control electronics (right).

Closed-Cycle Refrigerator for Optical Measurements: An indigenous closed-cycle refrigerator (4.2–300 K) was developed for optical and micro-Raman studies, substituting imports. Using this system, negative linear compressibility (NLC) of -20.5 Tpa^{-1} in orthorhombic CuCN was discovered up to 9.8 GPa. Raman and XRD analyses attribute this behavior to structural hinging in its “wine-rack” framework.

Crystal Growth of CsI:Tl for Gamma Spectrometers: Under AIC-BARC incubation, a Bridgman crystal growth facility was established at M/s Ace-ex, Mumbai, in collaboration with the Physics Group, BARC. High-quality 2-inch CsI:Tl crystals were successfully grown, leading to the development of handheld gamma spectrometers. The incubatee has secured GeM contracts to supply detectors to BARC divisions.

RF/DC Electronics for Mass Spectrometers: Compact RF/DC electronics for hydrogen–steam concentration monitoring systems (HSCMS) were developed, enhancing tuning, space efficiency, and EMI/EMC resilience. These systems are poised for deployment in the regular operations of NPCIL facilities at TAPS, RAPS, KGS, MAPS, and NAPS.

Table-Top Proton and Ion Acceleration: At the 200 TW Ti:sapphire laser system, target-normal sheath acceleration (TNSA) of ions was demonstrated via proton and multi-charged $\text{C}^{n+}/\text{Al}^{n+}$ spectra recorded using a Thomson Parabola Spectrometer. Simulations correlate q/m ratios with observed traces. Maximum proton energy reached $\sim 2 \text{ MeV}$ for 1.2 J laser energy, with a detection threshold of $\sim 28 \text{ keV}$.

Molecular Cluster Studies for Energy Applications: Laser-vaporization experiments on transition-metal clusters (Ti, V, Fe, Co, Ni) revealed distinct ammonia activation pathways and N–H bond-cleavage behavior, with Ni clusters showing complete NH_3 dehydrogenation.

Yttrium-oxide clusters (Y_nO_m) were found to promote O_2 activation via charge transfer, providing atomistic insight into catalytic processes relevant to nitrogen, hydrogen, and oxygen chemistry.

Fast-Neutron-Induced Fission of ^{232}Th : At FOTIA, fast-neutron-induced fission of ^{232}Th was studied using CeBr_3 detectors. Measured prompt γ -ray spectra ($> 0.1 \text{ MeV}$) show 40–50% higher total energy than model predictions, and reduced emission below 0.4 MeV relative to ^{252}Cf , ^{238}U , and ^{239}Pu . These results refine fission models and improve γ -heating estimates for Gen-IV systems.

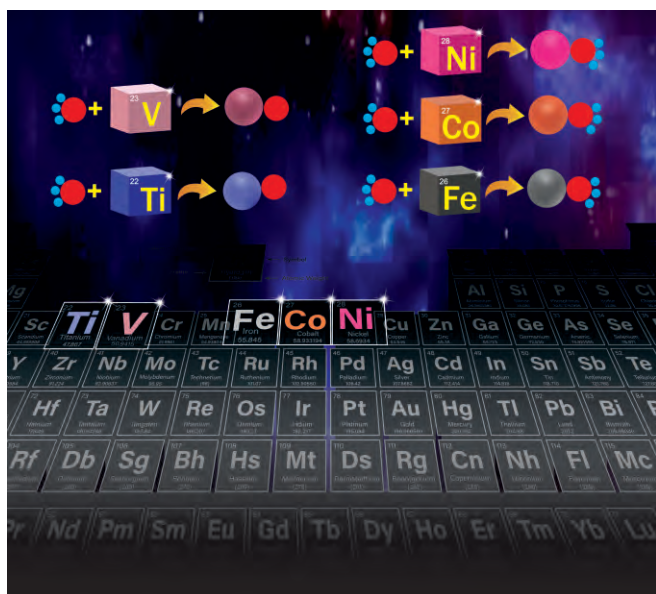


Illustration of ammonia activation pathways & bond cleavage, highlighting Ni clusters' complete NH_3 dehydrogenation. Published as a front cover of ACS' JPC A Vol. 129, No. 37.

Coherent Neutrino–Nucleus Scattering (ICNSE):

The Indian Coherent Neutrino–Nucleus Scattering Experiment (ICNSE) at BARC is being developed to measure CENNS using reactor antineutrinos. Studies indicate strong sensitivity to the weak mixing angle at low energies and to neutrino electromagnetic properties. Simulations further show capability for detecting supernova events within 750 pc and probing shock-revival dynamics via neutrino-flux time evolution.

Chemistry & Material Science

Development of NiMoCrTi-C Alloy for MSBR

Applications: A Ni-based NiMoCrTi-C alloy has been developed as a candidate structural material for molten salt reactors (MSR). Thermo-mechanical processing parameters, including hot deformation and heat treatment, have been optimized to manufacture plates, tubes, and other shapes from as-cast ingots. Using these parameters, large forged ingots have been successfully hot-rolled into thick plates of various dimensions. Additionally, the alloy's compatibility with fluoride salt environments at elevated temperatures was systematically evaluated across varying Mo/Cr and Fe/Cr ratios. Ni-Cr-Mo/Fe alloys such as Hastelloy N, Hastelloy X, Alloy 690, and Alloy 693, when exposed to FLiNaK salt under inert atmospheres, exhibited non-uniform corrosion and selective chromium dealloying. Increased Fe+Cr content and/or higher Cr/Mo ratios were found to enhance the corrosion susceptibility index.

Assessment of RPV Steel Properties:

Microstructural analysis of APURVA, an indigenously developed ultra-thick pressure vessel steel, revealed that ductile fracture occurs through nucleation, growth, and coalescence of micro-voids influenced by inclusions, second phases, and grain boundaries. Studies on quenched-tempered samples from various locations and orientations clarified its failure mechanisms. The ductile-to-brittle transition curve was established. Proton irradiation tests showed that indigenous eastern-grade RPV steel exhibits superior irradiation resistance compared to its imported counterpart.

Threshold Stress for Hydride Reorientation in Pressure Tube Materials:

For Zr-2.5Nb pressure tube materials from 220 and 700 MWe PHWRs, the threshold stress for radial hydride formation (RHF-50%) under both biaxial and uniaxial conditions was found to be 110–130 MPa, independent of stress state. The addition of yttrium (Y) significantly mitigated hydride formation, reducing hydride content by about 7%, even without metallurgical bonding, confirming Y's efficacy as a hydrogen getter.

Pre-oxidised Zr-2.5Nb pressure tubes with steam-formed oxide layers (400°C, 0.5 MPa, 36 h) exhibited parabolic oxidation kinetics in $\text{CO}_2 + 5\% \text{O}_2$, with reduced rates compared to bare specimens. Oxide characterization revealed transformation from tetragonal to monoclinic ZrO_2 over time, the formation of an n-type oxide on pre-oxidised tubes, and preferential oxidation along the β -phase.

Development of Accident Tolerant Claddings:

A Cr sputter coating technique was optimized to deposit 15–25 μm thick, dense, pore-free layers on Zr-4 substrates. The coating process parameters (argon gas pressure, substrate bias, and power) were refined for adhesion and uniformity. The Cr-coated Zr-4 showed excellent oxidation resistance due to a protective Cr_2O_3 layer, remaining intact up to 1200°C.

Advanced Ceramics, Composites, and Carbon

Materials: High-density, isotropic graphite blocks (75 × 100 mm and 200 × 200 × 400 mm^3) were produced using meso-carbon micro-beads (MCMB), achieving densities above 1.85 g/cc and isotropy near 1.05. Properties met ASTM standards. SiC– B_4C reaction-bonded composites exceeded 97% theoretical density via optimized molten-Si infiltration.

Continuous CNT fibers with high conductivity (1.85 MS/m), strain-to-failure (~16%), and modulus (1.4 GPa) were woven into fabrics acting as toxic gas sensors (NO , NH_3 , H_2S) with 50 ppb detection limits and rapid (<30 s) response.



Materials (ingots of varied configuration) for the erection of MSR loops.

Hydrogen Production and Storage Materials: A Mn–Co spinel ($\text{Mn}_{1.5}\text{Co}_{1.5}\text{O}_4$) coating process was developed for High-Temperature Steam Electrolysis (HTSE) interconnects using solution combustion synthesis and electrophoretic deposition, optimized for uniform, adherent, and dense coatings. Oxidation tests confirmed coating stability under HTSE conditions.

A $\text{SiO}_2\text{--Al}_2\text{O}_3\text{--CaO}$ glass sealant was synthesized (100 g batch) for hermetic HTSE sealing, demonstrating compatibility with interconnect and 8YSZ electrolyte at 800°C over 14 thermal cycles. Additionally, 10 L of Cr-doped Fe_2O_3 foam catalyst was produced for sulfuric acid decomposition in the I–S cycle.

Modified Route for Calcium Production: A modified aluminothermic reduction route yielded >99% pure calcium metal directly from CaO, bypassing distillation. Thermodynamic optimization enabled successful 100 g batch production suitable for reactive metal extraction.



Prototype of commercially available NO_x releasing dressing with brand name 'ColoNoX'.

Development of Alloys for Ore Grinding

Applications: U–Ti alloys (0.8–1.7 wt.% Ti) were developed for uranium ore grinding applications. Optimal heat treatment of U–1.5Ti alloy (450°C , 40 min) yielded peak hardness and higher wear resistance due to TiC and U_2Ti precipitates in the alpha-U matrix.

DFU Care with NO_x Releasing Dressing: Diabetes poses India a national health challenge. Among its severe complications, Diabetic Foot Ulcers (DFU) pose a major clinical and socioeconomic burden. Over a third of diabetics face DFU during their lifetime, with infection-driven chronic wounds often leading to amputation. Treatment remains limited to general wound care routines, underscoring the need for specific therapeutic solutions.

Addressing this gap, BARC has developed and patented a novel nitric oxide (NO_x) releasing wound dressing, recently approved by the Central Drugs Standard Control Organization (CDSCO) for clinical use. This innovation, now commercialized by Cologenesis Pvt. Ltd. under the brand name 'ColoNox', marks a breakthrough in targeted wound management for diabetic patients.

Nitric oxide plays a crucial biological role in wound healing through its antimicrobial and anti-inflammatory properties. Diabetic conditions impair endogenous NO production, hindering healing and tissue regeneration. The NO_x releasing dressing counteracts this deficiency by enabling controlled generation and gradual release of therapeutic nitric oxide at the wound site. Its collagen matrix enhances healing by promoting cell migration, relieving pain, and serving as a structural scaffold for new tissues.

Evolved from BARC's research on eco-friendly anti-fouling agents, the technology progressed through extensive laboratory studies, followed by successful clinical trials completed in 2024. With a shelf life of 2.5 years, the product is tailored for India's climatic and healthcare requirements and designed for its affordability and accessibility.

Applied as a two-part system, ColoNox ushers a new era of advanced wound care. It exemplifies India's capability to translate atomic research into socially transformative healthcare advancements, aligning with the vision of "Make in India for the World."

Hybrid granular sequencing batch reactor (hgSBR):

Biogranule-based wastewater treatment technology, developed by BARC, uses compact microbial aggregates called biogranules or bio-beads to efficiently treat domestic and industrial wastewater. Unlike conventional activated sludge systems that

require large land areas and multiple tanks, biogranules function within a single sequencing batch reactor, significantly reducing space and operational costs.

BARC's hybrid granular sequencing batch reactor (hgSBR) systems rely on naturally occurring microorganisms that self-assemble into dense granules capable of simultaneously removing organic matter, ammonium, etc. Biogranules exhibit exceptional settling properties and maintain stable performance across varying temperatures and pollutant concentrations, including heavy metals and antibiotics. The cultivation of bio-beads using indigenous microbes and granular activated carbon enhances granule formation and nutrient removal efficiency, for which BARC received a patent in 2021.

The full-scale demonstration plants treating up to 1500 m³/day have validated the hgSBR process under real conditions. Over 26 installations across India now operate using this technology, supported by technology transfer partnerships. Notably, the UP Jal Nigam deployed hgSBR-based sewage treatment plants during the Maha Kumbh Mela 2025 to maintain sanitation and protect the Ganga river ecosystem.

With effective biological oxygen demand reduction, nutrient removal, lower sludge generation, and smaller land footprint, biogranule systems offer a sustainable and cost-effective alternative to conventional methods. Future research aims to enhance granule stability, identify key structural biopolymers, and extend applications to industrial effluents and emerging contaminants such as pharmaceuticals and metals.

Health Physics - Radiation Safety via development of systems, monitoring & dosimetry

Mobile Gamma Screening System: A shielded, trolley-mounted NaI(Tl)-based detection unit facilitates rapid screening of food items for gamma-emitting radionuclides during radiation emergencies. With a 76 mm × 76 mm detector coupled to a 1K MCA and notebook interface, it achieves minimal detectable activities (MDAs) of 20–100 BqL⁻¹ for I-131, Cs-137, and Co-60, remaining below operational intervention limits.

Portable Whole-Body Contamination Monitor: A compact NaI(Tl) tabletop system enables rapid onsite assessment of internal contamination from high-energy photon emitters. Using a standing geometry and 76 mm × 76 mm detector with 1K MCA, it ensures efficient identification of multiple radionuclides under



The Wet-Oxidizer system for extraction of dissolved inorganic and organic species of C-14 in liquid samples.

elevated background conditions, allowing fast throughput during emergencies.

Compact Wound Contamination Analyzer: This portable, trolley-mounted system measures radionuclide deposition in wounds caused by photon emitter contamination. Equipped with an interlocked shielded chamber, LED-camera alignment, and 51 mm detectors, it achieves MDAs of ~2 Bq for Cs-137/Co-60 and ~1.3 Bq for Am-241 within 5 minutes, ensuring high precision in low-energy assessments.

Semi-Automatic Radiocarbon Combustion Unit: A cost-efficient system designed for high-sensitivity oxidation of biota samples extracts CO₂ containing Carbon-14 and tritiated combustion moisture for OBT estimation, improving sample throughput and combustion reliability.

System for Extraction of Carbon-14 species: The wet oxidizer system achieves 96–98% efficiency in extracting dissolved inorganic and organic carbon species via catalytic conversion to CO₂. Validation through spiked tests confirmed C-14 levels in river samples (DIC: 2.7 mBq/L; DOC: 1.29 mBq/L).

Local Scale Atmospheric Dispersion Model: A Lagrangian puff-based model simulating radionuclide dispersion supports multiple source and receptor grids. It accounts for decay, deposition, and meteorological variability, providing integrated radiological impact assessments for different age groups under both normal and accidental release scenarios.

RDD Aerosol Dynamics Model: A zero-dimensional numerical approach models aerosol evolution post-RDD explosion, incorporating thermal and

microphysical processes like coagulation and condensation. Validated for carbon and cobalt aerosols, the model identifies a dominant respirable fraction, enhancing near-field radiological impact predictions for emergency planning.

Baseline Environmental Surveillance: Environmental Surveillance Laboratories (ESL) conduct baseline radioactivity and meteorological monitoring at nuclear sites (GHAVP, Mahi Banswara, Vizag). ESL units function as regional Emergency Response Centres and engage in public outreach to foster nuclear energy awareness.

Alternate Crisis Management Centre: A remotely operable node outside BARC serves as a backup monitoring hub to the Integrated Centre for Crisis Management, ensuring data continuity, functional redundancy, and resilience against emergencies.

Instrumentation for Radiation Dosimetry: Optically Stimulated Luminescence (OSL) is becoming a widely recognised technique for measuring how much radiation a material has absorbed. It is used in fields such as environmental monitoring, and personal dosimetry. Scientists are continuously working to develop OSL-sensitive materials that more closely mimic human tissue and to build better instruments—called OSL readers—that can measure this light precisely. However, many of the readers available today are built for geological or archaeological dating and tend to be expensive. This has created a strong need for low-cost and compact systems to support radiation monitoring tasks.

Understanding this, BARC has designed a new, highly sensitive laser-based OSL reader that is both portable and affordable. At the heart of this system are two miniature lasers, each about the size of a matchbox, with wavelengths of 473 and 532 nanometers and a power output of 350 milliwatts. These lasers direct light through optical fibers to stimulate the radiation-sensitive sample evenly. A built-in touch-screen computer controls the entire process and ensures stable laser performance during operation.



Front and Back sides of Chest Neutron dosimeter developed in BARC.

The system detects emitted light using a sensitive photon counting module and specialized filters that block unwanted wavelengths, ensuring accurate readings. Extensive tests (evaluated by CW-OSL method followed by comparison with Riso reader) show that this laser-based reader not only matches but nearly doubles the sensitivity of commercial LED-based systems. Its compact design, fast response, and high accuracy make it ideal for radiation dose verification in hospitals and for advanced research in universities.

External Radiation Monitoring - Fresh Insights: BARC oversees the external radiation monitoring of over 250,000 workers in India's medical, nuclear, and industrial sectors using specialized dosimeters. To ensure international accuracy and reliability, it participated in the EURADOS Inter-Comparison Exercises IC2022ph (for photons) and IC2022n (for neutrons), benchmarking its monitoring systems against global standards.

For photon monitoring, BARC deployed $\text{CaSO}_4:\text{Dy}$ -based thermoluminescent dosimeter (TLD) badges. Each badge contains three discs shielded by filters to adjust for energy responses and differentiate radiation types. In IC2022ph, 30 selected badges with uniform sensitivity were exposed to a range of photon energies and doses at an Austrian laboratory. The TLD badges demonstrated reliable performance, precisely measuring personal dose equivalents $H_p(10)$ and $H_p(0.7)$ across multiple scenarios and energies. The badge responses fell well within ISO-14146 acceptance limits, confirming their accuracy, especially at low-dose ranges critical for routine occupational safety.

For neutron monitoring, BARC utilized CR-39 based dosimeters for the IC2022n exercise conducted in France. The neutron dosimeter, designed to withstand environmental challenges, was calibrated using controlled neutron sources. Dosimeters were processed with an advanced in-house Fast Neutron Imaging System, significantly improving track detection and measurement accuracy.

Results from both international inter-comparison exercises validated the efficacy and reliability of India's radiation dosimetry practices. The TLD system proved excellent for routine and low-dose monitoring. Meanwhile, participation in the neutron exercise underscored the advantages of BARC's indigenous imaging system and highlighted the need for continued improvement in detector materials through local development, ensuring robust protection for radiation workers.

ADVANCED TECHNOLOGY DEVELOPMENT



THE ADVANCED TECHNOLOGY DEVELOPMENT vertical sets out a comprehensive roadmap for advancing India's self-reliance in nuclear and related technologies to strengthen national energy security and technological independence. It prioritizes the development of indigenous cryogenic systems to support superconducting accelerators, scaling up to 4000 W at 2 K, which will reduce dependence on imported refrigeration technology. The hydrogen mission emphasizes innovation in green hydrogen production through electrochemical and thermochemical routes, efficient storage techniques, and safety management measures aimed at achieving the 2070 net-zero target. For fast breeder reactors, initiatives focus on domestic production of critical components, development of remote inspection systems, and creation of large-scale testing facilities to ensure operational reliability. Parallely, research into advanced semiconductor and superconducting radiation detectors supports nuclear safety, healthcare diagnostics, and non-destructive industrial testing. It also outlines breakthroughs in portable accelerator and cryo-cooler technologies and the indigenization of high-power RF systems essential for energy-efficient, compact accelerators. Collectively, these programs align with the 'Aatmanirbhar Bharat' vision and aim to position India as a global leader in sustainable nuclear innovation and advanced energy technologies.

Hydrogen Technologies

Alkaline Water-based Electrolyser: Indigenization of the Alkaline Water-based Electrolyser (AWE) manufacturing technology has been successfully achieved and consistently tested across capacities ranging from 20 NLph to 1,00,000 NLph. An Alkaline Water Electrolyzer of 0.5 MW capacity, with a hydrogen production rate of 100 Nm³/hr, has been developed and deployed at Cochin International Airport Limited (CIAL), Kochi, in collaboration with Bharat Petroleum Corporation Limited (BPCL) for establishing a green hydrogen fueling station. This stands as the only indigenous cell module technology in India utilizing domestically sourced components under the "Make in India" initiative. The system operates efficiently at a

pressure of 10 bar, achieving hydrogen purity greater than 99.5% and an electrical energy efficiency exceeding 72% at maximum capacity. Further scaling has led to the successful design, development, and testing of a prototype 1 MW stack with a hydrogen production capacity of 200 Nm³/hr. The Alkaline Water Electrolyzers are compact, bipolar plate, filter-press type units. This indigenous technology holds significant market potential for large-scale green hydrogen production, with industrial implementation planned through technology transfer mechanisms.

Laboratory hydrogen generator using AWE Tech: A Plug-in type Laboratory alkaline water electrolyser system was designed & fabricated using compact high integrity cylindrical cell. This system is designed for producing high-purity hydrogen onsite without any moving part. It was operated successfully for more than 100 hours, up to 20 NLPH Hydrogen production rate at 4 bar pressure and more than 99.9% purity at the cell stack outlet.

Indigenous diaphragm to replace asbestos in AWEs: Commercial-scale (2 m diameter, the largest available in the International market) Polysulfone-Zircona mixed-matrix membrane-diaphragm based on BARC-developed technology was launched in GH2INDIA EXPO 2025 in August, 2025. The indigenous diaphragm is going to replace asbestos and other imported separators in alkaline water electrolyser, which is going to be a key player in National Green Hydrogen Mission (NGHM) of Government of India.

PEM Electrolyser Development: The development of indigenous Proton Exchange Membrane (PEM) Electrolyser up to 50 NLph Hydrogen production capacity is completed and demonstrated the performance with more than 80%



Alkaline Water Electrolyser Plant installed at CIAL, Kochi.

energy efficiency. One such system was fabricated and tested using indigenously developed PEM electrolyser for pure water Electrolysis, with oxygen side pressurization for conversion of D_2O^{18} to H_2O^{18} .

Copper-Chlorine Thermochemical Cycle:

Under the “Nuclear Energy Mission for Viksit Bharat”, a first-of-its-kind Copper-Chlorine (Cu-Cl) thermochemical cycle integrated pilot-scale facility has been demonstrated for hydrogen production. This facility, with a design capacity of 150 NL/h, recorded a cumulative operation of 225 hours - being the highest operational duration achieved globally for any thermochemical cycle. Expedited demonstration and scale-up activities are being actively pursued for nuclear hydrogen production. Key initiatives include: Demonstrating coupling of the Cu-Cl cycle with the Fast Breeder Test Reactor (FBTR); Setting up a 3000 NL/h prototype facility; and Designing a Cu-Cl cycle system integrated with a proposed 5 MWth HTGCR for nuclear hydrogen generation.

Iodine-Sulphur Process: The Iodine-Sulphur (I-S) process involves sequential reactions for water splitting, the first reaction is Bunsen Reaction where water reacts with SO_2 and I_2 at approximately $80^\circ C$ in an exothermic process, producing sulphuric acid (SA) and hydriodic acid (HI). In the Sulphuric Acid Decomposition step where SA decomposes endothermically at around $850^\circ C$, yielding O_2 and SO_2 . In the Hydriodic Acid Decomposition step, HI decomposes endothermically at about $450^\circ C$, producing H_2 and I_2 .

After successful demonstration of the I-S process in a metallic system at 150 NLph, the process has been scaled up twenty-fold to 3 Nm^3/h capacity. The design of the scaled-up facility is complete, and tendering activities are in the advanced stage. This activity was undertaken in collaboration with the Heavy Water Board (HWB). Documentation for statutory clearances, including the Preliminary Safety Analysis Report and Design Basis Report, has been completed and submitted for AERB approval through HWB.

Modified Iodine-Sulphur Process: In the modified Iodine-Sulphur process, sulphuric acid is not decomposed but is instead retained as a valuable co-product, produced simultaneously with hydrogen. SO_2 is generated via combustion of



Cell for laboratory H_2 generator.

sulphur, and serves both as a reactant and an energy source for the process.

A 100 $kmol/hr$ hydrogen production facility based on the modified I-S process has been designed in collaboration with a private vendor under the Atal Incubation Scheme. Preparation of a Detailed Project Report for coupling this modified process with a Gas-Cooled Reactor (GCR) is currently in progress.

Iodine-Hydrogen Sulphide ($I-H_2S$) Process: As a spin off to Iodine-Sulphur process, a new process to utilize H_2S (a harmful refinery by product typically treated using claus process) is envisaged and successfully demonstrated in lab scale. This technology is now being advanced towards bench scale deployment along with refinery/private vendor, enabling cleaner hydrogen generation and conversion of a polluting waste stream into an energy resource.

In this process, H_2S reacts with iodine in the presence of water, forming hydriodic acid (HI) and solid sulphur. The sulphur is separated, and HI is fed into a decomposer to produce hydrogen and iodine. Feasibility studies have also been conducted using dimethylformamide in both glass and metallic reactors. A detailed study is planned to investigate the reaction of iodine with H_2S in an organic phase, aimed at generating comprehensive kinetic data for process optimization.

Hybrid-Sulphur Process: The Hybrid-Sulphur (HyS) process is a two-step water-splitting mechanism for hydrogen production. BARC has designed and commissioned a closed-loop HyS Process Engineering Facility with a capacity of 5 NLph hydrogen generation. Currently, a multi-stack Sulphur Dioxide Electrolysis cell is being fabricated, which will be installed and commissioned in the next phase of development.

Membrane Reactor Technology for High-yield Hydrogen Production: Indian patent on membrane reactor (MR) technology for enhanced HI decomposition (from ~22 % to ~95 % at 450°C; 2 bar) in I-S thermochemical process has been granted and know-how is transferred for commercialization. The technology is modified and extended to enhance H₂ production/recovery from waste gas stream containing NH₃ and H₂S. NH₃ to H₂ conversion of ~95% (500°C and 1 bar; against 80%) and H₂S to H₂ conversion of ~80% (1000°C, 1 bar; against 20%) was achieved using MR. This know-how is being commercialized to augment on-demand in situ high-purity hydrogen (≥99.9%) production through ammonia cracking, and production of MLD quantity of hydrogen & recovery of sulfur through treatment of industrial waste gas stream.

Development of Turbo-Molecular Pumps

Turbo-molecular Pump AnuTurbo-400: The AnuTurbo-400 system represents a high-performance, indigenously developed turbo-molecular pump designed for reliable and efficient vacuum generation. The ANU TURBO architecture integrates several critical subsystems to ensure high-speed operation and long-term consistency. Its rotor assembly comprises a precision-engineered rotating shaft and impeller, featuring multiple compression stages. The impeller has been entirely designed and fabricated in-house using additive manufacturing, aligning with a patent filed by BARC. Operating at a rotational speed of 24,000 rpm, the shaft incorporates rotors supported by both passive and active magnetic bearings, along with a BLDC

motor drive. The system employs two radial active magnetic bearings positioned at each end of the shaft to control radial vibrations, complemented by a central thrust active magnetic bearing to counter axial vibrations. These are further stabilized by passive permanent magnets. For additional safety, mechanical backup bearings are included to protect the system against accidental shocks, sudden air ingress, or power failures, though they remain disengaged during normal operation.

The system can operate reliably at temperatures up to 85°C, making it suitable for demanding and aggressive application environments. The electronic subsystems follow a modular design philosophy, facilitating ease of maintenance and upgrades. A dedicated user interface enables comprehensive monitoring, diagnostics, and control of the entire pumping system.

The pump has successfully undergone rigorous performance and endurance testing under laboratory conditions, followed by field trials at several constituent units of DAE.

The AnuTurbo-400 is suited for a wide range of advanced vacuum applications, including leak detection, mass spectrometry, electron microscopy, particle accelerators, electron beam welding among others.

High Performance Vacuum Pump: The AnuTurbo-80 high performance vacuum pump is an advanced multi-stage axial-flow turbomolecular pump integrating a unique combination of rotating and static blades. Its impeller, developed in-house using additive manufacturing based on a BARC-filed patent, ensures superior efficiency. Driven by a high-speed indigenously developed BLDC motor operating up to 36,000 rpm with an integrated sensor-less controller, the system employs precision ball-bearing support and fully in-house-designed components for vacuum integrity, housing, and rotor dynamics. Tested to 30,000 rpm, it achieves a compression ratio above 10,000 and an ultimate vacuum of 8.8×10^{-6} mbar. The pump finds applications in mass spectrometry, electron microscopy, plasma technology, nanotechnology, and high-energy physics. Its upcoming version, AnuTurbo-80R3, aims for a compression ratio beyond 100,000 and an ultimate vacuum of 10^{-7} mbar, featuring improved impellers, isolated bearings with temperature monitoring, a high-torque BLDC motor, and built-in air cooling for enhanced reliability.



AnuTurbo-400 System.

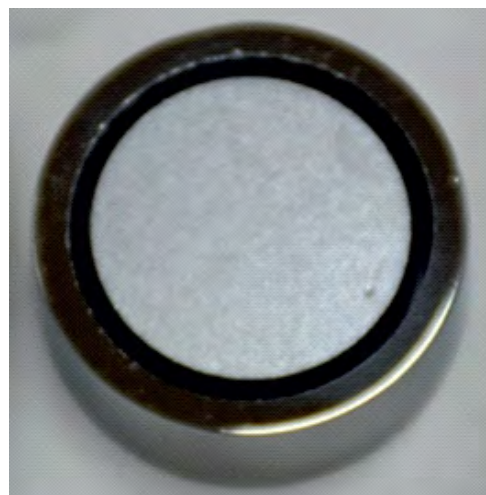
HPGe based Radiation Detectors: HPGe detectors are favored for high-resolution gamma and X-ray spectroscopy due to their excellent electron-hole pair generation efficiency, high atomic number, and superior energy resolution compared to other detectors. These detectors operate by detecting high-energy photons (100 keV to 10 MeV) interacting with electrons in germanium through photoelectric effect, Compton scattering, and pair production. A planar HPGe detector is typically constructed using p-type crystals with electrical contacts formed by lithium diffusion (n-contact) and boron implantation (p-contact), with the detector functioning upon application of reverse bias voltage to create a depletion region for charge collection.

The critical process of producing ultra-pure germanium crystals via zone refining and Czochralski crystal growth techniques helps in reducing impurities and defects, essential for achieving the high resolution. Crystal characterization techniques such as Hall measurements, X-ray diffraction, and lifetime measurements are employed for quality assurance.

Significant emphasis is placed on development of radiation detectors in BARC, covering chemical processing, fabrication of electrical contacts, surface passivation by RF sputtering, and cryostat design for cooling detectors to liquid N₂ temperatures (90-100 K), essential to reduce thermal noise. Both n-type and p-type HPGe detectors were fabricated and tested, exhibiting low leakage currents (<100 pA) and excellent energy resolution (FWHM of ~1.5 keV at 662 keV).

A fully indigenous technology chain for the production of HPGe detectors in BARC, encompassing raw material processing to high-resolution gamma spectroscopy instrumentation, meeting DAE requirements has been envisioned with ongoing efforts to scale detector volume and improve resolution. This makes India self-reliant in a critical area of nuclear technology.

PIXEL Detector for Particle Radiation Detection: PIXEL-type Particle Radiation Detector have been fabricated, using in-house/locally grown high purity prime grade silicon wafers. Detectors have been produced at a PSU's foundry facility, as per BARC technology and tested using laboratory alpha sources such as Americium-241 and Thorium-229. It has shown similar resolution and sensitivity, as compared to the best commercial detectors available



Fabricated HPGe diode.

in the market.

CFD Modelling & Development of Codes with GUI for Chemical Engg. Processes, Equipment: A continuum pseudo-fluid CFD model has been developed and validated for simulation of dense grain flows. CFD modelling has been used to simulate two-phase flow in half cells of alkaline water electrolyzers (AWEs) of different sizes. The results were used in an in-house code to quantify the flow distribution in the stacks of AWEs. Codes with GUI (ANUSim modules) were developed for simulating solute transport through liquid membrane immobilized in hollow fiber contactor, and for population balance modelling for estimating drop size in stirred liquid-liquid dispersions.

Technology Development for FBR Applications

Retrieval of Tilting Rail from PFBR under Sodium-filled Conditions: BARC has successfully retrieved a dislodged tilting rail from the Transfer Fuel Handling System of the PFBR under sodium-filled conditions. This complex operation required the development of a specialized machine equipped with force and position feedback mechanisms at the reactor top to extract the rail from the Inclined Fuel Transfer Machine (IFTM). The complete cycle - from conceptualization to deployment - was accomplished in a record period of 4.5 months. Removal of the rail was a pre-requisite to resume the long-pending fuel loading activities in the PFBR.

The Inclined Fuel Transfer Machine (IFTM), an ex-vessel handling system in the Transfer Bay (TTBR), facilitates transfer of core sub-assemblies between the In-Vessel Transfer Position (IVTP) and the Ex-Vessel Transfer Position (EVTP). After in-vessel cooling, irradiated sub-assemblies are moved into a sodium-filled transfer pot (TP), positioned at the IVTP of the IFTM, via a transfer arm.

The TP is lifted by a hoisting mechanism mounted atop the Rotatable Shield Leg (RSL), utilizing a chain and sprocket system. During lifting, the TP transitions from an inclination of 17° to 31° through the tilting rail system as it enters the Primary Tilting Mechanism (PTM). At the 31° position, the tilting rails serve a dual purpose - providing the required angular transition and acting as load-bearing members when the TP is stationed at the IVTP.

Following completion of blanket sub-assembly loading in the reactor core, and prior to initiating initial fuel loading (IFL), difficulties arose when the TP could not be lowered to its bottommost position at the IVTP. Subsequent ultrasonic testing under sodium conditions revealed that one of the 31° tilting rails had become dislodged from its mounting brackets. This condition is only possible if all sixteen fixing bolts securing the rail have failed, allowing it to slide down.



The machine with its Argon flask after removal from core.

Development of Rail Retrieval Machine: Before advancing further with fuel loading in PFBR, it was decided to remove the dislodged tilting rail from the PTM. The design, conceptualization, and manufacturing responsibilities for this task were assigned to BARC.

BARC developed a purely mechanical manipulator capable of operating under sodium at temperatures up to 220°C without the need for sodium draining. The manipulator is operated remotely using mechanical shafts from the reactor top, maintaining effective sealing to prevent sodium vapor and aerosol escape. The machine was designed using available in-house materials. Fabrication primarily employed waterjet cutting techniques to circumvent slower milling and lathe operations. Functional checks were integrated to detect dimensional errors & tolerance stack-ups, thereby eliminating the need for exhaustive component-level inspections. These design & fabrication optimizations enabled completion of the machine within 4.5 months using in-house workshop facilities.

Rail Retrieval Operation: Dry trials were conducted at BHAVINI using a dummy PTM (IFTM) to validate the manipulator's performance. The actual retrieval of the dislodged tilting rail from the reactor was executed on 6 September 2025 without draining the sodium, while maintaining a core temperature of 180°C. The blind operation was completed smoothly, with all force and position feedbacks responding accurately and reliably.

Advanced Technology, Computing & Secured Quantum Communication: BARC has prioritized the integration of modern computational techniques within nuclear research, focusing on High-Performance and Cloud Computing, Scientific Visualization, Machine Learning, Mass Storage, Information Security, and Advanced Database Systems. These initiatives support BARC's scientific research community through state-of-the-art computing, visualization, and storage infrastructure. The Mod Lab Computer Centre, established in 1977 to host a BESM-6 mainframe, has evolved significantly to accommodate a Petaflop-scale supercomputing facility, enhanced networking, and large-capacity storage. A 15-petabyte mass storage system has been deployed, managed by an indigenously developed storage management software - SANMAN. Administrative modernization includes the

complete digitization of the DPS purchase workflow, replacing physical files. To align BARC's infrastructure with emerging AI and Quantum technologies, R&D efforts are underway. Fabrication & room-temperature characterization of Al/AIO_x/Al Josephson Junction devices have been completed, with cryogenic studies planned next. In applied AI research, a Treatment Planning System and an AI-assisted Segmentation Suite for Radiotherapy have been developed to optimize cancer treatment parameters. A GPU-accelerated beta version deployed at TMC, Mumbai, achieved 90% segmentation accuracy with a 10-second prediction time per organ.

Additionally, an on-premise AI-driven drug discovery platform, 'SANJEEVANI', leveraging open-source AI frameworks, has been developed for centralized computational infrastructure. Parallel studies are examining Quantum Key Distribution (QKD) protocols using open-source quantum network simulators on the BARC network, marking significant progress towards secure quantum-era communication and computation capabilities.

Safe & Secure Systems for Nuclear Facilities: Control and Instrumentation (C&I) systems constitute the operational core of nuclear facilities, ensuring reliability, maintainability, and scalability through indigenous development. The existing hardware-based Alarm Annunciation System of FBTR has been upgraded to a modern configuration using the TPLC-32 platform integrated with the Distributed Plant Information and Supervisory Control System. The upgraded AAS consists of seven nodes, each comprising dual hot-standby TPLC-32 subsystems. Dual-redundant alarm servers and operator consoles based on DPISCS manage alarm visualization and archival via a redundant Ethernet network.

A Distributed Control System (DCS) for the INRP has been jointly developed with M/s. ECIL, Hyderabad, based on the indigenously built safe and secure NUCON-C PLC platform. The complete DCS for Reprocessing Blocks-1 and 2 at INRP-Tarapur has been manufactured, tested, and deployed. Parallel-plate gamma-compensated ionization chambers featuring advanced boron coating (developed in BARC) exhibit strong adhesion, thermal stability up to 600°C, $\pm 5\%$ signal linearity, and a gamma compensation ratio of $\sim 7.4\%$.



Upgraded MLCC and 15 PetaByte Storage Facility.

Indigenous instrumentation advances include an inline flow-through ultrasonic sensor with embedded thermocouple for isotopic purity analysis of heavy water (0-100% D₂O, 27-50°C), validated in simulated conditions. The Agglomeration Onset Detection System, employing attractor comparison for real-time "S parameter" estimation, now functions as an early-warning system at INRP-K. Similarly, an ultrasonic ammonium nitrate concentration monitoring system integrated with SCADA was developed and field-tested successfully.

Further developments include FPGA-based neutron assay electronics for MOX quantification, ultrasonic pulsation monitoring for uranium extraction optimization, and C&I architectures for next-generation reactors including IPR, HTGR, and BSMR. Reactor safety innovations include real-time loose-part monitoring algorithms and an AI-based image processing system for estimating drop size distribution in solvent extraction, enhancing analytical precision and operational safety.

Development of Tools and Techniques for Inspection of Critical Facilities: For assessing Tube-to-Tube Sheet (TTS) weld joints in heat exchangers and steam generators, an indigenous automated software analyzes batches of radiographic images to evaluate and categorize weld quality. In the domain of in-service inspections, negative-pressure adhesion-based robotic crawlers have been designed for examining stainless steel and nonmagnetic structures, operating on curved and vertical surfaces. To ensure reliability in

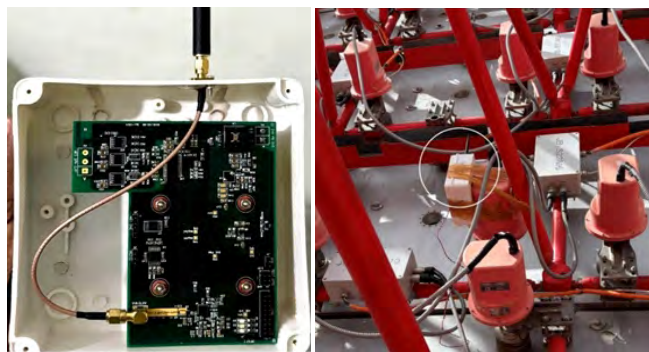
ultrasonic measurements, an automated ultrasonic immersion probe characterization system standardizes beam parameters such as focal length, beam width, and axis alignment. Additionally, a fully indigenous 8-channel ultrasonic and eddy current inspection system, integrated with data recording, flaw characterization, and analysis software, has been successfully implemented for reactor pressure vessel inspections in boiling water reactors.

C&I, Processing & Computation Systems for Applications in Frontiers of Basic Research:

Modern sensor and instrumentation technologies form the core of several Mega Science projects. The Giant Meterwave Radio Telescope serves as a premier astronomical facility, where its servo system ensures precise tracking of celestial objects using command inputs from the Central Station. A key upgrade features an optimal Linear Quadratic Gaussian (LQG) controller, implemented for the first time in India, in large telescopes at the GMRT's C04 unit resulting in a 3-fold disturbance attenuation over conventional systems. For the Major Atmospheric Cherenkov Experiment (MACE), Wireless Actuator Controller (WAC) and Mirror



Robotic crawlers designed for examining stainless steel and nonmagnetic structures.



The Wireless Actuator Control for deployment in MACE Telescope Facility.

Alignment Central Hub (MACH) electronics were developed to actively correct mirror alignment against gravity-induced deflections, with successful field trials completed. Additionally, a 32-channel neutron counting DAQ system for HARL in Gulmarg, and an indigenous 8-channel, 500 MSPS digitizer with FPGA-based architecture for high-energy physics applications were developed.

Physical and Cyber Security Systems: A major focus has been the advancement of ICS systems through sensor development. Photodiodes measuring 30 mm × 4 mm × 0.3 mm were designed and fabricated for ICS detector modules. Fifty integrated modules, each comprising 16 detector arrays with front-end electronics, were successfully tested. Additionally, progress has been made in developing a muon-based passive detection system for high-Z material identification. A prototype with 1 metre long drift tube detectors demonstrated good performance, exhibiting insulation resistance above $10^{13} \Omega$, stability up to 5 bar pressure, and a helium leak rate below 10^{-8} bar·L/sec, achieving approximately 85% muon detection efficiency.

In cybersecurity, Post-Quantum Cryptography (PQC) based VPN appliances have been developed to secure data communication against potential quantum-era threats. For enhanced physical security, a Bluetooth Low Energy (BLE) object and visitor tracking system integrated with RFID has been deployed across multiple facilities, including the BARC campus. Cyber threat analysis has been strengthened through a Security Information and Event Management (SIEM) system now operational at BARC Trombay, BARC Tarapur, and AERB. A Cyber Threat Intelligence Information Integration and Exchange System automates threat data acquisition and dissemination for proactive mitigation.

To ensure information integrity, the Generative AI Threat Elimination System (GAITE) was developed to monitor sensitive code uploads to AI platforms. A Dynamic User-Specific Digital Watermarking technology enables secure tracking of unauthorized video distribution. Additionally, 3D modeling and virtual-environment applications have been introduced for security training and scenario simulations, including a virtual walkthrough of high-security areas like Anushakti Nagar. A standalone encrypted application ensures protected access to these digital environments.

**HUMAN RESOURCE DEVELOPMENT,
PUBLIC AWARENESS, OUTREACH &
INTERNATIONAL COLLABORATIONS**



THE HUMAN RESOURCE DEVELOPMENT, PUBLIC AWARENESS & OUTREACH AND INTERNATIONAL COLLABORATIONS

vertical articulates DAE's vision for nurturing human capital, enhancing capacity, managing knowledge, and advancing technology to achieve self-reliance in India's nuclear energy sector.

Dr. Homi Jehangir Bhabha's foresight in cultivating a skilled workforce led to the founding of a specialized training school at the Trombay in 1957. This institution has evolved into a globally recognized center having trained around 11,000 scientists and engineers till date.

To support nuclear energy growth, plans are afoot for a consolidated training facility at BARC Visakhapatnam to centralize training for scientific officers, trainees, and administrative staff.

In knowledge management, BARC encourages its scientific community to publish research in leading journals under the ODOS framework. Public outreach initiatives across India, including scientific publications, and novel school outreach program promote awareness of nuclear technology benefits, dispel myths, and foster trust.

Atal incubation centers at BARC and other centres nurture start-ups bridging nuclear and non-nuclear fields, while the AKRUTI program deploys societal technologies via universities, NGOs, and MSMEs. DAE holds about 250 commercially transferable technologies, issues approximately 800 licenses, and mentors industry through incubation efforts.

Human Resource Development: Recognizing the vital role of skilled personnel in advancing India's multi-stage nuclear power programme, Dr. Bhabha established the BARC Training School at Trombay in 1957, shortly after founding AEET in 1954. Since then, the school has trained nearly 11,000 scientists and engineers, imparting multidisciplinary knowledge and practical experience critical for nuclear energy.

The 2024-2025 academic year saw about 179 graduates from the 68th batch of the Orientation Course for Engineering Graduates and Science Postgraduates (OCES) at the Mumbai campus.

This year's 68th batch produced 168 graduates as Scientific Officers who joined various BARC scientific groups, strengthening R&D efforts in engineering, science, and radiological safety. Complementing OCES is the DAE Graduate Fellowship Scheme (DGFS), linked to the Homi Bhabha National Institute, ensuring a steady stream of skilled personnel for DAE units.



A group photograph of meritorious officers who graduated from BARC Training School OCES-2024 program. They are joined by Dr. P. K. Mishra (in center), Chief Guest for Graduation Function & Principal Secretary to the Prime Minister, Dr. Ajit Kumar Mohanty, Secretary, DAE and Chairman, AEC and Mr. Vivek Bhasin, Director, BARC.

The program remains highly competitive, with about 85,000 applications in 2025 for roughly 250 seats. OCES attracts not only BARC candidates but also participants from PSUs and the Indian Armed Forces, whose enrollment has steadily grown. The year-long curriculum blends nuclear science fundamentals with advanced electives, experimental work, and projects to prepare graduates for diverse careers. The BARC Doctoral Programme integrates coursework and research, admitting 80 scholars in 2025 under the aegis of HBNI.

BARC also conducts pan-India outreach to raise awareness among students about opportunities at the center, ensuring a steady flow of talent supporting India's nuclear self-reliance and technological excellence.

Scientific Information Management and Outreach: Publishing is integral to BARC's knowledge management activities. Newsletters, web digests, and bulletins regularly highlight cutting-edge research at BARC and global peer institutions. Increasingly, books capturing notable scientific achievements at BARC and other DAE institutes are published. Under ODOS framework, BARC actively promotes open-access publishing in leading journals, with a clear upward trend in scientific dissemination. Since its introduction, around 300 publications were covered.

The BARC Central Library holds over 200,000 books and journals and 9,000 unique reports documenting India's nuclear journey. Smart digital infrastructure upgrades are underway to enhance user experience at the Central Library. To promote and expand readership of its extensive book collection, two editions of the Science and Technology Book Exhibition have been organized, attracting significant participation from the scientific community of BARC.



BARC Newsletter issues published during the review period of 2024-2025 showcasing prominent outcomes encompassing science and technology.



Mr. Vivek Bhasin, Director, BARC visited the Book Exhibition organized in Central Library in 2025.

BARC hosts the Trombay Colloquium, where eminent scientists and leaders share insights. Recent speakers include Dr. Soumya Swaminathan of WHO, Mr. Raj Chengappa of India Today Group, and Mr. Kiran Kumar of Department of Space in 2024, along with DRDO Chief Dr. Samir V. Kamat and DST Secretary Professor Abhay Karandikar in 2025.

There is strong emphasis on promoting Hindi in science and technology publications (newsletters, workshops, conferences), supporting official language policy. BARC's outreach engages citizens, especially youth, through campus visits and flagship events like National Science and National Technology Day, highlighting nuclear science and technology achievements cutting across interesting themes through interactive short films, videos and edutainment skits. An educational tour to BARC Trombay facilities was organized by BARC during September 1-3 this year for 16 meritorious students (enrolled in 9th-12th standard) of a pan-India quiz

competition conducted by Gujarat Council on Science and Technology (GUJCOST).

The Parmanu Jyoti program features BARC scientific officers conducting educational and cultural initiatives in remote schools, inspiring over 18,000 students across multiple states about nuclear energy's societal benefits during the year 2024. From its launch in 2022, the program has positively impacted more than 100,000 students across pan-India Jawahar Navodaya Vidyalayas.

Technology Management: BARC licenses numerous technologies to industry, fostering commercialization through incubation centers such as the Atal Incubation Centers, which link startups with nuclear innovations.

Annually, over 200 technology transfer agreements are signed, with more than 450 active licensees commercializing nuclear spin-off technologies.

For over seven decades, DAE has licensed nearly 250 technologies, issuing about 800 licenses to industry and rural sectors. Atal Incubation Centers across four DAE units, including BARC Trombay, connect India's startup ecosystem with nuclear and non-nuclear technologies, driving employment and entrepreneurship in critical tech fields. The newly formed AIC-ANUSHAKTI, part of the Atal Innovation Mission, is advancing deep-tech incubation and innovation in India. Recent milestones include MoUs



Amity Centre for Nuclear Biotechnology (Navi Mumbai) students visited BARC for an outreach programme.



A meritorious student of GUJCOST's pan-India S&T quiz competition felicitated by Dr. A.K. Dureja, Associate Director of Knowledge Management Group (KMG), BARC (on the left) and Mr. Manoj Singh, Head of the Scientific Information Resource Division, KMG.



The maiden Deep Tech Talk Series on “Harnessing the Power of Multiomics” held at DAE Convention Centre in Mumbai.

with HBNI and PanScience Innovations to boost entrepreneurship, the launch of a Deep Tech Talk Series featuring expert sessions, and active participation in events and outreach programs to strengthen collaboration and student engagement in the innovation ecosystem.

The AKRUTI (Advanced Knowledge and RUrban Technology Implementation) initiative expands societal technology deployment via universities, NGOs, and MSMEs to meet grassroots needs. Currently, 12 AKRUTI Kendras operate nationwide, promoting rural entrepreneurship, with plans for expansion.

Safety Council: The BARC Safety Council (BSC) commemorated its 25th anniversary, marking its dedicated service in ensuring the highest standards of safety across BARC's extensive network of facilities in Mumbai and other parts of the country. Its regulatory mandate encompasses research reactors, fuel fabrication and reprocessing plants, waste management centres, particle accelerators, and radiological laboratories.

BSC accomplished significant regulatory milestones. It issued a total of 131 regulatory clearances, covering commissioning, operational, and renewal approvals for major BARC projects such as RMRC in Kolkata, the MACE Telescope in Ladakh, the Dhruva Reactor, PREFRE-1 and PREFRE-2, SFSF, and FRFCF at

Kalpakkam. The council also conducted 131 regulatory inspections to ensure adherence to safety norms and compliance with its recommendations. In addition, it actively participated in 57 emergency exercises, which enhanced institutional preparedness for both radiological and fire-related contingencies. BSC's work further extended to the authorization of radioactive waste management; 34 authorizations and 11 special authorizations were granted in this domain. It also approved authorization to procure 255 radiation sources and 17 radiological laboratories, along with 41 shipments of radioactive materials.

To reinforce regulatory governance, BSC released several important safety documents. These included Event Reporting Procedure for BARC Facilities (BSC/SG/2025/13), Regulatory Inspection and Enforcement in BARC Facilities (BSC/SM/2025/7), Safe Operations of Chemical Laboratories (BSC/SG/2024/11), and Regulatory Consenting Process for Radiation Facilities (BSC/SG/2023/11).

As part of its training and awareness efforts, BSC organized a two-day Silver Jubilee Symposium on “Regulatory Role of BSC - Goals and Achievements,” held from May 2, 2025, which drew nearly 200 participants. Continuing its commitment to stakeholder engagement, the council also convened a thematic meeting on “Regulatory Measures for Radiation Facilities” on December 14, 2024. In addition, three training courses on “Safety and Regulatory Measures for BARC Facilities” were conducted at Mumbai, Kalpakkam, and Tarapur, and the 24th course on Material Handling Equipment was held at Trombay to enhance operational safety procedures.

In industrial hygiene and safety, BSC maintained momentum through its ongoing Accident Prevention Programme, which included hygiene surveillance and proactive safety promotion initiatives. It convened a 3-days Technical Meet from May 8, 2025, which was attended by 162 Safety Coordinators representing 80 divisions. The 55th National Safety Day was observed on March 4 with events such as poster, slogan, and play competitions designed to encourage safety awareness among employees. Further, the 40th training course on “Accident Prevention and Occupational Health and Safety,” conducted from July 7-18, 2025, trained 50 participants in best practices for workplace safety. On Founders Day 2024, the Director's Safety Shield Awards (DSS-2023) were presented to divisions demonstrating exemplary safety performance. Overall, BSC also trained around 1,500 CAT-I and CAT-II trainees in industrial hygiene and safety.



Inaugural session of 49th Training Course of Safety and Regulatory Measures of BARC Facilities.

HBSTM Awards



**for excellence in
nuclear science and technology**



Mr. Alok Prakash

Developmental work in Design & Development of Compact Nuclear Steam Generators

Mr. Alok Prakash, a Mechanical Engineer, graduated from the OCES 55th Batch of BARC Training School; and a recipient of Homi Bhabha Award. He joined Reactor Projects Group in 2012 as a Scientific Officer. He has been involved in design, development and fabrication of compact steam generators (SGs) for RPG projects.

The Homi Bhabha Science & Technology Maanpatra - 2024 was conferred on him for his contributions towards **Design & Development of Compact Nuclear Steam Generators.**

Shri Prakash designed and developed a first-of-its-kind 50 MW compact once-through type steam generator having novel features such as pluggability of individual leaky tubes and replaceable tube bundles. His ingenious design integrated multiple tube bundles within the same shell housing to facilitate emergency heat removal by natural circulation in addition to the normal transfer duty. His design, utilising indigenously developed titanium material, was completely amenable to manufacturing ease and stringent quality control

Mr. Prakash effectively utilised his overall expertise to develop the first-of-its-kind 50MW compact steam generator with several innovative and advanced design features.

requirements. He accomplished the challenging task of developing the process for end bends formation of the tube bundle using a custom-built CNC machine and qualification of the tube-to-tube sheet joints using micro-focal radiography technique meeting tight dimensional tolerances. He designed and realised a test facility, where the testing was performed on a scaled-down model of the equipment and validated the design from the point of view of flow induced vibrations. He also developed multiple scaled-down models to experimentally study overall equipment performance and flow instabilities associated with boiling flows in parallel channels. He effectively utilised his overall expertise to develop this novel steam generator with several innovative and advanced design features.

Advancements in Radiation & Cancer Biology and Drug Delivery Systems



Dr. Amit Kunwar

Dr. Amit Kunwar, Scientific Officer, Chemistry Group, was conferred with the prestigious 'Homi Bhabha Science & Technology Maanpatra (HBSTM)' by DAE for his outstanding contribution in the field of **"Radiation & Cancer Biology and Drug Delivery System"**.

Dr. Amit Kunwar joined BARC in 2005 through 48th batch of Training School (Bioscience) after completing his MSc (Biotechnology) from TNAU Coimbatore. He received his PhD (Chemical sciences) from HBNI and subsequently carried out postdoctoral research at Meakins Christie Laboratories, McGill University, Canada under prestigious "Richard and Edith Strauss Fellowship". His research interest includes understanding the redox biology of synthetic organoselenium compounds with an intent to explore such compounds as therapeutic agents against cancer. Additionally, he implies his multidisciplinary research experience to design protein-based drug delivery systems to improve the safety and specificity of existing chemotherapeutic drugs.

Briefly, there is a dire need for easily administrable oral radioprotectors and/or chemotherapeutics for use in clinics to prevent the radiotherapy/chemotherapy side effects and to improve the quality of life of cancer patients. His decade long research has led to the identification of DSePA as a very potent agent for management of radiation pneumonitis and lung cancer. The preclinical studies have been completed and currently, clinical studies (Phase I) of DSePA as a radiotherapy adjuvant drug is under progress at ACTREC/TMC.

The fundamental studies by Dr. Kunwar on the anti-cancer mechanisms of DSePA and other related organodiselenides have established that such compounds follow a novel mechanism of reductive stress. Till date, only a few research groups have reported the importance of reductive stress as one of the mechanisms of anticancer drugs. The findings of Dr. Kunwar research

The findings of Dr. Kunwar's research work has opened a new area of understanding the anticancer effect of organoselenium compounds. He also demonstrated the utility of deuterated DSePA as a considerably safer derivative for therapeutic application.

work has resulted in 2 USA patents and has also opened a new area of understanding the anticancer effect of organoselenium compounds. Recently, Dr. Kunwar's group in BARC also demonstrated the utility of deuterated DSePA as a considerably safer derivative for therapeutic application.

Dr. Kunwar has also contributed significantly to the antioxidant and anticancer research of "Curcumin" an active ingredient from turmeric. His group has designed albumin and gelatin based novel delivery systems for improving the cellular uptake of curcumin. The knowledge gained from these investigations has facilitated development of different nutraceutical formulation/technologies for general health benefits, translating into TWO technology transfers to the industry.

Dr. Kunwar is a recognized faculty of Homi Bhabha National Institute, has guided three PhD students, published 135 research articles (peer reviewed journals), 7 book chapters and 9 articles in BARC Newsletter, delivered 35 invited lectures and authored nearly 70 papers in national and international conferences.

He is also the recipient of several prestigious awards such as "Young Scientist Award" from Indian Academy of Biomedical Sciences (IABS), "DAE Group Achievement Award", "DAE Young Scientist Award", "HBNI Outstanding PhD Thesis Award" and "Young Scientist Award" from OCC, USA. Dr. Kunwar is the elected "Fellow of Maharashtra Academy Sciences", elected member of IABS, visiting faculty member to UM-DAE, CEBS & ACTREC/TMC.



Dr. Ashish Kumar Srivastava

Advancements in Establishing Core Regulators of Abiotic Stress Tolerance in Crops

Dr. Ashish Kumar Srivastava, Bio Science Group, is a recipient of Homi Bhabha Science and Technology Maanpatra Award. His research has established redox-state homeostasis, as one of the **core regulators of abiotic stress tolerance in crops**. He has successfully converted his research findings into innovative field-applicable technologies.

Notably, supplementation of thiourea (a non-physiological thiol) reduced arsenic accumulation within rice grains in naturally arsenic-contaminated fields of Nadia district, West-Bengal, India. Thiourea decreased arsenic accumulation by suppressing the expression of various arsenic transporters, which in turn improved the root-system architecture. Furthermore, the stress-ameliorating potential of thiourea was demonstrated in diverse crops such as mustard, rice, and soybean. Thiourea application was demonstrated to enhance seed yield by 14.92% at the national-level. Presently, the use of thiourea, has been recommended by All India Coordinated Research Project (AICRP) as a package-of-practice, for soybean cultivation in India.

He has developed another crop yield-enhancing technology “Anu-Chaitanya”, that employs gamma-irradiated chitosan. As, chitosan is a major waste product from sea-food industry, this application has contributed immensely to “wealth-from-waste” and “peaceful application of radiation” programs.

Using radiation-induced mutagenesis approach, a salt-tolerant sugarcane mutant “M4209” with significantly higher yield under saline field conditions was developed. Active transcriptional reprogramming of genes coupled

*Dr. Srivastava has also elucidated the critical role played by volatile and non-volatile metabolites in orchestrating the herbicidal and plant growth promotion activities of *Trichoderma virens*.*

with enhanced photosynthetic efficiency was responsible for the salt-tolerance in M4209. Recently, the mechanistic basis of halophytic adaptation was delineated in *Sesuvium portulacastrum* (L.), which grows naturally under high-saline environments. An open-access database named “*Sesuvium KB*” (<https://cb.imsc.res.in/sesuviumkb>) has been established to facilitate wide-scale gene function studies in *S. portulacastrum*. Dr. Srivastava has also elucidated the critical role played by volatile and non-volatile metabolites in orchestrating the herbicidal and plant-growth promotion activities of *Trichoderma virens*.

Dr. Srivastava has more than 90 research and review articles and book chapters to his credit. He has been awarded with Fulbright-Nehru Professional and Excellence Fellowship in 2024; Young Scientist Award by National Academy of Sciences, India (NASI), Allahabad in 2018; Young Scientist Medal from Indian National Science Academy (INSA) in 2014 and Young Scientist Award from Department of Atomic Energy (DAE) in 2014. He has also received the Newton-Bhabha International Grant from DBT-BBSRC in 2018, President International Fellowship from Chinese Academy of Sciences, China in 2016 and EMBO Short-Term Fellowship in 2011. He has edited three books for reputed publishers (Wiley, Springer and CRC Press).

Developmental work in Nuclear Waste Management



Dr. Gattu Suneel

Dr. Gattu Suneel, Nuclear Recycle Board, is a recipient of Homi Bhabha Science & Technology Maanpatra Award - 2024. Dr. Suneel made notable contributions to the management of radioactive waste from nuclear power reactors and in the indigenous development of vitrification technology and its implementation on industrial scale for the fixation of High-Level Radioactive Liquid Waste (HLW).

He developed a multi-physics-based finite element model for its analysis by coupling the system's thermos-physical properties with electrical, heat transfer, fluid flow, and reaction kinetics phenomena. The model was validated with experimental data and used for troubleshooting plant-scale operations besides being deployed as a reliable, predictive, and diagnostic tool. He played a key role in the deployment of the Cold Crucible Induction Melter (CCIM), a next-generation vitrification technology, on an industrial scale.

Dr. Suneel also developed process flow sheets for selective removal of radioactive constituents from nuclear waste streams. He was instrumental in synthesis of novel ion-exchange resins and associated processes for selective removal of specific radionuclides from HLW.

Dr. Suneel has significantly contributed for reducing the volume as well as radiotoxicity of waste forms requiring long-term storage and surveillance.

These flow sheets enable recovery of fission products and minor actinides, thereby reducing the radiotoxicity of HLW.

He has also commissioned the Uranium Oxide Facility (UOF) and Vitrified Waste Storage Facility (VWSF). Under his supervision, the Fluidized Bed Thermal Denitration Plant was successfully commissioned, for management of Ammonical effluents. Furthermore, he oversaw the construction, commissioning, and operation of the facilities for the storage of heavy metals and solid wastes disposal.

Through his extensive work in nuclear waste management, Dr. Gattu Suneel has significantly contributed for reducing the volume as well as radiotoxicity of waste forms requiring long-term storage and surveillance.



Dr. Mohit Tyagi

Advancements in Growth & Characterization of Single Crystals for Nuclear Radiation Detection

Dr. Mohit Tyagi, Scientific Officer, Physics Group, made significant contributions towards the development of advanced scintillating materials, aligning with department's mandate towards an 'Aatmanirbhar Bharat' (self-reliant India). His work on growth and characterization of single crystals for nuclear radiation detection applications has garnered national and international recognition. His systematic and comprehensive investigations into unresolved issues in scintillating crystals have been acknowledged by leading research groups worldwide. His integrated approach, combining experimental and theoretical studies, led to many novel discoveries in scintillators, some of which are reported first time and have been adopted by other researchers.

In India, he has pioneered development of advanced single crystal scintillators and devices. Through a deep understanding of various scintillating materials, he has developed high-performance devices in close collaboration with various end-users. These devices are now deployed across various departmental units. His work includes creation of compact and portable detectors for charged particles, gamma rays, neutrons, X-rays, and electrons. The single crystals of Ce doped $\text{Gd}_3\text{Ga}_3\text{Al}_2\text{O}_{12}$ (GGAG), grown at about 1900°C has shown the most versatile single crystal scintillator, reported so far. Its performance has been evaluated, in details, to detect various radiations like X-rays for beam profile monitor at

Dr. Tyagi's integrated approach - combining experimental and theoretical studies - led to many novel discoveries in scintillators, some of which are reported first time and have been adopted by other researchers.

RRCAT and flash X-rays at APPD, gamma at higher count rate at IRAD, alpha and beta discrimination at NRG, and thermal neutrons at FF and NISER etc.

A novel phoswich detector consisting of two single crystals, GGAG:Ce,B and CsI:Tl was also developed with excellent performance characteristics and a US patent was also granted to the DAE for this innovation. This detector has been also shown to detect and discriminate various radiations like alpha-beta, low energy gamma in presence of high energy gamma, thermal neutron-gamma etc. in mixed radiation fields with the highest figure of merit reported so far. Dr. Mohit Tyagi has also played an active role in the incubation of a portable radiation detector based on single crystal scintillator, which is one of the first completed incubation under Atal Incubation Centre of BARC. His current research is to develop novel radiation detection devices as per the end users' requirements for the departmental program.

Advancements in Nuclear Level Density and Nuclear Reaction Mechanisms



Dr. P. C. Rout

Dr. P. C. Rout, Scientific Officer, joined Physics Group after graduating from the 46th batch of OCES (Physics) of the BARC Training School and earned his Ph.D. in Nuclear Physics from HBNI, Mumbai. He was awarded the Best Graduate Student Award and University Gold Medals in both B.Sc. and M.Sc. for securing first rank before joining the department. For his notable contributions to STEM, he has received several prestigious recognitions, including the INSA Medal for Young Scientists (2014) by the Indian National Science Academy, New Delhi; the Young Physicist Colloquium Award (2014) by the Indian Physical Society, Kolkata; the DAE-Young Scientist Award (2014); and the DAE-Science and Technology Excellence Award (2019) by the Department of Atomic Energy. He has completed a five-year tenure as a selected Member of the Indian National Young Academy of Sciences (INYAS), New Delhi, and was selected as a Member of NASI in 2024.

Dr. Prakash Chandra Rout is an accomplished experimental nuclear physicist, recognized for **his extensive work on nuclear level density and nuclear reaction mechanisms** using the BARC-TIFR Pelletron and Linac facilities. He has also made significant contributions to the development of radiation detector systems for experimental nuclear physics.

Dr. Rout has investigated the collective enhancement of nuclear level density and its fade-out with excitation energy in deformed nuclei (^{161}Dy and ^{171}Yb) through

Dr. Rout's contributions encompass indigenous development and characterization of deuterated liquid scintillation detectors for neutron and neutrino measurements in nuclear and high-energy experiments.

exclusive measurements of neutron evaporation spectra using arrays of liquid scintillation detectors and Si-strip detectors. The significantly large collective enhancement inferred for the first time highlighted its importance in predicting radiative neutron capture cross sections of astrophysical interest. He was responsible for developing ancillary detectors, such as the CsI(Tl) detector array for light charged particle measurements by pulse-shape discrimination, and augmenting the BGO detector array for the study of radiative capture reactions. His research also extends to alpha-clustered nuclei, unraveling reaction mechanisms with weakly bound stable nuclei, understanding fusion-fission dynamics in both actinide and sub-lead regions, neutron multiplicity measurements to probe fission dynamics, and generating high-precision nuclear data relevant to both fundamental research and nuclear energy. Additionally, he has contributed to the indigenous development and characterization of deuterated liquid scintillation detectors for neutron and neutrino measurements in nuclear and high-energy experiments.



Dr. V. Nafees Ahmed

Developmental work in Iodine-Sulfur Thermochemical Process for Production of Hydrogen

Dr. V. Nafees Ahmed, Scientific Officer, Chemical Technology Group was conferred with the Homi Bhabha Science & Technology Maanpatra, for his outstanding contribution towards the “development of Iodine-Sulfur (I-S) thermochemical process for the production of hydrogen by splitting water”. He was instrumental in obtaining kinetic rate parameters for non-ideal, hazardous gas-liquid Bunsen reaction system. He has led the team to carry out all reactions & concentration steps of I-S process together to achieve closed loop operation to produce hydrogen at 150 Nlph with water & heat as input. According to the documented information available in the scholarly literature, India is the first country to carry out hydrogen production at this scale in a closed loop in industrial materials with all engineering features. His role in demonstration of closed loop I-S process has been remarkable.

The scaled up version (3Nm³/hr) of the I-S process developed at BARC is being setup in collaboration with Heavy Water Board. He was involved in design of scaled up process plant with electrical heat. In this, he has actively contributed in development of process flow sheet, P&ID, process equipment design, technical specifications preparation, system & plant layout, along with detailed safety analysis and documentation.

The modified I-S process is envisaged to co-generate hydrogen & sulphuric acid in industries such as sulfuric acid, Zinc & Copper. He was involved in working out feasibility of this concept. Through Atal Incubation route,

Dr. Ahmed spearheaded the team to carry out all reactions & concentration steps of Iodine-Sulphur process together to achieve closed loop operation to produce hydrogen at 150 Nlph with water & heat as input.

an MoU was inked with a domestic vendor for design & deployment of scaled up hydrogen plant using this process. In this, he was involved in finalization of process flow diagram, P&ID, heat recuperation studies & process equipment design. He was involved in design of a novel Bunsen reactor using lean and very lean SO₂ from the sulphur burner.

In refineries, sufficient amount of hydrogen sulphide (H₂S) is generated which is converted to sulfur, water & heat through Claus Process. Instead, when H₂ is extracted from H₂S & re-used in refinery, lot of methane combustion which is used for process heating is reduced, resulting in drastic reduction of CO₂ emissions. He has studied the reaction to extract H₂ from H₂S. The reaction of iodine & concentrated H₂S has been studied in detail along with development of novel reactor to produce hydroiodic acid & sulphur both in aqueous and organic phases. He was involved in development of a process for purification of sulphur from the I-H₂S reactor. He has developed process flow diagram to demonstrate I-H₂S process in closed cycle. He was involved in obtaining reaction kinetic parameters of iodine-H₂S reaction.

Developmental work in Fabrication of Advanced Nuclear Fuels for Research Reactor Applications



Dr. V.P. Sinha

Dr. Ved Prakash Sinha has joined Nuclear Fuels Group of BARC in the year 2002, through 45th batch of OCES programme in BARC Training School. Since then he has been actively engaged and participated in various advanced fuel development programmes for important departmental applications. Amongst them, one of the major accomplishment, where a team under his able leadership has overcome the challenges related to fabrication of fuel for Apsara-U reactor and have successfully implemented innovative upgrades to the process parameters for superior performance (*Apsara-U fuel has achieved average assembly & average plate burnup of 54,635 and 62,556 MWD/t respectively*) and enhanced acceptance rate was. He has also played a central and pivotal role in indigenous development & qualification of fuel fabrication process flow sheet for Apsara-U reactor including an innovative P/M (Powder Metallurgy) route for the synthesis of U₃Si₂ compound. Dr. Sinha has made valuable and indispensable contributions to ensure uninterrupted operation of dedicated radiological facilities engaged in the accomplishment of mandates related to very important departmental programmes, in compliance with stringent safety requirements and has ensured processing of record quantities of fissile material for nuclear fuel fabrication.

He has played a key role in setting-up and establishment of a state-of-the-art dedicated Special Plate Facility (SPF) for industrial scale manufacture of LEU (Low Enriched

Dr. Sinha has made valuable and indispensable contributions to ensure uninterrupted delivery of fuel for Apsara-U and Fission Moly programme and is also playing a lead role in the ongoing departmental efforts for the development and qualification of advanced fuel for upcoming departmental programmes of research and test reactor.

Uranium) based target elements for the Fission Moly programme. He has successfully developed, qualified and validated a complex process for indigenous manufacturing of LEU based target elements conforming to international quality standards. The process has been implemented at SPF for regular production of fission Mo targets facilitating domestic supply of the vital medical isotope, reducing our dependence on imports and positioning our country among a handful of nations possessing this capability. His sustained and committed efforts have allowed complete indigenization of sophisticated closely guarded technical capabilities in this field. Dr. Sinha is also playing a lead role in the ongoing departmental efforts for the development and qualification of advanced fuel options including ceramic, dispersion and metallic fuels, for upcoming research and test reactors being planned for future applications.

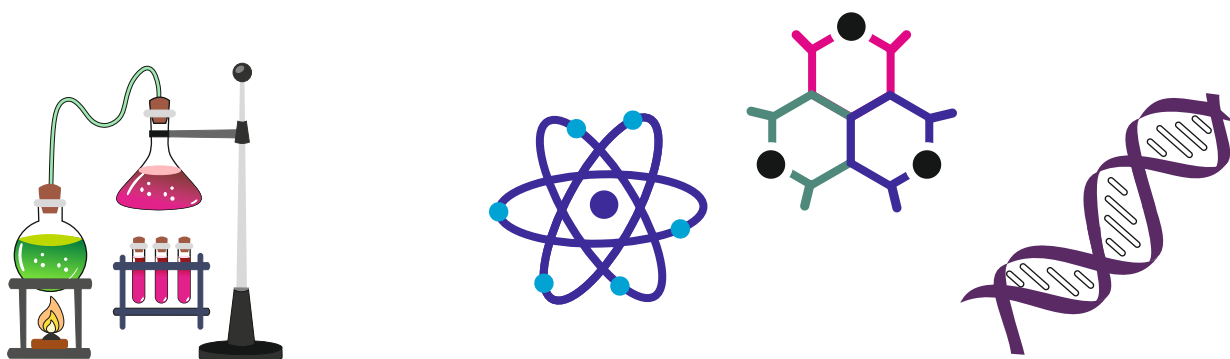


Mr. S. K. Vadali

Developmental work in Nuclear Fuel Fabrication

Mr. S.K. Vadali, Scientific Officer, Nuclear Fuels Group has made significant contributions in the field of **nuclear fuel fabrication**. He specializes in the field of fabrication of dispersion fuels for use in research as well as other types of nuclear reactors. He has “developed and optimised several metallurgical and mechanical processes used in the fabrication of dispersion fuels”. He was instrumental in setting up of new process lines for fabrication of dispersion fuel at Integrated Fuel Fabrication Facility, Nuclear Fuels Group, BARC.

Mr. Vadali was instrumental in setting up of new process lines for fabrication of dispersion fuel at a key integrated facility in BARC.



AWARDS & HONORS to BARC R&D Community



Dr. Aradhana K. Shrivastava, Physics Group



Fellow, Indian National Science Academy (FNA) (2026)

Fellow, National Academy of Sciences, India (FNASc) (2025)

Dr. Aradhana K. Shrivastava, Outstanding Scientist, Physics Group, BARC and a senior Professor of HBNI. She has been actively involved in the R&D activity utilizing BARC-TIFR Pelletron-LINAC facility at Mumbai. Her interests are broadly in the area of studying reaction dynamics with stable and weakly bound nuclei, shell effects in fusion-fission reaction and neutrino less double beta decay. Dr. Shrivastava has made significant contribution in identifying the origin of fusion hindrance observed at energies deep below the Coulomb barrier. This work in the area of nuclear physics that has important astrophysical implications related to the production of light-elements in stellar-environments was made possible due to her use of an innovative approach in selecting an asymmetric projectile-target system and a novel off-beam measurement technique. She has indigenously designed and developed a multi-anode Gas-Si hybrid detector for performing accelerator-based mass spectroscopy (AMS) of ^{36}Cl . Her team has developed various state-of-the-art experimental facilities at Pelletron LINAC Facility. She is recipient of DAE Homi Bhabha Science & Technology award, DAE Scientific & Technical Excellence Award and DAE Group Achievement Award. She has served as General Secretary of Indian Physics Association. She was a member of the drafting group for Mega-Science Vision 2035 document, written on initiative by the Office of the Principal Scientific Advisor to the Government of India.

Dr. Jyotirmayee Mohanty, Chemistry Group



Society for Materials Chemistry (SMC) - Distinguished Woman Scientist Award (2024)

Prof. (Mrs.) Archana Sharma Memorial Lecture Award, NASI (2025)

Dr. (Mrs.) Jyotirmayee Mohanty, Scientific Officer, Chemistry Group, has been conferred with the prestigious 'Distinguished Woman Scientist Award' by Society for Materials Chemistry (SMC) for her outstanding contribution to Materials Chemistry. She obtained her M. Sc. in Chemistry from Utkal University, Odisha in 1992 and joined Bhabha Atomic Research Centre, Mumbai, India, as Scientific Officer in 1994 after one-year advanced orientation course conducted by the institute. After her Ph.D. from the University of Mumbai in 2002, she carried out her postdoctoral research at Max-Planck Institute for

Biophysical Chemistry (MPIBPC), Göttingen and Jacobs University Bremen (JUB), Bremen, Germany, 2002-2004. She was a visiting scientist at JUB, Germany during Nov. 2013-Jan under Humboldt Fellowship for Experienced Researchers from Alexander von Humboldt Foundation. Her current research interests focus on the dynamics of noncovalent supramolecular/biomolecular assemblies and exploring their functional activities towards various applications such as on-off sensors, catalysts for H₂ generation, aqueous dye lasers, ^{99m}Tc generator bed, anti-cancer/anti-amyloidosis/antibacterial agents, etc. Her research contributions have been recognized in various national and international fora, such as IUPAC 2023 Distinguished Women in Chemistry or Chemical Engineering Award, Homi Bhabha Science & Technology Award from DAE (2019), CRSI Bronze medal-2017, SERB POWER Fellowship from ANRF, India, APA Prize for Young Scientist-2010 from the Asian-Oceanian Photochemistry Association (APA), Distinguished Lectureship Award-2009 from the Japan Chemical Society, Samanta Chandra Sekhar Award-2011 from Odisha Bigyan Academy. She is the Fellow of Maharashtra Academy of Sciences, National Academy of Sciences, India and Fellow of Royal Society of Chemistry (FRSC), London.

Dr. Seemita Banerjee, Chemistry Group

Society for Materials Chemistry (SMC) - Bronze Medal (2024)

Society for Materials Chemistry (SMC) - Bronze Medal (2024)

Dr. (Mrs.) Seemita Banerjee, Scientific Officer, Chemistry Group, has been awarded SMC bronze medal and elected as the member of NASI. She has been recognized for her overall research contributions in the area of hydrogen energy. She started her scientific carrier in the field of hydrogen storage and contributed significantly in this field thereafter. She successfully worked towards the development of magnesium-based materials, transition metal-based alloys, chemical hydrides, as well as carbon-based materials for hydrogen storage application. She has been extensively working on very important issues such as improvement of hydrogen storage capacities of different systems as well as their desorption temperatures and kinetics. She has contributed significantly for the development of different catalysts for in-situ generation of hydrogen from chemical hydrides at ambient temperature. Her work also involves development of material for supercapacitor and sensor applications as well as catalysts development for electrochemical hydrogen evolution reaction. She has published more than 60 peer reviewed papers in international journals of high impact. She has received DAE Young Scientist Award (2015).



Dr. Shilpa N. Sawant, Chemistry Group

Society for Materials Chemistry (SMC) - Silver Medal (2024)

Member, National Academy of Sciences (NASI), India (2024)

Dr. (Mrs.) Shilpa N. Sawant, Scientific Officer, Chemistry Group, has been awarded SMC silver medal and elected as the member of NASI. Dr. Sawant joined BARC in the year 1997, through 40th batch of Training School after completing her MSc (Chemistry) from IIT Bombay. She received her PhD from Tokyo Institute of Technology under the JSPS RONPAKU Fellowship. Dr. Sawant has made significant contributions to the development of electrochemical and colorimetric biosensors for detection of important analytes including metabolites, pathogenic bacteria, cancer biomarkers and cancer cells. Adopting several innovative strategies, she has contributed immensely to the fundamental understanding of various processes involved in development of sensors for medical diagnostic application. She has developed a novel electrochemical device (ECAA) for cancer detection by exploiting the difference in the glycolysis rate of normal and cancer cells. This device was validated using human tissue samples under a MoU with Tata Memorial Hospital. The technology for ECAA has been transferred to five private companies for commercialization. She has also developed a novel electrochemical device (BacSeNSe) consisting of sensor array for rapid microbial identification and antibiotic susceptibility testing in pathology samples. She has been conferred with DAE Scientific and Technical Excellence Award-2015 for her significant contribution in the field of conducting polymer-based biosensors.



Dr. Vinita Grover Gupta, Chemistry Group



Chemical Research Society of India (CRSI) - Bronze medal (2025)
Fellow, Royal Society of Chemistry (2025)

Dr. (Mrs.) Vinita Grover Gupta, Scientific Officer, Chemistry Group, has been awarded CRSI bronze medal and selected as the Fellow of Royal Society of Chemistry (FRSC). She is a materials chemist who works extensively on materials for nuclear and energy applications. Her area of expertise is design of materials for nuclear safety and advanced nuclear technologies that has led to indigenous database on structural, thermophysical and irradiation behavior of oxides and composites of nuclear relevance. She has developed rare earth-based, lead-free novel materials for energy applications such as ferroelectric relaxors, ionic conductors and phosphors based on crystal chemistry concepts. An import-substitute technology for flexible lead-free X-ray shielding formulations has been developed for medical applications. She is the recipient of several awards notable among which are DAE Scientific and Technical Excellence Award, DAE Young Scientist Award, CRSI-Bronze Medal, Young Scientist Awards bestowed by Indian Nuclear Society and Indian Society of Chemists and Biologists, IANCAS Dr. Tarun Dutta Memorial Award and winner of IUPAC Young Chemist Programme. She is also the Fellow of Royal Society of Chemistry and Maharashtra Academy of Sciences India. She is an elected Associate Academician, Asia Pacific Academy of Materials and Member, National Academy of Sciences India.

Dr. Adish Tyagi, Chemistry Group



Member, Indian National Young Academy of Sciences (INYNAS) (2025)
Young Associate, Maharashtra Academy of Sciences (2024)
Society for Materials Chemistry (SMC) - Bronze Medal (2024)

Dr. Adish Tyagi, Scientific Officer, Chemistry Group has been elected as young associate of Maharashtra Academy of Sciences, member of INYNAS and received bronze medal from SMC for his outstanding contributions to materials chemistry, with a particular focus on germanium ultra-purification and the development of materials for energy conversion and storage. Since joining BARC in 2011, he has played a significant role in optimizing zone refining parameters to upgrade commercial 4–5N germanium to ultra-pure levels. In the field of energy materials,

Dr. Tyagi has pioneered the use of single-source precursors for the synthesis of size- and composition-controlled metal chalcogenide and oxide nanomaterials, demonstrating their efficiency as photon absorbers in photoelectrochemical cells. He has also developed metal chalcogenide and porous carbon@metal chalcogenide nanocomposites as high-performance anodes for lithium-ion batteries. Dr. Tyagi's remarkable scientific contributions have been widely recognized through several prestigious awards from national scientific bodies.

Dr. Anup Kumar Bera, Physics Group



AONSA Science Award 2025

Dr. Anup Kumar Bera, Scientific Officer, Physics Group, Assistant Professor in Homi Bhabha National Institute, has been honored with the Asia-Oceania Neutron Scattering Association (AONSA) Science Award 2025 for his exceptional contributions to neutron science; groundbreaking experimental observations, including the realization of “Bethe Strings,” (after ~90 years of its theoretical prediction), and the discovery of novel quasi-particle excitations such as “doublons” and “quartons”, and his commitment to addressing complex scientific challenges.

Dr. Bera joined BARC as a Scientific Officer (D) in 2016. Before that, he earned his PhD in Physics from the University of Mumbai in December 2011, followed by postdoctoral research at Helmholtz-Zentrum Berlin für Materialien und Energie, Germany, from December 2011 to June 2015, and KSKRA at BARC during July 2015 to July 2016.

Dr. Bera's research interest includes strongly entangled quantum spin systems, quantum phenomena in low-dimensional magnetic materials, quantum phase transitions, quantum spin-liquids, and energy materials for future technology. He has authored over 95 research papers in leading international journals, including Nature, Nature Physics, and Nature Communications; along with 20 conference papers and two book chapters.

Dr. Bera's notable achievements include the Young Scientist Award (2018) from the DAE, Govt. of India, and the Young Achiever Award by the DAE-Solid State Physics Symposium. He has been elected as a Young Associate of the Maharashtra Academy of Sciences. He has delivered several invited lectures, including the notable Infosys Condensed Matter Seminar at the TIFR, Mumbai, and has received multiple best presentation awards at various prestigious conferences.

Dr. Balaji P Mandal, Chemistry Group

Silver Medal by Chirantan Rasayan Sanstha, India

Dr. Balaji P Mandal is a Scientific Officer in Chemistry Group, BARC and an Associate Professor in Homi Bhabha National Institute (HBNI), Mumbai. Dr. Mandal developed pyrochlore based ceramics with high radiation stability. He also contributed in multiferroics, high dielectric compounds and composites. He was awarded DAE-Young Scientist award in 2012 and received membership of the National Academy of Science, India. He is also recipient of DAE-SSPS Young Achiever Award in 2017. Dr. Mandal was awarded SMC-Bronze Medal in 2022 for his work in nuclear materials and solid state ionics. He has transferred technologies for electrode materials of lithium ion battery to different private firms in the recent past. He has more than 95 publications to his credit, published in internationally reputed journals. Recently, he has been awarded with Silver Medal by Chirantan Rasayan Sanstha, India in recognition of his notable contribution in materials chemistry and solid state ionics.



Mr. Bhumeshwar Ponagani, Multidisciplinary Research Group

Young Engineer Award, Indian Society for Particle Accelerators (ISPA), 2025

Mr. Bhumeshwar Ponagani made notable contributions to the field of superconducting radio-frequency (SRF) cavity design and accelerator control system development as part of the Indian Institutions and Fermilab Collaboration (IIFC) and the Indian accelerator programme.

He was involved in optimizing the use of circumferential stiffeners, and inclusion of internal stiffening plates on SSR cavities for IIFC. The same analysis framework was applied to optimize the electromechanical design of Medium Energy High Intensity Proton Accelerator (MEHIPA) SSR-B cavities.

In addition, he developed an eight-channel RF power monitoring system integrating it with EPICS for real-time measurement of forward, reflected, and cavity power. This indigenously designed system, based on SoC FPGA and Raspberry Pi, effectively replaces commercial RF power meters while offering enhanced flexibility and data accessibility.

He also designed a feedforward power stabilization system for the klystron driving the RFQ in LEHIPA in BARC, achieving flat power pulses and improved cavity conditioning. His work significantly strengthens India's capabilities in SRF and accelerator technologies.



Dr. Bijaideep Dutta, Chemistry Group



INIAS Best Thesis Award (2025)

Dr. Bijaideep Dutta, Scientific Officer, Chemistry Group has been awarded the 'Best Thesis Award' from INIAS. Dr. Dutta joined BARC in 2015 and has been actively engaged in activities associated with the design and development of innovative materials for affordable and effective cancer therapeutics. His research focuses on three key areas - rational design of biocompatible nanomaterials for targeted cancer therapy, development of integrated theranostic platforms for simultaneous imaging and treatment and formulation of advanced nutraceuticals with enhanced bioavailability. He has developed a cost-effective PEGylated liposomal doxorubicin formulation (BARC-LDOX) using FDA-approved, self-assembling ingredients, which demonstrates superior pharmacokinetics and biodistribution compared to free drug and performance comparable to commercial analogues. Validated in GLP facilities, BARC-LDOX is currently under patent drafting and holds strong translational promise. Dr. Dutta also engineered highly stable, bioavailable curcumin based nano-formulations capable of loading up to 50 mg/mL of curcumin with stability for over five years. This technology has been transferred to four Indian companies. Furthermore, he has pioneered pH-responsive magnetic nanoparticles for chelator-free bimodal (MRI/SPECT-CT) imaging and combinatorial chemo-thermal therapy. A recipient of numerous accolades, including seven best paper awards and honors such as the HBNI Outstanding Doctoral Student Award (2023), CRS Young Scientist Award, and SMC Emerging Young Scientist Award (2023), Dr. Dutta has published 42 peer-reviewed articles in leading journals (RSC Nanoscale, JMC B, ACS' AMI, ACS' Applied Biomaterials, Adv. Colloids Interface Sci.) and authored seven book chapters, establishing himself as a versatile and pioneering researcher in biomedical materials chemistry.

Dr. Brindaban Modak, Chemistry Group



Member, Indian National Young Academy of Sciences (INIAS) (2024)

Dr. Brindaban Modak, Scientific Officer, Chemistry Group, made notable contribution in the area of theoretical chemistry and computational material science of fundamental and practical interests. The major focus of his research activities includes developing novel materials for energy conversion, storage and environmental applications. He has demonstrated efficient strategy to engineer the band structure of the photocatalyst in a controlled manner through doping with a foreign element. The reported results were found to be of great interest and beneficial to the researchers working in the synthesis of new photocatalyst with improved features. Many of his predicted catalysts have already been synthesized by various experimental groups. Dr. Modak also made significant contribution in designing tunable materials for optoelectronics devices and radiation dosimetry. He has employed efficient strategies to tune the emission properties through defect and doping engineering. He has also predicted novel materials by investigating the microscopic origin of host emission, local site occupancy, defect evolution, in the doped and undoped host materials. His studies provide important guidelines for tuning the synthesis conditions to optimize functionalities based on different intrinsic defects. He has investigated different important thermophysical and thermodynamic properties of advanced fuel materials for nuclear reactors. He has also studied temperature dependency on thermal conductivity, heat capacity, and thermal expansion coefficient, which are very much related to heat transport phenomena. He has, to his credit, an impressive number of publications in reputed international journals which have been well cited in popular literature. Dr. Modak was awarded with NASI-Young Scientist Platinum Jubilee Award, DAE Young Scientist Award, NASI-Membership, Young Associate of the Maharashtra Academy of Sciences, Bronze Medal from Society of Material Chemistry, Homi Bhabha Prize and HBNI Outstanding Doctoral Student Award.

Dr. Debasis Sen, Physics Group

Society for Materials Chemistry (SMC) Silver Medal 2024

Dr. Debasis Sen, Scientific Officer, Physics Group has made outstanding contributions by establishing mesoscopic-structure-function correlation in materials through small-angle scattering of neutrons (SANS) and X-rays (SAXS). He has been instrumental in setting up the Small Angle X-ray Scattering beamline (BL-18) at Indus-2 and the MSANS facility at the guide tube laboratory, Dhruva reactor. He worked as a Visiting Scientist at CEA, Saclay in France. Dr. Sen has established a profound understanding of evaporation-induced assembly during drying of spray colloidal-droplet and formation of nano-structured porous micro-granules. He has established the method for tuning sphere to doughnut transformation during formation of these micro-granules. These micro-granules are found to be useful in: i) enhancing water permeability through ultra-filtration membranes, ii) dye sorption iii) microbe filtration, and iv) cementation. He has developed novel formalisms to estimate particle size distribution from scattering data without prior assumption of the form of distribution. He has been conferred with several prestigious awards including DAE-Homi Bhabha Science and Technology Award, DAE Scientific and Technical Excellence award, Young Achiever Award of DAE Solid State Physics Symposium. He is a Fellow of Maharashtra Academy of Sciences.



Dr. Deepak Tyagi, Chemistry Group

Young Associate of Maharashtra Academy of Science (2024)

Dr. Deepak Tyagi, Scientific Officer, Chemistry Group has been elected as a Young Associate of Maharashtra Academy of Science for his contribution in the field of heterogeneous catalysis with emphasis on development of suitable catalysts for the processes relevant to DAE's mandate such as mitigation of hydrogen in nuclear plant under LOCA conditions, catalyst for hydrogen generation from thermochemical cycles, catalysts for degradation of dioxin and furans generated by incineration of polymeric waste and root cause analysis of pressure tube failure at KAPS. For hydrogen production, he has developed platinum-based catalysts for liquid phase HI decomposition reaction, the hydrogen producing step of S-I cycle. He has also contributed to the hydrogen mitigation catalyst, the devices based on the catalyst have been deployed in all nuclear power plants in India. He has also developed a catalyst for U(VI) to U(IV) reduction reaction. The selected catalyst Pt (1 wt.%)/ZrO₂ was deployed in a pilot plant at Nuclear Recycle Group. For dioxin and furan degradation catalyst, he has developed mixed oxide catalysts. For root cause analysis of failures of pressure tube in KAPS, he made significant contributions in setting up an experimental facility at ISOMED, BRIT and Electron Beam Centre Kharghar. He was instrumental in generation and analyzing the radiolysis data for ethylene and other hydrocarbon impurities at 7 MeV LINAC. He is a recipient of Homi Bhabha medal 2009 and DAE Young Applied Scientist Award 2017. He is one of the recipients of DAE group achievement awards in year 2010, 2016 and 2018.



Dr. Gourab Karmakar

Society for Materials Chemistry (SMC) - Emerging Scientist Award (2024)

Dr. Gourab Karmakar, Scientific Officer, Chemistry Group, has been awarded Emerging Scientist Award from SMC for his significant contributions in the area of molecular and materials chemistry. His research focuses on single source molecular precursor-mediated low-temperature synthesis of metal chalcogenide nanostructures and thin films for energy conversion and storage. His work has led to the development of several chalcogen-bearing complexes of both transition and main-group metals featuring in-house developed internally functionalized hemilabile ligands. He has extensively explored these complexes as precursors for the fabrication of nanocrystalline metal chalcogenide semiconductors with tunable physical properties. He has successfully isolated several delicate compositions of copper, indium and tin chalcogenides, employing molecular precursor route. This was achieved mainly by keen selection of



reaction solvent and modulating reaction temperature. Substitution of different functional groups in the molecular precursor have also been explored for their effect on the final material. Dr. Karmakar's innovative idea have enabled the synthesis of mono-dispersed, phase-pure, high quality metal chalcogenides, showcasing the versatility of his approach. His research interest also extends to the scalable production of technologically superior ternary metal-chalcogenide nanostructures. Furthermore, the materials developed by Dr. Karmakar have shown remarkable performance as anode material in lithium-ion batteries (LIBs), with impressive charge-discharge capability accompanied with high cyclability.

Dr. Kaustava Bhattacharyya, Chemistry Group



CRS- Bronze Medal-2025 by Chirantan Rasayan Sanstha (CRS), India

Dr. Kaustava Bhattacharyya, Scientific Officer, Chemistry Group has made excellent contribution in the field of materials science, particularly towards development of heterogeneous catalysts pertaining towards the needs of energy resources and environmental remediation. He has made immense contributions in heterogeneous catalysis with emphasis on programs of relevance to DAE. His work in the field of energy sources has resulted in development of photocatalysts for selective CO₂ reduction to CH₄ and established its mechanism. He has developed several catalysts for the utilization of CO₂ in various forms. He has contributed towards the development for the mechanism of the Bunsen reaction step in S-I cycle of H₂ production. He has synthesised and established the mechanism for decomposition reaction of Cu₂OCl₂ in Cu-Cl cycle of H₂ production.

He has developed an analytical technique for measurement of Dioxin and Furan (D&F) and thermal catalysts for complete mineralization of D&F. His deep insight catalysis has led to establishment of primarily the effect of O-vacancies, other point defects and surface oxidation states in photocatalytic efficiency. He has developed various photocatalysts for abatement of different VOC's like para chlorophenol, ethylene, benzene, methane, CO, o-DCB, different toxic dyes and established their catalytic mechanism. His expertise in different surface technique related to XPS, and different operando techniques like in situ FT-IR, in situ EXAFS for mechanistic understanding has resulted in establishment for the mechanistic details for several processes which has prompted in increment in their catalytic efficiency in a positive way. He has special interests in the effects for surface sorption and separation of Uranyl and Plutonium ions in urine bioassays in order to develop a technique for their detection low concentration regime.

Dr. Mahesh Sundararajan, Chemistry Group



IANCAS' Dr. Tarun Datta Memorial Award (2024)

Dr. Sundararajan, Scientific Officer, Chemistry Group has been awarded IANCAS' Dr. Tarun Datta Memorial Award for significant contributions to theoretical and computational chemistry, particularly in the electronic structure calculations of speciation and extraction of heavy metal ions in different environments. Dr. Sundararajan joined BARC in 2010 through KSKRA Fellowship soon after completing his PhD (University of Manchester, UK) and Alexander von Humboldt Postdoctoral Fellowship (University of Bonn, Germany). Dr. Sundararajan was the first to propose the mechanism of uranyl reduction with Ru-nanoparticles through a disproportionation pathway, leading to the formation of U(V)-U(V) species, which has

since been experimentally characterized. His research on geochemical speciation of heavy metal ions such as uranyl, iodine, Cs⁺, and Sr²⁺ provided crucial insights into their mobility, which is largely controlled by humic substances. Using multi-scale models, he predicted their speciation in geochemical environments, revealing that water content and pH significantly dictate their binding behavior. His theoretical predictions have been validated through multiple theory-driven experiments. Dr. Sundararajan has authored 115 research papers, including three book chapters in high-impact peer-reviewed international journals such as JACS and Chemical Reviews. Currently, his h-index is 31, an i10 index of 70, and over 2,500 citations. His theoretical modelling of nuclear waste management processes has been widely recognized, earning him Indian Science Congress Young Scientist Award (2011), DAE Young scientist Award (2015) and SMC Bronze Medal (2023).

Dr. Manoj Kumbhakar, Chemistry Group

Fellow, National Academy of Sciences, India (NASI) (2025)

Dr. Manoj Kumbhakar, Scientific Officer, Chemistry Group, has been elected as a Fellow of the National Academy of Sciences, India (NASI) for his significant contributions in developing new techniques in single molecule spectroscopy and demonstrating their applications in bioimaging and diagnostics. Dr. Kumbhakar joined BARC in 2001 and obtained PhD in 2008 from University of Mumbai. He is an Alexander von Humboldt Fellow for postdoctoral research for the period 2010-2012. His recent research interests include bio-speciation and bio-sequestration of lanthanides and actinides using single molecule fluorescence spectroscopy and super-resolution imaging.



He is a recipient of Homi Bhabha Award in Chemistry for the year 2000–2001, NASI Young Scientist Award-2007, DAE Young Scientist Award-2008 and INSA Young Scientist Award-2010. The major scientific contribution of Dr. Manoj Kumbhakar has dimensions ranging from fundamental research in the field of chemical kinetics to its possible applications in the extremely challenging research area relevant for biochemical uptake, transport and internalization of radioactive metal ions. To execute his research ideas, he has developed a unique and first-of-its-kind fluorescence spectroscopy and multi-dimensional imaging facility in India, which can study molecular interactions over unprecedented broad temporal window of picosecond to seconds, with nano-scale spatial resolution as well as 3D orientation & vibronic information of single fluorophore.

Dr. Manoj Mohapatra, Radiochemistry & Isotope Group

Fellow, Indian Chemical Society (2024)

Dr. Tarun Datta Memorial Medal, IANCAS (2024)

Dr. Manoj Mohapatra is involved in the development of analytical methodologies for the complete CQC of MC, MO_x, BeO and Pu based alloy fuel samples for the past 20 years. He has spearheaded the campaign to prepare the in-house Certified Reference Material (CRM) for PuO₂ through an Inter Laboratory Comparison Experiment (ILCE). Dr. Mohapatra carried out extensive studies to assess the radiation stability of nuclear waste glass, especially designed to vitrify the research reactor nuclear waste at BARC, Trombay through spectroscopic techniques. Dr. Mohapatra has used time resolved Photoluminescence (PL), Electron Paramagnetic Resonance (EPR) and Thermally Stimulated Luminescence (TSL) correlation to address the interplay of structure and property in multi-functional materials. He has carried out speciation studies of actinides such as Uranium, Americium and Curium through the time resolved PL technique in solid host matrices. His work on luminescence properties of lanthanide systems has proved potential application in the areas of health, energy and environment.



Dr. Mayanak K. Gupta, Physics Group

N.S. Satya Murthy Young Scientist Award in Physics (2024)

Bronze Medal of the Society of Materials Chemistry (2024)

Dr. M.K. Gupta, Scientific Officer, Physics Group is a leading researcher in condensed matter physics and materials science, with a specific focus on energy materials and their atomic-scale behaviour. Dr. Gupta's expertise lies in his innovative approach, which combines advanced neutron scattering experiments with state-of-the-art simulations using machine learning techniques. This methodology allows him to investigate energy and charge transport in a variety of energy materials. His research has provided fundamental insights into solid electrolytes, thermoelectrics, and materials with negative thermal expansion, laying the groundwork for next-generation energy technologies. His significant contributions are well-documented in high-impact international journals. Recent publications in Nature Materials, Nature Physics, Energy and Environmental Science, Advanced Energy Materials, and the Journal of Materials Chemistry A, as well as



several noteworthy Physical Review papers, have advanced the understanding of energy and transport in solid electrolytes and thermoelectrics. With more than 100 research papers to his name in reputed journals, his work is widely cited within the fields of condensed matter and energy materials.

Dr. Gupta's scientific achievements have been recognized with prestigious awards, including the most coveted recognition of a young scientist in India, INSA Associate Fellow (2024), D.A.E. Young Achiever Award (2021) at 65th DAE SSPS, Young Scientist Award (2017) by the Department of Atomic Energy, and Best PhD Thesis from the Material Research Society of India (2017). These honours underscore his vital role in advancing India's scientific leadership in nuclear energy research and sustainable energy technologies.

Dr. Prabhat K. Singh, Chemistry Group



Fellow, Royal Society of Biology (2025)

Dr. Prabhat K. Singh, Scientific Officer, Chemistry Group has been selected as a Fellow of the Royal Society of Biology (FRSB). Dr. Singh joined BARC in 2006 after completing a one-year orientation program (49th Batch) of BARC Training School, receiving the Homi Bhabha Gold Medal. His current research interests include ultrafast spectroscopy and use of self-assembled materials for designing optical sensors for bio-sensing and chemo-sensing applications.

Dr. Singh has authored about 140 publications in peer-reviewed international journals, with an H-index of 38 and close to 4000 citations. He is a recipient of Young Scientist Award by DAE, Indian Science Congress Association (ISCA) and National Academy of Science, India (NASI). In recognition of his work, he was selected as a Member of INYAS (2017-2021) and NASI. Dr. Singh also served as a Young Associate of Indian Academy of Sciences (IASc), Bangalore (2017-2020) and Young Affiliate of Maharashtra Academy of Sciences. He also served as a Member of Global Young Academy (GYA), Berlin, Germany. Recently, he has been selected as a Fellow of the Indian Chemical Society, a Fellow of the Maharashtra Academy of Sciences, and an Associate Fellow of the Indian National Science Academy (INSA) in 2023. Recently, Dr. Singh has been awarded with the Fellow of the Royal Society of Chemistry (FRSC) and TWAS Young Affiliate (2023-2028) by World Academy of Sciences. He is also serving as a Member of the National Committee for International Union for Pure and Applied Chemistry (IUPAC)

Dr. Santosh Kumar Gupta, Radiochemistry & Isotope Group



Fellow, Asia Pacific Academy of Materials (FAPAM), Asia-Pacific Regions (2025)

Fellow, Institute of Physics (FInstP), London (2025)

Fellow, Institute of Materials, Minerals and Mining (FIMMM), London (2025)

Materials Research Society of India (MRSI) Medal (2024)

Dr. Santosh Kumar Gupta serves as a Scientific Officer in the Radiochemistry and Isotope Group at BARC, Mumbai, and as an Assistant Professor at the Homi Bhabha National Institute (HBNI), Mumbai. His research lies at the interface of materials science, photophysics, and spectroscopy, focusing on the design and development of advanced lanthanide- and actinide-doped phosphors and scintillators for energy conversion, solid-state lighting, optical sensing, and bioimaging. Dr. Gupta's work

integrates experimental spectroscopy and defect chemistry to uncover fundamental structure-property relationships governing light-matter interactions in luminescent materials. Through comprehensive studies using steady-state and time-resolved photoluminescence, thermoluminescence, and X-ray excited optical luminescence, he has advanced understanding of energy transfer dynamics, defect-mediated emissions, and persistent luminescence mechanisms. His investigations into actinide-doped systems have provided critical insights into f-f electronic transitions, radiation-induced defects, and optical behavior of 5f elements, with direct relevance to nuclear materials and sensor applications.

A prolific and highly cited materials chemist, Dr. Gupta has co-authored more than 285 peer-reviewed Journal publications, accumulating more than 8500 citations, with an h-index of 56 and an i10-index of 182. His pioneering contributions in spectroscopy-driven luminescent materials research in 2024-25 have been recognized through election as Fellow of the Asia Pacific Academy of Materials (FAPAM, Asia-

Pacific Region, 2025), Fellow of the Institute of Physics (FInstP, London, 2025), Fellow of the Institute of Materials, Minerals and Mining (FIMMM, London, 2025), and the award of the Materials Research Society of India (MRSI) Medal in 2024. These honors reflect his outstanding and sustained contributions to lanthanide- and actinide-based phosphors and scintillators, establishing him as a leading scientist in functional luminescent materials research in India and the Asia-Pacific region.

Dr. Srungarpu Nagabhusan Achary, Chemistry Group

Fellow, National Academy of Sciences, India (NASI) (2025)

Dr. S.N. Achary, Scientific Officer, Chemistry Group, has been elected as a Fellow of National Academy of Science, India in the year 2025. He joined BARC Mumbai after passing out successfully from the 38th Batch of BARC Training School program and is presently heading Nuclear and Energy Materials Section of Chemistry Division in BARC. Dr. Achary is an acclaimed solid-state chemist who has contributed immensely to materials chemistry, preparative solid-state chemistry, crystal chemistry of materials at high temperatures and high pressures, and structure–property correlations in materials. His studies have led to discovery of a number of metastable materials and novel functional materials such as negative and low thermal expansion materials, ionic conductors, high temperature ceramics, dielectrics and multiferroic materials and ion exchangers. He has extensively worked on crystal chemistry and stability of pyrochlore, zirconolite and hollandite-based titanates for possible matrices for nuclear waste immobilization. He has also worked on complex phosphates for ion exchanger or immobilization matrices. Dr. Achary has studied structural systematics for a number of zircon type materials with composition, temperature and pressure. He has authored over 250 articles in reputed international journals and contributed approximately 10 chapters to books. He has received the CRS Silver Medal (2024), DAE Homi Bhabha Science and Technology Award (2020) and DAE Scientific and Technical Excellence Award (2012) for his studies on hex-gas reduction. He was a member of the team that received the DAE Group Achievement Awards for their work on the development of hex-gas conversion technology (2012) and burnable neutron poison (2018). He was elected as a Fellow of Maharashtra Academy of Science in 2012.



Dr. Veerendra K. Sharma, Physics Group

Fellow of Maharashtra Academy of Science (2024)

Dr. Veerendra K. Sharma joined Physics Group, BARC in 2007 after securing first position in the 50th batch of the BARC Training School. He has since been actively involved in the neutron scattering-based R&D program, focusing on molecular motions in advanced functional materials, a field in which he was honored with the DAE Young Scientist Award (2013). He earned his PhD in Physics (2013) from the HBNI, where his thesis received the Outstanding Doctoral Thesis Award, and subsequently carried out postdoctoral research at the Oak Ridge National Laboratory, USA (2014-16).

Dr. Sharma's research spans soft matter, biophysics and energy materials, with seminal contributions to phase transitions and diffusion mechanisms in biomembranes, complex fluids, and hybrid perovskites. His key contributions include: Revealing new action mechanisms of antimicrobial peptides and ionic liquids in combating drug-resistant pathogens [JPCL 15 (2024) 7075; JPCL 7 (2016) 2394]; Introducing the non-Gaussian fractional Brownian motion model for glass formers [Phys. Rev. Lett. 132 (2024) 058202]; Demonstrating the role of halides and cations in stability and photovoltaic properties of hybrid perovskites [Small 21 (2025) 2504054; JPCL 11 (2020) 9669], and Elucidating diffusion mechanisms in lithium-based electrolytes [JPCL 14 (2023) 9766] and confined fluids [Rep. Prog. Phys. 84 (2021) 066501]

His contributions have earned him prestigious honors, including the INSA Distinguished Lecture Fellowship (2024), NASI-Young Scientist Award (2019), Associate, IASc (2020-23), IPA-Buti Foundation Award (2022), SMC Bronze Medal (2023), Best Young Physicist Award (2018), member of INYAS-INSA and NASI. Dr. Sharma has published over 100 research articles in leading international journals.



Visitors to BARC...

2024-2025



Distinguished policy maker, **Dr. P.K. Mishra** (Principal Secretary to the Prime Minister of India, Government of India), was invited to be the Chief Guest at the Graduation Function honors for the young graduates of the 68th Batch of BARC Training School in Mumbai, held during August 2025.

There are high hopes from nuclear energy as a source of clean and sustainable power... The criticality of safety aspect will be very vital and we need to revisit our whole mechanisms and undertake further research on the subject... We also need to ensure that there is a high level of confidence in the minds of the people about safety standards of our nuclear projects.



Professor Abhay Karandikar (Secretary to GoI, DST, Ministry of Science & Technology), who was instrumental in shaping India's telecom policy by establishing global 5G/6G standards and steering the nation's strategic vision for 6G adoption, was invited to BARC to deliver a talk on the topic 'Transforming Science & Technology Landscape' towards Viksit Bharat, at the popular Trombay Colloquium in August, 2025.

With the transition to 6G telecom services, India aims to secure at least 5% of global IPRs. Efforts are underway to deploy nearly 30,000 GPUs to strengthen cloud computing infrastructure in the country besides advancements in bio-engineering, precision bio-therapeutics, and setting up a robust Deep Tech ecosystem.



Dr. Trilochan Mohapatra (Chairperson, Protection of Plant Varieties & Farmers' Rights Authority Ministry of Agriculture & Farmers Welfare, GoI), was invited to BARC to deliver a talk on the topic 'Towards an Ever Green Revolution' that focused on economic, environmental, and social pillars of sustainable agriculture in India, at the popular Trombay Colloquium in July, 2025.

Increased private partnership and investment in agri sector, revisiting nuclear agriculture, discovering new molecules translating into enhanced local production of better pesticides and bio-stimulants, smart sensors and imaging would enable India's transformation to sustained Ever Green Revolution.



Shri S. A. Bhardwaj (Former Chairman, AERB) was invited as the Chief Guest to the National Science Day (NSD) 2025 program (28 February-2 March) held every year in BARC to commemorate the legacy of India's Nobel Laureate Sir C.V. Raman. This year, BARC marked the program with the theme 'Transition to Clean, Green Viksit Bharat: Advanced Materials & Nuclear Technology'.

Reduce, Recycle, and Reuse philosophy (continues to be) central to India's nuclear energy ecosystem.

...From the Ranks of STEM, Public Policy

2024-2025



Dr. Samir V. Kamat (Secretary, DDR&D and Chairman, DRDO, Ministry of Defence, GoI), who played a key role in advancing several critical materials programs at DRDO, including the development of high-strength steels for naval ship hulls, high-temperature titanium alloys, and nickel-based superalloy components for aero engines was invited to BARC to deliver a talk on the topic 'R&D in Defence Sector', at the popular Trombay Colloquium in January, 2025.

The civilian sector currently leads in AI and communication technologies adoption. DRDO is working to adapt these civilian innovations for military applications. The civil-military fusion approach is identified as a key factor for India's future defence technological competitiveness.



Mr. A.S. Kiran Kumar (Former Secretary in the Department of Space, GoI), who played a significant role in the success of India's Chandrayaan-I and Mars Orbiter Mission besides facilitating rapid development of earth observation, communication, navigation and space sciences, was invited to BARC to deliver a talk on the topic 'Indian Lunar Mission', at the popular Trombay Colloquium in September, 2024.

Push beyond your boundaries... True learning from mistakes may require more than a lifetime... Experience is less relevant. Knowledge and the ability to adapt are crucial for success in our rapidly evolving landscape.



Former Chief Scientist at World Health Organization and a distinguished pediatrician, **Dr. Soumya Swaminathan**, who was also credited with coordinating the scientific efforts at the World Health Organization during the COVID-19, was invited to BARC to deliver a talk on the topic 'My Journey as a Physician Scientist and Researcher', at the popular Trombay Colloquium in July, 2025.

India should take a leadership role in developing new vaccines by leveraging its full potential in scientific resources and expertise. Innovative vaccine development is essential not only for TB but for addressing broader public health challenges, especially in the context of lessons learned from the COVID-19 pandemic.

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