Director's Message

As a premier R&D centre of the Department of Atomic Energy (DAE), Bhabha Atomic Research Centre (BARC) has a mandate to provide R&D support to the nuclear power program, to pursue all activities related to nuclear fuel cycle, to operate research reactors for supporting beam research and supplying radioisotopes for various applications, to conduct frontline basic research in physical, chemical, biological and engineering sciences all of which leading towards improving the quality of life of citizens.

A hallmark of India's atomic energy program, founded seven decades ago under the leadership of Dr. Homi J. Bhabha, has been to achieve self-sufficiency in all aspects of applications of nuclear energy in the country.

The growth of BARC from a small nucleus to that of an internationally reputed scientific institution has been possible by a large body of dedicated scientists and engineers and supporting personnel. Through concerted efforts made by successive leaders over the years, we today possess know-how in almost all areas of nuclear science and technology, which include the entire gamut of operations relating to the nuclear fuel cycle i.e., prospecting, ore mining, fuel fabrication, reprocessing and waste management, as well as comprehensive capability in design and construction of research reactors of different types, production and applications of radioisotopes for industrial and medical purposes, materials development, electronics & instrumentation and many other uses of atomic energy.

As you all are aware nuclear energy program in India has now reached a level of maturity wherein the country is self sufficient in building nuclear power stations of 700 MWe capacities, and has gained mastery over the entire fuel cycle.

The spin-offs from our activities to the industry and contributions to areas of high societal value go substantially beyond nuclear energy. BARC has been contributing significantly to the industrial sector through the development of technologies for the manufacture of large and precision engineered components made to exceedingly high levels of tolerance and reliability.

Scientific achievements made by BARC are well documented in various publications of this centre as well as of DAE. Glimpses of recent research and development accomplishments is presented in the form of Founder's Day Special Issue, and I wish you an enjoyable reading.

Vivek Bhasin
Director
Bhabha Atomic Research Centre

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Founder's Day 2023 Special Issue

Expanding Physics Research into New and Multidisciplinary Domains

Physics Group, BARC carries out R&D in frontier areas of basic and applied physics domains in line with DAE mandate. The Group has been traditionally contributing to indigenous development of advanced technologies which are relevant to the DAE programs

Dr. S. M. YUSUF
Director
Physics Group
Bhabha Atomic Research Centre (BARC)

The basic research activities of Physics Group encompass condensed matter research; material investigation under different thermodynamic environments, such as temperature, magnetic field and pressure; nuclear physics research; spectroscopic research including cluster physics and nano materials research; and high energy astrophysics research using gamma ray astronomy. Nuclear research reactors, synchrotrons, ion accelerators and lasers are being fruitfully employed to investigate crucial physical phenomena in materials over wide length, energy and time scales.

Major facilities, operated by Physics Group for research in Physical sciences, include the BARC-TIFR Pelletron-Superconducting linear accelerator at TIFR, the National Facility for Neutron Beam Research (NFNBR) at Dhruva, a number of state-of-the-art beam lines at INDUS synchrotrons at RRCAT-Indore, the TeV Atmospheric Cherenkov Telescope with Imaging Camera (TACTIC) at GOALS-Mt. Abu, the MACE telescope at Hanle-Ladakh, fast neutron facilities at PURNIMA-BARC, and the recently commissioned 200 TW (5J, 25fs, 5Hz) Ti-sapphire laser system (λ=800nm) for investigation of novel laser-matter interactions at very high intensities including the studies of physics of laser-shocked samples.

Physics Group also has sustained programs for indigenous development of radiation detectors, sensors, mass spectrometers, leak detectors, magnets, imaging

Photograph of the coffee table booklet on the MACE telescope.

techniques and multilayer-mirrors.

Some of the important ongoing developmental activities are: Indian Scintillator Matrix for Reactor Anti-Neutrinos (ISMRAN), neutron guides, polarizers and supermirrors, Nb-based superconducting RF cavities, high purity Germanium detectors, Single crystal growth of research samples, High intensity D-T neutron generators, 2-D neutron detectors, optical devices and instruments, cryogen-free superconducting magnets, electromagnetic separator for radio-isotopes, nuclear batteries and radioisotope thermal generators (RTG) power source and liquid Hydrogen cold neutron source. Other activities include research & development towards quantum materials and quantum computing.

Major future projects include Neutron beam research at upcoming High Flux Research Reactor (HFRR) at BARC (Facilities) Vizag, Quantum Technology Laboratory in Vizag, Single Crystal Technology centre at BARC-Vizag, Stereo-MACE telescope at Hanle, Upgrade of BARC-TIFR Pelletron Linac facility, ECR based heavy ion accelerator facility at BARC Vizag, Radioactive ion beam program at Trombay & Vizag, and others.

Research & Developmental activities in Physics Group

MACE (Major Atmospheric Cherenkov Experiment) telescope was successfully commissioned at Hanle in the Union Territory of Ladakh. The telescope started its regular science observations for exploring the gamma-ray sky. Multi-layer supermirrors have been developed for X-ray and optical applications, indigenously. For heavy water leak monitoring, a laser spectroscopy based detector is developed in-house and deployed. A 200 TW laser facility has been commissioned for high pressure physics research. The role of nuclear dynamics in fission has been extensively investigated, and neutrino physics research with ISMRAN (Indian Scintillator Matrix for Reactor Antineutrino) at Dhruva reactor is initiated. A spin entanglement study carried out at near room temperature provides understanding of the quantum properties of materials that is useful for quantum technology. National Facility for neutron beam research (NFNBR) at Dhruva reactor, equipped with indigenously developed efficient neutron detectors, is being used for advanced research in condensed matter physics.

High Energy Astrophysics

The MACE telescope is an indigenously developed state-of-the-art instrument for pursuing front line high energy astrophysics research in the country. It was commissioned at Hanle, UT of Ladakh in 2021, after its first light with the detection of very high energy gamma-ray signal from the standard candle Crab Nebula. A coffee table booklet has also been brought out on the successful commissioning of the telescope.

Telegram sent to the international community following the detection of flaring activity from radio galaxy NGC 1275 with MACE telescope.

Visit of international delegates at the MACE Telescope site during May 2023.

MACE is now deployed for its regular science observations. It has detected very high energy gamma-ray signal from the radio galaxy NGC 1275 during its giant flaring activities on the nights of December 21-22, 2022 and January 10-11, 2023. The preliminary results from these observations were promptly communicated to the international community through the standard mode of Astronomer's Telegram. These are the first ever results from the MACE telescope well recognized and cited by the international community.

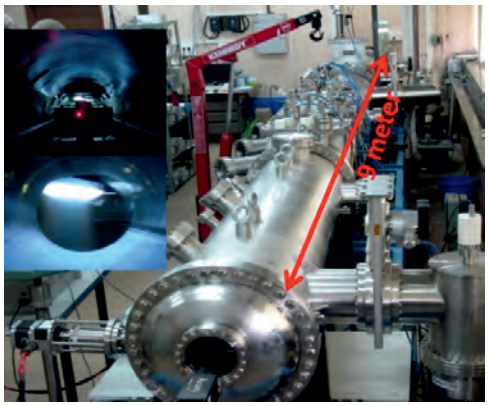
Apart from its scientific importance, the MACE telescope is also catching a significant attention in Astro-tourism of the Ladakh region. As part of activities planned for Azadi Ka Amrit Mahostav, the Indian Council for Cultural Relations (ICCR) organized a visit of young delegates at the MACE site on May 21, 2023. The visit was hosted under Gen-Next Democracy Network Program wherein 28 delegates from various countries like Cape Verde, Cyprus, the Gambia, Malta, Morocco, the Netherlands, Trinidad & Tobago, Tunisia and the UK had participated. The delegates were members of political parties (both ruling and opposition) and entrepreneurs and rising leaders in their respective countries. The visit was aimed at exposing the participants to India's ongoing efforts and experiments in astrophysics and related scientific achievements.

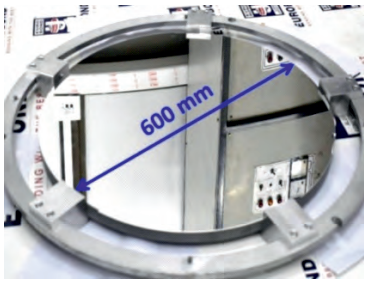
Large Area Mirrors & Supermirrors for Neutron, X-ray and Optical Applications

A 9 m long large area magnetron sputtering coating system has indigenously built, equipped with automated process control software in which uniform deposition of thin films and multilayers on substrates up to 1500 mm x 150 mm size can be carried out. Using this system, 98-layer large area Ni/Ti neutron supermirrors for the upgradation of Dhruva neutron guide tube has been developed and two prototype guide tube elementsof 500 mm and 1000 mm long have been fabricated and tested at Dhruva. More than 150 supermirrors have been fabricated using this system. A Cr/Au grazing incidence X-ray mirrors have also been developed using the system for Indus-1 synchrotron at RRCAT. Utilizing a recently developed thin film coating methodology, large area TACTIC (TeV Atmospheric Cherenkov Telescope with Imaging Camera) gamma ray telescope mirrors have been re-coated. The coating consisting of three layer design (SiO_2/Al/SiO_2) is implemented to achieve a reflectivity of 90 % with a surface roughness of 140nm over these 60 cm diameter concave mirrors.

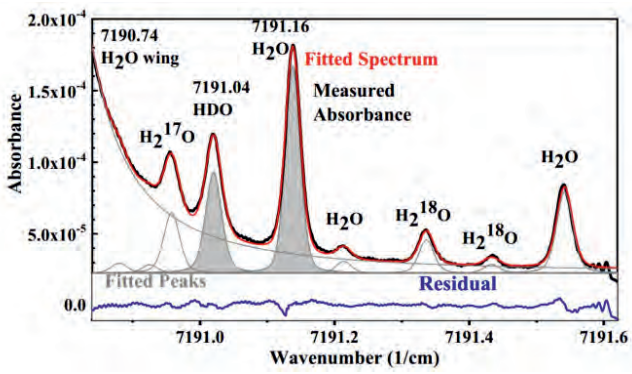
Heavy Water Leak Detection System

Continuous monitoring of heavy water leaks in a pressurised heavy water reactor (PHWR) is important for its economy and safety. A heavy water leak monitor for PHWRs has been developed, indigenously. The trace heavy water monitor is based on Laser Absorption Spectroscopy (LAS) technique, which has the advantages of real time monitoring, freedom from radioactive interference and compact instrumentation over conventional tritium activity monitors. The high

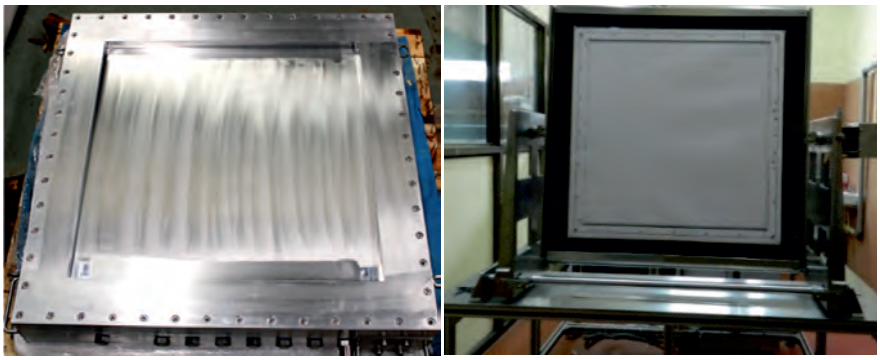




From Left to Right: In-house developed large area magnetron sputtering system, Ni/Ti neutron supermirror for Dhruva guide tube; and Re-coated large area mirror for TACTIC telescope situated at Mount Abu.



Spectrum of the Heavy water and light water absorption lines.



Left to Right: 2-D neutron PSD chamber (650 mm x 650 mm) enclosure; and Automated Grid Winding Machine showing multiwire PCB mounting frame.

sensitivity is achieved by using Cavity Enhanced Absorption Spectroscopy (CEAS) technique. The system measures HDO concentration using its absorption line at 1390 nm with a minimum detection limit of 250 ppbv for HDO concentration in air. The precision of measurement is ±2.4 ppm for real time measurement of D:H isotopic ratio in water content of air. This system is installed in Dhruva reactor for monitoring the loss of heavy water through the stack.

Installation & Commissioning of 200 TW Laser Facility

Petawatt-class of lasers deliver very high peak intensities of the order of 1018-1020 W/cm^2 and have opened up new possibilities in experimental studies of novel laser-matter interaction at very high intensities. During April 2023, installation and commissioning of 200TW (5J, 25fs, 5Hz) Ti-sapphire laser system (λ=800nm) has been completed. Subsequently, laser system has been transported to the target (vacuum) chamber. At present, test experiments such as generation and detection of x-rays, ex-situ studies of the laser-shocked samples are in progress.

Indigenous 2-D position Sensitive Detectors

The 2-D position sensitive detector (2D-PSD) finds extensive applications in imaging and can be deployed for exploring the anisotropic scattering of neutrons by samples. A large area 2D neutron PSD (650 mm × 650 mm) is designed and being developed indigenously. It consists of a ^{3}He gas filled chamber enclosing three orthogonal multiwire grids: Anode, X cathode and Y cathode. An Automated Grid Winding Machine (AWGM), which is used for making the multiwire grid in the detector, is indigenously developed to achieve accuracy in the grid making process. The machine can generate the wire grid with an accuracy of ±25 μm in position alignment and 1μm of wire position read.

Sealed Neutron Generators for Research and Industrial Applications

A portable neutron generator consisting of a DC accelerator-based source involving Deuterium (D)-Tritium (T) fusion reaction that produces 14.1 MeV neutrons is indigenously developed. It comprises of an ion source, compact linear DC accelerator and neutron production target, all placed in proximity with each other. A deuterium gas reservoir releases controlled gas in the ion source to produce D+ ions. These ions are extracted through the aperture in the ion source and accelerated up to 100kV DC before hitting the solid tritium target, producing fusion neutrons. Depending upon the mode of ion source operation, the generator can produce continuous or pulsed neutron beam. This generator has been used to develop a Prompt Fission Neutron (PFN) bore hole logging probe for in-situ uranium ore quantification. Field trials of this probe has also been carried out in a bore hole at Jamshedpur.

Crystal Growth Technology

Keeping in mind the ever-expanding demand for crystal based radiation detectors in homeland security, healthcare, and basic physics experiments, the underlying technology to grow such crystals were transferred to private companies like M/s. ANTS Industries, Thane in 2018 and M/s. ACE EX Industries, Mumbai in 2022. A full crystal growth laboratory was set up at ECIL, Hyderabad with training to their engineers for growing CsI:Tl single crystals of 2 inch diameter and 3 inch length. ECIL started producing and marketing these crystals.

To further facilitate private industries to take up this technology and sustain it in the long run, an incubation program with M/s. ACE EX Industries has been taken up under the BARC-ATAL INCUBATION CENTER initiative.

The CsI:Tl crystals have been further processed and developed to make 1-D pixelated detectors for X-ray Baggage Scanner and 2 dimensional array for gamma camera having application in cancer therapy.

Fifteen NaI:Tl single crystal based detector developed indigenously has been supplied for radiation surveillance at G-20 summit 2023. The 2-inch diameter and 2 inch length NaI:Tl single crystals were grown by the Bridgman technique and processed in the glove box. The detectors thus fabricated were coupled with

Backpack Gamma Spectrometer system. The energy resolution and linearity of these detectors were compared with Amcrys make detectors and found to be exactly similar.

Various oxide scintillator crystals like $YAlO_3$:Ce have also been grown by the Czochralski technique. In an attempt towards 'Atmanirbhar Bharat' the Czochralski crystal growth system has been developed indigenously and this technology has been transferred to Tamil Nadu based M/s. Raana Semiconductors.

Technology Transfer of H_2S and H_2 Gas Sensors

A catalytic type Hydrogen Gas Sensor (Model: TPD-BARC H_2-2021), Technology Code: AI34TPD, suitable for detection in the range from 0.5 to 4 % and a chemi-resistive type Hydrogen Sulfide Sensor (Model: TPD-BARC 1050), Technology code: CH03CHDTPD working in the range 10 to 50 ppm have been successfully developed.

The H_2S sensor technology was transferred to 3 private firms, namely

i. M/s. Hythane Labs, Thane on 20th June, 2023.
ii. M/s. Ants Smart Technologies Pvt. Ltd., on 4th Aug. 2022,
iii. M/s. Precision Instruments & Electronics Pvt. Ltd. Chennai few years ago. The H_2 gas sensor technology has been transferred to 2 private firms, namely

i. M/s. Ants Smart Technologies Pvt. Ltd., on 4th Aug., 2022 and
ii. M/s. Hythane Labs, Thane on 20th June, 2023.

H_2S sensors have found their utility in heavy water plants, sewage treatment plants, oil and gas industry, pulp and paper making industries, chemical industries, chemical laboratories.

Thermoelectric Power Generators

Thermoelectric power generators (TEG) are gaining importance for the conversion of waste heat directly into electricity. In the last two years, our efforts resulted in some significant achievements in the field of thermoelectric, which includes (a) Demonstration high figure-of-merit (~1.2) in bismuth telluride resulting in improvement in efficiency of uni-leg device from 6% to ~ 8%. (b) Since TEG are low voltage high current devices while practical application demand voltage ≥1.5V therefore a self-operable DC-DC booster circuit exhibiting efficiency of 70% and minimum operating voltage of 20mV was developed to boost the voltage of thermoelectric generator. (c) Conducting polymer films were explored for thermoelectric power generation and an air stable n-type conduction with giant Seebeck coefficient −2.7 mVK^{-1} was demonstrated in P3HT films.

Mass Spectrometers and Helium Leak Detectors

Physics group has a robust program for the indigenous developments of Mass Spectrometers and Helium Leak detectors for fulfilling the needs of various units of the Department. Some recent developments includes: (i) Three Hydrogen in Steam Concentration Measurement Systems based on BARC Quadrupole Mass Spectrometer technology, which aredeployed at KAPS & RAPS of NPCIL through ECIL; (ii) Two Helium Leak Detectors (He-MSLD) for corrosive/regular use deployed at ChTD, BARC; (iii) Compact 20cm electro-magnet Thermal Ionization Mass Spectrometers (TIMS): deployed at FRD, BARC and another ready for deployment at FRFCF, Kalpakkam. These will be used for the measurement of precise isotopic concentrations of Uranium and Plutonium; Two

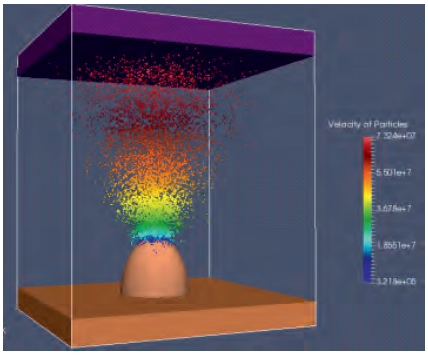
He Leak Detector.

10 cm Li TIMS for AMMD.

10cm permanent magnet based thermal ionisation mass spectrometers for the precise isotope ratio measurement of Lithium for a novel enrichment process, deployed in BARC. A high stability 10W, 20 kV & 30 kV High Voltage modules were developed for mass spectrometers and accelerators.

PASUPAT Software for Electromagnetics with Space Charge Effect

In BARC, there has been a rich tradition of development of indigenous technologies, including development of computational tools for diversified research domains. "Parallel Simulation Utility using Particle-in-Cell Technique" (PASUPAT), is one such tool developed at Physics Group, to support activities



Snapshot of simulation of field emission from a nano-tip.

based on interaction of electromagnetic field and charged particles. These activities include High Power Microwave (HPM) devices, Flash X-ray source, Proton Accelerator, Laser based isotope separation and Ultrashort Intense Laser interaction with matter. Particle-In-Cell (PIC) is a potent tool to model such problems. While major components of PASUPAT were developed in BARC, visualization of data is done using open source VTK library. The code has both electrostatic and electromagnetic solvers to solve Maxwell equation. Many of the libraries/module developed for PASUPAT can be re-used in other applications as well.

PASUPAT has proved to be useful in studies involving space charge limited and space charge affected emission from Pin shaped emitters. Ongoing development work would make this code capable to handle complicated device geometries and it will have a Large Area Field Emitter model based on research carried out in BARC.

Spin Quantum Entanglement Near Room Temperature

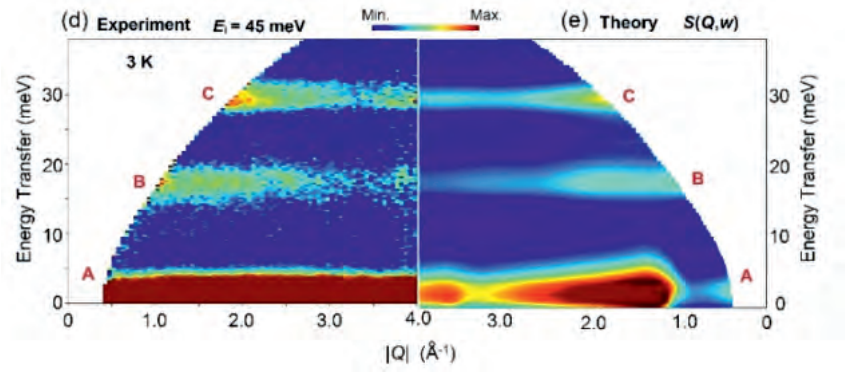
Quantum entanglement has drawn a tremendous attention of researchers for its importance in the upcoming quantum technology. Quantum entanglement phenomenon occurs when a group of quasi-particles interact and share spatial proximity in a way such that the quantum states of each particle of the group cannot be described independently of the states of the other particles. Recent study [A. K. Bera, S. M. Yusuf* et al., Nature Communications 13, 6888(2022)] has demonstrated for the first time the novel quasi-particle excitations of strong spin entangled ground state of a quantum spin-1/2 trimer-chain anti-ferromagnet. Such a model spin-1/2 trimer-chain anti-ferromagnet has been achieved in the compound $Na_2Cu_3Ge_4O_{12}$ where the group of three spin-1/2 of Cu^{+2} are strongly coupled to form a spin-trimer, and such trimers are magnetically weakly coupled to make a spin-chain. The ground state of such a spin-trimer system involves a quantum entangled wave function of two spins (out of the three spins). Most importantly, such entangled spin states are found to be very stable against temperature and persist up to near room temperature (~250 K), which has a special importance for practical device applications in the upcoming quantum technology.

Understanding the Stability of Metaminct Gadolinite

Vitrification is an important scheme of nuclear waste immobilization. For a better understanding of stability, atomic-scale structure and chemistry of (Fe, Y) wastes within glass, XAFS measurement of "metamict" gadolinite mineral is carried outat (Fe, Y) K-edge. It displays structural and chemical stability at high temperature and pressure, unlike reported Fe- and Y-based glasses. This is attributed this superior stability to the advantageous co-existence of (Fe, Y) atoms [vis-à-vis independent Fe and Y atoms] and site heterogeneity. Amorphous structure is found to be better stabilized around Fe than Y. Disparate crystallization rates around (Fe, Y) sites can be utilized for separation and recovery of raw materials from waste. These warrant that (Fe, Y) wastes are compatible with vitrification scheme. The conclusions for (Fe, Y) may be generalized to comprehend the control of generic amorphous structure with co-doping of transition metal and rare earth elements.

Influence of Metal Doping and Strain on Carbon based 2D Materials for Hydrogen Storage

Hydrogen is being considered as a 'fuel of the future,' but the challenge is the efficient and compact storage of hydrogen. The influence of transition metal doping and strain on hydrogen storage is investigated using DFT (Density Functional Theory). For Ti doped, nitrogen-rich BeN_4 monolayer, optimum adsorption energy of -0.36 eV/H_2 with gravimetric wt% as high as 14.21 wt% is observed. It is also observed that at 6 % of bi-axial



Experimental (inelastic neutron scattering) and Theoretical (ED-DMRG) realization of Quantum entangled spin-states in $Na_2Cu_3Ge_4O_{12}$.

Experimental setup established for the study of fast neutron induced fission of actinides at FOTIA, BARC.

compressive strain, a 4 x 4 x 1 supercell of graphene can adsorb 10 H_2 molecules above the graphene surface. The average binding energy of H_2 for this configuration is found to be -0.42 eV/H_2 (-0.11 eV without strain) along with 9.4 wt %, which is very suitable for reversible hydrogen adsorption.

New Insight into Nuclear Fission

Trombay group has a long tradition in nuclear fission research. Many pioneering contributions related to the damping of shell effects and dynamical aspects of nuclear reaction have been made in the past. Recently, low energy fission in pre-actinide region has drawn tremendous theoretical and experimental attention, as it promises to refine the present understanding. In this context, large body of data have been analyzed to develop a consistent prescription for the fission barrier and the nuclear level densities to remove the widespread ambiguities in fission barrier, a key ingredient for all fission studies. Through systematic experimental studies at BARC-TIFR Pelletron–Linac Facility, it was firmly established that nuclear dynamics plays a significant role in driving the asymmetric fission in the pre-actinide region. A striking connection between the pre-actinide and the actinide region has been found, which establishes the general dominance of proton shells in low-energy fission and could steer the strive for a unified theory of fission.

Prompt Gamma & Neutron Emission in Fast Neutron Induced Fission of ^{232}Th

Knowledge of prompt fission gamma spectra (PFGS) and prompt fission neutron spectra (PFNS) for fast neutron induced fission of actinides is essential for the development of GEN-IV fast reactors and Accelerator Driven Systems. While the PFGS play a crucial role for accurately estimating the gamma heating in reactor cores, the PFNS is vital for accurate predictions of nuclear criticality using neutron transport codes and other properties of nuclear systems. Most of the currently available models are data driven and limited experimental information exists on prompt gamma-rays and neutrons emission in the fast neutron induced fission of certain actinides, particularly ^{232}Th. To address these issues, prompt neutron and gamma-ray spectra in the fast neutron induced fission of ^{232}Th have been systematically measured using quasi-monoenergetic neutrons at the FOTIA facility and the results have been published in refereed journals.

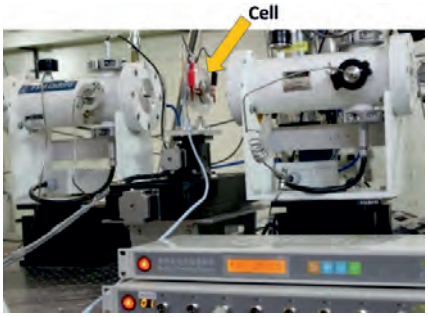
Neutrino Physics with ISMRAN

BARC has a neutrino physics programme, in which measurements of antineutrinos through inverse beta decay process is being carried out at Dhruva reactor. For this purpose, a large plastic scintillator detector ISMRAN (Indian Scintillator Matrix for Reactor Antineutrino) along with shielding was designed, fabricated and subsequently installed inside Dhruva reactor hall. ISMRAN presents the first attempt in the country towards building the capability to perform research in a totally new exciting area of reactor neutrino physics with primary goals of sterile neutrino search and resolution of reactor antineutrino anomaly. ISMRAN has acquired data in the round-the-clock mode since November 2021 and antineutrino like events have been detected. Extraction of the antineutrino energy spectra with more efficient suppression of background is expected.

Utilization of BARC-TIFR Pelletron-Linac Facility

The BARC-TIFR Pelletron-Linac Facility (PLF) consists of a 14UD Pelletron Accelerator and a superconducting Linac booster. The Pelletron

ISMRAN detector setup inside Dhruva Hall.



Cell mounted at the experimental station of BL-09 beamline at Indus-2 at RRCAT.

accelerator has been operational on a round the clock basis since 1988, serving diverse users from within and outside DAE. The accelerator is used for basic research in the fields of nuclear, atomic and condensed matter physics as well as material science. The application areas include accelerator mass spectrometry, production of track-etch membranes, radioisotopes production, radiation damage studies and secondary neutron production for cross section measurements. Experimental campaigns with 9Be beam are conducted at PLF, periodically. Additionally, 48,50Ti beam has been developed and accelerated through Linac. Recently, the facility has been enabled for the usage of radioactive targets (232Th, 235U, 238U, 237Np and 243Am).

In-situ Structural Studies on Electrode Materials of Li-ion batteries with Synchrotron Radiation

An electrochemical cell with kapton X-ray windows is developed in-house for in situ X-ray Absorption Spectroscopy (XAS) and in-situ X-ray diffraction measurements on electrode materials of Li-ion batteries using Indus-2 Synchrotron at RRCAT. The in-situ XAS measurements, on Li-ion batteries with $LiMn_2O_4$ as cathode material, reveal that electronic and structural changes at the Mn sites during the charging/discharging processes are not fully reversible when Li ions are de-intercalated and intercalated, respectively. In situ XAS measurements of the layer-structured lithium cobalt nickel manganese oxides or LNMC has been carried out. The results give useful insights in to the charging/discharging processes in the Li-ion batteries and have been published in reputed journals.

New High Pressure XAFS Facility at Indus-2

The application of (X-ray Absorption Fine Structure) XAFS technique has pervaded several scientific domains (due to unique advantages, vis-à-vis diffraction), necessitating adaptations of instrumentation. Two challenging facilities for XAFS experiments at Indus-2 beamlines viz., (a) Diamond Anvil Cell (DAC)- based High Pressure XAFS (HPXAFS) at BL-8 and (b) Bio-XAFS at BL-9 have been commissioned. A major advantage of XAFS (vis-à-vis crystallography) is its sensitivity to amorphous structure, which permits measurement of biological samples under real in-vivo conditions. BioXAFS experiments are challenged by statistical limitation due to low metal concentration and large disorder, which was overcome at BL-9 with the deployment of 4-element Silicon VORTEX detector and large Kapton sample container.

New Insights into the Anti-malarial Mechanism of Chloroquine

Malaria parasites generate toxic heme during hemoglobin digestion, which is neutralized by crystallizing into inert malarial pigment (ß-hematin or hemozoin). Chloroquine, an antimalarial drug, prevents this detoxification process, resulting in heme-mediated toxicity in malarial parasites. However, the exact working mechanism of chloroquine is unknown.
A study conducted for investigation of the impact of chloroquine on the transformation of heme into malarial pigment showed that the chloroquine does not completely halt the transformation process but rather slows it down. SEM and XRD studies indicate that the size of malarial pigment crystal particles and crystallite increases in the presence of chloroquine, suggesting that chloroquine does not hinder crystal growth. These findings suggest that chloroquine delays malarial pigment production by perturbing the nucleation events of crystals and/or the stability of crystal nuclei. Thus, contrary to existing belief, this study provides a new perspective on the working mechanism of chloroquine (Published in Singh et al., 2023, ACS infectious disease) as leading to crystal-mediated toxicity for Plasmodium.

BARC beamlines at Indus Synchrotron

The BARC synchrotron beamlines at Indus-1 and Indus-2 have been operating round-the-clock for the benefit of scientists and industrial users. In the year 2023, 379 users from various universities & institutes and 12 users from the industry have utilized the beamlines for their research work resulting in a total of 81 research papers in peer reviewed journals.

FOUNDER'S DAY 2023
special issue

R&D in Chemical Sciences for Energy, Environment and Health

Keeping in view sustainable development goals of the nation, Chemistry Group, BARC has taken up fundamental and application-oriented research in frontier areas of chemical sciences relevant to energy, environment and healthcare

Dr. A. K. TYAGI
Director
Chemistry Group
Bhabha Atomic Research Centre (BARC)

Chemistry Group, BARC has made significant contributions towards realising the vision programs of DAE. Some of the key research areas include nuclear materials, novel catalysts and materials for hydrogen technologies, ultrapurification of technologically relevant materials, energy storage materials, healthcare materials, radiation and photochemistry, reactor water chemistry, analytical services and reference materials.

Analytical services for DAE projects and societal applications

Quality analytical services were provided for various important projects of DAE as well as societal applications. Large varieties of materials were analyzed for chemical composition, trace constituent concentrations, surface and thermal properties etc. Suitable analytical techniques were selected based on the analyte, matrix and concentration levels of analytes. Indigenous instruments were also deployed for analytical purposes.

Important materials analyzed include Al/SS materials for new research reactors, Hf metal for reactor, U metal for fuel, high purity Zr, Zr-2.5Nb alloys, In-based solder wires for cryogenic applications, magnet material for Medical Cyclotron-Kolkata, silica based beads for iodine trapping, borated shielding materials, decayed [^{18}F]FTT for radiopharmaceutical program, process samples for Ga recovery /Lu enrichment program, dye effluents from Laser facility, plasma/tissues/bacterial cells for cancer research related

Some of the samples analyzed at ACD.

programs, digested rice/wheat for breeding program, polymeric membranes for desalination program, gas samples for He exploration studies/sludge irradiation, rock material for nuclear waste management, tannery effluents, geological samples from NPCIL Gorakhpur site, Pt/Co CNT based catalysts.

Development of Zirconium diboride in-house Reference Material

Zirconium diboride finds wide applications in nuclear, space and defense sectors. For ensuring material quality, characterization of material is essential. For critical applications, the analytical results need to be validated using Reference Materials. Therefore, a ZrB_2 Reference Material (RM) was prepared in-house for Quality Control of future consignments. For nuclear applications, ZrB_2 should conform to specifications with respect to boron and carbon. Therefore, the in-house developed RM was prepared with boron and carbon as target analytes. Homogeneity and stability studies were carried out. The concentration of boron and carbon along with associated uncertainties were evaluated as (18.5±0.45) % and (420±60) mg kg^{-1} respectively.

Production of Bauxite Certified Reference Material (BARC- B1201)

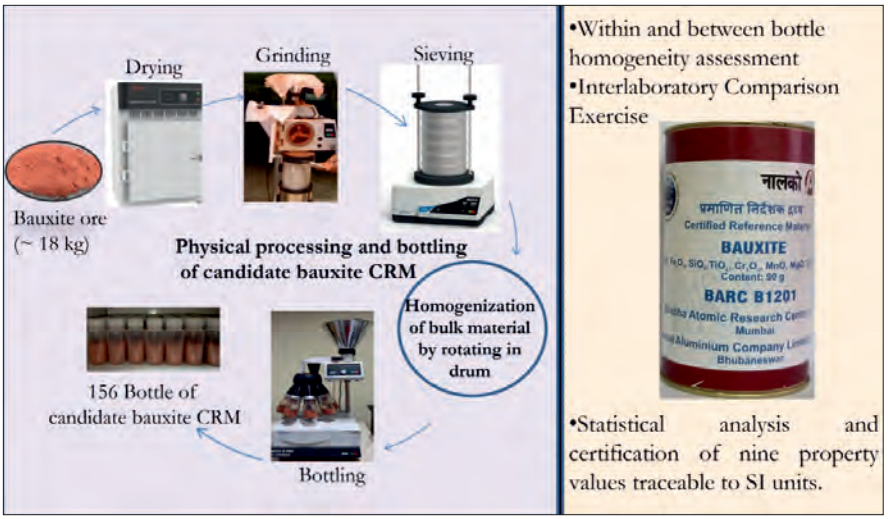
Certified Reference Materials (CRMs) play a key role in the quality control and quality assurance of analytical results. Use of CRM is a mandatory requirement for compliance of quality systems (ISO 9001 2008). The development of CRMs has been a key activity at NCCCM / BARC, Hyderabad – India, ever since its accreditation as CRM as per ISO 17034:2016 by National Accreditation Board for Testing and Calibration Laboratories (NABL), Delhi – India.
Many bauxite CRMs are available internationally. However, while, India is the fifth largest producer of bauxite, there is no Indian origin bauxite CRM, even though compositions of bauxites vary considerably between different geographies. BARC-NCCCM, in collaboration with National Aluminium Company Limited (NALCO), has focused a part of their activity on the production of a certified reference material of bauxite of Indian origin. The CRM developed was certified for nine property values; Al_2O_3, Fe_2O_3, SiO_2, TiO_2, V_2O_5, MnO, Cr2O3, MgO and LOI which are traceable to SI units.

R&D on Nuclear Materials

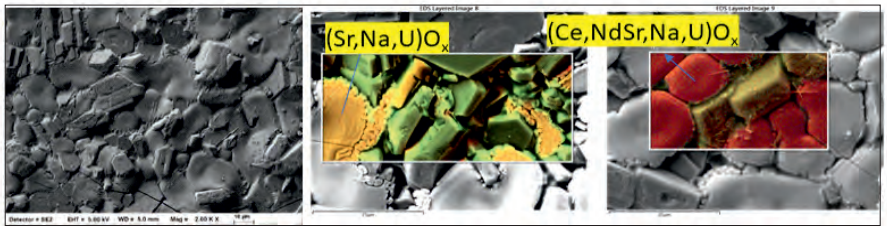
Research activities towards the development of sacrificial core catcher materials have been taken up. Sintering and melting behavior, thermal expansion, heat capacities and thermal conductivities of red-mud, a waste of alumina industry were investigated. A process to prepare useable sacrificial materials from red-mud were obtained. In order to investigate the interaction of red-mud based sacrificial core catcher material with possible elements like U, Sr, Zr, Ce, Nd and Mo of corium, several reactions among them were studied in progressively increasing temperature.

In order to understand the matrices for nuclear waste immobilization research activities on several ceramic and glass compositions have been studied. Redox behavior of UO_2-CeO_2 system and perovskite phases in Ba/SrO-$FeO_{1.5}$-$UO_{2.66}$ system have been studied. Thermal stabilities of rare-earth containing titanosilicate, like $Ln_2Ti_2SiO_9$ and perovskite related $Ba_6Ln_2Fe_4O_{15}$ (Ln = Nd and Pr) have also been studied. Activities towards the

Zirconium boride reference material.



Flow chart of the processes involved in development of Bauxite CRM.



SEM and EDS images of the interaction product of red-mud bricks and elements of corium.

determination of solubility limits and stabilities of various elements in Iron Phosphate Glass (IPG) have been taken up. Thermal stability IPG samples containing F^- ion along with Na, Ca and Ln (Ln = Nd^{3+}, Ce^{3+} and Sm^{3+}) have been studied by thermal analysis, Raman and FTIR techniques. Reliable database on high temperature thermophysical properties of a variety of nuclear fuels and related materials have been generated for various end-users for fuel cycle development purpose. These include multi-phase fuel alloys, fluoride salts for MSBR program, Zr-Fe alloys for hull management program and oxide-based inert matrix fuel hosts.

Polycrystalline diamond film-based alpha particle detectors were indigenously developed and tested for their application under air and corrosive liquid environment. Highly stable detectors with negligible self-polarization effect were successfully tested for gross actinide counting in air medium.

Porous metal organic frameworks (MOFs) were synthesized by the reaction of Al^{3+} with 4,4-oxybisdibenzoic acid (CAU-21-ODB) and Cr^{3+} with 1,4-dibenzoic acid under solvothermal condition for trapping of radioactive iodine.

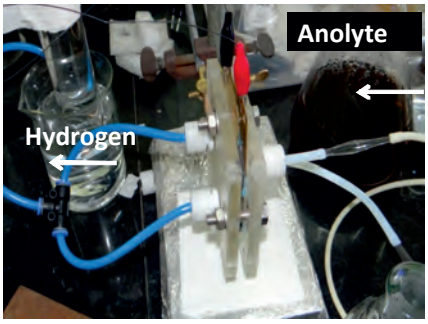
Hydrogen Production and Storage

Research activities are undertaken in Chemistry Division pertaining to four-step Cu-Cl process. The development of electrocatalyst, membrane electrode assembly (MEA), electrocatalyst, synthesis of phase pure Cu_2OCl_2 and its decomposition, development of spray and fixed bed reactor for $CuCl_2$ hydrolysis to study the reaction kinetics and mechanistic aspects of hydrolysis step are some of the major findings. A membrane electrode assembly (MEA) of active area 25 cm^2 was prepared in Chemistry Division using the Pt/C electrocatalyst and commercial proton exchange membrane. The MEA was employed in the CuCl/HCl electrolyser of the integrated closed loop operation of Cu-Cl thermochemical cycle in Chemical Engineering Division. A continuous H_2 evolution rate of 5 NLPH could be obtained for 40 h of operation.

Healthcare Materials

Polyphosphate grafted Fe_3O_4 nanomagnets (PPNMs) were developed for efficient delivery of anticancer drug gemcitabine hydrochloride (GEM). These nanocarriers are highly dispersible in physiological medium and possess sufficient surface charge (-25 mV) for electrostatic binding of positively charged GEM. The GEM loaded PPNMs (GEM-PPNMs) exhibited pH triggered release of the loaded drug, substantial cellular uptake, and higher toxicity towards human lung cancer (A549) and breast cancer (MCF-7) cell lines over pure drug. Further, the biodistribution of these nanocarriers was assessed by their tracking in a mouse model through radiolabeling with ^{64}Cu and ^{177}Lu. Though the radiolabeled system exhibited higher uptake in the liver and the spleen upon intravenous injection, a substantial uptake of the same was also found in the tumor.

Lanreotide peptide (LP), a somatostatin analogue having high affinity towards somatostatin receptor 2 (SSTR2) is widely explored for inhibiting neuroendocrine tumor growth. The potential of LP as a targeting moiety to promote selective uptake of gold nanoparticles (GNP) in SSTR2 expressing cancer cells has been explored. The cell viability and colony formation assay have demonstrated enhancement in radiosensitization of AR42J cells treated with GNP-LP and exposed to gamma-ray irradiation. Furthermore, the generation of elevated reactive oxygen species and correspondingly accelerated apoptosis of cells was observed



In-house developed membrane electrode assembly.

in AR42J cells treated with GNP-LP under gamma-ray irradiation.

Monodispersed core@shell-Fe_2O_3@Mn_xO_y nanoparticles have been prepared through thermolysis of iron and manganese oleate. Further, these prepared nanoparticles are coated with biocompatible substances such as silica and polyethylene glycol. In order to make them potential candidates for targeting to cancer cells, folic acid (FA) is tagged to the nanoparticles. Fluorescein isothiocyanate (FITC) is also tagged onto these nanoparticles for imaging. The developed - Fe_2O_3@Mn_xO_y@SiO_2 nanoparticle can act as single entity for therapy through AC magnetic field, imaging through FITC and targeting through folic acid simultaneously.

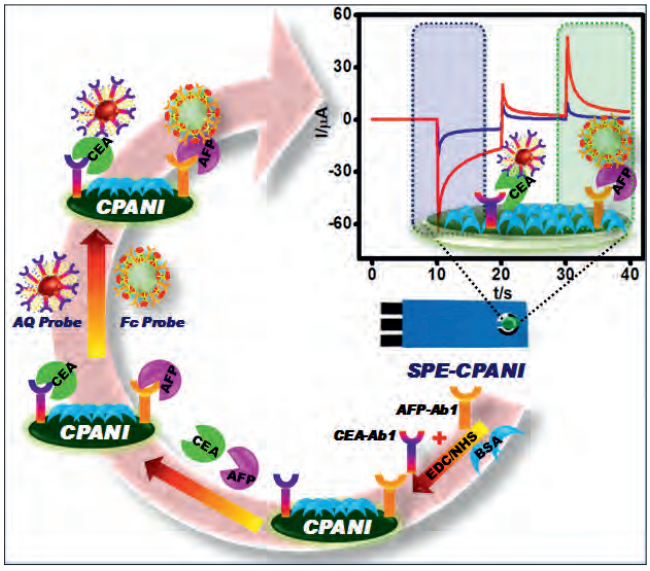
Simultaneous detection of multiple biomarkers can improve the accuracy of cancer diagnosis. An electrochemical sensor was developed for simultaneous determination of two cancer biomarkers, α-fetoprotein (AFP) and carcinoembryonic antigen (CEA), which are important markers for liver, gastric and lung cancer. Bio-functionalized nanoparticles grafted with redox tags were used as the detection probes which produced amperometric signal for the sandwich immunoassay. The sensor displayed wide linear range with detection limit 80 pg/ml for CEA and 30 pg/ml for AFP that are potentially suitable for point-of-care detection.

Radiation Chemistry Research

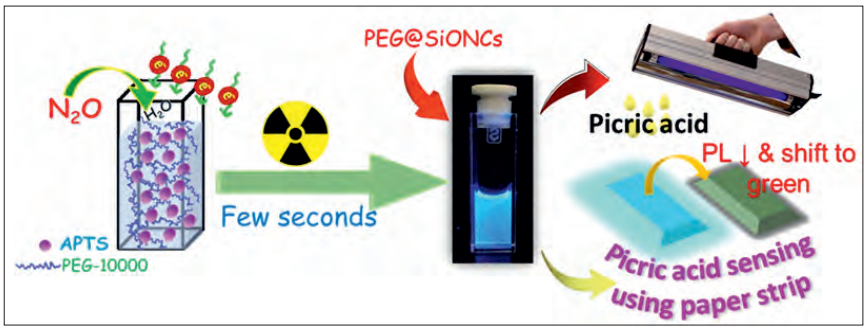
Chemistry Group is one of the leading groups in DAE wherein the effect of the radiation on different chemical systems, that are being used or planned to be used in Indian reactors, is being investigated to produce crucial data. The data could be useful in the present reactors as well as in planning the operation of future nuclear reactors. A unique high-temperature high-pressure experimental setup was developed to study the effect of radiation in different systems under extreme physicochemical conditions. Radiation is also being used judiciously for the synthesis of nanomaterials and polymers, which have wide applications in different sectors like energy, health, security, etc. For example, nanoparticles prepared by radiation route showed potential for detection of explosive picric acid, anticancer activity, supercapacitor, etc. Several radiation-mediated polymers have been synthesized for the fabrication of nuclear-grade detectors. Polymers produced through the radiation route were used successfully for the separation of gallium from Bayer's liquor, removal of cesium ions from nuclear waste and E. coli from water. Dose-dependent radiation-induced degradation of paints used in nuclear reactors identified several volatile organic products and their effect on the degradation of reactor structural materials.
New organo-selenium compounds were developed for radioprotection and chemotherapy applications. The manufacturing and accelerated stability testing of clinical grade capsule formulation of DSePA was completed, and approval from the institutional ethical committee of TMC was obtained for its clinical trial. Further, radioprotective activity in normal lung cells by deuterated DSePA (D-DSePA) was demonstrated. Diselenide grafted gelatin polymers (G-Se-Se-G) were developed for a wide range of applications, including wound healing, radiosensitization, drug delivery, etc.

Photochemical Research

Our expertise in supramolecular chemistry leads to the development of several fluorescence-based sensors for biologically relevant molecules, including acetylcholine



Biosensor construction for simultaneous detection of multiple cancer biomarker.



Radiolytically synthesized PEGylated silicon oxide nanocomposites (SiONCs) showed highly sensitive detection of picric acid.

(a neurotransmitter), RNA originating from lung cancer cells, neurotoxic amyloid fibrils, serotonin (a stress regulating hormone), creatinine (a kidney disease marker), etc. For security applications, several optical sensors were developed for the detection of explosive nitroaromatic molecules. Sensors for the detection of adulterants used in food technology, the cosmetic industry, and heavy metals (chromium, copper, uranyl, thorium, etc.) are also being developed.

Supramolecule assisted modulation in physicochemical properties was used for development of materials for green LED with superior optical properties, improving the antibacterial activity of ofloxacin drug and gold nanocomposites, synthesis of supramolecular polymer, stabilization of radical ions in aqueous solution, etc.

A metal-free supramolecular approach was adopted for the generation of hydrogen from ammonia borane with the potential for a sustainable "on-board" energy source. Cucurbituril-functionalized Co:Ni nanocomposite and aluminium nanoparticles and several electrocatalysts were developed to generate green hydrogen.

Efforts are being made to understand the effects of several environmentally hazardous compounds, like fluoroalkanes, epichlorohydrin, dioxolanes, methyl cyclopentene, etc. in our environment. An image analysis program was developed for the in-situ characterization of physical properties of aerosol particles during their hygroscopic growth. An experimental setup was fabricated to study gas uptake by aerosols. Mixed organic-inorganic aerosols, iodide, and iodate aerosols were characterized using such a facility.

Interface, a part of our daily life, behaves differently compared to the corresponding bulk phase. Using an indigenously developed state-of-the-art sum-frequency generation (SFG) spectrometer effect of additives (polymer, ions, etc.) on the nature of interfacial water molecules was investigated to gain knowledge on the interfacial interaction at the molecular level.

The development of state-of-the-art spectroscopic instruments is one of the major strengths of the Radiation & Photochemistry Division, Chemistry Group. A super-resolution orientation imaging facility with improved resolution (20 nm and 0.4 sr), which was developed for the first time in India, was used to image the orientation of fluorophores attached to amyloid fibrils. A femtosecond laser-based optical setup for in-situ generation of ultrashort electron pulse (~1 ps) was developed to study the effect of low energy (eV) radiation at an ultrafast time scale.

Ultrafast time-resolved spectroscopy was employed to provide mechanistic insights into the charge carrier dynamics in photovoltaic materials like organic singlet fission materials, Perovskites ($CsPbBr_3$, $CsPbCl_3$, Ni-doped α-$CsPbI_3$/WS_2 composites), photocatalyst for green hydrogen generation and reduction of CO_2 to valuable chemicals. Indigenously developed two-dimensional IR (2DIR) spectrometer was used to understand the transport mechanism in electrolytes for Zn^{2+} ion battery.

Reactor Water Chemistry

Water and Steam Chemistry Division (WSCD) has been instrumental in devising indigenous decontamination formulations and methodologies for safe and effective removal of radioactive metal oxide deposits from the coolant surfaces of operating nuclear power plants. Such decontamination campaigns help in reducing the man-rem during regular maintenance activities. As part of this, WSCD is constantly evolving new decontamination procedures. Recently, a new chemical formulation based on "ozone coupled permanganate" was developed and was tested on stainless steel surfaces – which showed promising results in reducing the total radioactive waste volume generation by

Plastic thin film detectors for real-time tritium detection.

The hgSBR plant installed at Kalpakkam township.

chemical decontamination and maintaining the corrosion oxide dissolution efficiency. As part of the broader objective of safe removal of radioactive metal ions, R&D activities were taken up for the design and synthesis of metal ion receptors that can safely immobilise the removed active metal ions – both during decontamination and back-end operations. For achieving this, an effective sorbent capable of removing radioactive antimony from highly acidic matrix was prepared using locally procured biomaterial chitosan and titanium dioxide. The viability of the sorbent material for the targeted application was demonstrated under flow conditions. Scaled up process for synthesis of the sorbent and its application was demonstrated as well. The developed sorbent had been effective in removing active isotopes of antimony during both decontamination and treatment of high level waste generated during reprocessing.

Biofouling and Biological Wastewater Treatment

R&D activities in Biofouling were focused towards understanding and mitigation of biofilm and macrofouling-related issues encountered during nuclear power plant operations, heavy water plants and allied units. Effect of continuous chlorination at cellular, biochemical and genetic level was determined on green mussels, dominant biofouling organism at Madras Atomic Power Station.

Alkylimidazolium ionic liquids have been found to be effective in preventing polymicrobial biofilms in freshwater and seawaters. These compounds were very effective in disinfecting the surfaces from diverse settings, suggesting their potential use in hygiene applications. The selected alkylimidazolium compounds have exhibited a strong anti-settlement activity on barnacle larvae at sub-lethal concentrations thereby suggesting their potential use in the development of sustainable biofouling control methods. The diversity of bacteriophages was determined in the seawater samples collected from the different sections of MAPS seawater cooling system. As a proof of concept, bacteriophages were isolated from different environmental settings and demonstrated their efficacy in preventing growth and biofilm formation by several bacterial strains. A nitric oxide-based wound dressing unit developed for advanced wound care in diabetic patients has entered into phase III clinical trials.

Biofilm-biotechnologies is an attractive-cum-efficient option for removing of contaminants and for achieving sustainable wastewater treatment. A novel biological treatment based on bio-beads (particulate biofilms/biogranules) was developed for bioremediation and wastewater treatment. A patent had been granted for this latest innovation. The bio-beads based biological treatment process often referred to as hybrid granular sequencing batch reactor (hgSBR) had been tested under different conditions. A total of 24 private companies, including M/s. Larsen and Toubro Construction Ltd., and M/s. Thermax Ltd., have inked an agreement with BARC for deployment of hgSBR technology for treating of wastewater. Some of the hgSBR technology licensees have already installed and commissioned sewage treatment plants with capacities of 50 m^3/d, 150 m^3/d and 600 m^3/d at Shirdi, Surat and Tiruchirapalli, respectively for treating of municipal wastewater. Extensive research revealed that bio-bead microbes are robust and can tolerate toxic pollutants and changes in the process and environmental conditions. Microbial bio-beads capable of removing BOD, COD, ammonium and phosphorus were cultivated from brackish water microbiome for saline wastewater treatment. To further improve environmental sustainability, green-colored bio-beads were developed by integrating phototrophic organisms (cyanobacteria and microalgae) and heterotrophic bacteria under saline conditions.

The work on installation of 1.5 MLD hgSBR based sewage treatment plant (STP) has been completed at DAE township, Kalpakkam. All civil, mechanical, electrical and Instrumentation engineering works were completed. The automation program for PLC and SCADA was also completed. The cold commissioning of all systems in the plant was completed using clean raw water.

Development of Advanced Materials for Holistic Growth of DAE Programs

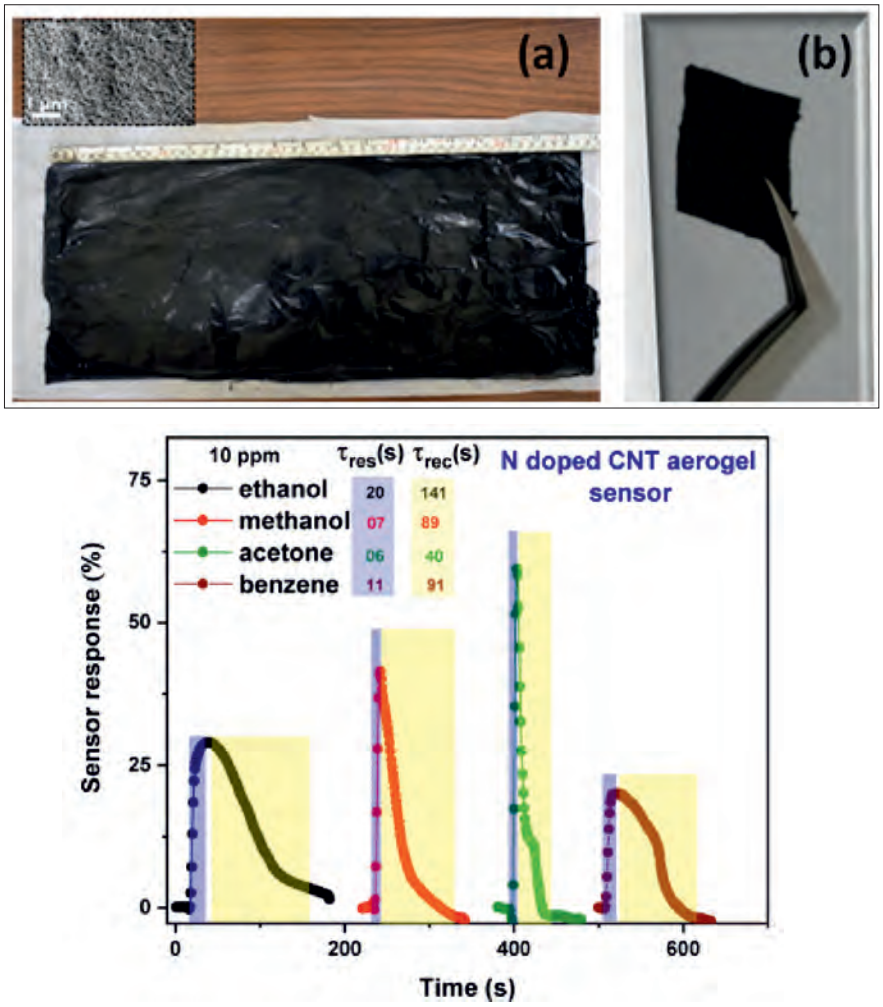
Development of cost effective techniques for producing advanced novel materials for nuclear and specialised applications through in-house efforts

Dr. R. TEWARI
Associate Director
Materials Group
Bhabha Atomic Research Centre (BARC)

Materials Group, BARC is mainly involved in the development of various materials required in the different DAE programs. A glimpse of some of the achievements is briefly presented here.

High-strength Carbide-free Low-carbon Nano-bainitic steel - A Potential Candidate for RPV Material

New generation bainitic steels, which have nanostructured carbide-free grains, show considerable promise in many engineering applications owing to their high tensile strength (~ 2.5 GPa) combined with high toughness (KIC~ 35 Mpa $m^{1/2}$). The strength of the new steel is nearly 1.5 to 2 times higher than the conventional steels. Such high strength steels would not only lower the thickness of the vessel, but would also considerably reduce the variation in the properties across the thickness. In contrast to conventional bainitic microstructure, these steels suppress the formation of detrimental carbides responsible for bringing down the toughness of the steel. In carbide-free nano-bainitic steel, finer bainitic ferrite plates (< 100 nm) increase the strength and hardening capability. Keeping the aforementioned benefits in view, a new class of carbide-free nano-bainitic steel with low carbon (~ 0.25 wt.%) has been designed, and the development of nano-bainitic microstructure in this steel through isothermal heat treatments has been achieved. The yield strength of the steel was 700-800 MPa, ductility 18% and tensile strength 1.5 GPa. The phase transformation domain, in terms of cooling



CNT sheet deployed as CNT chip bio sensor.

rates and heat-treatment temperatures, could be established to obtain a carbide-free nano-bainitic microstructure. Using combinatorial experimental techniques, such as dilatometry and electron microscopy, and calculations using thermodynamic packages, the critical cooling rate for formation of bainitic microstructure was determined. Cooling the steel at 3°C/s after austenitization followed by isothermal holding between 340°C and 460°C have been identified as the heat treatment parameters to obtain a nano-bainitic microstructure.

Development of Carbon Nanotube Sheet for Sensor Application

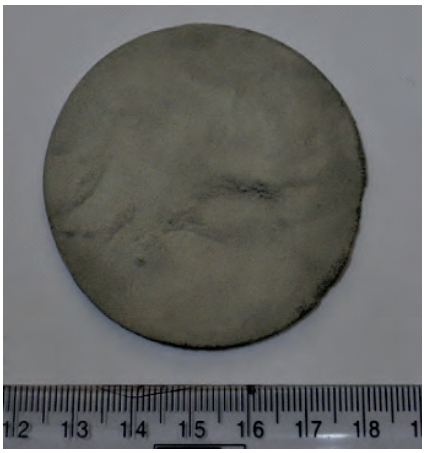
Carbon nanotubes (CNT) have several important applications, including as a sensor material. CNTs have very large surface areas which make them ideal for sensing applications as very low concentration of elements or compounds can be selectively detected. For this purpose, CNT sheet of dimension 48 cm x 18 cm with controlled orientation, was produced in a reproducible manner. The bio sensor chip fabricated from these CNT sheets showed capability of detecting DNA hybridization within 18 minutes with detection limit of 1pM. The N doped CNT sensor showed capability of selective detection of volatile organic compounds (VOCs, viz., ethanol, methanol, acetone and benzene) in ppb range.

Preparation of Aviation grade Ti Sponge with Enhanced Yield using Indigenous $TiCl_4$

Extraction of Ti using Kroll Process was established in BARC in 1970s and the associated technology was transferred to NFC, Hyderabad, a constituent unit of DAE. From NFC, the technology was further transferred to leading defense research body DMRL and subsequently to KMML. The current Indian industrial practice of Kroll process yields about 40% aviation grade Ti sponge. This poor yield results in the unavailability of aviation grade Ti for strategic applications despite a large installed capacity. This led the BARC Materials Group to develop a modified technology for production of aviation grade Ti with high throughput. Using this modified technology, aviation grade Ti sponge in the batch size of 0.5 kg has been successfully produced in reproducible manner. For this purpose, $TiCl_4$ (99.95%) purity from indigenous source was used and detailed thermodynamic calculations were carried out, wherein the possible interactions of $TiCl_4$ with crucible materials were factored in, and the possible pathways of impurity (Fe, Cr, Ni) ingress were identified. The setup was designed to maximize the reaction rate besides avoiding unnecessary reactions of remaining $TiCl_4$ with crucible materials. The yield of the Ti sponge was also consistent and reproducible. Currently, attempts are being made to scale up the product.

Development of Porous Nickel Electrode by Powder Metallurgy Route

Porous nickel electrodes are used to split water into hydrogen and oxygen through water electrolysis. The porosity in the electrode is required to improve the efficiency of the reaction. However, fabricating a porous material of desirable shape, microstructure and strength is a challenge. These problems are circumvented by using a mesh coated with Ni



Sintered porous Ni Body.

paste. A major problem in this approach is in controlling the por size.

In order to address the aforementioned issue a new approach for producing nickel electrode with tailored microstructure (porosity, pore size and its distribution etc.) by powder metallurgy technique has been taken up. The proposed size of the electrode of 50 mm diameter or above with 1 mm height with 50% porosity is challenging owing to its fragile nature and warping during its densification. These problems were solved by carrying out detailed set of experiments to optimize the composition of the initial raw material (NiO+C+Binder) and by standardizing the densification schedule. The measured porosity in the sample was in the range of 50-52% with its average size of around 25 µm.

Recycling E-waste for Rare Earth Elements

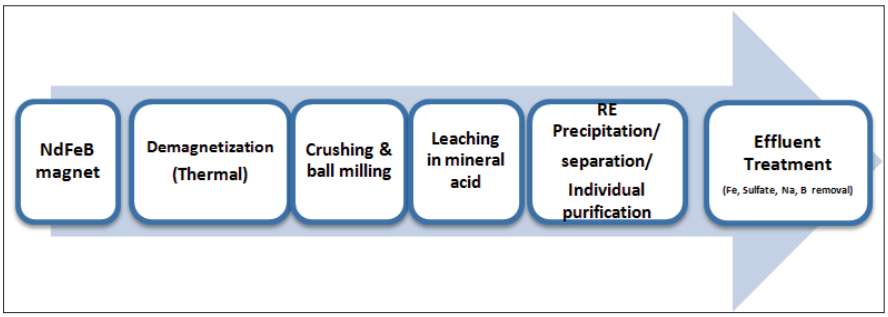
Rare earths (REs) are a key ingredient for renewable energy technologies needed to achieve low-or-zero-carbon footprint. Separation of critical rare earths needed for energy sector from Indian primary source of monazite is challenging and tedious due to their low concentration in mineral and its association with radioactive contamination. On the contrary, e-waste, rich in energy critical rare earths (permanent magnets, fluorescent lamps, batteries, and catalysts scrapes) offer a great potential for its recovery with minimum impact on the environment. In India, where significant quantities of electronic appliances, including RE phosphor-based energy saving lighting devices are discarded each year, accounts for roughly thousands of tons of these critical metals, which offer an opportunity to recycle REEs, securing a stable supply and reducing reliance on primary resources. Materials Group, BARC has developed scalable technologies with easily manageable effluents for the recycling of energy critical rare earths, namely Nd, Pr, Dy, Eu, Y & Tb from discarded computer hard disk drives (NdFeB magnet) and compact fluorescent lamps.

Technology Transfer- Recovery of Rare Earth Values from Computer Hard Disk Drives and Magnetic Scrap

BARC has developed an integrated hydrometallurgical process for recovering rare earth elements like neodymium (Nd), praseodymium (Pr), and dysprosium (Dy) from scrap HDDs and magnetic scrap, especially NdFeB magnets. The process encompasses various steps, including dismantling, demagnetization, pulverization, leaching, precipitation, and extraction. Notably, the developed technology resulted in recovering REEs with over 99% purity and more than 95% material recovery. The technology has been transferred to the Indian Rare Earths Limited (IREL) for demonstration in their Theme Park in Bhopal, garnering interest from major recyclers from India.

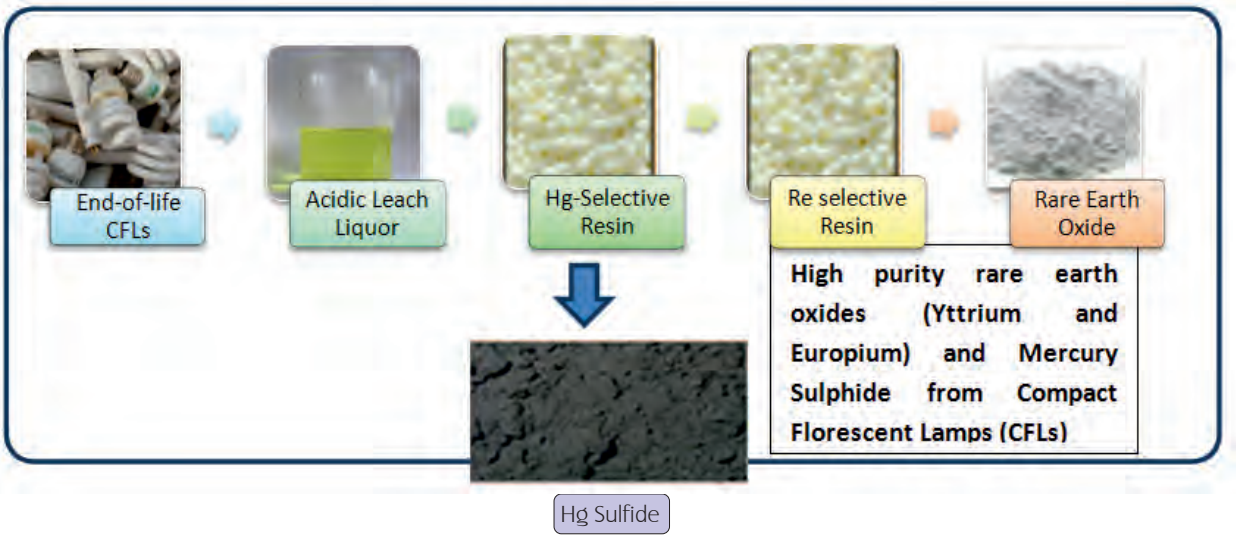
Technology Transfer - Removal of Mercury and Recovery of Rare Earths (Y, Eu) from End-of-Life Compact Fluorescent Lamps

The success of India's UJALA initiative (promoting use of LEDs) has led to a mass phase-out of CFLs, which constitute a significant part of e-waste. CFLs contain substantial amounts of rare earths, such as yttrium (Y) and europium (Eu), but they also contain toxic heavy metals like mercury, which needs to be separated. A process has been developed for the scaled-up production of high-purity rare



Magnetic scrap processing scheme.

HDD NdFeB magnets | NdFeB alloy powder | Nd-Pr oxide product



earth oxides (Y, Eu) while completely removing mercury from end-of-life CFLs. This process involves several steps, including crushing and segregation of CFLs, acid leaching, and mercury removal from the leach liquor, selective RE sorption/desorption using unique metal-selective polymeric resins (Thioglycolamide and BiPyridyl Diamide), precipitation, and filtration. The technology ensures zero-mercury discharge into the environment.

The advantages of this process include direct production of high-purity RE oxides from CFLs, effectively handling toxic mercury, scalability of unit operations with readily available equipment, and adaptability for various RE-bearing phosphor sources. This technology not only provides environmental benefits but also significant financial gains from rare earth recovery.

Fundamental Research and Application of Nuclear Radiations in Frontier Areas of Life Sciences

Basic research oriented towards understanding and developing cutting edge technologies in the field of nuclear sciences for food security, agriculture and health.

Dr. TAPAN K. GHANTY
Director
Bio-Science Group
Bhabha Atomic Research Centre (BARC)

The mission of Bio-Science Group in BARC is to enhance the understanding of the genetic, molecular and cellular responses to nuclear radiation using different life forms as model systems, and the use of innovative science generated therein for the development of cutting edge technologies and products for societal benefits. Some of the key achievements of of the Group are outlined here.

Applied Genomics

Research and development activities in applied genomics are focused on certain key areas of biological sciences with an emphasis on molecular biology and genomic approaches. The fundamental knowledge generated has also been utilized for development of technologies for bio-medical applications. One area of research has been on DNA damage repair and its implications in development of cancer. Impaired capacity to repair DNA double-strand breaks (DSBs) have been implicated in cancer development and lethality. Cells have mechanisms such as such as homologous recombination (HR) to repair DSBs. The interaction between BRCA2 and DSS1 is essential for RAD51 recruitment and repair of DSBs by HR. In one of our significant findings, published in Nature communication, it was demonstrated that the BRCA2-DSS1 complex is dispensable for RAD51 loading when the homologous DNA is close to the DSB. This work sheds light on the mechanistic aspect of DNA repair. Another investigation showed a supramolecular dye-host assembly, forming through non-covalent interaction between a cationic dye, quinaldine red (QR), and

polyanionic amphiphilic polymer, polystyrene sulfonate (PSS) has been demonstrated as an efficient fluorescence turn-on probe for sensing protamine (Pr). This allows estimation of protamine concentration very effectively, with limit of detection as low as ~14.8 nM in buffer solution and ~0.18 µMin 1% human serum sample. Since protamine is often administered as an antidote to unwarranted heparin in the patient blood, particularly after cardiac surgery, the ability to quantify protamine concentration in serum assumes importance.
A focus area has been on establishment of CRISPR technology in BARC and its in-house development for different applications in various model systems. High efficiency CRISPR based tools have been developed for programmable gene silencing.

Further, this expertise has been extended to develop methods for rapid and highly specific detection of viral diseases such as COVID-19. In a recent study, a diagnostic method capable of detecting monkeypox at single copy level has been demonstrated as a highly sensitive method. Approaches such as these can be integral to the preparedness of future health emergencies resulting from pathogen outbreak(s). Extending these studies, Rag1 knock-out mice have been generated under an MoU with IISER, Pune. Genome-edited mice are important for study of diseases and development of drugs.

A compact ultraportable integrated device called BARC-CRISPR-CUBE developed (in collaboration with EmA&ID) during the above activities, along with the detection technology has been transferred to two biomedical industry partners. Additionally, an in-house developed technology for gene silencing in bacteria has been transferred to biotech industry.

Nuclear Medicines
DAE is at the forefront of R&D and production of a variety of radiopharmaceuticals for supply to hospitals and nuclear medicine centres across the country, rendering the treatment in an affordable manner. Although the radiation sources, especially radioisotopes, are produced in-house in reactors and cyclotrons, the cost of the treatment is majorly dented by the import cost of the "targeting ligands". Of late, Bio-Organic Division (BOD) has been working relentlessly to indigenise the synthesis and development of radiopharmaceutical ligands, thus playing a major role in making the treatment cost-effective. BOD has already been successful in the synthesis and regular supply of ligands e.g. Cu[MIBI]4BF4, PSMA-617, PSMA-11 which have been successfully radiolabelled, RPC approved, and commercialized through BRIT for use in radiopharmaceutical centres across several nuclear medicine centres in India.

Active Pharmaceutical Ingredients (API)
Recently, the synthesis of o-Tolylbenzonitrile (OTBN), one of the most imported (approx. 2000 MT worth Rs. 500 crore per annum) drug intermediate for synthesis of anti-hypertensive drugs has been accomplished, and the technology has been transferred to multiple private entrepreneurs for bulk production.

Cancer Biology
Recent research is mainly focused on understanding the role of DNA DSB repair proteins in genomic stability, chemo-resistance and radio-resistance in cancer. Beside overexpression, most of the tumors are known to harbour mutations affecting a specific DNA repair pathway, which may result in hyper-dependence on a compensatory DNA repair pathway. These observations suggest that DNA repair-deficient tumors should exhibit heightened radio/ chemo-sensitivity if compensatory repair pathway is targeted. Hence, identification of defective DNA repair processes is warranted for pharmacological targeting of cancers for better clinical outcome. In this regard, our findings unravelled the role of RECQL helicase proteins like WRN and RECQL5 in DNA repair and their implications in radio-resistance and chemo-resistance in several preclinical knockout/ knockdown tumour models. Besides, several novel modulators are designed, synthesized and developed for targeting autophagy, TOP1, PARP1 etc for effective sensitization of cancer.

Functional Organic Materials
BARC has a strong mandate to use the expertise in synthesis of small functional organic molecules and material chemistry to produce several deliverables of departmental relevance and societal benefits. For this extensive work has been done to develop Boradipyrromethene (BODIPY), Diketopyrrolopyrrole (DPP) and Indolocarbazole (ICZ) based functional molecules, in the area of dosimetry, laser dyes, targeted photodynamic therapy, bio-sensors, organo-electronic applications etc.

Of late, a photodynamic dye was synthesized efficiently target endoplasmic reticulum and kill pancreatic cancers. A new class of dual state emissive dyes has been designed and fabricated supramolecular assembly on a silicon wafer with negative differential resistance (NDR) property of high peak-to-valley ratio (1000). Such a BODIPY-

based NDR system with potential application in molecular electronics is developed for the first time.

Food Technologies

BARC is engaged in R&D work in Radiation Processing of food to ensure food security, safety and trade promotion. An SOP was developed for sea-route shipment of radiation processed mangoes from India to USA and evaluated at commercial scale.

Molecular Biology

In Molecular Biology domain, research work is aimed at understanding the molecular mechanisms underlying stress response in biological systems and utilise the knowledge for biotechnological applications. Work has also been initiated on developing blood-based markers for neuroendocrine tumours (NET). Interactions between several uncharacterised DNA repair proteins, their regulation through DNA secondary structures and DNA binding regulators and kinases were shown to contribute to radioresistance of Deinococcus and Nostoc. 2-Cys-Prx protein of Nostoc was found to be primarily responsible for redox maintenance, while the nucleoside kinase TMK also regulated photosynthetic efficiency. Enhanced expression and export of exopolysaccharide (EPS) by ExoD overexpression in Nostoc resulted in higher metal tolerance. One of its metallothienin genes, NmtA was shown to be negatively regulated by AzuR. The irradiance shown by uranium tolerant bacterium Chryseobacteriumculicis strain PMSZPI was shown to be linked to its gliding motility.

Genomic duplication events were shown to contribute to divergence in rice and Arabidopsis. Cross-talk between epigenetics, alternative splicing, DNA damage and radiation resistance was shown in cancer cells. A novel highly sensitive RNA: DNA hybrid immunocapture based lateral flow assay (RDH-LFA) with 'Limit of detection' of 10 copies/ µl for visual detection of viral RNA was established. A 35-gene diagnostic signature for blood based markers for detection of neuroendocrine tumours (NET).

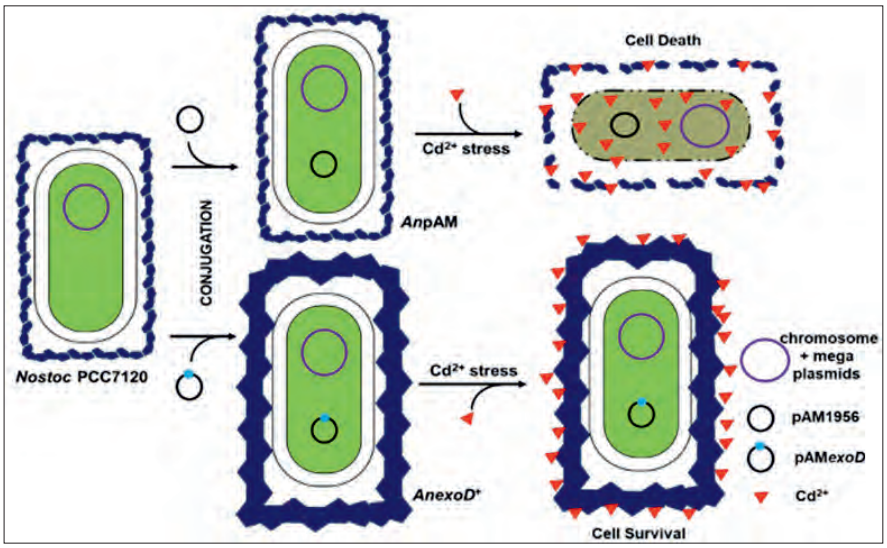
Nuclear Agriculture & Biotechnology

R&D in Nuclear Agriculture and Biotechnology covers research program in crop improvement and crop production/protection technologies under the non-power applications of atomic energy. The active collaborative pursuit of BARC with the Indian Council of Agricultural Research and various State Agricultural Universities has fructified in the release of several improved crop varieties and spin-off technologies in crop production and crop protection. The effective blend of mutation and recombination breeding at BARC has resulted in the release of 62 crop varieties for commercial cultivation across the country in 12 different crops (groundnut, mustard, soybean, sunflower, linseed, mungbean, blackgram, pigeonpea, cowpea, rice, sorghum and jute) and these have largely benefited the farmers nationwide. In addition, Trombay mutant lines have also extensively been used in several national breeding programs for crop improvement.

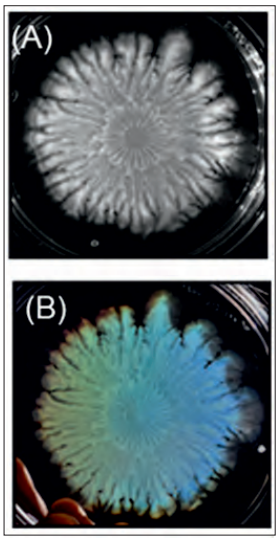
During 2022-2023, BARC achieved several milestones. Seven new Trombay crop varieties, which include one mustard variety Trombay Bidhan Mustard-143 (TBM-143) for West Bengal; two sorghum varieties: Trombay Raichur Jowar P-1-5 (TRJP1-5) for Karnataka; Trombay Akola Parch Sorghum-5 (TAKPS-5) for Maharashtra; one mungbean variety: Trombay Raichur Mungbean-147 (TRCRM-147) for Karnataka; and three blackgram varieties: Trombay Raichur blackgram-22 (TRCRU-22) for Karnataka; Trombay Jawahar Urid-339 (TJU-339) and Trombay Jawahar Urid-130 (TJU-130) have been released and Gazette-notified for commercial cultivation by the Ministry of Agriculture & Farmers Welfare, Government of India. A gamma ray induced groundnut mutant, TG 73 has been released and notified as GG 37 (Sorath Gaurav) for

Controlled condition cold storages was commissioned at KRUSHAK, Lasalgaon, Nashik for preservation of onion and other perishable agricultural products.

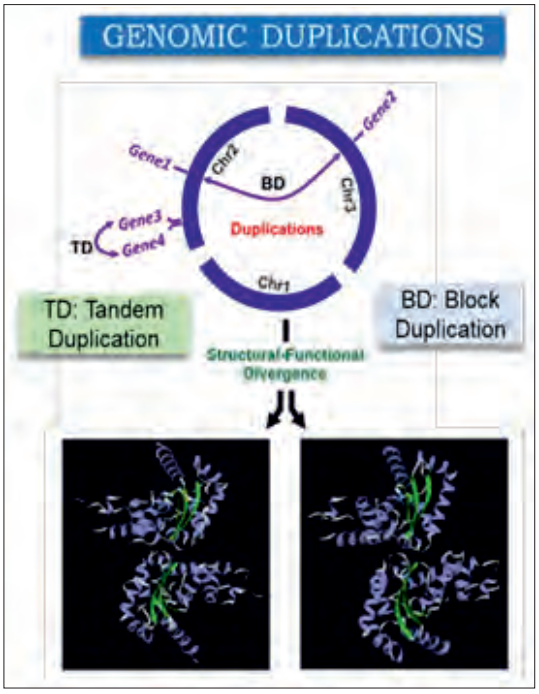
A Tripartite MoU was signed and executed among BARC-NCCF-DoCA for large-scale extended preservation of onion using radiation technology and controlled storage.



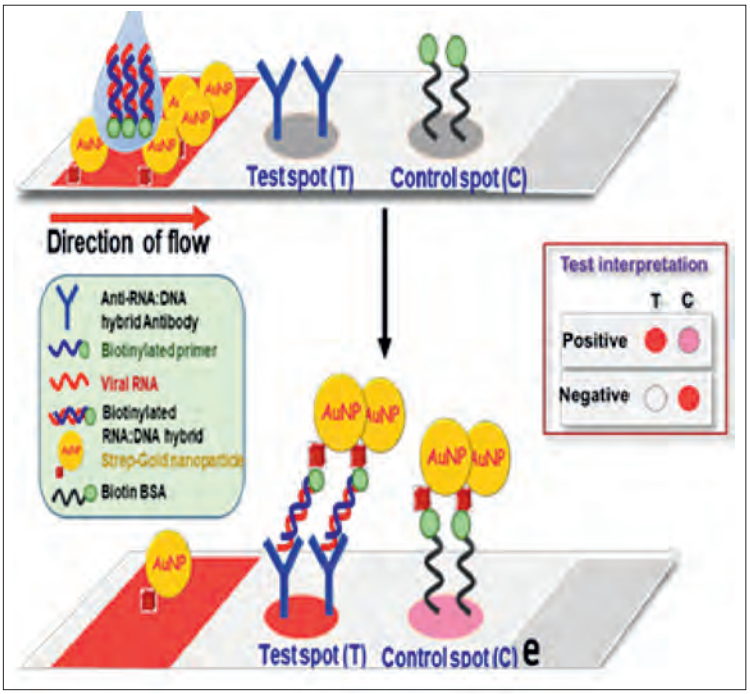
ExoD overexpression produces higher EPS, biofilms & confers Cd Tolerance in Nostoc.



Gliding motility & Iridescence in Chryseobacterium.



Genome duplications and gene divergence in plants.



RDH-LFA assay for ASARS-CoV-2 detection.

commercial summer cultivation in Gujarat. It was previously notified as TAG-73 for Maharashtra. Towards production of Trombay breeder seeds, 254 quintals of groundnut, 75 quintals of pulses and 80 quintals of rice varieties were produced and distributed to different seed producing agencies for foundation and certified seed production. A Trichoderma virens mutant based formulation ('TrichoBARC') has been registered with Central Insecticides Board & Registration Committee (CIB&RC), Govt. of India. It is the first mutant microorganism-based biopesticide registered for field applications. Recently, 'TrichoBARC' formulation has been recommended in package of practices by ICAR for seed treatment in chickpea. Using gamma-ray induced mutagenesis and genomic tools, a gene responsible for increased seed size, improved plant vigour, and tolerance to early salinity stress has been identified in chickpea. In groundnut, Quantitative Trait Loci (QTLs) associated with large seed size was mapped on linkage group A05 and A02, which contributed 18.07% and 11.95% phenotypic variation respectively. The major additive effect of qHKW_A05 was contributed by mutant allele. It was located between marker AhMITE470 and SNP_05_103140987 having a map interval 8.6 cM, corresponding to 4.53 Mbp (99.18–103.71 Mbp) in the

Field view of new sorghum variety Trombay Akola Suruchi (TAKPS-5).

Field view of Trombay Raichur Mungbean-147 (TRCRM-147).

genome. (5) A technology on an efficient, rapid and reproducible micropropagation protocol for ginger (Zingiber officinale L.) developed and transferred to one company. BARC has developed a superabsorbent hydrogel using natural polymer graft co-polymerised with synthetic precursor using gamma rays. BARC hydrogel can absorb and retain water up to several hundred times of its own weight and releases water upon root demand. BARC, in collaboration with Vasantdada Sugar Institute, Pune, has also developed a versatile bioregulator named "ANU-CHAITANYA" containing gamma-irradiated chitosan which boosts plant growth and activates plant defense mechanisms to tolerate abiotic/ biotic stresses. These technologies (Superabsorbent BARC-Hydrogel and ANU-CHAITANYA) developed by NA&BTD have been transferred to companies for commercialization.

Protein Crystallography

In Protein crystallography domain, work is underway in several SARS-CoV-2 proteins (PLpro, Mpro, nucleocapsid, etc.) to understand virus biology and identify potential inhibitors of its life cycle. PLpro of SARS-CoV-2 is a promising target due to its dual function in aiding viral replication and disrupting host's immune responses.In the quest for PLproinhibitors, a compound library was screened using biochemical assays and aurintricarboxylic acid (ATA) was identified as potential inhibitor (Ki= 16 µM). In vitro assays on virus-infected cells demonstrated ATA's potential as an antiviral agent (IC50= 50 µM). When administered orally to infected Syrian hamsters, ATA reduced viral load in the throat. However, no improvement in lung pathology was observed. Its therapeutic efficacy through other routes of administration is being explored.

Antiviral assay of ATA in Syrian hamsters. SARS-CoV-2 infected hamsters were divided into four groups of six animals each, one untreated control and three treatment groups (A, B and C). Viral load in throat swabs are plotted for each group. Significant reduction in viral load was observed for Group C where animals were treated with ATA @ 45 mg/kg body weight.

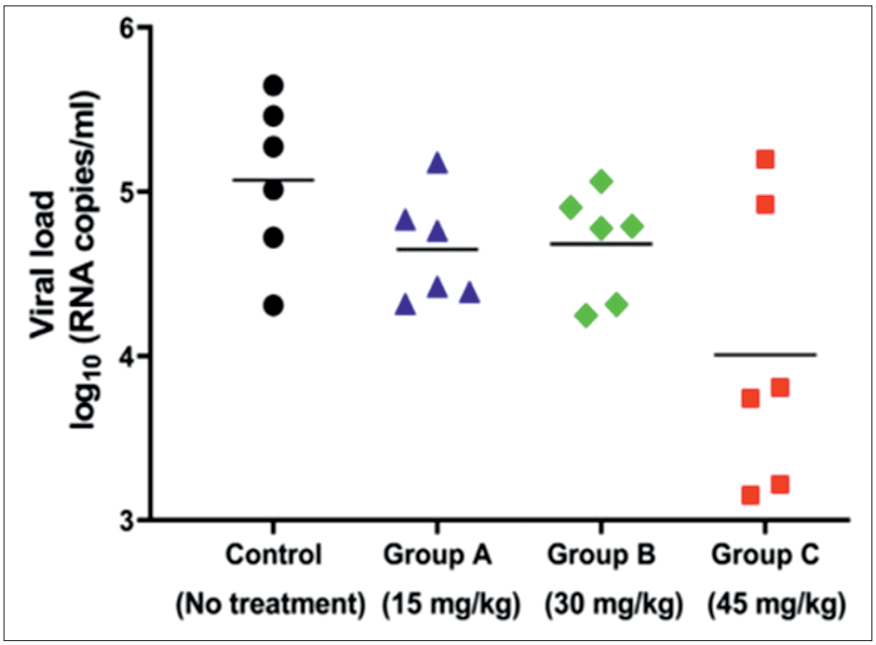
Radiation Biology & Health Sciences

Phase II clinical trial of Chlorophyllin in cancer patients suffering from radiotherapy induced urinary bladder toxicity showed significant radioprotective efficacy when it was given 1 to 25 years after radiation exposure. It was observed that levels of inflammatory cytokines were dysregulated in most of the patients and CHL administration reduced the inflammatory cytokines levels in all the patients within 90 days of treatment.

Liposomes carrying iron oxide nanoparticles and chemotherapeutic drug (Doxorubicin) showed targeted delivery to breast cancer cells and in fibrosarcoma tumor model of mice. The design of the nano-drug was recently granted an Indian Patent (no. 441803) and part of the research work has been published in prestigious journal 'Biomaterials Advances'.

Combination of immune check point therapy with CoX-2 inhibitor improved the outcome of tumour regression. Further, complete tumour regression was seen in COX-2 knock down breast cancer when combined with immune check point therapy.

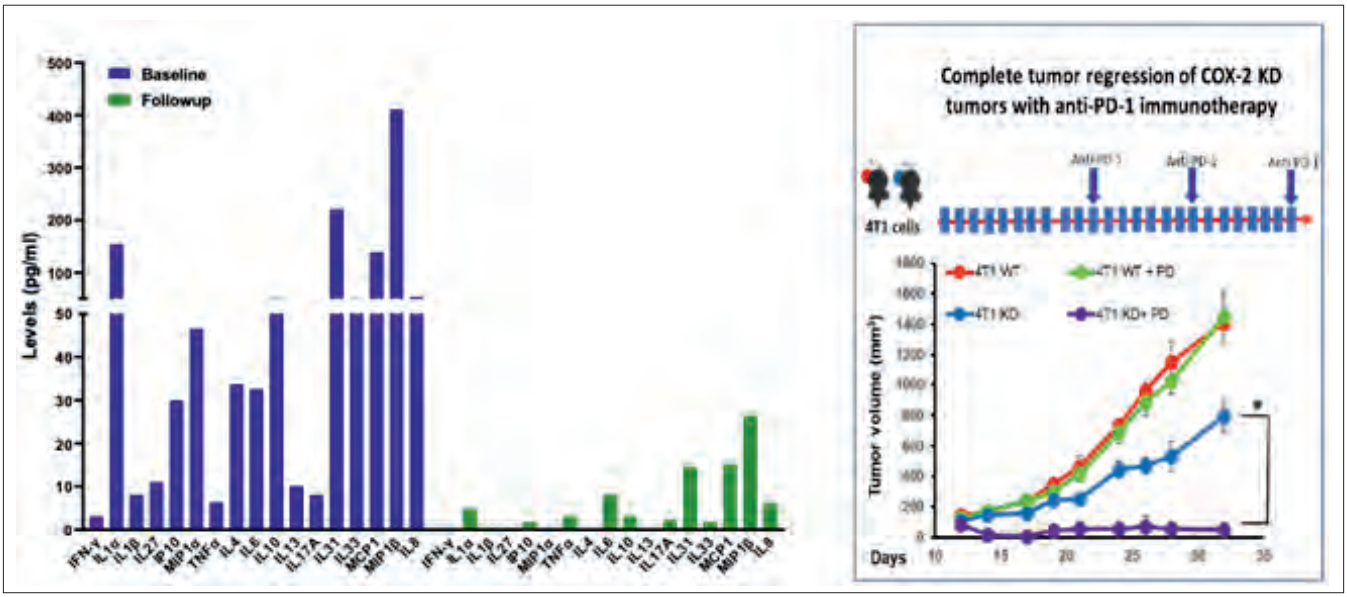
Epidemiological studies in high level natural radiation areas at of Kerala, India have shown that chronic exposure to cumulative dose of 100 to 600mSv does not increase cancer risk. A new-born survey conducted over last four decades showed that high level natural



Antiviral assay of ATA in Syrian hamsters with Viral load in throat swabs are plotted for each group.

radiation does not increase congenital malformations in children born to parents who had received a cumulative dose of up to 96 mSv.

Bystander effects were induced by Cold atmospheric plasma (CAP) on lung adenocarcinoma A549 cells. Our findings revealed that both CAP-exposed and bystander A549 cells show a significant decrease in cell survival, as evidenced by clonogenic assays. Moreover, an increase in DNA damage, and an upregulation of DNA damage response (DDR) signalling compared to control A549 cells was observed.



Complete regression of COX-2 KD tumours with anti-PD-1 immunotherapy.

FOUNDER'S DAY 2023 special issue

Directed Research in Frontier Areas of Radiochemistry and Radioisotope Applications

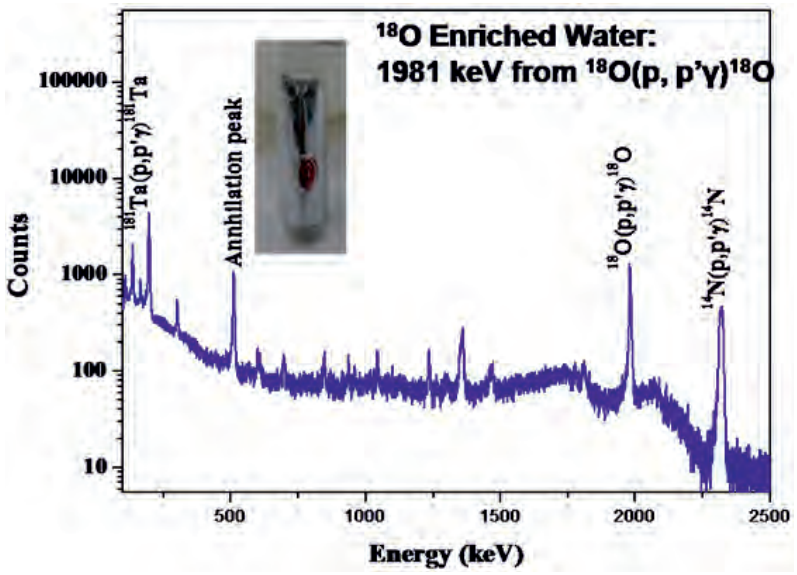
Supporting chemical quality control of FBTR and APSARA-U fuels and other nuclear materials as well as production, radiochemical processing and supply of radionuclides

Dr. P. K. MOHAPATRA
Associate Director
Radiochemistry & Isotope Group
Bhabha Atomic Research Centre (BARC)

The Radiochemistry & Isotope Group (RC&IG), BARC is involved in directed research in the frontier areas of nuclear and radiochemistry, including nuclear reactions, actinide chemistry, actinide spectroscopy and nuclear probes. Important contributions include chemical quality control (CQC) of nuclear fuel and nuclear materials, development of radiopharmaceuticals, isotope hydrology studies for water resources management, industrial applications of radioisotopes, radiation technology for development of materials, radiation applications in solid waste management. The RC&IG is also responsible of accounting of nuclear material under DAE and IAEA safeguarded facilities.

Radiochemistry

Research in Radiochemistry is directed at frontline areas of nuclear chemistry, nuclear probes, actinide chemistry, nuclear analytical methods and actinide spectroscopy. The Radiochemistry division (RCD) caters to the development of non-destructive assay (NDA) methods for the assay of special nuclear materials, chemical quality control (CQC) of nuclear materials (including Pu based advanced fuels) using latest spectroscopic methods and nuclear material accounting and control (NUMAC) of DAE and IAEA safeguarded facilities. Recently, it has developed external (in air) PIGE method using proton beam at FOTIA for rapid determination of 18O isotopic content using 1981 keV gamma-ray in addition to the already existing boron isotope analysis. The strategy of selective dissolution of actinide/lanthanide oxides in



External (in air) PIGE method using proton beam at FOTIA for rapid determination of ^{18}O isotopic content using 1981 keV gamma-ray in "as received" ^{18}O enriched water sample obtained from HWB, DAE.

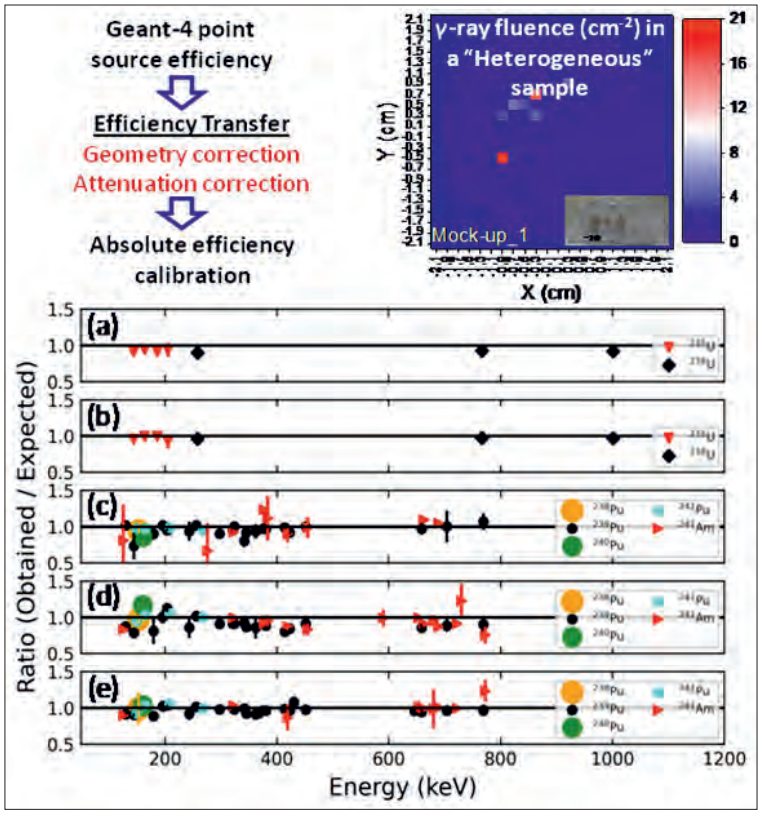
ionic liquids have given exceptionally large separation factor values giving a new paradigm in separation technology. In the last two years, RCD has made significant contributions in the area of lanthanide and actinide doped luminescent nanocrystals for imaging, ultra-long persistent X-ray phosphor, development of MOFs for gas sensing, development of pulsed positron beam, novel substrates for rapid separation of fission products (and heavier actinides), methodology for "on-site" assay of SNMs in random geometry sealed samples using gamma-ray spectrometry, etc. besides CQC work on trace metallic impurity analysis.

Fuel Chemistry

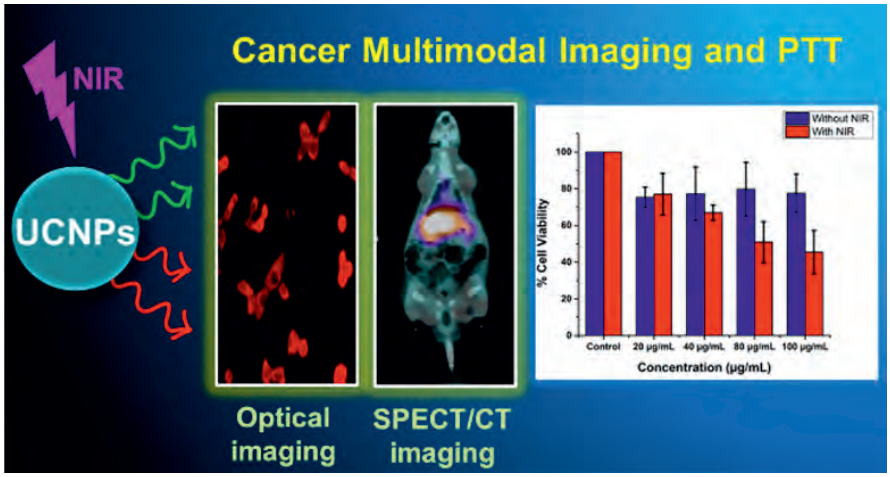
Research in Fuel Chemistry is focused on CQC of nuclear and related materials, thermo/electrochemistry of actinides under molten salt conditions, playing the role of a 'Reference Laboratory' in DAE, 'Quality Assurance' at the stage of pre-operation & during reactor operations, characterisation of fuels for nuclear energy programme, performing structural/thermodynamic studies of novel compounds of fuels, fuel materials and fission products. The recent achievements include developing innovative electrochemical solutions for aqueous and non-aqueous remediation. BARC has recently developed a novel deep eutectic based on alkyl triphenyl phosphonium bromide and decanoic acid, showing remarkable blue emission under UV-light. This exceptionally radiation-stable DES (up to 750 kGy) was investigated for its capabilities in uranyl ion speciation and solvation through a combination of electrochemical and spectroscopic techniques. They have recently ventured into Laser Ablated Molecular Isotopic Spectrometry (LAMIS), which unveils the isotopic composition information of the sample.

Radiopharmaceuticals

Production, radiochemical processing and supply of reactor-produced radionuclides and research, development, demonstration and deployment of state-of-the-art radiopharmaceuticals and production and supply of sealed radioactive sources are some of the focus areas in radiopharmaceuticals domain. Transarterial radioembolization (TARE) is one of the minimally



Non-destructive Assay: Development of a methodology for "on-site" assay of SNMs in random geometry sealed samples using gamma-ray spectrometry.



Remarkable enhancement in UVC and visible upconversion from $ZnAl_2O_4:Yb^{3+}$, Ho^{3+} on Na^+ doping and its efficacy towards cancer treatment and radiolabeling agent for theranostic purposes.

invasive, image-guided loco-regional liver therapies in clinical practice today. Radiopharmaceuticals Division, BARC has been proactive in making available in-house alternatives to clinically established TARE agents such as ^{90}Y-glass microspheres (TheraSphere™, Sir-Spheres®), ^{131}I-lipiodol and ^{188}Re-lipiodol. In the last few years, RPhD has developed in-house capability to produce all the three alternatives.

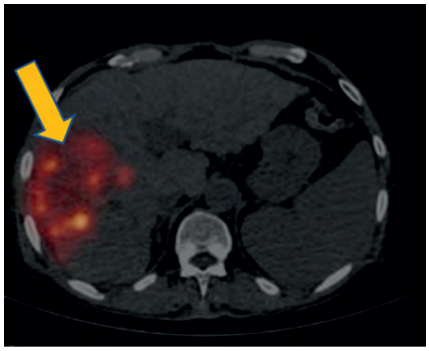
Radiopharmaceuticals Division, in collaboration with Glass and Advanced Materials Division of BARC, has developed BhabhaSpheres (^{90}Y-glass microspheres). Similarly, a two-vial kit for the preparation of ^{188}ReN-DEDC/lipiodol (DEDC-diethyl dithiocarbamate) was developed for use in nuclear medicine centers. Both these products have undergone multi-centre clinical evaluation and are available for clinical use.

Radiation Technology Development

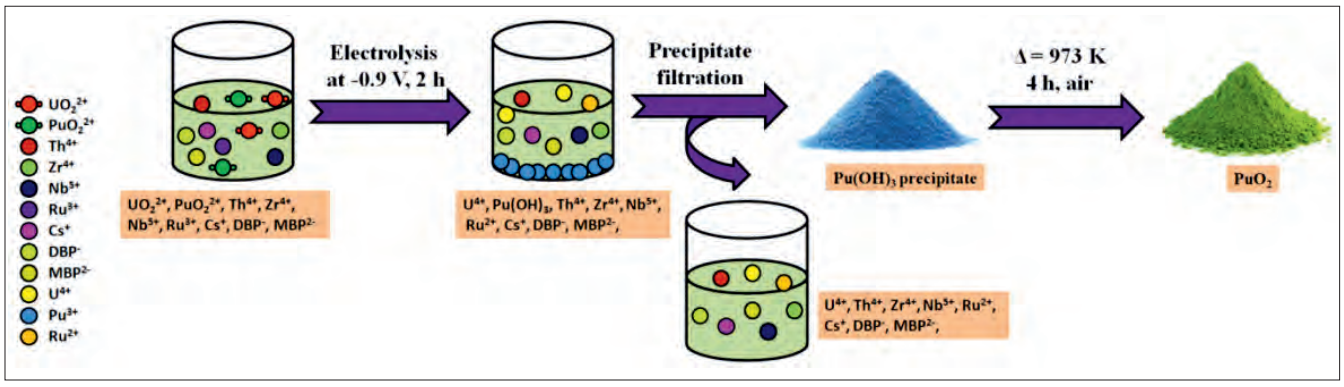
BARC is mandated to develop new applications of Radiation Technology in the area of healthcare, environment, and industry, by developing in-house R&D capabilities as well as pursuing joint R&D work with leading institutes and industries. BARC has recently developed radiation processed elastomeric nanocomposites for hybrid-fuel environment and implemented radiation technology for the development of textile wastewater management. They have explored low cost, renewable, biodegradable and naturally abundant cellulose as a base material ensuring recyclability of treated water to minimise the daily fresh water requirement of the industry. They have recently demonstrated biofuel compatibility of radiation cross linked nitrile butadiene rubber (NBR) which showed that gamma radiation can significantly improve the compatibility of cross linked NBR with biodiesel but not with petro-diesel.

Isotope & Radiation Application

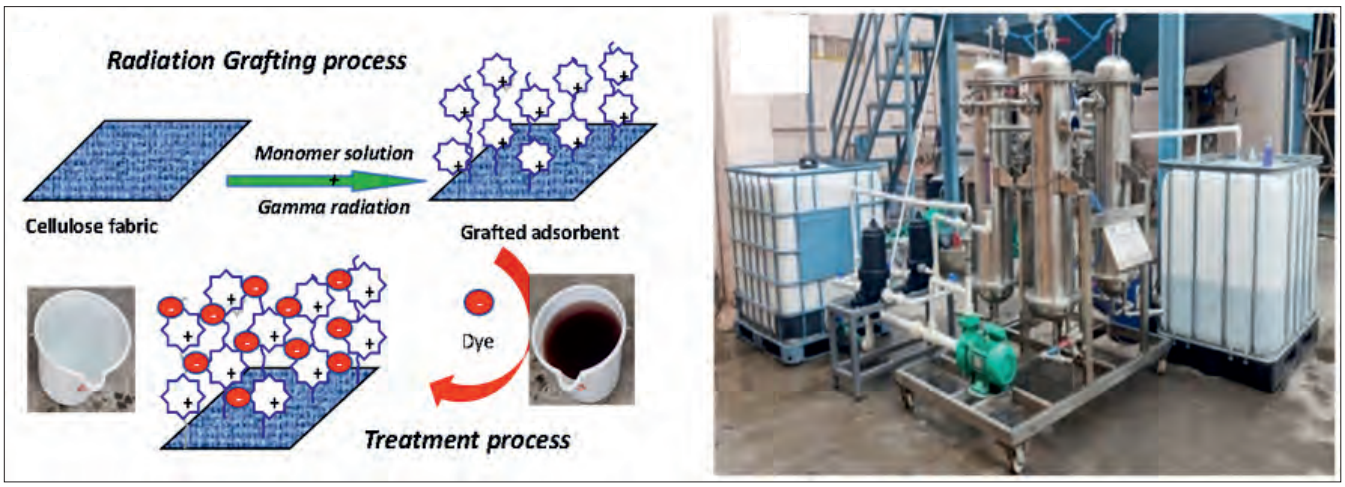
Development of isotope and radiation technologies for applications in industry, hydrology and environment are some of the prominent activities being pursued in the domain of Isotope and Radiation Application. Several radioisotope-based techniques have been developed and applied in the Indian industry for troubleshooting, measurement of hydrodynamic parameters, evaluation and validation of industrial process



A typical post-therapy transaxial PET/CT image of liver of a 56 y male patient with right lobe hepatocellular carcinoma 24 h after administration of 3.4 GBq of [^{90}Y]YAS glass microspheres ('Bhabha Sphere').



Electrodeposition scheme of Uranium and Plutonium separation.



Left to Right: Radiation grafting and dye effluent treatment process; and 30 KLPD demonstration plant.

Left to Right: Radiotracer experiments in a cross-flow reactor; and in a pulsed extraction column.

Activity on collection of samples for radiocarbon dating of deep aquifers underway at a remote location in India.

systems leading to significant revenue savings. Of late, BARC is engaged in the development of novel materials and processing of various industrial products for improving their property and value addition using electron beam and gamma radiation. BARC has also developed unique expertise in adapting isotope hydrology techniques for water resources development and management. In the last two years, several large scale hydrological investigations have been carried out for identifying the source of water recharge, contamination, flow dynamics and dating of groundwater in various parts of India leading to significant societal benefits.

Advancing Radiological Protection and Environmental Surveillance for DAE Programs

Ensuring robust national radiological protection and environmental surveillance, in adherence with regulatory guidelines, through capacity building and training of radiation safety professionals

Dr. D. K. ASWAL
Director
Health, Safety & Environment Group
Bhabha Atomic Research Centre (BARC)

The Health, Safety & Environment Group of BARC is mandated for ensuring radiological protection of occupational workers, general public and the environment under conditions of normal operations of the radiation facilities in the country as well as under nuclear or radiological emergencies. This has been pursued by frequent upgradation of measurement capabilities, development of need based techniques and theoretical models and readiness for emergency preparedness. Additionally, owing to the surge in applications of nuclear technologies, human resource development and training programmes are in place to cater to the ever increasing demand of certified radiation safety professionals.

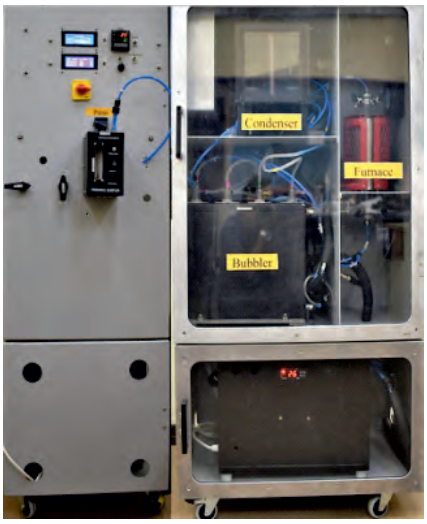
Radiological and Environmental Surveillance Systems

A country-wide environmental radiation monitoring network under Indian Environmental Radiation Monitoring Network (IERMON) programme has been established by installing 556 Environmental Radiation Monitors (ERM) in 27 out of 28 states and 7 out of 8 UTs of the country. Various versions of ERMs have been developed such as ERM with Satellite communication (ERM-SAT), the Environmental Gamma Spectroscopy System (EGSS), the Continuous Environmental Gamma Spectrometer (CEGS), among others.

A system for automatic collection of air moisture for analysis of ^{3}H has been designed, fabricated and technology is transferred

Environmental Radiation Monitor with Satellite communication (ERM-SAT).

Air Moisture Collector commissioned at ESL in Kakrapar, Gujarat.



Integrated Tritium and Radiocarbon Sampling System.

through TT&CD. The different variants of air moisture collectors (viz., Cumulative moisture collector, Hourly moisture collector etc.) are developed for applications covering occupational environment, locations where power supply is available/not available, sample duration etc. These are commissioned at all Environmental Survey Laboratories (ESLs) at NPP sites and at Trombay.An integrated, cost-effective instrument for simultaneous sampling of different species of ^{3}H and ^{14}C from air has also been developed for accurate differential evaluation and distinction of inorganic and organic forms of radionuclides.

Capacity Building - Nuclear Forensics

Towards nuclear forensic capacity building, a clean laboratory of Class 10,000, with a clean bench of Class 100, has been established at BARC Hospital, Anushaktinagar, for analysis of elemental, anionic and isotopic signatures in nuclear materials or contaminated environmental matrices at trace/ultra-trace level. Nuclear forensic analysis provides technical support in the response and prevention of nuclear incidents arising due to unauthorised use of nuclear or other radioactive materials. It involves the analysis of different signatures in seized illicit nuclear materials, either in bulk or particulate form, and the interpretation of data to identify the origin and intended use of the material.

Machine Learning based Applications

Thermoluminescent Dosimeter (TLD) badges, used in India for personnel monitoring of occupational exposures due to external X, beta and gamma radiations, go through various handling and treatment processes during their use. This can impact the TL emissions leading to abnormality in the shape of TL glow curves. Currently, either manual screening of glow curves or rule-based algorithms are used to ensure the accuracy of estimated doses. To provide a more adaptable and dependable process, machine learning (ML)-based algorithms have been developed to achieve a screening

Clean room facility of Class 10,000 with fume hood and Clean Bench of Class 100 for sample processing for ultra – trace analysis (EMAD Laboratory at BARC Hospital).

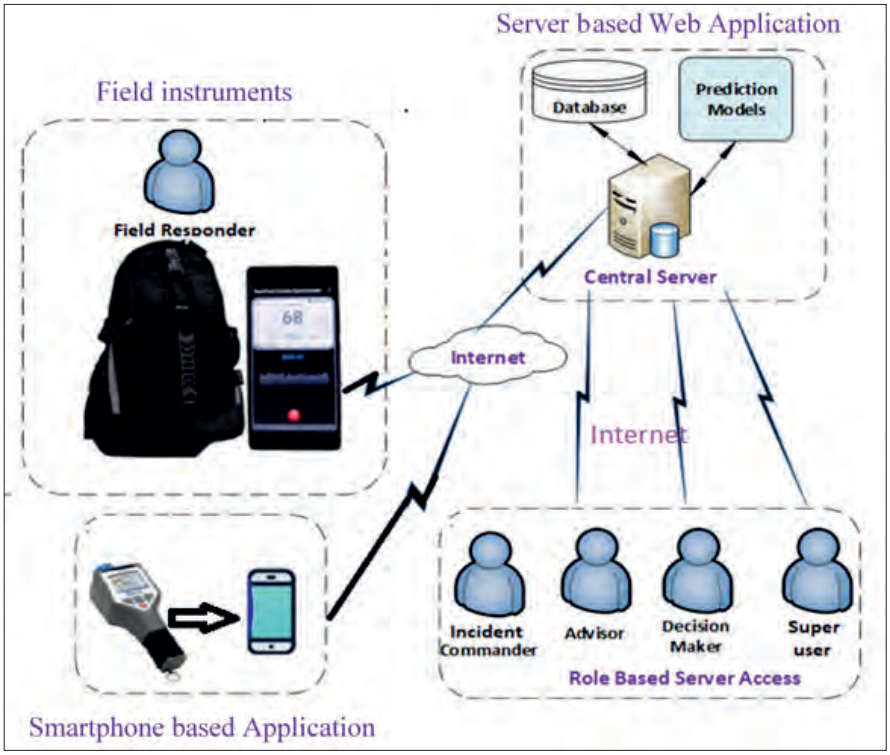
Screenshot of TPS indicating three cross sections of reconstructed CT images and dose distribution using colourwash/colourfill along with dose volume histogram.

accuracy of up to 99%. The ML model is integrated into the routine monitoring procedures by means of a graphical user interface developed using the R-shiny environment. Furthermore, $CaSO_4$:Dy dosimeters exhibit pronounced energy and angular dependence of response. Conventional dose evaluation algorithms face limitations in effectively modeling these dependencies due to several constraints. However, ML algorithms excel in mapping complex, multidimensional functions. A hybrid multistage ML model capable of estimating the average energy of radiation and the dose is developed to improve the accuracy of dose estimation.

ML algorithm was also developed to establish an empirical formula of full-energy peak efficiency (FEPE), for a Broad Energy High Purity Germanium (BEGe) type detector. FLUKA Monte Carlo-based code was used to simulate radiation transport in the BEGe detector, and FEPE values have been estimated for various gamma energies and wide range of detector configurations. Using ML-based non-linear regression models, an empirical formula relating FEPE values with detector configuration and incident gamma radiation (energy >122 keV) is obtained. At lower energies, the efficiency of the BEGe detector is higher than the coaxial detector due to its large diameter-to-length ratio. The derived empirical formula can be used to quickly estimate FEPE values and verify nominal geometric parameters provided by the manufacturer.

Development of Treatment Planning Software

As a collaborative effort by various groups of BARC, a treatment planning system (TPS) has been developed for visualization of the dose distribution prior to treatment using indigenously developed Bhabhatron Telecobalt machine. This system employs generalized field equations and a correction-based algorithm to calculate radiation doses in three-dimensional patient anatomies. Radiological Physics and Advisory Division (RP&AD) played a pivotal role in the



Architectural block diagram of Integrated Radiation Emergency Management System.

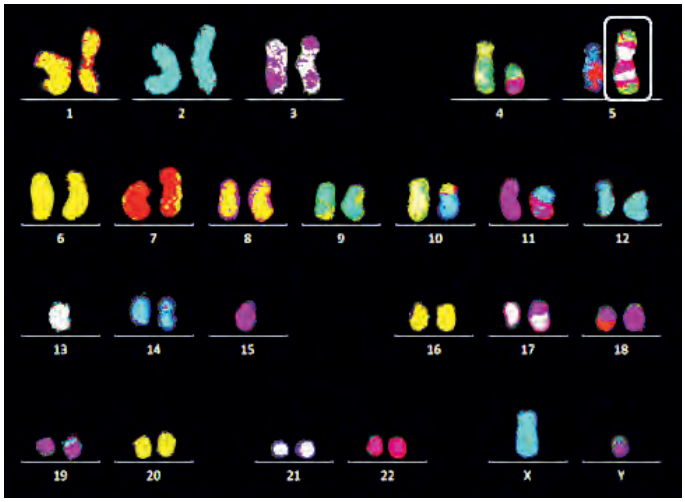
OSLD Badge reader system.

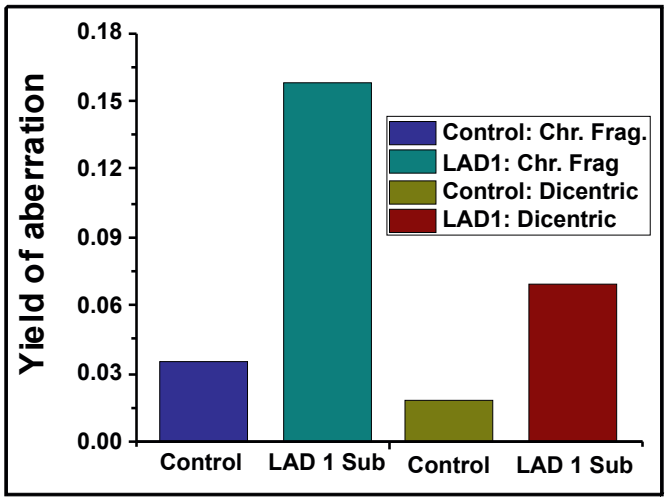
development of the dose engine for this Treatment Planning System. In addition, validation of computed doses by comparing them against measured values in both homogeneous and inhomogeneous media as prescribed in the IAEA Technical Document 1583 was also carried out.

Emergency Preparedness and Management

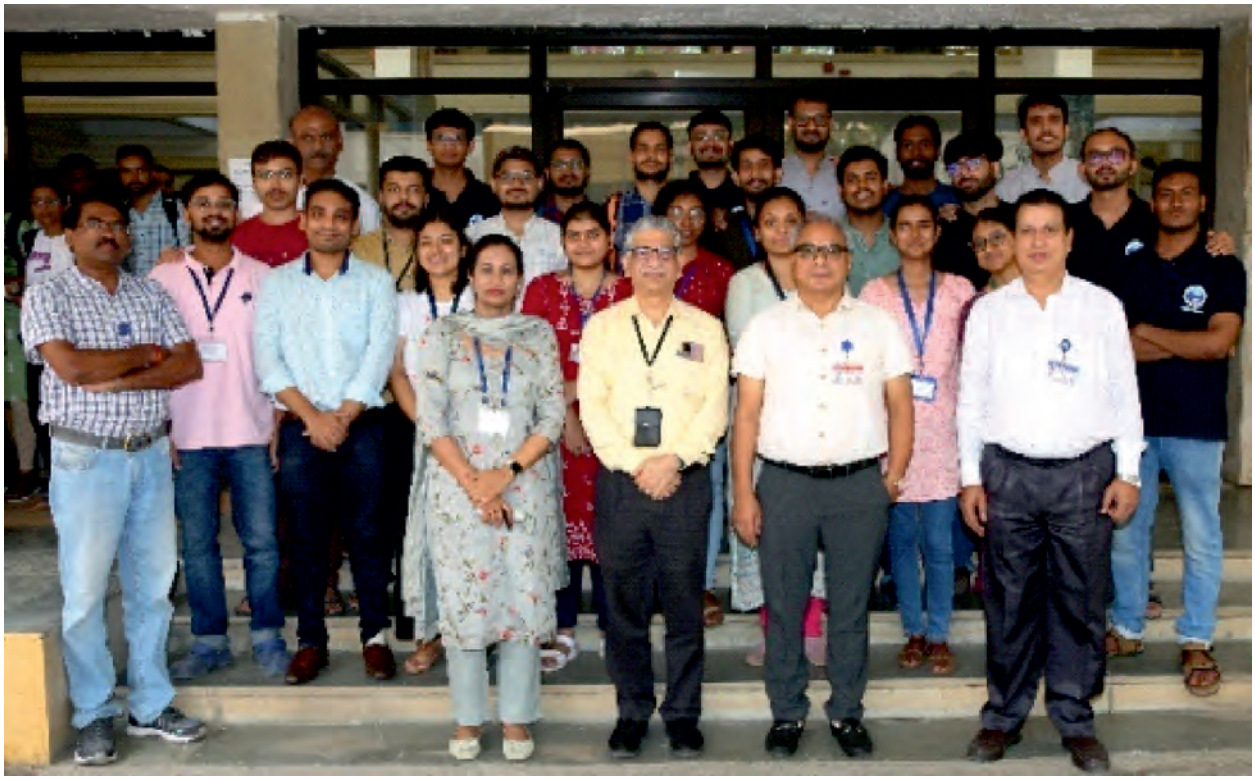
A comprehensive and efficient Integrated Radiation Emergency Management System (IREMS) has been developed to handle potential radiation emergencies. Powered by server-based web application, the system aims to streamline and enhance emergency response capabilities by integrating data collection, analysis, and decision-making processes. It offers a range of features, including role-based event management, real time integration of various field measured radiological data into a unified platform, manual data upload, data visualization, predictive modelling, and real-time communication among the users associated with a particular radiological event. The IREMS is envisaged to handle radiological emergencies involving multiple stakeholders.

For emergency response preparedness, a model has been developed to study the effectiveness of sheltering from radiation exposure due to accidental release of radioactivity. Sheltering, via structural shielding, is an important protective action during the early phase of an accident, as it reduces the direct exposure from plume/cloud shine and ground shine doses, as well as the airborne radioactivity concentration and inhalation dose. The model estimates the shielding factor for typical Indian human settlements for external exposure pathways using the FLUKA Monte Carlo based radiation transport code. Furthermore, the dose reduction factor due to exposure from the inhalation pathway is estimated using an indoor aerosol model, considering three major types of dwellings. This model provides important inputs for decision-making for sheltering or evacuation in case of any sudden release of radionuclides into the environment.





Left to Right: Depiction of a complex chromosomal structure composed of fragments from 3-4 distinct chromosomes; Comparative analysis of the prevalence of pre-repair (chromosomal fragments) and post-repair (dicentric) chromosomal events.



The incumbents of the 61st DipRP course.

Advancements in Passive Dosimetry

With the introduction of highly luminescence sensitive dosimetric material - Al_2O_3:C, the Optically Stimulated Luminescence (OSL) technology has gained momentum with a potential for paradigm shift from TL to OSL based dosimetry for various applications, including dosimetry of astronauts and the habitable volumes of spacecraft. RPAD has developed an OSLD based system for countrywide personnel monitoring. This includes a) process for large scale synthesis of dosimetry grade α-Al_2O_3:C by melt processing technique in the graphite ambience (in collaboration with TPD, BARC), b) four-element OSLD badge with different metal energy compensation filter combinations to discriminate between beta, X-ray and gamma components and c) OSLD Badge Reader to cater to personnel monitoring. A dose evaluation algorithm has been chalked out. The system has promising features that offer fast readout, high throughput coupled with inherent simplicity.

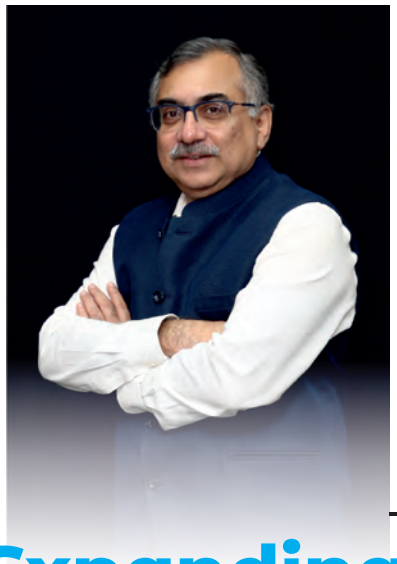
Clinical Implications of Cytogenetic Tools

Cytogenetic tools play a vital role in clinical diagnostics, encompassing cancer detection, genetic anomaly identification, and syndrome diagnosis by examining chromosomal and genetic variations at microscopic level. In a study focused on leukemia, multiplex FISH was employed to explore chromosomal rearrangements. Results revealed structural and numerical variations in chromosomal bodies, a unique chromosomal rearrangement wherein multiple distinct fragments fused, which emphasize the intricate nature of chromosomal alterations in leukemia. In another case study, the examined Leukocyte Adhesion Deficiency Type 1 (LAD1) revealed a 4.5-fold increase in chromosomal fragments, suggestive of inefficient double-strand break (DSB) repair. Concurrently, the dicentric chromosomes notably reduced, signifying a deceleration in DSB repair. In another case study focused on Fanconi anemia (FA), a rare and severe genetic disorder, a pediatric case was analyzed and the findings revealed significant genomic instability, marked by increased rates of chromosomal and chromatid breaks, as well as elevated post-repair events like dicentrics and translocations. These results emphasize the substantially elevated cancer risk in FA patients. Cytogenetic techniques remain invaluable in unraveling the complexities of these genetic conditions, significantly contributing to effective management strategies for improved patient outcomes.

Human Resource Development in Radiation Safety

RP&AD has been offering a one-year Post M.Sc. Diploma in Radiological Physics since 1962. Currently, the 60th course is in progress, and a total of 1096 candidates have successfully completed the course over the years. Many of these graduates have achieved notable success both in India and abroad. Graduates of the Dip. R. P. course are eligible to work as clinical medical physicists in hospitals upon successful completion of a one-year medical physics internship at AERB-recognized radiotherapy facilities. They are also qualified to be nominated as Radiological Safety Officers in medical, industrial, and research institutions. The Dip. R. P. program serves as a valuable source of well-qualified professionals for various institutions and facilities across the country, including the AERB and DAE establishments.

RP&AD also organizes a range of short-term certification courses in radiation safety for personnel from medical, industrial and research institutions, as mandated by the AERB. These courses are offered either independently or in collaboration with governmental and non-governmental organizations. Additionally, RP&AD conducts certification courses tailored for government agencies, including the Ministry of Defence, Ministry of Home Affairs, Customs House, and Ports.



Expanding the Ambit of Electronics, Instrumentation and Computing Research

Broadening nuclear energy and associated technologies through developing a gamut of next generation sensors, systems and processing tools

Dr. S. MUKHOPADHYAY
Director
Electronics & Instrumentation Group
Bhabha Atomic Research Centre (BARC)

The activities of Electronics & Instrumentation Group of BARC evolved to cover the entire spectrum of Control and Instrumentation. Ranging from fundamental aspects of sensing elements, acquisition and processing of information, intelligent systems, networking and communication technologies to security systems.

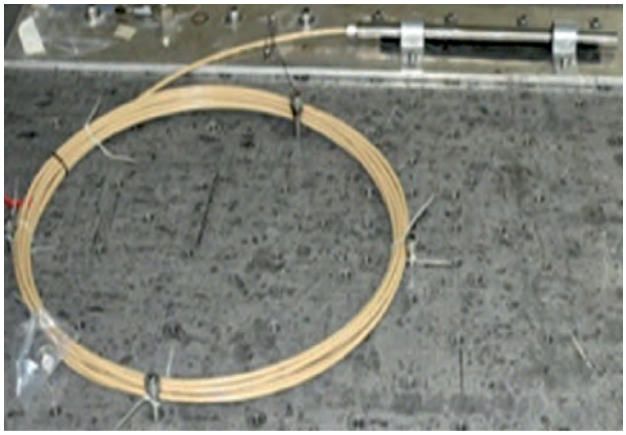
Sensors, Transducers and Associated Technologies

Sensing elements and embedded processing electronics are fundamental to any Control and Instrumentation system. Self-reliance in this area overcomes technological barriers and ensures uninterrupted availability of supply chain.

Development of Neutron Detectors for Reactor Facility

BARC continued to develop and supply boron coated detectors for various reactor facilities. Apart from the current set of detectors, high temperature operable neutron detectors are required for PFBR. Materials Group, BARC has successfully developed highly adherent B-coating technology with improved thickness uniformity and high temperature stability. Utilizing the improved B-coating technology, two numbers of boron lined proportional counters of 26mm OD X 110mm length were integrated in E&IG. The detectors were assembled, welded, leak tested, evacuated up to 10^{-5} torr and filled with Ar (95%) + CO_2 (5%) at 20cm Hg. The detectors were tested in D9/D10 location of CF reactor and have performed satisfactorily. They have ~0.4 cps/nv thermal neutron sensitivity which is 25% more

Natural boron coated proportional counteremploying dip coating method.



High sensitivity ^{3}He proportional counter for fuel loading in CLWR.

compared to the detectors developed by conventional boron coating method.

Indigenous in core high sensitivity ^{3}He proportional counters have been, developed, tested and qualified. The detector with small dimension to fit in narrow core tube gives neutron sensitivity of ~ 10 cps/nv resulting in improved counting statistics and reduces uncertainties during fuel loading, criticality and reactor start-up.

Nested Corrugated Capsules for Indigenous LOCA qualified DP Transmitter

Availability of sensing elements during LOCA conditions an essential pre-requisite for any nuclear reactor. Nested corrugated measuring and isolation capsules has been designed, developed, and fabricated. These capsules will be deployed as sensing elements in differential pressure transmitters for measurement of process parameters like flow, level, pressure in process systems of nuclear reactors. These capsules successfully passed the functional and LOCA qualification tests. A measurement accuracy in the range of 0.3% to 0.6% of span has been achieved.

Heated Junction Thermocouple based Sensors

In order to enable direct measurement of level and temperature of coolant inside reactor pressure vessel of future reactors Heated Junction Thermocouple based Sensors have been developed. Design, Fabrication, assembly and testing of prototypes of 1m and 2m length heated junction thermocouple-based sensors has been completed. Fabrication of full scale 8m long assembly is in progress.

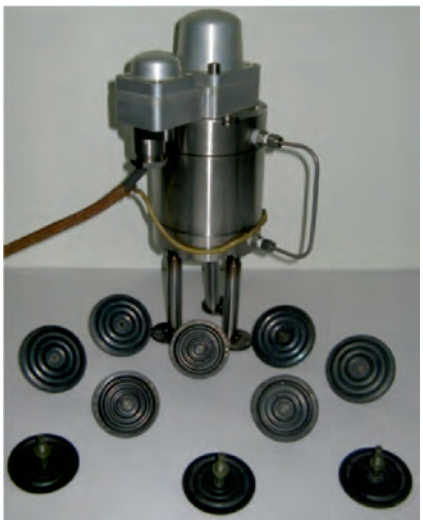
In-house Development of Prototype Detectors, Data Acquisition Module for Indian Cargo Scanner

Indigenous prototype photodiode detectors coupled to scintillator and DAM for ICS comprising seven detector modules with about 210-pixel detectors, 32-channel front end signal processing detector array board with programmable gain & integration time central acquisition board has been developed.

The indigenous detectors and electronics met the ANSI qualification criteria of i) 0.8 mm dia. Wire in air, ii) 5 mm spatial resolution, iii) 1% contrast, iv) 350 mm steel penetration at speed of 0.1 m/s. The system also demonstrated material discrimination capability in terms of well separated material discrimination curves for Perspex, Aluminium, Stainless Steel and Lead.

Development of Detectors and Electronics, and Performance Validation of Linear Array Detector System for Industrial Tomography

The Detector system for industrial tomography applications for has been designed, developed. and tested for its performance. The system comprises fine pitch linear array X-ray detectors of pitch of 1.3 mm, 64 channel readout electronics and data acquisition electronics and software for GUI, for calibration and gray scale raw image display. The developed system is suitable for high energy radiography up to few MeV.



Nested corrugated capsules and combined test setup assembly.

Small Scale prototype level sensor with standard sensor head.

Indigenous Linear Array X-ray Detectors for Dual Energy X-ray Baggage Inspection System

Indigenous Silicon photodiode-CsI array coupled 16-pixel X-ray detectors, front end electronics, and data acquisition & control electronics have been developed for dual energy XBIS. Ten detector cards comprising 640 pixels each of low energy and high energy detectors with individual programmable charge integrators and 16-bit ADC and a FPGA based DAQ card. The detector system integrated to dual energy XBIS, using standard test pieces gave imaging performance as per ANSI 42-22 international standards. Software has been developed for ECIL make Dual View XBIS (ECX6040: DVXBIS) to provide enhanced and reliable screening of baggage or parcels. The software provides dual view display of the bag being scanned from two orthogonal directions on two monitors to give better spatial understanding and improved detection.

Control and Instrumentation Systems

Smart control and instrumentation systems are the backbone of any operating Plant. Automating of complex control algorithms and providing operator information in a Graphical display ensures multiple advantages, including smooth plant operations and increased plant availability.

Launch of in-house PLC NUCON at ECIL

Development of Indigenous PLCs are a major step in achieving self-sufficiency in control & Instrumentation and ensuring safe and cyber resilient product for critical applications. Reactor Control Division, BARC in association with ECIL and IGCAR has developed Safe and Secure PLC NUCON series 1000 and 2000. A test set for demonstration with nearly 10,000 I/Os has been setup. Safety class IC version of this platform has been successfully evaluated by an independent committee. Three-day workshop to create awareness of this safe and cyber resilient was organised.

Specialized Electrical SCADA system for Dhruva

A TPLC-32 platform based Electrical Supervisory Control And Data Acquisition (ESCADA) system for interlocks and monitoring of Electrical Subsystems of Dhruva has been developed in-house, installed and commissioned.

Upgradation of Integrated Control and Information System of KAMINI

Design modifications in the software of ICIS of KAMINI facility in IGCAR has been completed. After carrying out independent verification and validation followed by sanction of regulatory approval by AERB Safety Committee, the upgraded software has been installed and at site. Site validation had been completed and the system is performing satisfactorily.

Inspection, Monitoring and Automation Systems for Nuclear Facilities

Development of modern inspection techniques and systems facilitates Nuclear Reactor Life Management by timely measurement and trending of key parameters.

KAPP-4 Coolant Channel Pre-service Inspection

Pre-Service Inspection of Nuclear Reactor generates base line data of vital components. This data in conjunction with In Service Inspection data forms the basis of coolant channel life management.

For performing Pre-Service Inspection of 700 MWe PHWR KAPP-4, BARCIS–220 system of KAPS 1&2 was integrated with upgraded control electronics and was adopted for 700 MWe inspection requirements. The

Baggage Inspection System ECX6040: DVXBIS.

Sub-System-II Panel of ICIS of KAMINI.

system was qualified for KAPP-4 PSI at the Full-Scale Coolant Channel Mock-up facility. Full volumetric UT inspection of 18 coolant channels along with wall thickness and internal diameter measurements were carried out. Inspection of 24 numbers of adjacent rolled joint regions was also completed.

Development of SiPM based Hand-held Gamma Monitor

A compact gamma monitor using indigenous SiPM (3 mm x 3 mm with 50 μm pixel size) coupled to a CsI (TL) scintillator detector has been developed for detecting gamma radiation. This is a smart device with PC and smart-phone connectivity for real-time dose-rate display in numerical and graphical formats, and data logging.

Portable Radioisotope Identifier Device

A portable, hand-held, rechargeable battery-operated device, Portable Radioisotope Identifier Device (PRID), is developed to identify the radioactive isotopes and measure the dose rate by analyzing the characteristic gamma energy spectrum of the material. It comprises a 1.5 inch x 1.5 inch NaI(Tl) scintillator detector coupled with photo multiplier tube (PMT) to detect the gamma isotopes in the energy range: 30 keV to 3 MeV and to measure the low dose rate in the range:10 μR/Hr to 15 mR/Hr. It also has a GM tube for high dose rate measurement in the range: 15 mR/Hr to 1 R/Hr. It is powered by a rechargeable battery and can be operated continuously for 10 hours with a fully charged battery.

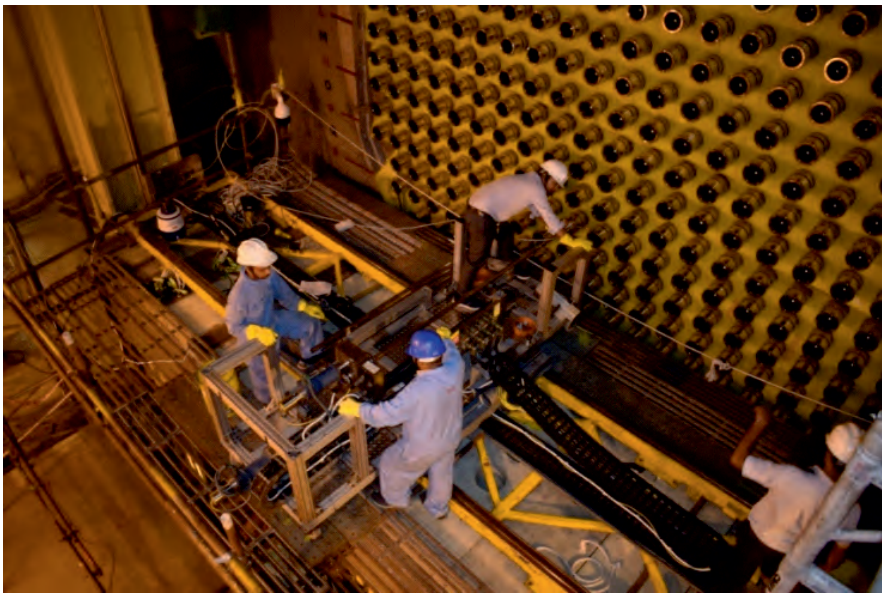
Multi-channel Structural Vibration & Pressure Pulsation Measurement System for Monitoring of PHT Components of 700MWe PHWRs

A multi-channel portable system has been developed for monitoring the health of PHT components of 700 MWe PHWR. The system consists of radiation hardened sensors, real-time data acquisition & processing system (DAPS) and remote monitoring system. Remote monitoring system runs a GUI to configure the system and to display analysis results in real-time.

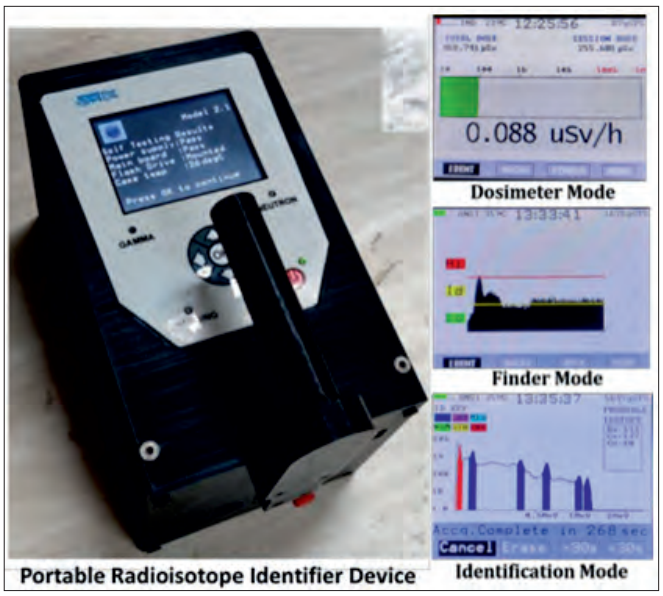
The system has been installed at KAPP-3 to investigate the effect of two-phase flow on structural vibrations. Radiation resistant uniaxial accelerometers are mounted on the D16 feeder and ROH interconnecting line of the reactor. No significant change was observed in the vibration characteristic of feeder and ROH interconnecting lines up to 90% full power (FP) operation however 94% onwards changes were observed indicating the onset of bulk boiling in the outlet of coolant channel.

Development and Deployment of Ultrasonic Isotopic Purity Estimation System for Heavy Water

A first-of-its-kind ultrasonic technology (UT) based online system for isotopic purity measurement of heavy water has been developed by designing a compact UT sensor (requiring only 8ml of sample volume in a constant temperature bath) and a USB powered electronics. The in-house developed user interface acquires and processes the UT signal for estimation of isotopic purity of heavy water in near real time. Multiple experiments were conducted in the purity range from 1.9% to 91.8% for generation of calibration curve.



Pre-Service Inspection being carried out in KAPP-4 Reactor.



The performance was validated with benchmark instruments.

Ultrasonic Imaging and Gauging Systems

FPGA-based ultrasonic pipe inspection and gauging system has been designed & developed. The water-immersible instrumentation operates on the principle of Pulse-Echo mode and consists of a 2-channel Ultrasonic Pulser, DAQ module & two modules for HV-LV DC supplies generated using Lithium batteries & regulator boards, mounted inside IP67 grade enclosures. A 4-Channel Ultrasonic Imaging System has been designed and developed. The automated imaging system acquires ultrasonic cross-sectional images of Concrete and RCC materials in Pulse-Echo/Transmit-Receive mode. The system employing Ultrasonic Pulse Velocity (UPV) mode & using 54KHz/92KHz/ 108KHz piezo-electric transducers measures acoustic velocity of unknown concrete materials to assess the compressive strength and soundness. The unique feature of imaging system over other systems is water-immersion mode to inspect under-water Concrete/RCC structures using longitudinal-wave, immersion transducers.

Robotic Work Cell for Automated Drum Handling for D_2O Evacuation & Filling

A Robotic work cell has been designed and developed to facilitate automated remote filling and emptying of SS storage drums with D_2O at HWD upgradation plant. It comprises a 7-axis robot with gripper for capping/de-capping, roller bed belt conveyor for drum transfer, profiling sensor & software to estimate the exact position & orientation of cap. It mitigates risks involved in handling of contaminated drums, reduces man-rem dose and streamlines operation.

Development of AI based Systems and Algorithms

Increasing computing power has resulted in development of complex algorithms for solving critical problems. In addition to computing resources, availability of large amounts of data has led to the development of Machine Learning solutions.

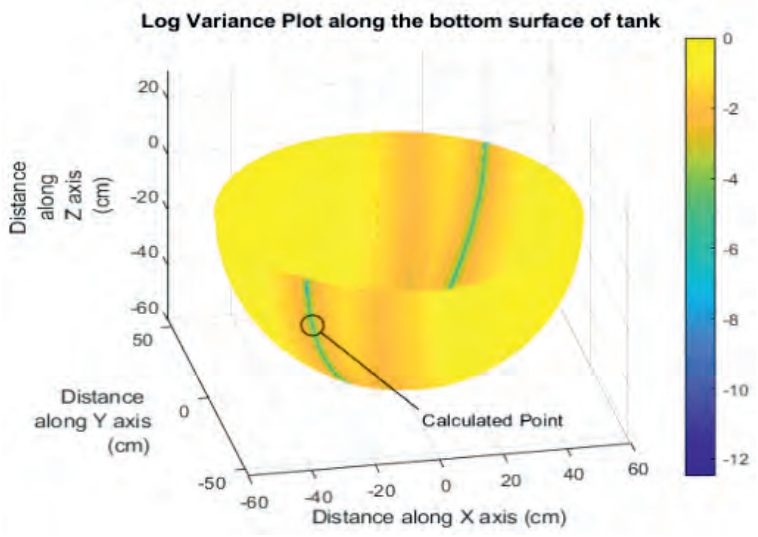
Development of Algorithms for Loose Part Monitoring

An algorithm based on time of arrival difference (TOAD), computed from Short Time Fourier Transform of acoustic emission sensor signals, has been developed to estimate the exact location of loose part impacts in process equipment. Estimation accuracy of the developed technique under noisy background is experimentally validated in a storage tank of the Flow-meter calibration facility.

Detection of Postulated Initiating Events (PIE) using Supervised Learning Algorithms

A Deep recurrent neural network (RNN) has been developed for detection of PIEs in nuclear reactors. Typical datasets for normal power operation and SB-LOCA was

Evacuation of SS storage drums filled with D_2O in progress.



Output of the localization algorithm, indicating the point of impact in 3D geometry.

generated using APWR simulator from IAEA, with which the network is trained. The PIESLA network could successfully classify the test patterns (a random subset of the training set).

Development of Dose Engine for Bhabhatron for Asymmetric and Wedge Fields and Treatment Planning System

A dose computation engine has been developed for treatment planning system of Bhabhatron. It is able to compute the dose dictribution in the patient's body, taking into account symmetric as well as asymmetric field openings and wedge fields. The dose engine is integrated with Treatment Planning System and validated for typical test cases using measured data in a Thorax Phantom.

'DOSAGE', a Treatment Planning System (TPS) for Bhabhatron-II automates steps involved in Radiotherapy treatment planning enhancing the outcome of treatment.

Salient features of the system include Multi-planar reconstruction of CT images, Contouring tools, Plan Creation Visualisation and Validation, Dose Calculation Engine, Visualisation of dose distribution. Dosimetric performance of TPS was evaluated as per IAEA-TECDOC-1583. The application can also be used for LINAC based Teletherapy systems.

Virtual Fence (V-Fence)

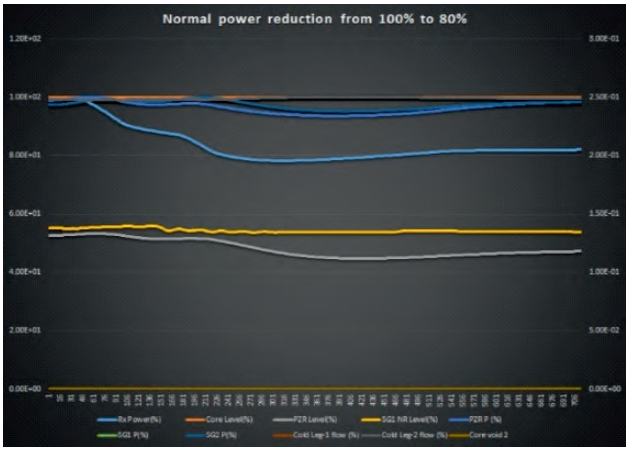
Virtual Fence, detects intrusions in multiple geographically isolated cameras and integrates the outputs on a GIS Map. Feed from multiple cameras is acquired and processed at the centralised GPU server (Pragya). Deep learning-based, object-based models are trained for detection of intrusions and an in-House developed algorithm (inverse-DLT) is used to recover the 3D coordinates of the intrusion. The user interface is through a browser-based application.

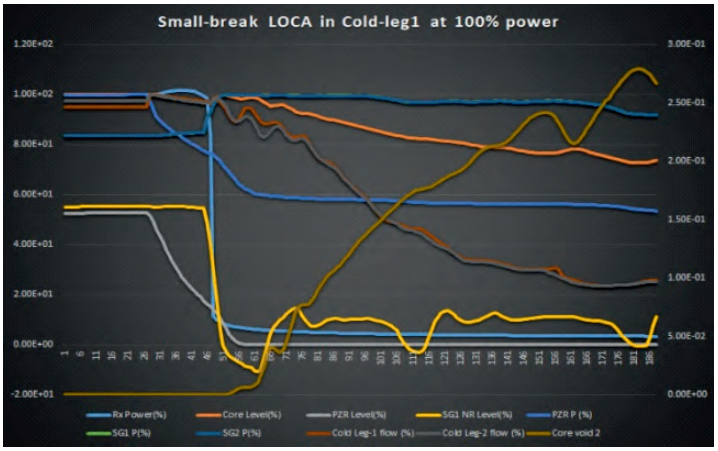
Multi-factor Authentication based Access Control Device

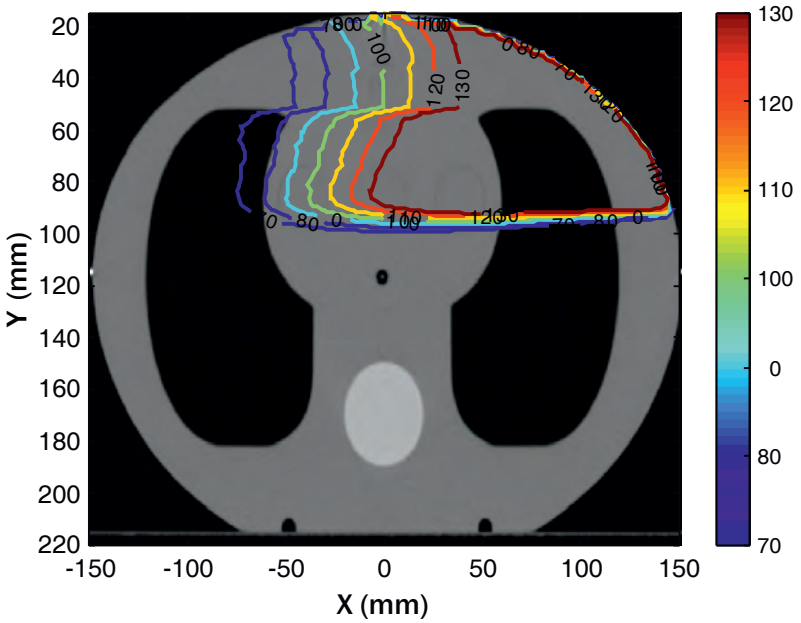
Computer Division has developed Multi-factor authentication (MFA) based Access Control Device for sensitive environments where strict access controls need to be enforced. MFA forces the use of multiple methods of authentication from independent categories to verify user's identity to grant access. AI based Face verification system & RFID based BARC identity card reader running on small factor edge devices are integrated to realize such a system.

Control and Instrumentation Systems for Scientific Instruments and Programmes

Modern Science Experiments and scientific facilities rely on Advanced Control and Instrumentation systems, High Performance computing systems and High-speed communication systems. E&IG has always played a key role in development of these systems.







Iso-dose distribution computed in a Thorax Phantom for a 10cm×15cm field with 15W×20 cm physical wedge (WA = 45°) for gantry angle = 90°, collimator angle = 270°.

Development of Scanning Electron Microscope

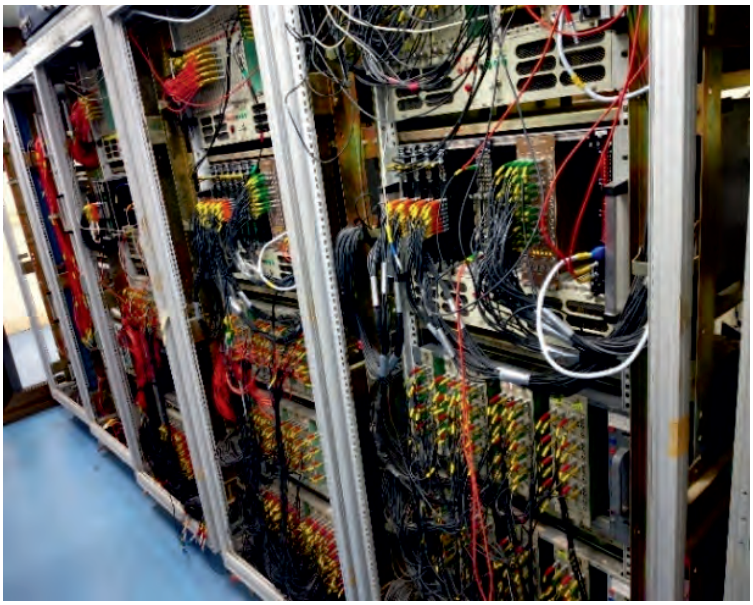
The in-house-made tungsten filament based SEM has been deployed at Central Instrumentation & Research Facility (CIRF), IIT, Bhubaneswar to cater to routine microscopy requirements and to provide user evaluation for SEM design refinements. Operational and basic maintenance training has been imparted to users. Provision has been made available for remote operation of SEM for occasional developer configurations and software upgradation.

Installation and Commissioning of Upgraded TACTIC Data Acquisition System

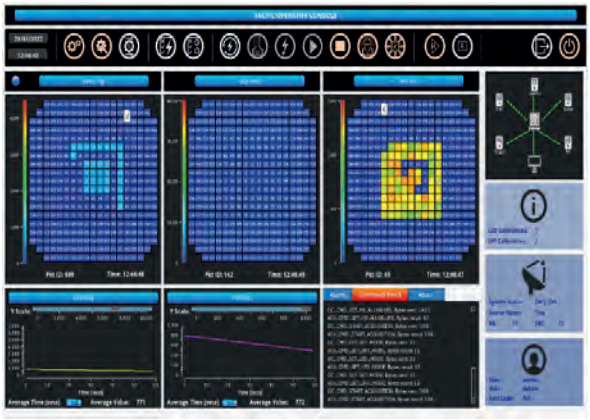
The TACTIC gamma ray telescope incorporating an imaging camera of 349-pixels of Photo Multiplier Tubes (PMT) has been in operation at Mt. Abu, India since 2001. TACTIC has been upgraded and provided with distributed DAS. It consists of eight CAMAC nodes, High Voltage nodes, trigger generator node over Ethernet and data acquisition software. The software of upgraded DAS comprises HV & CAMAC controllers TACTIC Engine and TACTIC Clients for control, monitoring and data archival with safety features for PMTs against over exposure.

128-channel Data Acquisition Module with built-in FPGA based Time-to-digital Converter

A low-power, high performance 128-channel DAM has been developed for Iron Calorimeter experiment of India based Neutrino Observatory (INO). The module incorporating FPGA based 128-channel precision Time-to-Digital Converter (TDC) with 40 µs dynamic range & 84.4 pico second resolution facilitates trigger and triggerless data acquisition modes. The DAM also includes LVDS I/O interfaces, an in-house developed multi-hit ANUPAL-II-TDC ASIC, ARM Cortex-M4 micro controller, Ethernet interface, an in-built



Upgraded DAQ at TACTIC, Mount Abu.



TACTIC Run Console.

Multi-factor authentication System.

BARC SEM installed at IIT-Bhubhaneshwar.

power supply unit and controls for external peripherals. The module targets muon tomography and other high energy physics experiments requiring large number of readout channels.

In-house Developed Multichannel Prototype DAQ System for Pulse Digitization and Time Stamping in ISMRAN Setup

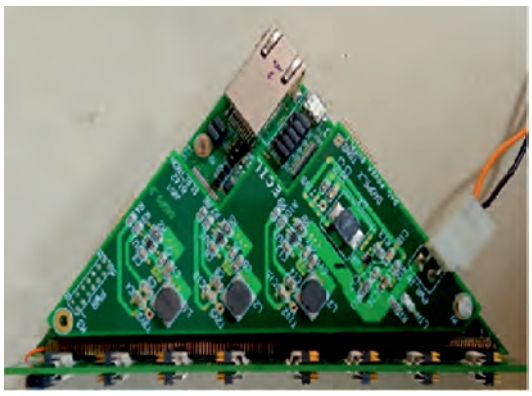
A prototype 4-channel fast DAQ System is developed and tested with ISMRAN detector. The pulse output from the PMT has 5 nanosecond rise time and 30nanosecond fall time. It is necessary to detect the coincidence of these two pulses with around 25 nanoseconds window. The requirement is to measure the timing between the two pulses acquired in both the PMTs with the help of high-speed digitizers. A prototype development for the timing measurement with ISMRAN detector is demonstrated with 250 MSPS Digitizer (HSD-02250). Data Acquisition (DAQ) software and FPGA firmware for timing and energy measurement are also developed. The results are comparable with the commercial systems.

Power Converters for Facility for Antiproton and Ion Research (FAIR), Germany

The FAIR is being set up at Institute for Heavy Ion Research (GSI), in Darmstadt, Germany under the aegis of International Cooperation of a group of countries including India. BARC and ECIL have jointly taken up the design, manufacture, testing and supply of 5 varieties of power converters. Till date, 48 converters have been delivered to FAIR from a total of 75 such units. These convertors will be employed in systems for driving warm magnets of FAIR, having requirement of 100 ppm stability.

Integration & Commissioning of 150kV, 100Amp Solid State Pulse Modulator with Klystron at EBC, Kharghar

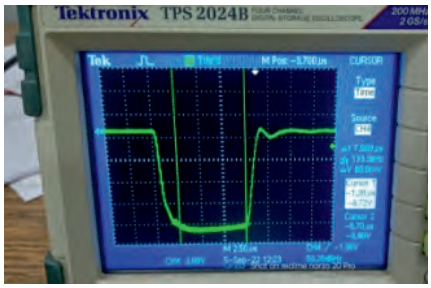
Solid-state pulse modulator generates high-voltage pulses with specified rise/fall time & pulse width for driving Klystron. Indigenously developed solid-state Pulse Modulator uses low voltage (~1 kVDC) at the input, generates 150kV rectangular pulse.



128-channel DAQ system.

525Amp, 53.5V Power Converters HB.Q11 (35 Nos).

Solid State Pulse Modulator (Front side view).



Klystron Current Pulse 90 Amp, 7.5µsec.

It was integrated and commissioned with Klystron of the Electron LINAC at EBC, Kharghar and tested up to 136kV, 90A, 150Hz PRF having 12.2MW peak power, 13.77kW average power with a Klystron output average power of 5.6kW.

Communication, Networking and Computing Systems

High speed and highly reliable communication systems and networks are the backbone of today's interconnected world. With interconnected systems spread apart at different geographical locations, protection and security of these assets is also a challenge. E&IG has always taken a lead in development of security systems.

Secure Network Access System

Secure Network Access System is an indigenously developed integrated network security appliance consisting of multiple security components like Network Admission Control (NAC), Dynamic Host-aware Next-generation Firewall, Network Monitoring System (NMS), USB Device Control and Endpoint Application Behaviour monitoring among others. SNAS has also been augmented with consumption of external threat intelligence received from central agencies as well as openly available sources. Apart from BARC facilities it has also been successfully deployed in various prestigious organizations across the country. This includes ISRO Headquarters, Bengaluru; TBRL, Chandigarh; NPCIL TAPS & NAPS; AERB to mention but a few.

Network security audits of few isolated I&C networks were conducted using a Secure Network Access System developed specifically for such environments. SNAS has also been released on BARC website as a technology available for transfer to industry.

Security Operations Centre

A Security Network Operations Centre application has been developed that collects logs from different firewall/network devices, classifies them and generates alerts for anomalous communication. The application generates a baseline of the traffic patterns and identifies anomalies. The anomaly detection algorithm uses Rule-based, and Machine Learning based approaches to detect anomalous traffic. It has been deployed on Anunet and it is being used to bring greater visibility to network traffic.

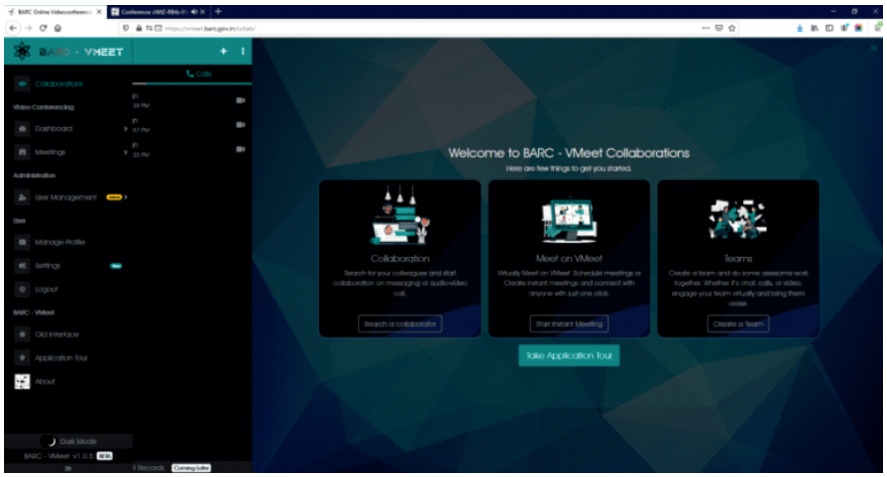
DAE Meeting & VMeet equipped with Collaboration and Network Infrastructure

An indigenous secure online web-based video conferencing solution has been developed. The system supports audio/video/text/documents-based communications with a collaboration platform for team-based communications. The system has been deployed on BARC-Intranet and ANUNET networks. It has been widely used to conduct nearly 1500 meetings per year. The system also supports Webinar mode.

Supercomputing

BARC has developed the 'PRAGYA' Supercomputer, which is dedicated to Machine Learning Applications. It comprises 12 high-end AI servers, where each server is equipped with two 48 core EPYC CPUs of AMD make, four Nvidia A100 GPUs and 1 Tera Bytes of RAM. The software stack of the system is equipped with CUDA SDK, RAPIDS toolkit, Anaconda Python and ML libraries, viz. CuDNN, CuML, Tensorflow, TensorRT and Keras. The benchmarked

Security Operations Centre Dashboard.



User interface of web based video conferencing solution developed in BARC.

PRAGYA Supercomputer developed in BARC.

performance of the system is 683 TFLOPs (HPL Fp64). The system offers dedicated hardware and software resources for executing the training, testing and inference phases of Machine Learning applications. A high throughput data staging system of 1 Peta Byte capacity also has been developed and integrated.

Centralized Data Storage Facility

Computer Division has augmented the Centralized Data Storage Facility of BARC by 15 PetaBytes of storage capacity to cater to the increasing storage demand from the users of ANUPAM Supercomuter, AMBAR Facility, Megh cloud Computing Facility and to archive continuously generated Video data.

Networking and Communication facilities

ANUNET is a wide area network connecting major DAE units with robust multi-layer connectivity. The capacity augmentation of multiple leased links has been achieved to cater to the increased bandwidth requirements. The link between BARC Trombay and Hanle, Ladakh has been upgraded to 200Mbps. The link between BARC-Mumbai and BARC-Tarapur has been augmented to 100Mbps. New sites have been added to Anunet for wider network access to remote DAE locations. The BARC Telecom Network was successfully augmented to support two telecom service providers for external telephone calls with minimal downtime. Anushare, the indigenously developed secure DAE-wide file sharing system hosted on Anunet, has been effectively used by employees of various DAE units for sharing around 8000 documents with a total size of 1.2 TB.

Low Energy High Intensity Proton Accelerator (LEHIPA)

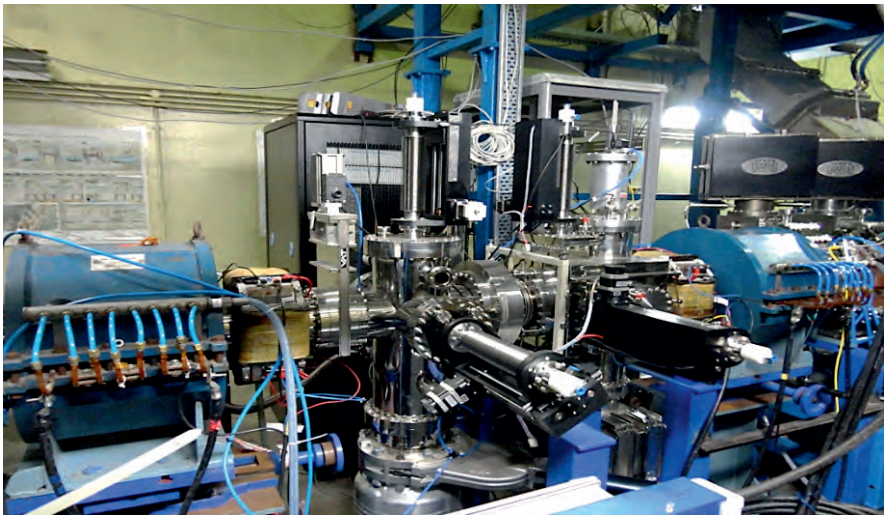
At the forefront of efforts to establish a vibrant Ion Accelerator research and development program in BARC

U. D. MALSHE
Associate Director
Multidisciplinary Research Group
Bhabha Atomic Research Centre (BARC)

A 20 MeV Low Energy High Intensity Proton accelerator (LEHIPA) has been commissioned successfully on 4th of August 2023 in BARC, Mumbai. LEHIPA mainly consists of a 50 keV Electron Cyclotron Resonance Ion Source (ECRIS), 2.7 m long, two solenoid based Low Energy Beam Transport (LEBT) line, a 4 m long, 3 MeV Radio Frequency Quadrupole (RFQ) accelerator, 1.2 m long Medium Energy Beam Transport (MEBT) line and 12 m long, 20 MeV Drift Tube Linac (DTL). The accelerating structures are powered using three 1 MW Klystrons operating at 352 MHz.

LEHIPA

Accelerator Driven Systems (ADS) are attracting worldwide attention due to their capability to incinerate minor actinides (MA), long-lived fission products (LLFP) and thorium utilization as a nuclear fuel for energy production. India has vast resources of thorium, so our interest in ADS is to utilize the thorium for future clean nuclear energy production with minimum amount of nuclear waste generation. The ADS mainly consists of three sub-systems -- High current proton accelerator (1 GeV, 10s of mA current), Spallation target, and the sub-critical reactor. The development of high power accelerator was planned in phase manner, namely 20 MeV, 200 MeV and 1 GeV. The low energy part of high power accelerator is particularly challenging because of high space-charge forces. In the first phase, BARC has initiated the development of 20 MeV high current proton accelerator (LEHIPA). The standalone



Two-solenoid based LEBT Line in LEHIPA.

LEHIPA accelerator can be used to produce neutrons for material research and also for production of PET isotopes for diagnosis. The LEHIPA at the Bhabha Atomic Research Centre (BARC) has reached the target energy of 20 MeV on 4th of August 2023, with peak current intensity of about 2 mA. Successful acceleration to the desired energy involved indigenous design & development of several key technologies meeting multidisciplinary stringent requirements simultaneously.

ECR Ion Source and LEBT

A high current Electron Cyclotron resonance (ECR) proton ion source with a three-electrode extraction geometry has been designed and developed for LEHIPA. This is a 50 keV ECR-IS operating at 2.45 GHz, delivering 10 mA peak proton current with1 ms pulse structure at 2 Hz repetition rate. The ion source is capable of delivering CW beams. A two-solenoid based 2.7 m long, low energy beam transport (LEBT) line was used to match the beam from the ECRIS to the 3 MeV RFQ. LEBT also has a pair of steerer magnets and beam diagnostic elements for beam profile, emittance and beam current measurements.

Radio Frequency Quadrupole

The RFQ accepts the 50 keV DC beam and accelerates it to 3 MeV in a length of 4 m. The 4 m long RFQ is fabricated in four segments, each of length 1 m. The 2-meter-long sections are coupled via a coupling cell. The average bore radius of RFQ is 3 mm, with a vane voltage of 68 kV. The mechanical structure of RFQ consists of two major and two minor vanes, machined in OFE copper and are brazed together. The allowed tolerances in the RFQ internal surface are within 50 µm. This required brazing of 64 tuners along with several other ultrahigh vacuum compatible joints. This complex technology was successfully developed after several stages of prototyping.

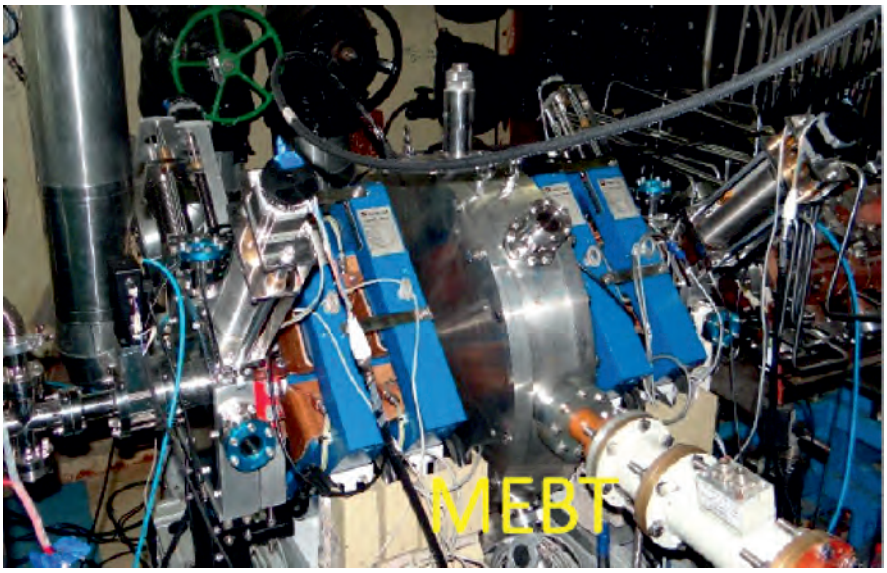
Medium Energy Beam Transport Line

A 1.2 m long MEBT line of LEHIPA is used to match the beam from RFQ to DTL in both longitudinal and transverse directions. It mainly consists of 4 quadrupole singlets of effective length 80 mm each and a double gap re-buncher cavity. It also has steerer magnets and various diagnostics elements for beam position, profile, and current monitoring.

Drift Tube Linac

The LEHIPA DTL is designed to accept the bunched beam at 3 MeV and accelerate it to 20 MeV in a length of 12 m. The DTL was fabricated in 4 different tanks of length 3 m each. This modular design not only simplifies the tuning and stabilization process but also allows the independent commissioning of each tank. The 3-meter-long DTL tank is fabricated in two 1.5 m sections. The DTL tanks are fabricated in mild steel (MS) with copper plating on the inner RF surface for a thickness of 200 µm. The drift tube assembly is made of OFHC copper. There are more than 100 drift tubes in the entire DTL. Laser welding technique has been used in the drift tubes, enclosing the high

The RFQ in LEHIPA.



The MEBT line in LEHIPA consisting of four quadrupoles and one re-buncher cavity.

gradient permanent magnet quadrupoles (PMQs). The drift tubes are aligned to within 150 µm accuracy with respect to the tank axis using laser tracker.

High Power RF Couplers

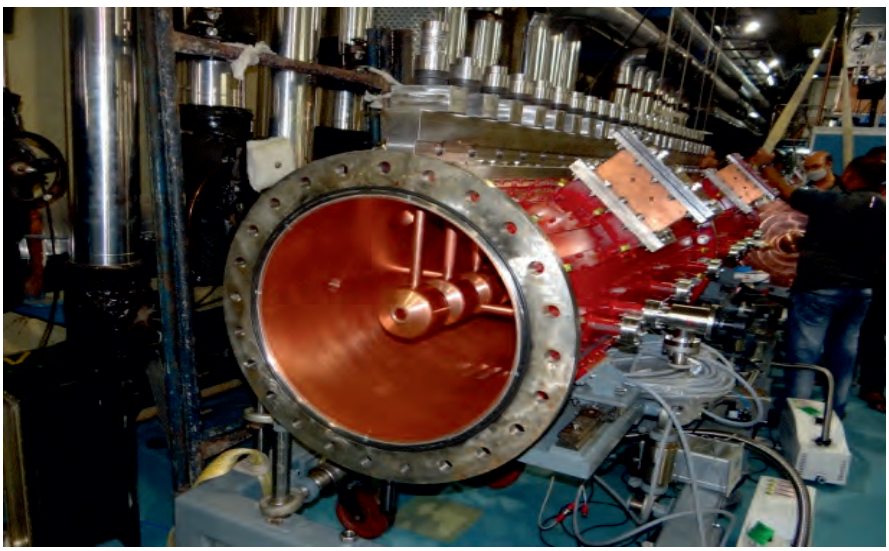
RF power couplers couple the power from the RF amplifiers to the accelerating cavities by matching the waveguide transmission line impedance to the RF cavity impedance. High power ridge waveguide couplers for 250 kW CWRF power have been designed and developed for the LEHIPA cavities. The power is coupled through an iris of 1.55 mm between the end ridge and the accelerator cavity. These water-cooled structures are made of OFE copper material with several brazed joints and tested for ultra high vacuum requirements. Two couplers are used in RFQ and a total of 8 couplers are used for the DTL.

Low Power RF Characterization

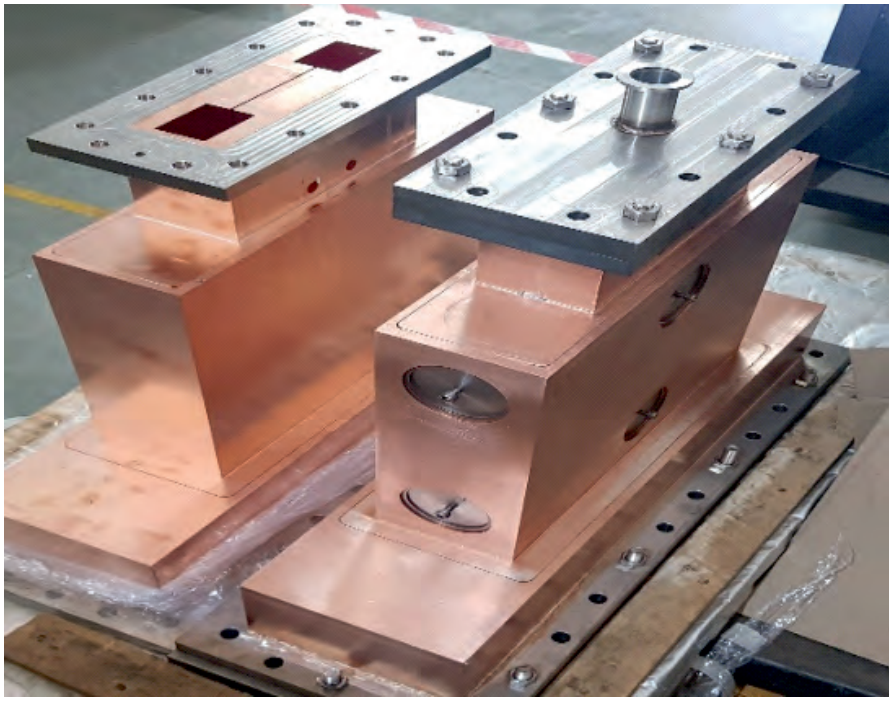
Dimensional errorsduring RF cavity fabrication and assembly can lead to deviations in the operating mode frequency of the cavity and E-M field profiles in the cavity. The low-level RF characterization of RFQ and DTL mainly involves the identification and stabilization of cavity operating mode and E-field tuning. Bead-pull measurement technique has been used for the E-field measurements in the accelerating cavities. In the case of RFQ, the E-field profiles in all 4 quadrants were measured and the Electric field flatness of < 5% was achieved by insertion length optimization of 64 tuners in the RFQ cavity and the dipole mode separation was achieved to > 2 MHz using dipole stabilizer rods. The Field tuning and stabilization in DTL has been achieved by optimization of ~10 post couplers and 6 tuners in each tank. Tilt sensitivity of < ±25 %/ MHz and E-field flatness of < ± 3% of the design value at the operating mode frequency has been achieved for all DTL tanks.

Beam Diagnostics

A variety of beam diagnostic devices have been developed for the beam characterization and accelerator control in LEHIPA. High resolution beam measurements in both space and time with least invasive techniques are required for continuous monitoring of high intensity beams. These are machine specific devices with high commercial procurement costs and hence many of them are developed in-house. Beam diagnostic devices have been developed for measurement of transverse and longitudinal beam profile, beam current, beam position transverse and longitudinal beam emittance measurements. These include, wire scanner and gas sheet based transverse beam profile measurement setups, button pickup beam position monitors (BPMs), Faraday cups for beam current measurements, wide bandwidth (>7 GHz) fast Faraday cups (FFCs) and wall current monitors (WCMs) for beam bunch structure (~200 psrms) measurements, slit-wire and Allison scanner based transverse beam emittance measurement setups and movable BPM based beam energy measurement setups.



The Drift Tube Linac in LEHIPA.



The two ridge waveguide couplers of LEHIPA.

Control System

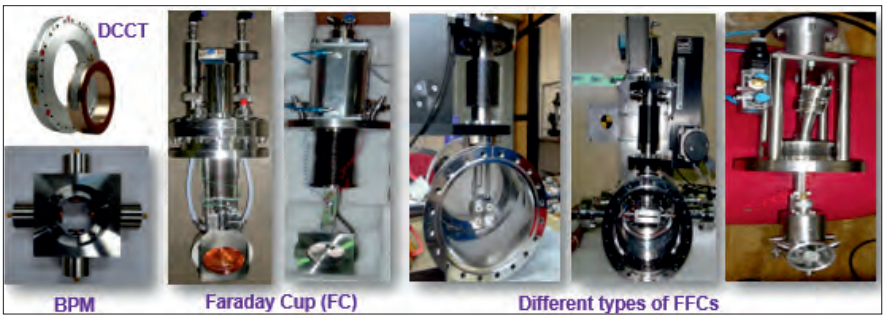
The control system of LEHIPA is a distributed control system. Each of the LEHIPA subsystems have their own local control stations (LCSs) to meet own data acquisition and control requirements. These subsystems are then interconnected to the control room servers and Operator Work Stations (OWS) using high speed redundant via a Local Area Network (LAN) along with the Interlock and Timing Signals. As Integrated Control System (ICS) is being implemented to provide the required global control for LEHIPA with the subsystems. The ICS communicates with each of the LCSs and synchronize the various operations to start the accelerator, provide synchronization requirements for various subsystems during operation, tune the beam for required characteristics, shutdown the accelerator under normal condition and emergency condition, provides overall machine protection and interface various subsystems to the operator in a homogeneous manner for comprehensive operations, troubleshooting and maintenance in addition to archiving of data from different subsystems for future reference/provision of history. The ICS provide online support and operator guidance and displays data on control room displays. The control system works on Linux operating system and uses EPICS based SCADA framework for LCS and EPICSQt based GUI panels for operator workstation.

RF Amplifiers and Waveguide Transmission System

Three Klystrons of 1 MW each and a 10 kW solid state amplifier are used in LEHIPA to power the RFQ, DTLs and re-buncher cavity. The 1 MW Klystrons (Model: TH2089) operate at RF frequency of 352 MHz. The klystron filament power supplies, electro-magnet and vacuum power supplies, HV anode bias network, solid state RF drivers along with the interlock and protection system (IPS) have been developed indigenously by ACnD, BARC. The high-power RF waveguide transmission system connecting the RF amplifiers to the linac have been developed in-house by ACnD, BARC, which include WR2300 waveguide straight sections, E/H plane bends, directions couplers, magic tees, phase shifters, RF vacuum windows, RF loads etc.

Low Level RF (LLRF) System

Low Level RF system is essential to control the amplitude and phase of the RF fields inside the cavity. The hardware of the system consists of an Analog conditioning module (ACM) and a cPCI based digital board built around an FPGA. The ACM consists of input buffer/attenuation and the output drive amplifier sections. RF buffer/attenuationunit at the input and RF amplifier unit at the output provide input protection and help in achieving wide dynamic ranges. The digital LLRF using FPGA for fast implementation of the required control algorithms, can achieve the required field regulation in few 10s of micro-seconds. Windows based GUI application software has been developed for control and display of parameters and data. LEHIPA has total of four LLRF systems for the control of RF



Various diagnostics used in LEHIPA.

The RHVPS system for LEHIPA.

fields in RFQ, re-buncher, DTL 1&2 and DTL 3&4. The system was developed in BARC through in-house efforts and has been used in LEHIPA to stabilize the cavity amplitude and phase within 1% and 1 degree, respectively.

Regulated High Voltage Power Supply

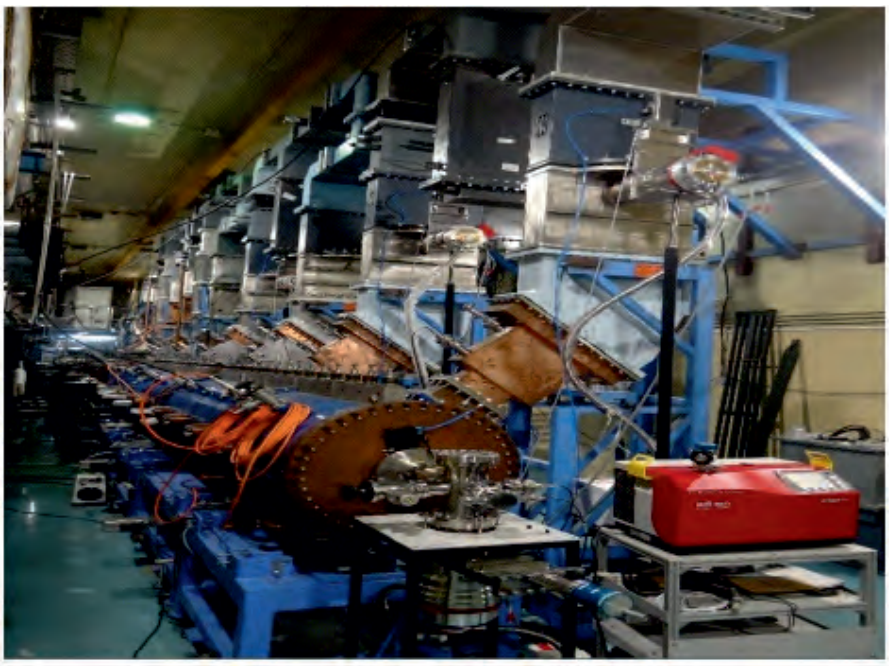
The RHVPS for the 1 MW klystron is switched power module (SPM) based 100 kV, 25 A, CW power supply, designed by IPR, Gandhinagar and developed by ECIL, Hyderabad in a joint collaboration effort with BARC. Two multi-secondary oil-cooled transformers feed the 96 SPM modules whose outputs are connected in series. FPGA-based C&I has been used for fast pulsing pulse step modulation (PSM) sequence, feedback control of output voltage, fast interlocks and online health monitoring of all modules. The criteria that, <10 J energy deposit in klystron in an event of arcing/short circuit, is ensured by the fast cut-off of gate pulses and has been tested by wire-sustainability tests. For the phase stability of RF power output of klystron, the ripple in the output voltage need to be better than +/- 1%, and this has been achieved by feedback control of output voltage. The Presently, Klystron for RFQ cavity is being biased with pulsed modulator developed by RRCAT, a constituent unit of DAE.

Vacuum System

Base vacuum of the order of 1×10^{-7} Torr or better has been maintained throughout LEHIPA beamline to minimize the undesired scattering of beam by residual gas molecules which can result in beam loss and emittance growth. Also, the accelerating cavities need to maintain ultra-high vacuum to achieve the high electric field gradients required for beam acceleration. Lumped pumping scheme has been employed in LEHIPA beam line using Turbo Molecular pumping system in each linac section at optimized location to obtain the required base vacuum. A total of 25 turbo molecular pumps backed up by dry pumps have been deployed in LEHIPA linac line. Sputter Ion Pumps (SIPs) have been additionally used in RFQ to overcome the low conductance of the structure. Radiation resistant Pirani and Penning gauges have been used to monitor the vacuum level remotely from the control room.

Low Conductivity Water System

Low Conductivity Water (LCW) system is designed to remove more than 8 MW heat generated from the various components and subsystems of the linac, including ECR-IS, RFQ, DTL tanks, electromagnets and power supplies of the beam transport lines, RF power amplifiers consisting of three, 1 MW Klystrons and solid state amplifier and beam dump. The heat load on the LCW system is transferred to the secondary coolant system through a set of heat exchangers. The water chemistry has been maintained by control of dissolved oxygen, pH, conductivity, and particulate matter by



LEHIPA accelerator view from exit side.

circulation through a purification circuit. A Data Acquisition System (DAS) with Graphical User Interface is used for logging of all the important process parameters at regular intervals and to generate necessary interlocks and alarms. A computer-based system namely (LCW-DAS) is used for the above purpose. The LCW system was developed fully in BARC.

Beam Commissioning

The commissioning of LEHIPA was executed in eight distinct sequential stages. The commissioning of the ECR-IS, in conjunction with the Low-Energy Beam Transport (LEBT) system was the first stage. The commissioning of the half section (2 m) of RFQ to 1.24 MeV energy was done in the next stage. The 3 MeV proton beam has been recently utilized for irradiation experiments in BARC. MEBT was assembled and commissioned after RFQ. DTL tank 1 was commissioned next, by beam acceleration to 6.8 MeV in March 2022. The 11 MeV beam acceleration through DTL tanks 1 and 2 was achieved in May 2022. After that, DTL tanks 3&4 were assembled and commissioned to the design energy of 20 MeV on 4th of August 2023. Detailed beam characterization was done using indigenously developed beam diagnostic devices during each stage of commissioning. The beam energy has been measured using different techniques like bending magnet, Time of Flight (ToF) measurement, Rutherford Back Scattering (RBS) technique etc.

Technological Challenges in LEHIPA Development

Successful acceleration to the desired energy involved indigenous design & development of several key technologies meeting multidisciplinary stringent requirements simultaneously. Some examples of the important technologies developed are briefly discussed here. Vacuum brazing of structures was done to obtain post brazing dimensional tolerances of better than +/- 50 microns in 4 m long Radio-Frequency Quadrupole (RFQ) cavity and +/- 100 microns in ridge waveguide RF couplers. More than 200 joints of RFQ were required to meet ultra-high vacuum operating conditions. Laser welding process was developed for Drift Tube Linac (DTL) copper components housing permanent magnets to achieve alignment of more than 100 magnets within 150 microns inside DTL tanks over 12-meter length. Indigenous development of 100 kV, 20 Amp regulated high voltage power supplies was completed with better than +/-1% amplitude stability. This power supply is used for biasing the high power klystrons. Power supply of this scale and required regulation is developed first time indigenously. Design & development of Electron Cyclotron Resonance (ECR) ion source was completed with its extraction geometry to obtain more than 10 mA proton beam with emittance better than 0.27 π.mm.mrad at less than one third cost of a commercial ion source. LLRF system was developed to obtain field amplitude stability within 1 % and phase stability of better than 1 deg. Synchronized operation of several RF sources and resonator cavities along with various subsystems by indigenously developed control system was implemented.
All these sub-systems were developed mostly with small scale industry by improving their understanding to take up such challenging tasks. Integration of all the subsystems during commissioning and during accelerator operation has provided significant insight to take up challenges of design and deployment of accelerators delivering higher energy and intensity proton beams.

FOUNDER'S DAY 2023
special issue

In Pursuit of Greater Indigenisation in Advanced Beam Technologies

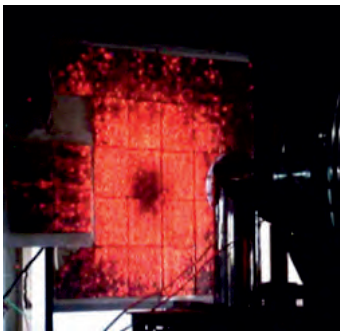
Beam Technology Development Group has the mandate to perform R&D work on various systems by employing lasers, plasma and electron beams for ensuring directed applications in India's Nuclear Power Program

Dr. ARCHANA SHARMA
Director
Beam Technology Development Group
Bhabha Atomic Research Centre (BARC)

Beam Technology Development Group, BARC comprises four divisions, namely Laser and Plasma Technology Division (L&PTD), Advanced Tunable Laser Application Division (ATLAD), Accelerator and pulsed power division (APPD), Pulsed Power and Electro-Magnetics Division (PP&EMD BARC Vizag). A dedicated project namely Electron Beam Centre at Kharghar, Mumbai is also a part of BTDG. These divisions focus on different aspects of BARC mandate.

Accelerator & Pulse Power Activities

In India, pulsed power work was started at BARC in 1960s. The Kilo Ampere Linear Injector (KALI) series systems were commissioned. KALI 30 GW (1 MV, 30 kA, 80 ns) system (2004) is the most powerful of all of them. This pulse power system is based on the topology of Marx generator discharging on a load through coaxial blumlein pulse forming line (CBPFL). Length of the CBPFL decides the output pulse duration. At KALI 30 GW system maximum FXR dose of 1.2 R at 1 meter from source and 1.4 GW HPM power at 3.28 GHz frequency have been recorded. The HPM generation experiments were carried out using device known as backward wave oscillators (BWO). LIA 400 (400 kV, 4 kA, 120 ns) system (2014) is having the highest pulse repetition frequency from 8 Hz at full rating to 300 Hz at lower ratings. This system generates 300 MW peak HPM power with Magnetron at 3.0 GHz HPM frequency.



Clockwise from top: KALI 30 GW pulse power system. Illumination of neon bulb array upon HPM irradiation and LIA 400 pulse power system with Magnetron.

The compact Marx generator based pulsed power systems have been developed for Flash X-ray radiography and high power microwave generation applications. The four channel Marx generators are being used for dynamic radiography applications A new compact Marx with Permanent magnet for repetitive HPM generation in X-band frequency is also under operation.

Another important area of Pulse Power technology is the Magnetic Pulsed Welding (MPW) of special metals (ODS, D9, Al) for reactor fuel pin fabrication. It is a solid state welding with no heat affected weld zone. BARC has made significant progress in joining dissimilar metals having vast variation in their mechanical properties using this method. Recently, the feasibility of MPW in Dhruva reactor fuel pin clad and end plug joining has been carried out successfully in an in-house joint collaboration project.

The weld qualifications criteria to be satisfied are: Glycol test and Helium Leak Test, UT confirmation of bonding, helium leak test after the sample is subjected to thermal cycles (up to 150°C), pressure burst test up to 8 bar, weld confirmation by optical microscope and SEM.

Pulsed Power & Electro-Magnetics

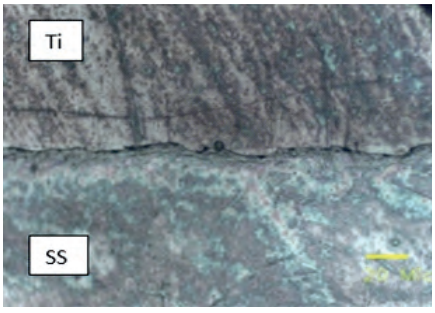
MPW technique is employed successfully in joining Ti tube to SS tube using a multi-turn and shaper tool coil at a peak magnetic field of 33T, 17 kHz frequency and impact velocity in the range of 300-400 m/s.

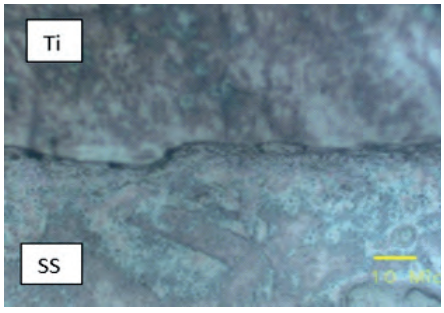
In a phased development program, linear transformer driver of LTD 300 is undergoing commissioning activities. The specified output is 300kV, 100kA and 60ns pulse at the matched resistive load or diode assembly of 3Ω.

Experiments for Enhanced Oil recovery in some of the Indian Oil wells using BARC developed technology viz. Ultrafast pulsed plasma based shock wave generator has been successfully conducted up to 1.825 km depth in Indian oil wells under MoU between BARC and ONGC.

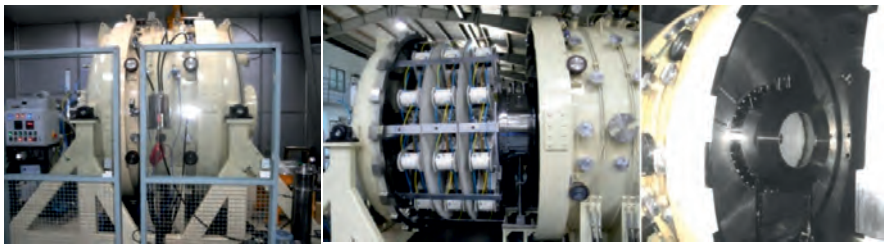
Air plasmatron is operated at 50 kW, 190A at BARC (Facilities), Visakhapatnam in short time operation. The compressed dry air is fed to air plasmatron to generate high enthalpy air plasma at the torch exit. Further enhancement of the power and duration of operation is currently being planned.

Nearly 30 grams of tungsten nano-powder is recently produced in a couple of days by the indigenously developed machine which is forwarded to Materials group BARC for further using it in R&D activity in the field of material research.





Ti- SS weld interface at 500 X resolution and at 1000X resolution.



LTD-300kV.

Radiation processing applications in 10 MeV, 3 kW accelerator at EBC, Kharghar.

9 MeV RF Electron LINAC has been successfully demonstrated for neutron radiography application in photo-neutron production scheme. By proper gating of the ICCD imaging camera neutron radiograph of adequate resolution was obtained even at low thermal neutron flux. This is first demonstration in India for photo-neutron based radiography.

Electron Beam

In the early nineties, industrial applications of electron accelerator attracted significant interest within BARC for their utility in multidisciplinary areas alongside basic research. Therefore indigenous developments of industrial electron accelerators program are taken up by BARC. First indigenous Cockroft-Walton accelerator of 500 keV was commissioned by BARC at BRIT, Vashi, Navi Mumbai, in 1998. Subsequently, BARC has set up a new facility namely Electron Beam Centre (EBC) at Kharghar, Navi Mumbai, to meet the further developmental objectives of higher energy electron accelerators and their respective uses. EBC has developed several accelerators of different types to tackle a broad range of applications.

10 MeV, 3 kW LINAC

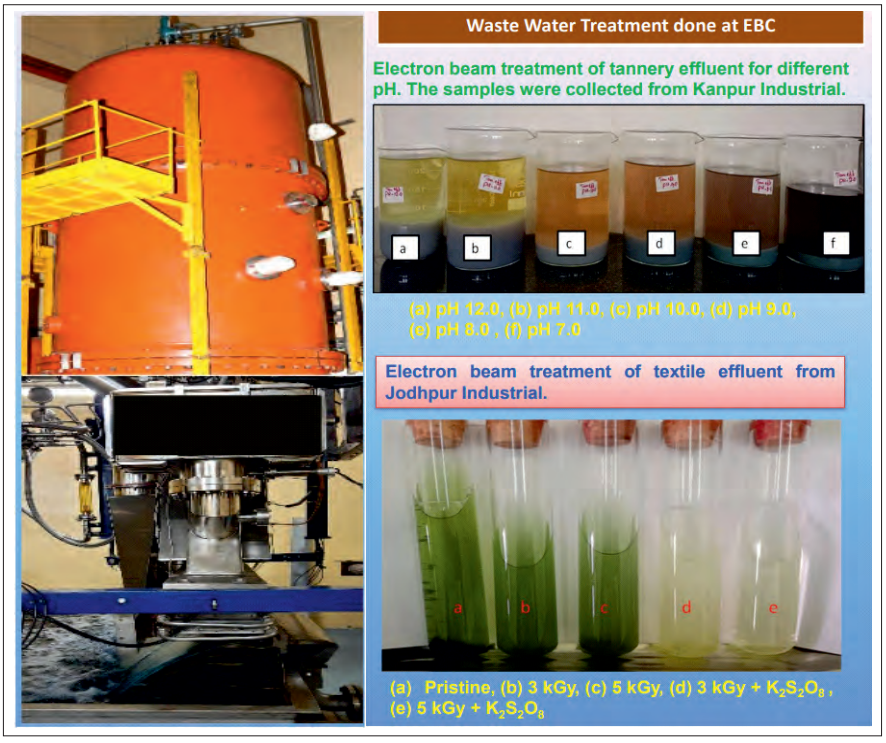
This LINAC has vertical configuration and is being utilized for various fields. Out of these, several applications were identified, including in cables, semiconductor modifications, gemstone coloration, polymers, bio stimulators etc., have achieved the industrial level of maturity and are applied for actual utilization. Ruggedness of the system has successfully been tested by running it round the clock reproducibly without any trip. Recently, this facility is transferred from DSRC-AP to OPSRC for regular operations based on the successful performance of the LINAC and its subsystems.

1 MeV DC Accelerator

1 MeV DC accelerator is based upon symmetric Cockroft Walton principle. The system is qualified for the ruggedness check for 24 hours continuous operation. Presently the system is operational at 50 kW beam power and the experiments on waste water treatments are going on. The successful demonstration of this accelerator has provided us the opportunity for deployment of 1 MeV DC accelerator at Unnao (Uttar Pradesh) for treatment of tannery water as part of 'National Mission for Cleaning Ganga (NMCG)'.

10 MeV, 5 kW LINAC

This is a compact and table top accelerator, having pre-buncher cavity set up, to test the locally developed components at higher beam power. The beam transmission achieved through



1MeV DC accelerator employed for waste water treatment (on the left) Water from dye units treated with DC accelerator (top right), and change in optical density of dye water after application of optimum dose at EBC facility.

the pre-buncher beam line is 99%. Additionally the improved thermal design has been incorporated in this Linac through jacketed type cooling arrangement to remove heat efficiently and operate the system at higher power continuously.

Advanced Tunable Laser Applications

Radioisotopes are commonly used worldwide in various fields, including medicine, agriculture, industry and research. In general, radioisotopes are formed through nuclear reactions inside a reactor or an accelerator which subsequently processed to bring them in useful form. In the case of radiopharmaceuticals, high specific activity and high radionuclide purity is desired for therapeutic as well as diagnostic purposes. Therefore, it specifically requires isotopic enrichment along with high elemental purity. Laser based isotope separation technique using indigenously developed narrowband tunable lasers, is being employed in BARC for the enrichment of various isotopes of lanthanides for medical applications.

Of late, BARC successfully demonstrated high enrichment of Lu-176, Yb-176, Yb-174, Yb-168 and Sm-152 isotopes with isotopic purity adequate for their intended purposes. Clinical-grade Lu-177, produced from the enriched Lu-176, is being routinely used in various hospitals in India. The focus of BARC is to enhance the production rate of some of these isotopes through process optimization and thereby making India self-reliant in this critical domain.

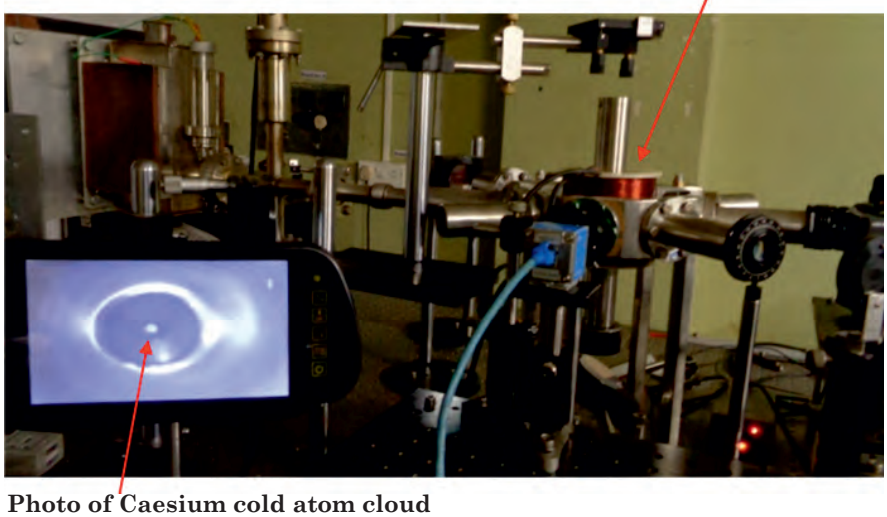
Precisely tunable diode lasers find wide applications in the field of laser cooling of atoms and ions. BARC is also pursuing laser cooling and trapping of neutral atoms for demonstration of atom-based quantum computing. Quantum computing has numerous future potential applications such as simulation of quantum processes, development of new drugs, storage and fast processing of huge data, secure communication, artificial intelligence etc. In this regard, laser cooling and trapping of Caesium atoms in a Magneto-Optical-Trap (MOT) using the phenomenon of Doppler shift has been demonstrated. Fluorescence image of the cold atom cloud was recorded by a CCD camera. The size of the cloud was estimated to be ~1 mm and total number of cold atoms was estimated to be ~106 using the rate of emission of photons from the atomic cloud. The cooling laser was locked at a frequency red shifted by ~10MHz from the transition $6s_{1/2}\ F = 4 \rightarrow 6s_{3/2}\ F' = 5$ (resonant frequency 0=351.7219605 THz). The re-pump laser was locked at $6s_{1/2}\ F = 3 \rightarrow 6s_{3/2}\ F' = 4$ transition (resonant frequency 0=351.7309022 THz). Magnetic field gradient was maintained at ~ 10 gauss/cm. The intensity of the cooling laser beam was ~ 0.5 mw/beam. Presently, experiments are being planned for decreasing the temperature of atomic cloud further below to ~10 K using Sisyphus technique so that they can be trapped in the optical tweezers (potential wells) created by highly focused laser beams for establishing qubits.

Laser & Plasma Technologies

An EFCAP (Excitation Frequency Controlled Cold Atmospheric Pressure Plasma) torch operating between 10 kHz and 100 kHz is being developed for biomedical application. Research on the effect of frequency on the cancer cells (MCF-7 and MDAMB-231) is being investigated. At an operating frequency of 11 kHz it was found to show a higher death of cancer cells due to higher ROS generation.

To precisely align the fuelling machine with the end fittings in PHWR reactors, a fibre optic based non-contact fuelling machine tilt measurement system has been developed for NPCIL. It is based on optical triangulation technique. The system is successfully tested at the Calibration and Maintenance Facility (CMF) of TAPS-3 & 4.

Pulsed laser deposition of ZrO_2 thin film on Ti6Al4V bioalloy revealed improved wear resistance, corrosion resistance and hemocompatibility of the samples when coating took place at higher substrate temperature of 800°C.



Experimental setup for obtaining laser cooling and trapping of neutral atoms.

Expanding Frontiers of Scientific R&D through Cutting-edge Chemical Engineering for DAE Programs

Developing & deploying processes and technologies for a vibrant nuclear fuel cycle, energy security, water security, and environment management

K. T. SHENOY
Director
Chemical Engineering Group
Bhabha Atomic Research Centre (BARC)

Chemical Engineering Group, BARC is engaged in diverse R&D activities, projects and O&M activities primarily aimed at serving the DAE mandate. The Group's activities encompass development and deployment of novel processes, technologies, equipment, materials, import substitutes and to ensure uninterrupted supply of special materials.

Fluidized Bed Thermal Denitration

Fluidized bed thermal denitration technology finds several applications for waste management and process intensification in the nuclear fuel cycle. Fluidized bed thermal denitration technology for treatment of NH_4NO_3 waste stream was deployed in the back-end of the nuclear fuel cycle at Uranium Oxide Facility, Kalpakkam (UOF-K). Direct denitration of uranyl nitrate to produce UO_3 using fluidized bed thermal denitration was demonstrated at bench scale Direct Denitration Demonstration Plant (DDDP) at a Nuclear Recycle Board site using quality grade uranyl nitrate solution.

Bench-scale Synthesis and Purification of Sr-selective Crown Ether DTBDCH$_1$8C6

The process for synthesis of Sr selective advanced crown ether ditertiary-butyl- dicyclohexano-18-crown-6 (DTBDCH18C6) was successfully developed. The in-house synthesized product has purity of 93% and a distribution coefficient of Sr (>7) with high separation factor against Ca, Am and Cs. A 1 kg/batch plant has been set up for recovery of Sr-90 from high level nuclear waste.

Pulsed Disc and Doughnut Column (PDDC) demonstration setup at Uranium Extraction Division in BARC.

Demonstration of Close Loop High Purity Poly-silicon production

India is the third largest producer of Silicon metal and one of the leading consumers of Silicon. However, the country does not produce polysilicon ingots, which is the basic raw material for semiconductor industry. Three process steps were envisioned to address this shortcoming properly, namely Fluidized bed reactor for Trichloro Silane (TCS) feedstock production from Metallurgical grade (MG) Silicon, followed by purification of TCS to high purity grade (>10N purity) by distillation and finally polysilicon manufacturing in a Chemical Vapor Deposition (CVD) reactor. For the first time in the country, a close loop high purity polysilicon production has been demonstrated from MG Silicon. The product purity is also confirmed to high purity grade (~9N).

Pulsed Disc and Doughnut Column for Solvent Extraction Process

In a collaborative work with Materials Group, BARC, Pulsed Disc and Doughnut Column (a differential contactor) was successfully demonstrated for uranium extraction in the front-end fuel cycle at Uranium Metal Plant facility, BARC. Deployment of this technology in uranium refining process plants would lead to significant process intensification alongside ensuring high safety during the plant operations.

Technology for Industrial Scale Alkaline Water Electrolyser

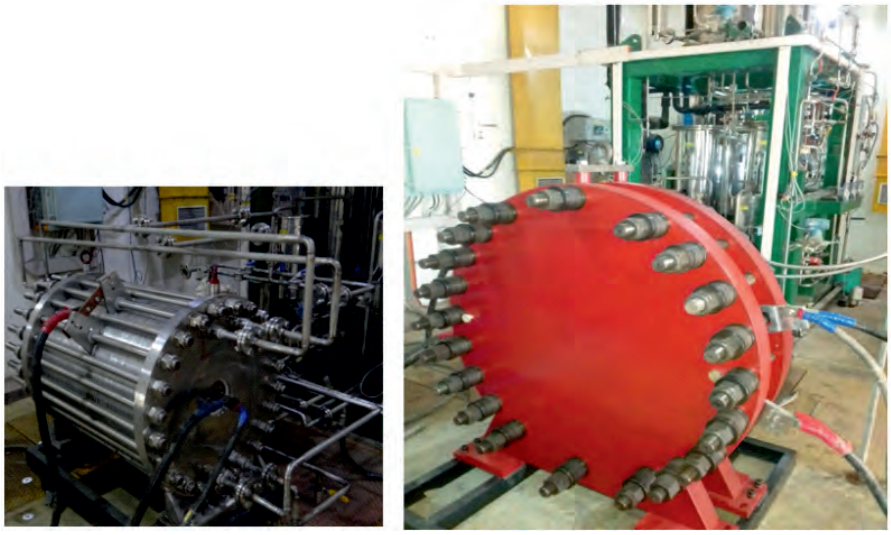
BARC has developed an in-house compact Alkaline Water Electrolysis Technology for high purity Hydrogen and Oxygen production (50KW, 10,000 Nlph hydrogen). The technology was transferred to different industries, including leading PSU refineries such as BPCL and HPCL. A prototype electrolyser cell module stack (0.5MW, 100,000 Nlph hydrogen) has also been designed, developed and tested. This is a first-of-its kind indigenous cell module developed in the country confirming to all performance parameters at par with the international standards.

Copper-chlorine Thermochemical Cycle for Nuclear Hydrogen Production

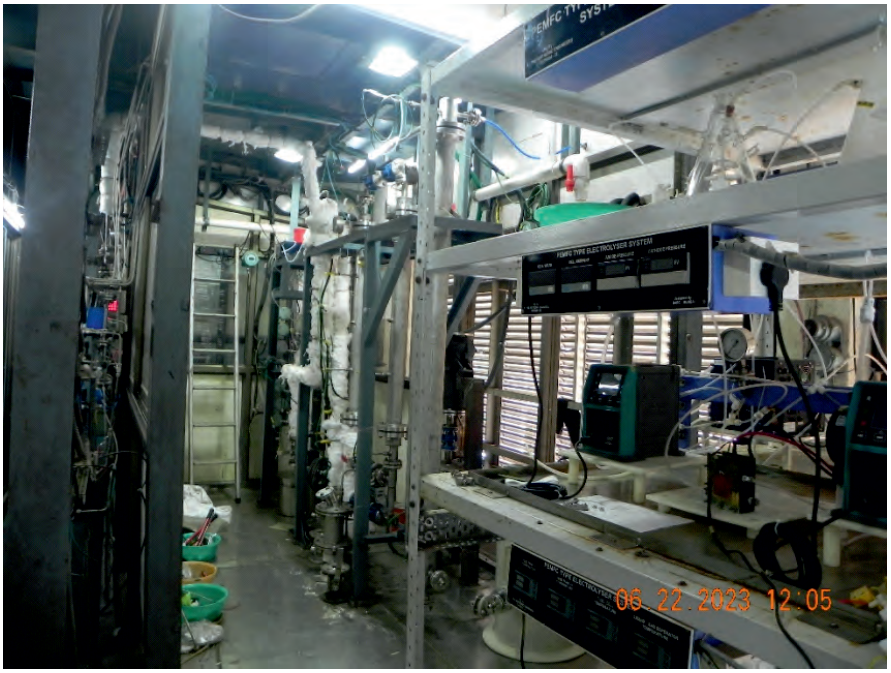
In its quest for establishing nuclear hydrogen, an integrated facility for hydrogen production by Cu-Cl thermochemical cycle was commissioned in BARC and production of hydrogen at 4-5 NL/h throughput was successfully demonstrated for a period of 40 hours. It is a first-of its-kind integrated four-step demonstration facility operational in the world.

Lab-scale Water Electrolysers for High Purity Hydrogen

A lab-scale Proton Exchange Membrane (PEM) based pure water electrolyser cell has been developed using completely in-house Membrane Electrode Assembly (MEA) technology. This cell was operated up to 10,000 amperes per square meter (ASM) current density at maximum operating voltage of 1.92V (~77% efficiency). Further endurance trial of PEM water electrolyser cell was carried out at current density of ~5000 ASM for >300 hours without any significant performance degradation. A capillary based lab scale electrolyser cell has also been developed and demonstrated. This system does not require any separate gas liquid separators and it produces high purity hydrogen from cell module itself. The system is operated at room temperature and at a current density of 1500 ASM with ~99.9% gas purity.



Left to Right: 50kW Electrolyser cell module; and prototype to 0.5MW cell, integrated with the plant.



First-of-its-kind integrated closed loop metallic Copper-Chlorine facility in BARC.

Enhanced HI Decomposition in I-S Thermochemical Process

A multi-tube Ta membrane reactor of 50 LPH hydrogen production capacity was designed, developed and demonstrated for enhanced (≥ 85%) single-pass HI to H_2 conversion compared to that of a conventional reactor with a conversion of up to 22 %.

Membrane Diaphragm for Alkaline Water Electrolysers

Import substitutes like Zirfon, Polysulfone-ZrO_2 mixed-matrix membrane diaphragms were developed using indigenously design and fabricated membrane casting machine as an alternative to asbestos. The performance of in-house diaphragm was found to be at par with asbestos and commercially imported alternatives (~2.97±1% V at a current density of 5000 ASM; ~2.99 V for Zirfon), while being 5-10 times cheaper. The technology has been transferred to several private entrepreneurs (including four Indian manufacturers) for commercialization and deployment.

Metal Membrane Permeator for High Temperature Steam Electrolysis

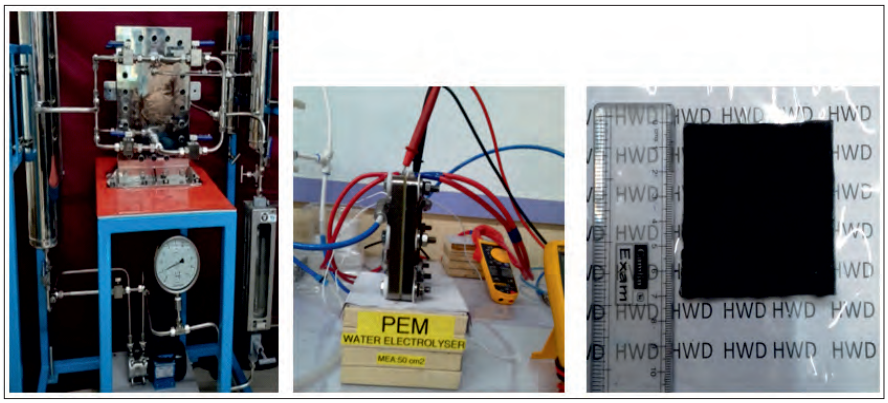
In order to decrease thermal burden in HTSE process, a Pd-Ag metal membrane permeator was developed and successfully tested for steam-hydrogen separation. For a steam-hydrogen mixture (75:25), the metal membrane permeator offered a hydrogen flux of 5 LPH with >98% pure hydrogen at 50 mbar and ~150° C. This has paved way for ex-situ and in-situ separation of hydrogen-steam mixture in HTSE process.

Thermal Desalination Technology

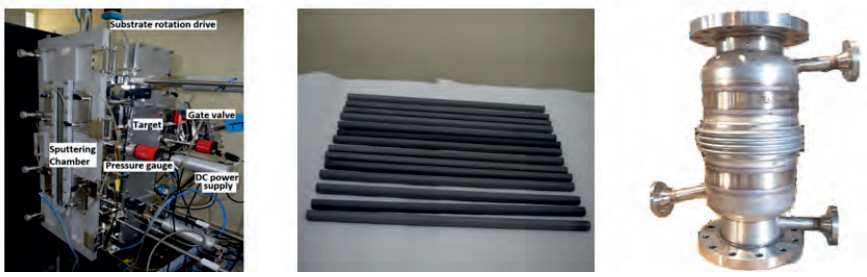
BARC has setup an in-house developed MED-TVC desalination plant at IREL OSCOM for field demonstration under I&M project to produce distilled quality water directly from seawater. The one MLD MED-TVC technology was transferred to two more Indian manufacturers taking the total number of technology licensees to six. Preparation for setting up a 2 MLD MED-TVC desalination plant at Madras Atomic Power Station for nuclear desalination is underway.

Deployment of Desalination & Water Purification Technologies in Remote Locations

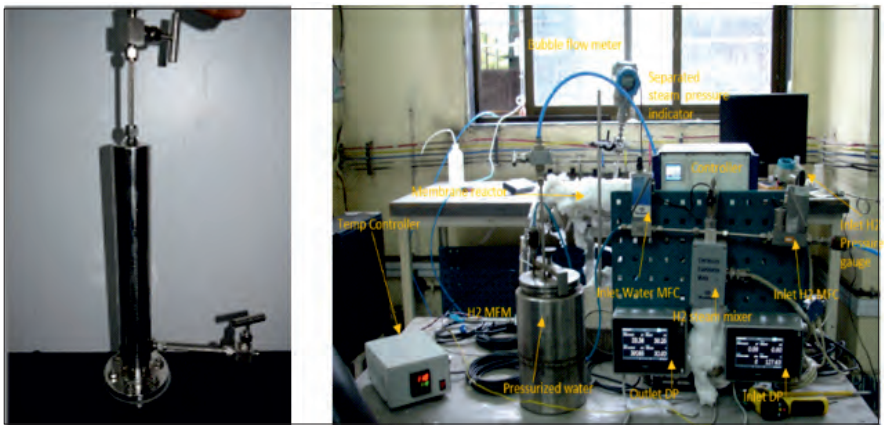
Under Vision-VI of DAE, with an aim of translation of indigenously developed



Left to Right: Capillary electrolyser set-up, PEM water electrolyser and in-house developed MEA.



Left to Right: Indigenously designed magnetron sputtering machine; Produced metal membranes; and multitube membrane reactor.

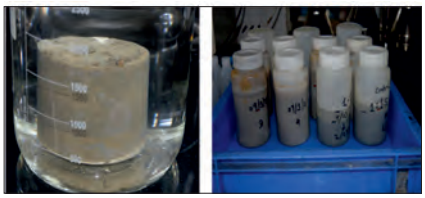


Left to Right: Metal membrane permeator; and the setup for hydrogen-steam separation studies using metal membrane.

Two 250,000 litres-per-day MED-TVC Plant at IREL, OSCOM.

Left to Right: Water purification unit commissioned at Creek BOP, Bhuj, Gujarat; and another at Sandeep BOP, Bhuj, Gujarat.

Senior officials of BARC and ONGC during the inauguration of AEWTP at ONGC, Mehsana.



Studies on leaching of arsenic from immobilized sludge in concrete.

technologies from lab to land, BARC has deployed place-and case-specific desalination & water purification technologies in rural and remote locations of India. Notable amongst them are arsenic-affected habitations of West Bengal and Bihar, tribal belt of Odisha and Indo-Pak border areas of Gujarat.

On-site demonstration of Advanced Effluent Water Treatment Plant

The Advance Effluent Water Treatment Plant (AEWTP) based technology developed in BARC to treat effluent water contaminated with oil and salt was installed and commissioned for field demonstration at ONGC Mehsana Asset under an MoU between BARC and ONGC Energy Centre Trust. The plant has been in operation for more than two months producing product water of desired specifications at rated capacity of 500 LPH. More than 2 lakh litres of effluent water has been treated so far.

Decontamination of Arsenic from Groundwater and Utilization of Sludge

For sustainable management of arsenic-bearing sludge generated from arsenic removal plants, studies on its potential immobilisation in concrete were carried out. It was confirmed that arsenic immobilised concrete matrix has sufficient strength and low leaching tendency, for its suitable deployment as a low-level (M-15) construction material.

Development of Iodine-Sulphur based Thermochemical Processes for Hydrogen Production

In pursuit of developing cleaner fuels through strong in-house R&D efforts to address national energy security goals

A. K. KALBURGI
Director
Chemical Technology Group
Bhabha Atomic Research Centre (BARC)

Hydrogen can play an important role to establish clean energy system which is the global need of the hour. By combining chemical reactions, water can be decomposed thermo-chemically at relatively lower temperature (850°C). Chemical Technology Group (ChTG), BARC, Mumbai has been working on the development of Iodine-Sulphur (I-S) based processes. Towards this, it has successfully demonstrated the process for production of hydrogen. A few I-S based processes have been conceptualized and demonstrated for the production of Hydrogen.

Iodine-Sulphur (I-S) Process

The I-S process in closed loop comprises three sections namely, Bunsen Section; H_2SO_4 Decomposition Section; and HI Decomposition Section.
The net inputs to the closed loop arewater & heat, whereas the net outputs are hydrogen & oxygen. While the hydrogen production @ 30NLPH by aforesaid process was already developed & demonstrated in glass loopin the year 2013, demonstration of the process in metallic closed loop could only be achieved in April-2022, wherein hydrogen was produced at its design capacity of 150NLPH for about 5 hours. This technology is now being scaled up to 3 Nm^3/h capacity in a joint collaboration activity with Heavy Water Board, Mumbai.

Modified Iodine-Sulphur based Thermochemical Process

Modified I-S process is

The Metallic Closed loop I-S process facility at CEL-III in BARC.

essentially an I-S process in closed loop without the H_2SO_4 Decomposition Section. The net inputs to the process are SO_2, water & heat and the outputs are H_2SO_4 & hydrogen. This loop can be a part of a sulphuric acid production plant and can used for co-production of hydrogen in addition to sulphuric acid. The modified process can also be utilized as a co-production facility in various industries meant for production of zinc, copper etc wherein SO_2 is a by-product. An industrial scale facility using the modified I-S process as a co-production facility has been planned in incubation mode in collaboration with a private sector partner.

Conversion of Hydrogen Sulphide Produced in Refineries

In refineries, during desulfurization process of crude petrochemicals, huge amount of H_2S gas is generated. The gas, being highly toxic, needs to be treated properly before its disposal, wherein with the help of Claus process it is converted into water and sulphur.

In BARC, a process to convert H_2S into hydrogen & sulphur has been conceptualized and demonstrated at an experimental level. In this scheme, H_2S is made to react with iodine, to get hydriodic acid (HI) and sulphur. The HI is decomposed into hydrogen & iodine. Iodine is recycled back into the reaction with H_2S, whereas hydrogen can be reused for desulphurization process. The process holds a huge potential of converting H_2S gas generated in the refineries for recovering hydrogen which can be reused for desulphurization process.

Ushering in an Era of Excellence in Reactor Engineering & Safety

Research & Development in the area of nuclear reactor technology encompassing design, safety, operation, inspection and integrity assessment for nuclear power reactors and other nuclear facilities

VIVEK BHASIN
Director
Reactor Design & Development Group
Bhabha Atomic Research Centre (BARC)

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Five-Axes Sub Reflector Positioning Mechanism for 32m DSN Antenna for ISRO. As a part of India's space research and exploration program requirements, a 5-axis mechanism for dynamic positioning of sub-reflector has been designed and manufactured for integrated with 32m deep space network antenna at ISTRAC, Bengaluru for dynamic positioning of 3.2m diameter sub-reflector which will be used for tracking and sending/receiving signals from satellite.

Robotic Arm and Bionic Hand
The proof of concepts studies using a robotic arm and bionic hand for replacing human to perform bag-in and bag-out operations inside a glove box for MOX fuel pellet fabrication has been carried out. The robotic arm was programmed for picking and inserting a container through a glove port of glove box, synchronized sealing and cutting operation through centralized control program has been done.

Aero-Ball Monitoring System and its Installation at Critical Facility
A pneumatically operated Aero-ball Monitoring System (AMS) has been developed and commissioned for measurement of in-core neutron flux of nuclear reactors and also as reference instrumentation system for calibration of the in-core Self Powered Neutron Detector (SPND) instrumentation in Light Water Reactors.

Robot performing the bag-in operation.

Numerical Analysis of EB weld joint SS pipe and Experimental Validation
Experimental and numerical analyses have been carried out with an aim to develop optimum welding parameters for joining austenitic stainless steel pipe using electron beam welding process with respect to weld pool geometry, deformation and residual stresses joints.

Structural Integrity Assessment of Calandria of 700 MWe PHWR for in-vessel Corium Retention
To estimate the in-Calandria retention time of core debris for a 700 MWe Indian PHWR under a postulated severe accident scenario, structural failure of Calandria is assessed as per plastic instability, large inelastic strains and creep-stress rupture based criteria. It is seen that the Calandria is able to retain the core debris up to 42 hours before undergoing failure due to creep stress rupture in the weld region in the annular plate.

Rolled Joint Circumferential Scraping Tool for 540 MWe PHWR
Fuelling machine operated Circumferential Scraping Tool for 540 MWe PHWR has been developed. Functional testing of the tool has been carried out.

Indigenous Development Seismic Switch EMI/EMC and its Qualification
Simultaneous spurious actuation of seismic switches due to lightening was required to be resolved during monsoon. Root cause of the problem was investigated and a suitable configuration of power supply and Seismic Switch developed which passed the performance criteria. This configuration will be adopted by site in present and future installations.

Indigenous Design and Development of Acoustic Sensors
A Resonant Acoustic Sensor is being developed indigenously for leak detection system. The results of the indigenous and imported sensors were compared. The indigenous sensor performed at par or better that the imported sensors.

Molten Salt Flow Measurement using High Temperature Ultrasonic Flow Meter
Molten Salt (MS) flow measurement has been successfully demonstrated in 1-inch pipeline at 300°C at Forced Circulation Molten Salt Loop (FCMSL) using UFM.

Accident Source Term and Radiation Risk Analysis Code PRABHAVINI v3.0
The accident source term and radiation risk analysis code PRABHAVINI v3.0 has been released to the users. This version is updated with
(i) improved formulation of two fluid model PRAVAH, incorporating Pressure-Enthalpy-Internal Energy scheme, hybrid formulation for fast execution, inclusion of steam separator model as a special process model
(ii) inclusion of 1-D simplified momentum equation and improved formulation (pressure implicit scheme) for PARIRODHAN.

And also with the (iii) inclusion of 2-D implicit formulation of conduction in reactor core (RCORE) and lower plenum (LP), 1-D (radial) formulation of melting in LP and interfacing between RCORE and LP for axial conduction for ABHA
(iv) inclusion of plume shine dose model for VIKIRAN
(v) new module RASAYAN, addressing radio-iodine chemistry in reactor system and
(vi) new module VASPA-CHAKRA, addressing plant steam cycle.

Model for Flame Acceleration and Deflagration-to-detonation Transition in OpenFOAM
A mathematical model related to hydrogen combustion has been developed and implemented in OpenFOAM CFD software for Flame Acceleration (FA) and Deflagration-to-Detonation Transition (DDT) phenomena. The developed modelling approach has been validated with experimental data and can be used for safety assessment involving FA and DDT at containment scale.

Cs-137 Source based Agro Irradiation Facility
An Agro Irradiation Facility (AIF) has been built for technology demonstration of utilization of Cs-137 as gamma source for disinfestation of food grains for long term storage.

Physics Design of IMSBR and IHTRs
Two comprehensive reports, consolidating all relevant physics design work carried out during past several years for the Compact High Temperature Reactor (CHTR) and the Indian Pebble-Bed HTR (IHTR-20), have been prepared. The detailed report outlines the objectives of physics design, TRISO fuel particle simulations, Lattice & Pebble analysis, Reactivity coefficients, Control systems, Fuelling schemes, Core reactivity Management and Coupled Neutronics-TH safety analysis at high temperatures etc. These reports are intended to serve as informative documents for any future Indian HTRs design and analysis activities.

FOUNDER'S DAY 2023
special issue

Incorporating High Degree of Operational Safety & Improving Availability of Research Reactors

At the forefront of national efforts for production of radioisotopes for medical, agricultural, neutron beam research, and industrial applications

C. G. KARHADKAR
Director
Reactor Group
Bhabha Atomic Research Centre (BARC)

The research reactors at BARC, Trombay continue to operate with high levels of safety and availability. Indigenously built research reactors Dhruva and Apsara-U continued to serve as the national facilities for production of radioisotopes for neutron beam research, medical, agricultural and industrial applications.

Dhruva Reactor

Dhruva was operated at an availability factor which is upwards of 73% (in the year 2022) over the last two years, despite shut down refuelling which limits the maximum availability to 80%. Around 510 samples of radioisotopes were irradiated in Tray rod facility; 98 samples for short duration in Pneumatic Carrier Facility (PCF); 8 samples in Self-Serve facility. 48 plates were trial irradiated in Special Tray Rod facility for production of fission Moly.

A study was carried out for production of high specific activity (more than 650 Ci/ gm) of Ir-192 for making Brachytherapy sources, by carrying out trial irradiations of enriched (80%) samples of Iridium in the reactor facility. Special Antimony Tray Rod irradiation was completed, to provide a start-up source for PRP.

Design of seismic instrumentation to incorporate seismic alarm/trip for the reactor was completed.

Fission Moly Tray Rod Commissioning

Fission Moly tray rod (FMTR) was commissioned at F-11 pile position for irradiation of

Fission Moly targets and hot trials have been successfully carried out at Dhruva and FMP.

Upgradation of Accumulated Heavy Water

The campaign for upgradation of accumulated Heavy Water in Dhruva at NPCIL facility at Tarapur plant was completed. 7.8 ton of upgraded heavy water (100% basis) was received at Dhruva from Tarapur during this year.

Reactor Physics Analysis Experiments at Dhruva

Reactor Physics analysis, including optimization of axial position of the hybrid cluster has been carried out for the modified experimental assembly containing hybrid cluster of twisted and cylindrical fuel pins, proposed to be irradiated in Dhruva reactor.

Seismic Re-qualification of Dhruva Shut-off Rods

The test set-up for seismic re-qualification of Dhruva shut off rod was erected at 'Pseudo Dynamic Test' facility of Advanced Seismic Testing & Research Laboratory, CSIR-SERC, Chennai and the seismic re-qualification was carried out successfully during May 2022.

The test was carried out by exciting seismic motion at four excitation points at four different elevations of Shut off rod. The spectrum compatible time histories corresponding to the Trombay site specific envelope response spectra of X-Y directions were generated for the seismic motion excitation. The tests were carried out for 50%, 100% and 140% of DBE loading and the drop times of shut off rod were recorded. No change in drop time was recorded at 50% & 100% DBE loading and was well within the acceptable limits.

Dhruva Shut-off Rod Headgears

To overcome ageing of Dhruva shut off rod headgears, ten new headgears along with adequate spare parts were manufactured. In compliance with the recommendations of safety committee, qualification testing of all 10 new modified headgears were conducted and made ready for installation & commissioning in Dhruva.

Apsara-U

Apsara-U was operated at a maximum power of 2.0 MWt and at an availability factor which is upwards of 52% during the year 2022. For monitoring of reactor core, three pulse channel fission counter assemblies were installed in core. Detectors of fission counter assemblies were replaced with newly procured one.

A neutron imaging and neutron depth profile facility is being erected at beam port#7 of the reactor.

The reactor continued to serve as the national facility for production of radioisotopes for medical, agricultural and industrial applications and neutron beam research.

Silicon Wafer Trial Irradiation at Apsara-U

Silicon wafers of 100 mm diameter were irradiated at the immediate vicinity of reactor core for development of silicon-based radiation detectors as part of feasibility study for neutron transmutation doping of silicon in Apsara-U reactor.

Critical Facility

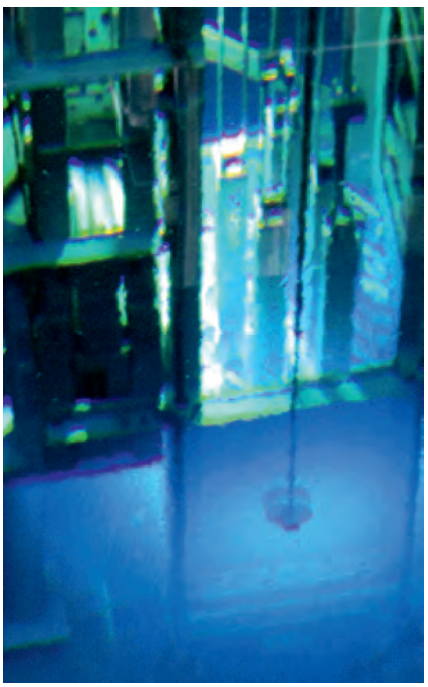
Reactor was operated on an average more than 68 times during the last two years for surveillance, irradiation experiments, neutron activation and testing of detectors. B-10 lined uncompensated ion chambers, fission counters and B-10 lined proportional counters of Apsara-U were tested in CF. Activation of 166 samples was done as per requirements of different divisions of BARC. Helium detectors were tested to meet the desired requirements of sensitivity.

CIRUS

CIRUS reactor remained under deferred decommissioning (safe storage) state. The reactor building is being utilized for installation and commission of new facilities, including Iodine-131 processing facility, TFLS & TLC production facility.

Five samples of 50 mm diameter each were cut from reactor vessel through the beam holes for material and radio characterization as part of aggregating ageing data.

At CIRUS material samples are being collected for creating a data base of material irradiation properties to be used for design of future reaators. Radiation field on contact of the sample was 200-300 mR/hr.



Silicon Irradiation underway in Apsara-U.

FOUNDER'S DAY 2023
special issue

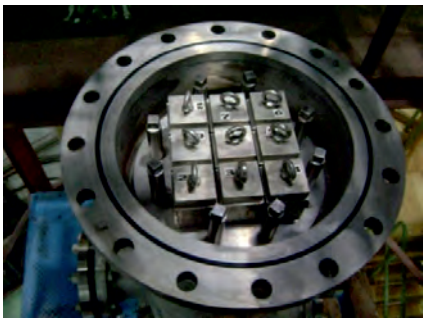
Building Advanced Systems for HFRR, and Design Validation of CLOE

Efforts for design of fuel locking mock-up system for High Flux Research Reactor; and development of Prototype Process Loop for Experimental validation of CLOE design as a part of in-kind contribution to Jules-Horowitz Reactor.

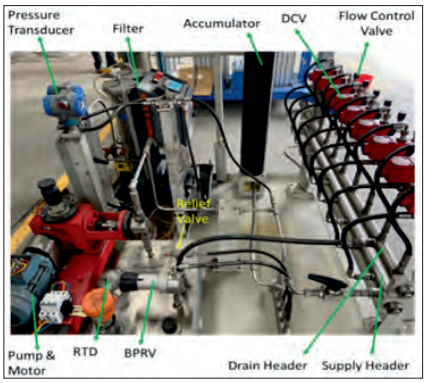
JOE MOHAN
Associate Director
Reactor Projects Group
Bhabha Atomic Research Centre (BARC)

A fuel locking mock-up system has been manufactured and installed at BARC for validating the design of fuel locking mechanism (FLM) proposed for locking of each fuel assembly of the High Flux Research Reactor (HFRR). It consists of the fuel locking mechanism and associated hydraulic system for locking/unlocking operation of dummy fuel assemblies. A prototype process loop (PPL) has been designed, manufactured and installed at BARC for validate the design of CLOE (corrosion loop of experiments) being developed for Jules-Horowitz Reactor (JHR) being constructed at Cadarache, France. The loop consists of a number of first-of-a-kind (FOAK) components, which need to be established through experiments planned to be carried out in the PPL test facility.

A fuel locking system is developed for reliable locking /unlocking of fuel assemblies of HFRR through a remotely operated hydraulic system to avoid ejection of fuel assemblies from the reactor core against upward drag force of coolant. The fuel locking system ensures that individual fuel assembly can be independently locked. To establish the functionality and efficacy of the FLM system, a full-scale facility with 9 dummy fuel assemblies (3 x 3 grid) was designed and erected at BARC, Mumbai. Operation of the fuel locking system was tested in the mock-up facility. Testing of all dummy fuel assemblies for 1000 cycles completed along with stage-wise inspections (at every 250 cycles).

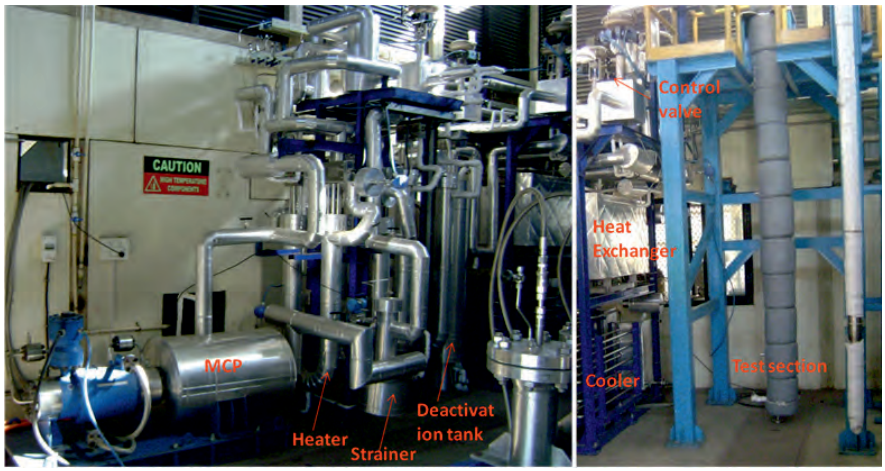


Top view with 9 dummy assemblies of HFRR.



Hydraulic system for fuel locking/unlocking operation of HFRR.

Elevation of fuel locking mechanism of HFRR.



High temperature equipment/components of a test facility established for carrying out experimental validation of CLOE.

Normal temperature Equipment/components of a test facility established for carrying out experimental validation of CLOE.

A test facility was fabricated, installed in the near vicinity of research reactor CIRUS for carrying out experimental validation of CLOE. After availing regulatory clearance from BARC Safety Council, commissioning of the loop has been successfully completed. Subsequently, stage-wise steady state operations at different temperatures (150°C and 260°C), the loop was operated at maximum working temperature of 340°C and pressure of 200 bar with precise control.

The design of process control of the high pressure and temperature loop, development of FOAK components like multi-stage high-pressure high-temperature canned motor pump, main loop heaters, autoclave heaters, regenerative heat exchangers, main cooler, purification cooler, control valves, test section and deactivation tank was validated through subsequent operational campaigns.

Sustaining a Vibrant Fuel Reprocessing & Establishing Effective Waste Management Practices

Enshrining new state-of-art practices for effective fuel reprocessing and safe management of spent fuels in tune with the DAE mandate

SMITA MANOHAR
Director
Nuclear Recycle Group
Bhabha Atomic Research Centre (BARC)

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The mainstay of Fuel
Reprocessing activities, Plutonium Plant, continues to be the mainstay of the back-end of the nuclear fuel cycle by reprocessing spent fuel from research reactor, starting from 1964. In tune with its mandate, various aged systems have been refurbished as part of ageing management activities. Being the first reprocessing plant in the country, Plutonium Plant has generated valuable operational feedback thereby enabling standardisation of design of subsequent reprocessing plants that had come up in the country. As a part of ageing management, all major process systems and auxiliary systems were refurbished with the objective of enhancing the safety and availability of systems in order to extend the safe service life period of the plant. In addition, several utility systems, including ventilation system, compressed air system, chilled water and air conditioning system, local area network and surveillance systems, power distribution panels were also taken up for refurbishment. Testing and commissioning of refurbished systems were carried out to ensure functional capabilities of all important systems. One batch covering 10 units of un-irradiated Dhruva rods was processed successfully to demonstrate the performance of plant systems under simulated condition. The Plant has resumed its regular operations soon after obtaining necessary regulatory clearance.

Management of High-Level Liquid Waste
High Level radioactive liquid wastes pose immense challenges and it required a very unique

Plutonium Plant in BARC, Trombay.

Solvent extraction system for High Level Liquid Waste in WIP, Trombay.

method for treatment and conditioning. The management of High-Level Liquid Waste (HLLW) streams was successfully continued at Waste Immobilisation Plant (WIP), Trombay using the solvent extraction system. Experience generated thereof has helped in adequately modifying the process wherever necessary for handling waste streams. These waste streams contain MWPF raffinates, which are laden with high salt content alongside lesser quantities of radionuclides and alpha emitters. Partitioning was deployed for its management and has been continued as a pre-treatment process followed by Vitrification of radioactive component in a glass matrix.

Around 50,000 litres of U & Cs lean stream was subjected to TEHDGA cycle for selective recovery of Sr-An product from various contaminants. The generated Sr-An product was further concentrated in the waste concentration system to obtain an excellent volume reduction factor.

Management of MWPF Waste

The raffinates resulting from processing of metallurgical waste (MWPF) as part of value recovery of SNM from slag and crucible residue also contain high concentration of inactive salts. These are highly corrosive in nature due to the presence of fluoride ions and acids. A process scheme based on solvent extraction was developed and deployed in the plant operations for management of MWPF effectively. Around 16 cu.m. of these raffinates were successfully dealt with by following partitioning process route at WIP Trombay. This has helped significantly in separation of actinides as well as in achieving a DF of 5000 for actinides. The generated product stream was later concentrated for desired VRF; and the downstream effluents were managed at LL Bay by special chemical dosing and neutralization process.

Management of De-clad Intermediate Level Liquid Waste

Treatment of Intermediate Level Liquid Wastes (ILLW) commenced upon completion of refurbishment of Pump House Ion-Exchange (PHIX) system. The ILLW stream (of decladding origin) comprises high salt load, inactive aluminium and comparatively low levels of Cesium. This has necessitated a highly selective separation process - Ion Exchange - with radionuclide specific resins. After completion of testing and commissioning of Ion Exchange process with various automation steps, the processing of de-clad ILW commenced.

Treatment of Intermediate Liquid waste

The de-clad ILLW is being treated at PHIX facility using ion exchange system consisting of highly selective resins for Cesium and Strontium. Around 935 cu.m. of de-clad waste was treated successfully by 50 kgs of resin in ten loading - regeneration cycles. The recovered Caesium-rich stream was subjected to further concentration at WIP, thereby giving a VRF of 200. An excellent DF of the order of 10,000 was obtained in the process with respect to Caesium. could treat 935 cu.m. of ILLW and completely empty out one tank contents. In the process, ILLW was converted to LLLW by selective partitioning

MWPF Raffinate Conditioning and Transfer System at WIP, Trombay.

Ion Exchange columns at PHIX System.

UF system for recovery of water from LL effluent and re-use as process water.

based on Ion Exchange process and was safely managed. The spent Ion Exchange columns equipped with resins were thoroughly eluted and air-dried. After radiation survey, it has been transferred to RSMS for final disposal. The Caesium specific resin used during the campaign was synthesized in-house and its performance had been excellent.

Pilot-scale System for Decontamination and Recycling of Radioactive Wastewater

The feasibility of decontamination of radioactive wastewater and its recycling has been demonstrated by operating a pilot-scale hybrid system equipped with membrane processes and ion exchange process at the Effluent Treatment Plant (ETP) in BARC.

Recovery of Water from LL Effluent and Re-use as Process Water

A hybrid UF-RO-IX pilot plant is in operation at ETP for demonstrating "Waste to Water" concept. The plant had successfully recovered 110,000 litres of water from processing of radioactive effluents. The radioactivity associated with this stream was identified to be almost zero. From the recovered water, 60,100 litres has been re-used in ETP for in-house activities, including chemical preparation, treatment and decontamination.

Ion-exchange Process for Effective Reduction of Radioactivity during LLW Management

Zeolite-based Ion Exchange Plant of 200,000 L/day capacity has been installed at ETP, Trombay for treatment of very low level radioactive liquid wastes. After extensive testing, cold commissioning and receipt of safety clearances, trial operations of the plant were carried out. Approximately 10,983 m^3 of very low-level effluent had been processed. 68% reduction in activity was obtained in the discharge stream over the entire operation period by using this additional polishing step. The overall volume reduction factor had been at 4000.

Volume Reduction of Radioactive Solid Waste using Plasma based System

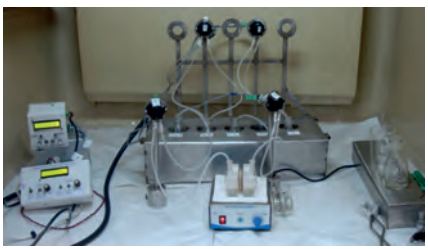
Rubber and plastic waste constitute around 75% of the total volume of combustible radioactive solid wastes, in addition to presence of cellulosic wastes. To achieve volume reduction factor (VRF) upwards of 30, and for reducing the footprint of NSDF effectively, a high temperature plasma-assisted pyrolysis-based incineration demonstration facility was setup at RSMS, Trombay. Efforts made for increasing the operating life of plasma torch of the incinerator had resulted in good throughput. The plasma-based system is being operated in an integrated mode with the existing old conventional diesel-fired incinerator for processing of mixed combustible and cellulosic wastes. During the process, the concentration of dioxin and furans in the exhaust gas was measured through isokinetic sampling system and also through an in-house developed methodology (worked out in collaboration with NEERI, meeting USEPA-23 guidelines). The concentration of dioxin and furans was less than 0.1 ngTEQ/Nm^3, which is well within the acceptable limit stipulated by the CPCB. A wet-off gas system was also installed and integrated with the plasma and conventional incineration systems to further reduce this concentration and to achieve a higher Decontamination Factor for flue gases in terms of radioactivity contamination.

Wealth from Waste: Production of Cesium Glass Pencils

A solvent extraction-based facility has been deployed at Waste Immobilisation Plant, Trombay, for large-scale separation of ^{137}Cs from highly radioactive acidic solutions. The caesium rich product stream was concentrated and used for making of Cs source in glass pencil form for gamma irradiation applications.
10 units of Cs-glass pencils of 2Ci/gm specific activity were produced in the facility during the period 2022-23, and were supplied to different hospitals in the country through an arrangement with BRIT, a constituent unit of DAE. Since 2016, around 240 Caesium pencils were supplied to several hospitals in the country.

Milking of ^{90}Y from ^{90}Sr

Milking of carrier free radiopharmaceutical grade ^{90}Y from ^{90}Sr-^{90}Y solution using supported liquid membrane (SLM Generator) system is being carried out on a regular basis for supply ^{90}Y for



^{90}Sr-^{90}Y SLM radiochemical generator.

RuBy plaques of varied configuration (Left to Right): Round Plaque, Notched Plaque, Paediatric, and Crescent moon.

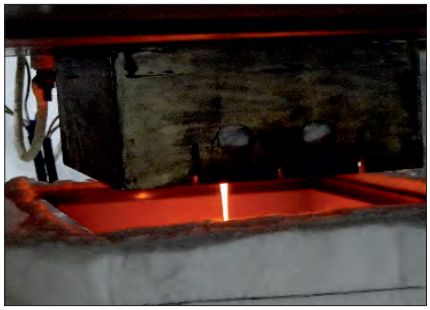
treatment of Neuroendocrine Tumor (NET). Use of 90Y along with Lu has given encouraging results for treatment of Neuro Endocrine Tumor (NET). Production of ^{90}Y through fission product route has inherent advantages, mainly in obtaining the product with higher specific activity and is therefore highly preferred one. Till date, a total of 161 batches of ^{90}Y were supplied to RMC, Parel. In our efforts to enhance the plant capacity to maintain adequate supply of ^{90}Y, ultra-pure ^{90}Sr solution was recovered from HLLW by deploying multi-step separation techniques along with the development of a scaled-up system with provision for remote operation. Adequate improvisation in process systems was carried out to enable the supply of ^{90}Y to desired levels for addressing the increased demand for treatment of Neuro Endocrine Tumor (NET). The scaled-up system with remote operation has enabled supply of ^{90}Y up to 0.5 Ci/week by maintaining personnel exposure to minimum levels.

Production and Supply of RuBy Plaques

^{106}Ru which has a half-life of 373 days is one of the important fission products obtained during thermal fission of uranium. However, its daughter product, ^{106}Rh emits high energy beta radiation, which has brachytherapy applications, particularly in eye cancer treatment. The separation of ^{106}Ru is carried out from raffinate in a three-cycle solvent extraction process. Design, engineering and manufacturing procedure of plaque was established and fabricated. The testing and qualification of the fabricated plaques as per the procedure stipulated by AERB were carried out. 13 units of round-shaped, 9 units of notch-shaped and 1unit for paediatrics were produced and supplied to various hospitals through an arrangement with BRIT for cancer treatment. In September 2022, the first paediatric plaque was handed over to a hospital. Of late, RuBy plaque of crescent moon configuration had been approved by AERB for brachytheraphy applications.

Development work for Radiation Shielding Window Glass

A cold crucible induction melter with electric plenum heater for melter start-up was developed to demonstrate melting of Radiation Shielding Window (RSW) glass cullets. The activities on installation of $MoSiO_2$ based plenum heater (36 kW) and electric power connection from main supply, installation and commissioning of Thyristor based power supply were completed. The RSW glass



Casting Trial of 200 x 200 glass slab.

cullets were fed into the CCIM and the melter cooling water was continuously circulated through the loop. The plenum heater was energized and the glass temperature was monitored with platinum thermocouple. A maximum glass temperature of 950°C was achieved with the installed start-up heater. The system was controlled through PLC based controller.

Further experiments for RSW glass melting and casting were carried out to establish the process parameters. A 200x200x50mm thick glass slab was cast in a mould and subsequently put into annealing furnace for its annealing. The slab was cut into segments in a glass cutting machine after undergoing 8-day annealing cycle which demonstrated improved properties as desired by annealing. Further trials are planned to improve the final glass product.

Excellence through Engineering Design & Infrastructure Development

Expansion and upkeep of engineering infrastructure for a vibrant atomic energy R&D program

K. SRINIVAS
Director
Engineering Services Group
Bhabha Atomic Research Centre (BARC)

Engineering Services Group (ESG), BARC is engaged in setting up of state-of-art infrastructure, operation & maintenance of high value assets and centralised engineering services in the areas of civil, electrical, mechanical engineering and landscape & horticultural works in BARC facilities. ESG is committed to efforts aimed at continuously improving existing processes to meet world class standards.

KRUSHAK Facility

A cold storage facility for storing of fruits and vegetables, especially Onion/Garlic/Banana/Mango was planned in the operating KRUSHAK facility premises at Lasalgaon, Nashik (Maharashtra) under the project entitled "Setting up of R&D facility at KRUSHAK, Lasalgaon for irradiation of fruits and vegetables". The facility will have one storage chamber of 250 MT capacity for Onion, two storage chambers of 10 MT for Potato/Onion with varying relative humidity (RH) and temperature conditions, one Pre-cooling/Re-heating chamber of 50MT storage, one ripening chamber of 5MT storage capacity for Banana/Mango/Papaya; and also a small routine quality control laboratory and a discussion room for conducting workshop/outreach activities with the end-users.

Bio Safety Level-3 Laboratories

A Bio Safety Level 3 (BSL-3) designated laboratory to study the spread of infectious agents (bacteria/virus) in air which can cause potentially lethal infections was successfully

Radiation Processing of onions underway at KRUSHAK facility.

commissioned in May, 2023 at RMC Parel. The facility is fully equipped to carry out research activities on tuberculosis disease, drug discovery efforts in tuberculosis besides studies on the efficacy of the vaccine.

Construction of Desalination Plant at OSCOM (IREL), Odisha

Construction package of seawater intake and outfall system comprising offshore and onshore works, civil works, mechanical works, electrical and instrumentation works, installation, testing and commissioning, for BARC's 5.0 MLD sea water desalination plant at OSCOM, IREL in Odisha's Ganjam district.

Construction of RCC road and platform near the civil facilities, including pump house and electrical building has been completed. The RCC road was constructed through mobilising, levelling and rolling of local sands (247 trucks), murrum (15 trucks) and GSB (12 trucks). The supply of seawater for trial run of pumps installed in the pump house and desalination plant are performing satisfactorily.

Inception of Mural at APSARA-U Reactor Complex

A mural crafted on the theme "Flight of Phoenix" has been commissioned on the outer wall of APSARA-U reactor building. It depicts the birth of APSARA-U research reactor on September 10, 2018. The mural portrays the resurrection of the mythological bird Phoenix thriving from the ashes. It showcases various technologies developed by BARC as well as the portrait of the founding father of atomic energy activities in India Dr. Homi. J. Bhabha.

BARC Hospital

Full Occupancy Certificate from BMC was received on 30th December 2022 for New BARC Hospital, including the Service building.

Bhabha Botanical Garden

The South Site Park developed in early 1970s at BARC Trombay to serve as a repository of living botanical specimens, had been revived by planting a new plant species on the World Environment Day (5th of June, 2022). It was renamed as "Bhabha Botanical Garden".

Sludge Hygienisation Facility

The work on Sludge Pre-Conditioning System at AMC (in Ahmedabad) and Sludge Hygienisation System at IMC (in Indore) has been completed.

Operation and Maintenance

Engineering Services Group, BARC has achieved more than 97% overall availability of all Civil, Electrical, HVAC, Mechanical utility Services and Landscape & Cosmetic Maintenance Services.

RMRC Project, Kolkata

A new Radiation Medicine Centre at DAE Campus, Rajarhat in Kolkata has been set up for strengthening and providing full-fledged nuclear medicine services to patients of Eastern and Northern states of India. The construction work on the project had been completed and the occupancy certificate from Local Government Authority (NKDA) was obtained on 03.08.2022.

Digitization of flora of BARC Trombay & Anushaktinagar

An exhaustive list with information on 172 plant species/subspecies/varieties present in BARC Trombay and Anushaktinagar has been prepared and published on web portals for the benefit of wider audience.

Flora of BARC Trombay.

FOUNDER'S DAY 2023
special issue

Expanding Frontiers of Scientific R&D through Robust Knowledge Management

Enhancing HR capabilities by enabling seamless access to scientific information resources and creating a robust technology management program

Dr. SOUMYAKANTI ADHIKARI
Associate Director
Knowledge Management Group
Bhabha Atomic Research Centre (BARC)

The Knowledge Management Group of BARC over the years transformed itself into a formidable force with a strong footprint in diversified areas that contribute to the overall growth of scientific R&D and for ensuring robust technology management in nuclear energy and allied domains.

BARC Training School
India's atomic energy visionary, Dr. Homi J. Bhabha, who founded BARC (erstwhile AEET) in 1954 understood the prominent role of trained skilled workforce for expanding India's nascent scientific and technological landscape. Dr. Bhabha believed that "When nuclear energy has been successfully applied for power production in say a couple of decades from now, India will not have to look around for its experts but will find them ready at hand". In line with this philosophy, the BARC Training School he established in 1957 has been successfully providing a sustained pool of high quality trained professionals for fuelling the growth of India's atomic energy program besides supporting a string of organizations and institutes of excellence within the country and abroad. In its successful journey encompassing over six decades, more than 9500 well-rounded individuals graduated from the BARC Training School with flying colours.

Scientific Information Resources Management
BARC has been steadfastly implementing new initiatives to cater to the fast expanding information needs of its vast scientific community. The information services unit which began its journey through

Young Graduates of BARC Training School 66th batch pose for a photograph with Chief Guest Shri Shaktikanta Das, Chairman AEC and senior officers of BARC.

providing translation of published scientific literature from major foreign languages mostly into English, over the years, has transformed itself into a one-stop centre enabling seamless access to high quality information services. With the advent of new-age information technologies, it has chalked out a prospective roadmap to revolutionize the user experience of information resources through setting up of state-of-art infrastructure and through adoption of smart digital architecture practices. With its vast domain expertise, it has also been aiding various units of the Department of Atomic Energy in their efforts to establish holistic information management systems.

As the nerve centre of scientific information activities, the BARC Central Library facility houses a rich collection of more than 200,000 books and popular journals on diversified science and technology subjects. The centre is also blessed with a vast resource of more than 9000 unique e-reports with information on nuclear energy activities in India and abroad. Efforts are underway for organizing, managing and hosting of archives of the centre and the DAE in a time-bound manner.

Information dissemination on important developments in nuclear energy activities through publication of newsletters, books and bulletins regularly and outreach activities is another area of deep interest to BARC. The Scientific Information Resource Division has been collaborating vigorously with various internal and external teams to educate pan-India audience by organizing various events that help propagate positive benefits of nuclear energy. Of late, BARC has been collaborating with the DAE in organizing of Parmanu Jyoti program, which aims at sensitising the students of pan-India Jawahar Navodaya Vidyalayas (JNVs) about the positive benefits of nuclear energy science and technology activities. Besides, it has been encouraging various stakeholders, including mediapersons, eminent individuals in science and technology arena, and VIPs to visit BARC frequently to get first hand information on various activities in BARC.

As one of the designated nodal centres of IAEA global nuclear information collaboration network – INIS – BARC has been contributing positively to the international efforts to ensure seamless access to diversified sources of scientific information in the field of nuclear energy among the member countries.

BARC has a strongly established tradition of facilitating intellectual interactions of its scientific community with their global peers. The Trombay Colloquium format has played host to eminent individuals cutting across science, technology and other fields of prominence, who could share with BARC community their insights and breakthrough developments in science & technology.

Technology Management

By virtue of a strong multidisciplinary culture in its R&D programs, BARC has been able to expand its technology development portfolio. Through its continuously evolving linkage programs with the industry partners, it has been promoting a vibrant start-up ecosystem among the budding entrepreneurs for scaling-up nuclear sector technologies. In the year 2022 itself, more than 200 technology transfer agreements were inked with the industry partners and 450 licencees are actively engaged in commercializing these technologies.

School children of Jawahar Navodaya Vidyalalya listen to the address by Shri K. N. Vyas, Former Chairman AEC.

FOUNDER'S DAY 2023
special issue

Ensuring Workplace Safety through Adoption of Inclusive Regulatory Practices & Training

Towards ushering in an era of vibrant safety culture at workplace through hands-on training and public awareness programs

CLEMENT C. VERGHESE
Chairman
BARC Safety Council
Bhabha Atomic Research Centre (BARC)

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Safety Measures

BARC prioritizes safety of workers, public, and environment at all times. The BARC Safety Council (BSC) regulates safety across all facilities and projects across the country, supported by safety committees and BSC Secretariat (BSCS). The BSCS conducts short term training courses for scientific and technical personnel of BARC facilities regularly.

Important topics addressed in these safety courses include regulatory framework of BARC, radiation basics and natural radiation, radiological safety in front-end and back-end nuclear facilities, electrical safety, occupational health care, biological effects of radiation, industrial hygiene and safety, safety in storage and handling of chemicals, industrial safety aspects in fuel fabrication facilities, safety aspects of material handling equipment, regulatory aspects of radioactive waste management, regulatory inspections, event reporting, emergency preparedness and response to nuclear & radiological emergencies, and improvement of safety culture in the facilities. In the year 2022, BSC granted regulatory clearances for renewal/extension of authorization for operation of 13 nuclear and radiological facilities, and various consenting stages of 29 projects in BARC.

It also granted regulatory clearances for 22 conventional type facilities/projects, and carried out inspections and granted authorizations and permissions for transport of radioactive materials.

IAEA Director General visits BARC

1 Lauding India's contributions to nuclear energy sector, Mr. Rafael Mariano Grossi, Director General, IAEA said that the Vienna-headquartered international body would intensify its joint collaboration activities with India encompassing advanced areas of nuclear science and technology, crop improvement programs and affordable healthcare.

2 Calling India a strategic partner of IAEA, Mr. Grossi said that in his discussion with the Prime Minister of India Shri Narendra Modi on 23 October 2023, the latter has assured India's full support to the IAEA's 'Rays of Hope' initiative for expanding radiological based oncology services among the under-reached populations.

3 Mr. Grossi said that the global Small Modular Reactor (SMR) and Micro Reactor technology landscape is expanding considerably and added that India's presence in this domain is extremely vital.

4 Mr. Grossi announced that the IAEA has planned to organize a first-of-its-kind global nuclear energy summit next year similar to the maiden landmark UN Atoms for Peace Conference held in 1955 at the majestic Palais des Nations in Geneva for which India's atomic energy pioneer, Dr. Homi J. Bhabha, acted as the Chairman. The upcoming conference apart from its main agenda of improving the prospects of nuclear energy, also aims to garner widespread acceptability for nuclear energy activities globally.

Nuclear energy is not a thing of past but a beacon of hope for bright future

Mr. Rafael Mariano Grossi said in his talk entitled 'In the Footsteps of Homi Bhabha: The IAEA, India and life-affirming journey of nuclear energy and science' at Special Trombay Colloquium in BARC on 26th October 2023.

FOUNDER'S DAY 2023 special issue

AWARDS & HONORS to BARC Scientific Community

Dr. Dimple P. Dutta

Elected Fellow of the Royal Society of Chemistry (FRSC), UK

Dr. Dimple P. Dutta, Scientific Officer, BARC has made excellent contribution in the field of chemical science, particularly towards development of functional materials using soft chemical techniques for energy storage, energy conversion and water remediation applications. In the field of energy storage, Dr. Dutta has developed novel electrode and electrolyte materials for lithium-ion and sodium-ion batteries. Many electrode materials, including cathodes of layered oxides, polyanionic compounds, and anodes of carbonaceous materials, titanium-based compounds, alloys, as well as electrolytes, binders, and conductive additives, have been explored extensively by her. She has patented an economic and environment-friendly technique to obtain carbon from biowaste which can be used in sodium ion coin cell as anodes. She has also developed flexible and thermally stable gel polymer electrolyte materials for LIBs and various mixed polyanion glass-ceramic cathode and electrolyte systems for solid state battery applications. For societal application, she has also developed a series of inorganic and carbon-based nanomaterials which shows exceptional affinity towards sorption of organic pollutants and heavy metal ions.

Dr. Jyotirmayee Mohanty

Fellow of Royal Society of Chemistry (FRSC), UK (2022)
SERB POWER Fellowship, SERB, DST (2022)

Dr. Jyotirmayee Mohanty, Scientific Officer, BARC has been recognized for her overall research contributions in the area of Supramolecular & Biomolecular Host-Guest Chemistry. Dr. Mohanty has been persistently making noteworthy contributions in the frontier areas of chemical sciences by developing novel stimuli-responsive supramolecular/biomolecular assemblies as on-off sensors, catalysts for clean H_2 production, aqueous dye lasers, and 99mTc generator bed for theranostic applications, etc. Also, her group has developed methodologies using macrocycles/nanocomposites/dyes for in vivo disintegration of amyloid fibrils, enhancing the antibacterial efficacy and stabilizing G-quadruplex DNA, therapeutic strategies for Alzheimer's/Parkinson's diseases, bacterial infections and cancer treatment. Recently, they have demonstrated a novel, cost-effective, metal-free supramolecular approach for the deployment of ammonia borane into a practical hydrogen storage material for fuel cell applications.

Dr. Nandita Maiti

Fellow of the Royal Society of Chemistry, (FRSC), UK (2023).
Life Fellow of the Indian Chemical Society (2023).
Dr. Nandita Maiti, Scientific Officer, BARC has made significant contributions in the frontier areas of "Surface chemistry, Nanomaterials and Raman spectroscopy". Her research work involving the "Development of smart plasmonic nanomaterials for photocatalytic, biosensing and therapeutic applications" has direct societal relevance. She has been involved in designing a simple, user-friendly and cost-effective methodology for the detection of milk adulterant "melamine". She was also involved in the fabrication of novel nanosensors for the trace-level detection of drugs, toxic heavy metal ions and pesticides. Recently, she was also involved in the fabrication of nanoparticle loaded polymeric films for radiosensitization applications in nanoparticle-aided brachytherapy.

Dr. Rimpi Dawar

ITAS Young Scientist Award by Indian Thermal Analysis Society (2022).
Dr. Rimpi Dawar, Scientific Officer, BARC has made outstanding contributions in the field of thermochemical studies on nuclear materials for Indian fast and molten salt breeder reactor. She has generated large volume of useful database on thermophysical and thermochemical properties of oxide and fluoride based nuclear fuel materials.
The most significant contribution of Dr. Dawar is the measurement of oxygen potential for high Pu containing MOX fuel, done for the first time. She has successfully designed and commissioned a high temperature experimental setup inside a radioactive glove box, required for this measurement. Oxygen potential data is considered crucial to predicting the extent of fuel-clad & fuel-coolant chemical interaction and fabrication of nuclear fuel with specific composition.
Dr. Dawar has accomplished a substantial progress in the high-temperature chemistry and thermodynamics of fluoride salts required for the design of Indian Molten Salt Breeder Reactors (IMSBR). She has measured thermo physical properties viz., viscosity, density, eutectic composition and temperature, heat capacity, thermal conductivity of proposed fuel and coolant salt systems. The above studies are useful in choosing right fluoride salt as candidate for fuel and coolant salt in IMSBR. The data generated by her on nuclear materials is useful in providing R&D support for design and safety of nuclear reactors.

Dr. Sangita D. Kumar

Selected among 75 Women in "SHE IS - 75 WOMEN IN CHEMISTRY" (2023).
Dr. Sangita D. Kumar, Scientific Officer, BARC has been bestowed with this recognition for significant contributions to the development of analytical methodologies for trace and ultra trace analysis using chromatography, electroanalytical and mass spectrometry techniques. The analysis of nuclear materials has led to an understanding of failure of the components, optimization of process parameters and protection of environment. Towards sustainable development goals she has lead to the development of polymeric membrane sorbents for the removal of metal ions, pollutants and contaminants etc. from various streams. Developing ecofriendly methods like optodes for detection of heavy metals is other goal being pursued for sustainable lifestyle. She has delivered invited talks on Separation Science at Schools in Analytical Chemistry, National & International conferences. As Prof HBNI & Guide Mumbai University she has mentored students for the award of PhD & MSc. Degrees.

Dr. Sharmistha Dutta Choudhury

Fellow of Maharashtra Academy of Sciences (2022).
Selected among 75 Women in "SHE IS - 75 WOMEN IN CHEMISTRY" (2023).
Dr. Sharmistha Dutta Choudhury, Scientific Officer, BARC has contributed to the areas of plasmon-coupled fluorescence and supramolecular photophysics. By integrating fluorophores with plasmonic nanostructures and photonic crystals, she has obtained exciting results that cannot be realized by classical fluorescence. The conversion of isotropic fluorescence into directional and polarized emission is one of her notable achievements that is promising for portable diagnostics and bioassays. Her recent demonstration of fluorescence coupling with transition metal nitrides is an important step for cost-effective plasmonics alternative to Au and Ag.

Dr. Umasankari Kannan

Fellow of Indian National Academy of Engineering (2023)

Dr. Umasankari Kannan, Ex-Head, Reactor Physics Design Division, retired as Outstanding Scientist from BARC where she was heading the Reactor Physics Design Division. Her specialisation includes thorium utilisation in advanced reactors, nuclear data physics and physics of the nuclear fuel cycle. She has contributed significantly to the design of Advanced Heavy Water Reactor (AHWR) with multiple fuel cycles using plutonium and Low Enriched Uranium (LEU) as external fissile feed with thorium. She has designed several irradiation experiments for qualifying the safety of thorium-based fuels and performed studies for the reprocessing of irradiated thorium fuel. Her designs for Indian Pressurised Water Reactor (IPWR) and Molten Salt Reactor (MSR) are also significant. She has also developed and benchmarked coupled neutronic and thermal-hydraulic codes for reactor safety studies. Her experimental investigations led to optimising the engineering design of both operating and new nuclear reactors. She has co-authored a book titled "Physics of Nuclear Reactors".

Dr. Archana Sharma, Director Beam Technology Development Group, BARC

EMC Engineer of the year in Asia-Pacific Conclave by SEMC in the Asia-Pacific Conclave (2023).
Achiever Award, by IWSA in 2023, the Golden Jubilee Year.
Top 75 Women in Science & Technology, awarded by jointly by Principle Scientific Adviser (PSA), Govt. of India and British High Commission(2022).
"WE-75", Woman in Engineering, Recognized by INAE in book published by Vigyan Prasar, Delhi (2022).

Dr. Archana Sharma, Outstanding Scientist, BARC, currently leads the Beam Technology Development Group, BTDG. Dr. Archana is spearheading the technology development in the fields of High-Power Accelerators, Lasers, Plasma and Electron Beam spanning the entire gamut from design to deployment. The myriad applications developed by these technologies are in the field of Water treatment, Cargo scanner development, Plasma MSW processing, dissimilar metal welding for critical applications by electron beam, food irradiation, Laser based surface non contact instrumentation and surface treatment. Recently, ATLA Division, BTDG has prepared the enriched stable lanthanide isotope (^{177}Lu) by Laser isotope separation Process. This indigenously produced isotopic target has been utilized for radiopharmaceutical application in India in an inter-Group collaborative effort. She has been actively involved in guiding, training young researchers as a Ph.D. Guide, has been a member of the Board of Studies, HBNI. Dr. Sharma has authored several publications in peer reviewed journals and contributed to the promotion of S&T in India.

Elina Mishra

Young Engineer Award by Indian Society for Particle Accelerators (ISPA) (2023)

Elina Mishra has made significant contributions towards several important programmes and projects of DAE in the area of high field magnets and accelerator development. These include 10-20 MeV Drift Tube Linac for LEHIPA and MEBT and low beta/high beta section magnets for high energy, high intensity PIP-II accelerator under Indian Institutions Fermilab(IIFC) Collaboration. Under LEHIPA, she has participated in the design, development and magnetic qualification of Permanent Magnet Quadrupole based Drift Tubes for transverse focusing of proton beam. For carrying out low power RF measurements in 10-20 MeV DTL cavities, she has developed bead-pull setup and tuned key RF performance parameters of the cavity including Q, Resonant frequency, E-field flatness, tilt sensitivity to achieve the requisite electromagnetic fields, modes and resultant acceleration. She has designed, developed and qualified several focusing quadrupoles, dipole correctors and bending magnets for national and international projects. She has also designed and developed dipole analysing magnets for several mass spectrometers for BARC's specific programs on isotope composition including EMIS, TIMS, PGMS. She has also developed tunable permanent magnet system for magneto-caloric studies in XRD beamline at INDUS-II. She has participated in the development of magnetic measurement lab at BARC for carrying out extensive electromagnetic qualifications and characterisation of multi-pole magnets. These include rotating-coil, stretch wire benches and hall probe magnetometers.

Dr. Celin Acharya

Fellow of Maharashtra Academy of Sciences (2022)

Dr. Celin Acharya has made excellent contributions towards the fundamental understanding of metal-microbe interactions and metal homeostasis with special emphasis on uranium in bacteria isolated from contaminated and uranium rich sites in India. Through her work, she has established uranium interrelations with proteins such as metallothioneins, phosphatases, PIBtype-ATPases or biopolymers like polyphosphates and extracellular polymeric substances (EPS) in various microbes. She showed that the recombinant cyanobacterial metallothionein (SmtA) interacts with uranyl ions via glutamate and aspartate residues, resulting the formation of heterometallic $(UO_2)_nZn_4$SmtA species. Further, for the first time, she has demonstrated the negative regulation of AnabaenaNmtA by AzuR (Anabaena zinc uptake regulator, Alr0831) belonging to SmtB/ArsR family of transcriptional repressors, and demonstrated its importance in maintaining metal homeostasis. Using biochemical, biophysical, molecular genetics, microbiological and high throughput genomic approaches, Dr. Acharya has demonstrated the mechanistic details underlying heavy metal including uranium, tolerance and resistance to gamma radiation in Chryseobacteriumculicis strain PMSZPI, a native of the uranium ore deposit in India. She could successfully establish the interesting phenomenon of iridescence in PMSZPI that was found to be associated with its gliding motility.

Smita Manohar, Director, Nuclear Recycle Group, BARC

- Elected Fellow of Indian National Academy of Engineering (2022).

Dr. Gopika Vinod

- Elected Indian National Academy of Engineering (2022). Her outstanding contributions in framing methodology for Risk informed Decision Making, reliability analysis of digital systems and passive systems, all of which have helped in ensuring reactor safety and planning life management activities.

Dr. Vinita G. Gupta

- Awarded SMC-Bronze Medal. Dr. Vinita G. Gupta, Scientific Officer, BARC was awarded SMC-Bronze medal for her exemplary work on frontline areas on complex oxides as nuclear and electrical materials, and radiation shielding materials for medical applications.

Anupama Prabhala

- Awarded Women in Chemistry-75 (2022). The award recognises Anupama Prabhala for her enormous contribution in process development in the field of Separation Science, with applications in radiopharmaceuticals, environmental remediation and work associated with rare-nuclear material recovery from waste.

Sutanwi Lahiri

- ChE Award (2023)-NOCIL Award for the Excellence in Design and Development of Process Plant and Equipment.

Dr. Ruma Gupta

- Elected as a Young Associate of Maharashtra Academy of Sciences (2023).

Dr. Neena Shetake

- Asian Association of Radiation Research (AARR), Young Scientist Award (2022) for her significant contributions in designing novel nanoparticle-based formulations for targeted chemotherapy and improvement of cancer radiotherapy.

Dr. Pallavi Singhal

- Awarded Platinum Medal of National Academy of Sciences, India (2022).

Dr. A. K. Tyagi, Director, Chemistry Group, BARC

Fellow, Indian National Academy of Engineering (2022).
Honorary Professor, Jawaharlal Nehru Centre for Advanced Scientific Research (2022).
Fellow, World Academy of Ceramics (2022).

Dr. A. K. Tyagi's research interests are in the field of nanomaterials, energy materials, functional materials, nuclear materials, metastable materials and hybrid materials. He is a Fellow of all the major science and Engineering academies in India such as the National Academy of Sciences, India; Indian Academy of Sciences; Indian National Academy of Engineering and Indian National Science Academy. He has been conferred with several prestigious awards such as DAE-Homi Bhabha Science and Technology Award, DAE-SRC Outstanding Researcher Award, MRSI Medal; MRSI-ICSC Materials Science Senior Award; MRSI-CNR Rao Prize in Advanced Materials; CRSI Bronze Medal; CRSI-CNR Rao National Prize in Chemical Sciences; CRSI-Silver Medal; Medal of Indian Nuclear Society; Rajib Goyal Prize in Chemical Sciences; Metallurgist of the Year award from Ministry of Steel, GoI; JNCASR-National Prize in Solid State and Materials Chemistry; ISCA Acharya PC Ray Memorial Award and JNCASR-Prof. AV Rama Rao Foundation Lecture Award.

Dr. S. M. Yusuf, Director, Physics Group

Fellow, Indian National Science Academy (2022).
Distinguished Lecturership Award, Materials Research Society of India.

Dr. S. M. Yusuf, Dsc (hc), FNA, FASc, FNAS currently serves as Director, Physics Group of BARC, and senior Professor of HBNI. He also served as Director, Institute of Physics, Bhubaneswar, India. He was a post-doctoral fellow at Argonne National Laboratory, USA, and a visiting scientist at the Institute of Materials Science, Spain. He has made outstanding contributions in the area of magnetism and neutron scattering. He has published more than 300 research articles in international journals, and obtained US and European patents. His publication H-index is 53. Dr. Yusuf, through his innovative neutron scattering work, has made incisive contributions to the fundamental understanding of magnetic phenomenon/ordering in low dimensional magnetism, magnetization reversal, exchange-bias switching, molecular magnetism, manganites, high magneto caloric materials, magnetic proximity effect, and multiferroics. He has also built an innovative neutron instruments for magnetic scattering. Research work, carried out by him on the magnetic nanoparticles, has helped him to build a prototype magnetic-nanoparticle-loaded medical grade membrane device for use in artificial heart pump support, and obtained international patents. He has made visible contributions in promoting neutron scattering in material research in the country and also in the Asia-Oceania Region by serving in various bodies. Presently, he serves as (i) Vice-President and Board member of Asia-Oceania Neutron Scattering Association, (ii) President of Indian Physics Association, (iii) Vice-President, Materials Research Society of India, (iv) Council member of The National Academy of Sciences, India, and (v) INSA nominated member of the National Committee for IUCr. He also served as (i) Vice Chair, Division of Condensed Matter Physics, Association of Asia Pacific Physical Society, (ii) President, Neutron Scattering Society of India, (iii) Vice-President of Indian Physics Association, (iv) Vice President, Indian Crystallographic Association, (v) Member of Neutron Science Review Committee, Oak Ridge National Laboratory, USA for eight years during 2013 – 2021.

Dr. Awadhesh Kumar

Fellow of the National Academy of Sciences, India (FNASc) (2022)

Dr. Awadhesh Kumar, Scientific Officer, BARC elected a Fellow of the National Academy of Sciences, India (FNASc) in recognition of his significant contributions to gas phase research in chemical dynamics, laser photochemistry and spectroscopy.

Dr. Kumar along with his colleagues, provided an immense impetus to the research programme by setting up several advanced research facilities, such as LIF and REMPI, and addressed various challenging problems. The highlights of his major scientific contributions include understanding of structures and dynamics at interfaces, photo dissociation dynamics of polyatomic molecules, atmospheric impact of VOCs and energy transfer processes at molecular level. For interfacial studies a sophisticated nonlinear sum-frequency generation facility, first of its kind in India, was set up for investigating the structure and dynamics of interfacial molecules. He applied a holistic approach to research by corroborating his experimental work through theoretical modeling and calculations.

Dr. K. R. S. Chandrakumar

The Chemical Research Society of India (CRSI) Bronze Medal (2023).

Dr. Chandrakumar's research work is primarily concept-driven, aiming at predicting and understanding of molecules as well as materials at the molecular level through the principles of physics and chemistry. In particular, for the last five years, he has been working on the following topics: (i) Energy research program (hydrogen generation & storage) (ii) Chemistry of nuclear materials and iii) Insights into the chemical reactions under quantum confinement (iv) Growth mechanism and catalytic properties of nanomaterials.

One of his important areas of research work is related to the energy-related applications, especially to develop materials for hydrogen storage and generation purposes. He has proposed different types of materials for hydrogen storage based on some of the elegant chemical concepts, such as aromaticity, curvature, electrostatic forces, etc. In particular, one of the proposed materials, namely the alkali metal-doped fullerenes have been demonstrated as one of the most effective hydrogen storage materials known till date. His earlier work on the self-assembly process dealing with the nucleation and growth of carbon nanotubes is also very significant. This work primarily addresses how the carbon nanotube growth dynamics is severely affected if the size or the composition of the catalysts are altered. It is noteworthy to highlight another recent work on the separation of zirconium and hafnium ions in nuclear industry. His work explains how the phosphate based ligand along with pyridyl amide group can have a remarkable potential to control the thermodynamics of the metal ion selectivity in aqueous solution under mild conditions. In brief, most of the materials proposed and designed based on these conceptually new ideas are first of its kind in the literature and these ideas are now increasingly becoming very useful among the experimental groups as well.

Dr. Amit Kunwar

Young Scientist Award of the Indian Academy of Biomedical Sciences (2022).
Fellow of Maharashtra Academy of Sciences (2022).

Dr. Amit Kunwar, Scientific Officer, BARC research work focuses on the evaluation of synthetic organo-selenium compounds, natural products and their nano-formulations for radioprotective/anticancer activity using cellular and mice model systems and understanding their mechanism of actions. His decade long research on organoselenium compound has led to the identification of 3'3-diselenodipropionic acid (DSePA) as potent candidate drug molecule against radiation induced pneumonitis and lung cancer.

Dr. Prabhat K. Singh

TWAS Young Affiliate(2023-2028) of World Academy of Sciences (2023).
Associate Fellow of Indian National Science Academy (INSA) (2023).

Dr. Prabhat K. Singh, Scientific Officer, BARC has made notable contributions in the area of ultrafast chemical reaction dynamics, bio-physical chemistry, and the spectroscopy of self-assembled materials. His original work, particularly in the realm of ultrafast time-resolved fluorescence, has delivered a pioneering account of the fluorescence sensing activity mechanism of the eminent amyloid fibril sensor, Thioflavin-T (ThT). Dr. Singh has achieved notable advancements in the realm of spectroscopic investigation of self-assembled materials. His unique and innovative methodologies have established innovative sensing schemes for a vast array of clinically significant analytes, which include, but not limited to, Heparin, Protamine, Thrombin, Heparinase, Trypsin, Pesticides, amino acids, amyloid fibrils, ATP, amino acids, Alkaline Phosphatase and Perrhenate ion. Originating from a background as a trained spectroscopist, Dr. Singh remarkably expanded his horizons into an interdisciplinary domain, harnessing the potential of luminescent materials for intricate sensing of analytes in various body fluids, most prominently in serum.

Dr. Biswajit Manna

NASI-Platinum Jubilee Young Scientist Award by the National Academy of Science, India (NASI) (2022).

Dr. Biswajit Manna, Scientific Officer, BARC has been recognized for his significant contributions towards the development of terahertz spectrometer and exploring the exciton dynamics of organic nanomaterials as well as identifying potential organic semiconductors nanomaterial for applications in photovoltaics, organic lightening and invisible ink-based application.

Dr. Raghumani Singh Ningthoujam

Awarded MRSI Medal (2022).

Dr. Raghumani Singh Ningthoujam, Scientific Officer, BARC received the honour in recognition of his significant contributions to the field of Materials Science and Engineering.

He has distinguished between free water on surface of particles and confined water in pores or interstitial water in hexagonal orthophosphate. This confined water is not frozen down to -50°C and stable up to 800°C. He developed many potential luminescence materials including rare-earth doped compounds, quantum dots for diagnosis and therapy. He carried out cancer therapy using Fe_3O_4 nanoparticles in AC magnetic field and showed significant decrease of tumour size in mice. He has made significant contributions on early diagnosis and treatment of cancer using 2-deoxy-d-glucose attached to delay luminescence nanoparticles towards affordable treatment. He developed core@shell nanoparticles and hollow gold or silver nanoparticles for therapy as well as imaging of cancer in in-vitro and mice models.

Dr. Dhiman Chakravarty

Young Scientist Platinum Jubilee Award (2022).

Dr. Dhiman Chakravarty's research focused on deciphering the fundamental mechanisms responsible for overcoming environmental stresses in the agriculturally important nitrogen-fixing cyanobacterium Anabaena. As a part of his work, he showed that the Mn-catalase KatB was induced in response to salt stress/desiccation stress in Anabaena. In fact, salt-triggered accumulation of the thermostable KatB protein protected Anabaena from oxidative stress imposed by H_2O_2. The katB promoter was found to be active only in the vegetative cells (but not heterocysts) of Anabaena. These findings have unravelled the role of Mn-catalase in acclimatization to salt/oxidative stress in cyanobacteria. The Mn-catalase KatB was shown to be a robust, thermostable catalase with an alkaline pH optimum. Using crystallographic and other molecular biology techniques, Dr. Chakravarty was able to demonstrate the importance of N-terminal region in the high thermostability of the enzyme. Since such thermostable catalases were not known and could have a potential use in textile industry, a strategy was devised to purify this protein using simple physical methods, obviating the need of expensive resins. This line of work showcased the potential of Anabaena to be a suitable photoautotrophic alternative to the

Dr. Adish Tyagi

Young Applied Scientist/Technologist Award.

Dr. Adish Tyagi, Scientific Officer, BARC has been conferred with the Young Applied Scientist/Technologist Award for the outstanding contributions in purification of germanium for HPGe detector, synthesis of organic-inorganic materials for radiation detection and evolution of molecular precursors as a simple and viable route to access technologically important binary and ternary metal chalcogenide nanostructure. During the course of work, he has standardized the experimental parameters for achieving ultra-high purity of germanium, developed a facile synthesis route for organic-inorganic scintillators for radiation monitoring system and executed molecular precursor route to synthesize technologically important metal chalcogenides for energy conversion and storage. Furthermore, he has evolved a simple and easily scalable path for photo-responsive, phase pure ternary nanostructure phase pure materials.

Dr. Mohit Tyagi

Elected Member Indian National Young Academy of Sciences (2022).

Dr. Mohit Tyagi, Scientific Officer, BARC is currently working on the growth and characterisation of single crystal scintillators for nuclear radiation detection. He has successfully grown single crystals of novel scintillating materials like $Gd_3Ga_3Al_2O_{12}$:Ce, B which has shown the most versatile performance among other scintillators. He has been involved in the development of various novel devices for the departmental applications. He has published 6 patents and about 80 papers in international journals. For his outstanding track record as a successful scientist and his commitment to applying science for the benefit of society. Dr. Tyagi was selected as a member of the Indian Young Academy of Science (INYAS).

Dr. Ranjan Mittal

Society for Materials Chemistry (SMC) Silver Medal (2022).

Dr. Ranjan Mittal, Head, Inelastic Neutron Scattering Section, Solid State Physics Division, BARC. He is regarded as one of the prominent individuals in the field of modeling of anomalous thermodynamic properties of complex solids using neutron scattering experiments and simulations. His work on energy materials identified unique structures and dynamical descriptors to accelerate the discovery and design of advanced energy materials. He has thoroughly investigated graphite samples that had been irradiated with neutrons over 50 years in the CIRUS research reactor; and for the first time identified the atomic-level defect topologies, and mechanism of defect annihilation on heating and release of the Wigner energy. His recent work on alpha-uranium has provided the explanation of multiple Kohn anomalies in uranium. The work on negative thermal expansion compounds provided understanding of the underlying mechanism in terms of specific anharmonic phonons involving translation, rotation and distortion of polyhedral units. His extensive studies on several multiferroics and other perovskites have provided a clear understanding of the role of structural distortions and their correlation to phonon instabilities, leading to phase transitions in these compounds.

Dr. Mayanak K. Gupta

Elected Fellow INSA (2023).

Dr. Mayanak Gupta, Scientific Officer, Solid State Physics Division, BARC, made outstanding contributions to the structure and dynamics of materials by integrating neutron scattering experiments with quantum mechanical simulations and machine-learning methods. Dr. Gupta also led himself the computational modelling of these materials with first-principles methods and machine learning accelerated large scale molecular dynamics simulations, enabling him to directly capture the experimentally observed effects. This has allowed him to extract the key lattice dynamics of the host framework for the first time, enabling liquid like ionic diffusivities in these unique superionic crystals. Specifically, Dr. Gupta's innovative idea to constrain the machine-learned molecular dynamics simulations and compute the resulting dynamical structure factor and quasielastic scattering was key and enabled the first unambiguous determination of critical anharmonic phonon modes.

Dr. Veerendra K. Sharma

Society for Materials Chemistry (SMC) Bronze Medal (2023).
IPA Buti Foundation Award for Excellence in Theoretical Physics, Astrophysics and Biophysics (2022).

Dr. Veerendra Sharma, Scientific Officer, Solid State Physics Division, BARC has made an outstanding contribution on the understanding of dynamical processes in condensed matter using neutron scattering and molecular dynamics simulation techniques. He is internationally renowned for his work on lipid diffusion in biomembrane. His research led to discovery of a new action mechanism of antimicrobial peptide (AMP), a potential candidate for drug-resistant bacteria. His pioneer investigation unveiled the lateral segregation of lipids induced by an AMP and demonstrated their selective binding to bacterial membranes, positioning them as valuable probe for in-situ infection imaging. Dr. Sharma's exploration of drug-membrane interactions has established a critical link between membrane structure, dynamics, and the therapeutic actions and side effects of drugs. Furthermore, his studies delved into the impact of ionic liquids (ILs) on lipid membranes, disrupting phase behavior and inducing interdigitated domains. ILs also accelerated membrane dynamics, correlating with cellular toxicity, which he demonstrated could be modulated by altering the alkyl chain length.

Dr. K. Tirumalesh

National Geoscience Award (2022).

Dr. K. Tirumalesh, Scientific Officer, BARC was conferred with the National Geoscience Award for the year 2022 jointly with Dr. Harish Bahuguna, Director, Geological Survey of India, Jammu. Dr. Tirumalesh received the award under the Applied Geology category for his outstanding contributions to water resources development and management using isotope technology. The award, instituted by the Ministry of Mines, Government of India, was conferred upon him by President of India. Dr. Tirumalesh is a recipient of Indian Association of Nuclear Chemists and Allied Scientists' (IANCAS) Dr. Tarun Datta Memorial Medal.

Dr. Santosh Kumar Gupta

Member Indian National Young Academy of Sciences (2022).
Dr. Santosh Kumar Gupta, Scientific Officer, BARC has been elected as a Member of Indian National Young Academy of Sciences (INSA-INYAS) and also of National Academy of Sciences (NASI). Dr. Gupta has been awarded Society of Materials Chemistry (SMC) Bronze Medal, Chirantan Rasayan Sanstha (CRS) Silver Medal as well as the Indian Association of Nuclear Chemists and Allied Scientists' (IANCAS) Dr. Tarun Datta Memorial Medal.

Dr. Seraj Ansari

Member of National Academy of Sciences (NASI).
Dr. Seraj Ansari, Scientific Officer, BARC has been selected as member of National Academy of Sciences (NASI) based on his work on the complexation thermodynamics and separation of actinides with state of art designed organic ligands.

Dr. Prasun Kumar Mukherjee

- Elected Fellow Indian National Science Academy (INSA) (with effect from 1st January 2022).

Dr. Srinivas Krishnagopal

- Elected Fellow American Physical Society.

Dr. Sugam Kumar

- Elected Associate Indian Academy of Sciences.
- Young Scientist Platinum Jubilee Award.

Dr. Hirakendu Basu

- Young Associate Maharashtra Academy of Sciences.

Dr. Ashish Srivastava

- Awarded Fulbright-Nehru Academic and Professional Excellence Fellowship.

Dr B. N. Pandey

- Awarded prestigious Society for Cancer Research and Communication (SCRAC) 24th Annual Award 2023 for his significant contribution to Biology of Radiation and Hyperthermia.

Dr. Sandeep K. C., Sachin Kamath, Ashok Kumar M, Saikat Saha, S. P. S. Somvanshi, R. M. Rakate, A. K. Chatterjee, and C. K. Warghat

- Nina Saxena Excellence in Technology Award (2022) from IIT, Kharagpur, for indigenous development of Compact Alkaline Water Electrolyser Technology for simultaneous production of high purity Hydrogen and Oxygen by splitting of water.

R. S. Agrahari

- President of India's Award for Meritorious service (2023).

E. K. Nile

- DG FSDC&HG Bronze Disc (2022).

Flora at BARC Trombay

Bird's eye view of BARC under night sky