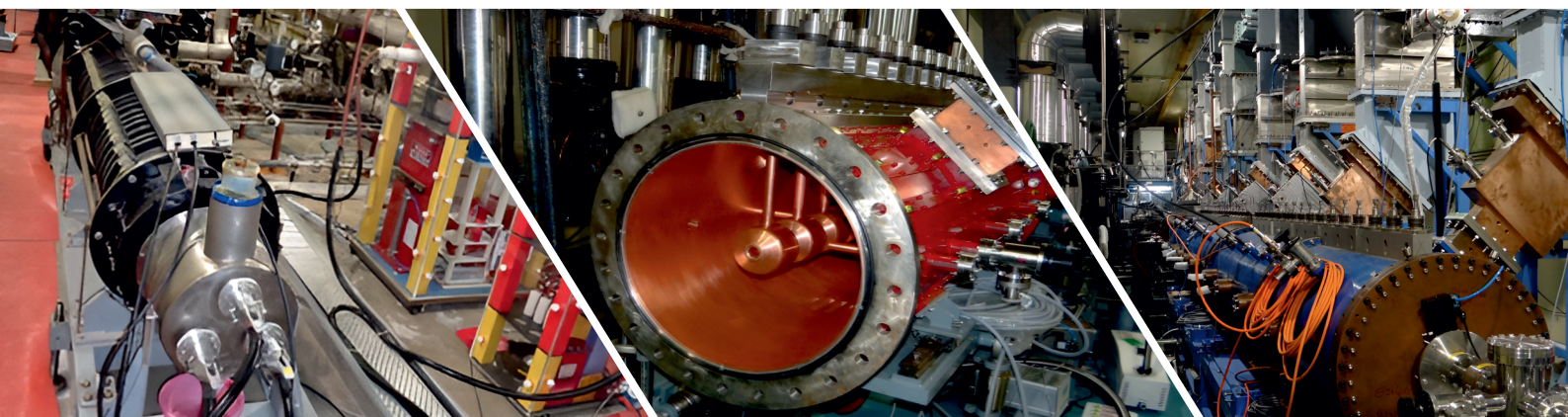




Government of India
Bhabha Atomic Research Centre

ANNUAL REPORT 2023



BARC VISTA



Title:

BARC VISTA: Annual Report 2023

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On the front cover: Important systems and sub-systems of LEHIPA Facility in BARC Trombay.

On the back cover: The state-of-art technologies developed in BARC with important applications in healthcare, industry and water purification.



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Director's Message



Bhabha Atomic Research Centre (BARC) continues to play a pivotal role in addressing the requirements of India's atomic energy program. One of the defining aspects of its success is its firm adherence to safety and sustainability across all verticals of research and development programs.

As BARC steers itself into a new era of history by virtue of completion of 70 years since its inception in 1954, the range of ongoing and future programs at its various centres would be guided by the philosophy that nuclear technology is harnessed responsibly and for the greater good.

During the year 2023, BARC has made the most of its mandate and resources to help find promising solutions to daunting challenges in the field of nuclear science and technology. Some of the noteworthy developments and contributions at our Centre include successful demonstration of Low Energy High Intensity Proton Accelerator (LEHIPA) beam to 20 MeV energy level thereby opening up new possibilities in radiation therapy for cancer treatment, for production of radioisotopes, and paving way towards future accelerator-driven reactor systems.

Radioisotope production activity continues to perform robustly supported by higher availability of research reactor facilities Dhruva and Apsara-U. In our pursuit of National Hydrogen Mission mandated goals, the first-of-its-kind integrated Copper-Chlorine cycle-based process for hydrogen production had clocked impressive outcomes. The R&D programs in frontier areas associated with Physical Sciences, Chemical Sciences, Biology and several others continued to make good strides in the overall scheme of nuclear energy development activities.

BARC has been enabling the expansion of start-up ecosystem in the country through transfer of its spin-off technologies. During the year, 188 technology transfer agreements were inked with private sector partners for commercialization of 105 technologies, with an eye on ensuring that these affordable technologies bring about a positive change in the lives of grass root sections of the society.

A key pillar of BARC's life-long mission is to sensitize and engage citizenry about the positive impact of atomic energy activities in the overall national development. Under the novel Parmanu Jyoti outreach program, young scientific officers of BARC have travelled to schools situated in remote areas of the country to propagate this message more effectively among the younger generation.

We hope BARC VISTA 2023 would certainly serve as a point of ready reference for anyone seeking information about the ongoing activities in BARC and on specific domains of nuclear energy sector. I complement Scientific Information Resource Division for carrying out the task of creating this comprehensive document in a timely and systematic manner.

Vivek Bhasin



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INDIAN NUCLEAR POWER PROGRAM

BARC is engaged in multi-disciplinary and multi-scale activities leading to the development of technologies related to India's nuclear power program. These include fuel fabrication, quality assurance, in-service inspection, post irradiation examination, inspection tools for research reactors, Pressurized Heavy Water Reactors (PHWRs). The technologies related to front and back end of the nuclear fuel cycle, which includes spent fuel reprocessing and nuclear waste disposal, are within the ambit of forefront research areas of this centre. The activities under these thrust areas cover the first three vision programmes of BARC, the highlights of which are sketched in this section.



The facility commissioned in BARC for carrying out advanced NDE studies for monitoring the integrity of PHWRs coolant channels.

Indian Nuclear Power Program

Development of Inspection Systems

Automated Facility for Advanced NDE Studies & Calibration of BARCIS Inspection Heads

An Automated Horizontal Facility was commissioned in BARC for carrying out advanced Non-Destructive Examination studies for monitoring the condition of PHWRs coolant channels. The facility simulates In-Service Inspection environment with closed loop water circulation inside the coolant channel assembly under reactor shutdown condition besides enabling Ultrasonic examination of Pressure Tube (PT). PT reference standard spools of a range of lengths (200 mm to 1500 mm) for 220 MWe as well 540 and 700 MWe PHWRs can be accommodated, thus making it a versatile facility for carrying out advanced NDE studies. A

number of 220MWe and 540MWe BARCIS Inspection Heads calibrated on this facility have been delivered and deployed for In-Service Inspection at various PHWR Stations. The systems at the facility were designed and developed through in-house efforts.

Multi-channel Structural Vibration & Pressure Pulsation Measurement System

Multi-channel portable system for structural vibration and pressure pulsation measurement has been developed for health monitoring of PHT components for 700 MWe PHWR. The system consists of radiation hardened accelerometers & flow DP transmitters, real-time data acquisition & processing system (DAPS) and remote monitoring system. The system has been installed at KAPP-3 for studying the effect of two-phase flow conditions on structural vibrations.

Software for ECT based Inspection of Steam Generator Tubes' Inner Diameter

Auto Decision Assist Software for identification of defects and abnormalities in Steam Generator tubes from ECT signals was developed and deployed in the operations of Nuclear Fuel Complex. The software was validated against existing inspection data.

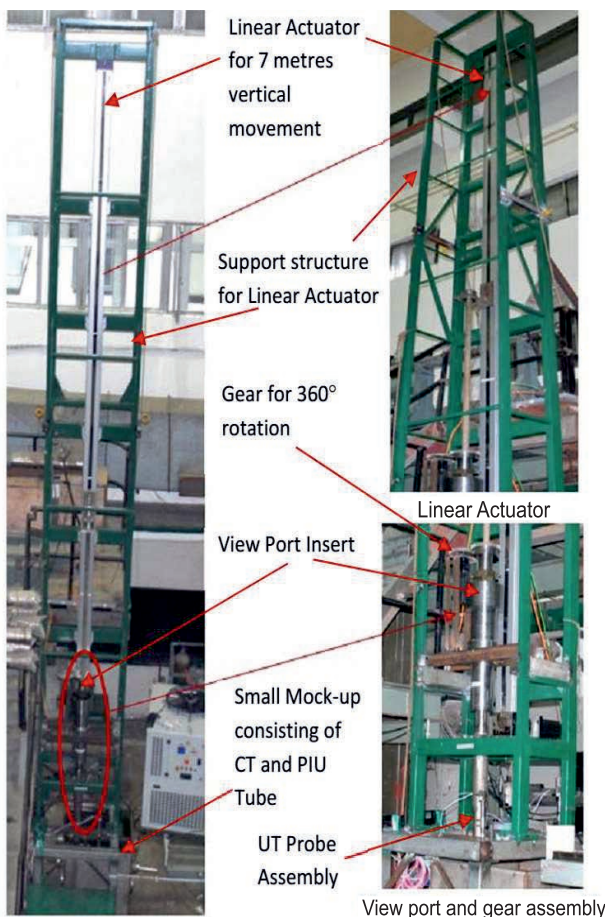
Calandria Tube and Poison Injection Unit Tube Gap Measurement System

A CTPIU system was developed for measurement of the gap between Calandria Tube (CT) and Poison Injection Unit (PIU) tubes in TAPS-3&4 PHWRs. It consists of 15 meter long Mechanical Assembly, Linear Actuator for vertical travel, gear for rotation and Control & Automation module. The mechanical assembly houses an ultrasonic testing (UT) probe assembly which is maneuvered in rotary and in vertical directions, using various mechanisms of the system. The system was

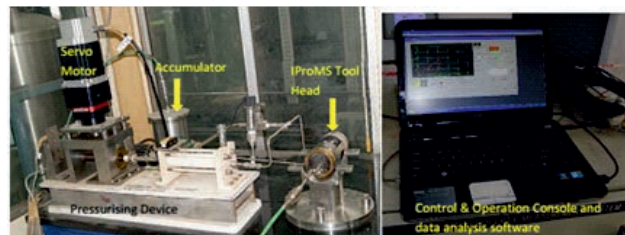
successfully tested and qualified in a mock-up. PIU tubes are typically aligned horizontally in perpendicular direction to the coolant channels. A design-gap is provided during installation in the vertical plane between the Calandria Tube and the PIU tube. The gap keeps reducing during reactor operation life-time due to creep sag of the coolant channels. There is a requirement to measure the gap between CTs and PIU tubes in order to assess the time of contact between them.

In-situ Property Measurement System

An in-situ Property Measurement System was developed for measurement of mechanical properties of pressure tube during its operating life by cyclic ball indentation test. The data of load and depth of indentation are recorded remotely during the test and used to evaluate the mechanical properties. IProMS was successfully deployed for the first time in four numbers of pressure tubes of Rajasthan Atomic Power Station reactor unit #3



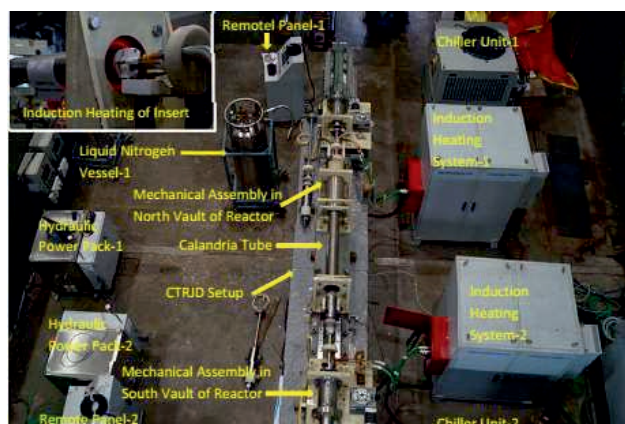
CTPIU Gap Measurement system undergoing qualification tests.



IProMS operated at RAPS-3.

Calandria Tube Rolled Joint Detachment System

A Calandria Tube Rolled Joint Detachment System for 540/700 MWe PHWRs was developed for removing calandria tube from End Shield without



CTRJD-540/700 along with its sub-systems.

degrading the integrity of rolling grooves. The system works on the principle of shock heating and cooling of insert and calandria tube assembly. An axial force is further applied for removal of insert and calandria tube. Experimental trials were successfully completed in a mock-up setup.

Tube Rolled Joint Setup

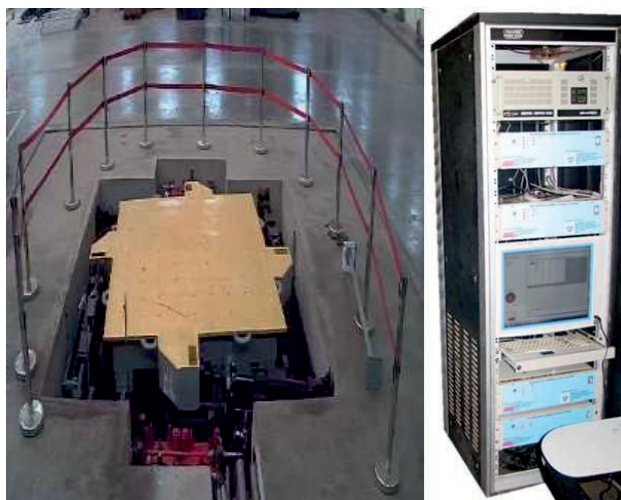
A tube rolled joint set up and short length rolling tools of four different sizes have been developed for fabricating reactor grade rolled joints. The setup along with the rolling tools has been installed and will be used to carry out development studies related to different configurations of tube rolled joints.



Rolling Tools & Rolled Joint Specimen.

Servo Hydraulic Shake Table for Seismic Qualification of Nuclear Reactor Structures

A state-of-the-art 5Te servo hydraulic shake table has been developed making it a vital tool for the seismic qualification of nuclear reactor structures and systems. This has six degrees of freedom (6 DOF) and is capable of accelerating at 1g a five-ton



Shake Table with Servo Controller.

(5T) specimen simultaneously in three axes and

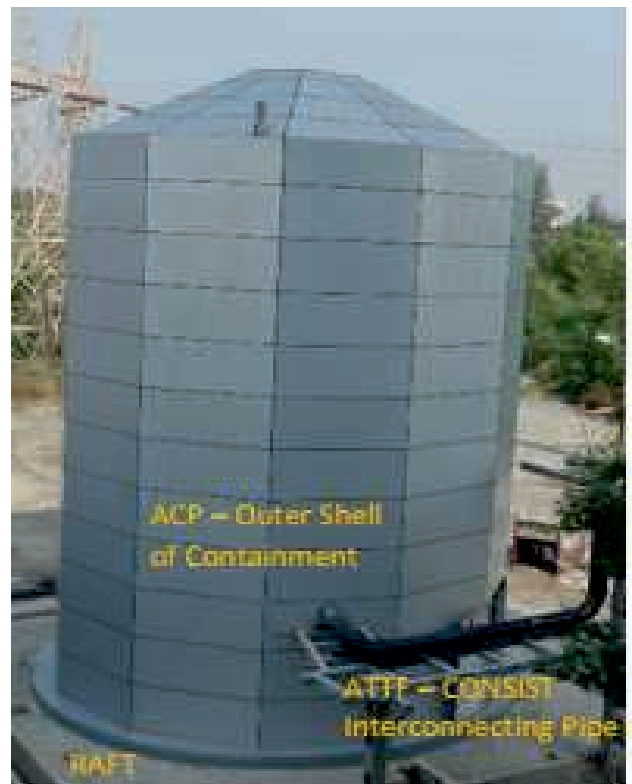
across a frequency range of 0.1Hz to 50Hz. The high bandwidth (50Hz) and precise motion (40micron) servo hydraulic linear actuator is achieved with improved hydrostatic bearings and usage of high bulk modulus oil. A multi-axis digital Servo Controller controls eight servo hydraulic actuators in real-time and carries out complex calculations. The in-house developed GUI-based computer software and 128 Channel Data Acquisition System enhances the systems operability and capability.

Double Sliding Friction Dampers

Double Sliding Friction Dampers (DFSD) have been developed to reduce the seismic response in safety related process vessels. This has been tested for a typical safety related process vessel and found to meet the seismic requirements as prescribed by the code.

Containment System Integral Simulation Test (CONSIST) Facility

CONSIST is a scaled integral test facility, which is in operation at NPCIL R&D Centre, Tarapur, for carrying out experimental studies on reactor containment thermal-hydraulics. The facility simulates reactor containment along with its



CONSIST Facility.

various passive systems. It is also integrated to the ATTF which simulates the Main Heat Transport Systems (MHTS) and Emergency Core Cooling Systems (ECCS). The civil structure of the facility is made of temperature controlled M60 grade RCC with a steel liner. To improve the leak tightness of the structure at the test condition, the unlined surface of the structure was coated with polyurea. The facility is fully instrumented with about 400 sensors for measurement of pressure, temperature, water level and humidity. Simulated LOCA experiments will be conducted in the facility and effectiveness of various passive safety systems established.

Air Injection into Suppression Pool

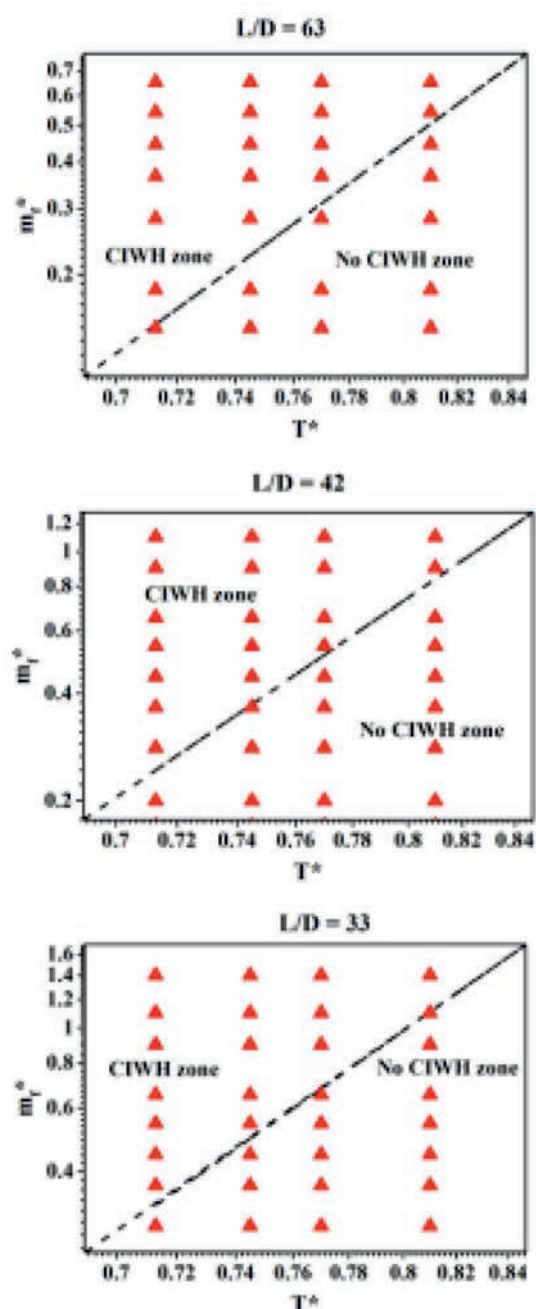
Experiments were conducted in the Water and Steam Interaction Facility-II at SRI, Kalpakkam to investigate suppression pool hydrodynamics. These tests involved releasing air through a 50NB diameter vent pipe submerged in a pool of water. Experiments were conducted by varying air injection rates and submergence depth. A CFD simulation was also carried out to complement the experimental findings, replicating a specific scenario.



WASIF-II Test Vessel for Suppression Pool Simulation studies.

Condensation Induced Water Hammer

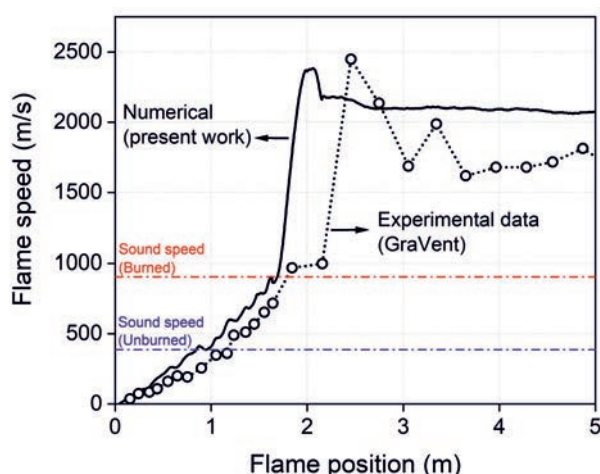
A correlation has been developed to predict the initiation of Condensation Induced Water Hammer (CIWH) event from the several experiments conducted at Water and Steam Interaction Facility (WASIF), Kalpakkam. It can be used for checking possibility of the water hammer due to water and steam interaction in a horizontal pipeline. A non-dimensional regime maps derived from the correlation, illustrates the zones of occurrence or non-occurrence of CIWH for different length-to-diameter ratios.



Non-dimensional regime map for onset of CIWH as per developed correlation.

A Model for Flame Acceleration and Deflagration-to-Detonation Transition

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 methodology augments the standard Turbulence Flame Closure (TFC) with auto-ignition modelling, which can capture whole phenomena leading to DDT in a single unified framework. The developed modelling approach has been validated with experimental data and can be used for reactor containment related safety assessment.



Validation of numerical result with experimental data for GraVent shock tube.

Recovery of Nuclear Minerals

Recovery of Uranium and Rare Earth values from Uranium Resource at Geratiyon-Ki-Dhani (GKD) in Rajasthan

The uranium resource at Geratiyon-Ki-Dhani (GKD) in Rajasthan is an important area of North Delhi Fold Belt (NDFB) known for the structure-controlled, hydrothermal U-REE mineralization. The ore contains 0.025% U_3O_8 and 920 ppm TREE as valuable minerals along with major gangue such as 62-64% SiO_2 , 17-18% Al_2O_3 . Presence of Uranium in the form of refractory minerals, like Davidite and Brannerite, and optimization of leaching parameters for simultaneous extraction of Uranium and REE are the two challenges in development of flowsheet for processing the

Geratiyon-ki-Dhani (GKD) uranium ore. Pug-cure leaching technique was successfully applied, out of several alternative extraction methods, to recover 85% of U and 80% of REE values present in the ore under optimized conditions.

Purification of Uranium from Fluoride-containing Slag Leached Solution

A Solvent Extraction Facility (SEF) for purification of uranium from SLS had been commissioned for purification of uranium from slag leached solution (SLS) at the capacity of 2.0-4 kg U/hr. The new flow sheet obviates two operation steps besides reducing the requirement of manpower, chemical consumption and effluent generation effectively. The regular operation has been started. Uranium locked in MgF_2 slag is leached out by HNO_3 . The slag leached solution (SLS) contains 30 to 40 gpl uranium, 0.8-1.2 (N) FA (HNO_3), 500-3000 ppm Fluoride and other impurities mainly iron, magnesium, etc. Fluoride is first fixed using aluminum nitrate and then the uranium in SLS is purified to nuclear grade uranium by solvent extraction (SX) method.

Production of Uranium Oxide Powder from Direct Denitration Demonstration Plant at NRB Tarapur

The Direct Denitration Demonstration Plant was operated using reprocessed uranyl nitrate solution generated at PREFRE-2, Tarapur to produce uranium oxide powder. About 500 L of quality uranyl nitrate solution of varying U concentration



Uranium Oxide Powder (orange color).

was processed in continuous mode to produce orange oxide powder. Continuous smooth operation of the reactor was observed.

Investigation of Dissolution Process for Production of Silica-free Zirconium Nitrate Solution

A novel dissolution process was investigated for production of silica-free zirconium nitrate solution. Bench-scale facility for cold dissolution consisting of 35 L dissolution reactor along with accessories, including chiller unit, condenser was tested with 7.5 kg of washed dry frit. The water leaching of reaction mixture generated 15 L zirconium nitrate concentrated solution containing 65 g/L Zr, 2 g/L Hf and 300 ppm silica in 6N free acidity against 6500 ppm silica via hot dissolution.



Bench scale set up of cold dissolution.

Production of Dysprosium & Yttrium Metals

Dysprosium metal is an essential alloying element in Nd-Fe-B permanent magnets for improved magnetic properties. The demand for Nd-Fe-B based permanent magnets is growing due to their applications in cleaner energy systems. Currently, demand for Dysprosium metal in India is being met through imports. The technology for the production of dysprosium metal from indigenous raw material produced at IREL has been successfully developed and demonstrated by BARC. Acalcio thermic reduction-based technology for the production of yttrium metal using IREL-produced yttrium oxide was developed

to fulfil the potential requirements in the department. Yttrium metal produced is being tested and evaluated for its application in pressure tubes. Yttrium metal is a promising hydrogen getter material with the potential to enhance the life of PHWR pressure tubes.



Dysprosium metal



Yttrium metal

Comprehensive Extraction Process Scheme for Recovery of REE & Nb from Bhatikhera Ore (Rajasthan)

A hard rock REE deposit at Bhatikhera (Rajasthan), assaying 0.36% TREE, has been found to contain higher concentration of commercially attractive heavier rare earths (40% of TREE), besides 0.036% of valuable Nb metal values. The major gangue consists of 70% SiO_2 , 8.6% Fe_2O_3 . The comprehensive process flow sheet developed for the recovery of REE and Nb consists of various steps viz. reduction in the particle size of the ore, sulphation roasting followed by water leaching for extraction of REE and Nb, purification by solvent extraction, and precipitation. The solvent extraction scheme developed consisted of selective extraction of Nb from the REE bearing

Securing New Material Resources

- ✧ A complete process flow sheet has been developed for both synthesis and densification of Zirconium Carbide (ZrC) powder, which involves carbothermic reduction of ZrO_2 at high temperatures in vacuum environment, resulting in the production of single-phase ZrC.
- ✧ A laboratory scale study was undertaken to understand titanium sponge production with enhanced yield. 99.95% pure TiCl_4 received from indigenous sources, was used as the starting material for preparing around 1 kg aviation grade titanium sponge in a single tranche with enhanced yield.
- ✧ About 92% of Lithium values present in Spodumene mineral concentrate extracted from the pegmatite rocks in Mangaluru area (in Karnataka) were recovered, resulting in a Lithium Carbonate product of 96% purity.

leachate using Aliquat 336 in kerosene and iso-decanol as modifier. Stripping of Nb was achieved using 3M HCl. REE from the raffinate after Nb extraction was precipitated as REE fluorides. The overall process developed showed the feasibility of recovering about 80% of REE values and 50% of Nb values present in the ore.

Thermo-chemical Treatment of Sodium Sulphate

Hydrogen sulphide (H_2S) gas serves the purpose of carrier gas in Exchange Unit for deuterium transfer and enrichment in liquid phase in Heavy Water Production Plants. H_2S gas is generated by reaction between sodium sulphide (Na_2S) and sulfuric acid. A considerable amount sodium sulphate (Na_2SO_4) solution is generated in this process. Feasibility of a high temperature fluidized bed reactor-based process for reconversion of Na_2SO_4 to Na_2S was demonstrated. Operating parameters such as fluidization velocities, temperature, carbon to sulphate ratio were optimized to maximize conversion of Na_2SO_4 to Na_2S .

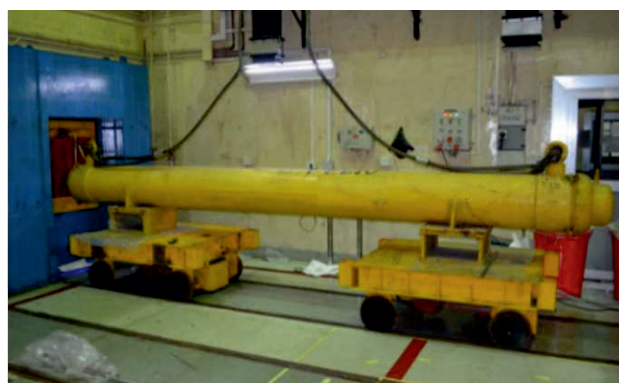
Post Irradiation Examination

Post Irradiation Examination of PHWR Pressure Tubes from Power Reactors

Integrity of pressure tube is central to safety of pressurised heavy water reactors (PHWRs). Post irradiation examination (PIE) of pressure tubes provides vital information on service induced degradation of pressure tube material due to irradiation, oxidation, hydriding etc., and characteristics of flaws observed during in-service inspection. These inputs are crucial for reactor

designers, pressure tube manufacturers, reactor operators and regulatory body for safe and efficient operation of PHWRs.

Post irradiation examination (PIE) is essential for assessing the in-reactor performance and generation of metallurgical properties database on Indian manufactured PHWR pressure tubes. Pressure tubes from KAPS-1 and MAPS-1 PHWRs were subjected to comprehensive PIE. Detailed microstructural examination and hydrogen analysis of pressure tubes have been carried out to assess their performance in terms of corrosion behaviour, hydrogen pick-up and mechanical properties. Mechanical property determination of pressure tubes was carried out inside lead shielded testing facilities. These properties provide vital inputs for fitness-for-assessment of pressure tubes.



Shielding cask containing pressure tube docked to the port of New Hot Cell Facility.

Failure Analysis of Out-of-core Structural Components from Nuclear Power Plants

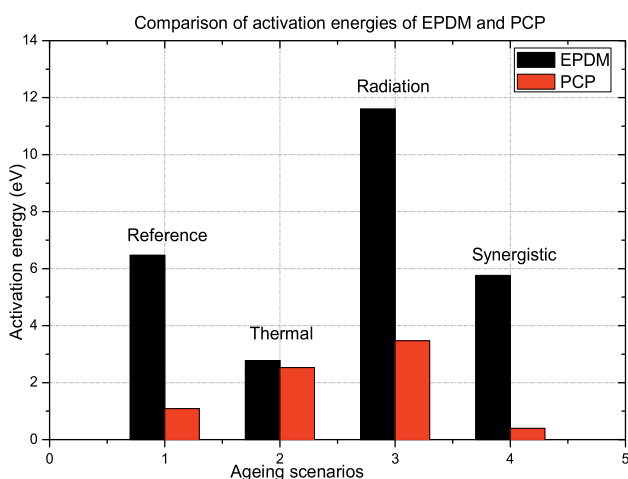
Variety of materials is used during manufacturing of components and equipment in Indian Nuclear Power Plants. The components inside the nuclear

core are primarily fabricated from zirconium alloys but those outside the core are manufactured from different alloys depending on the operating conditions and requirements of metallurgical properties.

Failure and performance analysis of out-of-core components is carried out using various techniques. The failure location is subjected to detailed investigations involving microstructure analysis, X-Ray diffraction studies, spectroscopic studies, chemical characterization etc. to arrive at the root cause of failure.

Activation Energies of I&C Cable Insulation Materials

Instrumentation and Control (I&C) cables in Nuclear Power Plants are subjected to a variety of ageing and degradation stressors over a time period. Sequential and synergistic ageing due to thermal and radiation environment were carried out on Ethylene Propylene Diene Monomer (EPDM) and PolyChloroPrene (PCP). These were for radiation levels up to 100MRad (at 100°C) and thermal ageing from ambient to 700°C under nitrogen atmosphere. The activation energies



Comparison of activation energies under sequential and synergistic ageing scenarios.

corresponding to weight loss of 5% were determined from Thermo-gravimetric analysis.

Environment Monitoring

Prototype Integrated System for Simultaneous Sampling of Tritium and Carbon-14 in Air

An important feature of radiation protection and regulatory requirement is the assessment of ^3H (Tritium) and ^{14}C (Carbon) radioactivity levels in the workplace and environment due to their ubiquitous presence in all living and non-living things. In order to facilitate long term sampling along with speciation capabilities, an indigenous automated air-Tritium and Carbon- sampler has been designed, fabricated and tested in BARC. The system comprises three modules to collect different chemical forms of Tritium and Carbon-14, viz., a condenser unit to collect air moisture by condensation process, a Bubbler unit to trap the CO_2 and a Furnace unit for catalytic conversion of air tritium in HT form and Carbon -14 in hydrocarbon or CO form. The instrument is useful for monitoring and speciation studies of air ^3H in both HTO & HT forms and ^{14}C in $^{14}\text{CO}_2$, ^{14}C -hydrocarbons and CO forms simultaneously.



Prototype Integrated Tritium and Radiocarbon Sampling System developed in BARC.

Robust Post Irradiation Examination Practices



The Post Irradiation Examination (PIE) facility has been upgraded with commissioning of a new gamma scanning set-up and a system for dimension measurements. In gamma scanning set-up, variable slit for intensity of gamma radiation entering the detector can be controlled in a fool-proof manner. Potentiometer based length measurement system has led to accurate determination of change in length of fuel element during irradiation.

Environmental Surveillance at Trombay and Vizag facilities, and Nuclear Power Plant Sites

The radiological safety of general public around nuclear facilities is accorded top-most priority during design, construction and operation of DAE facilities. Environmental Survey Laboratories (ESLs) established at each facility periodically collect, process and analyse various environmental matrices upto 30 km radial distance for activity content using various radiometric techniques. The results clearly indicated that the dose to the member of public at fence post (1.6 km) is only a small fraction of regulatory limit of 1000 micro sievert per year. ESLs are also involved in public awareness programs at Nuclear Power Plants sites and in collection of site specific pre-operational radioactivity and meteorological data at the upcoming facilities. A detailed analysis of two decades (years 2000-2020) of environmental data collected at NPP sites indicated negligible radiological impact of Indian Nuclear Power Plants on the environment and the public.

Environmental Monitoring, Migration and Remediation Studies of Radionuclides for Radiation Safety and Protection

Egg shell, a bio-waste material known for its enriched Calcium content, was modified with phosphate for use as an efficient adsorbent for decontamination of uranium from aqueous media. Adsorption studies indicated very good U removal efficiency (>98%, at 10 ppm U concentration in water at pH 6). The material also showed good regeneration capabilities.



A Clean room (ISO 7) with clean bench facility (ISO 5) was established in BARC.

Use of Lead-bismuth eutectic (LBE), a promising material for coolant and target material in accelerator-driven sub-critical systems (ADSS), leads to an unavoidable production of ^{210}Po , during the neutron irradiation of ^{209}Bi in the system. A radiochemical separation and measurement technique has been evolved using passivated ion-implanted planar silicon (PIPS) based alpha spectrometry system. For measurement of radionuclides at trace and ultra-trace levels (ng to pg/mL), a clean room (ISO7) with clean bench facility (ISO 5) is established for processing of samples.

Optically Stimulated Luminescence Dosimetry System for Personnel Monitoring

An Optically Stimulated Luminescence Dosimetry (OSLD) based system was devised in BARC for nationwide personnel monitoring. The system comprises large-scale phosphor synthesis of dosimetry-grade $\alpha\text{-Al}_2\text{O}_3:\text{C}$ using the melt processing technique. The synthesized material exhibits TL/OSL sensitivity comparable to commercially available options. OSLD badge consisting of four different filters to discern a beta, X-ray, and gamma component was developed. An OSL reader featuring a PMT-based photon counting module was designed and developed to read the four element OSL badge. Controlled by a microcontroller-based embedded system, the reader achieves a Minimum Measurable Dose of 30 μGy , displaying dose linearity from 50 μGy to 10 Gy. The system has promising features that offers fast readout, high throughput and inherent simplicity.



OSLD Badge reader system.

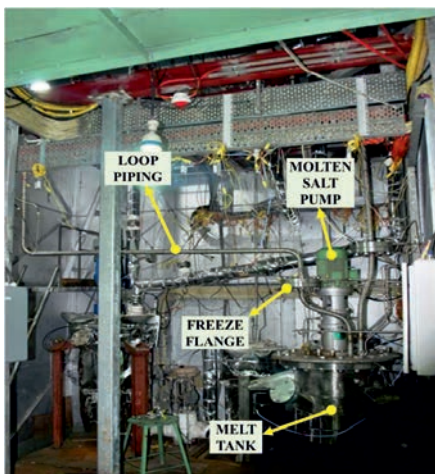
Advanced Reactors & Associated Materials Research

Reactor Physics Analysis of Molten Salt and Gas Cooled Reactors

Reactor Physics simulations were carried out to design a 5MWth molten salt reactor with $\text{LiF-BeF}_2\text{-ThF}_4\text{-PuF}_3$ fuel salt circulating in graphite channels. Different fuel salt compositions and core configurations have been studied to estimate fuel salt inventory, core reactivity, energy and spatial distribution of neutron flux, fuel cycle length etc. in static and flowing conditions of fuel salt. Further, the physics design of a 5MWth Gas Cooled Reactor (GCR) has also been worked out. The core is graphite-moderated with CO_2 as coolant and having an outlet temperature of 650°C . The active core consists of 21 fuel clusters, each embedded in a square graphite block, and with a provision to insert control/shutoff rods in the inter-channel locations. The fuel cluster is contained in graphite sleeves and has 24 SEU oxide-based fuel pins and SS clad. Extensive neutronic studies have been carried out to achieve desired core life, negative reactivity coefficients, accommodating independent and diverse shut down system and for control design optimization.

Forced Circulation Molten Salt Loop (FCMSL)

The FCMSL has been developed for carrying out thermal-hydraulic studies and component development related to molten salt reactors. It was



The FCMSL Facility.

commissioned and operated for 750 hours continuously with molten nitrate salt at 325°C and flow rate of 100LPM. The performance testing of developed components like pump, freeze flanges, heat exchangers and instrumentation were carried out in this loop conditions. The Molten Salt flow rate was measured using non-intrusive high temperature ultrasonic flow meter. This direct method facilitates in evaluation of loop heat balance and the pump characteristics.

Forced Circulation Liquid Metal Loop (FCLML)

This facility has been developed for carrying out thermal hydraulics and component development related studies for high temperature reactor. This loop has Lead-Bismuth Eutectic as coolant and consists of major components like vertical shaft and magnetically coupled centrifugal pump, heat exchangers, level sensor, oxygen sensor and related instrumentations. An in-house developed sensor made of Yttria Stabilized Zirconia tube and joined to a long alumina tube with SS316 housing was made for oxygen monitoring in the loop. Experiments have been carried out at different heater power levels in this facility.



The FCLML Facility.

Neutron Irradiation of Indigenous RPV Steel Forgings

The microstructure of shell forgings of 20MnMoNi55 reactor pressure vessel (RPV) steel varies considerably from surface (ID) to centre (T/2) due to its large thickness and to compare their irradiation responses, samples from ID and T/2 locations were irradiated with fast neutrons in Apsara-U to 0.02, 0.05 and 0.1 dpa damage. Line

profile analysis of X-ray diffraction patterns of unirradiated and irradiated samples was carried out using Rietveld refinement method. The ID location exhibited a lower domain size as compared to T/2 in the unirradiated state, and correspondingly higher microhardness. After irradiation, domain size decreased more for T/2 location. Microhardness increased for both locations upon irradiation.

Development of NiMoCrTi-C Alloy for Molten Salt Breeder Reactor Loop

The fabrication of components for MSBR loop, tubes (67 mm OD X 13 mm WT x 3000 mm L) from the forged ingots made from NiMoCrTi-C alloy were successfully hot extruded at 1130°C based on the inputs from processing map. The forged billets were re-crystallized optimally by annealing at 1080°C for 15 min. Subsequently, the 21 mm diameter tubes with wall thickness of 2.77 ± 0.2 mm were produced from the forged billets using the 3 stage pilgering route with an intermediate annealing at 1120°C for 6 min. The lab scale heat treatment & micro-structural analysis showed strain free grains after heat treatment at 1120°C. The mechanical properties of the tubes produced by heat-treating at 1120°C for 6 minutes were found to be satisfactory. The tube fabrication from the forged billet was carried out at NFC, Hyderabad and the same route is being followed to fabricate 6 mm and 10 mm diameter tubes.

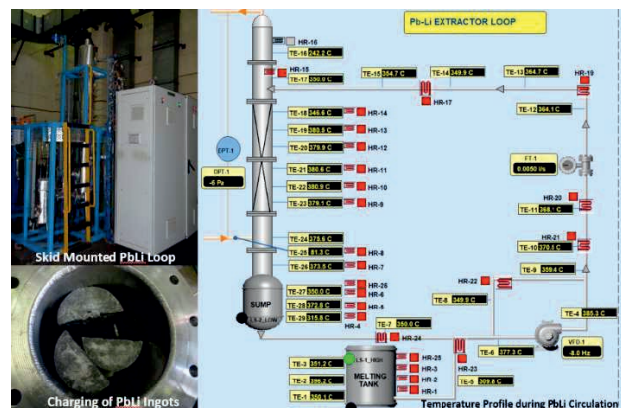


Different stages involved in the fabrication of 21 mm diameter NiMoCrTi-C alloy tube.

Lead-Lithium (Pb-Li) Extractor Loop

Pb-Li Eutectic is identified as one of the potential breeder and coolant for the thermonuclear Fusion energy. A demonstration loop for extraction of Hydrogen Isotope from Pb-Li eutectic has been established complete with instrumentation and SCADA system. Pb-Li circulation has been carried out successfully at 350-400 deg. C range for sustained period, with molten metal electromagnetic pump. Hydrodynamic parameters of the hydrogen isotope extraction column have

been estimated with Helium purge gas flow rate ranges 50-900 NLPH and empirical correlations were established based on the experimental results.



Experimental system for Pb-Li system.

Advanced Lattice Neutron Transport Code n-TRAC

A Neutron Transport Analysis Code (n-TRAC) based on Method of Characteristics (MOC) has been developed for reactor physics analysis of advanced reactors in 2-D hexagonal/square geometry. It uses the Bowyer-Watson algorithm to discretize the problem domain into Delaunay triangulation and incorporates characteristic ray tracing through the problem domain. A library processing module is incorporated to read and process the cross-section data from a standard multi-group nuclear data library. The evaluation of critical reactor spectral indices ($\rho^{28}, \delta^{28}, \delta^{25}, \xi^{25}$) helps to compare the results of different codes and libraries and provides more insight into the reaction rates in different energy regions. The code has been well benchmarked by analyzing multiple problems viz. AERE, BAPL, VVER-1000 lattices.

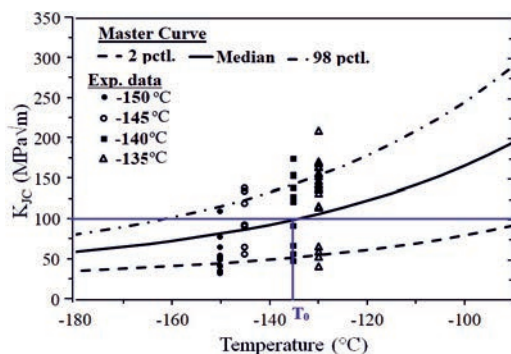
Multi-group Covariance Library for Uncertainty Analysis in Reactor Physics

The cross-section uncertainties in the evaluated nuclear data libraries are considered as a significant uncertainty source in reactor physics analysis. A multi-group covariance library is required to estimate the nuclear data uncertainty propagation in reactor physics calculations. The covariance library has been generated using NJOY2016 code system for primary fuel and non-

fuel isotopes such as ^{235}U , ^{238}U , ^1H , ^{16}O etc. The point data sets for generating covariance library are taken from ENDF/B-VII.I and ENDF/B-VIII. The covariance library has been generated using WIMS library group structure.

Reactor Pressure Vessel Steel Fracture Toughness Master Curve

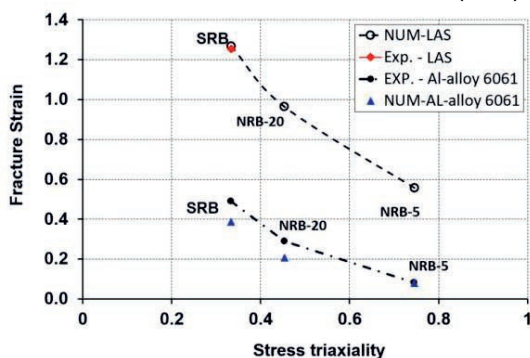
The fracture toughness in the ductile-to-brittle transition temperature regime has been evaluated using sub-sized compact tension specimens machined from forged block of 20MnMoNi55 grade pressure vessel steel. These have been evaluated from the experimental load-displacement data in terms of K_{IC}. The reference transition temperature T₀ has been evaluated as -135°C. A total of 54 tests were carried out and the scatter in test data along with the bounds and median values of master curve plotted.



Fracture Toughness data and scatter.

Damage in Low Alloy Steel & Aluminium Alloys under different Stress Loadings

The existing material damage model under the continuum damage mechanics framework has been improved for prediction of the ductile fracture in a metallic material. The fracture strains in tensile specimens such as smooth round bar (SRB) and

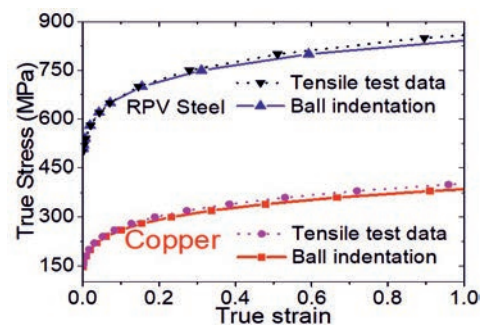


Fracture Toughness data and scatter.

notched round bar (NRB) of low alloy steel (LAS) and aluminium alloys materials under different stress triaxiality have been predicted using the improved model. The predictions compare well with experimental results with fracture strain decreasing in an exponential manner with an increase in stress triaxiality.

Ball Indentation Test to Evaluate Stress-strain Curve of Thin Sections

A ball-indentation based test procedure has been developed incorporating the effect of specimen thickness for a range of 0.1 to 1.5 mm. This has been validated with standard tensile tests on different materials (i.e., RPV steel, Copper, Zr-4 and Zr2.5Nb). The true stress-strain curve as evaluated using the new procedure has been compared with standard tensile test data.



Fracture Toughness data and scatter.

Tungsten-Rich Ni-W/Ni-W-P Alloy Coatings

Electroplated hard chromium due to its exceptional hardness, wear resistance and corrosion resistance is a preferred choice for coating and surface finishing applications in nuclear industry. The precursor to this coating, hexavalent chromium (Cr (VI)), is however a carcinogen. Three alloy coatings namely Ni-50.7 wt.% W (Ni-W), Ni-36.3wt% W-3.3wt% P (Ni-W-LP) and Ni-19.5wt% W-7.7wt% P (Ni-W-HP) were therefore studied as a substitute through electrode deposition on SS304 substrate for hardness and tribological performance. The low phosphorus (Ni-W-LP) coating heat-treated at 400 $^{\circ}\text{C}$ exhibited the best wear performance. The self-lubricating nature of tungsten reduced the coefficient of friction and this coating did not exhibit severe wear even under very high contact pressure.

In pursuit of Futuristic Reactor Systems

- ✱ The thermodynamic activities of LiF, NaF and KF in molten FLiNaK were measured in the temperature range 950–1000 K and the results would be useful in predicting the formation of compounds in the Li-M-F, Na-M-F and K-M-F systems (M = Ni, Fe, Cr and Mn) during molten salt reactor operation

Spent Fuel Reprocessing & Radioactive Waste Management

Recovery of ^{90}Sr and Milking of ^{90}Y

The process for recovery of pure ^{90}Sr (free from radio-chemical contaminants) from High Level Liquid Waste (HLLW) using multi-step separation processes was standardised. The process for recovery of Yttrium-90 (^{90}Y) has been modified. In this connection, the process system of supported liquid membrane for milking of ^{90}Y was upgraded by imparting the provision of remote operation, resulting in reduced contact operation while milking of ^{90}Y . The system was scaled up to ensure supply ~ 0.5 Ci of ^{90}Y each week. Carrier-free ^{90}Y should be extracted without contamination of other radionuclides for its application in radiotherapy.

Process Modification in Synthesis of Sr-selective Crown Ether

Di-tertiarybutyldicyclohexano-18-crown-6 (DTBDCH18C6) is used for separation of strontium from high level radioactive waste. Solvent washing and modified chromatography column purification process was developed to purify black crude DTBDB18C6 (purity 50%) to white powder of DTBDB18C6 of 99.5% purity. In house synthesized and purified DTBDB18C6 was hydrogenated to DTBDCH18C6 (94% purity). Scale-up of hydrogenation process was successfully carried out to synthesize 500 gm DTBDCH18C6 (94% purity).



500 gm DTBDB18C6 (Purity 94%).

Retro fitment of Effluent Polishing System at WIP Trombay

Radioactive effluents generated during the processing of various nuclear wastes, including High Level Liquid Waste, MWPF Raffinate and Thorium-lean Raffinate are commonly polished (filtered) at a designated system to achieve the desired levels of decontamination before feeding them at an adjusted pH level to the ETP plant. The process filtration system along with its associated piping and instrumentation was retrofitted at LL Bay of WIP Trombay. 7 m³ of Thorium-lean Radioactive effluent had been successfully treated and a DF of 3 in terms of β activity and 10 for α activity was achieved during filtration. Further, during ion-exchange stage, a DF of 10 for β and 10 for α was achieved.

Trials on Geopolymer based Material for Radioactive Waste Disposal

As part of efforts to develop a highly effective new geo-polymer material for disposal and decontamination of long-lived fission products, trials were carried out on industrial waste materials suitable for this purpose. Technetium-bearing sludge waste at 150 kg scale provided a product material with leach index of more than 9 with respect to ^{99}Tc . Geopolymers comprise silico-alumino-network (poly sialate) matrix to impart high chemical durability and low porosity to the structure and can be prepared at ambient to low temperatures (less than 200°C).

Shielding Measurements at NRB Tarapur

High-energy gamma radiometry testing was carried out to identify presence of defects in biological shielding of cells at AVS facility in NRB Tarapur. The plant, comprising 2 cells (Melter cell and Decommissioning Cell), had been designed and equipped to condition an annual 120 m³ of High-Level Waste generated from the Reprocessing Plant.

Manufacturing and Fabrication of Radiation Shielding Windows

Manufacturing and assembling of RSW Glass slabs of 600 mm x 245 mm x 100 mm Thk, 5.2 g/cc specification for hot cells as well activity on fabrication of carbon steel housing for radiation shielding windows of Fuel Reprocessing facilities in Trombay was completed during the year.

In-house Efforts for Development of Gauntlets for Radioactive Applications

An activity on development of seamless gauntlets for radioactive applications was initiated in BARC. Various formulations of Neoprene Latex were developed and chemically tested for ascertaining suitability in regular operations. The suitability of developed gauntlets was compared with the commercially available imported product and was found to be quite satisfactory both in terms of quality and functionality aspects. Efforts are underway to reduce the level of dependency on imported components in the manufactured gauntlets.

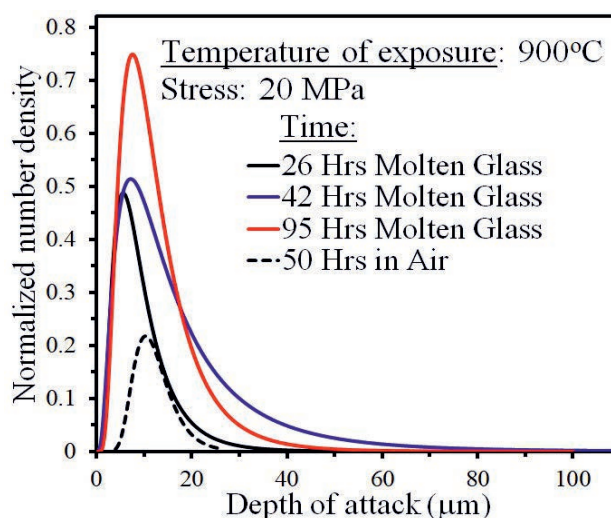


Set-up created in BARC for development of Gauntlets for radioactive applications.

Statistical Analysis of Corrosion Attacks on Alloy 690 of Vitrification Melter

In nuclear waste management plants, the Alloy 690 material-based process pot and susceptor vessel

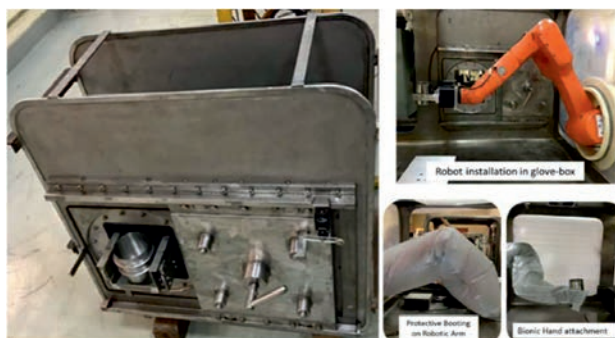
of vitrification melters are susceptible to chromium depletion leading to corrosion attacks in molten glass environment. Experiments have been carried out considering various temperature, stress levels and times of exposure. It is observed that the number density of corrosion defects increases with time at a given temperature of 900°C and 20 MPa stress. This data will be useful for integrity analysis of vitrification melter.



Variation of normalized number density of corrosion defects with depth of corrosion in molten glass environment.

Automation Systems for Glove-box Operations

An automated transfer system has been developed to facilitate the transfer of highly radioactive materials between adjacent glove-boxes. Robotic arms with suitable booting, bionic hand and torque-force controlled gripper provide easy and precise robotic manipulation of material/object inside the glove-box. This can thereby reduce human exposure during material handling and improve operational safety.



Automated Tunnel Transfer System.

Robust Waste Management Practices

63,000m³ of radioactive effluents generated by various plants and laboratories in BARC Trombay during the year were managed safely. 950 m³ of LLW was treated by Chemical Treatment Flow sheet involving various processes, including chemical co-precipitation, centrifugation and cementation generating 15 nos. of cementized waste product. 228 nos. of cut-end rods were decontaminated and 232 nos. of Al Shields and 228 nos. of SS Plugs were recycled and routed back to mainstream operations.

Work on activities related to Plutonium Plant ageing management program, including replacement of aged equipment, rectification of failed process routes, refurbishment of process control laboratory, re-conversion laboratory and up-gradation of ADU system, replacement of PLC-SCADA based I&C system, aged PDB panels & cables, refurbishment of utility and services was completed.

The Metallurgical Waste Processing Facility was operated regularly wherein filtered dissolution product was processed through solvent extraction and ion exchange processes for recovery of special nuclear material (SNM).

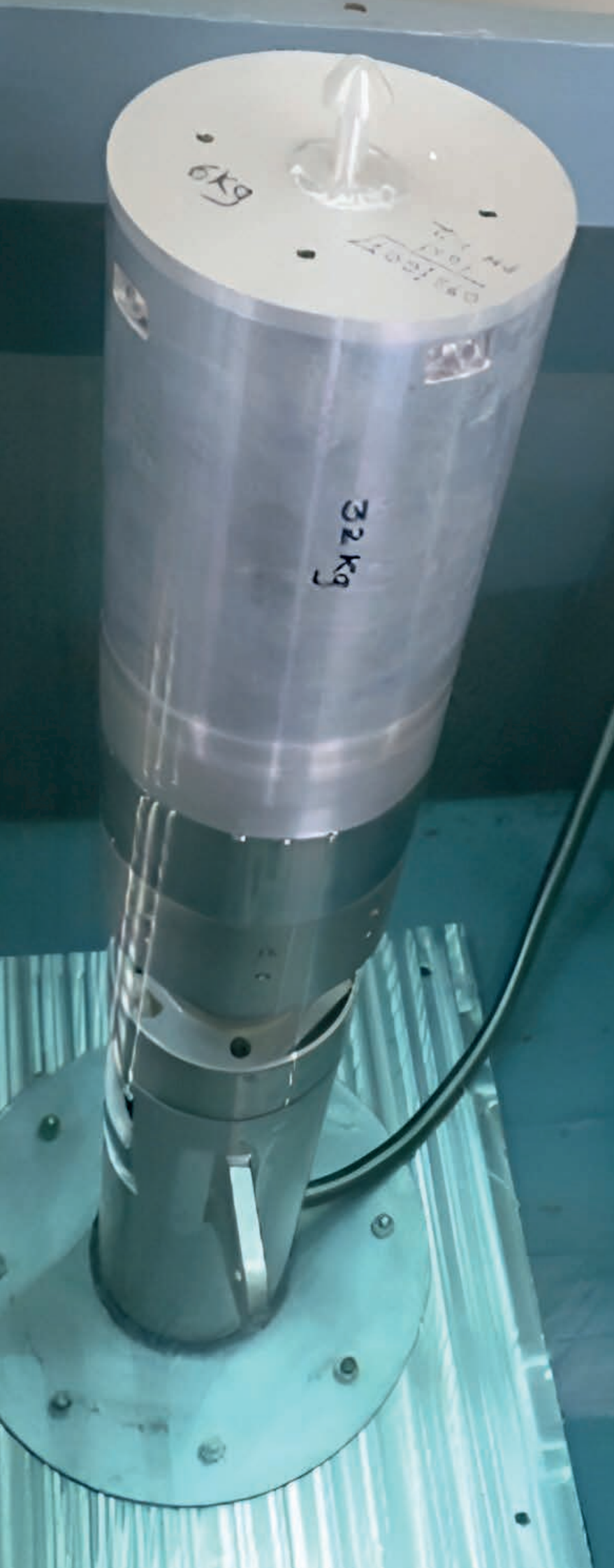
Work on up-grading of vital radiation waste management facilities in Trombay was initiated during the year wherein works on repairing of SS lining, fabrication of remote handling equipment, setting up of a new exhaust building, installation of

an in-cell crane of 2 Te capacity, a remotely operated welding machine have been mostly completed. An inactive demonstration facility was also commissioned and thoroughly operated to validate design modifications in the vitrification system.

In-pile radiation and ion bombardment studies were carried out to ascertain the capability of high alpha bearing glasses to withstand long term radiation exposure. Experiments simulating up to 1020 α/g were carried out on NBS glasses (22.5Na₂O-18B₂O₃-49.5SiO₂-10ZnO). Ion bombardment was employed to represent alpha and recoil damage using He and Xe. Raman spectroscopy technique and leaching studies were employed for verifying structural degradation of material due to bombardment.

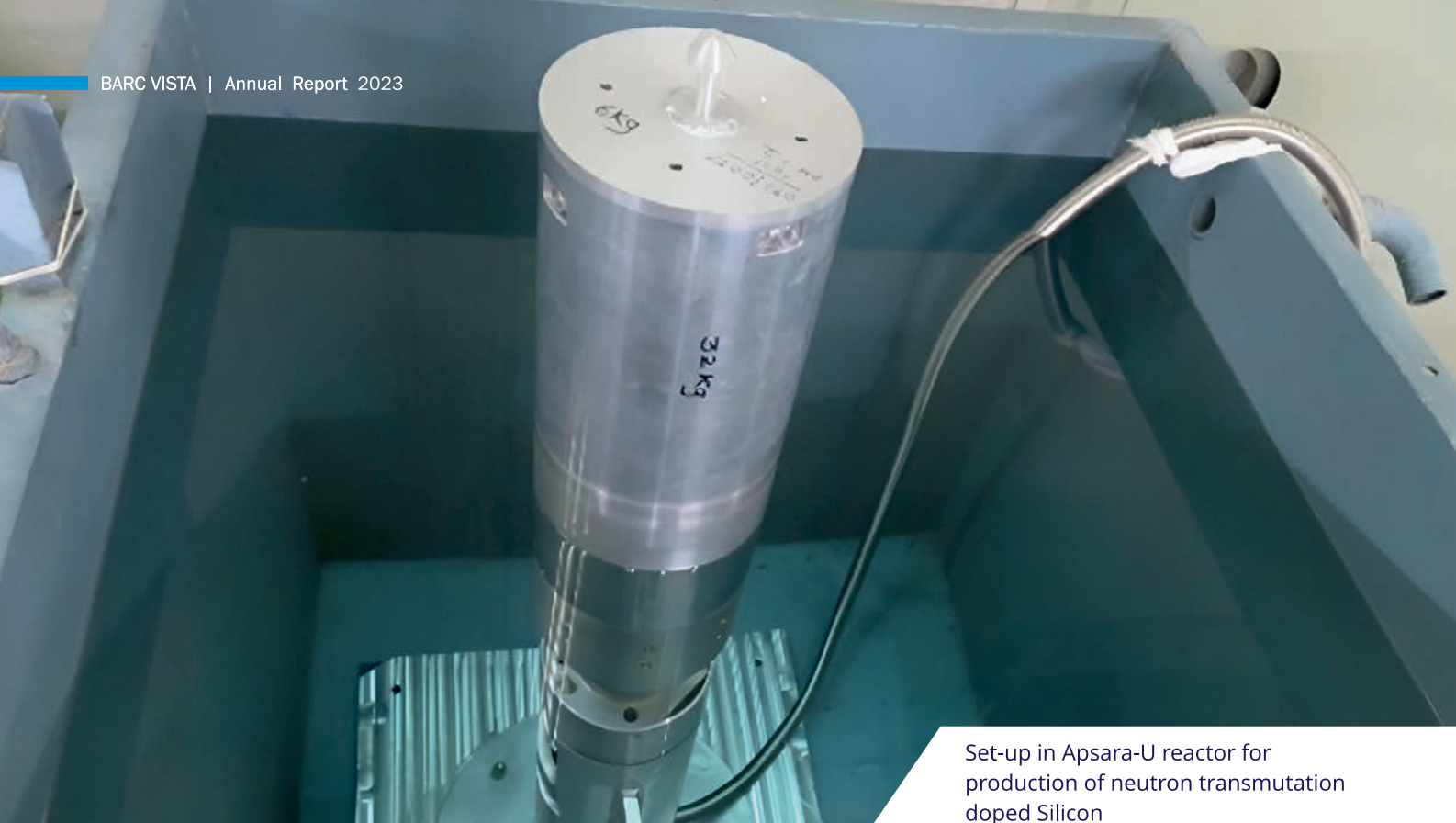
A demonstration setup was installed for carrying out inactive experiments for pyrolysis & incineration-based process for pre-treatment of cellulosic & polymeric waste. The demonstration system is being operated at 1kg/h feed rate for optimization of process parameters.

The activities associated with the recovery of Ruthenium from radioactive waste were continued during the year and the requirement of Ru Plaque in hospitals for eye cancer treatment was sufficiently met. A series of dummy plaques were fabricated and tested as per AERB SS3 guideline as part of efforts for development of crescent moon shaped Ru plaque.



ADVANCED TECHNOLOGIES, RADIATION TECHNOLOGIES & APPLICATIONS

Research and Development program in BARC is focused on achieving self-reliance. Over the years, this approach has resulted in development of advanced technologies indigenously in the areas of Research Reactors, Accelerators, Lasers, Sensors, Detectors, Radiopharmaceuticals, Materials for Energy Storage, Management of Surface Water and Groundwater Resources, Solid Waste Management, Agriculture, Food, Healthcare and various niche domains.



Set-up in Apsara-U reactor for production of neutron transmutation doped Silicon

Advanced Technologies, Radiation Technologies & Applications

Research Reactors

Apsara-U

Research reactor Apsara-U was operated up to 1.0 MW to meet the desired user requirements. A tray rod was designed and fabricated for irradiation of Fission Moly targets at Apsara-U. Qualification tests of the tray rod and fission moly handling tools were carried out successfully. Augmentation of shielding was done by erecting lead-filled MS structures around the Tray Rod Facility structure (wall & roof).

Design work on the installation of a new irradiation facility for neutron transmutation doping (NTD) of silicon ingots of 4-inch to 8-inch diameter and 10-inch length is being implemented in Apsara-U.

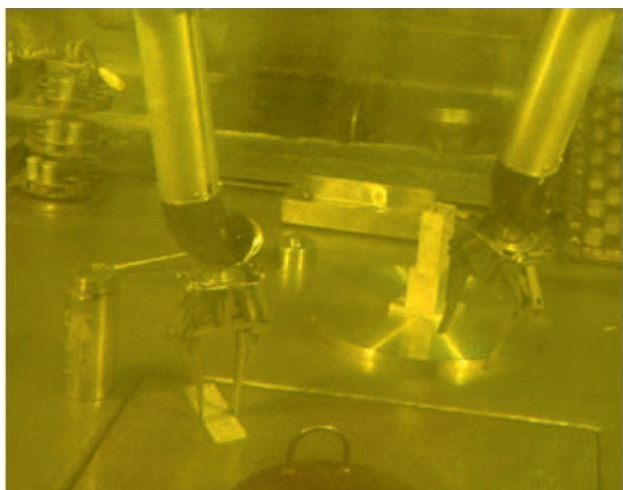
A turn-table assembly having silicon irradiation basket with water lubricated bearings and gear box, flexible shaft and geared motor drive unit was designed and fabricated for rotating the silicon ingot at a uniform speed of 2.0 rpm.

A radiation survey study carried out by erecting a neutron imaging and depth profiling beam line at BT-7 port outside the shielding structure of the reactor at 1 MW power yielded satisfactory outcomes.

Reactivity Meter Module Testing and validation of associated algorithm was carried out satisfactorily under different reactivity transients using an offline PC and real online data of Apsara-U COIS data server.

Dhruva Reactor

Research Reactor Dhruva was operated up to a rated power of 100 MW with an availability of 76.5% for isotope production and neutron beam research. An 'off-power' Tray Rod for irradiation of Fission Molybdenum targets was commissioned at the reactor. Around 96 Fission Moly plates were irradiated and delivered to Fission Moly Processing Plant (FMP) for initial commissioning & subsequently for regular production of pharmaceutical grade Molybdenum-99. Three batches of 12 dummy target plates of aluminium were irradiated for undertaking detailed studies. Irradiation trial run of an experimental special fuel assembly containing hybrid irradiation cluster (HIC) of twisted and cylindrical fuel pins was carried out in Dhruva.



Handling of Fission Moly plates in Hot Cell.

Carbon steel components of Flow Test Station of Dhruva Fuel Assemblies, including piping, valves, microfilter housing were replaced with stainless-steel components to minimize crud pick-up during flow testing. Neutron beam hole CS-3003 and R-1108 (300 mm and 100 mm beam hole) inspection was carried out as part of ageing studies using a Radiation Resistant camera which was inserted up to rolled joint by deploying a specially designed tool. Helium sniffing and Tritium sniffing tests carried out on the rolled joint confirmed its good condition.

As part of efforts to maintain and improve Dhruva main coolant outlet header pressure during main coolant pumps down-state, a fourth auxiliary

coolant pump (XCP-4) was procured for installation. Performance and endurance test were completed. New power supply panels were installed in place of existing panels (3.3 KV) associated with sea water pumps. Cathodic protection units for seawater system were replaced with fresh units as part of ageing management.

Heavy water Upgradation Plant (UGP) was operated round-the-clock for processing of downgraded heavy water of research reactor Dhruva. Up to 12 tons of downgraded heavy water was processed at UGP. The up-graded heavy water was dispatched to meet the requirements of Dhruva during the year.

An Automatic water sprinkler system was commissioned for 10 MVA Transformer to cater to the safety requirements. A new 750KVA water cooled Emergency Diesel Generator set was commissioned in Dhruva service building after completing the specified testing procedures (IEEE-387, including 72-hour load test). This would lead to an improved reliability and availability of Class III power supply system.

A project to upgrade seawater intake system for Dhruva was taken up to overcome long term difficulties associated with the intake of adequate seawater during low tide as well as deposition of excessive silt around the seawater intake chambers. However, a periodic de-silting of the caisson chambers and dredging near the present intake chambers was envisaged in the short-term to address this problem.

New Radiation Resistant CCTV cameras with enhanced life times were commissioned in Dhruva loop rooms. A new E-SCADA system for display of status and parameters of electrical equipment at centralized location (substation) and storage of data was installed in Dhruva Sub-Station.

An on-site Nitrogen generator plant was commissioned to cater to requirement of cover gas

in fueling machine operations. This would reduce logistics involved in arranging of nitrogen cylinders.

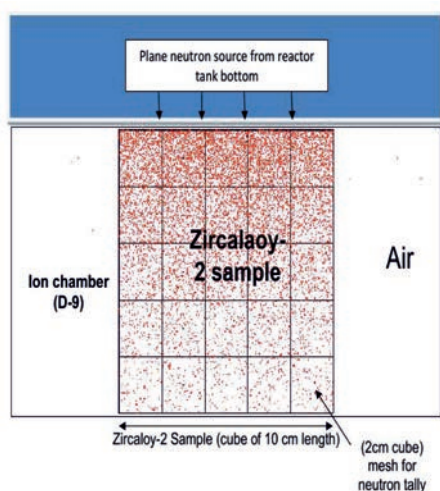


The newly installed E-SCADA system in Dhruva Sub-Station.

Critical Facility

The reactor at the Critical Facility was operated 67 times during the year for various activities, including surveillance, irradiation experiments, neutron activation and testing of detectors.

Large Size Neutron Activation Analysis (LSNAA) requires large size irradiation locations with uniform thermal flux distribution. The availability of such a location in the bottom reflector region of Critical Facility (CF) makes it suitable for such irradiations. For planning the LSNAA experiment, an in-depth neutron flux profile analysis of a 10cm x 10cm x 10cm zircaloy-2 irradiation sample using Monte Carlo code was carried out. It was found that the CF can be used for LSNAA of Zr-2 like samples which contain elements with a relatively high thermal neutron cross section.



Particle tracks in sample generated by Monte Carlo code.

CIRUS

CIRUS reactor remained under deferred decommissioning (safe storage) state. Dismantling and cutting of primary coolant and seawater system lines/components located in Primary Coolant Heat Exchanger room is in progress. Radiological characterization of Reactor Vessel samples and analysis of mechanical properties was taken up during the year. The fast neutron fluence recorded by the RV was $7.1 \times 10^{20} \text{ n/cm}^2$. Radiometry of process cells of a new Iodine-131 Processing Facility (IPF) equipped with a production capacity of 100 Ci/batch was carried out using 20 Ci and 60 Ci of Tellurium source in CIRUS. Post successful hot commissioning trials, a total of 10 Ci I-131 was extracted. Hot commissioning trials were carried out for production of Tritium Filled Light Source (TFLS) and Tritium Labelled Compound (TLC) at the associated facilities in CIRUS reactor complex. Around 150 TFLS were produced and transferred to BRIT to meet the demand for these products in defence applications.

The cutting of damaged spent fuel rods stored under water in CIRUS is required for their easy disposal. A Rod Cutting Gadget (RCG) has been developed for this purpose. This uses a hydraulic shear cutter which can be manoeuvred all over the storage bay using carriage-trolley, mast, and cutter swivel mechanisms. The gadget has been installed in CIRUS storage bay and cutting of rods has been demonstrated.



Rod Cutting Gadget in operation.

Upkeep and Upgrade

- ✱ Select upgrades were carried out on High-Q neutron diffractometer which is deployed for elucidating short and intermediate range order in liquids and glasses. The copper monochromator and the in-pile collimator were replaced and four Söller collimators were configured to the diffractometer. Validation runs showed an impressive 600% gain for the 0.783 Å wavelength with the (220) reflection in vertically focusing mode.

Accelerator, Laser and Plasma

Magnetic Pulse Welding of SS-Ti

Magnetic Pulse Welding (MPW) was successfully demonstrated for dissimilar metal joining and the technique was implemented for welding of a 0.5 mm thick titanium (Ti) flyer tube to Stainless Steel (SS-304L) tube by using a multi-turn EM coil. The microscopic analysis of weld joints showed a 2-2.5 mm bond between the impacting tubes for a peak discharged magnetic pressure of 450 MPa corresponding to peak magnetic field of 35 T and the observed frequency of loading was 12 kHz.

Development of 10kW Electron Beam Melting Machine

BARC has developed a 10 kW Electron Beam Melting machine. The key specifications of this machine include maximum beam power of 10kW, accelerating voltage of 5 kV to 15 kV. The orientation of the machine's gun unit can be both vertical and horizontal housed in a cubic process/vacuum chamber of 600mm each side. The operation of the system is through Interactive PC based SCADA control with touch screen HMI. EBM system is a sophisticated melting technology that utilizes an electron beam to melt refractory and reactive materials and alloys (such as Nb, Ti, Zr alloys among others).



10kW Electron Beam Melting machine installed in BARC.

100 kW Air Plasma Torch for Incineration/Gasification

A 100-kW torch has been designed using Zhukov's similarity criteria, simulated and fabricated. The torch has been tested up to 100 kW power with air as plasma gas. Performance parameters like arc current, air flow and arc voltage were recorded and were found to be in good agreement with the design parameters. Hollow Cathode (HC) air plasma torches are generally deployed in high-power applications of thermal plasma like MSW incineration/gasification. It consists of two hollow electrodes made of copper and is separated by a gap of 2 mm. Air as plasma gas is injected through a vortex chamber to achieve swirl action. Arc root attachments in both the electrodes move continuously thereby ensuring the electrodes long-life.

Catalytic Air Plasma System

A unique atmospheric pressure portable catalytic air plasma system for fast synthesis of aqueous nitrite and nitrate fertilizer in high concentration was developed in BARC. The unit is capable of generating 10000 litres of aqueous nitrogen fertilizer, suitable for administering to plants. The product concentration remains constant even after 30 days of storage.



100 kW Air Plasma Torch.

Sensors, Detectors and Specialized Instruments

Microscope-based Image Analyzer System for Fast Neutron Dosimetry of Chemically-etched CR-39 Detectors

An automated microscope-based scanning and image analyser system has been designed and developed for neutron track counting of a batch of CR-39 detectors used for neutron personnel dose monitoring. The system comprises a two-axis motorized tray scanning system to scan up to thirty-six detectors sequentially, imaging optics to adjust the detector's region of interest, and control system with application software to acquire multiple focused images at various programmed positions of each detector. In addition, the imaging setup has auto-focusing ability to automatically determine the best focus position using image sharpness metrics.

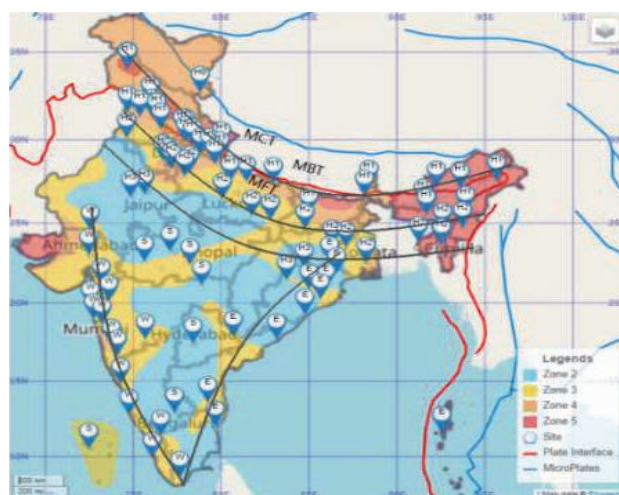


Microscope based Image Analyzer System.

Indian Network for Detection of Radon Anomaly for Seismic Alert (INDRA-SA) with 100 observatories

As part of Indian Network for Detection of Radon Anomaly for Seismic Alert (INDRA-SA) project, a network of 100 in-house developed Bhabha Radon Observatory for Seismic Application (BhaROSA) was commissioned to investigate earthquake precursory research. The project focuses on monitoring radon, a potential precursor to seismic events, with the ultimate goal of establishing

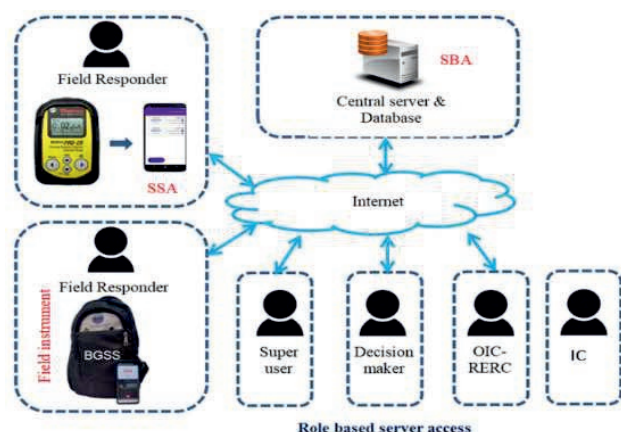
correlations using machine learning techniques. BhaROSA observatories have been placed strategically in the Indian Tectonic Plate. Locations were chosen based on terrain characteristics, proximity to major faults, and historical seismic activity. Each BhaROSA observatory operates on solar power, ensuring sustainability. Vital data, including Radon concentration, temperature, humidity, and pressure, are transmitted securely to a central station in Mumbai every 15 minutes via a Virtual Private Network (VPN) established using 3G/4G GPRS technology. The central station collates and logs observed precursory signals from the entire network. This represents a significant step forward in earthquake precursory research using a novel technique of radon monitoring using accumulator which amplifies the signal due to radon gradient at soil-air interface.



Radon observatory network in India.

Integrated Radiation Emergency Management System

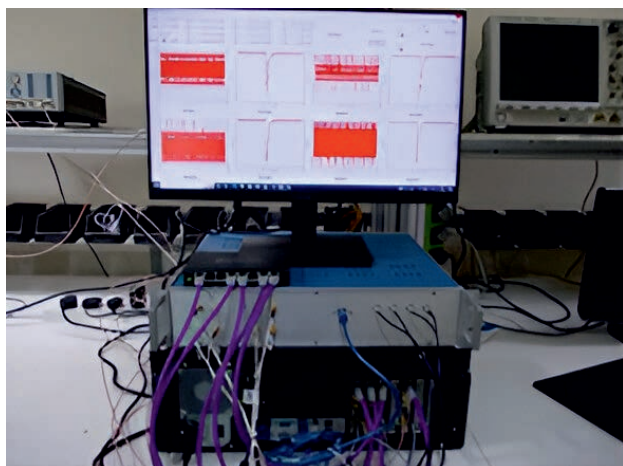
An Integrated Radiation Emergency Management System (IREMS) for efficient handling of radiological emergencies was developed in BARC. The IREMS is a web-based application hosted on a server and facilitates real-time assessment of the radiological situation in the field. Key features of the IREMS include the integration of field monitoring instruments, the utilization of radiological impact assessment models, role-based access control for different users, and real-time communication capabilities to facilitate information exchange.



The IREMS Architecture diagram

8-channel DAQ System for Cosmic Muon Measurements

An Eight-channel fast DAQ system was developed and integrated with four plastic scintillator detectors. The system with online digital processing hardware and acquisition software has been characterized for background cosmic muon measurement at user lab. The system is subjected to Energy Characterization wherein energy versus charge linearity curve is computed. The linearity curve obtained in calibration with five sources is satisfactory, implying the correctness of on-line digital processing blocks for charge computation. Energy and timing measurements for the background cosmic muons is also carried out and the timing distributions is found to be satisfactory for no source and when the Na-22 source is placed at different positions on the bar. The cosmic muon energy deposition bump at higher values of charge had been consistent.



Eight channel Digitization system.

Indigenous SiPM-based Hand-held Gamma Spectrometer coupled with Detector

A gamma spectrometer based on an indigenous SiPM (3mm x 3mm with 50µm pixel size) coupled with a CsI scintillator detector is developed. This is a smart device having smart-phone connectivity for real-time display in numerical and graphical formats, and data logging. The current pulse due to the interaction of gamma photons with the scintillator is integrated and shaped into a Gaussian pulse. A peak detector circuit issued to aid the ADC in accurately sampling the pulse amplitude. A threshold generator and comparator are used to prevent the counting of noise pulses. The MCU collects the resulting peak data and count data, which is transferred to a smart-phone for spectrum display and dose rate monitoring. The data is further stored with time stamp and GPS coordinates for post analysis.

Upgraded X-ray Baggage Inspection System and Fabrication of Detectors

The software of X-ray Baggage Inspection System (XBIS) has been up-graded to comply to MHA and BCAS specifications, with advanced features for online checking of defective detectors, steel penetration for 35 mm of thickness and software controlled diagnostic report. It also facilitates up-gradation of Threat Image Projection (TIP) image library with explosive devices, knives and firearms in various sizes, shapes, locations and orientations. A total of 750 detectors, each of these having



XBIS Electronics mounted on X-ray machine.

16-pixel photodiode linear array with a pixel size of 3.2 x 1.4 mm² coupled with CsI scintillator array, were fabricated for XBIS. The detectors were tested and characterized for forward and reverse characteristics and noise performance.

Radiopharmaceuticals

Production & Supply of Radiochemical Formulations for Healthcare Applications

During the year, a total of 146 TBq (3960 Ci) quantity of radioisotopes were produced, radiochemically processed and supplied for healthcare applications. These include ¹³¹I [59.2 TBq (1600 Ci)], ¹⁷⁷Lu [45.5 TBq (1230 Ci)], ⁹⁹Mo [39.7 TBq (1074 Ci)], ¹⁵³Sm [1.6 TBq (44 Ci)], ⁹⁰Y [117 GBq (3.2 Ci)], ¹²⁵I [178 GBq (4.8 Ci)] and ⁶⁴Cu [56 GBq (1.5 Ci)].

Supply of Ready-to-Use Radiopharmaceuticals for Patient Care

During the year-under-review, 61 doses of injectable formulation of ⁹⁰Y-HA [370 MBq (10 mCi) each dose, HA: Hydroxyapatite particles] and 5 customized doses of ⁹⁰Y-labeled yttria-alumino-silicate glass microsphere ('Bhabha Sphere') were formulated and supplied for treatment of patients suffering from inflammatory joint disease and liver cancer, respectively. Customised doses of ready-to-inject ⁶⁴CuCl₂ formulation [370 MBq (10 mCi) in each dose] were prepared in four batches and supplied to RMC (Mumbai) for PET (Positron Emission Tomography) imaging of prostate carcinoma and glioblastoma patients.

Production and Supply of ¹⁷⁷LuCl₃ using Indigenously Enriched Lu(NO₃)₃ Target

Indigenously prepared isotopically enriched Lu(NO₃)₃ target (isotopic enrichment ranging from 76-91 % in ¹⁷⁶Lu) was utilized for preparation of clinical grade ¹⁷⁷LuCl₃ radiochemical formulation. 13 batches comprising 11 TBq (297 Ci) ¹⁷⁷LuCl₃ activity were produced from the indigenously prepared target and supplied for formulation of various radiopharmaceuticals.

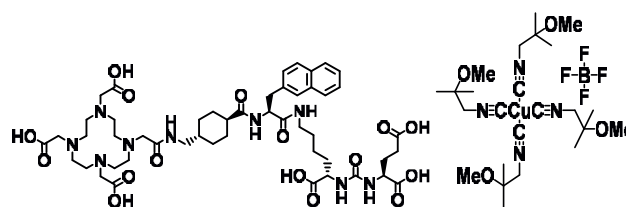
Production and Supply of Radioactive Sealed Sources for Industrial and Medical Applications

663 sealed sources, including regular beta, gamma sealed sources (154 Nos.), ⁶⁰Co-polymer film

sources (350 Nos.), ⁶⁰Co electrodeposited sources (2 Nos.) and ⁹⁰Sr/⁹⁰Y monitor sources were prepared and supplied to various DAE units, institutes, industries and hospitals for various industrial applications. For healthcare applications, ¹²⁵I-BARC Ocular seeds (18 Nos.) and ¹²⁵I-Prosta seeds (125 Nos.) were prepared and supplied for brachytherapy of eye cancer and prostate cancer, respectively.

Synthesis & Regular supply of PSMA-617 and [Cu(MIBI)₄]BF₄

PSMA-617 is used as a radiopharmaceutical ligand for prostate cancer therapy, and we have been regularly supplying indigenously synthesized and RPC-approved PSMA-617 to BRIT for preparation of ¹⁷⁷Lu-PSMA kit (Product Code: LUM-5). This year, around 148 mg of PSMA-617, has been utilized to prepare kits and supply in hospitals pan India. This has benefited over 600 patients this year. [Cu(MIBI)₄]BF₄ is used as a radiopharmaceutical ligand for myocardial perfusion imaging, and we have been regularly supplying indigenously synthesized and RPC-approved [Cu(MIBI)₄]BF₄ to BRIT for preparation of ^{99m}Tc-MIBI kit (Product Code: TCK-50). This year, BARC supplied approximately 2gm, which was deployed in the preparation of kits and supply thereof across pan-India hospitals thereby benefiting over 8000 patients during this year.

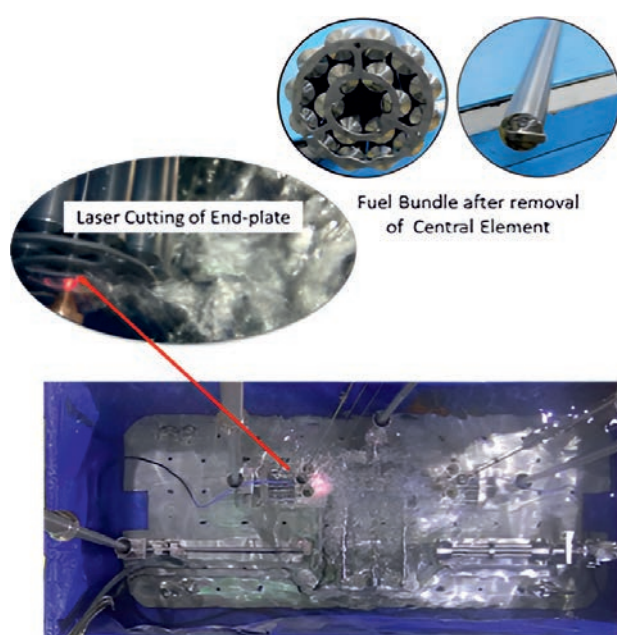


Chemical structure of PSMA-617 and [Cu(MIBI)₄]BF₄ ligand.

Remote Cutting & Pin Retrieval System

A scheme has been devised for the production of radio-isotope Co-60 by irradiating a modified fuel bundle (named as Co-NU bundle) in PHWRs. Experimental irradiations of the Co-NU bundle consisting of a central cobalt element surrounded by natural uranium fuel elements has been carried out in the 220MWe PHWR- KGS-3&4. In

collaboration with RRCAT, a Laser cutting based Remote Cutting & Pin Retrieval System (RCPRS) has been developed to detach the central cobalt element from the bundle underwater in Fuel Storage Bay. The system has provisions to facilitate under-water transfer of the separated cobalt element into a shielded transportation cask for further processing. The RCPRS has been qualified for use through mockup trials carried out on 19-element dummy bundles.



The Remote Cutting & Pin Retrieval System.

Water Purification, Groundwater Management & Solid Waste Management

Electron Beam DC Accelerator for Ternary Water Treatment

Under an active MoU between BARC and 'Namami Gange - National Mission for Clean Ganga (NMCG)' for deployment of Electron Beam DC Accelerator at Unnao site in Uttar Pradesh for ternary water treatment. Multiple experiments have been conducted and significant reduction in chromium content has been observed. The work on parametric optimization on Electron Beam DC Accelerator for this purpose is currently in progress.

Deployment of BARC Water Technologies

Under the DAE's Project on *Deployment of water purification technologies in rural India*, 3 units of 1000 LPH capacity SWRO plants were installed and handed over to BSF in creek area of Indo-Pak border, Gujarat. The units are catering to the potable/ drinking and non-potable water requirements of BSF personnel at the Border Outposts, wherein the seawater with a salinity of 34,000 ppm is treated to provide product water with salinity < 100 ppm. 11 units of 1000 LPH capacity BWRO based community scale water treatment plant were deployed in villages of Odisha, Chhattisgarh, Karnataka & Maharashtra. Around 4500 point-of-use water decontamination devices were deployed across villages of Kerala, Odisha, West Bengal & Maharashtra. A total 140 equivalent villages in India have been covered by BARC water treatment technology.



BWRO based water treatment unit deployed at Chitradurga.



Distribution of household point of use water treatment units in Kerala.

Treatment of Dye Waste Water at Demonstration Plant

Radiation-grafted cellulose fabric-based pilot plant for mitigation of ionic dyes from industrial waste water was installed at industrial site in Jodhpur, Rajasthan for large scale demonstration. The plant with treatment capacity of 30 kilo liter per day (30 KLD) was extensively tested under industrial conditions. Over 7 lakh liters of cotton textile dye effluent was decolorized and treated water was reemployed by the industry for their immediate requirement. The plant was augmented to 75 KLD capacity by integrating it with a plant of 40 KLD capacity fabricated by BARC.



The 75 KLD capacity demonstration plant for de-coloration of dye industry wastewater.

hgSBR Technology for Sustainable Wastewater Treatment

The hybrid granular sequencing batch reactor (hgSBR) is a patented technology that relies on the development of compact and fast-settling bio-beads for biological treatment of domestic wastewater in wastewater treatment plants (WWTPs). During the year, ten private companies, including M/s. Thermax Ltd., signed technology transfer agreement to deploy technology in WWTPs. So far, 24 private companies have signed a technology transfer agreements with BARC for building hgSBR-based WWTPs. During the year, four plants with different capacities, such as 10 KLD (at Perambalur in Tamil Nadu), 50 KLD (at Shirdi in Maharashtra), 150 KLD (at Surat in Gujarat) and 500 KLD (at Tiruchirapalli in Tamil Nadu) have been installed and operationalized for sewage treatment.



150 KLD plant at Surat, GUJ



50 KLD plant at Shirdi, MH



500 KLD plant at Tiruchirapalli, TN



The 150 KLD, 50 KLD and 500 KLD hgSBR-based sewage treatment plants.

A Novel Bi-functional Resin for Selective Removal of Uranium from Mine Water

A novel bi-functional resin, namely, Ionic Core Embedded Bi-functional resin (ICEBR) is designed and developed on the basis of structure activity relationship using DFT calculations. ICEBR presents a new class of resin to the world, wherein the cationic and anionic functionality present in resin matrix can take care of various species of uranium present in effluents originating from its processing. ICEBR has shown very fast uptake kinetics and excellent uranium sorption from mine water bringing the uranium content from ~2000 ppb to less than 30 ppb (IAEA/WHO limit for water), thereby making it amenable for house-hold applications.

Nuclear Desalination Demonstration Plant at Kalpakkam

The Nuclear Desalination Demonstration Plant (NDDP) at Kalpakkam, comprising Multi Stage Flash (MSF) and Seawater Reverse Osmosis (SWRO) desalination plants, was in operation in 2023. A total about 118 million litres of good quality water was supplied to Madras Atomic Power Station (MAPS), NPCIL. About 26 million litres of Hybrid water was supplied to IGCAR reservoir, Kalpakkam. Civil structural repair work of MSF modules, Lamella Clarifier and NDDP pump house was completed. For Project- 2 MGD SWRO plant, work

on civil structural supports and Box Culvert for seawater intake piping had been completed. Work on GRP and MSRL pipe erection is currently under progress for the project. Besides, EC-CRZ proposal for Desalination plants, including a 2.0 MGD SWRO Plant at NDDP, Kalpakkam, was recommended by a Technical Expert Committee followed by the Tamil Nadu State CZMA.

Field Application of Indigenous Desalination Technologies

Two units of Multi Effect Distillation with ThermoVapour Compressor (MED-TVC) desalination plant at its design production capacity of 250m³/d were successfully commissioned. Product water of conductivity <2 µS/cm was produced directly from seawater having a conductivity of 46 mS/cm. Minimum product water conductivity of 0.75 µS/cm was achieved. All sub-systems of MED-TVC plant were tested and have demonstrated seamless operation. In SWRO plant, piping installation is in progress. Pump house shore protection (stone boulders) is completed. SS-piping work for vacuum pumps and UPVC- piping works for hypochlorite dosing system is completed. Reject disposal system including diffuser section is tested and commissioned.



2 x 250 m³/d MED-TVC Desalination Plant at IREL, OSCOM.

Humidification & Dehumidification Desalination

A 25 litres-per-day water purification unit based on humidification-dehumidification for household domestic use to produce pure drinking water from air in high humidity region as well as saline feedstock in arid regions using refrigeration circuit was installed. Experimental runs were performed

on HDH based water purification unit, and unit is producing potable water more than @ 4 lph in dry atmospheric condition (RH <50%) by humidifying the incoming air using normal seawater and brine having conductivity ranges of 30-70 mS/cm. Product water conductivity ranges between 20µS/cm and 50 µS/cm.

Development of Hollow Fibre Membranes for Water Purification

Process for preparation of polyethersulfone hollow fibre ultrafiltration membrane with ID: 200µm & OD: 270 µm & of ID:700µm & OD: 1120 µm was developed. These fibres were spun using hollow fibre spinning machine and winded for continuous length of 1000m. Several batches of such fibres were prepared to ensure reproducibility. The turbidity removal from seawater was demonstrated using these hollow fibre membranes.

Design & Fabrication of Hollow-fibre Membrane-based Water Purifying Bottle

A prototype hollow-fibre membrane-based water purifying bottle capable of removing turbidity of water from > 100 NTU to less than 1 NTU with purified water output of 200 ml in 20 minutes was tested and fabricated in BARC.

Demonstration of Advanced Effluent Water Treatment Plant at ONGC Mehsana

An Advanced Effluent Water Treatment Plant (AEWTP) based on technology developed in BARC was installed and commissioned at ONGC, Mehsana site (North Santhal ETP) to treat oil-contaminated-water with high salinity. The plant was operated for six months at its rated capacity of 500 litres per hour to demonstrate sustained operation under site conditions producing treated water of desired specifications. The project was initiated under an MoU between BARC and ONGC Energy Centre Trust.



AEWTP Installed at ONGC, Mehsana Site.

Applications of Environmental Isotopes in Hydrological Studies

An isotope-geochemical investigation was carried out at Tummalapalle in Andhra Pradesh to identify the plausible reasons for elevated levels of uranium in a few bore wells of the surrounding villages and to evaluate aspects, including groundwater dynamics, interconnection between mine effluent and groundwater etc. A total of 155 water samples were collected from the tube wells, bore wells, hand pumps, surface waters (canal and river), mine seepage water, tailing and decant ponds during monsoon and post-monsoon seasons. The results indicated that $\delta^2\text{H}$ and $\delta^{18}\text{O}$ values of groundwater containing high uranium concentration do not match with that of tailing pond values. Similarly, $\delta^{13}\text{C}$ and $\delta^{34}\text{S}$ values of groundwater were found to be different from that of sample sourced from the tailing pond. The radioisotope data suggested that groundwater with highest Uranium concentration is very old as compared to uncontaminated waters, thus refuting the possibility of tailing pond contribution towards uranium contamination in groundwater. Findings from this multi-isotope investigation clearly suggest that tailing ponds do not contribute to uranium contamination in groundwater of this region, however geogenic sources such as rocks containing uranium minerals act as the main source of groundwater contamination.

Studies were carried out for assessing groundwater recharge through defunct dug wells in Nuapada (Odisha) and Gaya (Bihar) regions. The outcome of this research has great significance in

water scarce regions for planning rainwater harvesting through defunct dug-wells. River water – groundwater interactions were also studied in Yamuna and Hindon River Plains of Uttar Pradesh and results suggested that deep aquifers are sustained by lateral groundwater flows. Sources and mechanism of groundwater contamination were evaluated in coastal Balasore (Odisha) and Mosabani mining area (Jharkhand). Isotope analysis results helped in delineating the contaminated zones and in identifying the factors leading to groundwater contamination.



Environmental isotopes-based studies for assessing groundwater recharge at a remote location at Nuapada in Odisha.

Isotope-based Geochemical Investigation

As a part of national Jal Shakti Abhiyan, an isotope geochemical investigation was carried out in Srikakulam district of Andhra Pradesh to identify the recharge process and dynamics of groundwater system. A total of 205 water samples in the vicinity of nine recharge tanks were collected during pre-monsoon and post monsoon seasons. Analysis of samples by application of End Member Mixing Model (EMMA) indicated that contribution of recharge tank to groundwater is highly localized and shows a wide variation. The tank recharge to groundwater was found to be highly dependent on the host rock and its fracture density rather than the tank capacity. Tanks falling in the Granitic Gneiss formation are more effective in recharging groundwater followed by Khondalite and Quartzite formations. The average percentage of tank

recharge to groundwater is found to be 10% during pre-monsoon which increases to 36% during post-monsoon season. In addition to periodic desiltation of the tanks, it is recommended that tank specific interventions such as construction of recharge shafts, injection wells & percolation wells will boost the groundwater recharge through tanks. It is also recommended that artificial recharge measures, including step wells and contour bunds in rock exposures and foothill regions would be effective means of replenishing groundwater both locally and regionally, leading to sustainable groundwater management. The findings of this investigation were collated into a report and submitted to Ministry of Jal Shakti, Govt. India. Select recommendations have been made to the local District Water Management Authority in Srikakulam, Andhra Pradesh for effective implementation of Jal Shakti Abhiyan mandated activities.



Isotope based geochemical investigation studies to understand recharge process and dynamics of groundwater system in Srikakulam district of Andhra Pradesh.

Transforming Agricultural Waste into Functional Adsorbent

Radiation-induced grafting-co-interpenetrating network formation was adopted to convert agricultural waste (Parali) into functional adsorbent with an aim to mitigate the need for Parali burning and to re-purpose this agricultural residue into an efficient wastewater treatment adsorbent. The synthesis process reduces homopolymer formation markedly, reducing waste generation and improving economics. Functionalized Parali is effective in removing dyes and metal ions from wastewater with a notable dye uptake capacity (> 500 mg/g for cationic dyes and

anionic dyes). Tests demonstrated the efficacy of product in removing heavy metal ions such as Copper, Chromium, Iron, Cobalt, and Lead from solutions. Its reproducibility, regeneration capability, and thermal stability render it as an efficacious solution for waste water management and environmental conservation.

Agriculture and Food Technologies

Large-scale Storage Studies of Irradiated Winter season Onion crop for Shelf-life Extension under BARC-developed Protocol

Winter season (Rabi) onion harvest (1000 tons) stored under an MoU between BARC & Ministry of Consumer Affairs (NCCF-DoCA) and 30 tons of onion was stored in the newly commissioned cold storage facility (at KRUSHAK) under the specified conditions for extended preservation showed retention of quality till 7 months of storage with minimal weight loss.



Outside view of 250 MT capacity cold storage chamber



Harvested onions stored at the newly commissioned cold storage facility at KRUSHAK in Nashik.

Monitoring Aroma changes associated with Fermented Low sugar Pomegranate Juice

The aroma profile of fermented low sugar pomegranate juice was evaluated. In total 10 volatiles were identified in GC profile of

pomegranate. The identified aroma volatiles were hexenal, 2-hexenal, 2-octanone, ethyl acetate, phenyl ethyl acetate, 1-heptanol, 2-ethyl, 1-hexanol, alpha terpineol, 4-terpineol, p-cymene-2-ol. Low sugar pomegranate juice demonstrated enhancement in phenyl ethyl acetate upon fermentation.

Field Trial and Dose Inter-comparison Study of Dye-based Dosimeter

Inter-comparison study of developed dye-based system with imported optichromic dosimeters was carried out at commercial irradiation facility (MSAMB, Vashi). The freshly prepared dye dosimeter showed average variation within $\pm 10\%$. The dosimeters sealed in glass ampules and stored for 270 days in ambient exhibited encouraging results with average variation $< \pm 3\%$.

Radiation Technology for Crop Improvement

Radiations and radioisotopes are used in agricultural research to develop improved varieties for enhancing agricultural productivity to meet challenges like feeding increasing population, climate change, and consumer preferences. Towards this, radiation induced mutagenesis along with recombination breeding has been used to develop two new blackgram varieties: Trombay Jawahar Uradbean-339(TJU 339) and Trombay Jawahar Uradbean-130 (TJU-130). It has been released and Gazette notified for commercial cultivation by the Ministry of Agriculture & Farmers Welfare, Government of India. Towards the production of Trombay breeder seeds, 320 quintals of groundnut, 35 quintals of pulses, and 200 quintals of rice varieties were produced and distributed to different seed producing agencies for foundation and certified seed production and final deployment to the farmers in different states of India. To demonstrate the performance of rice mutant varieties (TCDM-1, Vikram-TCR, TCVM, TCSD, and CG JawaphoolTrombay) frontline demonstration and field day were carried out in farmers' fields at Bilaspur, Chhattisgarh.



New black gram variety - Trombay Jawahar. Uridbean-339 (TJU 339)



A farm plot showing large-scale breeder seed multiplication of Trombay rice in Chhattisgarh.

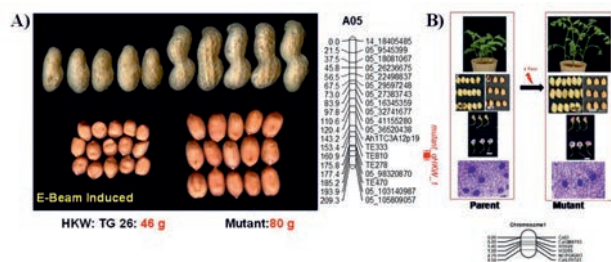
Biotechnology for Crop Improvement

In groundnut, seed size is the main yield contributing trait. A large seed electron beam mutant based F_2 population was used to construct a genetic linkage map spanning 3891.3 cM. Quantitative trait loci (QTL) analysis using F_2 population segregating for seed size revealed two major QTLs, one each on linkage group A05 and A02 explaining 18.07% and 11.95% phenotypic variation respectively. The major additive effect of qHKW_A05 was contributed by the 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 genome. Chickpea is among the top three legumes produced and consumed worldwide. A gamma-ray-induced chickpea mutant (eIm) exhibits increased early vigor and seed size. Genetic mapping of the mutant locus (*CaEI*) identified a previously uncharacterized gene (101503252) in chromosome 1 of the chickpea genome. There is a deletion of this gene in the mutant with a complete loss of expression.

Ensuring food security & Development of climate resilient crops

- ✧ Molecular mechanism pertaining to inhibition of sprouting in onion was studied by subjecting them to radiation processing at a dose of 60 Gy. Transcriptome analysis indicated down regulation of genes associated with the cell division, cell cycle, cellular growth as well as embryo development in radiation treated onion bulbs compared to unirradiated onion.
- ✧ Transcriptome Analysis of radiation processed Kesar mangoes was carried out to understand the up-regulation of major categories of genes at the end of storage period of 25 days. Analysis showed no significant up-regulation of any of these genes during the initial storage period.
- ✧ NIR spectroscopy intensive methodology was employed to detect the presence of synthetic adulterants in turmeric wherein 90% of adulterated samples could be successfully identified.
- ✧ Microbiological evaluation of faecal samples of Balb/C Mice fed with millet-based potential functional food for a duration of 32 days showed higher total viable plate count (aerobic and anaerobic) (TPC) and bifidobacterium count in fecal samples as compared with mice fed with either chow diet or high fat, high sugar (HFHS) diet.
- ✧ Radiation induced mutagenesis along with recombination breeding has been used to develop two new blackgram varieties – Trombay Jawahar Uradbean-339 (TJU 339) and Trombay Jawahar Uradbean-130 (TJU-130) and the varieties have been released and Gazette-notified for commercial cultivation by the Ministry of Agriculture & Farmers Welfare, Govt. of India. Additionally, frontline demonstrations were carried out in farmers' fields at Bilaspur, Chhattisgarh to demonstrate the performance of Trombay rice mutant varieties -- TCDM-1, Vikram-TCR, TCVM, TCSM, and CG Jawaphool Trombay.

Transcriptome profiling identified differentially regulated transcripts related to cell division, expansion, cell wall organization, and metabolism in the mutant.



A) Electron beam induced large seed size mutant in groundnut and genomic region associated with large seed size trait of mutant identified through QTL mapping. B) Increased organ size, cell size in chickpea mutant and genetic linkage map of chromosome 1 showing marker position with respect to the CaEl locus

Nitrogen-rich Bio manure Preparation Facility

As a part of implementing better waste management practices and for utilization of ammonium nitrate effluent generated in ADU precipitation process, a demonstration facility has been proposed to install at nursery area for regular requirement. It is being explored that the waste ammonium nitrate is a potential source of

nutrients in fertilization for increasing the productivity of crop plants. Lab scale experiments have been completed for evaluation of suitability. A demonstration facility has been installed at nursery area for regular operation.



Nitrogen enriched manure production facility.

Healthcare Technologies

X-band 6 MeV LINAC as an Alternative to Co-60 in Teletherapy

An X-band 6 MeV LINAC has been deployed and qualified for medical applications as a possible alternative for Cobalt-60 in teletherapy. The technology is being integrated in ring gantry with industrial partner/incubate as a part of Atal incubation activities of BARC.

Handheld Biosensor Impedance Meter for Detection of Cancerous Cells

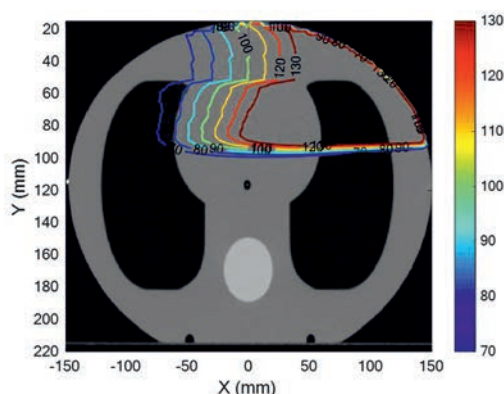
A Biosensor Impedance Meter (BIM) is developed to detect the cancerous cells. It measures and displays the real and imaginary impedance of a biosensor in real-time on a PC through the USB protocol. The BIM will be used for monitoring the change in the impedance of the electrochemical cell comprising a porous silicon anode immobilized with antibodies, a platinum cathode, and a phosphate buffered saline electrolyte. Upon introduction of an antigen to the electrolyte, the transient change in the impedance will show signature of healthy or diseased cells. The performance of the indigenous BIM has been validated by comparison with a commercial equipment - Biologic Impedance Analyzer SP200. The deviation was found to be within 8%.



Hand-held biosensor for the detection of cancerous cells.

Development of Dose Engine for Bhabhatron for Asymmetric and Wedge Fields

Dose computation engine, which is the heart of the Treatment Planning System (TPS) of Bhabhatron, has been augmented to account for asymmetric field openings and wedge fields. Augmented dose



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°.

engine has been integrated with TPS and validated for typical test cases using measured data in a Thorax Phantom as per IAEA TEC-DOC 1583.

Homogeneous Spherical Graphite Ionization Chamber for Source Strength Determination of High Dose Rate Brachytherapy Sources

The accuracy of radiation dose delivery to cancer patients depends on the accurate measurement of source strength of brachytherapy sources using a reliable dosimetry system. In this connection, a homogeneous spherical graphite ionization chamber of sensitive volume 228 cm³ was designed and fabricated for use as a reference ionization chamber to determine the strength of high dose rate (HDR) brachytherapy sources in terms of reference air kerma rate (RAKR). The chamber has nominal diameter of 76 mm. The main components are the wall and central electrode made up of graphite, insulating material, the ventilating hole at the right side of the bottom, the electrical connections to the wall and central electrode. The nominal estimated volume is around 228 cm³. The chamber has been tested at hospital having HDR unit loaded with Ir-192 source. The basic dosimetric characteristics such as charge leakage, reproducibility/precision, linearity and



Experimental set-up used for characterisation of this ionization chamber.

stability were evaluated. The measured dosimetric characteristics of the graphite cavity ionization chamber indicate that the chamber fulfils the requirement of RAKR standard for HDR brachytherapy sources. This newly developed graphite ionization chamber is used to standardize the high dose rate brachytherapy sources, which in turn, is used to calibrate hospital dosimeters. Having the uniform response, this spherical chamber will help in enhancing the accuracy of dose delivery to the patients treated by the HDR brachytherapy sources.

Dosimetry for Clinical Implementation of Indigenous Ru-106 Eye Plaques

Dosimetry of indigenous notch type as well as round type Ru-106 eye plaques were carried out using radiochromic films and diode detector in a water phantom. The dose response calibration of radiochromic film was done in 6 MeV therapeutic electron beam from a medical electron linear accelerator. A dedicated eye phantom was developed for the accurate and reproducible positioning of the eye plaques. A stack of circular samples of radiochromic films of gradually increasing diameter was used to fill up the cavity that was formed due to internal concave surface of the plaque and a stack of rectangular films was placed over the circular film stack for measuring the dose distribution beyond the lugs level. The films were scanned after 24 hours of irradiation and analysed using indigenously developed image-based dosimetry system. The dose rates at 1 mm and 2 mm depths of one of notch type eye plaques was found to be 319.3 mGy/min and 255.5 mGy/min respectively. The uniformity of activity distribution over the plaque was found to be within 20%. The dosimetry data generated was used for regulatory approval and clinical application of the plaques. The measured data dose data is utilized in treatment planning system to assess dose non-uniformities and target coverage and to protect critical structures during treatment. Ophthalmic brachytherapy has emerged as the viable alternative of enucleation as it is capable of offering

an equally effective local control in 90% of patients with the added benefit of eye preservation and functional vision retention in some cases.

Audit of Source Strength Measurements in High Dose Rate Brachytherapy

Independent verification of brachytherapy source strength measured by hospitals is one of the important components of the quality control program in brachytherapy. To fulfil this requirement a remote audit method for source strength verification in high dose rate (HDR) brachytherapy under the IAEA dosimetry audit project was established. In this context, a brachytherapy postal audit phantom has been designed and fabricated. The phantom has the provision to measure the dose around the source at a number of points 5 cm away from the centre of the source using Thermo-Luminescent Dosimeter (TLD) capsules. The source is positioned at the centre of the phantom using a catheter and source guide tubes of the HDR unit. During measurements, each TLD capsule is irradiated for a dose of 1 Gy using the treatment time and methods used by the hospitals for the treatment of the patient. In fact the TLD is calibrated in reference air kerma (RAKR) which helps in determining the strength of the source in RAKR.



Brachytherapy postal audit phantom.

Measurement of Spectrum of Diagnostic X-ray Beam

The characterization of diagnostic x-ray beams (DXRBs) requires the spectrum to be known accurately, the spectrum measurement presents problem because of high photon fluence rate which ranges from 10^6 - 10^{10} photons/mm²sec for the typical parameters set for diagnostic radiological examinations. At high photon fluence rates the detection system (detector and electronics) suffers from the problem of pulse pile-up, which leads to the spectral distortion. To handle this problem, a pin-hole collimator (PHC) was designed, developed and used for the spectrum measurement of 40, 50, 60, 70, 81, 90 and 100 kVp DXRBs. The Cadmium Zinc Telluride (CdZnTe) detector placed inside the PHC was set at the distance of 100 cm from the focal spot of x-ray tube and the field size of 20 x 20 cm² was used for the spectrum measurement purpose, the energy calibration of the detection system was carried out using ²⁴¹Am and ¹³³Ba reference gamma ray sources. The mean energy of the DXRBs determined from the measured spectrum ranges from 27.22-30.73 keV and agreed within 1% with published values for 40 kV spectrum. Thus, PHC provides an effective solution to the problem of pulse pile-up.



Experimental set-up used for measurement of diagnostic x-ray beam spectrum.

Testing of X-ray Radiation Protection Apparels/Samples

As part of efforts to minimize the potential exposure of workers to occupational dose as well as patient comforters in diagnostic radiology, personal radiation protective garments and other shielding devices are commonly used. A product having lead equivalence of 0.50 mm is able to

provide approximately 95% X-ray attenuation at 100 kVp X-ray energy. Almost all personal radiation protective products used in radiology have lead equivalence in the range of 0.25 to 0.50 mm and provide X-ray attenuation of more than 85% at 100 kVp X-ray beam energy. Testing and certification of such products received from various manufacturers/suppliers and research laboratories are carried out using protocols in conformance with the requirements stipulated by the international standard IEC 61331-1. Around 70 samples are tested annually.

Hydrogen Technologies

Technology of Alkaline Water Electrolyzer for Green Hydrogen Production

The Alkaline Water Electrolyser (AWE) technology (TRL=9) for production of 10 Nm³/hr (50 kW) hydrogen has been transferred to about 10 industries. An incubation agreement under Atal Incubation Centre (AIC) for the development of 120 Nm³/hr (150 kW) H₂ generation plant based on AWE has been signed. Design parameters of the scaled-up version of AWE was carried out in BARC and the fabrication was carried out by the technology incubatee. The unit was operated up to a current density of ~4500 A/m² with a cell voltage of ~2 V at 50°C, meeting all design intents. In keeping pace with current market demand for a MW scale AWE plant, BARC signed a MoA with PSU refinery M/s. BPCL for activities involving scaling-up, demonstration and deployment of a suitable AWE system. A prototype 0.5MW stack (with 5 Nm³/hr capacity) was fabricated, assembled and installed. The testing of this prototype stack was carried out successfully thereby validating all process related design parameters. Besides, based on alkaline water electrolysis technology, an improved version of table top type laboratory scale hydrogen generator was developed to deliver ~20 NLPH of hydrogen at a pressure of ~3 to 5 bar (g) and >99.9 % purity.



Prototype to 0.5MW AWE cell stack.

Proton Exchange Membrane (PEM) Water Electrolyzer

A Membrane Electrode Assembly (MEA) with $\sim 50 \text{ cm}^2$ active area was prepared in-house using commercial Proton Exchange Membranes (PEM). The electrolyzer equipped with this MEA was successfully tested up to 12,000 ASM current density at a maximum operating voltage of $\sim 1.9 \text{ V}$. The endurance trial of PEM water electrolyser cell was carried out at a current density of $\sim 6000 \text{ ASM}$ for more than 1000 hours without any noticeable performance degradation. At ambient operating temperature of $\sim 30^\circ\text{C}$, the cell voltage is nearly constant ($\sim 1.73 \text{ V}$) with a hydrogen production rate of 12 NLPH (purity of 99.95%) at $\sim 85\%$ overall energy efficiency.

Capillary Electrolyser

The Capillary Electrolyser system was operated at room temperature and current density of $\sim 1500 \text{ ASM}$ corresponding to hydrogen production of $\sim 6 \text{ NLPH}$ with 99.9% purity. Capillary electrolyser is a passive type of alkaline water electrolyser cell system without process plant components such as electrolyte circulation pump, gas-liquid separators and water scrubbers.

Copper-chlorine Thermochemical Cycle for Hydrogen Production

A novel integrated Cu-Cl cycle was developed and demonstrated in metallic equipment along with all the auxiliary steps. Sustained hydrogen production was demonstrated at a throughput of 5 NL/h for a

time duration of 170 hours thereby making it the highest recorded duration by any thermochemical cycle, globally. The cycle has maximum temperature requirement of $\sim 500^\circ\text{C}$ and an expected thermal to hydrogen efficiency of 45-50%, thereby making it highly prospective for near term coupling with medium temperature heat sources from next generation nuclear reactors, solar and industrial waste heat. The developed cycle has several unique advantages such as reduced energy duty, intensified plant footprint with least number of auxiliary steps and novel engineered separation systems. The installation of pilot scale facility is in progress and further scale-up is planned in a sequential time-bound manner towards commercialization of the technology.

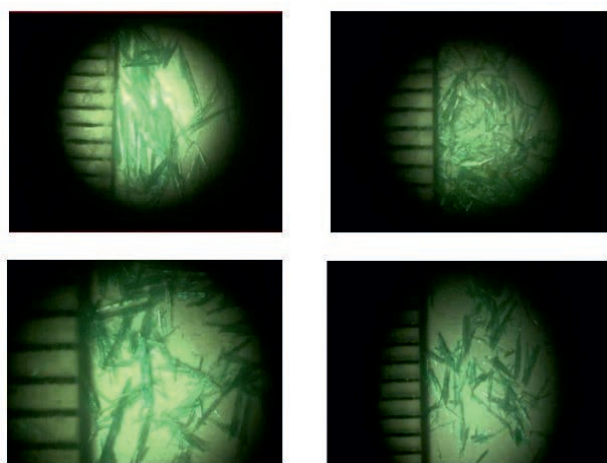


A first-of-its kind integrated metallic bench scale Copper-Chlorine facility in BARC.

Batch Crystallization Experiments on Crystallization Step of Cu-Cl Thermochemical Cycle

Batch crystallization experiments were conducted to simulate crystallization of CuCl_2 from spent electrolyte of electrolysis step of Cu-Cl cycle. Around 30% crystal yield is found at 0°C for 2 hour of batch time with simulated spent electrolyte having 8 N acidity and 70% conversion. Maximum crystals were having size in the range from 0.4 to 0.7 mm in batch time of 2 hour. The size range is found to be 2.5 to 3mm for 24hour batchtime. It is observed that with an increase in batch time the size of the crystals increases but does not have significant effect on the yield. Crystal yield is found to be increasing with increase in electrolytic conversion

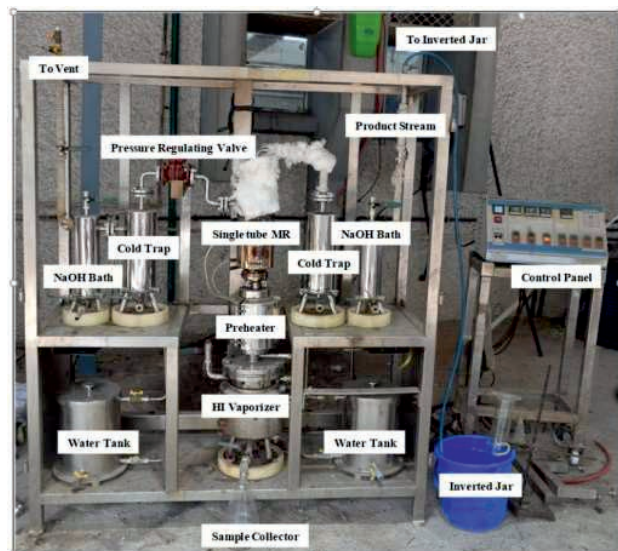
and acidity. Yield is found to be increasing with reducing crystallization temperature. A correlation relating crystallization yield to temperature of crystallization is obtained for spent electrolyte having 8N HCl and 70% conversion of CuCl for batch time of 2 hours. Effect of temperature and time on drying of crystals is seen for 80, 100 and 120°C at regular intervals up to 2 hours. It is observed that while 1 hour is sufficient for drying of samples at 120°C, 1.5 hour is required for drying at 100°C.



Microscopic image of crystals obtained in batch experiments.

Refractory Metal Membrane Reactor for Enhanced HI Decomposition

HI decomposition studies using Ta-W membrane reactor (single tube) were carried out at 450°C and 1 bar at different vaporization temperatures (130–190°C) and different reactor temperatures (300–450°C). Maximum hydrogen flow rate of 8 LPH was



HI decomposition setup using Ta-W membrane reactor.

achieved through a membrane surface area of 50 cm² at a vaporization temperature of 190°C while the conversion of HI was found to be ~90%.

Noble Metal Membrane Permeator for Steam-Hydrogen Separation in 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 feed (in a ratio of 75:25), a hydrogen flux of ~5 LPH was obtained at a pressure difference ~30 mbar and temperature of ~150°C (using a membrane area of ~80 cm²). Hydrogen concentration (vol%) in reject (steam) line was found to be ~5% (in line with the desired parameter) with ~2% steam loss in the product stream.

Development of Catalysts for Sunlight-driven Hydrogen Generation

Metal nanoparticle-loaded graphitic carbon nitrides, M/CN, are attractive materials for photocatalytic hydrogen generation. To understand the behaviour of metal nanoparticle induced Mott-Schottky heterojunction photocatalysts for water splitting applications, nanoparticles (nps) of different metals (Pt, Au, Ag, Pd, Cu) were dispersed on CN surface. The morphology, electronic properties, metal-support interactions, band structure, life-time measurements of charge carriers were investigated by relevant techniques and correlated

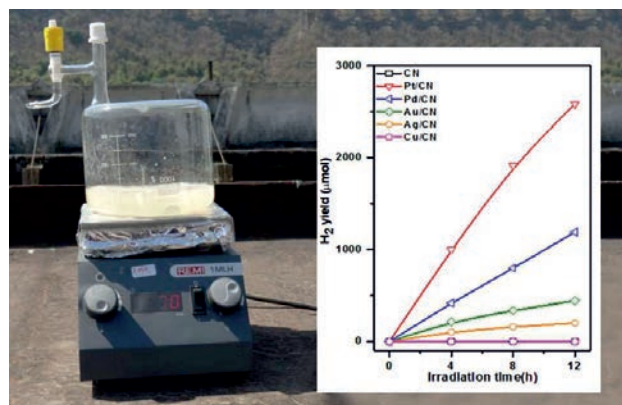


Photo-catalytic H₂ generation at different time interval over M/CN samples under sunlight.

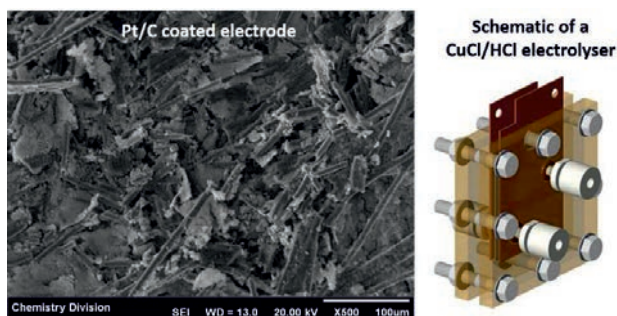
with photocatalytic hydrogen yield in different M/CN samples. These studies helped in comparing the precise role of different metal nanoparticles as co-catalyst in determining the photocatalytic activity of CN. Among all the samples, Pt/CN was found to be the best performer as compared to other metals both under sunlight and UV-visible light.

Hydrogen Production through Iodine-Sulphur Thermochemical Process

BARC has successfully demonstrated Iodine-Sulphur thermochemical as well as hybrid sulphur process for production of Green Hydrogen. It has clocked hydrogen production at its design capacity of @ 150 normal litres per hour (NLPH). The net input to the entire process cycle is water and heat, whereas all other chemicals deployed in the process, including Iodine & SO_2 are recycled back. The Iodine-Sulphur (I-S) cycle is among the widely studied thermo-chemical water splitting processes for large-scale production of hydrogen worldwide.

Development of Electrocatalyst and Membrane Electrode Assembly for CuCl/HCl Electrolysis for Hydrogen Generation by Cu-Cl Thermochemical Cycle

Pt/C based electrocatalyst and membrane electrode assembly (MEA) of 4 cm^2 active area for CuCl/HCl electrolysis was fabricated and tested in a proton exchange membrane-based electrolyzer for the above process. Subsequently, MEA's of 25 cm^2 active area was fabricated and successfully employed in the CuCl/HCl electrolyzer of the integrated closed loop operation of Cu-Cl thermochemical cycle. The CuCl/HCl electrolysis is the crucial hydrogen generating electrochemical step of the Cu-Cl thermochemical water splitting cycle for hydrogen generation. In order to decrease the activation barrier, the use of electrocatalysts and to process the electrochemical reaction in a proton exchange membrane (PEM) based electrolyzer the development of membrane electrode assembly (MEA) is essential for efficient



Scanning electron micrograph image of Pt/C electrocatalyst based electrode (on the left-hand side), and a schematic of electrolyzer in which it was tested for CuCl/HCl electrolysis.

operation of this step. Pt/C electrocatalyst based MEA for CuCl/HCl electrolysis in a PEM based electrolyzer, with the Pt/C electrocatalyst on the cathode side, was fabricated and evaluated for the performance. After successful operation of the MEA for H_2 evolution in CuCl/HCl electrolysis for 40 h, another MEA was fabricated and utilized in the Cu-Cl process for an even longer duration (~169 hrs).

Bulk-scale Preparation of Magnesium Hydride (MgH_2) for Hydrogen Storage Applications

The challenges involved in storing of hydrogen are one of the most critical in utilizing hydrogen economy to its full potential. Storing hydrogen in hydrogen storage materials in solid state is among the safest routes without any need of pressurization. Magnesium hydride (MgH_2) is one of the promising candidates and has attracted intense attention worldwide because of its higher gravimetric capacity (7.6 wt.%), good reversibility and abundance of Mg in earth crust. However,



0.5 kg scale MgH_2 synthesis set-up developed in-house.

preparation of MgH_2 in bulk quantity is technically challenging. A hydride producing facility is designed, fabricated and installed for producing magnesium hydride (MgH_2) in bulk quantity. The process parameters for preparation of high purity MgH_2 in 0.5 kg scale were optimized using commercially available magnesium powder. The product MgH_2 was confirmed by characterizing its phase, morphology and dehydrogenation temperature.

Scaled-up Preparation of Supported Noble Metal Catalyst for Ultra-purification of Products from Water Electrolyzer

Hydrogen and oxygen gases produced through Alkaline Water Electrolyzer (AWE) have contamination of oxygen and hydrogen (~2% v/v maximum), respectively. These streams can be purified by carrying out $\text{H}_2 + 1/2 \text{O}_2 = \text{H}_2\text{O}$ reaction followed by removal of H_2O by condensation and adsorption by molecular sieves. Various supported noble metal catalysts based on γ -alumina balls, activated alumina extrudes, cordierite beads and tin oxide tablets with varying loading of Pd or Pt or both, were screened during initial studies and 1% Pd on γ -alumina balls was identified as the most efficient catalyst for this purpose with $t_{1/2}$ value of 8.5 - 9.5 min for ~4% hydrogen in air. The catalyst preparation route was optimized for controlled loading of noble metal and its reduction. The catalyst was produced at batches of 12g to 30g to 100g scale, with reproducible catalytic activity. Finally, the lab scale production has been carried at 8 kg batch scale.

The catalytic activity was evaluated under static mode in 40 litre reactor with provision for continuous hydrogen concentration monitoring. It has been observed that the catalytic activity was retained with consistent $t_{1/2}$ of about 9 minutes as the production process was scaled-up from 12g batch to 8 kg batch. The catalysts at all stages have been evaluated in a bench scale set up for catalytic activity using a recirculating packed bed catalytic

reactor under complete recycle flow and the reaction rates observed for small scale batch have been reproduced for kg scale batch also.



1% Pd on Alumina catalyst for ultra-purification of AWE products.



8kg batch of supported noble metal catalyst.

Specialized Technologies

Development of Turbo Charger as an Import Substitute Technology

The development of Turbo Charger has been taken up for use in desalination plant as an import substitute. A Turbo Charger acts as second pump and reduces the quantum of pressure that the high-pressure pump has to generate. It is powered by hydraulic turbine rather than a traditional electric motor. In a desalination plant, its purpose is to recover energy from the pressurized reject

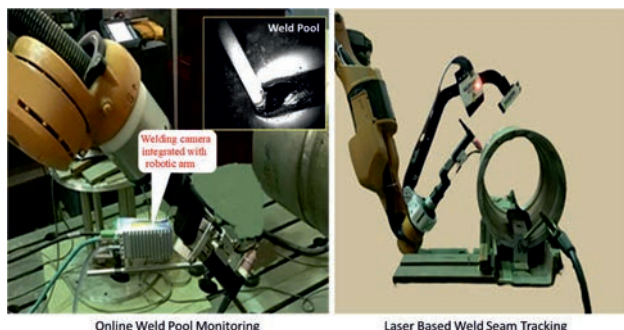
brine stream and thereby decrease the running cost. An improved version with separable volute has been designed for ease of manufacturing and replacement. A sample unit has also been manufactured at CDM for performance evaluation and testing.



Turbo Charger-Mark II.

Robotic Technology for Welding of Critical Nuclear Components

Robotic technology has been developed for narrow gap – 'nozzle to nozzle' welding required in the manufacture of critical nuclear components. This includes features like online monitoring and recording of weld pool and Laser based tracking of weld seam to achieve consistent weld quality with minimum distortion and residual stresses in constrained space.



Online Weld Pooling Monitor and laser-based Weld Seam Tracking.

Welded Plate Compact Heat Exchanger

Plate type heat exchangers provide the benefit of compactness, but their gaskets typically limit its operation to 30 bars pressure. To overcome this

limitation, a fully welded plate compact heat exchanger for high pressure applications has been developed using an innovative hydro-forming fabrication technique.



Welded Plate Compact Heat Exchanger.

Development of Hot Shutdown Passive Valve

Hot shutdown passive valve (HSPV) for use in reactor decay heat removal system has been developed. A prototype of this has been tested for performance aspects and for seismic qualification.

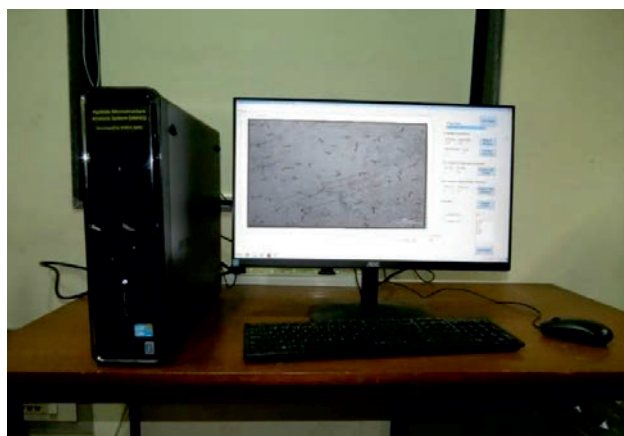
Industrial Applications of Radiotracers

Radiotracer investigations were carried out for process diagnosis and design evaluation in a cross-flow reactor at M/s. BPCL, Noida, pulse extraction column and pulse disc-doughnut column in BARC facilities. ^{82}Br and $^{99\text{m}}\text{Tc}$ were employed as radiotracers for tracing the aqueous phase. Various hydrodynamic parameters were measured and the radiotracer data was modelled using suitable mathematical models. The results of the investigation were used for validation of numerical models and scaling up of existing processes.

Installation of Hydride Microstructure Analysis System (HMAS)

An Image Analysis (IA) based software was developed to quantify hydride microstructure in the fuel clad images for crack initiation & propagation studies. The IA software aims to find different parameters, including hydride length, hydride counts at different angles, hydride fraction, etc. in order to assess the likelihood of development of crack. A personal computer-based

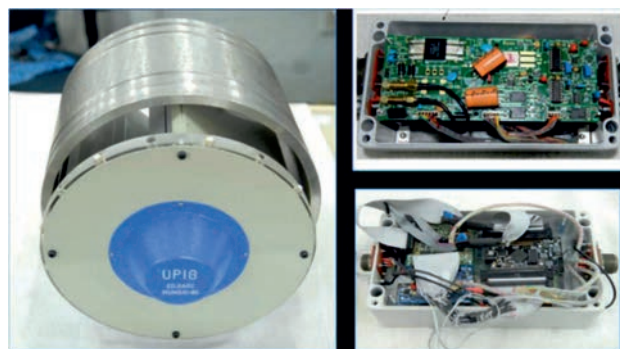
prototypeHydride Microstructure Analysis System (HMAS) has been developed executing IA software for detection and analysis of hydrides in images of fuel clad, in order to find out the clad integrity. The software inspects microscopic images to automatically detect the hydrides and calculates their orientations as well as the percentage fraction of hydrides oriented in the radial/horizontal directions. The HMAS was installed at the user location for regular use.



PC-based prototype HMAS installed at PIED, BARC.

2-Channel Ultrasonic Tube/ Pipe Inspection & Gauging System

A FPGA-based ultrasonic pipe inspection and gauging system has been designed and developed in BARC. The water-immersible instrumentation system 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. The modules are mounted inside the inspection head with two ultrasonic spherically focused transducers placed 180 degrees apart to measure wall-Thickness, ID and OD of the tube/ pipe under testing & detects 60% loss of wall thickness with + or -2% accuracy. The system is suitable to gauge pipes carrying a fluid at a velocity of 100mm/sec. The system was evaluated for detection of standard volumetric and planar flaws in pipes, namely Flat Bottom Holes (FBH) and notches. Such indigenous system is one-of-its-kind and can acquire data for 5 hours to acquire 200MB gauging data, with the help of Li-ion batteries.



Inspection head mounted inside pipe and Pulser & DAQ Modules of System.

Ultrasonic Technology based System for Measuring Isotopic Purity of Heavy Water

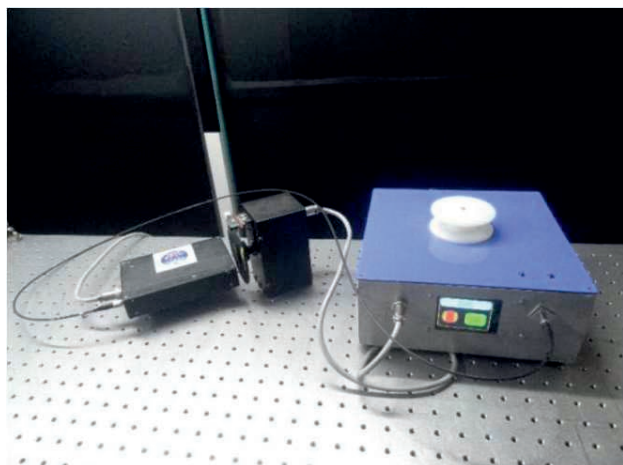
A first-of-its-kind ultrasonic technology (UT) based online system for isotopic purity measurement of heavy water is developed by designing a small UT sensor (requiring only 8ml of sample volume in a constant temperature bath) and a USB powered electronics. The in-house-developed user interface acquires and processes the UT signal for estimation of isotopic purity of heavy water in near real time. Multiple experiments were conducted using heavy water of isotopic purity range from 1.9% to 91.8% for generation of calibration curve and system performance was validated with measurements from benchmark instruments of higher accuracy. The sensing system is deployed in the operations of BARC.

Imaging System for Material Integrity Test under Cyclic Loading

A desktop PC based prototype Imaging System has been developed for conducting miniature Specimen Integrity Test (SIT) for structural safety analysis of aged/irradiated materials. It facilitates online image grab of the sample, corresponding to 10Hz & 20Hz cyclic load imparted by the dynamic loading machine employed. The system comprises of a 500fps video camera to capture image with 800x600 resolution for measurement of strain and crack-growth from miniature specimen (typically ≈5mm thickness and ≈10mm length/width) under fatigue test.

On-line Taggant Detection System

The up-conversion fluorescence based fast detection system, with detection time of less than 20 ms was developed for detection of taggant in the moving paper for its authentication. Its performance has been tested to the satisfaction using taggant paper on rotating disc.



Inspection head mounted inside pipe and Pulser & DAQ Modules of System.

Solar-powered Two-phase Induction Motor Drive

A variable frequency two phase induction motor drive powered by DC supply from solar PV panels, using constant volt/hertz is designed and developed. The drive is universal in nature and is able to drive both two phase as well as three phase loads. The AC drive system consists of two boards – Power & Controller Board. The three-leg inverter with IGBT modules is placed on the power board along with driver card, voltage and current sensors. The controller board contains the Microcontroller



PC-based prototype HMAS installed in BARC.

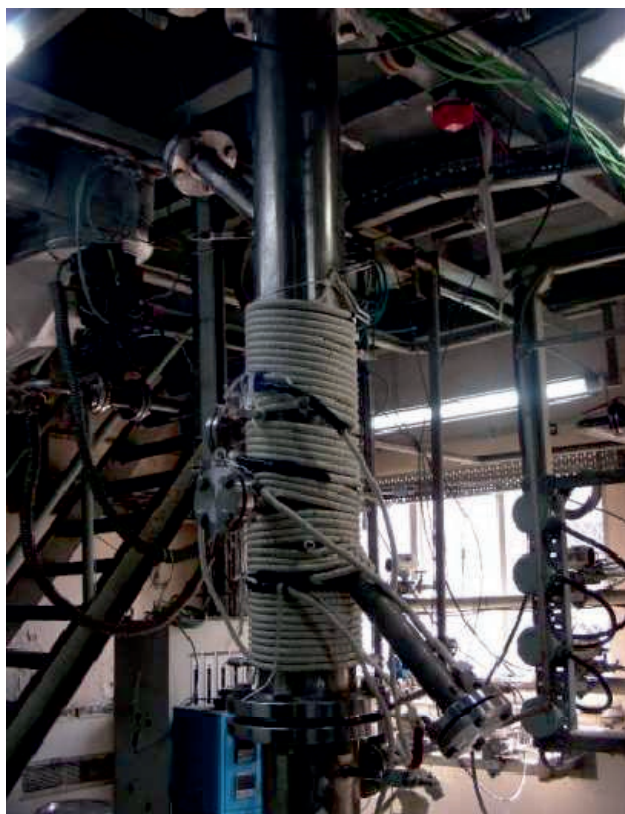
and Signal conditioning circuits. The controller generates IGBT PWM control pulses based on Maximum Power Point Tracking (MPPT) algorithm to regulate motor speed at desired frequencies. The performance analysis and characterization of the prototype solar powered two-phase induction motor drive is satisfactorily completed in both AC mode and solar PV mode.

Shock-wave Generator using Pulse Power System for Oil Well

A Shock wave generator tool of 495 J capacitor energy ($C = 1.1 \mu\text{F}$, $V_{ch} = 30 \text{ kV}$) assisted with two wire operating mechanism was developed in BARC. The components of the system were tested rigorously for ensuring smooth operation. The system components were sealed SS-316 pipe with inside diameter of 87mm and outside diameter of 102mm having required I/Os outside with help of feed through. The tool has been tested under BARC-ONGC MoU, inside the oil wells from 760m to 1530m at 150 bar pressure for more than 24 hours.

Integrated Demonstration Plant for High purity Polysilicon Production

Three process steps are required for purification & production of Polysilicon by Siemens process, namely Fluidized bed reactor for Trichloro Silane (TCS) feedstock production from Metallurgical grade (MG) Silicon, then purification of TCS to high purity grade ($>10\text{N}$ purity) by distillation and finally polysilicon manufacture in a Chemical Vapor Deposition (CVD) reactor. First time in the country, a close loop high purity polysilicon ingot production has been demonstrated from MG Silicon. Product purity is also confirmed to high purity ($>7\text{N}$) grade. Further a pilot scale (5MTPY) high purity polysilicon production demonstration plant design has been completed for establishing complete polysilicon production industrial technology with recycling of process streams.



PC-based prototype HMAS installed in BARC.

Ceramic Membrane Reactor for Enhanced H_2S Decomposition

For application in hydrogen recovery from coke oven gas stream of steel industry and waste gas streams of refineries, H_2S decomposition studies were carried out using ceramic membrane reactor. Clay-alumina membranes were developed using extrusion process. At a temperature of $1300^\circ C$ and a pressure of 0.5 bar, a conversion of $\sim 90\%$ was obtained using ceramic membrane reactor as compared to a conversion of $\sim 50\%$ in conventional packed bed reactor. The technology titled "Composite metal membrane reactor for production/separation/recovery of high-purity hydrogen" has been advertised for incubation and expression of interest has been received from steel industries producing coke oven gas.

Low pressure Chemical Vapour Deposition (LP-CVD) Facility

Pertaining to one of the most preliminary ways to successfully meet the requirement of accident tolerant fuel cladding for Gen III-IV PHWRs, thin film ($\sim 8-12 \mu m$) of silicon carbide (SiC) needs to be

simultaneously deposited on inner and outer surfaces of all tubes in zircaloy-4 tube bundle. Presently, low-pressure chemical vapor deposition (LP-CVD) process is being commissioned to simultaneously attain coating of SiC on all tubular surfaces of tube. The process employs non-chlorine-based precursor for SiC deposition. Low pressure process minimizes substrate surface temperature required for deposition which maintains integrity of tube material during coating process.



LP-CVD facility in BARC.

Isolated Multi-channel DAQ for Multi-cell Stack Systems

The Isolated Multi-channel DAQ for Multi-cell Stack Systems is a compact unit developed and packaged for retro fit installation in fuel-cell stack and for similar systems. The system facilitates monitoring of voltage across all proton exchange membranes with programmable alarms, temperature of stack at various points, control of hydrogen flow through the stack, power control and alarms. The system also offers touchscreen based local GUI along with PC based interface. The system has an extended



Isolated Multi-channel DAQ for Multi-cell Stack Systems.

access over Modbus RTU to SCADA mainstream software. The equipment can suitably become an import substitute to a high density programmable modular DAQ system.

Development of Liquid Helium Dewars

Four numbers of liquid helium Dewars of 30, 100, 250 and 500 litre capacities, were designed and fabricated with the aim of indigenously developing standalone liquid helium Dewars spanning the commonly required capacity range of 30 to 500 litres for laboratory and commercial usage. The liquid helium Dewars are of double walled construction interspaced with thermal shield and MLI under high vacuum. The designed evaporation rate conforms to international standards (lower than 2% per day for all Dewars except the smallest one for which the rate is 5%). These Dewars have come out as an import substitution product and has been approved for technology transfer. Local manufacturers have purchased the helium Dewar technology.



Helium Dewar showing thermal shield and MLI.



Final Helium Dewars after fabrication.

Helium Refrigeration System

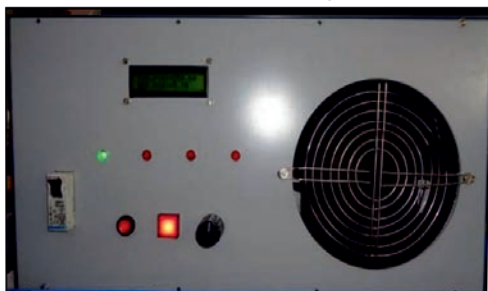
A 2 kW at 20 K helium refrigerator cold box was modified through refurbishment of internal piping and turbo expander mount so as to enable usage of appropriate aerostatic bearing-based turbo expanders in lieu of less reliable large size

aerodynamic bearing-based turbo expanders. The refrigeration process was modeled on a standard reverse Brayton thermodynamic cycle. The refrigeration system, along with its component subsystems such as the high-speed aerostatic bearing-based turbo expanders and heat exchangers, performed consistently during the week-long trial run. During the plant operation, the two turbo expanders registered steady operating speeds of 2270 Hz and 2240 Hz respectively, which was higher than the design speed of 2000 Hz. Throughout the period of the plant run, it exhibited a steady refrigeration capacity of about 1700 W at 19.6 K. The refrigeration load was simulated using a gas heater. The successful plant run with rugged aerostatic bearing-based turbo expanders opens up avenues of using the same technologies for larger cryogenic plants needed for systems such as cryogenic plants for high energy accelerators. Particularly significant is the fact that these technologies are very robust and can handle exigencies such as power failure without compromising the plant life.

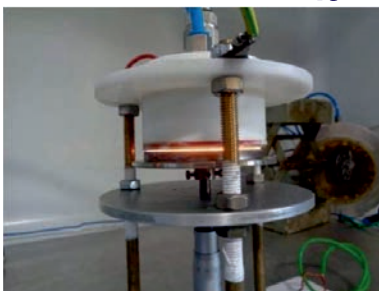
Development of 200 and 1000 W, 13.56 MHz RF systems

Indigenous, narrow bandwidth, standalone and plug and play 13.56 MHz RF power system at 200 W have been designed and developed to achieve high efficiency with cost effectiveness. The RF system inclusive of directional coupler is coupled to cold plasma device in BARC and operated with combinations of Helium, Argon & Oxygen gas. This can be used for pathogen killing or sterilization via cold plasma. The Indigenous standalone 13.56 MHz, 1 kW RF system has also been developed, which can be used for plasma generation or RF sputtering.

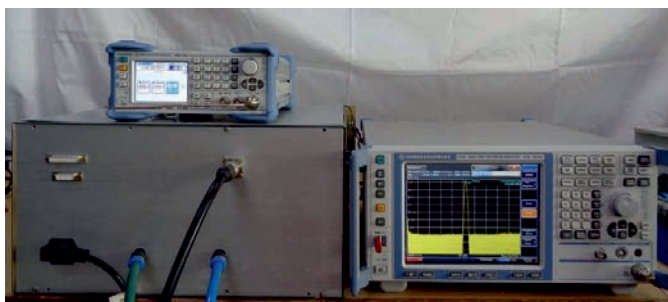
13.56 MHz, 200 W RF System.



Cold Plasma with He, Ar and O₂ gas.



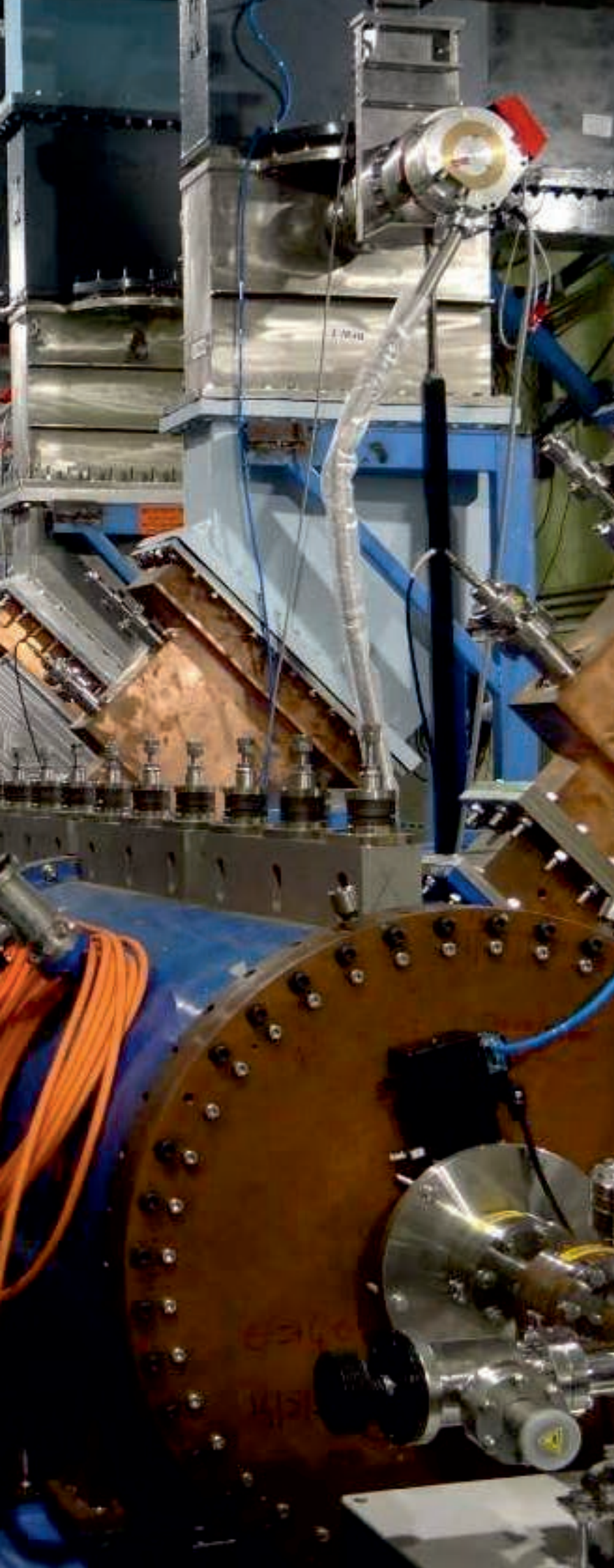
ArCold Plasma.



Indigenous 13.56 MHz, 1 kW RF System.

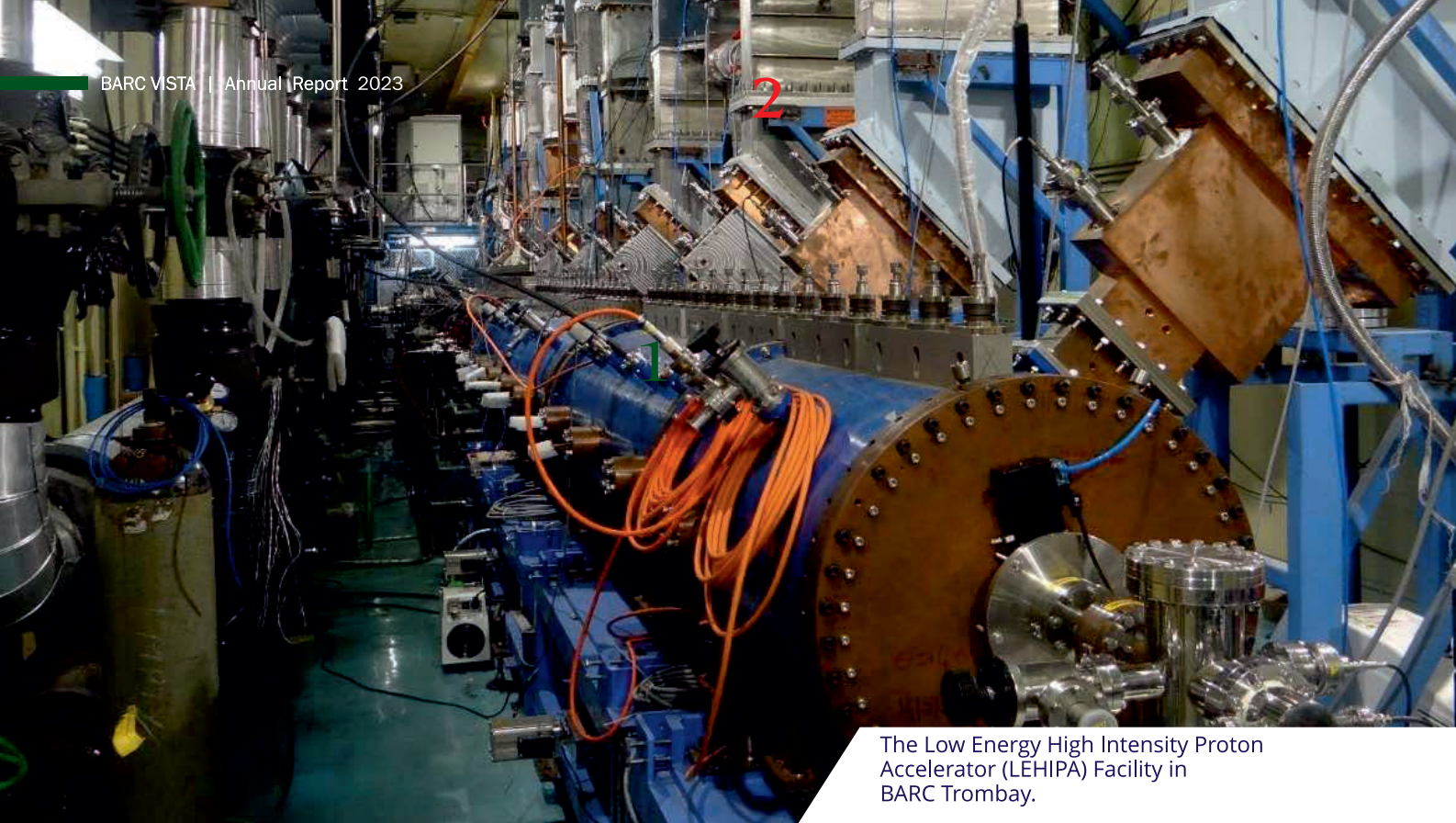
Robust industrial economy of scale

- ⚗ NH₃ decomposition studies carried out using Packed Bed Catalytic Membrane Reactor (PBCMR) at 700°C and 1 bar using Pd-Ag alloy membrane resulted in a conversion of ~93% of NH₃ as against a conversion of ~80% in conventional packed bed reactor at similar operating conditions. Application of membrane reactor will lead to a potential 30% saving in capital cost for ammonia cracker unit.



BASIC AND DIRECTED RESEARCH

BARC has a highly competent workforce which is ingrained in pursuing specialized research in fundamental aspects of sciences, to complement inherently complex nuclear technologies. Over the years, research in basic sciences has expanded significantly from the traditional domains into new and emerging areas with a clear emphasis on ensuring directed outcomes that would contribute immensely towards improving the overall standard of living. In line with this philosophy, sustained efforts are underway in physical sciences, chemistry, biology, water resources management, radiotherapy and radiopharmaceuticals, mutation breeding for improved crop varieties, food preservation approaches and waste management, to achieve the desired outcomes.



The Low Energy High Intensity Proton Accelerator (LEHIPA) Facility in BARC Trombay.

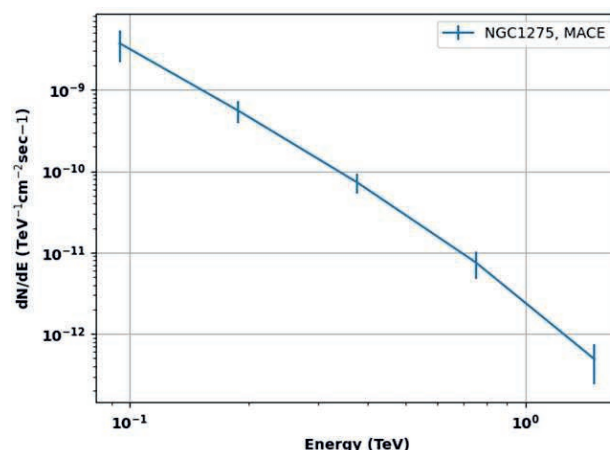
Basic and Directed Research

Astrophysical Sciences

MACE Observations

The MACE telescope has been successfully operated for more than 400 hours to collect science data on a number of potential gamma-ray sources in the sky. Apart from the regular detection of very high energy gamma-ray emission from the standard candle Crab Nebula in our Milky-Way Galaxy, statistically significant signals have also been measured from the extragalactic sources such as NGC 1275, Markarian 501 and 1ES 1959+650. The differential energy spectrum of the radio galaxy NGC 1275 during its high activity state as measured by the MACE telescope is depicted in the figure. It is well described by a power law with experimental cut-off in the energy range from 80 GeV to ~2 TeV. The spectrum is found to be consistent with the near simultaneous space-based measurements in the high energy range 0.1-300 GeV by the Large Area Telescope on board the NASA's Fermi satellite. These combined

measurements are important to understand the physical process involved in the gamma-ray emission from radio galaxies.



Gamma ray differential energy spectrum of the radio galaxy NGC 1275 measured by the MACE telescope.

Phenomenological Studies in Astrophysics

Very high-energy gamma-ray spectra of distant blazars were utilized to study the Extragalactic Background Light, the combined light of all stars and galaxies across the cosmic history. This study

Up-gradation of Experimental Facilities

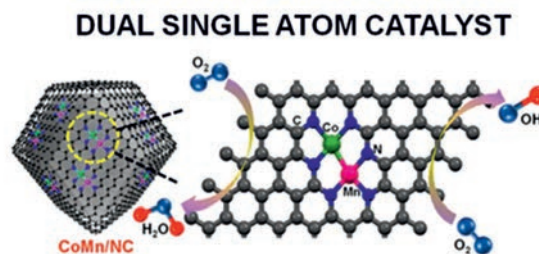
- ✱ A major upgrade work has been undertaken with an aim to improve the performance of existing experimental facilities at GOALS-Mount Abu and HARL-Gulmarg.

holds potential for unravelling the mysteries of the earliest, yet unobserved stars. Phenomenological studies have been performed to model the broadband spectral energy distributions of a number of extragalactic sources. We have detected a high frequency quasi-periodic oscillation in the hard spectral state of black hole binary MAXI J1348-630 using X-ray data from NICER onboard International Space Station. A robust classification model based on the eXtreme Gradient Boosting (XGBoost), a supervised machine learning algorithm, is developed to identify the exact astrophysical nature of a special class of high energy gamma-ray sources called Blazars. It is also demonstrated for the first time that the distance (generally given by the redshift) of blazars plays an important role in their classification. In order to overcome the challenges of creating a large simulation database for performance evaluation of the ground-based telescopes like MACE, a machine learning method called Generative Adversarial Network (GAN) is being used for synthetic data generation.

Synchrotron Beamline

Dual Single Atom based Electrocatalyst at Beamline-09 at Indus-2

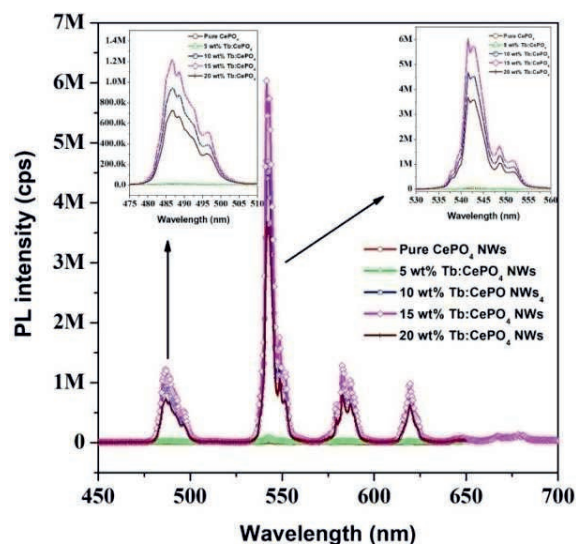
The EXAFS beamline (BL-09, Indus-2) has led to the characterization of many electro-catalysts this year. Among them is a dual single atom catalyst (DSAC) used in the oxygen reduction reaction (ORR). EXAFS studies performed on these samples revealed the details of bond distances and local structural environment of the metal centers. The confirmation about the presence of Co-Mn site has led to the revelation of bridge-site based reaction pathway. This work enhances our understanding of non-precious DSACs as attractive ORR catalysts.



Atomic model of the CoMn/NC dual single atom catalyst.

Photoluminescence and Resonance Photoelectron Spectroscopy on Terbium doped Cerium Phosphate Nanowires

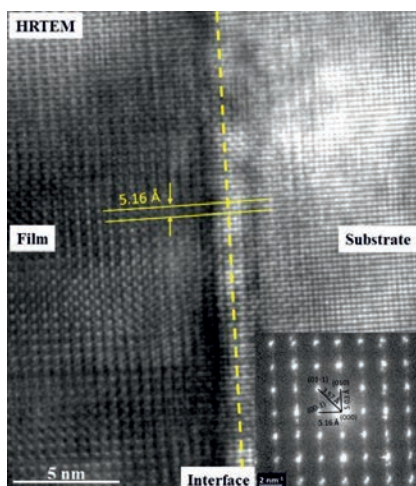
Nanomaterials made of a combination of Terbium and CePO_4 in nanowire form are known to exhibit bright green light emission. The valence band data recorded using RPES showed that efficient energy transfer takes place from Ce^{3+} to Tb^{3+} ions. Corresponding PL spectroscopy experiments on these nanowires showed that due to this energy transfer, intense PL occurs. Also, the concentration of Terbium has a strong influence on the intensity of light emission. Overall results are found to be helpful in controlling the material's structural and optical properties and the material is useful in photoluminescent devices as well as in glucose sensing.



Photoluminescence spectra recorded on varying concentrations of Terbium (5 weight % (wt%) to 20 wt%).

Photoelectron Spectroscopy and X-ray Absorption Spectroscopy on Yttrium doped Hafnium Oxide Thin Films

Nanomaterials in the form of thin films were prepared using Yttrium (Y) combined with Hafnium oxide (HfO_2) with varying concentrations of Yttrium ranging from 0 to 20%. The technique used for depositing these thin films on Ytria stabilized zirconia substrates was pulsed laser deposition with the varying flow of oxygen during deposition. Photoelectron spectroscopy was utilized to extract the composition of the films. X-ray diffraction showed that HfO_2 film without Y has monoclinic crystalline phase, while with Y doping, it transforms to stable cubic crystalline phase. The XAS experiments showed the changes at atomic level in bond distances and disorder when Y is introduced in HfO_2 . These result in increase in the oxygen vacancies as evident from both XAS and photoluminescence studies. The results are useful for understanding of phase change, local structure, optical properties as these films are useful in dielectric and ferroelectric applications.



Schematic of LEHIPA beam line after the DTL.

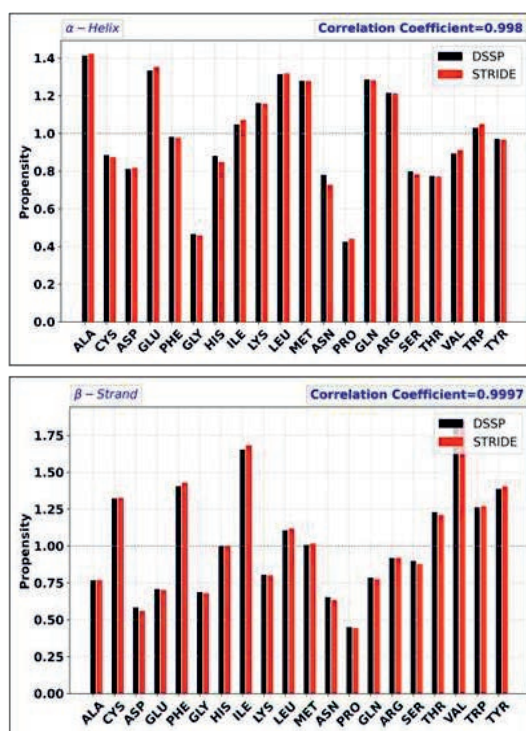
Crystal Structure & Mechanism of Human Beta-alanyl-lysine dipeptidase

Beta-alanyl-lysine dipeptidase is a proof-reading enzyme during carnosine synthesis. Carnosine is important for many normal body functions. This enzyme is recombinantly purified and crystallized at the beamline facility. Its native and mutant crystal structures ($\sim 2\text{\AA}$) have been determined at BL21 beamline of Indus-2. The crystal structures and biochemical experiments revealed the

molecular mechanism of proof-reading activity of the enzyme. The enzyme exploits an essential tyrosine residue at the active site for sensing the correct substrates.

Software for High-throughput Analysis of Protein Structures

A software was developed through in-house efforts to facilitate high-throughput analysis of protein structures. Employing a class-based framework in C++, the software's architecture draws inspiration from the inherent structural hierarchy observed in proteins. The back-end of the application, integrates two state-of-the-art algorithms, namely DSSP and STRIDE, for the precise annotation of secondary structures. ASSP is designed to conduct comprehensive analyses on a diverse dataset of protein structures, encompassing both experimentally determined and computationally generated (e.g., AlphaFold2) structures in a single execution. The software systematically explores various structural characteristics of proteins, including but not limited to temperature factor, solvent accessibility, dihedral angles, and residue preferences. Serving as a pivotal tool, ASSP enables



The plots showing the preferences of amino acids for the two most prominent protein structures alpha-helix and beta-sheets calculated using ~ 6000 protein structures by the software.

the application of Machine Learning-based methodologies for in-depth investigations into protein structures and their folding mechanisms. The software has revealed the average propensities of amino acids for different secondary structures of proteins that could acts as a standard reference for international community for designing and engineering novel proteins.

High Pressure Extended X-ray Absorption Fine Structure Facility at BL-11 at Indus-2

A scanning extended x-ray absorption fine structure (EXAFS) facility has been developed to study the element specific local structure evolution under high pressures at 'Extreme Condition X-ray Diffraction Beamline' (BL-11) Indus-2 RRCAT Indore. At this beamline the synchrotron radiation beam spot size at sample has been reduced to about 30 microns, which helped in setting up the diamond anvil cell based EXAFS facility. For the first time, a high quality, 12\AA^{-1} data is recorded from inside the diamond anvil cell up to 20 GPa. With this development, it is now possible to probe local structure of crystalline as well as amorphous phases of materials under high-pressure conditions. This facility has been quite useful in our recent study on the mechanism of high-pressure amorphization in $\text{Y}_{1.8}\text{Eu}_{0.2}\text{Ge}_2\text{O}_7$, an important photoluminescent material. Our studies show pressure-induced amorphization in $\text{Y}_{1.8}\text{Eu}_{0.2}\text{Ge}_2\text{O}_7$ accompanied by partial transformation to a poorly crystallised phase above ~ 14.0 GPa. The local structure of high-pressure amorphous as well as crystalline phases is determined by XAS measurements at BL-11, Indus-2. The analysis show that the coordination number of Y (7) and Ge (4) changes to 8 and 6 respectively under pressure, which leads to amorphization at high pressures.

Ion Accelerator

Commissioning of 20 MeV Beam in LEHIPA

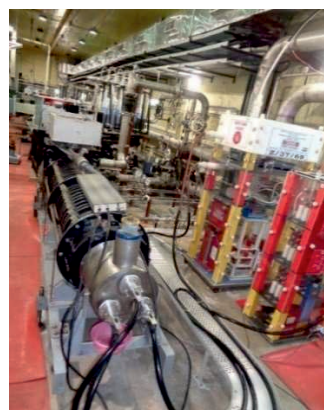
The Low Energy High Intensity Proton Accelerator (LEHIPA) facility successfully achieved its designed energy of 20 MeV in pulsed mode on 4th August,

2023. After accelerating the beam to 11 MeV, DTL tanks 3 and 4 were integrated followed by their conditioning to RF power levels of 350 kW each. Subsequently, these tanks facilitated the acceleration of the proton beam from 11 MeV to the target energy of 20 MeV. The beam energy was measured using the Time of Flight (ToF) technique with two Fast Current Transformers (FCTs) positioned at a known distance of 135.7 mm. The time difference between the signals from the two FCTs measured approximately 2.2 ns, corresponding to energy of 20 MeV. For accelerating the beam to the designed energy of 20 MeV, LEHIPA utilized three 1 MW, 352 MHz Klystron RF amplifiers. Out of these three klystrons, one RF klystron required reconditioning and separate testing. Subsequent to its reconditioning and testing it was then coupled to DTL tanks 3 & 4.

This accomplishment marks a significant milestone in our future high-intensity proton accelerator program. Numerous key technologies were indigenously designed and developed, contributing to the growth of small and medium-



The time difference between the two FCT signals measured to be 2.2 ns.

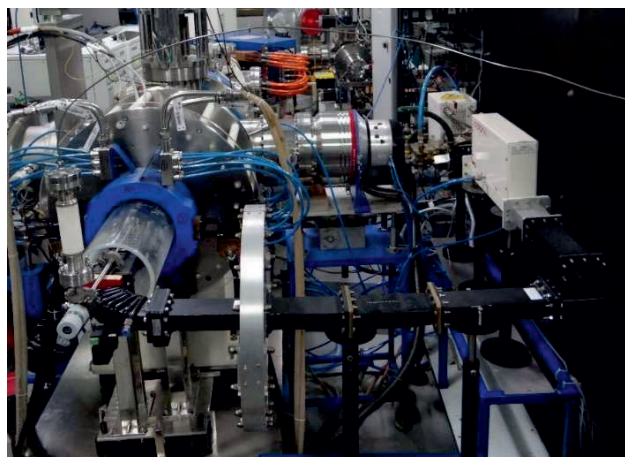


1 MW Klystron RF amplifier.

scale industries in the country. The 20 MeV beam produced by LEHIPA can be utilized to generate Neutrons, Radioactive Ion Beams (RIB), and Radioisotopes, marking the dawn of a new era for high-intensity proton accelerators in India.

ECR Ion Source

The characterization of the five electrode ECR ion source has been done. The beam current and emittance was measured using DC Current Transformer (DCCT) and Allison scanner respectively. A significant challenge lies in comprehending the non-linear behavior of the plasma and optimizing various parameters to achieve lower beam emittance at higher currents. The measured beam parameters at 50 keV extractor voltage are emittance of 0.36π mm-mrad at maximum beam current of 10 mA.



Five Electrode ECR Ion Source beam.

Wall Current Monitor

Wall Current Monitor (WCM) is an important beam diagnostic device used in RF accelerators to measure beam bunch profile, beam current and longitudinal emittance by virtue of the EM fields and image currents associated with the beam. This non-interceptive device allows for online monitoring of beam bunches of high average power. The design and development of a large band-width (~ 10 GHz) WCM for LEHIPA facility has been carried out. A prototype based on the design has been fabricated and detailed characterization has been done. The measurement results match well with the design simulations.



Prototype WCM.

Folded Tandem Ion Accelerator (FOTIA) Facility

The FOTIA facility was operated for more than 2300 hours. Ion beams generated from accelerators were utilised for carrying out various experiments during the year. Some of the experiments conducted were neutron production in inverse kinematics, study of neutron induced reactions with Sb, Nb, Mo, Ta, Ni, Ag targets, measurement of prompt fission gamma in the fast neutron induced fission of Th^{232} among others. Commercial utilization of the external PIGE beam line of FOTIA has been done for Boron (B^{10}) isotope content determination in B_4C samples by an industry partner from private sector.



Experimental set-up for fast neutron induced fission experiments at FOTIA.

Batteries

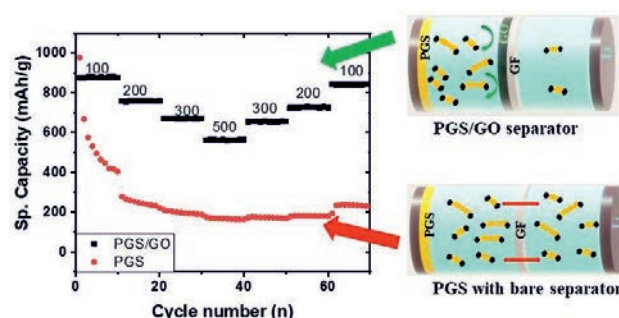
Synthesis, Characterization and Evaluation of Efficiency of Materials for Hybrid Li/Na Battery

A novel type of Li^+/Na^+ hybrid-ion battery with $\text{LiNa}_2\text{V}_2(\text{PO}_4)_2\text{F}_3@\text{C}$ as the cathode, metallic Na as the anode, and a lithium-ion electrolyte has been fabricated. Electrochemical measurements are performed using CR2032 coin cells and the $\text{LiNa}_2\text{V}_2(\text{PO}_4)_2\text{F}_3@\text{C}$ cathode is prepared via the slurry coating method. The slurries are composed of 80 wt% $\text{LiNa}_2\text{V}_2(\text{PO}_4)_2\text{F}_3@\text{C}$, 10 wt% acetylene black, and 10 wt% polyvinylidene fluoride (PVDF) binder in a solvent of N-methyl-2-pyrrolidone (NMP). A discharge specific capacity of $134 \text{ mAh}\cdot\text{g}^{-1}$ is delivered at a current density of $100 \text{ mA}\cdot\text{g}^{-1}$ in the range of 2.5–4.2 V. Besides, when the current density increases to $1000 \text{ mA}\cdot\text{g}^{-1}$, the specific density can reach a value of $113 \text{ mAh}\cdot\text{g}^{-1}$, which indicates superior rate performance. After 800 cycles, a retention rate of 83% of original capacity is observed at a high current rate of $1000 \text{ mA}\cdot\text{g}^{-1}$. This simple design strategy for Li/Na hybrid-ion batteries harvests the synergetic contribution of Li^+ and Na^+ ions and provides an efficient solution to further improve hybrid-ion battery performance.

Modification of Components in Li-S Battery to enhance its Electrochemical Performance

In case of lithium sulfur battery, highly resistive sulfur and polysulfide shuttling are two main reasons for low capacity and fast capacity decay. PANI and reduced graphene oxide (rGO) framework has been used for improving conductivity and mechanical stability of cathode. However, development of electrode and modification of separator are two essential aspects to realize high energy density Li-S battery. In this endeavour, the cathode has been fabricated by incorporating sulfur in PANI/rGO composite and the separator has been modified by coating graphene oxide over it. Graphene oxide coated separator acts as a second barrier layer to suppress lithium polysulfide migration and support the

cathode current collector to enhance sulfur utilization. Electrochemical characterization of cells was performed by cyclic voltammetry, electrochemical impedance spectroscopy and galvanostatic cycling. The coin cell delivered a superior initial capacity of 807 mAh/g at 100 mA/g current density. Upon cycling at a high current density of 1 A/g it delivered a capacity of 478 mAh/g with excellent stability for 500 cycles and lower capacity fade of 0.02% per cycle. These studies indicate that modification of separator leads to higher capacity at different current density.



Specific capacity of Li-S battery using PGS/GO and PGS separator.

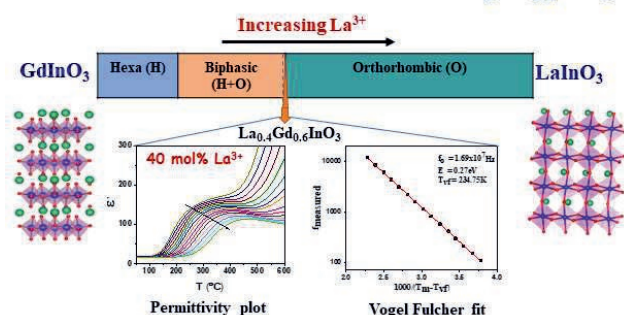
Research on Lead-free Relaxors for Energy Storage Applications

Relaxor ferroelectric materials are desired for high power density E-storage devices. Recently, there has been a continual quest to develop lead (Pb) free relaxors to phase out the presently used Pb based relaxor ferroelectrics. This attracts for exploration on different types of classical ferroelectrics and dielectrics to induce relaxor properties by tuning composition and structure.

In this direction, detailed structural and electrical properties of samples in $\text{Gd}_{1-x}\text{La}_x\text{InO}_3\text{F}_2$ ($0.0 \leq x \leq 1.0$) system have been studied. The system yielded interesting metastable phases which are guided by both ionic radius and controlled synthesis conditions. Detailed PE measurements and AC impedance studies showed a gradual appearance of relaxor behaviour in GdInO_3 upon La^{3+} -substitution and finally to a weak but classical relaxor behavior at the nominal composition $\text{La}_{0.4}\text{Gd}_{0.6}\text{InO}_3$. The PE studies done on Gd^{3+} -rich region showed abrupt narrowing down of PE loop for the nominal compositions with 30 and 40 mol%

La^{3+} in GdInO_3 . This was accompanied by a broad peak in dielectric constant vs T plot for the nominal composition $\text{La}_{0.4}\text{Gd}_{0.6}\text{InO}_3$ whose frequency followed Vogel-Fulcher behavior thus pointing towards relaxor-type behaviour. The study has significance in context of understanding structurally controlled electrical behaviour to develop low loss lead-free relaxors.

Introduction of Relaxor behavior in $\text{La}_x\text{Gd}_{1-x}\text{InO}_3$



Spin Seebeck effect measurement setup.

Facile Synthesis of Copper Telluride Nanostructures for LIB Anode Materials

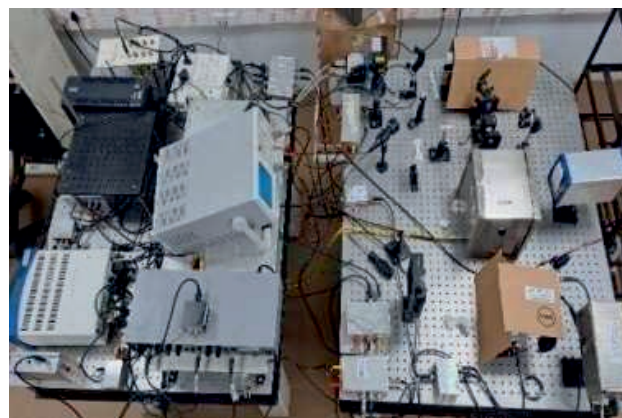
Stoichiometric and non-stoichiometric copper tellurides, recently have been in focus as a potential candidate for electrocatalyst for water splitting, battery anodes and photodetectors, etc due to their composition and phase dependent properties. While applications of copper tellurides are in nascent stage, synthesis of phase pure metal tellurides is challenging, often associated with unwanted impurities due to fragile Cu-Te bond. Therefore, anticipation of a facile synthesis protocol for copper tellurides is warranted. Accordingly, a simplistic single source molecular precursor pathway for the synthesis of orthorhombic- $\text{Cu}_{2.86}\text{Te}_2$ nano blocks and - $\text{Cu}_{31}\text{Te}_{24}$ faceted nanocrystals employing $[\text{Cu}\{\text{TeC}_5\text{H}_3(\text{Me}-5)\text{N}\}]_4$ cluster in thermolysis and pyrolysis, respectively has been probed. The pristine nanostructures were carefully characterized by p-XRD, EDS, electron microscopic techniques (SEM and TEM) and diffuse reflectance spectroscopy to know the crystal structure, phase purity, elemental composition, distribution of elements, morphology and optical band gap. These measurements suggest that different reaction conditions fetch nanostructures of different size, crystal structure,

morphology and band gap. As prepared nanostructures were evaluated for lithium-ion batteries (LIBs) anode material. The cell fabricated with orthorhombic $\text{Cu}_{2.86}\text{Te}_2$ and orthorhombic $\text{Cu}_{31}\text{Te}_{24}$ nanostructures deliver capacity 68 mAh/g and 118 mAh/g after 100 cycles. LIB anode made up of $\text{Cu}_{31}\text{Te}_{24}$ faceted nanocrystals exhibited good cyclability and mechanical stability.

Atomic and Molecular Physics

Quantum Optics-based Experimental Set-up at BARC(F) Visakhapatnam

A quantum optics setup for basic experiments in superposition of quantum states and quantum interference is established at BARC(F) Vizag. The setup consists of a diode laser source locked to a specific atomic transition of Rubidium atom for measuring quantum interference signal in non-degenerate as well as degenerate atomic levels. The quantum sensor based on magnetic resonance using cycling transition useful for magnetic field measurement is demonstrated using this setup. Apart from application in quantum sensors, the setup can be used to study quantum superposition of states for generating quantum entanglement.

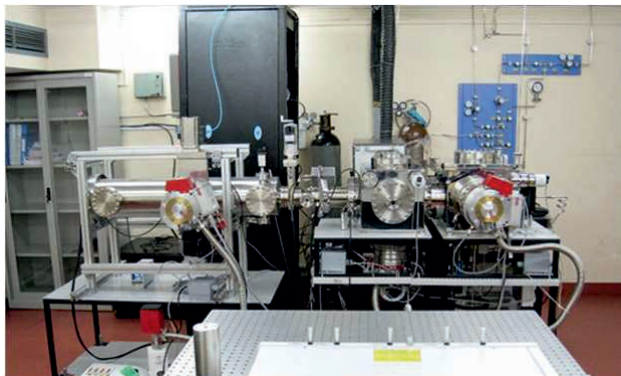


The basic quantum optics based experimental set-up.

Studies on Lanthanum and Lanthanum Monoxide Clusters

Indigenous recently built Laser-vaporization Supersonic Expansion Metal Cluster Beam Setup has been employed to synthesize small lanthanum and lanthanum monoxide clusters in the gas phase. The ground-state geometric structures of 2

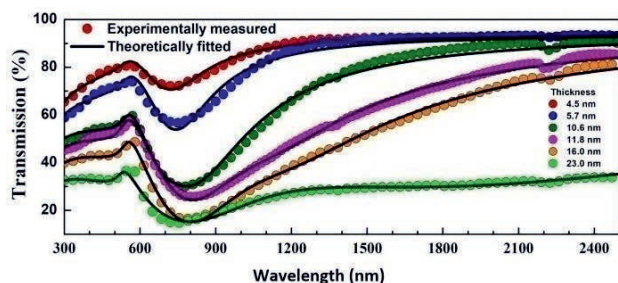
to 10 atom pure metal and metal oxide clusters have been determined with combined experimental and theoretical investigation. The chemical bonding between the La and O atoms is found to be ionic, and ionization occurs from a delocalized s and s-d hybrid orbital as opposed to the previously envisaged localized d orbital. The results are important to develop nanoscale metal oxide material for hydrogen storage application.



Indigenous supersonic metal cluster beam set-up.

Broadband Localised Surface Plasmon Resonance in Ultra-thin Copper Films

Ultrathin Copper Island Films (UCIFs) of thickness in the range of 4.5-23 nm have been deposited on fused silica substrates using thermal evaporation. The films show broadband Localized Surface Plasmon Resonance (LSPR) in the transmission spectrum, which can be used for developing new nano plasmonic thinfilm devices. It is found that the LSPR properties can be precisely controlled by varying the thickness of the films, opening the scope of their practical applications in LSPR based sensors.



Measured and best-fit transmission spectra of UCIF showing LSPR.

Development of High-capacity Thin Film Lithium-ion Batteries with TiO_2/ZnO Multilayer Electrodes

Li ion batteries (LIBs) with TiO_2/ZnO and ZnO/TiO_2 thin film bi-layer electrodes have been developed

for obtaining high capacity and high structural stability. Batteries made with $\text{ZnO}:\text{TiO}_2$ thin film layers over gold coated stainless steel have shown excellent specific capacities of up to 1302 mAhg^{-1} at current density of 0.3 Ag^{-1} even after 1000 cycles of battery operation. Commercially available Li-ion batteries have typical capacities of 160 mAhg^{-1} . This development has potential application in long life performing Li-ion batteries using easily scalable and highly reproducible magnetron sputtering techniques.

Development of High-performance Symmetric Supercapacitors based on Gold-incorporated CrN Thin Films

Gold incorporated CrN (Au-CrN) thin films synthesized using reactive magnetron co-sputtering technique is investigated for application as supercapacitor electrode material useful in developing supercapacitors. Supercapacitors made by sandwiching two Au-CrN thin film electrodes, have found to deliver excellent specific capacitance of 86.03 mFcm^{-2} at 1.0 mAcm^{-2} discharge current density upto 20000 cycles. The electrochemical properties of these supercapacitors are better than those reported so far in the literature with using CrN electrodes.

Large Area High Reflection Coating for TACTIC Gamma Ray Telescope Mirror

The TACTIC (TeV Atmospheric Cherenkov Telescope with Imaging Camera) gamma ray telescope at Mount Abu has 34 front face aluminium coated, glass spherical mirrors of 60 cm diameter, with a reflectance of 85% at 400 nm light wavelength. The reflectivities of these mirrors deteriorate over a period of time due to environmental effects. In order to refurbish these mirrors by improving their reflectivities, a novel 3-layer optical thin film structure has been designed and optimized. The design consisting of silica-aluminium-silica layers of 40nm, 100nm and 50 nm respectively has been implemented by physical vapour deposition. The refurbished mirror has a reflectivity of 90% at 400 nm wavelength with a surface roughness of 140 nm, yielding a focal

spot size of 3 mm as desired. The figure shows the thin film layer structure and the photograph of the coated mirror.

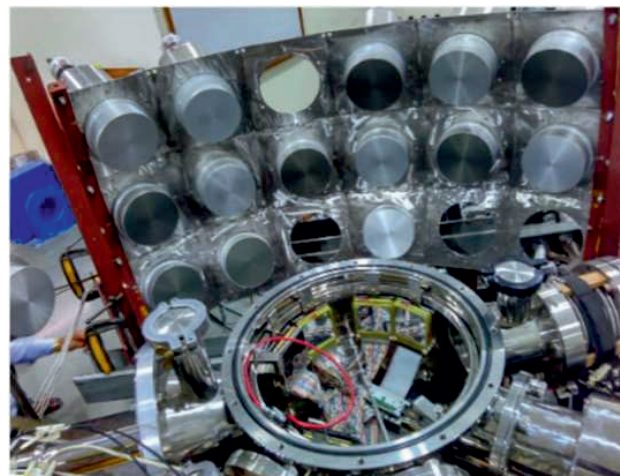


High reflection thin film coated 60 cm dia. TACTIC telescope mirror.

Nuclear Physics

Experimental Evidence of Large Collective Enhancement of Nuclear Level Density and its Significance in Radiative Neutron Capture

The collective enhancement of nuclear level density and its fade out with excitation in the deformed ^{171}Yb nucleus has been inferred through an exclusive measurement of neutron spectra. The statistical model analysis of neutron spectra demonstrated a large collective enhancement factor of 40 ± 3 , a value consistent with recent microscopic model predictions but is an anomalous result compared with the measurements in the nearby deformed nuclei. This is the largest collective enhancement factor reported in any system to date, and it fades out at an energy of 14 ± 1 MeV. The complete picture of the energy dependent collective enhancement has been obtained by combining the present results with those obtained with the Oslo method below neutron binding energy. It is also found that a suitable level-density prescription with appropriate collective enhancement significantly improves the prediction of stellar neutron capture cross sections.



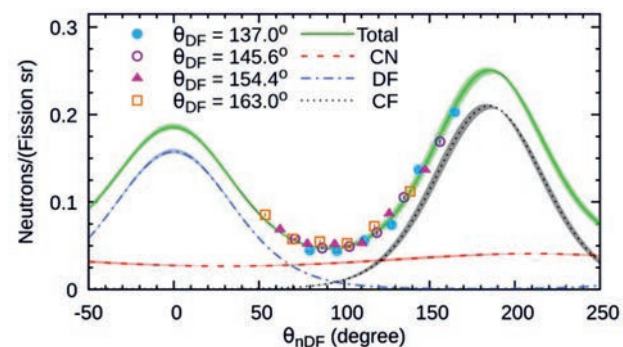
Experimental setup, involving liquid scintillators for neutron detection and Si Strip telescopes for charged particle detection, used for nuclear level density measurement.

Precise Ground State Shape of ^{28}Si

Using the quasi-elastic scattering (QEL) measurements performed at BARC-TIFR PelletronLinac Facility, it has been determined for the first time that ^{28}Si is unambiguously an oblate shaped nucleus in its ground state with a precise value of hexadecapole deformation. The present results pave the way for using QEL probe to rare exotic nuclei using RIBs, where beam intensity is a major concern.

Quest for Understanding Neutron Emission in Fission

Neutron emission in fission continues to be of great interest as it not only helps sustaining chain reaction in nuclear reactors, but also carries signatures of the nuclear potential energy landscape and dynamics. Recent measurements of neutron energy spectra in fission at low excitation energy have been conducted using BARC-TIFR Pelletron LINAC facility, manifesting a large excess

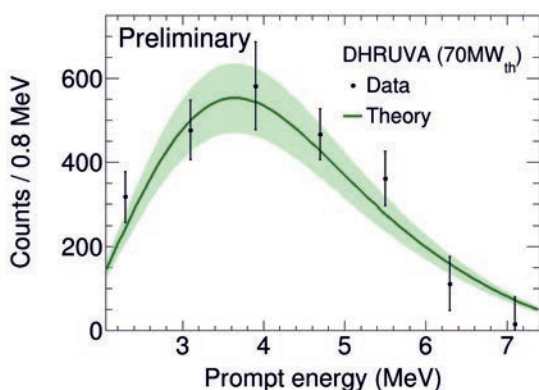


Shedding light on fission mechanism by kinematic disentangling of angular distribution of fission neutrons coming from the compound nucleus and two fragments.

of yields as compared to the predictions of existing theoretical models. This discrepancy has reinvigorated the debate on neutron emission from the neutron-rich low-density nuclear matter at the neck connecting the two fragments at scission, an obscure phenomenon.

Neutrino Physics Studies with ISMRAN Detector at Dhruva Reactor

The detection of antineutrino flux and its energy spectra can be utilized to understand the fundamental interactions of neutrinos and to discover possibly the new physics aspects beyond the Standard model. A large plastic scintillator ISMRAN (Indian Scintillator Matrix for Reactor Antineutrino) detector setup has acquired data for more than a year in the round-the-clock mode and measured antineutrino-like candidate events at Dhruva reactor. To improve the signal to background ratio, ISMRAN has been relocated to a new location that provides more favourable conditions of antineutrino detection. Ongoing measurements have provided a preliminary energy spectrum that agreed well with the established theoretical expectations.



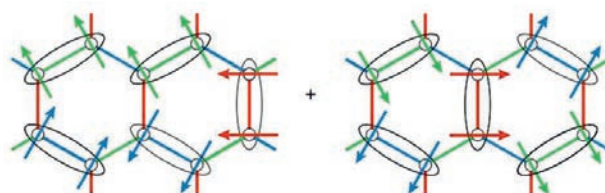
Prompt energy spectrum corresponding to anti-neutrino detection measured by ISMRAN detector setup at Dhruva reactor.

Solid State Physics

Proximate Quantum Spin-liquid (QSL) State in 2D Honeycomb Magnet $\text{Na}_2\text{Co}_2\text{TeO}_6$

Emergent quantum excitations of the Kitaev QSL (Majorana fermions) constitute a promising concept in fault-tolerant quantum computation.

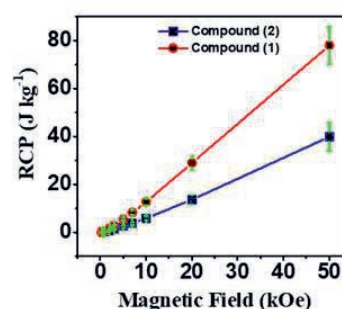
Searching for new materials for Kitaev QSL is at forefront of modern condensed matter physics. One possible Kitaev QSL candidate is $\text{Na}_2\text{Co}_2\text{TeO}_6$ realizing a honeycomb lattice of pseudo-spin-1/2. Our field-dependent neutron diffraction and THz spectroscopy studies on single-crystal $\text{Na}_2\text{Co}_2\text{TeO}_6$ have provided the microscopic spin-spin correlations and quantum spin dynamics for in-plane field directions. Our results reveal a combination of the sharp and continuum excitations featuring spin fluctuations of a proximate Kitaev QSL. Present study provides a benchmark for a quantitative description of the magnetic properties of Kitaev QSL.



A Kitaev quantum-spin-liquid state in $\text{Na}_2\text{Co}_2\text{TeO}_6$; a quantum superposition of entangled states with different distributions of spin-paired bonds.

Magnetocaloric Effect at Low Temperature in Open Framework Compounds of Prussian Blue Analogues Magnets

The magnetocaloric effect, in which temperature of the material changes when exposed to the changing magnetic field is an important property desirable for future magnetic refrigeration technology. The copper hexacyanoferrate Prussian blue analogue materials have been studied and found interesting for exhibiting magnetocaloric properties below liquid nitrogen temperature. The maximum magnetic entropy change, a measure of cooling power, under a magnetic field of 50 kOe is found to be ≈ 6.61 at 20 K. The relative cooling

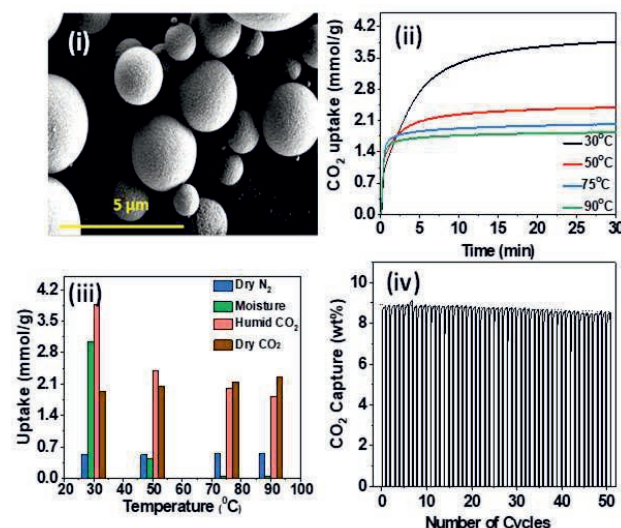


The relative cooling power (RCP) of the Prussian blue analogue magnets at 20 K.

power is also found to be 78.3 J kg^{-1} for compound. The studied compounds are promising for magnetic cooling at low temperatures.

Solid-adsorbent Microspheres for CO_2 Capture through a Scalable Approach

Solid amine-based nano-adsorbents have shown tremendous potential for mitigating CO_2 emissions and a novel scalable method is need of hour. An evaporation-induced assembly approach is developed, with capability of scalability to industrial scale, to achieve amine loaded microspheres. An excellent CO_2 adsorption characteristic have been found with regeneration capability up to 50 cycles due to the unique pore morphology and strong amine confinement. The CO_2 -specific interaction of amine sites allows good selectivity of CO_2 adsorption against N_2 and H_2O . The fast uptake kinetics of adsorbent was attributed to the inter-connectivity among meso and macropores.

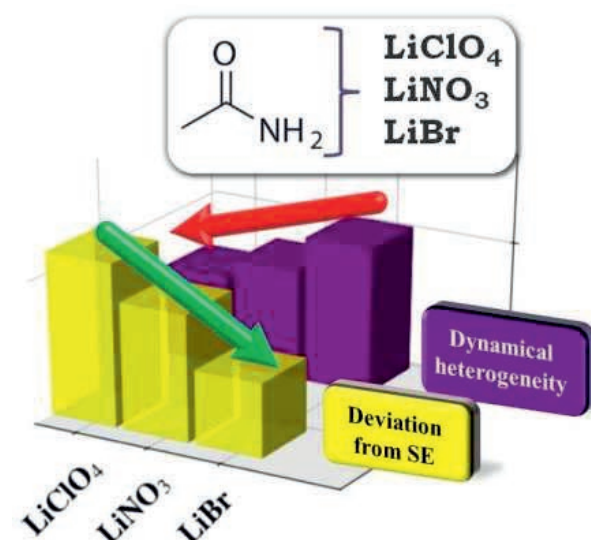


(i) Nano-adsorbent microspheres (ii) Fast CO_2 uptake kinetics (iii) High CO_2 selectivity (iv) High renderability shown up to 50 cycles.

Unusual Relationship between Stokes-Einstein breakdown and dynamical heterogeneity

The relationship between Stokes-Einstein breakdown and dynamical heterogeneity is of paramount importance in the physical chemistry of complex fluids. Dynamical heterogeneity and Stokes-Einstein breakdown in a series of deep

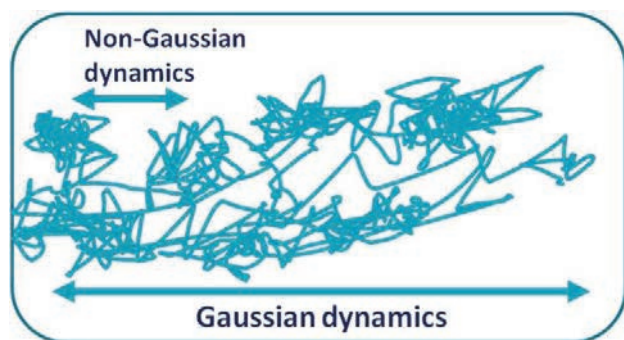
eutectic solvents composed of acetamide and lithium salts, were probed. Quasielastic neutron scattering uncovers Stokes-Einstein breakdown in acetamide jump diffusion, exhibiting a fractional Stokes-Einstein relationship. Surprisingly, lithium perchlorate displays the most pronounced Stokes-Einstein breakdown, while lithium bromide shows the weakest, contrary to their heterogeneity. This counterintuitive relationship between dynamical heterogeneity and Stokes-Einstein breakdown far from the glass-transition temperature, contribute valuable insights about the physical chemistry of complex fluids.



Schematic showing that the dynamical heterogeneity increases while going from LiClO_4 to LiBr , deviation from Stoke-Einstein behaviour shows the opposite behaviour.

Modelling Sub-diffusion Crossovers in Molecular and Polymeric Glassformers

The traditional Brownian motion, where displacements follow Gaussian distribution, fails to explain molecular diffusion in supercooled and glass-forming liquids. Introducing the non-Gaussian fractional Brownian motion model, this study addresses the limitations of the Brownian model, particularly the transition from non-Gaussian to Gaussian sub-diffusion observed in glass-forming fluids. This is a universal model that captures non-Gaussian motion at short lengths but transitions to Gaussian behavior at longer lengths. This model is vindicated by neutron scattering data over a wide variety of systems in literature, showing the universality of the developed model developed.



Schematic showing the trajectory of dynamics transitioning from non-Gaussian at small lengths to Gaussian at large length scales.

Discovery of a New Phase of the Simplest Organic Acid (HCOOH)

A new structure of formic acid, the simplest organic acid, has been discovered upon pressurizing it upto 20 GPa, which settled a long-standing controversy in basic sciences of hydrogen bonding. Furthermore, it is interesting to note that the new structure, consisting of long chains of polyether, resembles a well-known cosmo polymer found widely in interstellar dust. Thus, the findings provide a glimpse of the complex structural assemblies that might have resulted from simple molecular systems in the evolution of organic matter under extreme conditions.

Electride Phase Formation in Calcium Metal under Pressure

Calcium is a simple metal at ambient pressure but shows considerably complex behaviour under high pressure which causes inconsistent experimental and theoretical findings about its structural, electronic and transport properties. Using density functional theory along with hybrid exchange-correlation function we have shown that Ca forms electride at pressure as low as 8 GPa. An electride consists of metal cations and interstitially localized valence electrons which behave like an anion i.e., simple metal becomes ionic solid. Ca near 8 GPa behaves like NaCl solid and near 32 GPa it behaves like CsCl which is similar to simple cubic phase of Ca earlier observed in experiments. Also, our calculated electrical resistance for these electride phases matches well with that of earlier experiments.

Technical Physics

Field Trials of PFN Logging Probe at AMD Jamshedpur

A PFN logging probe consisting of pulsed neutron generator and epithermal neutron detector was assembled for field testing at Kudada, AMD Jamshedpur in a HQ Borehole no KDD-81. The housing was built so as to contain all the HV electronics, preamplifier units and communication module inside a single 70 mm diameter stainless steel cylindrical container. The up-hole system consisted of a multi-channel scaler unit to record the detector pulsed in synchronization with the neutron pulse. The associated electronic control and communication system were tested at different depths of the borehole and were found to work satisfactorily. The neutron source was put ON and the neutron generator was operated at 1kHz frequency and the neutron yield was 1×10^7 n/s with 300us pulse-width. The neutron events were recorded using epithermal neutron detector system that was part of the PFN Probe assembly down-hole and the data was recorded by multi-channel scaler up-hole. The expected uranium concentration at this depth was found to be within the background level.

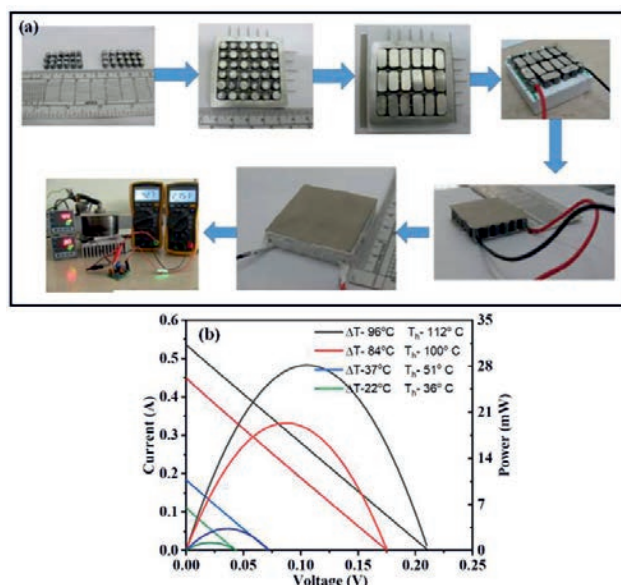


Photograph of the experiment being carried at Kudada, AMD Jamshedpur using indigenously developed PFN probe.

Thermoelectric Generator

A thermoelectric generator consisting of 18 p-n couples made using p-type MgAgSb and n-type Ag₂Se was fabricated. The diffusion bonded low resistivity Ag electrical contacts were developed on both of these materials. The device showed an

open circuit voltage of 220 mV, current~495mA and power of 28 mW for a very small temperature difference of 96°C. The output voltage of device was boosted using a newly designed DC-DC boost converter and used to demonstrate LED glowing.



(a) Fabrication details of a thermoelectric generator consisting of 18 p-n couples made using p-type MgAgSb & n-type Ag₂Se. The last image shows the photograph of a demonstration set-up for the device (b) Current-voltage and power-voltage characteristics of the device under different temperature difference.

Development of Rotational Diamond Anvil Cell

A new indigenous design of a motorized high-pressure RDAC has been developed. As compared to conventional DAC, this cell has an additional degree of freedom of unlimited relative rotation of diamond anvils under extreme load conditions, facilitating unlimited accumulated plastic shear strain which cannot be achieved in conventional DAC. The large symmetric conical opening in this high-pressure cell allows in situ X-ray diffraction and spectroscopic studies on materials under complex load-shear conditions during severe plastic deformation at high pressures. The RDAC has been used to study phase transition in Zr_{2.5}Nb alloy, an important structural material for nuclear reactors. Our study shows important role of shear stresses and an order of magnitude reduction in the phase transition pressure under simultaneous compression and torsion.

Chemical Sciences

Dendrimer-functionalized Carbon Nanomaterials based Super Adsorbent for Efficient Uranyl & Thorium up-take

Multi-functional poly(amidoamine), PAMAM, dendrimer up to generation 5 were covalently grown step by step from generation zero on carbon nanotubes (CNT) and graphene oxides (GO), followed by its physiochemical characterization using FTIR, CHNO analyser, Titration, Raman, TGA, XRD and DLS measurement. The adsorptive separation of uranyl ions by these nanomaterials were evaluated varying different process parameters in aqueous medium. The CNT-PAMAM was found to have higher adsorption capacity (435 mg/g) compared to GO-PAMAM (164mg/g) at pH 6 in room temperature. The extraction of neutral uranyl nitrate from aqueous medium to the functionalized nanostructures through binding with the amine, amide and carbonyl basic sites was observed from computational modelling studies.

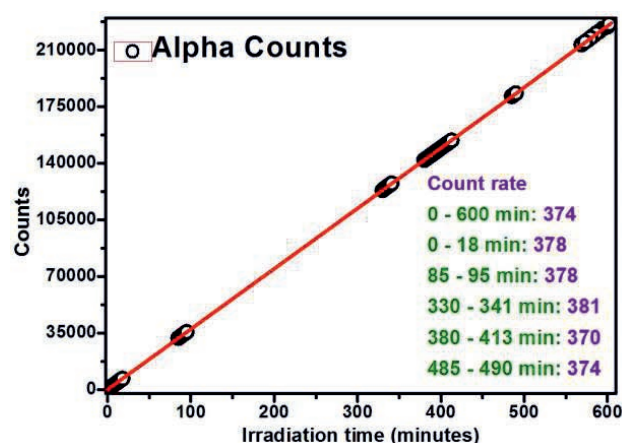
In-house-developed Alpha Particle Counters

Indigenous technologies for radiation detection are essential towards self-reliance in overall nuclear fuel cycle. Diamond is an excellent solid-state host for radiation detection, especially under harsh environments. With optimum chemistry control, CVD method has enabled diamond's lab-synthesis to yield thin films, coatings and plates. Methodology to grow detector-grade polycrystalline diamond films has been developed. Indigenous technology for ambient temperature operational radiation detectors for gross estimation of alpha emitting sources has been demonstrated in ambient air. Plasma chemical vapor deposition technique has been used to synthesize high quality polycrystalline diamond films (10-30 μm thick) over silicon substrates (up to 50 mm diameter). Films were processed to minimize structural and chemical imperfections and in-house configured into detectors. Detectors were tested using actinides (natural uranium, ²⁴¹Am and Pu) taken in the form of thin films and pellets.

Under ambient atmosphere, exceptionally linear and reproducible performance of these detectors up to 10 hours continuous irradiation demonstrated the utility of developed technology for gross alpha monitoring of solid sources.



PCD-based alpha detectors.

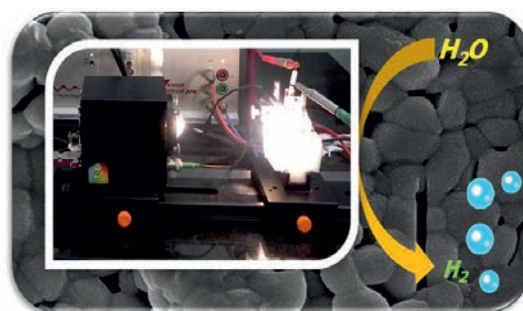


Linear performance of PCD alpha detector.

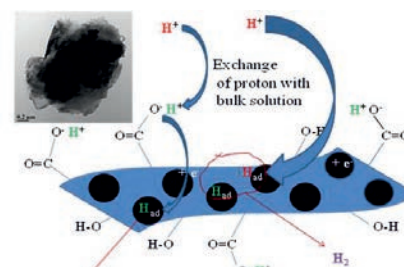
Development of Photoanode and Photocathode for Sustainable Generation of Hydrogen from Water using Solar Light

As the efficient photoanode, BiVO_4 has been synthesized using chemical and electrodeposition route with optimized surface characteristics, the $\text{SnO}_2/\text{BiVO}_4$ heterojunction has been formed with CoB_i as co-catalysts and TiO_2 as surface passivating layer and photoanode has been fabricated. For the development of photocathode, the CuBi_2O_4 as an improvised photocathode material has been synthesized and electrode was fabricated. The stability of photoanodes was established for over 4 hours of operation at 8% efficiency. The stabilization of surface states, decrease in photo-corrosion enhanced the performance and stability.

In the photocathode materials, the layered $\text{MoS}_2/3\text{D-Graphene}$ (3D-G) oxide composite as electrocatalyst provided stable performance at 12% electrocatalytic efficiency. Stable catalytic current has been observed with over 4 hours of operation. The enhanced charge transfer kinetics, enhance mass flow due to exchangeable protons.



Photocathode in operation



Layered MoS_2 /graphene oxide

Linear performance of PCD alpha detector.

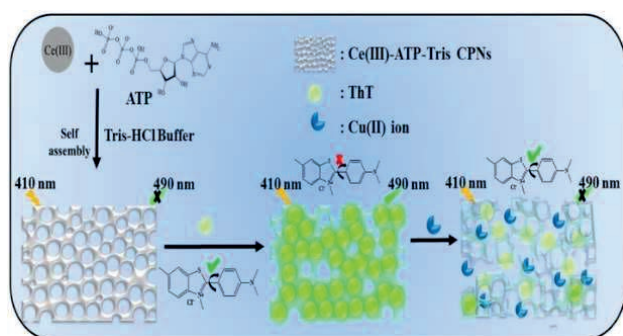
Fluorescence Sensor for Detection of Heparinase and Oversulfated Chondroitin Sulfate

Heparinase plays a critical role in the breakdown of the blood-anticoagulant heparin, making it a key marker for malignant diseases. This research introduces a fluorescence sensor for heparinase detection, utilizing the aggregation of a tetra-cationic porphyrin derivative, TMPyP^{4+} , on a heparin template. Heparinase activity disrupts heparin's structure, leading to the dissociation of TMPyP^{4+} aggregates and creating an optical signal. This sensor demonstrates high sensitivity and selectivity towards heparinase, with a detection limit of 0.3 pmol/L. Additionally, the sensor detects traces of Oversulfated Chondroitin Sulphate (OSCS) in heparin by leveraging the inhibitory effect of OSCS on heparinase activity. This impacts the photophysical properties of the TMPyP^{4+} -heparin-heparinase system. The selectivity of the sensor

was confirmed using various enzymes, and its effectiveness was validated against established methods. This study offers a novel approach for heparinase detection and expands the optical methods available for this purpose.

Thioflavin-T encapsuated Cerium-ATP Coordination Polymer Nanoparticles for Selective and Sensitive Cu(II) Detection in E-Waste and Biological Samples

This study focuses on the development of cerium-based coordination polymer nanoparticles (Ce-CPNs) using adenosine tri-phosphate (ATP) as a cross-linking ligand. The inclusion of the molecular rotor-type dye Thioflavin-T (ThT) into the CPNs' porous network resulted in a significant enhancement of ThT's emission intensity. The unique property of ThT@Ce(III)-ATP-Tris CPNs is their emission intensity being severely quenched by Cu(II) ions, enabling the selective detection of Cu(II). The developed methodology exhibits high selectivity for Cu(II) ions, even in the presence of other metal ions and biomolecules. The limit of detection (LOD) for Cu(II) is 660 nM (42 ppb), notably lower than the US-EPA's prescribed limit in water. The methodology was successfully applied to measure Cu(II) concentrations in e-waste leachate and spiked human serum samples, demonstrating its potential in both environmental and biological contexts.



Schematic of Fluorescence Turn-off response towards Cu (II).

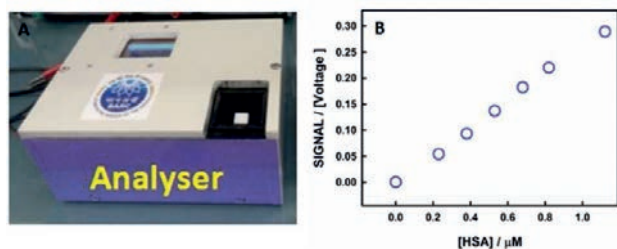
Aggregation-induced Emission-based Fluorescence Sensor for Protamine and Trypsin

This research presents a novel fluorescence sensor for the sensitive and selective detection of

protamine and trypsin, two biomolecules with significant clinical and biological applications. The sensor is based on an anionic derivative of tetraphenylethene (TPE-PO₄), known for its aggregation-induced emission (AIE) characteristics and ability to interact electrostatically with protamine and trypsin. The sensor displayed a linear response range from 0.1 to 10 µg/mL for protamine and 0.01 to 1 µg/mL for trypsin. It also demonstrated high selectivity against other proteins and enzymes and maintained stability under various environmental conditions. Notably, the sensor system was successfully applied to detect protamine and trypsin in human urine samples, showcasing its potential for biomedical and clinical applications.

Fluorescence-based Sensitive Detection of Albumin in Artificial Urine

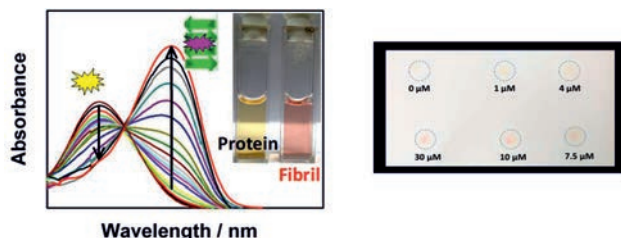
Kidney function is crucial for filtering waste from the blood while retaining essential proteins like albumin. Excessive protein in urine is a significant indicator of chronic kidney diseases. Diabetic nephrosis studies have identified microalbuminuria, a condition marked by slightly elevated urine protein levels (0.4-4 M), as an early sign of kidney damage. Traditional diagnostic methods rely on pH-sensitive dye-impregnated dipsticks for urine testing. However, these dipsticks fall short in sensitivity for accurate detection of microalbuminuria, highlighting the clinical necessity for more effective methods in urinary protein detection and quantification. In response to this need, a new approach has been developed involving a tetraphenylethylene-based probe (BSPOTPE) that exhibits increased emission intensity in the presence of human serum albumin due to reduced non-radiative processes in the probe. This method is sensitive and selective, making it a promising tool for early detection of kidney diseases. A compact, table-top fluorescence detection module has been designed for this purpose. This setup can detect albumin with a limit of detection (LOD) of 0.1 µM within a linear range of 0-1.2 µM.



(A) Picture of the set-up (B) Response curve generated as a function of Albumin concentration.

Colorimetric Detection of Amyloid Fibrils with Picomolar Sensitivity

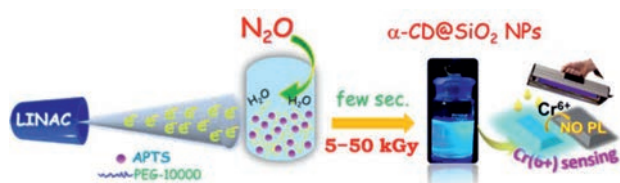
Amyloid fibrils are the ordered protein aggregates which are associated with several neurological diseases. LDS 698 shows change in colour from yellow in its aqueous solution to pink in the presence of amyloid fibrils. Such colorimetric response has been utilized to develop a simple and cost-effective paper-based detection of protein aggregates with limit of detection (LOD) of less than 2 pM. Such changes have been rationalized on the basis of differences in hydrogen bonding and halogen bonding properties of the dye, LDS 698, in fibril as compared to that of its aqueous solution.



Absorption spectra of LDS 698 in water with addition of insulin fibril.

Radiolytically Manufactured Cyclodextrin-functionalized Silica Nanoparticles for Sensing of Highly Toxic Cr Ions

Electron-beam assisted approach used for the rapid synthesis of blue photoluminescent cyclodextrin functionalized Silica nanoparticles (CD@SiO₂ Nps). CD@SiO₂ Nps exhibited highly



Schematic illustration of the radiation-assisted preparation of CD@SiO₂ NPs and their application for the paper strip-based highly sensitive sensing of toxic Cr (VI) ions.

selective sensing of toxic Cr (VI) ions (detection limit ~30 ppb). Paper strips were prepared using CD@SiO₂ NPs, and samples were tested to check their practicality for real-time detection of Cr (VI) ions under a handheld UV lamp.

Highly selective and Sensitive Detection of ATP in Water based on ESIPT Probe

1'-hydroxy-2'-acetonaphthone (HAN) is a well-known excited-state intramolecular proton-transfer (ESIPT) dye. First, a detailed investigation of the interaction of HAN with copper ions (Cu²⁺) was conducted. In the presence of Cu²⁺, HAN shows distinct changes in its absorption properties and undergoes complete fluorescence quenching upon the formation of the Cu²⁺ complex. Further, the response of this HAN-Cu²⁺ complex was then examined for different bio analytes. It was found that the complex was highly selective and sensitive to ATP compared to other bio analytes. When ATP was added, the HAN- Cu²⁺ complex exhibited increased absorbance along with a blue shift in the absorption peak, and fluorescence got switched on. The observed results indicate that in the presence of ATP, the HAN- Cu²⁺ complex dissociates and releases the HAN in the solution. The calculated limit of detection is 0.4 μM . The present system is simple, highly selective, and sensitive to ATP. The present system can offer a new flexible method for the logical design of metal complex ensemble-based chemo sensors for the detection of ATP in biological samples.

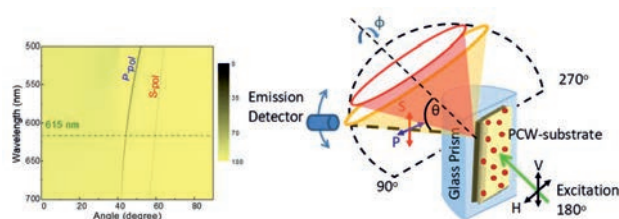
A Novel Fluorescence “Turn-On” Ratiometric Sensor for Creatinine Detection

Kidney disorders require early diagnosis for effective treatment. This study introduces a fluorescence “Turn-On” ratio metric sensor for creatinine detection in aqueous media, with a detection limit of 0.4 μM and linear response region of 0-200 μM . The sensor utilizes Sulphated- β Cyclodextrin and the dye Thioflavin-T, responding to Al³⁺ ions and creatinine to generate a signal. This approach offers advantages like using readily

available dye, improved quantitative accuracy, and compatibility with complex media. The system effectively detected creatinine in artificial urine, suggesting potential benefits for diagnosing kidney disorders.

Controllable Emission Polarization via Plasmon-coupled Waveguide

Plasmon-coupled waveguide (PCW) is an interesting structure that combines plasmons with dielectric waveguides to achieve dual polarization and improved properties of optical modes that are beneficial for fluorescence modulations. For practical applications, it is important to understand the effect of dipole orientations on coupling of radiated power with co-existing orthogonally polarized optical modes present in these substrates. With this objective, a PCW structure composed of a nano meter thick silver film and a dielectric layer was designed and fabricated, to support one S- and one P-polarized waveguide mode. Interesting variations in angular fluorescence intensity distribution patterns of the wave guide coupled emissions were observed with change in wavelength and polarization of excitation light. The results have been interpreted based on creation of highly oriented populations of fluorophores due to photo selection. A parameter, orientation ratio (R), has been defined to quantify the changes in emission with fluorophore concentration. The value of R is found to be positive for collinear and negative for non-collinear excitation/emission transition dipoles. The orientation-based filtering of emission by PCW-substrates is not only of interest for display applications and light emitting devices but can also be useful for deciphering molecular orientations on the substrates.



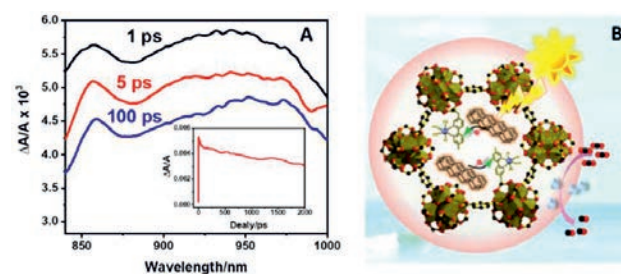
Optical modes in PCW-substrate and orientation-based filtering of the coupled emission.

Femtosecond Transient Spectroscopy Unveils Mechanism of Enhanced Photocatalytic Hydrogen Generation in Molecule-MOF Hybrid

Renewable energy driven hydrogen generation is considered one of the most promising futuristic sustainable and carbon-footprint-free energy landscape. Development of hybrid materials with enhanced solar light absorption and efficient water splitting is long sought for efficient H_2 generation, which relies on favorable charge carrier kinetics. Using femtosecond transient spectroscopy, it is shown that ultrafast (in less than a picosecond timescale) electron transfer from light absorbing Zirconium based MOF (namely UiO66) to covalently appended molecular catalytic centre (namely Cobaloxime) enhances photocatalytic H_2 generation manifold, showing prospect for future development of better catalytic systems for green H_2 generation.

Ultrafast Spectroscopy of the MOF based Photocatalyst for CO_2 Reduction Reaction

Ultrafast spectroscopy was used to understand the photocatalytic reduction of carbon dioxide to carbon monoxide using tetracene encapsulated MOF in water without using any sacrificial agent. Spectroscopic studies show the formation of aggregates of tetracene, which act as photosensitizer in the confined environment of MOF. A Re(I) complex was incorporated inside the MOF for the catalytic conversion of CO_2 to CO. Femtosecond transient absorption studies show that the electron was transferred very fast (<150 fs) from photoexcited aggregated tetracene to Re(I)

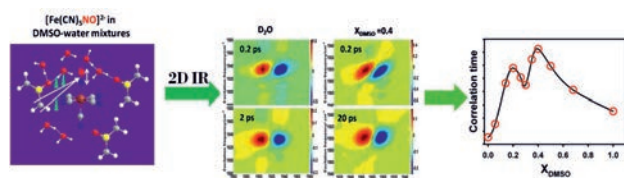


(A) Transient absorption spectra of tetracene encapsulated MOF. Inset shows the decay kinetics of tetracene cation generated due to photoinduced electron transfer to Re(I) complex. (B) Schematic presentation of the catalytic conversion of CO_2 to CO by MOF based photocatalyst.

complex catalyst. The kinetic analysis of the photogenerated tetracene cation radical further confirms the availability of large fraction (>90%) of photogenerated electron for the photocatalysis reaction.

Anomalous Hydration Dynamics in Aqueous DMSO Solution Probed by 2DIR Spectroscopy

The structural dynamics of aqueous DMSO solutions has been investigated using nitrosyl stretch of sodium nitroprusside (SNP) as a local vibrational probe with the help of two-dimensional Infrared (2DIR) spectroscopy. Composition dependent 2D-IR spectroscopy of NO stretch of SNP reveals that the dynamics gets slower in intermediate DMSO concentrations than that of pure DMSO or pure water. A careful analysis reveals two anomalous regions of hydrogen bond dynamics at two different mole fractions of DMSO ($X_{\text{DMSO}} \sim 0.2$ and 0.4) suggesting different hydrogen bonded structures exist in these two regions which can be effectively probed by SNP that remained elusive by previous vibrational probe-based investigations.



2DIR measurements of SNP in D₂O and D₂O-DMSO mixtures with $X_{\text{DMSO}} \sim 0.4$. Variation in the spectral diffusion time measured by 2DIR with X_{DMSO} .

2DIR Spectroscopic Studies on Hydration Dynamics inside Macrocyclic Cavitand

Hydration dynamics inside macrocyclic cavitand, -cyclodextrin has been investigated using 2DIR spectroscopy. Here, we have utilized strong affinity of azido-adamantane (Ad-N₃) towards-cyclodextrin to unravel the dynamics inside cavity. From detailed analysis, 2DIR spectrum of free Ad-N₃ as well as SBE-CD bound Ad-N₃ revealed that the hydration dynamics were slowed down inside the cavity. Molecular dynamics simulations revealed that the residence time of water as well as

hydrogen bond lifetimes were drastically slowed down inside SBE-CD cavity than that of bulk water.

Zr Co-doping-assisted Enhanced Photoluminescence of Y₂Sn₂O₇:Eu Phosphor

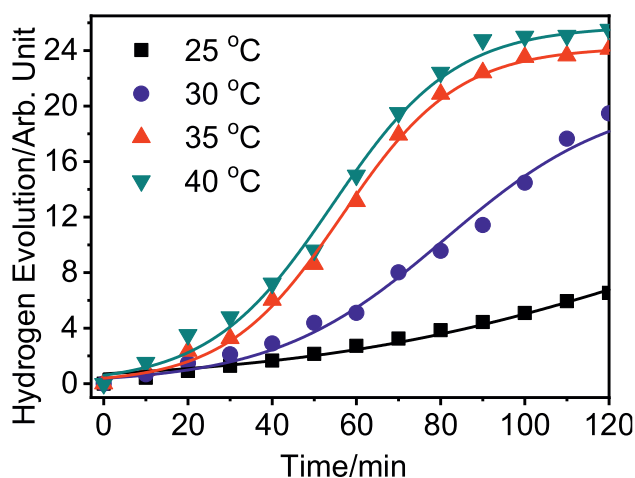
Nano size phosphors are processable and flexible for next stage device packaging, however side effects of their large surface area i.e., range of frustrated coordination, dangling bonds, moisture vicinity declines their phosphor efficiency. Efficiency of Y₂Sn₂O₇:Eu nano phosphor also get decline due to surface effects. Present work shows the revival of suppressed luminescence of Y₂Sn₂O₇:Eu phosphor by Zr⁴⁺ co-doping strategy. Whilst the Y₂Sn₂O₇:Eu nano-phosphor have suppressed lifetime ~ 0.9 ms, the Zr co-doping (Y₂Sn_{2-x}Zr_xO₇:Eu; $x=0.25, 0.5$) leads to five to six fold augmentation in the lifetime values. This multi-fold increase has been attributed to the fact that whereas in Y₂Sn₂O₇:Eu nano-phosphor surface effects mediated non-radiative transition suppress the lifetime values, contrary in Zr-co-dopant sample Eu³⁺ ions prefer to occupy the interior region of nanoparticle and in turn bypass the surface effects.

Development of Catalyst for Ammonia Borane (AB) Hydrolysis

Though ammonia borane (AB) is considered as one of the potential hydrogen storage materials, the effective and economical utilization of AB hydrolysis for efficient hydrogen release encounters hindrances primarily due to unavailability of appropriate catalyst. Novel MOF based catalyst has been developed with superior hydrogen (H₂) production via ammonia borane (AB) hydrolysis with an activation energy of 32.1 kJmol⁻¹. Significant uptake of ammonia by the catalysts promising in safeguarding fuel cells. The developed catalyst serves the dual purpose of sustainable release of hydrogen as well as ammonia capture. Hydrogen release has been demonstrated at room temperature and by varying several experimental parameters. The reaction mechanism involved in AB hydrolysis process has been identified.

Chemical Characterization & Analysis

- ✧ The role of anions on the properties of ferrite films formed on carbon steel through application of Hydrothermal Process in presence of Zn^{2+} and Ni^{2+} salts, was studied in BARC.
- ✧ Ruthenium-selective cerium hydroxide incorporated cross-linked chitosan beads were prepared for large-scale applications in radioactive waste volume reduction processes and studies showed that 95% of Ruthenium from typical active effluent solutions could be removed.
- ✧ Detailed investigation on the scale deposits from the carbon steel pipelines of the recirculating cooling water system of FBTR was carried out through chemical characterization studies to identify the possible reasons for heavy scaling effect.
- ✧ Zirconium Diboride (ZrB_2) Reference Material was prepared through in-house efforts. It is being used for making borated zirconium alloy for use as burnable absorber rods in compact light water reactors.
- ✧ The indigenously processed and purified chemicals of ethylene glycol, N-Methylpyrrolidone, hexamethyldisilazane, tetramethylammonium hydroxide, photo-resist CS600 and ethyl lactate chemicals with applications in semiconductor industry were characterised by GF-AAS for their ultra trace level impurities.
- ✧ A simple and efficient two-step closed microwave-assisted digestion (MWD) method was developed in BARC Quantification of Rare-earth Elements in Granite for Mining Exploration.



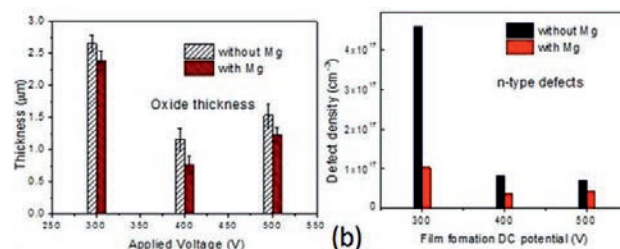
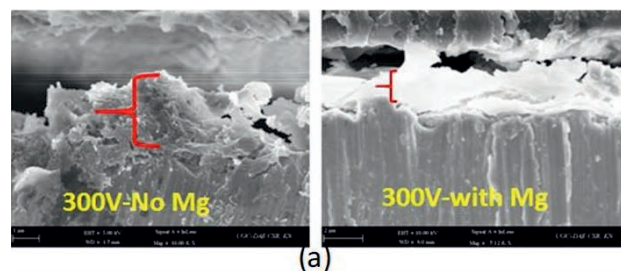
Hydrogen release from ammonia borane under ambient conditions.

Reactor Water Chemistry

Inorganic Additives for Modifying Oxide Growth Rate on Zircaloy-2 under Normal and Breakaway Corrosion Regimes

Plasma electrolytic oxidation was carried out to develop oxide on Zircaloy-2 using different DC potentials (300-500V) in the presence and absence of Mg^{2+} to understand the morphology, protectiveness and semiconducting properties of

the Mg-modified oxide. The compressive stresses in the oxide lead to the stabilization of the tetragonal phase at the metal oxide interface. With increasing film thickness, the stress drops below the level necessary to stabilize the tetragonal phase, converting the tetragonal phase to monoclinic and associated volume changes result in the crack formation near the transition zone. The micro-cracks were reduced in the presence of Mg.



Cross sectional SEM images showing the oxide thickness at (a) 300 V and (b) variation of oxide thickness and n-type defect densities in the film formed on Zircaloy-2 by Plasma electrolytic oxidation process.

Mg is incorporated in ZrO_2 by co-precipitation, forming stable t- ZrO_2 in higher quantities in the films developed in 300 and 400V. The presence of both tetragonal and monoclinic ZrO_2 forms a p-n junction, creating a barrier that impedes the diffusion of oxygen ions across the oxide layer. This, in turn, diminishes the electrolyte diffusion paths, effectively reducing the corrosion rate. In the case of 500V, this beneficial effect of added Mg is negated by the dielectric breakdown of the film at high voltage, resulting in highly porous oxide with inferior corrosion characteristics.

HF-free Chemical Decontamination Process for Zircaloy Surfaces

Chemical decontamination processes are extensively used in nuclear industries to reduce radiation exposure hazards, remove radioactive nuclides from components to reuse and improve waste management practices. Decontamination of zirconium alloys is challenging due to their high resistance to chemical attack from the inherent ZrO_2 oxide layer. Chemical decontamination of Zircaloy-based material is limited to lab-scale or pilot-scale processes with HF or a combination of HF/ HNO_3 chemical formulations. An alkali-based fusion process was developed, which is free from HF. In the alkali fusion process (AFP), zirconium-based samples are fused with alkali and then the fusion melt is dissolved by acids/complexing agents. Alkali melting temperature (AMT) and concentration of dissolving media were optimised. The process was tested on Zircaloy specimens covered with ZrO_2 oxide film (monoclinic phase) prepared by an anodization process. The AFP could dissolve $1\mu\text{m}$ of ZrO_2 on the Zircaloy surface at 300°C .

Analytical Services

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, structural, surface and

thermal properties etc. (3975 samples with 10529 determinations). The materials include metals/alloys, nuclear materials, environmental, biological, archaeological, industrial, and process samples. Suitable analytical techniques were selected based on the analyte, matrix and concentration levels of analytes. Indigenous instruments were also deployed for analytical purposes.



Different materials analyzed in BARC for chemical composition.

Bauxite Certified Reference Material (BARC-B1201) for Aluminium industry

BARC and NALCO have produced an Indian origin bauxite certified reference material (CRM), referred to as BARC-B1201, for the certification of major (Al_2O_3 , Fe_2O_3 , SiO_2 , TiO_2 , loss on ignition - LOI) and trace contents (V_2O_5 , MnO , Cr_2O_3 , MgO). Characterisation was undertaken by strict adherence to ISO Guides (17025 and 17034). A validated analytical method developed at BARC/NCCCM (Chemistry Group) using a single step bauxite dissolution and subsequent quantitation (Al_2O_3 , Fe_2O_3 , SiO_2 , TiO_2 , V_2O_5 , MnO , Cr_2O_3 and MgO) by ICP-AES (SSBD ICP-AES) was used for homogeneity studies and an inter-laboratory comparison exercise (ILCE) of the candidate CRM. LOI was determined by thermo-gravimetric analysis. Property values were assigned after an interlaboratory comparison exercise with the participation of seventeen reputed government and private sector laboratories in India. The CRM was certified for nine property values; Al_2O_3 , Fe_2O_3 , SiO_2 , TiO_2 , V_2O_5 , MnO , Cr_2O_3 , MgO and LOI which are traceable to SI units. This bauxite CRM was released jointly by BARC and NALCO in March, 2023.

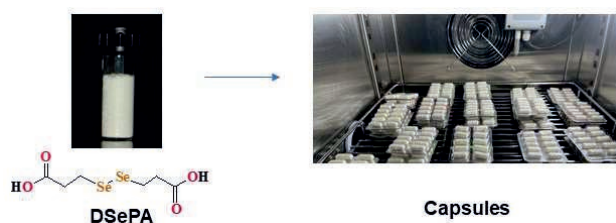


Bauxite Certified Reference Material (BARC-B1201) for Aluminium industry.

Healthcare Materials and Drug Discovery

Organoselenium Compound for Healthcare Applications

A diselenide compound, 3'3'- diselenopropionic acid abbreviated as DSePA has been prepared with API grade purity. About seven batches of 10 g each have been prepared in-house and supplied to Yenepoya Technology Incubation Centre, Mangalore where oral formulation has been made ready in the form of capsules. Some of the batches of DSePA is also being utilized for nasal formulation. The purity of API has been ascertained to >99.8% by LCMS. The oral formulation aimed to facilitate the clinical trial of this potent molecule to prevent & mitigate radiation induced pneumonitis which has been granted by BIRAC-DBT, Govt. of India. The API has previously been extensively investigated under BARC-ACTREC collaboration and it has been revealed that DSePA exhibits the characteristics which are crucial for drug development, as follows. It could be easily administrable oral radioprotector with high bioavailability for use in clinics to prevent radiation induced pneumonitis and fibrosis, it is also a potent



chemotherapeutic and radio-sensitizing agent against lung cancer with minimal toxicity on long-term usage.

Development of ^{68}Ga -labelled Theragnostic Silver (Ag) for Targeting and Diagnosis of *Staphylococcus aureus* Bacterial Infections with SPECT/CT Imaging

The new era of oncology has employed the non-invasive nano-formulations for detection, diagnosis and treatment of diverse cancers including gliomas. Among the various causes, the bacterial species (*Helicobacter*, *Staphylococcus*, *Salmonella*, *Chlamydia* or *Candida* etc.) have been found to be associated with cancerous states. Hence, in oncology research, in recent times, the linking of bacterial infections with diverse malignancies (including gliomas) have been explored which has revealed that such bacterial infections are early indicators of cancers as well as have effect on survival rates and even in some cases lead to enhanced survival in post treatment of glioblastomas. In view of this, to identify and treat the bacteria infections is necessary. In our efforts, we have developed multimodal bio-compatible, non-invasive formulations along with theragnostic utility to evaluate the success of cancer treatment. In this work, we have developed *Staphylococcus aureus* targeting nano-formulations consisting of ^{68}Ga labelled citrate capped Ag or luminescent nanoparticles-based formulations. We have evaluated their stability and biocompatibility at physiological conditions *in-vitro*. Then, these nano-formulations were intravenously injected in Wistar rats induced with infection of *Staphylococcus aureus* bacteria. The test formulations exhibited affinity for bacterial cell membranes and detected the bacterial infections through *in-vivo* SPECT/CT bio-imaging. These test formulations have potential for further pharmacological evaluations.

Surface Modification of Implant Material using Laser

Picosecond laser-induced Hierarchy groove structures on Ti6Al4V bio alloy were found to

improve osseointegration by 5-fold, protein and cell adhesion by 2.5 times. The ceramic coating on this laser micro-structured sample improved the anti-corrosion efficiency by 62%, gave the added benefit of wear debris trapping in the microgrooves thereby restricting their dispersion in the blood stream. A 50% reduction in bacterial growth (*S. Aureus*) on ceramic coated laser micro-structured samples was also observed. The large improvement in the overall functionality of the biomaterial due to laser assisted surface modification calls for replication of the same on real implants and continued studies.

Luminescent Nanocrystals for Photothermal Cancer Therapy and SPECT Imaging

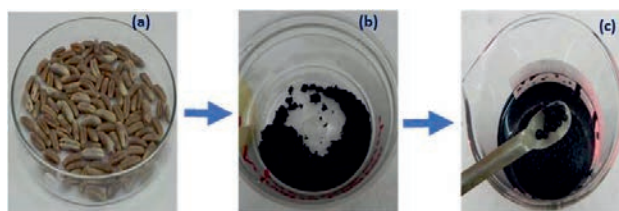
Na^+ co-doped $\text{ZnAl}_2\text{O}_4:\text{Ho}^{3+}, \text{Yb}^{3+}$ up-conversion nanoparticles (UCNPs) with remarkably enhanced up-conversion luminescence (UCL) have demonstrated good cellular up-take, bio/cyto compatibility and anticancer efficacy in C_6 glioma cells. The % cell viability of C_6 cells treated with UCNPs decreased to 46% under 980 nm near infrared (NIR) laser exposure exhibiting an excellent potential in photothermal therapy (PTT). The Na^+ ion co-doping resulted in a significant lowering of zinc vacancies in $\text{ZnAl}_2\text{O}_4:\text{Ho}^{3+}, \text{Yb}^{3+}$, indicating its effective role in eliminating defect-induced non-radiative channels. Intrinsically ($^{166}\text{Holmium}$) radio-labelled $\text{ZnAl}_2\text{O}_4:\text{Yb}^{3+}, ^{166}\text{Ho}^{3+}$, Na^+ have also shown great potential towards *in vivo* single-photon emission computed tomography (SPECT) imaging. It has important applications in Photothermal cancer therapy for Glioblastoma multiforme (GBM)- one the most fatal brain tumor.

Environmental and Separation Science

Sorption of Metal Ions on Activated Carbon impregnated in Ca-Alginate Beads

As different ions like Cu, Fe, Co, Cr, Zn, Cd and Ni are present in the e-waste leached solution in varying concentration ranges, the sorption of those

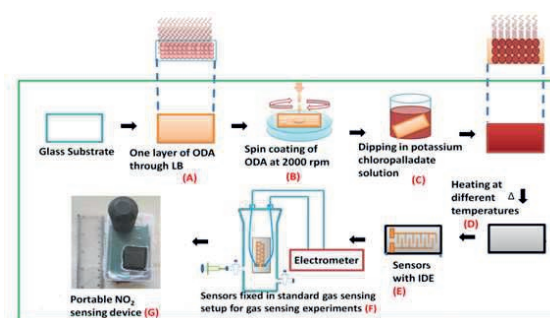
elements on activated carbon-Ca-Alg beads was studied. The uptake of different ions in percentage as a function of the initial concentration of that particular ion was observed. Although at very diluted solutions (initial concentration $\approx 0.1 \text{ mg L}^{-1}$) all the ions show high sorption on the beads with increase in the initial concentration the sorption rates decrease rapidly. Only iron (sorption $> 90\%$) and Chromium (sorption $> 70\%$) shows high sorption values at high concentration values. So, these two interfering ions (Fe, Cr) should be separated from the leached e-waste solution before using AC-Ca-Alg beads for lead recovery.



Photographs of (a) date seeds; (b) synthesized AC; (c) AC-Ca-Alg beads.

NO_2 Gas Sensing and Alert System based on Nanocrystalline Pd-PdO Thin Film

Miniaturized, cost effective, reliable, stable and portable gas sensors are required to detect various toxic gases produced due to increasing industrialization and environmental pollution. PdO thin films deposited on modified glass substrates, calcined at 400°C show sensitivity of 60% and 100% response for 500 ppb and 1 ppm NO_2 at room-temperature. After extensive studies on the time dependent, temperature dependent, humidity dependent sensor response characteristics and other studies such as sensitivity, selectivity, repeatability, stability etc., wearable devices for NO_2 sensing with a home-made sensor circuit of size $8 \text{ cm} \times 5 \text{ cm}$ were fabricated.



Working of NO_2 Gas Sensing and Alert System.

Materials Science

Determination of Effect of Manufacturing Route on Delayed Hydride Cracking Behavior of Zr-2.5 Nb Pressure Tube Material for 220 MWe IPHWR

The Delayed Hydride cracking (DHC) is the one of the sub-critical crack growth mechanisms in Zr-2.5 Nb Pressure tube (PT) material. The PT used in IPHWR220 were earlier manufactured from old route employing hot extrusion to break the cast structure but are now being manufactured by new route employing hot radial forging to break the cast structure. The DHC behavior of the Zr-2.5Nb alloy pressure tubes manufactured by old route and new route was investigated between 125-350°C the yield strength in the temperature range of 250-450°C. The yield strength and DHC velocity (V_{DHC}) of PT manufactured by new route is higher as compared to old route. The DHC is reported to show inversion and crack arrest temperature during cooling as well as heating temperature approaches. The inversion and crack arrest temperature for test temperature being approached by cooling and heating for new route tube were 325°C and 225°C, respectively. For old route tube, the inversion and crack arrest temperature were 325 and 212°C for cooling and heating approach respectively. The activation energy for heating and cooling approach of old route and new route tubes were 26.5 and 47.3 KJ/mol, and 32.6 and 55.1 KJ/mol, respectively.

Effect of Radial Hydrides on Fracture Behavior of Pressure Tube Material

The presence of radial hydrides in Zr-2.5Nb pressure tube (PT) material poses a significant threat, as it substantially degrades the fracture toughness of the PT material. The fracture toughness of Zr-2.5Nb PT material containing radial hydrides with different hydrogen concentrations which are possible during reactor operation in normal and accidental conditions are not available. So, the fracture toughness of Zr-2.5Nb PT material containing radial hydrides with

hydrogen concentrations between 30 and 300wppm was evaluated. The fracture toughness of Zr-2.5Nb PT material containing radial hydrides with different hydrogen concentrations was evaluated between 25 and 300°C covering lower-shelf, transition and upper-shelf temperatures. The fracture toughness vs. temperature curves showed S curve behaviour. In the lower-shelf region, specimens failed in a brittle manner with unstable crack growth, whereas in the upper-shelf region, specimens showed ductile fracture with stable crack growth. The S curve shifted to higher temperatures with hydrogen concentration, with saturation of lower-shelf, transition and upper-shelf temperatures between 100 and 300wppm. In lower-shelf region, the fracture toughness is also affected by hydrogen concentration. Operating the reactor with 100wppm and higher hydrogen concentrations is not advisable due to reduced pressure margins at 250°C. Additionally, cold pressurization is not recommended for hydrogen concentrations exceeding 30wppm.

Hydrogen Embrittlement Studies of VVER-RPV Steel using in-situ Electrochemical Charging Technique

Reactor pressure vessel (RPV) of pressurized water reactor tends to be exposed to hydrogen during service through radiolysis of coolant water and local corrosion reactions. The lack of incontrovertible proof that the austenitic clad can altogether prevent the hydrogen to reach and degrade the underlying ferritic vessel as a result of long-term use under radiation, provides strong reasons to study the basic manifestation of hydrogen embrittlement (HE) in low alloy steels for RPV applications. The combined action of coolant pressure, temperature and radiation during service are expected to increase the probability for HE of the RPV steel which is of concern for long term safety.

Development of Cr₂AlC MAX-Phase Coating on Zircaloy-4 for Accident Tolerant Fuel Clad Application

Cr₂AlC MAX-phase is a promising candidate material for high temperature oxidation resistant

coatings on to Zr-based clad for accident tolerant fuel (ATF) cladding applications due to its several unique properties such as low neutron absorption cross-section, high thermal conductivity, oxidation resistance at high temperature due to formation of protective Al_2O_3 layer under steam environment. Cr_2AlC MAX-phase also acts as barrier for hydrogen diffusion, thus limiting the hydride formation and expected to enhance the fuel cladding performance. Thus, Cr_2AlC MAX-phase coatings on to Zr-alloys based cladding should offer improved performance during both normal as well as accidental conditions of nuclear reactors.

X-ray Scatterer Component for POLIX Instrument of ISRO's XPoSat Mission

X-ray scatterer component made of light metal was required for its use in POLIX payload developed by Raman Research Institute, Bengaluru. The POLIX payload is part of X-ray Polarimeter Satellite (XPoSat) launched by ISRO for the measurement of polarimetry parameters of cosmic X-ray sources in medium energy range of 8-30 keV. The scatterer disc of 332 mm dia x 34 mm height was fabricated by powder metallurgy route followed by precision machining to the required dimensions.

Demonstration of High Temperature Steam Electrolysis Process

Steady performance of single tubular HTSE cell has been demonstrated for more than 150 hours at 800°C generating hydrogen @4 Nlph. Degradation of glass/ceramic sealant and metallic end connectors under the HTSE operating condition have been found to be the limiting factors for long term operation. Work has been taken up to develop these materials indigenously.

Development of Pt-loaded Alumina Ceramic Foam for use as Catalyst in I-S process of Hydrogen Production

Alumina ceramic foam has been chosen as the support for loading of Pt which acts as a catalyst for HI decomposition in Iodine-Sulphur (I-S) thermochemical cycle for green hydrogen production. Polymeric sponge replication based novel process has been developed to prepare

alumina ceramic foam. In order to increase the surface area of the α -alumina based macro-porous support it is coated with γ -alumina. For Pt loading the ceramic foam is impregnated with an aqueous solution of platinum salt followed by heat treatment resulting in formation of nanoparticles of catalytically active platinum phase. The ceramic foam catalyst thus developed has 83-85% porosity and about 35 m^2/gm specific surface area. The prepared catalyst has shown HI decomposition yield close to equilibrium. The developed Pt loaded alumina foam catalyst has been used in the closed loop I-S process in Chemical Technology Division, BARC and 150 Nlph of hydrogen production has been demonstrated. The foam catalyst remained in shape after operation.

Development of Carbon Nanotube Sheet for Sensor Application

Self-standing carbon nanotube sheets (CNT sheets) comprising self-assembled 3-D network of long CNTs was produced by floating catalyst chemical vapor deposition (FCCVD) process. CNT chips were prepared from these sheets as sensors. In gas sensing application, the CNT chip sensor excels in detecting volatile organic compounds (VOCs) in ppb level. The bio-sensor using CNT chip is capable of detecting DNA hybridization, facilitated by a quantifiable change in electrochemical impedance achieving a remarkable limit of detection of 1 pM and a rapid turnaround time of less than 20 minutes.



Self-assembled CNT sheet (inset SEM image).



CNT chip.



CNT based VOC sensing device.

Advanced Material Studies

- ✧ Lead silicate glass (LG_18) of composition (wt.%) $7.5\text{BaO}-55\text{PbO}-10\text{K}_2\text{O}-22.5\text{SiO}_2-2.5\text{B}_2\text{O}_3-2.5\text{Bi}_2\text{O}_3$ was prepared for desired application in radiation shielding window.
- ✧ The low temperature eutectic phase between Al_2O_3 - Y_2O_3 around yttria alumina garnet (YAG) composition was explored to join SiC components.
- ✧ Nanoscale Phase Transformation Studies were done in thermally-aged structural materials using APT & SANS Fe-1.4 Cu-1.4 Ni model alloy.
- ✧ Detailed atom probe analyses were performed on thermally aged (at 400°C) duplex stainless steel (DSS) samples to probe the effect of long-term aging on the ferrite phase at near-atomic scale.

Development of Isotropic High-density Graphite

A new technology has been adopted in which mesocarbon microbeads (MCMBs) were used as starting material and converted into high density graphite in a single cycle of heat-treatment after isostatic compaction without any further impregnation. Graphite cylinders of 75 mm diameter and 150 mm length having density more than 1.85 g/cc with isotropy ratio of 1.02 were prepared by this process.

Technology for Production of Cerium-doped LED Phosphor

Cerium doped yttrium aluminium garnet (YAG:Ce) is widely used phosphor in white light emitting diodes (LED) due to low electric consumption, high brightness and long lifetime. Development of energy efficient technology for the production of YAG:Ce using indigenous raw materials is important. The traditionally used solid-phase method has shortcomings such as high synthesis temperature, longer reaction time, larger and hard

particles. To overcome these, the method of Co-precipitation was adopted and YAG:Ce phosphor was successfully prepared at 250g/batch scale with good quantum efficiency suitable for LED application. Technology has been transferred to IREL for pilot plant demonstration at RETTP, Bhopal.

SLSR based Electrical Heating System on Anhydrous HF Cylinder

An SLSR based cylinder heating system was designed to ensure complete evaporation of AHF before entering HF feeding line. Application of the system showed a marked improvement in flow measurement and control of AHF stream. The system brings many benefits to the process by decreasing the number of equipment (Doser is eliminated) and their associated maintenance. Accurate monitoring and control of AHF ensures higher process efficiency and improved optimization of effluent management.

Computation and Modelling

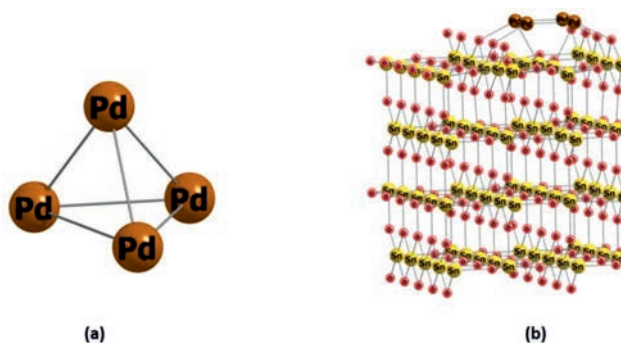
Support-induced Dimensionality Change in Pd Cluster

The chemical properties of small metal clusters on the substrate/support have a significant influence on catalytic reactions by supplying charges, adsorption sites, and new reaction paths. Motivated by this, Density Functional Theory (DFT) calculations have been carried out to predict geometry, electronic structure, and energetics of Pd_n cluster on SnO_2 on $\text{SnO}_2(110)$ surface/support.



YAG: Ce phosphor.

Surprisingly, whilst the isolated Pd_4 adopts a tetrahedral structure, deposition of this cluster on SnO_2 (110) support leads to change the structure to flat and square geometry. The change in dimensionality also leads to significant change in its electronic structure. Subsequently other Pd_n clusters of higher size ($n=5-10$) grow inside the surface channel of bridging oxygen atoms as they all have the Pd-O bonds with the vertically out bridging oxygen on either edge of cluster. The observed growth pattern endorses the pivotal role of surface channel of bridging oxygen atoms in growth of Pd_n cluster on SnO_2 (110) surface. Based on structure property correlation one expects the drastic change in physico-chemical properties of this catalytic cluster.



Structural transformation of isolated Pd_4 cluster upon interaction with SnO_2 (110) substrate.

Thermal Properties of U & U-Zr Alloy Fuel

Recently, a renewed interest has grown to include metallic uranium alloying with zirconium (U-Zr) as fuel in low power reactors and fast breeder reactors due to high burn-up ability, excellent neutron economy and also due to the capability of incorporation of the long-lived minor actinides. In this work, first principles-based calculations are performed on metallic U and U-Zr alloy structures using density functional theory-based calculations. The volume (per formula unit) of α U108 structure from our DFT+U calculations is 20.85 \AA^3 , which is matching with previous experimental and DFT calculations. Similarly, the volume for U-Zr alloy is 21.35 \AA^3 from our calculations. The DFT calculations with Zr in α -U shows that volume is increasing compared to pure α -U lattice. The specific heat

capacity at constant pressure (C_p) calculated for metallic uranium is matching with experimental measurements. The C_p values obtained for U-Zr (10 at%) alloy shows slight decrease compared to α -U at temperatures above 100K.

Development of ELECTROSim-AWE Module of ANUSim Software

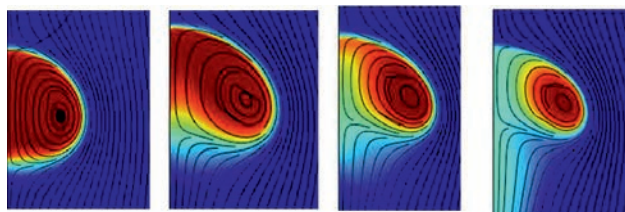
A new module of ANUSim named as ELECTROSim-AWE was developed to predict two-phase flow distribution in stack of Alkaline Water Electrolysers of different geometries. The coding for the module was done in python. AGUI was also developed to ensure ease of use of the module by the end-users.

Modelling of Two-phase Flow in the Electrolyser used in Electrolysis Step of Cu-Cl Cycle

3D CFD two-phase model was developed to study two-phase flow in a typical electrolyser used in Cu-Cl cycle. Validation was done with experimentally measured values of pressure drop. Validated model was used to evaluate different scale-up approaches and the most suitable scale-up approach was identified.

Modelling of Solvent Extraction Equipment and Underlying Phenomena

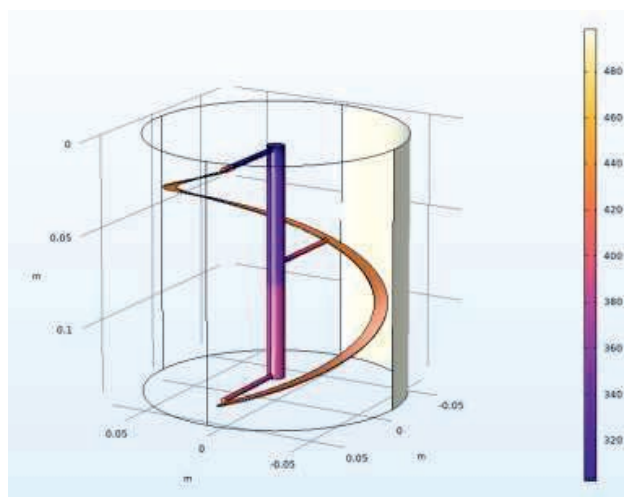
In a work relevant to solvent extraction, the most commonly used separation process in nuclear fuel cycle, an Arbitrary Lagrangian Eulerian (ALE) method based CFD model which can predict shape and mass transfer rate from a drop rising or falling at terminal settling velocity was developed. Model can predict drop shape, terminal settling velocity of the drop and mass transfer coefficient. Model was validated for its capability to predict droplet shape, terminal settling velocity and mass transfer rate using literature data. Validated model was used for parametric analysis to understand the effect of droplet size, physical properties (continuous and dispersed phase viscosities and densities, interfacial tension) on Sherwood number.



Concentration profiles and flow streamlines during mass transfer from a deformable drop rising with terminal settling velocity.

CFD Modelling to Estimate Heat Transfer Coefficient in a Vessel Equipped with Helical Ribbon Impeller

In a work relevant to designing polymerization reactor, a 3D CFD based model was developed to predict heat transfer coefficient in a vessel equipped with a helical ribbon impeller. Unsteady state simulations were carried out to determine the evolution of temperature at the centre of the vessel for a given wall temperature. Heat transfer coefficient values obtained from CFD were compared with values obtained from the correlation reported in literature for different impeller speeds (130, 145 and 160 RPM). The match between the two sets of values was quite good with average absolute relative deviation of ~ 4.32%.

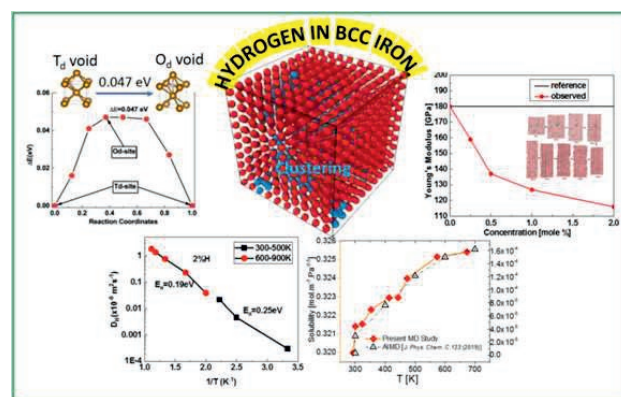


Surface contour of temperature for cylindrical vessel equipped with a helical ribbon impeller at 100 RPM rotational speed of the impeller.

Understanding the Adsorption, Diffusion and Solubility of Hydrogen in BCC Iron

MD studies were performed for fundamental understanding about concentration and temperature dependent adsorption, diffusion and solubility of hydrogen in BCC iron, evaluation of

which is essential to predict the leakage and embrittlement of hydrogen in separation of hydrogen and isotopes as well as hydrogen storage application. The interaction between atoms was performed using Modified Embedded-Atom Method (MEAM) potential. Nudge Elastic Band (NEB) calculations report the T_d void as the most preferred position of hydrogen within Fe lattice. Energy barrier of 0.047 eV was estimated for diffusion of hydrogen from one tetrahedral site to adjacent tetrahedral site via octahedral site. Further, results reported the reduced elastic strength of iron (measured with Young's Modulus) by 35.25% while increasing H concentration from zero to 2%. The diminishing strength of iron with hydrogen addition was also supported by the decreasing cohesive energy (by 1.18% while increasing H concentration from zero to 2%). The results show increasing solubility of hydrogen in iron increasing system temperature as observed from experimental studies. On average, adsorption of 1.25 hydrogen atom per Fe atom was noted, which is in good agreement with theoretical and experimental assumption.



Adsorption, diffusion, clustering and solubility of hydrogen atoms in BCC iron matrix, and its impact on the mechanical strength of BCC iron structure.

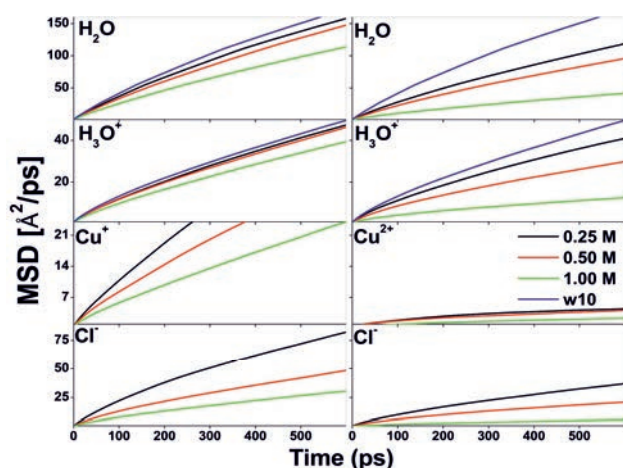
Transport and Interaction of H_3O^+ through Nafion Membrane in Cu-Cl Electrolyzer

Considering the daunting competition of H_3O^+ with Cu^+/Cu^{2+} ions to migrate through electrolyte chamber of Nafion membrane during electrolysis step used in Cu-Cl cycle, the deprotonated nafion membrane with 10% hydration level was simulated in presence of Cu^+/Cu^{2+} ions, with copper concentration varied as 0.25 M, 0.50 M, and 1.00M

Density Functional Theory Studies

- ✱ The structures of CuCl, CuCl₂, CuO, Cu₂OCl₂ were optimized using AIMD simulations. The calculated lattice parameters were compared with literature values and found to be in good agreement with the experimental values.
- ✱ A database on dissolution enthalpy, diffusion, permeation and solubility of hydrogen isotopes in Fe, Cr, W and Ti using atomistic simulation was completed.

(as per concentration copper ion concentration in Cu-Cl electrolyzer). Different set of studies were performed for monovalent and divalent Cu⁺/Cu⁺⁺ ions. The addition of Cu⁺ and Cu²⁺ ions lead to increase in density of system due to increase in number of ionic moieties. The density of system was estimated to be higher in presence of Cu⁺⁺ ions than that of Cu⁺. Further, attributed to the increasing participation of water molecules for hydration of the copper ions, the average hydrogen bonding among water molecules was reduced. S-Oh interactions are greatly reduced while addition of Cu⁺/Cu⁺⁺ ions as expected. However, reducing pairs of S-Oh as well as S-Cu with increasing copper concentration reflects that reduced interaction of Nafion SO₃⁻ group with hydronium ion (while increasing copper ion concentration) is not due to competition with copper ions but happens because of preferential ion pairing of H₃O⁺/Cu⁺/Cu⁺⁺ with chloride ions. Nevertheless, the results reflect the preferential uptake of hydronium ions over Cu ions by Nafion SO₃⁻ group. Also, it was found that more Cu⁺⁺ ions are aggregated in the peripheral of nafion than that of Cu⁺ ions due to higher electrostatic interaction.



Data representing density and mobility of component species as a function of Cu⁺/Cu⁺⁺ concentration.

Radiochemistry

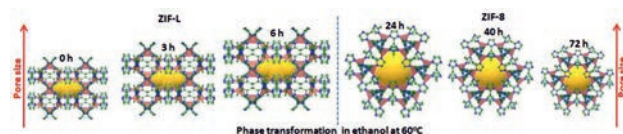
Stabilization of Tetravalent Uranium in Aqueous Medium under Aerobic Conditions

Uranium is stable in hexavalent state. Complexation studies of uranium and neptunium in their different oxidation states were carried out with a pyridine diphosphonate ligand at variable pH using absorption, luminescence and vibrational spectroscopic studies. Cyclic voltammetry studies were carried out in order to understand the role of this ligand in the redox behavior of these two 'f' block elements. The results indicated higher stabilization of U and Np in their tetra and hexavalent states as compared to the pentavalent one in presence of this ligand which leads to the disproportionation of these metal ions. This effect is more pronounced as the pH is decreased. U⁴⁺, therefore, could be stabilized for months in the open atmosphere at pH2 in the presence of this ligand. Such a high stability of U⁴⁺ complex of this ligand is supported using DFT calculations.

Tunable Pore Architecture and Morphology Studies on Metal-Organic Frameworks

Pore architecture and flexibility of the Zeolitic imidazolate frameworks (ZIF-8) have been fine-tuned through ligand mixing, metal mixing and phase transformation methodologies. The modifications in the pore architecture and flexibility have been quantitatively determined using positron annihilation spectroscopy measurements carried out under vacuum as well as under different gas pressures. Through these systematic studies, it has been established that ZIF-8 with tunable pore architecture can be prepared

through phase transformation of ZIF-L in environmental benign solvents.



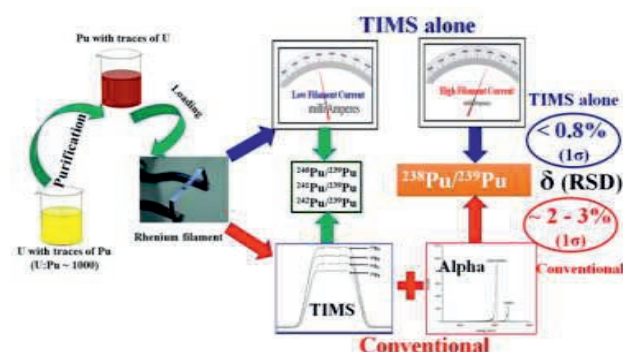
Phase transformation of ZIF-L to ZIF-8 investigated using positron annihilation spectroscopy.

Non-Destructive Assay of Actinide-bearing Samples of Non-standard Geometry

Absolute non-destructive assay of Pu and other actinides in samples of non-standard geometry, unknown chemical form and density is seen as a major challenge. By addressing the challenges associated with the efficiency calibration and attenuation, a rapid assay methodology exclusively based on high resolution gamma-ray spectrometry was developed in BARC. The method is highly versatile and can be used, in addition to nuclear fuel cycle, in areas such as nuclear forensics and security.

Isotopic Composition Analysis by TIMS & LAMIS

A rapid and reliable method based on membrane pre-concentration was developed for determining $^{238}\text{Pu}/^{239}\text{Pu}$ ratio by Thermal Ionization Mass Spectrometry. A Calibration free Laser Ablation Molecular Isotopic Spectrometry (LAMIS) technique was developed with an accuracy and precision of <3 % for the prediction of ^{10}B content.



Phase transformation of ZIF-L to ZIF-8 investigated using positron annihilation spectroscopy.

Methods for Separation of Lanthanide Fission Products

An electrochemical method devoid of any organic additives and amenable to remote handling was developed for recovery of Pu and U from aqueous acidic waste solution. A high-performance liquid chromatography (HPLC) method based on extraction chromatography was developed for the separation of lanthanide fission products, uranium and plutonium from irradiated fuel samples.



Electrochemical method scheme for Recovery of U and Pu.

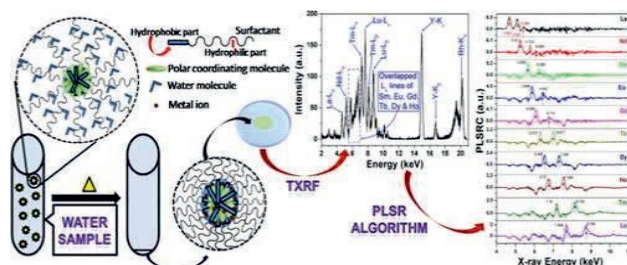
Actinide Extraction and Analysis

A novel Deep Eutectic Solvent (DES) was synthesised and explored for the extraction of actinides such as UO_2^{2+} , Pu^{4+} and Am^{3+} from nitric acid medium. An ultra-trace analytical method based on Total Reflection X-ray Fluorescence (TXRF) was developed for simultaneous determination of Lanthanides. A methodology based on Laser Induced Breakdown Spectroscopy was developed for the determination of U and Th in $\text{UF}_4\text{-ThF}_4\text{-LiF}$ MSR salt using chemometric calibration approach.

Cloud Point Extraction of Lanthanides

A novel cloud point extraction assisted TXRF analysis of ten lanthanides at ultra-trace levels was established. N,N,N',N'-tetraoctyldiglycolamide in triton X-114 micelles was found to offer a selective cloud point extraction of all of the lanthanides in the presence of higher concentrations of naturally abundant cations and anions. A multivariate partial least-squares regression (PLSR) calibration approach was preferred due to the highly-complex overlapped spectra of L lines of the lanthanides in TXRF. Ten lanthanides were simultaneously determined by this method, having concentrations in the range from 10 to $5 \times 10^3 \mu\text{g L}^{-1}$ with an RSD of less than 10%. The complete analysis procedure is

schematically represented in Fig. 7. The proposed method was validated by analyzing three certified reference materials viz., 'NASS-7' seawater, 'SRLS-6' river water and 'NIST 1640a' natural water.



Cloud point assisted extraction of lanthanides followed by their determination using TXRF.

Ion Chromatography Methods for Separation

An ion chromatography method was developed for the separation of Hf and Zr for their analytical determination in high acidic medium. A simple spectrophotometric method for the determination of boron in borated Zr-Nb alloy using methylene blue was proposed whereas for ultra-trace level concentration of boron in uranium matrices, a high sensitivity method was developed using time resolved fluorescence. With a view to separate lanthanides in a lanthanide matrix, temperature dependent mechanism of separation with different stationary phases has been investigated. Determination of sulphur and phosphorus in TiO_2 was accomplished using ion chromatography.

Studies on Sorption and Migration of Cs(I) and Am(III)

Sorption behavior of Cs(I) and Am(III) on Vindhyan clays has been extensively studied. Adsorption of anionic long lived fission products such as Se-79 on hematite was investigated for the solid varying reactivity under morphological changes. Surface complexation modelling was done for explaining the binding of the metal bearing species to the clay material.

Diffusion of D and H Gases in Zircaloy

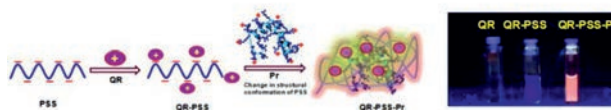
For better life time management of zirconium based nuclear structural materials, the diffusion coefficients of D/H have been determined under several conditions. The effect of grain size on

diffusion of D was studied. For this purpose, virgin zircaloy-4 clad tube material was annealed at 1073 K for different time intervals to increase the grain size. One end of these sample pieces was charged with deuterium by electrochemical method and then annealed at 623 K for 100 h for its diffusion. D profile was determined employing hot vacuum extraction-quadrupole mass spectrometer technique. Preliminary results show that D_H value was decreasing with increasing grain size of zircaloy.

Biology

Development of Fluorescent Supramolecular Architectures for Bio-analyte Sensing

Several supramolecular architectures that display significant change in fluorescence as a function of concentration of the bio-analytes has been developed in BARC. This has been exploited to detect bio-analytes, including spermine, milkallergen, ATP and protamine down to nanomolar (nM) level not only in aqueous medium but also in real bio-fluids (milk matrix, urine, serum). It is considered to be a good match to other methods like Capillary Electrophoresis, HPLC, Mass Spectrometry, SDS-PAGE Analysis etc. Moreover, high reproducibility, high throughput, simple operation, low cost etc. make fluorescence-based detection probes a highly attractive choice. Efforts are underway in BARC to develop a tabletop instrument based on this technique.

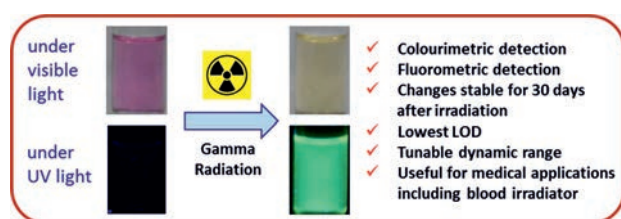


Fluorescent Supramolecular Architectures for Bio-analyte Sensing.

Development of BODIPY based Highly Sensitive Fluorescent Dosimeter for Low dose -radiation

Accurate measurement of low dose gamma (γ) radiation is highly important to avoid any damage to human being and the materials used for exposure. We have developed highly sensitive fluorescent dosimeters based on BODIPY dyes. In

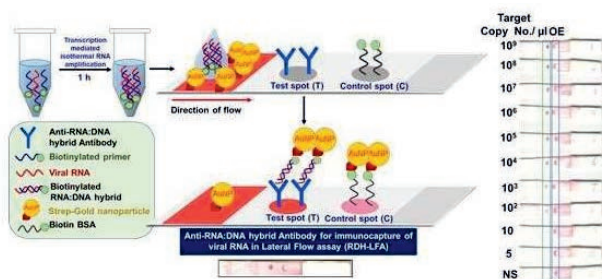
one case, 8-(N,N-dimethylanilino) BODIPY were used to develop a ratio metric "off-on" fluorescence γ -dosimeter applicable in the range of 0.5–150 Gy with limit of detection (LOD) of 0.5 Gy. This dosimeter will be useful for absorbed dose measurement in food irradiation processes (sprouting inhibition). In another approach, amino-BODIPY dye-based fluorescent -dosimeter is developed which showed ratio metric change in absorbance and "off-on" fluorescence under very low dose -exposure in chloroform. The -dosimeter has extremely low LOD (0.001 Gy). Thus, the dosimeter will be useful for measuring accurate -doses in radiodiagnosis and therapy. The dynamic range of the dosimeter can be tuned by changing the dye concentration. The dosimeter with 57.0 mM dye is capable of colorimetric and fluorometric measurement of -doses in blood irradiation.



BODIPY based highly sensitive fluorescent dosimeter for low dose γ -radiation

Sensitive Detection System for Viral RNA

A method employing anti-RNA:DNA hybrid (anti-RDH) antibody-based biosensor for visual,

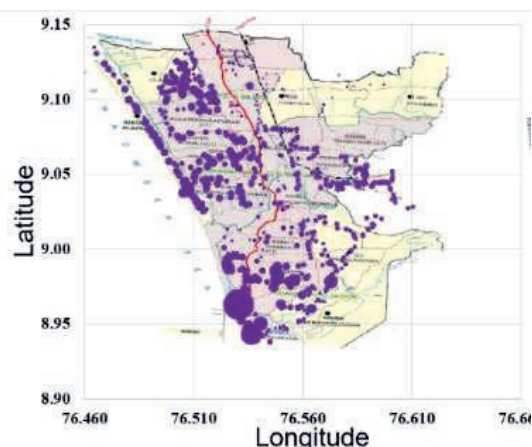


Viral RNA detection using RNA:DNA hybrid immunocapture based lateral flow assay.

colorimetric lateral flow assay (RDH-LFA) for viral RNA detection was developed. RDH-LFA exploits the high affinity and specificity of anti-RDH antibody for immunocapture of RNA in lateral flow assay. This method is sensitive (LoD:10 copies/ μ l), specific, isothermal, user-friendly, and can be used at the point of care without sophisticated instrumentation. This technique can also be used for detection of cancer RNA biomarkers.

Development of Android App for Applications in Radiation Dosimetry and Health Records

Digitization of natural background radiation dose in relation to human health was completed in Karunagapally Taluk of Kollam, Kerala. An Android App was developed by BARC for integration of health records and radiation dose. Relative gamma radiation dose (violet circles) at different geographical coordinates (Longitude and Latitude) in Karunagapally taluk represent high level natural radiation. Highest recorded gamma radiation dose was 173mGy per year. High background radiation did not increase DNA strand breaks. The high background natural radiation did not reduce human life-span in the population residing in Kollam, Kerala.



Relative gamma radiation dose (violet circles) at different geographical coordinates (Longitude and Latitude) in Karunagapally taluk.

Advanced Biological Studies

- ✧ A new class of dual emissive dyes based on β -carboline boron complexes were designed and synthesized as part of ongoing studies to understand their Electroluminescence property for unlocking potential applications in organic light emitting diodes (OLEDs).
- ✧ Lyophilized *Chryseobacterium* cells immobilized in Ca alginate beads and polyacrylamide gel were deployed to understand their ability to remove Uranium via phosphatase mediated uranium precipitation from aqueous solutions.
- ✧ DNA repair mechanisms in bacteria were studied through a comparative phosphoproteomic analysis of Ndk overexpressing *Nostoc* 7120 (Anndk+) and vector control (AnpAM).
- ✧ Oxidative Stress Tolerance in Cyanobacteria towards selenium was studied.
- ✧ Studies were taken up to understand the role played by Bromodomain-containing Proteins in Plants, initially among 80 plant species.
- ✧ Comprehensive Analysis of the Evolution of Mutations in the SARS-CoV-2 Genome. The clinical variants of 14 million SARS-CoV-2 sequences available until December 2022 were deployed in the analysis.
- ✧ Biochemical and biophysical studies were carried out to develop crystallographic insights into SARS-CoV-2 Papain-like Protease (PLpro) for drug development.
- ✧ Nucleocapsid Phosphoprotein Inhibitors and their Binding Characterization was identified for development of new molecules for potential therapeutics.
- ✧ Work on developing a new CRISPR-based method for detection of mpox virus was initiated.
- ✧ A CRISPR-based gene silencing method was developed and was used to screen essential genes in *Mycobacterium* with a view to recognize novel drug targets for mycobacterial infections.
- ✧ A simple, rapid and cost-effective protocol with minimal hands-on time was developed for cfDNA extraction from cell conditioned media.
- ✧ A method for determining the T_m of proteins using the supramolecular interaction between Quinaldine Red (QR) and proteins was demonstrated.

Advanced Radiopharmaceuticals

Laser-based Isotopic Enrichment of Lu-176 and Yb-176

Efforts in isotope enrichment of Lu-176 activity were expanded further to enhance the production of highly enriched (>85%) Lutetium-176 isotope from its natural abundance of ~2.6% by using laser-based isotope separation route. Presently, routine production capacity of 4mg/month has been achieved and maintained since last six months. Lutetium-177 based radiopharmaceuticals produced from enriched Lutetium-176 isotope after neutron irradiation are being administered across several hospitals in India. A modular atomic

vapour source, made using compatible container materials, for requisite atom density and Doppler width and with clog free operation of its nozzle emanating vapour was developed and



Enriched Lu-176 and Yb-176.

characterized for laser based isotopic enrichment of Ytterbium-176. It consists of linearly adjoining two vapour sources of 200mm each. The desired isotopic enrichment of Yb-176 >95% at a rate of around 7 mg/h was achieved from natural abundance of Ytterbium-176 at ~13%. The modularity of the vapour generator is useful for linear scaling-up of facility.

Yield of ^{99}Mo from $^{100}\text{Mo}(\gamma, n)^{99}\text{Mo}$ reaction using LINAC

A lab-scale experimental study was carried out to explore the option of production of ^{99}Mo using $^{100}\text{Mo}(\gamma, n)^{99}\text{Mo}$ reaction. For this purpose, a sample of MoF_6 was irradiated in a 15 MeV clinical electron LINAC. The gamma activity induced in the irradiated sample was found to be 3.23 $\mu\text{Ci}/\text{gram}$ using activation method with gamma spectroscopy by High Purity Germanium Detector (HPGe).



15 MeV clinical electron LINAC.
Photo courtesy of Varian (<https://www.varian.com/products/radiotherapy>)

Solid-Phase Synthesis of HER2-targeting Peptidomimetics for Breast Cancer

Three different combinations of A9 peptide (QDVNTAVAW), namely (i) *retro*-A9 [WAVATNVDQ, with reversed peptide sequence of L-amino acids], (ii) *inverso*-A9 [QDVNTAVAW, L-amino acids replaced with D-amino acids], and (iii) *retro-inverso*-A9 [WAVATNVDQ, reverse sequence of D-amino acids] were synthesized and radiolabelled with ^{177}Lu for targeting HER2-receptors (over-expressed in breast cancer). Pre-clinical evaluation demonstrated ^{177}Lu -labeled *retro*-A9 peptideto be the most promising compound as it exhibited high tumor uptake and retention therein along with good metabolic stability.

Limited Clinical Evaluation of ^{177}Lu -Trastuzumab in Breast Cancer Patients

The clinical evaluation of in-house formulated ^{177}Lu -Trastuzumab has been initiated in breast cancer patients expressing HER-2 (Human Epidermal Growth Factor Receptor 2) receptors in collaboration with JIPMER, Puducherry. Post-therapy whole-body scans revealed accumulation of ^{177}Lu -Trastuzumab in the metastatic lesions indicating the potential of the agent for targeted radionuclide therapy of breast cancer over-expressing HER-2 receptors.

Development of ^{99m}Tc -HYNIC-Duramycin as Infection Imaging Agent

Duramycin, an antimicrobial peptide was conjugated with HYNIC and radiolabelled with ^{99m}Tc for targeting phosphatidyl-ethanolamine (PE) lipid found in the bacterial membranes (*E. coli*) for infection imaging. Bacterial binding studies carried out with ^{99m}Tc -HYNIC-Duramycin showed specific uptake of the agent only in *E. coli* cells. SPECT imaging and biodistribution studies in animal model confirmed uptake of the tracer in *E. coli* induced infection showing potential of ^{99m}Tc -HYNIC-Duramycin as an infection imaging agent.

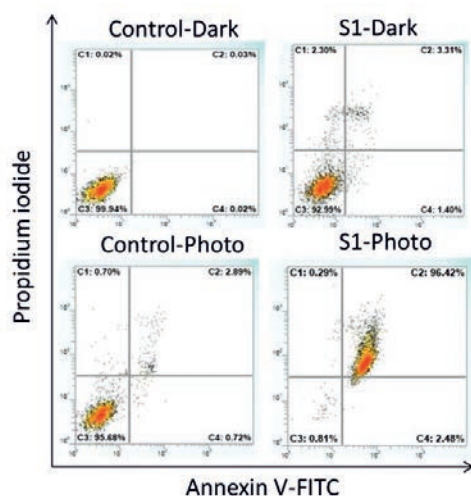
Cancer Studies

Singlet Oxygen Species Generation and Apoptotic Cell Death in Breast Cancer Cells

Near IR absorbing curcuminoid- BF_2 derivatives are known to produce reactive oxygen species and hence can be used as photosensitizer in photodynamic therapy. Initially, to increase their solubility and cellular uptake their nanoaggregates were prepared and encapsulated with Pluronic F127. The lung (A549) and breast (MCF-7) cancer cells were treated with 0-25 μM of Curcuminoid BF_2 chelate nano formulation for 5-6 hrs followed by light exposure (~650 nm) for 20-25 mins. The dark cell toxicity was found to be almost zero, whereas the IC_{50} values of light induced cytotoxicity was found to be $12.29 \pm 1.02 \mu\text{M}$ and $14.85 \pm 2.02 \mu\text{M}$ for MCF-7 and A549 cells, respectively. The cells were

also investigated for reactive oxygen species formation by using redox sensitive dye DCFDA.

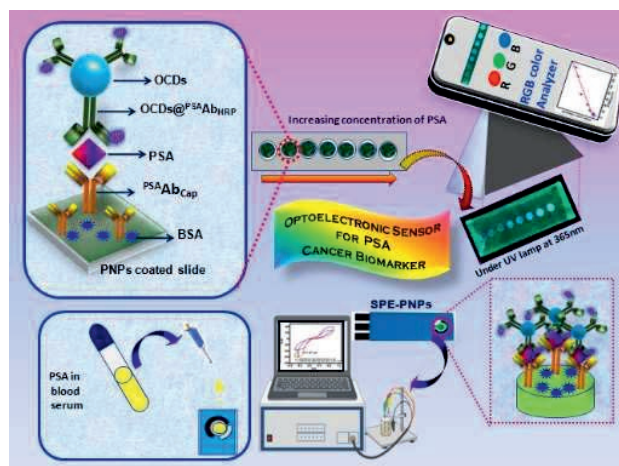
Cells treated with Curcuminoid BF₂ and exposed to 650 nm light showed generation of reactive oxygen species as compared with cells exposed to just light and cells treated with Curcuminoid BF₂ but not exposed to light. Furthermore, the annexin V/PI apoptosis assay was performed to confirm the cell death was occurring through apoptosis induction and not through necrosis of cells.



Apoptosis assay of Curcuminoid-BF₂ derivative under dark and light exposure.

Bio-conjugated Carbon Dots for Bimodal Detection of Prostate Cancer Biomarker via Sandwich Fluorescence and Electrochemical Immunoassay

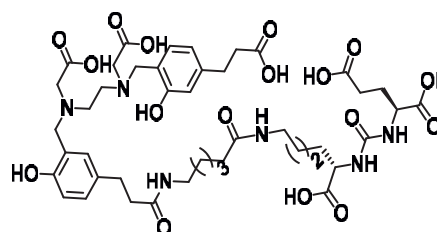
Bimodal detection facilitates accurate and reliable detection of cancer biomarker which can assist in early diagnosis of cancer. Sulphur doped and blue emissive carbon dots were synthesized by the hydrothermal method. The carbon dots were conjugated with antibody to design a nanoprobe for detection of Prostate Specific Antigen (PSA), a blood serum based prostate cancer biomarker. The detection probe enabled bimodal assay of PSA via fluorescence and electrochemical immunoassay. Paper based and smartphone integrated fluorescence immuno-array developed using the detection probe provided cost-effective and rapid detection, while the electrochemical immunoassay provided high sensitivity and low detection limit for PSA detection.



Bi modal (fluorescence and electrochemical) sandwich immunoassay for detection of prostate specific antigen in human blood serum.

RPC Approval for Radiopharmaceutical Ligand PSMA-11

PSMA-11 is used as a radiopharmaceutical ligand for diagnosis of prostate cancer. This year, after submission of required data, the DAE-RPC has approved the clinical use of in-house synthesized PSMA-11 for preparation of ⁶⁸Ga-PSMA-11 radiopharmaceutical kit. This will benefit a large number of prostate cancer patients nationwide. The kit will be launched by BRIT for supply in pan India.

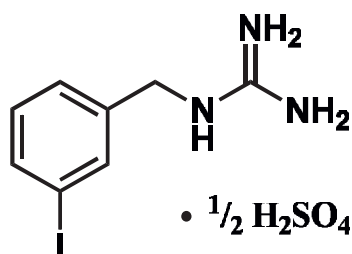


Chemical structure of PSMA-11.

Synthesis of m-Iodobenzyl guanidine (mIBG) hemisulfate

mIBGhemisulfate, a guanithidineanalog, labelled with either ¹²³I or ¹³¹I, is used for imaging and therapy of neuroblastomas and various neural crest tumours like paragangliomas, pheochromocytomas, medullary cancer of thyroid and carcinoids. This is a costly API and is imported in India. Last year, synthetic protocol was developed for in-house synthesis of mIBGhemisulfate, and was delivered to BRIT for radiolabelling studies. The radiolabelling studies were completed, and the in-house developed ligand showed comparable radiolabelling with that

of imported ligand. Next, we have synthesized 6 different batches of the ligand using the indigenous process, and have delivered to BRIT for further preclinical studies.



Chemical structure of mIBG hemisulfate.

AKTOCYTE Tablets for Pelvic Cancer Patients

The AKTOCYTE tablets showed remarkable results in pelvic cancer patients suffering from radiotherapy-induced Cystitis (Blood in urine). Patients treated with AKTOCYTE demonstrated an extraordinary recovery, eliminating the need for surgical removal of the urinary bladder. The tablets, designed as an adjuvant to cancer radiotherapy, regenerative nutraceutical, immunomodulator, and antioxidant, mark a significant advancement in cancer care. This product has been developed in collaboration with Tata Memorial Centre, Mumbai.



AKTOCYTE tablets of 750 mg, 500 mg and 100 mg.

Release of Sanjeevani Medicinal Rice

Sanjeevani Rice was shown to boost immune responses against bacteria and for removal of dead cells. Sanjeevani Brown rice contains more than 350 different phytochemicals. Many of these phytochemicals are known to improve immunity, kill cancer cells and enhance antioxidant / detoxification responses and rejuvenation. This rice was released by state variety release committee of Chhattisgarh. The rice products, including *Sanjeevani Kalka* were launched by

Honourable Vice President of India for human consumption.



Sanjeevani rice preparation-Kalka.

Clobetasol Propionate Sensitizes Human Lung Cancer cells to Radiation-induced Killing

Clobetasol Propionate (CP) exhibited potent radiosensitization in human lung cancer cells via inhibition of Nrf-2, leading to increased reactive oxygen species. Gene expression analysis revealed significant modulation of pathways related to ferroptosis. Pretreatment of cells with CP followed by exposure to radiation resulted in ferroptotic death. CP induced iron release, mitochondrial ROS, and lipid peroxidation, indicating ferroptosis induction when combined with radiation. Interestingly, Nrf-2 overexpressing A549 cells were refractory to CP mediated ferroptosis induction and radiosensitization.

Ferroptosis in Anti-cancer Efficacy of Targeted Magneto-liposomes (T-LMD) in Triple Negative Breast Cancer (TNBC) Models

T-LMD showed higher anti-cancer efficacy in TNBC cell lines (MDAMB-231, MDAMB-468 and 4T1) and human xenograft mice model of MDAMB-231 as compared to commercial liposomal nano-drug (Lippod™). The ferroptosis nano-inducer (T-LMD) comprises of a liposome with oleic acid (OA) coated iron oxide nanoparticles (IONPs) and doxorubicin (DOX) co-encapsulated in the membrane and core of the liposomes, respectively. This design integrates the reactive oxygen species (ROS) generation ability due to presence of un-saturated fatty acid (OA) and IONPs; as well as DNA intercalation and ROS generation ability of DOX in a tumor-specific nano-vehicle. Moreover, the strategic placement of IONPs in the liposome bilayer facilitates the sensitization of MDAMB-231

Design of new cancer therapies for ensuring affordable Healthcare

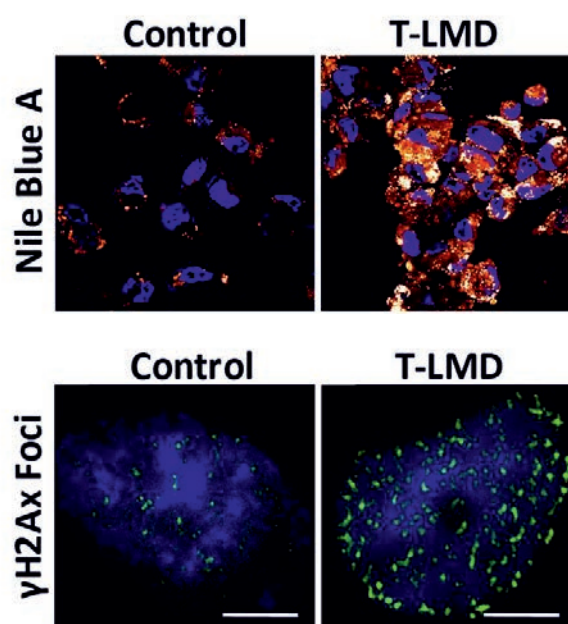
- ✧ Heavy atom-free Triplet Photosensitizers were designed and synthesized for potential applications in photodynamic therapy of cancer.
- ✧ Using liquid biopsy approach, blood samples of NET patients and healthy volunteers were collected and the transcriptome sequencing was performed in pursuit of bio-markers identification in neuroendocrine tumors.
- ✧ Radio resistance in cancer cells was studied extensively. Bystander A549 cells and bystander 5F-A549 cells showed higher cell survival as compared to their respective control A549 cells.
- ✧ Transcriptomic studies of Thorium-induced carcinogenesis in mice liver were taken up. The long-term effects (6 and 12 months) of Th-232 (4, 10 and 20 mg/kg) have been investigated on gene expression in mice liver (major target organ) after intravenous administration.
- ✧ The role of dendritic cells in anti-tumor effects of EP2/4 antagonists was studied. Treatment of 4T1 breast cancer bearing mice with EP2 antagonist PF04217329 and EP4 antagonist MK2894 significantly decreased the tumor burden.
- ✧ A new class of MOF nanoplateforms which will be useful for assigning newer drugs for use in Chemo Dynamic Therapy were identified based on performance evaluation studies of copper-based metal organic frameworks.
- ✧ Activities on synthesis of m-Iodobenzyl Guanidine (mIBG)-conjugated Doxorubicin as targeted chemotherapeutics were taken up during the year.
- ✧ Synthesis of a series of polyphenolic diarylpropenoids linked with alkyl-TPP cation having varied alkyl chain length had been accomplished.

cells to ferroptosis activation predominantly via iron/lipid metabolism and NRF2-Keap1 pathway accompanied by LPO and ROS generation resulting in release of LDH and HMGB1, mitochondrial fusion and enhanced DNA double strand breaks.

Signaling Underlying in Tunneling Nanotubes Formation in Breast Cancer Cells

Tunneling Nanotubes (TNTs) are intercellular bridges between cancer cells to promote growth, invasion and therapy resistance in cancer. Secreted proteins from macrophage conditioned medium (MΦCM) induced TNT formation in breast cancer (MCF-7) cells which led to increased resistance to chemotherapy drug doxorubicin. MΦCM treated MCF-7 cells showed enrichment of NFκB and focal adhesion pathway as well as upregulation of genes involved in cancer progression, extracellular remodeling and actin cytoskeleton reorganization. Inhibition of PKC, Src, NFκB and p38 inhibited macrophage induced TNT formation in MCF-7 cells. These results reveal novel role of PKC and Src in

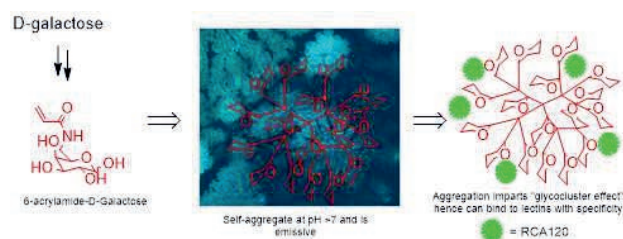
inducing TNT formation in cancer cells and suggest that inhibition of PKC and Src activity may likely contribute to reduced macrophage-breast cancer cell interaction and potential therapeutic strategy of cancer.



Internalization of T-LMD in MDAMB-231 cells as visualized by Nile blue A staining and (B) Visualization of γH2Ax foci in MDAMB-231 cells after treatment T-LMD at 24 h.

Synthesis of GalactoAcrylamide for Targeting Liver Cancer

In order to achieve galactoacrylamide for the sequestration and for study of carbohydrate binding proteins, a new sugar-based acrylamide, 6-*N*-acrylamido-D-galactopyranose, was synthesized from D-galactose in six steps. Fractal type assembly formed in the solution of Gal-acryl diffusion limited aggregation was used to study specific interaction with lectin RCA120 using fluorescence-based method. The fluorescence quenching studies with FITC-RCA120 afforded the K_a value as $6.34 \times 10^5 \text{ M}^{-1}$, which is much higher than K_a values observed for small galactose derivatives. This study is aimed towards the development of glycomaterials that could find applications in drug delivery, bio-sensing, tissue engineering, and as ligands to asialoglycoprotein receptors that are exclusively expressed by liver cancer cells.



Formation of fractal and its interaction with lectin RCA-120.

Mega Science & International Collaboration

Indian Institutes and Fermi Lab Collaboration Activities

As a part of Indian Institutes and Fermi Lab Collaboration activities, several new and advanced technologies for high-intensity proton accelerators are being developed at multiple centres of DAE, including in BARC, RRCAT and VECC. BARC, in particular, plays a pivotal role in a diverse array of technical areas, encompassing Spoke Cavities, 325 MHz Solid State RadioFrequency (RF) Amplifiers, 325 and 650 MHz RF Power Couplers, Cryogenic Systems, Magnets (Warm and Superconducting), Low Level RF (LLRF), Resonance Control (RCS) and RF Protection Interlock (RFPI) systems. Also, work on manufacturing of several components of Single Spoke Resonator (SSR) cavities and its tuner is currently under progress in BARC.



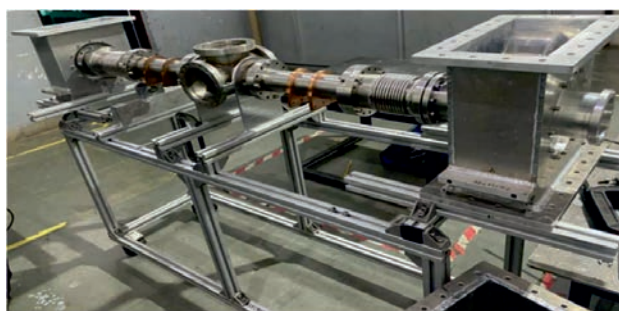
Formation of fractal and its interaction with lectin RCA-120.

Solid State Amplifier (SSA) 20 kW, 325 MHz

The Final Design Review (FDR) of the 20 kW, 325 MHz solid-state amplifier system had been successfully completed by an international team of experts from CERN, SLAC, Fermilab (FNAL), and DAE laboratories.

RF Couplers

Two RF power couplers, operating at 325 MHz and 650 MHz, are currently in the development phase. All components have been machined, and two 650 MHz RF couplers have been assembled on a test bench at the vendor's site. The testing of these couplers is currently under progress.



650 MHz RF couplers.

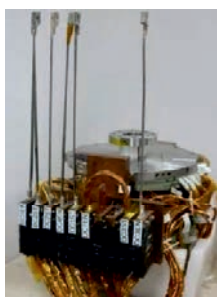
Cryogenic System

A cryogenic plant providing refrigeration in excess of 2000 W at 2K for superconducting cavities of accelerator is being delivered as in-kind contribution under IIFC collaboration. Final Design Review (FDR) and Production Readiness Review (PRR) have been completed along with few component inspection visits at vendor and sub-vendor locations. Fabrication of the cryogenic plant

cold box components such as sub-cooler heat exchanger, vertical heat exchanger, horizontal heat exchanger battery, 2 K phase separator vessel and cold box vacuum vessel are completed at vendor site.

Magnets (Cold & Warm)

First pre-series conduction cooled magnet assembly was successfully test up to the magnetic field of 7 T and an integral field of $4.5 \text{ T}^2\text{m}$ and were delivered to FNAL, USA. The final set of warm quadrupoles and corrector magnets for 650 MHz cryomodule were delivered to FNAL, USA.



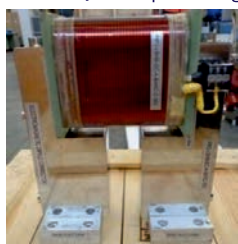
Pre-series Conduction cooled Superconducting lens for spoke resonator cryomodule.



Test stand for cryogenic testing of superconducting magnet assembly.



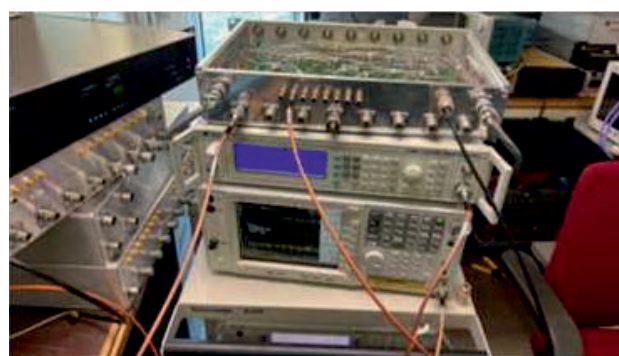
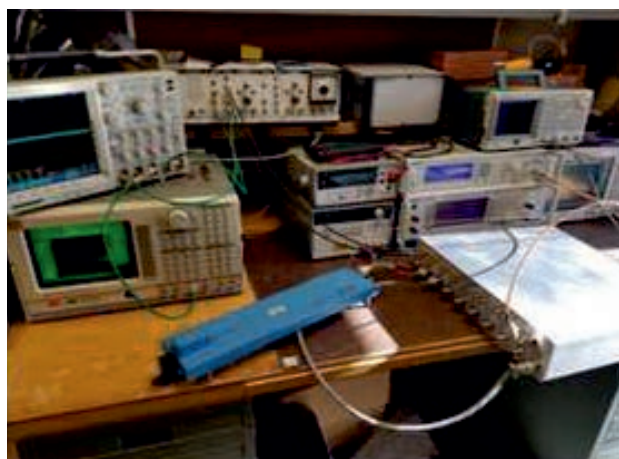
HB/LB 650 Quadrupole magnet.



HB/LB 650 Dipole corrector magnet.

LLRF, RCS and RFPI

LLRF control system with RCS and RFPI system are essential elements for the efficient and smooth operation of the accelerator and its protection. The LLRF system for SSR cavities at 325 MHz as well as elliptical cavities at 650 MHz, RCS with advanced features, and RFPI systems underwent indigenous development and testing on the Horizontal Test Stand (HTS) at RRCAT in Indore. Following successful testing in Indore, two RFPI systems and an LLRF System, along with RCS systems, were delivered to FNAL in the USA. Currently, testing is underway at FNAL. These systems can be tailored for use in Indiana ccelerator program.

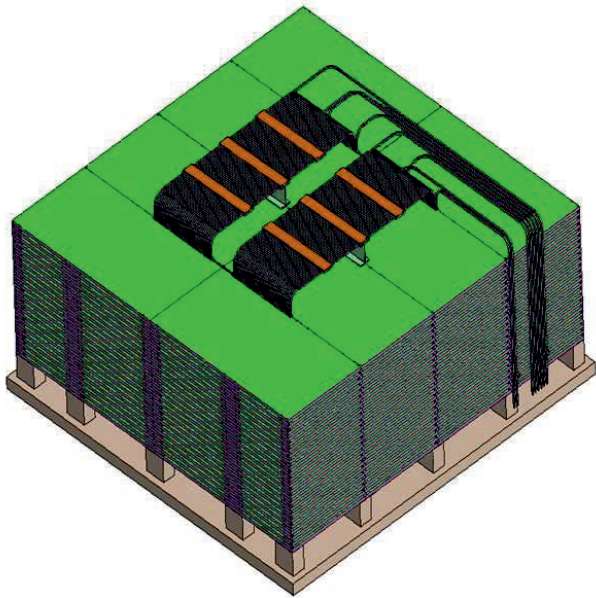


Testing of LLRF, RCS and RFPI at FNAL.

Copper Coil Components for E-ICAL Magnet of INO Project

The Indian Neutrino Observatory (INO) project is a mega science project aimed at constructing an underground laboratory to study the fundamental particle called neutrino. For this, an Engineering Iron Calorimeter (E-ICAL) of size $8\text{m} \times 8\text{m} \times 3.1\text{m}$ size weighing 700-ton and equipped with 23 soft iron layers was planned for establishing

engineering and manufacturing aspects. The copper coil components for the E-ICAL magnet were fabricated after unwinding from spool followed by de-twisting, straightening, forming and machining activities.



Graphical representation of Engineering Iron Calorimeter Magnet.

Quarter Wave Resonator for Superconducting LINAC

Niobium-based superconducting Quarter Wave Resonator is being developed for the BARC-TIFR superconducting LINAC. This requires manufacture of intricate shaped components and sequentially welding them using Electron Beam Process. A prototype of this using Stainless Steel Quarter Wave Resonator was fabricated in BARC.



Stainless Steel Quarter Wave Resonator.



HUMAN RESOURCES, SCIENTIFIC INFORMATION AND TECHNOLOGY MANAGEMENT

BARC appoints scientific and technical manpower for its pan-India facilities through a carefully crafted testing process wherein selected candidates, mostly fresh graduate engineers, and masters from university systems are subjected to a rigorous program of training at its well equipped Training School facility in Mumbai. BARC houses a large treasure of scientific literature which is stored in physical as well as in digital form to meet the requirements of the centre. Understanding the growing desire among users to increasingly access information virtually, it is continuously implementing new state-of-art technologies to ensure seamless access to first-hand high quality scientific data. To boost entrepreneurial zeal among the young generation, BARC has expanded its technology incubation infrastructure at its Mumbai campus and is also offering a wide gamut of technologies for mass production.



Shri Shaktikanta Das, Governor, RBI visited BARC in 2023. He presided over Graduation Function-2023 event as the chief guest. Dr. Ajit Kumar Mohanty, Chairman, AEC and Secretary, DAE is seen next to him.

Human Resources, Scientific Information and Technology Management

Human Resources

BARC Training School

Dr. Homi J. Bhabha strongly professed that in order to achieve self-reliance in the nuclear energy sector, it is imperative for the country to build a sustained pool of highly skilled human resources from the ranks of talented workforce readily available within the country. In line with this philosophy, Dr. Bhabha had conceptualized the creation of Training School system in DAE, and the first training school was established in 1957, as a centre of excellence for training of professionals through in-house efforts. Over the years, close to 9500 well-rounded individuals graduated from the training schools with flying colors.

Recruitment

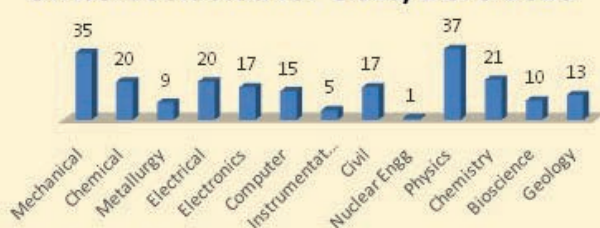
The Human Resources Development Division (HRDD) of BARC provides highly skilled human resources to DAE through two flagship programs, OCES (Orientation Course for Engineering graduates and Science Postgraduates) and DGFS (DAE Graduate Fellowship Scheme). The linkage of BARC Training School programs with Homi Bhabha National Institute (HBNI) ensures continuous availability of professionally qualified, well trained and motivated scientific and technical manpower for induction into various DAE units.

A total of 87 graduating TSOs of 66th batch of OCES/DGFS-2022 (62 engineering + 9 physics + 6 chemistry + 10 RSES), after successful completion

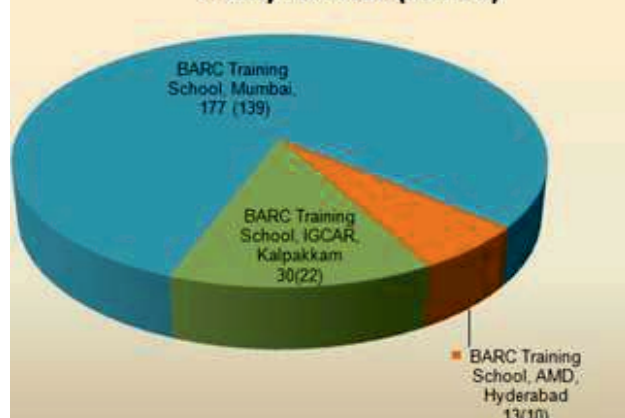
of training, were placed in various units of DAE. There were 7 Trainee Defence Officers, who passed out with this batch and were assigned to different Divisions/Units for undertaking project for M. Tech. In addition, 4 NTPC officers, 2 ECIL and 9 IPR trainees completed their training in the OCES-2022 Batch.

While the academic programme of the 66th batch was underway, screening examination for 9 engineering and 4 science disciplines for the 67th batch was organized successfully at 123 venues in 49 cities. The number of applicants for OCES/DGFS-2023 was 64,447 as compared to 85,586 in the previous year. Of them, 41,873 candidates appeared in the online examination as compared to 44,744 in the previous year. A total of 220 candidates (139 Engineering, 37 Physics, 21 Chemistry, 10 Bioscience, 13 Geology) were selected for OCES/DGFS-2023 as compared to 187 last year. Out of selected 220 OCES candidates, ten candidates were absorbed in DGFS-2023 programme at IIT Bombay and IIT Madras. The groundwork for recruitment for OCES/DGFS-24 (68th Batch) began in November-December, 2023

Discipline-wise Trainee Scientific Officers Selected for OCES/DGFS-2023



OCES/DGFS-2023 Number of candidates finally selected (Joined)



with the preparation of advertisement to be published in the last week of December, 2023. Efforts are already underway to popularize DAE recruitment, including OCES/DGFS-2024 programme.

141 candidates were shortlisted for interview under the DAE Doctoral Fellowship Scheme (DDFS). 1,165 applications were received from interested individuals for securing a position in the scheme. Of the 30 selected candidates, 25 candidates joined in various DAE units (BARC-16; IGCAR-2 & IPR-7).

43 candidates (OCES Batch 2018: 6; OCES Batch 2019: 9; OCES Batch 2020: 28) have submitted their thesis as part of their regular M. Tech during 2023. HRDD, BARC coordinates for organizing a 1–2-month duration practical training program and also offers 3–12-month duration academic projects in BARC for students of B.E. / B. Tech / M. Tech / M.E. / M. Sc / MCA / JRF / SRF from all over the country. During the year, close to 2000 applications were received (till date) and 1600 of them have been approved for admission in these short-term training programs. The QUEST programme under DAE's Continuing Education Programme (CEP) is conducted by HRDD. During the year, it offered courses on Process Modelling, Simulation and Optimization and Reliability Engineering for PhD students and also DAE employees. HRDD has adhered to the Right to Information Act, 2005. And till date, HRDD has received 200 RTI queries related to OCES Recruitment and related activities. All queries have been addressed satisfactorily and no queries are pending as on date.

Up-skilling of Scientific and Technical Manpower

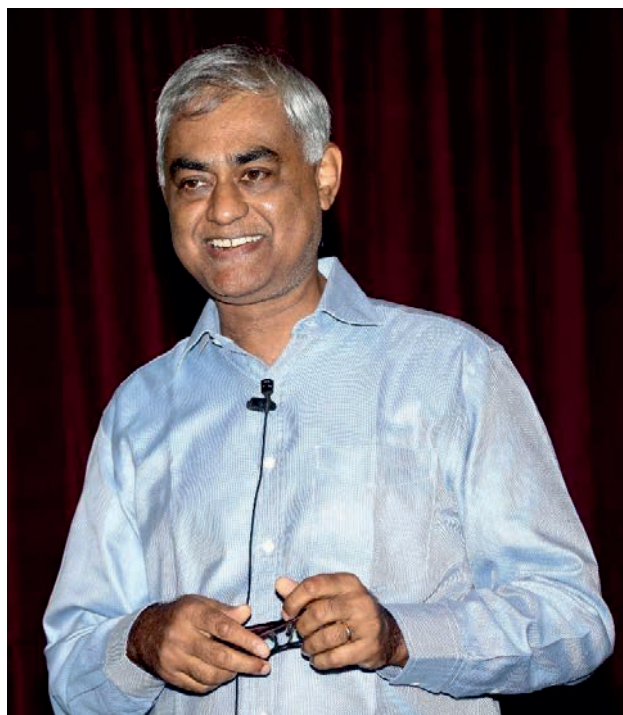
During the year, BARC conducted various training courses and certification programs on radiation safety in medical, industrial and research applications of radiation sources for societal benefits. Under this, it offered a one-year Post M.Sc. Diploma course during the year. A training programme was organized for the personnel from National Disaster Response Force, and defence

establishments of India. These courses are mandatory as per AERB /BSC regulations. About 50 training/certification courses were also conducted. About 2000 candidates participated and 1200 of them were certified.

Scientific Information Resources

Trombay Colloquium

BARC organizes Trombay Colloquium for the benefit of its scientific community. Under this format, eminent individuals belonging to wide spectrum of science & technology and allied domains visit BARC to deliver captivating talks on emerging trends in science and their transformative effect on technology landscape. During the year, Prof. Vidita A. Vaidya, Prof. Sandip Trivedi and Prof. Jayaram N. Chengalur of TIFR; Prof. Naba K. Mondal and Prof. Gautam Bhattacharyya of SINP, Kolkata; Dr. N. Kalaiselvi, Director General of CSIR and Dr. Raghunath A. Mashelkar, Former Director General, CSIR; Ambassador Mr. Syed Akbaruddin visited BARC to deliver enriching talks in their areas of expertise. Mr. Rafael M. Grossi, Director General of Vienna-headquartered International Atomic Energy

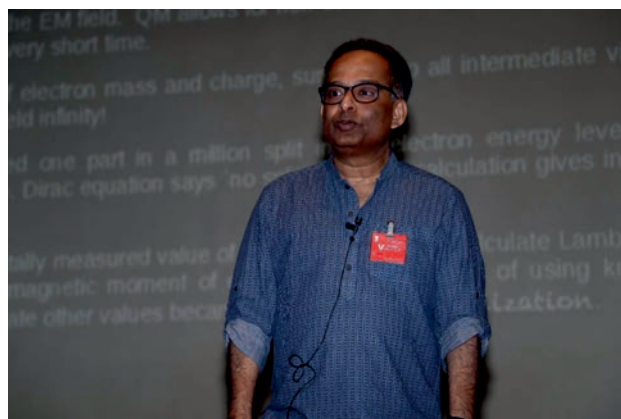


Prof. Sandip Trivedi, Distinguished Professor, TIFR delivering a talk entitled *The Entanglement Frontier* at Trombay Colloquium on January 19, 2023.

Agency (IAEA) delivered a special talk entitled *In the footsteps of Homi Bhabha: The IAEA, India & life-affirming journey of nuclear energy and science* at the Trombay Colloquium during his India visit in October 2023.



Ambassador Mr. Syed Akbaruddin, Dean of Kautilya School of Public Policy, shares pleasantries with Dr. Ajit Kumar Mohanty, Chairman AEC and Secretary, DAE during his visit to BARC on March 30, 2023 to deliver a highly captivating Trombay Colloquium talk entitled *India on the Global Stage*.



Prof. Gautam Bhattacharyya, Director, Saha Institute of Nuclear Physics, Kolkata delivered a Trombay Colloquium talk entitled *A brief ancestral history of the Higgs boson* on April 20, 2023.



Prof. Vidita Vaidya of Department of Biological Sciences, TIFR presented a Trombay Colloquium talk on the subject *Serotonergic Psychedelics: 'Mushroom' for Discussion* on May 31, 2023.



Dr. N. Kalaiselvi, Director General, CSIR delivered a talk at Trombay Colloquium on the topic *Energy Management: Indian Perspectives* on June 12, 2023.



Prof. Jayaram N. Chengalur, Director, TIFR delivered a Trombay Colloquium talk entitled *Studying Galaxy Evolution with the GMRT* on October 5, 2023.



Prof. Naba K. Mondal, INSA Senior Scientist, SINP delivered a Trombay Colloquium talk entitled *From Cosmic Rays to Neutrinos – History of Experimental Particle Physics Research in India* on July 27, 2023.



Mr. Rafael M. Grossi, Director General of Vienna-headquartered International Atomic Energy Agency (IAEA) delivered a special Trombay Colloquium talk entitled *In the footsteps of Homi Bhabha: The IAEA, India & life-affirming journey of nuclear energy and science during his India visit* in October.



Dr. Raghunath A. Mashelkar, Former Director General, CSIR presented a Trombay Colloquium talk entitled *Doing and Leading Science in India – Lessons from my Book of Life* on August 24, 2023.



Dr. Ajit Sapre, Group President (R&D), Reliance Industries Ltd. receiving memento from Shri Vivek Bhasin, Director, BARC. Dr. Sapre delivered a Trombay Colloquium talk on the theme *Economy, Energy, Ecology & AI – Some Thoughts* on November 23, 2023.

Chintan Baithak

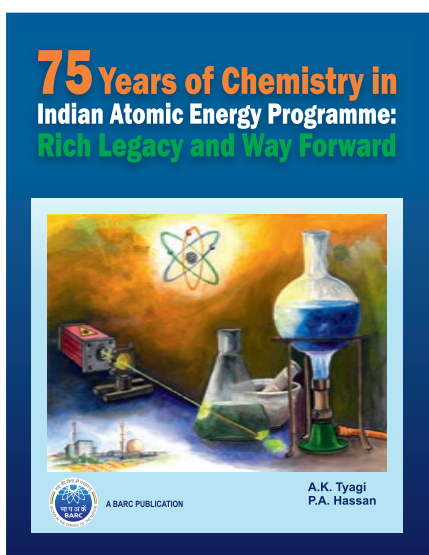
A unique platform for brainstorming science and technology activities in BARC, Chintan Baithak is designed to facilitate a stimulating atmosphere for sustained candid discussions among the BARC scientific community for ensuring tangible outcomes on several ongoing R&D activities in the centre in the sphere of atomic energy. Under this format, three rounds of discussions have already taken place and the areas covered during the year 2023 include Hydrogen energy activities, crystal technologies, and futuristic reactor systems and associated technologies.

Remote Access to Information Resources & Archiving

The Home Office Anywhere (HoOA) facility provided secured remote access to important information resources to BARC users. More than 100 individuals have registered for availing this service during the year. Digitization of printed copies of proceedings of BRNS conferences was carried out during the year. Activities on archiving of very old information resources were continued.

Book Publication

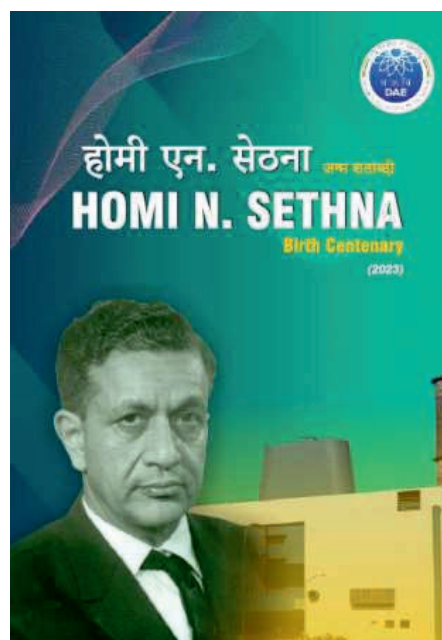
BARC has chronicled the historical journey of chemistry activities in the overall scheme of atomic energy program in India and this information was curated and published in a new ISBN recognized book entitled *75 years of Chemistry in Indian Atomic Energy: A Rich Legacy and Way Forward*. Around



284 books were added to BARC Central Library book collection during the year. The existing collection of Hindi books was augmented by procuring new books on interesting and popular subjects. Special display of Hindi books was organized during October, 2023 as part of efforts to popularize Hindi implementation among BARC staff.

Birth Centenary Event

BARC, DAE Secretariat and several other constituent units of the department have joined hands to organize a one-day event on December 7th to commemorate the birth centenary of India's atomic energy stalwart Dr. Homi Nusserwanji Sethna. A special commemorative volume and a memoir on the pioneering contributions of Dr. Sethna to India's atomic energy program during his tenure in DAE had been officially released during the event. A short film showcasing major accomplishments in the life and professional career of Dr. Sethna was also screened at the one-day event. Dr. Sethna served as the Chairman of AEC (1972-83) for the second longest tenure after Dr. Homi J. Bhabha.



Reports

The glimpses of scientific and technological R&D activities carried out in BARC during the calendar year 2022 were compiled and published in the annual report VISTA-2022. Internal, External and Restricted

reports were prepared and published during the year. These reports comprised specific scientific and technology outcomes of R&D work in BARC.

Newsletter, Web Digest, Information Bulletins, and Foreign Language Services

Six issues of BARC newsletter on important and interesting themes, with articles mostly on scientific research and technology development activities in BARC, were published during the year. These pertain to latest R&D developments associated with Health, Safety & Environment, Applications of Computational Fluid Dynamics in Chemical Engineering, Materials Science & Safety, Founder's Day Special Issue, and Crystal Technologies. News coverage of prominent developments in nuclear energy domain in popular media networks and other related sources were collated and published regularly in the weekly Nuclear News Web Digest. More than 48 issues of the Digest were published during the year. Scientific Information Bulletins were published throughout the year. Foreign language interpretation services were also provided to meet the desired requirement.



Journals and Allied Activities

BARC Central Library subscribed to more than 436 journals in electronic form and up to 50 print-based journals besides popular magazines. e-journal gateway J-Gate+ and paid journals repository Lakshya were updated regularly. New standards,

databases and codes were acquired or renewed to meet the desired requirement. As part of BARC's commitment to maintaining of highest ethical standards in its scientific publications, 1043 research articles, 114 PhD/M.Tech theses, 82 book chapters and 133 conference papers were screened for the originality of research work prior to their publications.

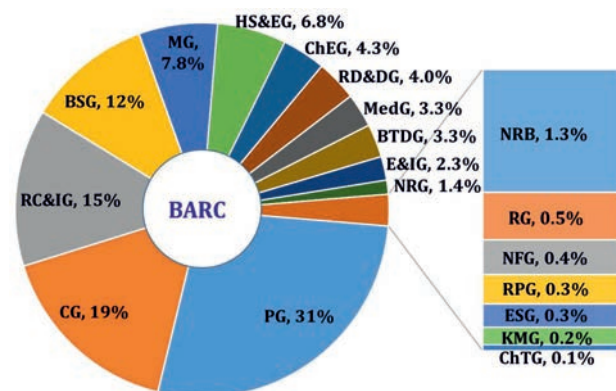
Journal Publications

Journal articles published by BARC scientists across various disciplines during the calendar year 2023 is presented here.

Sr#	Subject Category	Articles	Citations	Cit./Art.
1	Biology	143	174	1.22
2	Chemistry	425	481	1.13
3	Engineering	280	425	1.52
4	Materials Science	230	369	1.60
5	Multidisciplinary	148	144	0.97
6	Physics	359	397	1.11
Total		1,585	1,990	1.26

Source: Scopus database (accessed on 16 April, 2024)

Group-wise percentage of journal articles published by BARC scientific community in the calendar year 2023.



BSG	Bio-Science Group
BTDG	Beam Technology Development Group
CG	Chemistry Group
ChEG	Chemical Engineering Group
ChTG	Chemical Technology Group
E&IG	Electronics & Instrumentation Group
ESG	Engineering Services Group
HS&EG	Health Safety & Environment Group
KMG	Knowledge Management Group
MedG	Medical Group
MG	Materials Group
NFG	Nuclear Fuels Group
NRB	Nuclear Recycle Board
NRG	Nuclear Recycle Group
PG	Physics Group
RC&IG	Radio Chemistry & Isotope Group
RD&DG	Reactor Design & Development Group
RG	Reactor Group
RPG	Reactor Projects Group

Sr. No	Name of Journal	Impact Factor	Journal Articles Published
1	Physical Review B	3.908	27
2	Journal of Molecular Liquids	6.633	24
3	Radiation Physics and Chemistry	2.776	20
4	Separation Science and Technology (Philadelphia)	2.799	20
5	Physical Review C	3.199	19
6	Physics Letters B	4.95	19
7	Nuclear and Particle Physics Proceedings	0.42	18
8	Physical Chemistry Chemical Physics	3.945	18
9	ACS Omega	4.1	17
10	Applied Radiation and Isotopes	1.787	17
11	Journal of Radioanalytical and Nuclear Chemistry	1.754	17
12	New Journal of Chemistry	3.925	17
13	Inorganic Chemistry	5.436	16
14	Journal of Alloys and Compounds	6.371	15
15	Journal of Magnetism and Magnetic Materials	3.097	15
16	Journal of Physical Chemistry C	4.177	15
17	Mapan - Journal of Metrology Society of India	1.446	15
18	Langmuir	4.331	14
19	Journal of Materials Science: Materials in Electronics	2.779	13
20	Ceramics International	5.532	12
21	European Physical Journal C	4.991	12
22	International Journal of Hydrogen Energy	7.139	12
23	Materials Chemistry and Physics	4.778	12
24	Physical Review D	5.407	12
25	Physical Review Letters	9.185	12
26	Chemistry Select	2.307	11
27	Nuclear Science and Engineering	1.46	11
28	Industrial and Engineering Chemistry Research	4.2	10
29	Journal of High Energy Physics	6.379	10
30	Journal of Molecular Structure	3.841	10
31	Journal of Photochemistry and Photobiology A: Chemistry	5.141	10
32	Journal of Physical Chemistry Letters	6.888	10
33	Materials Today Communications	3.662	10
34	[Other Journals]	--	1,095
Total			1,585

Institutional publication output is often used as a measure of the research productivity and impact made by the institution, as well as the intellectual contributions of its researchers.

In the year 2022, BARC published a total of 1,565 journal articles (BARC VISTA 2022). Compared to last year, BARC scientists and engineers published marginally more i.e., 1,585 journal articles in the year 2023. These publications attracted immediate attention from scientific community across the world.

Official Language (Rajbhasha) Implementation

Popularization of Hindi (Rajbhasha) at Workplace

The Hindi Section in BARC is at the forefront of activities aimed at providing translation of various official documents from English to Hindi and vice-versa, and the section also organizes regularly Official Language Implementation Committee meetings, Hindi training classes; events such as World Hindi Day, Hindi Workshops, Hindi Seminars, Hindi promotional activities like Hindi Day/Hindi Fortnight celebrations etc. The Centre made commendable strides in meeting the targets set by the Department of Official Language through the year-round programs. During the year under review, four Hindi workshops were conducted in BARC as part of measures to train and encourage officials to carry out adequate work in Hindi. In line with this, 92 officers/employees participated in related workshops. 'Hindi Maah' (Hindi Month)-2023 was organized from 4th September to 13th October, 2023 to instill positive interest among the workforce towards Hindi implementation in their day-to-day work. Several competitions were conducted during this special drive which saw a collective participation of more than 600 staff. Meritorious staff numbering more than 100 were feted with cash prizes, which will be distributed to them during the 'Vishwa Hindi Diwas' (World Hindi Day) event to be held on 10th January 2024 in BARC Central Complex.



Glimpses of Hindi Maah (Hindi Month) activities in BARC held during September-October 2023.



Glimpses of Hindi Maah (Hindi Month) activities in BARC held during September-October 2023.

New Scientific Publications in Hindi

Publications prepared by Hindi section during the year include *Vishisth Sankalan* (Hindi translation of select nuclear technology related articles published in bi-monthly BARC Newsletter), *Nayee Peedhi ke Naabhikiya Reactor* (National Science Day 2023 souvenir), *Parmanu Oorja ka ek dashak – "NUCDECA (2014-2023)"*, and *Anusandhan Evam Vikas - Oonchaayion Ka Nav Keerthimaan* (BARC Info in Hindi).



Release of 'Vishisth Sankalan' publication (curation of select articles published in bi-monthly BARC Newsletter) during World Hindi Day 2023.

Technology Management

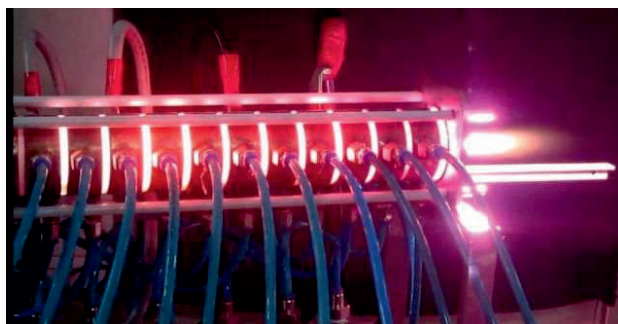
Technology Sharing

At BARC, a total of 188 agreements were signed for transferring 105 technologies. The technologies were transferred after assessing the prospective transferees' capabilities and interest in commercialization. 17 new technologies were assessed and released in the public domain. Also, licenses for four technologies were renewed during the year.

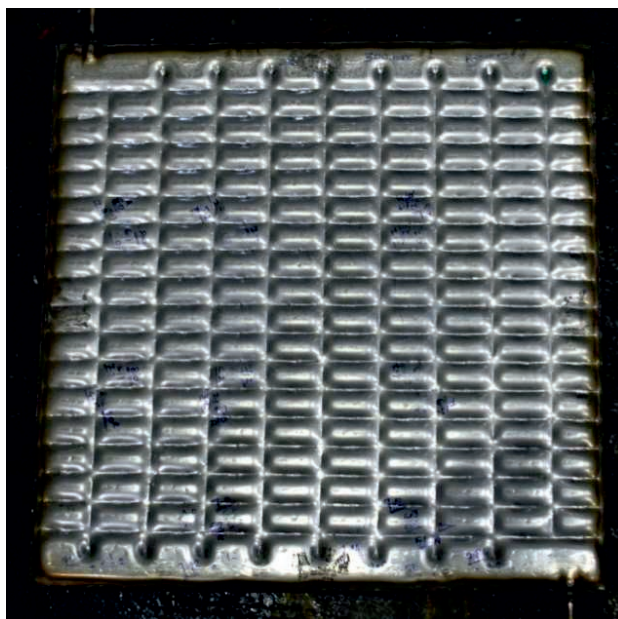
Technology Category	Technologies (no.)	Transfer Agreements (no.)
Advanced Instrumentation	9	9
Agriculture & Bioscience	30	73
Chemical	16	23
Engineering	13	19
Environment	4	25
Medical equipment	5	5
Radiation	6	6
Water	18	24

1. Active Reagent Cartridge for Hazardous Fume Extraction from Chemical Storage Cabinet.
2. Production of oxides single crystals (Al_2O_3 , $\text{Y}_3\text{Al}_5\text{O}_{12}$) of 25 mm diameter and 75 mm length.
3. Digital Current Integrator developed by VECC, Kolkata.
4. Secure Network Access System (SNAS) technology for cyber security applications.
5. Magnetically Coupled Stirrer for high Temperature Reactive Liquids (MACSTER).
6. Production of cobalt metal powder, and fabrication of cobalt metal shapes.
7. Penetration enhancing Activated Flux for TIG welding of Stainless Steels.
8. High Efficiency Particulate Filter (HEPA) Test Rig.
9. Welded Plate Compact Heat Exchanger (WPCHE) with compactness of $400 \text{ m}^2/\text{m}^3$.
10. Leak Tight Flange and Gasket assembly for Instrumentation/Power Cables for Chemical and Radiochemical Facility.
11. Remotely-operated Self-Locking Fixture for Wall Mounted Equipment for Contaminated Enclosures.
12. Manufacturing of Special Category Lead Glass Slab.
13. UV Sterilization System for bulk inward goods and hand-held luggage.
14. Production of Resorcinol Formaldehyde Polycondensation Resin (RFPR).
15. Technology for producing Freestanding Carbon Nanotube Sheet.
16. Radiation assisted Adsorbent technology for Textile Effluent Decolouration (RAD-TED).
17. The technology of Argon Plasma Torch (5kW-50kW).

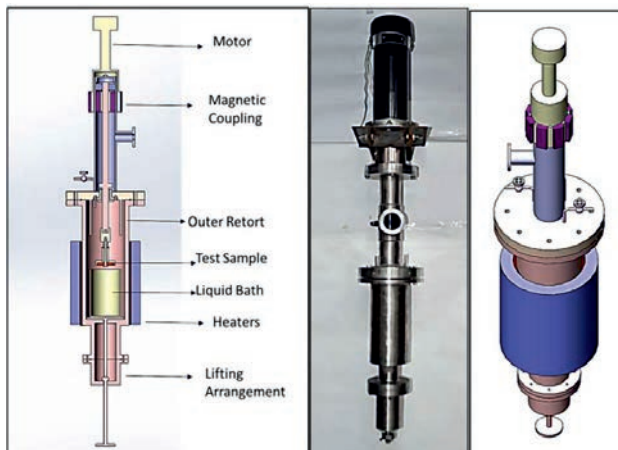
The Technologies for which licenses were renewed



Argon Plasma Torch developed in BARC



Welded Plate Compact Heat Exchanger (WPCHE) with compactness of $400 \text{ m}^2/\text{m}^3$.



Magnetically Coupled Stirrer for high Temperature Reactive Liquids.

during the year are Auto TLD Badge Reader, On-line Domestic Water Purifier based on Ultrafiltration Polysulfone Membrane, Auto TLD Badge Reader technology, DK-Fluoride Detection Kit for Groundwater. The license to produce these technologies was renewed for a period of up to 5 years. During the year, technology awareness & technology transfer meets, lectures on technology transfer mechanism in DAE, technology transfer focused outreach programs and exhibitions were organized under the ambit of Technology Transfer and Collaboration programme in BARC. A series of technology transfer focused publications were published during the year, including The Technology Powerhouse Book-I, comprising exhaustive information on Agriculture, Bio-sciences and Food Preservation technologies.

Technology Incubation Activities

BARC has in place a dedicated technology incubation program to boost entrepreneurship activities using technologies it has developed in-house.

As per the directions of Govt. of India's apex planning body Niti Aayog's mission activities, new AICs were established throughout the country under the aegis of Atal Innovation Mission (AIM) scheme to foster a culture of innovation and entrepreneurship to take deep tech innovations to the industry for the benefit of society. AIC's have become operational in four DAE units at BARC, RRCAT, IGCAR and IPR. The technology of Iodine-sulphur thermochemical process plant for hydrogen production by splitting water, and the technology of Radiation Shielding Lead Glass Slab Manufacturing was covered under technology incubation.

Several workshops and training sessions were conducted in BARC for the benefit of aspiring young entrepreneurs from engineering colleges and also new technology-based start-ups. The technology for Development of Titanium based Hydrogen Storage Material for Transport Applications, Anu-Chaitanya - A Versatile Bio-regulator for Sustainable Crop Production, and



The signing of technology transfer agreement between BARC and a Maharashtra-based private firm M/s. Integrated Energy Engineering.

Portable Raman Spectroscopy system for oral cancer were advertised under Atal Incubation program.

Workshops on “Dry and Wet waste management technologies” and “Clean Water Technologies” were organized in BARC's Mumbai campus for the benefit of young entrepreneurs.

Patenting Activities

During the year, four patent proposals forwarded by BARC were processed and these are as follows.

1. Synergistic process for delaying ripening of mango to enable cost-effective sea-route export received from Food Technology Division, Bio Science Group, BARC.
2. Integral impeller for Turbomolecular Pump, received from Control Systems Development Division, Chemical Technology Group, BARC.
3. Atmospheric Pressure Portable Catalytic Air Plasma System for Fast Synthesis of Aqueous NO₂-and NO₃- Fertilizer in High Concentration received from Beam Technology Development Group, BARC.

4. Mutual separation of Neodymium (Nd) and Praseodymium (Pr) by selective dissolution of their oxides into ionic liquid using pyrazolone received from Radiochemistry Division, Radiochemistry and Isotope Group, BARC.

Advanced Knowledge and RUrban Technology (AKRUTI) Implementation

Four AKRUTI agreements were signed with eligible partners for deployment of BARC technologies in remote areas of the country. This has led to disbursement of 17 licenses for 10 technologies. The technologies broadly covered are Foldable Solar Dryer; Solar Dryer; Soil Organic Carbon Detection & Testing Kit; Nisargruna-Biogas plant based on biodegradable waste; Mass Multiplication Medium of Biofungicide *Trichoderma* spp; Microfine Neem Biopesticide; Rapid Bio Composting Process for Dry Leaves, Kitchen waste and Temple waste; and Domestic Water Purifier technology. DAE has endeavored to expand AKRUTI program at its various units all over India. Under the Corporate Social Responsibility (CSR) program, NPCIL has already set up AKRUTI Centres for demonstration of DAE-developed technologies in the vicinity of Nuclear Power Plant sites.



OUTREACH

Being a highly reputed multi-disciplinary R&D centre for advancement of nuclear energy activities in the country, BARC is committed towards educating citizens on the positive benefits of nuclear energy in the long term. Students of all levels, Private persons, Defence staff, VIPs and members of the Press are provided multiple opportunities to visit BARC to gain first-hand information on the day-to-day activities conducted in BARC.



Glimpses of Parmanu Jyoti 2023: Young Scientific Officers of BARC interacting with students of JNVs in various parts of the country.

Outreach

Sensitizing the Younger Generation on Science and Technology through Outreach

A key pillar of BARC's life-long mission is to sensitize and engage citizens of all demographics, enthuse them about the exciting aspects of scientific research and technology development underpinning BARC's research and its positive impact on overall S&T landscape. As a part of its outreach program, BARC offers school children as well as engineering college students from across the country with an opportunity to visit facilities in Trombay campus to gain first-hand knowledge about the range of multidisciplinary activities in BARC. Such events are also focused towards

inspiring students to pursue careers in science and engineering.

Student contingents from colleges in Maharashtra and neighboring states have visited BARC campus during the calendar year 2023. In addition to this, senior scientific officers of BARC have visited campuses of prominent colleges across India to propagate among the younger generation the developmental objective of India's atomic energy program. During the year, students and faculty members from Shri Rajarshi Shahu Vidyalyaya, Thane and IIT Mumbai were hosted in BARC. The visit covered facilities in BARC, including Dhruva reactor, FTD and Computer Divisions.



Photograph taken during a Scientific Outreach Programme conducted across colleges in Jammu by BARC officials.

A Scientific Outreach Programme was conducted at five colleges in Jammu covering more than 1000 students of Central University of Jammu, University of Jammu, Maulana Azad Memorial Cluster University, Shri Mata Vaishno Devi University (SMVDU), Katra and IIT Jammu, during 9-13 October 2023. The programme included lectures on myths and misconceptions about radiation, food irradiation technology, reactor technology, careers & opportunities in DAE quiz programme for students from Std. 12 to M.Sc. levels, edutainment

skits followed by interactive Question-Answer sessions.

An outreach program was organized by DAE in collaboration with NISER and IOP, Bhubaneswar where BARC Official Language (Hindi) Section officials have delivered a lecture on positive impact of nuclear energy in India's national development, for the benefit of students of Kalinga Institute of Social Sciences, Bhubaneswar.



BARC Official Language (Hindi) Section official addressing the students of Kalinga Institute of Social Sciences, Bhubaneswar during an outreach program.

Parmanu Jyoti Program

Parmanu Jyoti is a novel school-outreach initiative, aligned with the Scientific Social Responsibility, where the young and experienced scientific officers of BARC designated as 'Parmanu Mitras' reach out to school students in remote areas. Mooted by the Department of Atomic Energy (DAE), the program aims to inspire and educate the student community about the contributions and achievements of atomic energy towards nation building. BARC has joined hands with the DAE for implementing the activities planned under this program across pan-India Jawahar Navodaya Vidyalaya (JNV) schools during the year 2023 and has been able to reach out to over 10,000 students in 48 JNVs across the states of Andhra Pradesh, Karnataka, Kerala, and Telangana during the year.

Glimpses of Parmanu Jyoti-2023



Dr. Ajit Kumar Mohanty, Chairman AEC and Secretary, DAE addressing the stakeholders of Parmanu Jyoti program remotely from his office in Mumbai.

...this programme is aptly named Parmanu Jyoti as it aims to spread the light of knowledge about atomic energy in India.

-Dr. Ajit Kumar Mohanty
Chairman, AEC &
Secretary, DAE

परमाणु ज्योति

60000+ STUDENTS
150+ SCHOOLS
100+ SCIENTISTS
34 STATES &UTs
3 MONTHS
1 MISSION



#BackToSchool



Young Parmanu Mitras of BARC interacting with the students of JNV Idduki in Kerala (left) and at JNV Medak in Telangana (right).



With the students of JNV Nellore in Andhra Pradesh (left) and of JNV Kalaburgi II in Karnataka (right).



With the students of JNV Alappuzha in Kerala.

Visits of prominent persons to BARC

BARC organizes Graduation Function event each year to mark the successful completion of training program of young graduates who have joined the ranks of scientific officers of the organization through the popular training school scheme. For the Graduation Function in BARC in 2023, Shri Shaktikanta Das, Governor of Reserve Bank of India graced the event as the chief guest. In his speech aimed at the young scientific officers of BARC, the chief guest articulated 5-point mantra for success which focused on Institutional Pride, Positive Mindset, Work-Life Balance, Learning, and Teamwork.

Science and Technology Events in BARC

Events of national significance in the field of science and technology such as National Science Day, National Technology Day are celebrated in BARC with heightened interest. People of eminence in S&T landscape are invited to BARC to deliver captivating lectures on popular themes for the benefit of BARC scientific community and the student community. Students of schools and colleges attending these events in BARC network with the celebrated scientists as well as scientific community of BARC.



College students present during the National Science Day 2023 program in BARC pose for a group photograph.



SAFE AND SECURED WORKPLACE

BARC has been working proactively for the development of advanced technologies and systems in order to address the potential dangers to its physical and virtual infrastructure through deterrence, avoidance, prevention, detection and reaction to events promptly. In addition, fire safety is given utmost importance within the BARC campus, and the scientific community is provided with comprehensive training sessions to equip them with the knowledge and skills necessary for the prevention and mitigation of fire-related incidents in high duty engineering plants and workplaces.



BARC security and CISF personnel during a joint drill in BARC, Trombay.

Safe and Secured Workplace

Information Security

Development of USB-based 'Anu Nishta' Hardware for Operating System Integrity

A portable, USB based 'Anu Nishta' hardware has been developed to secure portable computing



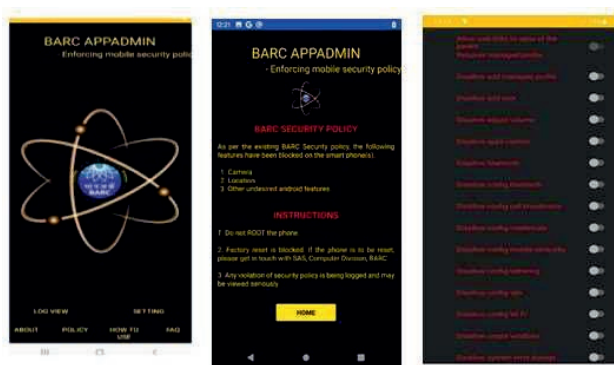
USB based ANU NISHTA Board.

devices like computers and laptops; servers and workstations deployed in nuclear power plant Control & Instrumentation systems. 'Anu Nishta' verifies Operating System integrity before booting and permits only registered applications to run on the computer.

Android based App Administrator for Smartphones Operating in Restricted Environments

With the introduction of next level communication technologies, including 5G and 6G thereby leading to a steady phasing out of 2G communication infrastructure by service providers, BARC has designed and developed Android based Application "App Administrator". The development of application allows any organization to apply and enforce their organization specific mobile policies and any violation(s) are logged and alerts can be raised if desired. This application runs in the background without any user intervention and

raises alerts for any policy violation(s). It provides a number of features like blocking of SIM/Camera/GPS, restrict application permissions, suspend unwanted applications, disable Wi-Fi, disable data transfer over USB and so on. Further, the Android application has been successfully tested on various version of Android OS. The usage of mobile phones is highly restricted in BARC and other critical facilities of DAE. Presently, second generation (2G) based basic mobile phones are being provided to senior officials to cater to specific communication requirements.



"App Administrator" for smartphone usage in restricted environments.

SNAS based Software Tools for enhancement of Cyber Security Posture of Digital Assets in Operating Plants and Facilities

In order to assess and strengthen the security of various isolated C&I networks, multiple applications have been developed and integrated with Secure Network Access System (SNAS), which is an indigenously developed network security appliance. The security solution consists of an agent application which runs on a networked computer and monitors the running applications, TCP and UDP based network connections created by them along with the application executable metadata. The information received at the server end from the agent application is matched with whitelisted and blacklisted applications to assess the overall security state of the network. The agent application also identifies the USB devices connected to the computers. In order to avoid any changes to C&I networks, the agent application runs as a standalone application without administrative privileges in a monitoring mode. It does not require installation of any application package/service.

Multi-factor Authentication-based Linux RFID Identity Card Reader

BARC has developed a prototype Linux based reader using Raspberry Pi that supports ISO-7816 communication and ISO-14443 RFID interface. To serve a requirement of multi-factor authentication for personnel verification at high security zones, the existing Linux-based RFID reader had been modified to accommodate face-recognition system's inputs and employee access is granted only when both "face" and "RFID" information match; thus, making it a multi-factor authentication-based RFID reader. A new GUI and software workflow is designed in order to ensure face recognition and RFID sub-system(s) can function smoothly. Presently, this setup is installed as a prototype for testing and evaluation. It was planned to merge both the units into one single unit with multi-factor authentication options.



"App Administrator" for smartphone usage in restricted environments.

Safety Measures

BARC Safety Council (BSC) and the Committees functioning under BSC have carried out safety review of all BARC facilities, including research reactors, reprocessing plants, spent fuel storage facilities, fuel fabrication facilities, radiological laboratories and conventional facilities and projects under their purview.

The second-tier committees, viz. Operating Plants Safety Review Committee (OPSRC), Conventional and Fire Safety Review Committee (CFSRC), Committee to Review Applications for Authorization of Safe Transfer/Disposal of Radioactive Waste (CRAASDRW) and Physical Protection Systems Review Committee (PPSRC) have conducted several meetings to review safety

issues and for ensuring safety of facilities. ULSCs and DSRCs also conducted several meetings to review the proposals from various facilities, significant events and other regulatory issues.

During the year BARC Safety Council conducted eight meetings. Safety committees of BSC held 193 meetings, including meetings of three-tier committees as well as of DSRCs and Expert Committees. Major activities of BSC during the period-under-review include according of regulatory clearances for 83 facilities/projects, granting of 11 Special Authorizations for transfer and disposal of radioactive waste, granting of authorizations to procure/use of 93 radiation sources and 3 radiological laboratories as well as approval for transportation of 27 radioactive shipments, regulatory inspections at 115 projects/facilities and for organizing site emergency exercise at 37 facilities.

BSC published two documents viz. 'Safety Manual on Ageing Management & Structural Assessment of Existing Concrete Structures', and 'Safe operation of Chemical laboratories. It has reviewed Dose data and waste transfer/disposal data for BARC facilities and also a survey report on Effluent water quality monitoring for BARC, Trombay. It also accorded approval of 62 Radiological Safety Officers (RSO).

BSC conducted three training courses on "Safety and Regulatory Measures for BARC Facilities," at Tarapur, Kalpakkam and Visakhapatnam. It also conducted a training course titled "Crane and Forklift Operation" on material handling equipment at SFSF, Tarapur.



Photograph of the inaugural day event of 46th BSC training course on Safety and Regulatory Measures in BARC Facilities organized at BARC (Facilities) Visakhapatnam during Oct 11-14, 2023.

Fire Safety

Fire safety is given due attention in BARC campus at all times through implementation of various training programs and workshops. Knowledge on prevention and mitigation of fire-related incidents at workplaces, high duty engineering plants is imparted to scientific community through organizing of practical training sessions periodically. Fire safety awareness campaigns (such as 'Fire Fighting and Rescue Demonstrations') are organized each year at BARC workplaces as well as at multiple locations in Anushaktinagar to improve general awareness among BARC community on standard operating procedures for prevention of fire mishaps. BARC has developed a fire extinguisher refilling and hydrotesting cask as part of measures to ensure enhanced safety of its fire personnel. Hydrotesting of fire extinguishers is typically done at 21 bars pressure and refilling of fire extinguishers is carried out at 15 bars pressure.



The refilling cask of Fire Extinguisher.



A view of Fire safety demonstration drill organized in BARC.



A view of Fire safety demonstration drill organized in BARC.

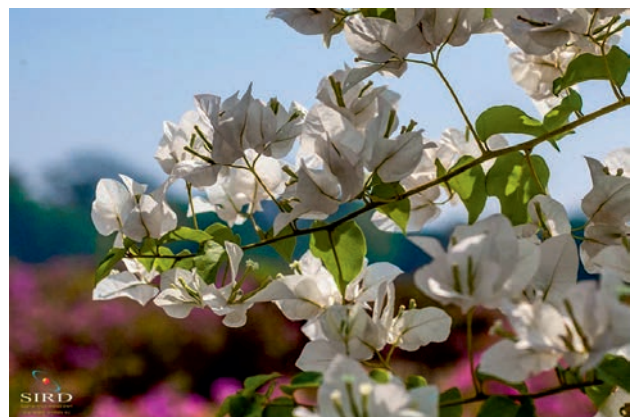
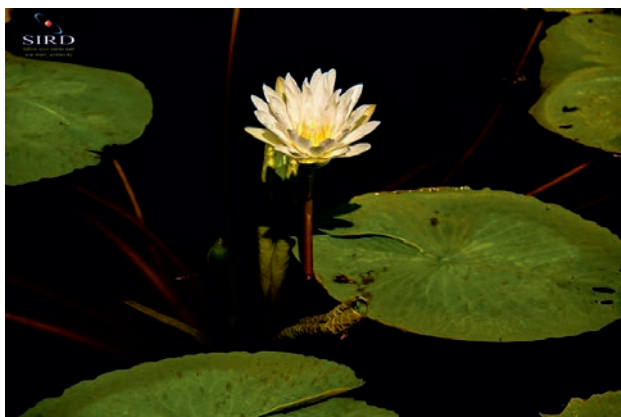


A view of safety drill being performed by BARC fire safety personnel.



Shri Vivek Bhasin, Director, BARC inaugurating an exhibition of fire safety equipment organized in BARC.

Flora in BARC Trombay



Flora maintained and curated by Landscape and Cosmetic Maintenance Section, A&SED, BARC
Photo courtesy of Scientific Information Resource Division (SIRD), BARC.

Collection of select Art works in Central Library & other facilities in BARC



Wooden art work.



Wooden art work.



Wooden art work.



Ceramic art work.



Metal art work.



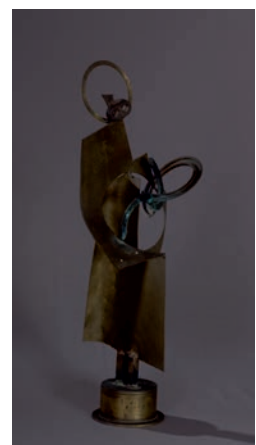
Ceramic art work.



Rising Man
Metal art work.



Wooden art work.



Metal art work.



Refurbished lobby area of BARC Training School in Anushaktinagar, Mumbai



The newly erected fountain in the precincts of Van de Graff facility in BARC Trombay.



50 MVA Transformer (TF-2) commissioned in BARC Trombay.

INFRASTRUCTURE DEVELOPMENT



A view of mural in full display on Apsara-U Building in BARC Trombay.

Infrastructure development is one of the important mandates of BARC for sustaining high-end R&D work and housing of state-of-art facilities. Some of the major works carried during the period-under-review are as follows.

- ✧ A facility for cold storage of fruits and vegetables (Onion/Garlic/Banana/Mango) was established at the premises of KRUSHAK Plant at Nashik in Maharashtra under the DAE project entitled Setting up of R&D facility at KRUSHAK, Lasalgaon for irradiation of fruits and vegetables. The facility was inaugurated jointly by Chairman, AEC and Secretary, DAE, and Director, BARC. Coinciding with the inauguration of the facility, a 'KISAN MELA' event was organized on December 8, 2023 for the benefit of farmer communities.
- ✧ As part of upgrades to power supply system infrastructure in BARC, a new 50 MVA Transformer (TF-2), equipped with state-of-art technology and high velocity water sprinkler system (HVVSS) capable of functioning as fire protection system, was commissioned. Power supply to BARC North Site was being fed through two 50 MVA, 110/22/11 kV Power Transformers, which were first installed in 1977 and have completed a service life of more than 45 years.
- ✧ Automation technology was implemented as part of major software upgrades to the servers of engineering services, which will ensure seamless centralized access to end-users.
- ✧ The civil, electrical, HVAC, mechanical utility services & security systems and L&CM and their associated engineering services have clocked an impressive 97% availability during the year.
- ✧ New development works were implemented in BARC to mark the special occasion of completion of 70 years (Platinum Jubilee) of the centre. The landscape adjoining Van-de-Graff facility was beautified and a new fountain was erected to mark this important historical milestone. Chairman, AEC and Director, BARC accompanied by senior officials of BARC inaugurated the curated landscape on January 5, 2024.
- ✧ BARC Training School Complex facilities in Anushaktinagar, mainly entrance lobby, security counter and reception were completely refurbished and inaugurated on January 03, 2024.
- ✧ An artistically prescient mural depicting the theme of Flight of Phoenix which resonates with the birth of Apsara-U research reactor, was inaugurated in BARC. The mural depicts the rise of the new reactor in the place of decommissioned Apsara reactor, first established in 1956 in Trombay under the leadership of atomic energy pioneer Dr. Homi J. Bhabha.

